DESIGN STRATEGIES FOR ENVIRONMENTALLY SUSTAINABLE RESIDENTIAL TALL BUILDINGS IN THE COOL TEMPERATE CLIMATES OF EUROPE AND NORTH AMERICA

Sabina Fazlic

PhD candidate 2013
Welsh School of Architecture
Cardiff University

Abstract

As the aspirations for tall buildings have shifted towards sustainability, architects face newfound challenges in finding sufficient information on environmental strategies and ways in which to apply them, particularly when specific climatic and functional aspects are considered. This research thus aims to find principles of environmentally sustainable design to contribute to the creation of residential tall buildings in the cool temperate climates of Europe and North America and to organize them to best inform architects during the schematic design stage.

Generated as an iterative series of trials, which are characterized by the application of a 'framework' version in the design of towers for specific sites, the research consists of three stages. All develop the main elements of the framework – the environmental 'design principles', the 'framework matrix' that organizes the principles based on the interaction of climatic influence and design stage and a 'step sequence' that further specifies their placement within each interaction – but each also has a particular focus. Stage 1 concentrates on the strategies of Ken Yeang as a starting point and finds, through a case study comparison, a lack of their comprehensive use in practices. Stage 2 applies the framework on two sites to evaluate the impact of climatic and urban variations within the climate type and provides an assessment with rating systems to examine the framework's focus within those systems. In Stage 3, students test the framework's usability; their feedback and a further literature review inform the fourth version of the framework.

The research suggests that bioclimatic design principles can be presented comprehensively and organized hierarchically to best inform architects during the schematic design stage. Adequate information is required, including qualifications, limitations, options and links between principles. It recommends further framework development and proposes that research be more fully integrated into teaching modules and practice.

Form: PGR_Submission_2012

NOTICE OF SUBMISSION OF THESIS FORM:
POSTGRADUATE RESEARCH

APPENDIX 1:
Specimen layout for Thesis Summary and Declaration/Statements page to be included in a Thesis

DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any degree or other award.

Signed …… (candidate) Date ……

STATEMENT 1

This thesis is being submitted in partial fulfillment of the requirements for the degree of ……(insert MCh, MD, MPhil, PhD etc, as appropriate)

Signed …… (candidate) Date ……

STATEMENT 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references. The views expressed are my own.

Signed …… (candidate) Date ……

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed …… (candidate) Date ……

STATEMENT 4: PREVIOUSLY APPROVED BAR ON ACCESS

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans **after expiry of a bar on access previously approved by the Academic Standards & Quality Committee.**

Signed …… (candidate) Date ……

TABLE OF CONTENTS

Summary i

Declaration ii

Table of contents iii

List of figures vi

Acknowledgements ix

1 Introduction 1 1
- 1.1 Research aim and objectives 1
- 1.2 Thesis structure 2
- 1.3 The early history of the tall building 4
- 1.4 Modernist tall buildings 7
- 1.5 Contemporary tall buildings 8
- 1.6 Environmental sustainability and tall buildings 11
- 1.7 Sustainability in contemporary tall buildings 16
- 1.8 Summary 22

2 Literature survey: research and frameworks 23
- 2.1 Research on tall buildings 23
  - 2.1.1 Academic research 23
  - 2.1.2 Research in university-based design studios 29
  - 2.1.3 Research within practice 30
  - 2.1.4 Research in organizations 32
- 2.2 Design Research 33
- 2.3 Design frameworks 37
  - 2.3.1 Checklists, assessments tools and general design guides 37
  - 2.3.2 Differing approaches to design within professions 43
- 2.4 Ken Yeang and his framework 45
  - 2.4.1 Ken Yeang introduction 46
  - 2.4.2 Ken Yeang's framework overview 47
  - 2.4.3 Ken Yeang's framework review 51
- 2.5 Summary 55

3 Methodology 56
- 3.1 Research question and limitations 56
- 3.2 Overall research process 59
- 3.3 Research aims and objectives 62
- 3.4 Stage 1 62
  - 3.4.1 Extraction and presentation of principles from Ken Yeang's text (1) 62
  - 3.4.2 Case study comparison with principles (1) 64
  - 3.4.3 Applications of principles in practice and teaching (1) 64
  - 3.4.4 Organization of principles (2) 65
  - 3.4.5 Birmingham test tower and required changes to framework (1) (2) 66
- 3.5 Stage 2 67
  - 3.5.1 Climatic and urban variations (1) (2) 67
  - 3.5.2 Assessment with rating systems (1) 68
  - 3.5.3 Required changes to framework (1) (2) 68
- 3.6 Stage 3 68
  - 3.6.1 Usability of framework on student test towers (1) (2) 69
  - 3.6.2 Required changes to framework (1) (2) 71
- 3.6 Summary 71

4 Stage 1: Initial Development and Birmingham test tower 72
4.1 Ken Yeang design principles 72
4.2 Case studies 74
4.2.1 North American case studies 80
4.2.2 European case studies 113
4.2.3 Case study comparison results 147
4.3 Observations and applications in education and practice 155
4.3.1 Broadway Malyan Birmingham proposal 155
4.3.2 Nottingham design studio observation 161
4.4 Framework attempts prior to version 1 164
4.4.1 Early attempts at organization 164
4.4.2 Labeling of categories 170
4.4.3 Climate specificity 171
4.5 Stage 1 final framework matrix 172
4.6 Birmingham test tower 175
4.7 Stage 1 framework and tower analysis 182

5 Stage 2: New York and London test towers 185
5.1 Test tower city choice 185
5.2 Building program 186
5.3 London: context 188
5.4 London: test tower site 192
5.5 London: test tower steps 194
5.6 London test tower flowchart 199
5.7 Resulting London test tower 202
5.8 New York: context 203
5.9 New York: test tower site 204
5.10 New York: test tower steps 209
5.11 New York: test tower flowchart 212
5.12 Resulting New York test tower 214
5.13 London and New York Test towers: comparative analysis 215
5.13.1 Climatic and urban variations 215
5.13.2 LEED and Code for Sustainable Homes assessment systems 217
5.13.3 Environmental assessments of test towers 220
5.13.4 London test tower: Code for Sustainable Homes analysis 221
5.13.5 New York Test tower: LEED analysis 225
5.13.6 Design framework: LEED and Code for Sustainable Homes analysis 229
5.13.7 Stage 2 framework analysis summary 232

6 Stage 3: Student testing 234
6.1 Student groups 234
6.1.1 Composition 234
6.1.2 Resources 236
6.1.3 Design Briefs 237
6.1.4 Site 239
6.1.5 Approaches to environmental design prior to testing 240
6.2 Design process 241
6.2.1 Nottingham 241
6.2.2 Cardiff 249
6.3 Questionnaire 255
6.3.1 Effect of the framework on design assumptions 256
6.3.2 Framework utility 257
6.3.3 Areas for improvement 264
6.3.4 Restrictions 267
6.3.5 Strengths 268

6.3.6 Weaknesses 268
6.3.7 Design challenges 270
6.3.8 Student questionnaire results summary 271
6.3.9 Critique of questionnaire design 272
6.4 Design principles applied by students 274
6.5 Additional areas of misunderstanding and assumptions 282
6.5.1 Visible radiation 282
6.5.2 Ventilation 282
6.5.3 Non-bioclimatic strategies 283
6.6 Design evaluations by students 283
6.7 Ian Simpson Architects comparison 285
6.8 Summary 287
7 Conclusion 288
7.1 Summary of findings 288
7.1.1 Research process 288
7.1.2 Research results 292
7.2 Limitations of research 297
7.3 Implications of research 298
7.4 Areas for further research 299
7.5 Conclusions 302
Works Cited 303

Annexe: Version 4 Framework

Appendix A: Stage 1 supplementary material

Appendix B: Stage 2 supplementary material

Appendix C: Stage 3 supplementary material

LIST OF FIGURES

Figure 1.1: 'Race to the sky'
Figure 1.2: Energy costs of a commercial skyscraper
Figure 1.3: 'Five energy generations of tall buildings'
Figure 2.1: Timeline of Design Research
Figure 2.2: SPeAR Assessment Tool
Figure 2.3: 'Energy Savings by Global Regions'
Figure 2.4: General Systems Theory
Figure 2.5: Partitioned Matrix
Figure 2.6: Interaction descriptions
Figure 3.1: Research development flowchart
Figure 3.2: Köppen System classification of climate
Figure 4.1: Design strategy identification within case studies
Figure 4.2: List of design principles extracted from Yeang, and their correlation with the case study key and final framework
Figure 4.3: Categorization of building elements
Figure 4.4: Categorization of climatic and environmental strategies
Figure 4.5: 340 on the Park
Figure 4.6: 340 on the Park strategies
Figure 4.7: Chicago Spire
Figure 4.8: Chicago Spire strategies
Figure 4.9: Solstice on the Park
Figure 4.10: Solstice on the Park strategies
Figure 4.11: Four Times Square
Figure 4.12: Four Times Square strategies
Figure 4.13: The Solaire
Figure 4.14: The Solaire strategies
Figure 4.15: Hearst Headquarters
Figure 4.16: Hearst Headquarters strategy
Figure 4.17: The New York Times Building
Figure 4.18: The New York Times Building strategy
Figure 4.19 Bank of America Tower
Figure 4.20: Bank of America Tower strategy
Figure 4.21: Freedom Tower
Figure 4.22: Freedom Tower strategy
Figure 4.23: Commerzbank
Figure 4.24: Commerzbank Headquarters strategy
Figure 4.25 RWE Tower
Figure 4.26: RWE Tower strategy
Figure 4.27: SEG Apartment Tower
Figure 4.28: SEG Apartment Tower strategy
Figure 4.29: 30 St Mary Axe
Figure 4.30: 30 St Mary Axe strategy
Figure 4.31: The Leadenhall Building
Figure 4.32: The Leadenhall Building strategy
Figure 4.33: London Bridge Tower
Figure 4.34: London Bridge tower strategy
Figure 4.35: CityZED
Figure 4.36: CityZED strategy
Figure 4.37: Skyhouse
Figure 4.38: Skyhouse strategy
Figure 4.39: Kite Tower
Figure 4.40: Kite Tower strategy

Figure 4.41: Elephant and Castle Eco-Tower
Figure 4.42: Elephant and Castle Eco-Tower strategy
Figure 4.43: Overlay of case study strategies
Figure 4.44: Broadway Malyan proposal strategies
Figure 4.45: Birmingham tower rendering
Figure 4.46: Birmingham tower solar strategy
Figure 4.47: Birmingham tower wind strategy
Figure 4.48: 2007 Nottingham Projects
Figure 4.49: An early graphic representation
Figure 4.50: Early attempt at a table format
Figure 4.51: Table with improved building element categories
Figure 4.52: Expanded table with eight subcategories per cell
Figure 4.53: Framework matrix Stage 1
Figure 4.54: Site building cluster
Figure 4.55: Birmingham aerial view of site
Figure 4.56: Sunpath diagram
Figure 4.57: Annual average prevailing wind directions
Figure 4.58: Monthly average wind directions
Figure 4.59: View of tower from various directions
Figure 4.60: Flowchart of design decisions
Figure 4.61: Evolution of building form
Figure 4.62: Birmingham tower final illustration
Figure 5.1: Climatic comparison between London and New York
Figure 5.2: Urban density map of London
Figure 5.3: London context illustrations
Figure 5.4: London site
Figure 5.5: ‘Skylab’
Figure 5.6: ‘A Home in the City’
Figure 5.7: Yeang’s proposal
Figure 5.8: London climatic site analysis
Figure 5.9: London tower steps
Figure 5.10: London flowchart
Figure 5.11: Flowchart/framework relation
Figure 5.12: Birmingham test tower south facade
Figure 5.13: Typical residential floor
Figure 5.14: Urban density map of New York City
Figure 5.15: New York site model
Figure 5.16: New York context illustrations
Figure 5.17: Greenwich Street South redevelopment plan
Figure 5.18: Artist’s impression of park adjacent to tower
Figure 5.19: New York climatic site analysis
Figure 5.20: New York tower steps
Figure 5.21: New York flowchart
Figure 5.22: Principle links
Figure 5.23: North/east facades
Figure 5.24: South/west facades
Figure 5.25: Floorplan
Figure 5.26: Categories and weightings in the Code
Figure 5.27: London apartment numbers relating to SAP rating
Figure 5.28: Summary of SAP calculations
Figure 5.29: Code for Sustainable Homes credit checklist based on documents
Figure 5.30: LEED Checklist with additional credits highlighted
Figure 5.31: Code for Sustainable Homes within the framework
Figure 6.1: Blackfriars Road site plan
Figure 6.2: Nottingham students’ site study

Figure 6.3: NF Visit 2 proposal
Figure 6.4: NF Visit 3 proposal
Figure 6.5: NF Visit 4 proposal
Figure 6.6: NF Final Review poster
Figure 6.7: NN Final Review poster
Figure 6.8: Student test steps and principles
Figure 6.9: Steps applied by student groups
Figure 6.10: Percentages of steps applied
Figure 6.11 1 Blackfriars Road proposal
Figure 7.1: Summary of changes to framework elements
Figure 7.2: Origin of principles
Figure 7.3: Framework matrix Version 1
Figure 7.4: Framework matrix Version 4
Figure 7.5: Step links

Acknowledgements

I would first like to thank my supervisors, Wayne Forster and Mike Fedeski, for their guidance and support throughout this research. Wayne's encouragement and enthusiasm and Mike's rigor in reasoning and attention to detail helped to progress my initial curiosity in this topic into the large research project that it became. Also at the WSA, I would like to thank Simon Lannon for his assistance with SAP calculations and Spyridon Stravoravdis for his help with Ecotect. Katrina Lewis has provided instrumental answers to my numerous questions and requests.

This study would not be complete without the generous participation of students at the Cardiff University and the University of Nottingham. I would like to thank Mike Fedeski and Sarah McCormack for arranging student tests in Cardiff and David Nicholson-Cole and Philip Oldfield for doing the same in Nottingham, and more generally for inviting me to contribute to their brilliant design modules. I would also like to thank the CTBUH, particularly Antony Wood, for contacts with the Nottingham staff and for my subsequent involvement with the organization's activities.

My colleagues and students from the Centre for Alternative Technology deserve special acknowledgement, as my experiences teaching sustainable design there have undoubtedly added to my knowledge of the field and an awareness of issues educators and students face. A special thanks to Damian Randle for unreservedly offering an optional module to test this framework.

Several architectural practices and individuals also provided insights and material from which the study benefited greatly. Stephen Stock and the staff at Broadway Malyan in Birmingham deserve special mention for enabling the research to be applied in practice. Thanks to Christian Male at Ian Simpson Architects for generously providing data and an interview for the London site. Adrian Smith and the Chicago office of Skidmore, Owings & Merrill were exceptionally helpful for providing the context CAD model for the New York test tower. Also in Chicago, thanks to Edward L. Deam for his general guidance and encouragement in research related to design. Early discussions with Mike Frisch from Solomon Cordwell Buenz Architecture highlighted the need for further guidance for green towers, which I hope the framework now offers. Thanks also to David Buckland at Atkins for reviewing early parts of the research and Kenny Brown at the Birmingham City Council for the discussion and data for the Birmingham test tower.

I would like to thank Steve Watts and Alastair Collins at Davis Langdon for supporting funding for my attendance and poster presentation at the 2008 CTBUH Congress in Dubai. Thanks also to the Overseas Research Students Awards Scheme for funding part of this research.

Last, but by no means least, I would like to thank my family. My deepest appreciation goes to my parents for the unending support during my study. Special acknowledgments to my mother, Senada, for her willingness to travel internationally and to provide wonderful childcare during the most intense periods of study, and to my father, Zlatko, for being a role model in education and patience. Thanks to my brother, Senad, who can always be relied upon for help and humor, for providing a stream of laptops and his unparalleled technical assistance. Special acknowledgements also go to my husband, Hazim, for his great support during this long and demanding period. Finally, I would like to thank my children, Amina and Yusuf, for bringing moments of laughter and happiness to each day, and for being the cause of my persistence during the most trialing times of this study.

1 INTRODUCTION

As a result of greater environmental awareness and increasing urbanization, the last two decades have seen a growing interest in the sustainable tall building. This concern has been explored at global and local scales, as regulatory bodies and architectural practices have adopted environmental credentials as part of their mainstream strategies. Despite this interest, however, the application of sustainable, particularly passive, design methods for tall buildings remains incomprehensive. This condition is especially true in the cool temperate climates of Europe and North America, where the type's lack of bioclimatic response has remained for the most part unchanged, notwithstanding the field's advocated urgency in creating more environmentally responsive models. The failure encompasses specific guidance for the design of residential towers, which represent an increasing number of tall building projects.

This chapter will therefore outline the aims and objectives of this research, as well as set out the thesis structure in which they will be explored. It will also expand on the context of the research, briefly stated above, by providing a literature survey relating to tall buildings and sustainability. The survey considers a general history of tall buildings, their later connections with the environmental movement, contemporary green versions and arguments for their health, economic and environmental benefits. The historical aspect of this research helps to strengthen the argument that tall buildings can be designed environmentally, as early skyscrapers had the advantages of natural daylighting and ventilation. The survey furthermore questions the notion that modernism is primarily responsible for the subsequent environmental failures of tall buildings, as many of the founders of modernism were highly influenced by the natural world and architecture's relationship with it. It therefore presents a case, and a context, for sustainable tall buildings.

1.1 Research aim and objectives

The research aim can be summarized as:

- To determine the content and organization of environmental design principles to inform the design of residential tall buildings in the cool temperate climates of Europe and North America.

The objectives of this research are therefore as follows:

- To find principles of environmentally sustainable design which would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America;
- To organize these principles so that they can best inform architects during the schematic design stage.

1.2 Thesis structure

The research is based on an iterative series of trials presented as three main stages, which are discussed, respectively, in Chapters 4, 5 and 6. Each stage includes the application of a version of a design guide, here referred to as the 'framework', in order to create a tower for a specific site. Nonetheless, each stage also has a different focus, discussed below. The research structure is more fully specified in the Methodology chapter, which loosely correlates with the structure of the thesis chapters.

Chapter 1: Introduction
The Introduction provides a brief overview of the research aims, objectives and structures, followed by a discussion on the historical and conceptual context of this research. This discussion, in the form of a survey, focuses on a historical progress of and arguments for both tall buildings and sustainability, and highlights some links between the two. It maintains that sustainability is not foreign to the tall building, but has only recently been separated from its functional aspirations and therefore needs to be reinstated in its design. In so doing, an early case is made for the framework developed in this study.

Chapter 2: Literature review: research and frameworks
The first part of the Literature Review examines research relating to sustainable tall buildings. Although relatively little contemporary research exists, the review includes key investigations by various professionals, including those in academia and practice. An assessment of design research and design approaches follows, many of which are not as specific to the building type but whose existence is significant in the framework's formation. A consideration of the differing notions of design approaches between architects and engineers follows. Ken Yeang's more general framework is then presented and critiqued.

Chapter 3: Methodology

Chapter 3 outlines the methodology of the study. It considers the research aims, objectives and organisation, including the '3-stage' advancement of the design principles and their organization, in sum referred to as the 'framework'. Each stage acts as an iterative series of trials consisting of a design process and resulting in tall building designs. The stages are discussed in detail in Chapters 4 to 6. Recurring themes and issues within the research development are examined here.

Chapter 4: Stage 1: Initial Development and Birmingham test tower

As the second chapter discussed the framework set out by Ken Yeang, this chapter focuses on the choice and organization of his design principles. It will first outline these principles, extracting ones relevant to the climate type and building function from his texts. Although carried out throughout the research, the verification of these principles is provided in Chapter 7 in the final version of the framework, as requested by students. This chapter will instead discuss his use of the principles and their adaptation for the earliest organization attempts. Some observations from previous student work and the author's related experience in practice are also included. Findings from case study tall buildings from various architectural practices, which provide a comparison with Yeang and point to gaps in his approach, are presented. Some observations from student work and from practice are also included. Early framework attempts are then presented, culminating in a first major version, which is then tested on an initial pilot study, a tower in Birmingham. The analysis considers the outcome, mainly relating to the organization of the framework.

Chapter 5: Stage 2: New York and London test towers

Stage 2 focuses on urban and climatic variations within the climate type, as well as assessments through two major rating systems. This stage utilizes an adjusted version of the framework, based on the analysis in Chapter 4. A brief program and context are provided for the second pilot study, consisting of two towers. London and New York sites are chosen to allow for comparisons in differing urban and climatic conditions. The framework is then applied, and the resulting buildings are assessed with the LEED and the Code for Sustainable Homes rating systems. The analysis therefore considers the outcome as it relates to environmental assessment and organization refinement.

Chapter 6: Stage 3: Student testing

The framework is adjusted again, prior to being applied by students at Cardiff University and the University of Nottingham on a test site in London. The analysis, consisting of student feedback through a questionnaire, notes and observations, therefore focuses on the outcome mainly as it relates to the usability of the framework, including its clarity and flexibility.

Chapter 8: Conclusion

The Conclusion provides a summary of findings, the limitations and implications of the research and areas for further study.

The final framework is presented in the Annexe. It should be noted here that the term 'final framework' could be deceptive in that it suggests a definitive level of completion. Its intended meaning, however, advocates the end of a development stage, here referred to as 'Stage 3' that is appropriate for the various constraints imposed on research fulfilled at this level. Likewise, it cannot be considered flawless as the advice contained therein may, and is in fact explicitly expected to, adjust to new advances and feedback. It is hoped, however, that the research method and its execution is sound, forming a reliable basis on which future versions of the framework can be developed and implemented.

1.3 The early history of the tall building

In any discussion on the history of the tall building, the question of an appropriate definition inevitably arises. Numerous attempts exist, ranging from the Council on Tall Buildings and Urban Habitat's categorization as a building that, 'by virtue of its height, requires its own special engineering systems' (Yeang, 2000) to poetic descriptions, such as William Pedersen's 'aspiration, one that intends to link earth and sky.' (Höweler 2003: 7); yet not one is universally accepted. Acknowledging the diversity, this thesis has nonetheless adopts the definition of Emporis (2005), an extensive database on buildings and the real estate industry, as 'a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels' due to its broad applicability and relevance to the case studies.

The title of 'the first tall building' is just as debatable. The tall building existed long before the first modern skyscraper was constructed, as 35-meter timber-frame houses in Ancient Rome had been assembled (Eisele, 2003: 11) and 'the Manhattan in the desert' of 16th-century, five to eleven story residences still stands in Shibam,

Yemen (Foster, 2008: 54). Other tall structures, such as obelisks, bell-towers, minarets and monuments have dominated city skylines for centuries. Yet the nineteenth-century tall building, the modern skyscraper, was unique in that it initiated the global proliferation of the type, unmatched in history in both the height and number.

It is usually accepted that the modern tall building first appeared in America in the late nineteenth century, most directly as a result of two inventions: the iron frame and the elevator (Lepik 2008: 5). Although they are considered of primary importance, other factors existed that made the tall building a commercially viable type. In terms of structure and technology, these include:

- new methods of making foundations;
- air-conditioning;
- flush toilets;
- large elements of glazing and window framing;
- advanced telecommunications and electronics;
- advanced indoor lighting;
- improved mechanical ventilation;
- improved cleaning technologies (Ali, 1995: 145).

However, the tall building would have not been financially feasible if it was not for economic factors: the rising cost of urban land and a surge in the need for office space. This was especially true in the United States, and particularly in Chicago as it needed to quickly rebuild from the devastating Great Fire of 1871 that had destroyed over a third of the city. The city soon became home of what is widely considered as the first skyscraper, the 1885 Home Insurance Building, and subsequently confirmed its standing as a world leader in tall buildings. The name of that building, and numerous others, highlights the leading role that large corporations had in the type's development, as they quickly became aware of the skyscraper's promotional value and drove the race towards greater height (Ascher, 2011: 14). Nonetheless, as Ascher (2011: 15) points out, most towers of that period were speculative, but the need for downtown office space ensured that developers could rely on rental income.

In a broader sense, then, the proliferation of tall buildings was also a result greater societal change, including the growing influence of large corporations and, subsequently, the increasing urbanization of America as workers moved to cities for

employment. Despite these promising circumstances, the numbers, height and forms of such buildings would not remain unrestricted as legal and regulatory demands led to localized interpretations. The cities of Chicago and New York exemplify their impact: whereas 1983 Chicago municipal laws limited the heights to 130 feet and resulted in 'boxy' towers with large footprints and atriums, New York's lack of height restrictions at that time resulted in taller, slender towers (Ascher, 2011: 14). However, the 1915 Equitable Building's unprecedented mass and negative impact on the light and air available to surrounding spaces soon questioned this permissive stance; New York City's 1916 Zoning Resolution therefore not only allowed unrestricted heights to one quarter of the building's lot and instituted setback rules for particular heights, but it also introduced district zoning for particular building types. These laws would be amended in the following decades, but they nonetheless informed the aesthetics of tall buildings in each city for a long time to come.

As the new building type began to flourish, debate within the architectural community focused on the structure's stylistic origins; this discussion is examined thoroughly in Paul Goldberger's *The Skyscraper* (1981). He identifies at this early stage two opposing ideologies in relation to its design, which are exemplified by the towers of Chicago and New York. Chicago, home to the 'great theorists of the skyscraper,' Louis Sullivan and John Wellborn Root, symbolized a theoretical approach based on the expression of technological innovation. Its lack of tradition, both architectural and cultural, allowed for greater experimentation. In contrast, the more 'traditional' architects of New York looked to Europe, and later to the city itself, for historical and visual styles of reference. Their towers then not only lacked the expression of the technological innovation but also purposely hid it. These opposing approaches to the tall building, theoretical and visual, would continue through to the designs of contemporary towers, as discussed later in this chapter.

Despite these differences, the cities shared a title that continues to maintain an allure in many parts of the world: the world's tallest building. In New York, with bedrock not far beneath the earth's surface, tall buildings had less difficulty anchoring their foundations than they had in the sandy soil of Chicago, and so it was unsurprising that New York would hold the height records for sixty years (Lepik 2008: 9). More significantly, this competition would lead to the search for new functions for tall buildings. New York would as well become home to what is considered the first tower for residential purposes, the 1926 Ritz Tower, a 41-storey apartment hotel. Purely

residential towers followed, including the 1929 San Remo, the 1930 Eldorado and Majestic and the 1931 Century Apartments (Binder, 2002).

Europe for the most part remained inactive in skyscraper construction. It did however theorize about its design, as illustrated by many futuristic proposals by visionaries such as Anoni Gaudí, Auguste Perret, Antonio Sant'Elia, Chiattone and El Lissitzky (Lepik, 2008: 10). More influentially, Mies van der Rohe's 1922 competition entry for a tower at the Friedrichstrasse station in Berlin would drastically shape the modernist skyscraper's glass-skin ideal (2008: 12). The United States, however, would remain untouched by these visions until well into the 1930s, a few decades after the 1922 Chicago Tribune Tower competition entries from European designers exposed the country to unadorned forms. A after a brief interest in Art Deco towers, culminating in the Empire State Building, modernism had become the prevalent by the 1950s (2008: 13).

1.4 Modernist tall buildings

In 1951, Mies van der Rohe, at that time settled in Chicago, completed the 26-storey 860-880 Lake Shore Drive Apartments. This was not his first residential high-rise in the city, but its glass and steel façade materialized the vision of his famous competition entry and established the construction method's prevalence among such towers, as well as among modern architecture in general. That is not to say that concrete residential high-rises ceased to be built; in fact, some of the most memorable residential towers of the period were of concrete. I. M. Pei designed a number of such buildings throughout the United States in the 1960s and Chicago's most famous twin towers, Marina City, were completed during the decade. However, the curtain-wall image continued to gain influence throughout the century and would dominate skyscraper design by its end (Binder, 2002). Even when new structural concepts in the 1970s renewed an interest in building heights, the modernist uniform glass façade remained, as exemplified by the 1989 residential John Hancock Center and its 1973 commercial neighbor, the Sears Tower.

Europe was quick to embrace this style and so more enthusiastically welcomed the skyscraper. Although less standardized in form than American towers, in façade the same sleek curtain wall was favored, as illustrated by towers such Thyssenhaus in Düsseldorf and Torre Pirelli in Milan. The differing building forms were driven in part by various building regulations on the continent, for example the German

requirement that all workstations should be no more than 7m from the window (Lepik, 2008: 15).

A short-lived shift in stylistic preference occurred in the late 1970s and early 1980s. What became apparent was that the 'modernist box' was no longer a practical option. As Goldberger points out, not only was it 'no longer the clean and exhilarating structure that would serve as a clarion call to a new age' but it became impracticable, as it was 'generally inefficient from the standpoint of energy, and it was not as marketable from the viewpoint of real estate operations either.' Just as economics had led to modernism's success, Goldberger states, it was once again economics that turned architects away from it (1981: 139-40). He describes the emerging trend as a stylistic concern that attempted to regress to the 'architecture of visual stimulation' of the 1920s. Unsurprisingly mainly a New York preoccupation, the 'postmodern' tower again focused on history and its connection to the city, even if it required an anachronistic and incoherent approach to its design. Yet, despite this brief fascination with historical reference, and in contrast to Goldberger's expectations at that time, by the end of the century modernism had re-emerged as the main stylistic preference amongst architects. However, the plurality in modernism's interpretation that already existed in European towers now started to emerge in North American ones, resulting in the contemporary form of modernism.

1.5 Contemporary tall buildings

The discussion on tall buildings thus far has clearly been predisposed towards towers in Europe and North America; the topic of the thesis further ensures that this is the case. Yet a survey would be incomplete without mention of international trends. Although the number of towers outside of the two continents began to grow in the 1930s, in cities such as Paris, Sydney and São Paolo (Binder, 2002), overwhelmingly the most active cities were located in America for the rest of the 20th century. The first quarter of this century, however, has seen a sharp escalation in the number and location of tall buildings worldwide. This is depicted well in a document spanning to to 2002 by OMA/AMO, reprinted in Lepik's text and here in Figure 1.1, which shows the increasingly Asian dominance in terms of tall building numbers. CTBUH's 2012 review of buildings 200 meters or taller confirms this trend, as that year the region saw the completion of 35 such buildings, or 53% of the total; North America, in contrast, was home to only 6 and Europe to 2 (Brass et al., 2013). In the organization's conferences, too, the shift is unsurprisingly eastwards, and

exemplified by CTBUH Shanghai 2012 World Congress, and signals a dominance of the Eastern hemisphere for some time to come. The forms of the towers in that region can be just as, if not more, varied as those in the West, but their scale and urban context is often unimaginable in European or North American cities. High-rise cities, such as Hong Kong and Singapore, with clusters composed of thirty or more towers, fifty stories or higher, are inconceivable in a Western country. Middle Eastern countries, competing with their neighbors or with Asia, now also dominate the race for the world's tallest building; in fact, three out of four of the tallest buildings completed in 2012 are in Dubai and the fourth one is in Mecca (Brass et al., 2013). The cultural, economic and aesthetic contexts in Eastern countries warrant further study on their own.

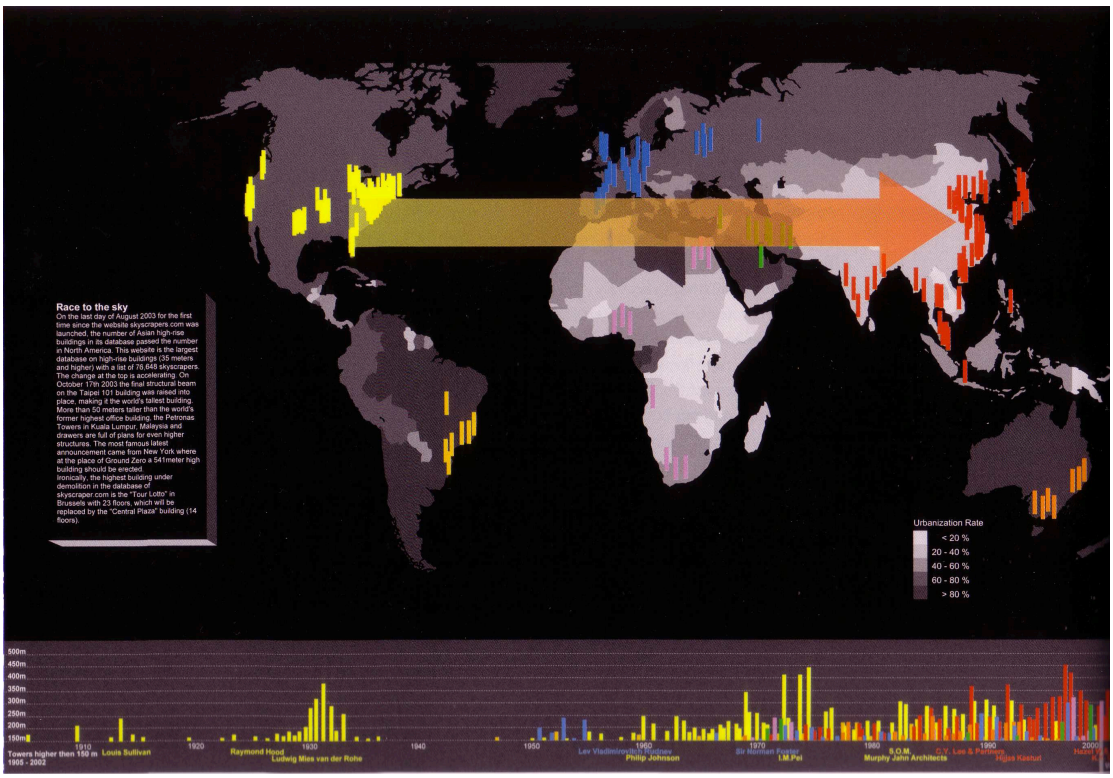


Figure 1.1: 'Race to the sky' (OMA/AMO in Lepik, 2008: 26)

This is not to say that skyscrapers in the West are in decline; far from it, their numbers and heights continue to grow, even if the recent recession has slowed down that growth considerably since 2008. Europe has witnessed the revival of the 'classic modernist residential high-rise,' the 25- to 35- storey tower, but this has also been complemented by an increased interest in mixed-use and super-tall residential buildings. Cities such as Rotterdam, Barcelona, Malmö and Moscow are now recognizable by their iconic towers, and others such as Miami and Toronto have

earned a reputation of for sky-high living, with the latter's residential towers accounting for up to 80 per cent of all skyscrapers constructed (*Emporis*, 2005). Even traditionally low-rise cities have adopted the form, admittedly with much caution and with carefully formed high-rise planning policies. In London, for example, the shortage of housing and a market for high specifications has encouraged a move towards residential towers: two-thirds of its towers in 2005 were designated for residential purposes (*Emporis*, 2005). Some of these towers will be discussed further as case studies in Chapter 4.

What has changed are some of the drivers behind their adoption. Many of the same reasons, such as high land value, that existed at the initiation of the skyscraper era are still relevant today, but others, such as the representation of a company's reputation trough novel designs, are no longer as powerful. The race towards the world's highest building in the West has lost much of its intensity, as buildings' varied roof forms have become incomparable and heights have become more restricted by zoning and economics rather than technological advancements. As discussed by Yeang (1996), recent arguments over the effect of personal computers in the office and security issues have failed to impede the abundance of skyscrapers, instead only influencing their design by improving technologies and convincing the construction industry to realize the non-commercial opportunities of high-rises. Of course, there are also the environmental arguments for, and against, tall buildings, which are discussed in Section 1.7.

In terms of tower design, though, advances in technology, allowing for a greater variety of expression, have led Goldberger's early distinctions between visual and theoretical approaches to evolve into a number of sub-categories. In his survey of contemporary skyscrapers, Eric Höweler (2003: 10) classifies the recent diverging design strategies into seven types that are applicable to residential as well as commercial skyscrapers. They are unusual in that they form a system of categorizing towers based on design, rather than by structural organization or relationship with the sky. The strategy types, some characteristics and examples are:

- 'global/local' – regionalist, nostalgic – Petronas Towers;
- 'high-tech' – 'aesthetics of assembly' – Honkong Shanghai Bank Headquarters;
- 'monolithic' – scalesness, sculptural simplicity – London Bridge Tower;
- 'kinetic' – movement and transformation – Turning Torso;

- ‘scenographic’ – ‘urban theatre’, unexpected forms and facades;
- ‘mediatic’ – ‘hyper-presence’, landmarks, built spectacle – Tour Sans Fins;
- ‘ecological’ – conservation/production of energy, recycling – SEG Apartment Tower.

While each of these categories can be further critiqued, and skyscrapers, such as the London Bridge Tower, can inhabit more than one of these types, it is argued that this last approach can respond to the challenges of climate change in a creative and effective manner. Furthermore, as environmental design becomes more common, this inclusive strategy can encompass and enhance the remaining six Höweler categories. The next section will therefore examine on this strategy in a more general sense, its history, benefits and current practice.

1.6 Environmental sustainability and tall buildings

In order to put the ecological skyscraper in the wider context of green architecture, this section initially aims to question the assumption that modern architecture necessarily is antithetical to sustainability. It will therefore show examples where nature and modern architecture comfortably coexist, arguing that the split is due to a specific form of modernism that has isolated more contextual approaches. In so doing, it is hoped that a less negative approach will be more practical for contemporary practice.

First though, as in the case with a discussion on the history of tall buildings, a definition of sustainability inevitably arises. Currently, the most recognized definition of sustainability is that of the 1992 Rio de Janeiro Earth Summit, which states that ‘Sustainable development involves... meeting the needs of the present without compromising the ability of future generations to meet their own needs.’ More specifically, in the field of architecture, RIBA adopts the definition of sustainable development from the UN’s Brundtland Report: ‘Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Sullivan, 2012). The American Institute of Architects’ (AIA website, no date) definition of sustainable design is more elaborate:

> The linked domains of sustainability are environmental (natural patterns and flows), economic (financial patterns and equity), and social (human, cultural, and spiritual). Sustainable design is a collaborative process that involves thinking ecologically—studying systems, relationships, and interactions—in order to design in ways that remove rather than contribute stress from

systems. The sustainable design process holistically and creatively connects land use and design at the regional level and addresses community design and mobility; site ecology and water use; place-based energy generation, performance, and security; materials and construction; light and air; bioclimatic design; and issues of long life and loose fit. True sustainable design is beautiful, humane, socially appropriate, and restorative.

What is apparent in the last two definitions, as with numerous others, is that generally sustainability is considered to embody three aspects – environmental sustainability, social sustainability and economic sustainability. This research is concerned particularly with the environmental aspect of sustainability, so the general term 'sustainability' will commonly refer to this aspect. The terms sustainable, green and environmental will be used interchangeably.

The movement for the protection of the environment and the species that inhabit it came at a period when Modernism prevailed as the preferred skyscraper style. First supported mainly by scientists and conservationists, its public popularity was amplified greatly in the 1960s, with publications such as Rachel Carson's *Silent Spring* (1962). Yet this movement appeared just as cheap oil prices lead to a decrease of interest in environmental factors by those in the construction industry, so initially it had very little effect on tall building design.

The green movement flourished in the 1970s, when the rationing of oil supplies to the West by OPEC countries forced governments to search for alternative sources of energy and to reduce their overall consumption. As these were more economic than environmental issues, the guidance and legislation passed by governments was inconsistent and reactive. These recommendations continued into the 1980s, but most architects remained skeptical, seeing them 'as practical aspects of design that had to be faced up to and incorporated within a pre-existing design philosophy' (Jones, 1998: 12). It would take a further two decades before the emphasis on energy efficiency would become somewhat more comprehensive and consistent in both government policy and architectural practice.

The first skyscrapers of Chicago and New York were arguably also the first environmental skyscrapers. The lack of technologies, and afterwards their high cost, forced architects to consider and adapt to the local climate and employ passive measures such as narrow floor plates for daylighting and natural ventilation. Such an approach can be described as the Vitruvian model of design, where architecture is seen as the 'mediation between unpredictable climate and the more stable conditions necessary to sustain functions of human society' (Dean and Forster, 2002: 23). Yet

by the time Modernism emerged, sustainability was no longer a prerequisite but merely an option. The design of taller and more complex building structures then required a large team of specialists in their design, with architects and engineers now acting in different domains. The engineer became responsible for the environmental function of architecture and so the architect focused on the stylistic and spatial concerns of design, disregarding the passive strategies common in earlier towers (2002: 23). With resulting forms often in opposition to climatic requirements, the building fabric soon became no longer seen as a 'mediator' but a 'barrier' to environmental influences.

Contemporary architecture's focus on rationality and the machine aesthetic can be traced to the work of Le Corbusier, but the reasoning behind such a preference has undergone great alteration. What is seldom pointed out is the prevalence of nature in Le Corbusier's writings and works. As David Lloyd Jones affirms, 'he considered nature an agent for the moral regeneration of mankind, capable of rekindling the humanitarian values lost to industrialized society' (1998: 23).

In his early villas, integration with nature is exemplified through the use of roof gardens. The fact that this was one of his noted five points of architecture, as exemplified by Villa Savoye, highlights nature's influence. Yet his rational side also found a use for nature, as a counter-measure to the thermally-induced expansion of concrete and a way to limit rainwater run-off (Dunnet, 2008: 68) Later, particularly in his high-rise projects, Le Corbusier rejected the roof garden, but only as he though it countered his aim of integration with nature. His new approach was to cut out the middle ground, or the city, by placing a parapet enclosing the terrace, so that the view would be on the horizon, nature (2008: 68). Whether this was beneficial or detrimental is arguable, but the fact remains that nature was a key concern of his designs.

A building that represents his later approach, as well as a further focus on building form, is his 1952 Unité d'Habitation in Marseilles, a social housing project widely emulated after World War II. David Jenkins, in a monograph of the project, indicates that it is rooted in Le Corbusier's concept of a vertical garden city. This concept is the synthesis of two modes of urban development in Europe, the suburban garden city, exemplified by individual dwellings and a relationship between architecture and nature, and the city proper, represented by complexity and density (1993: 6).

Corbusier himself proclaims the vertical garden city's two aims (Le Homme et l'Architecture,1947, cited in 1993: 7):

> The first: to provide with peace and solitude before the sun, space and greenery, a dwelling which will be the perfect receptacle for the family. The second: to set up in God's good nature beneath the sky and in the sun, a magisterial work of architecture, the product of rigour, grandeur, nobility, happiness and elegance .

This sentiment would be echoed indirectly in the work of contemporary architects, such as Ken Yeang, who writes of vertical theories of urban design and bioclimatic skyscrapers, although for the next half century the vertical garden city concept remained for the most part forgotten.

At 135 meters long, 24 meters deep, and 50 meters wide, the resulting twelve-storey concrete building, although not a skyscraper in today's terms, nonetheless stood out in low-rise Marseilles. It housed 1600 residents, from single persons to families of ten, in 330 units of 23 different forms (Girardet, 2008: 159-60). The roof was reserved as a public space, with a crèche, gymnasium, running track, children's pool and play area shared amongst its inhabitants. Further services were available at ground level and a mid-level shopping street. Le Corbusier's design of a space 'beneath the sky and in the sun,' although not as verdant as expected of a roof garden, nonetheless was an early example of what is currently regarded as social sustainability.

However, the Unité was more visually successful in its approach to the climate-responsive skin, especially in its use of the brise-soleil. The brise-soleil is a move from the inefficient glass façade and is described as 'the heavy, passive and low-technology counterpart to the mechanical environmental control systems implicit in the notion of the machine à habiter' (Jenkins, 1993: 8). These external, fixed devices are designed to block out solar gain during the summer months and admit it during the winter, while allowing each apartment to benefit form a minimum two hours of daylight (1993: 8).

Yet the orientation of the building undermines their efficacy. Sheltered from the Mistral winds from the north, the block is placed at an oblique angle. This in itself is a climate-responsive strategy, but it weakens the argument for the brises-soleil. The combination of the two, and Le Corbusier's indiscrimination between their depths in the south, east and west facades, creates disparity within the building. While the south façade functions are preferred, the west elevation allows for only two hours of daylight in the summer and about twenty minutes in the winter. Although the

apartments are dual-aspect, the quality of daylight between east and west double-height living rooms is particularly compromised. As Jenkins deduces, 'Ultimately, since the brises-soleil on the east and west facades are of equal depth and position, despite their diametrically-opposed orientation, one is forced to conclude that they have more to do with art than science' (1993: 9).

The Unité d'Habitation in Marseilles, clearly, is not a model for a sustainable residential block. Nonetheless, the ideas behind it, the vertical garden city, with roof gardens and passive solar devices, have only been reintroduced into tall building architecture in the last decade. Much like the proposals of contemporary 'skyscraper as city' projects, Corbusier's idealized location for further blocks is in vast parks, as proposed through his Radiant City model of 1933, in which 88% of land is covered by parks and sports grounds, as well as his later proposal for a linear industrial city (Dunnet, 2008: 69). As Dunnet (2008: 66) points out:

> The specific threat that carbon emissions from industrial processes would lead to global warming and a destructive rise in sea levels, which is of such concern now, had not been identified at that time. But the risk to the health of man from pollution and lack of sunlight common in the dense industrial city were central concerns, and the need to husband the resources of nature, to avoid the waste both of time and materials, was fundamental to his thought.

He further states that Le Corbusier's greatest claim to sustainability was to eliminate what is termed as the Great Waste ('le grand gaspillage'), the waste caused by unnecessary travel caused by suburbia, which, alongside the waste caused by using inefficient construction techniques, would ultimately leave enough free time for man to 'get closer to himself and nature' (Dunnet, 2008: 69).

Le Cobusier's fascination with nature is not unique in early modernism. Jones, in *Architecture and the Environment*, examines the work of modernist architects Alvar Aalto, Frank Lloyd Wright and Richard Buckminster Fuller, all of whom were concerned with nature and who were involved to some degree in larger projects. However, as cities and economies grew, early modern dialogues with nature were displaced with more pragmatic construction systems and the 'purist' aesthetics of Walter Gropius, Mies van der Rohe and Marcel Breuer. As Jones describes, 'This debased brand of Modernism had scant regard for place, economy of means, sensitivity to setting and symbolic relationships between built form and nature' (1998: 31).

This ‘purist’ version of modernism continues to flourish through the present time. Nonetheless, by the 1970s, early signs of a design change were evident in two commercial skyscrapers of that period. The Citicorp Center, completed in 1977, is a New York skyscraper defined by its slanted roof, unlike the majority of the flat-roofed structures of the time. This slanting was in fact designed to hold a giant solar panel array, but was never realized (Lepik, 2008: 98). Likewise, the Hongkong and Shanghai Bank Headquarters, constructed from 1979-1986, also had a strategy regarded as ecological. The provision of natural lighting in the interiors through the use of an external structural system accompanied the building’s use of the cool sea air for air-conditioning and toilets (Lepik, 2008: 98). Yet neither building was envisaged as an environmental skyscraper at its outset, and both towers’ innovations can be seen as a response to the oil crisis occurring during the period.

It was only in the 1990s, when green issues had a higher profile and the International Panel for Climatic Change confirmed that the planet was warming up from the burning of fossil fuels, that architects’ priorities began to change. As Jones (1998: 12) points out once again:

> Finally, architects were forced to re-evaluate the impact that environmentally sound measures could have on their buildings. Gradually it became evident that such measures could contribute in a positive way to a building’s design; that considerations of orientation, natural ventilation, daylight, solar control and thermal capacity could result in potent form-finding building elements. Taken together, they could trigger a new architectural language.

Through new methods, he argues, architects could overcome the ‘sterility’ of the 1980s, contribute altruistically and test out new technologies (1998: 12). It was during this period that the traces of Höweler’s ‘ecological’ skyscraper emerged and famed international architects, not noted for environmental issues, turned to green approaches.

1.7 Sustainability in contemporary tall buildings

During the last two decades, unprecedented awareness has grown regarding global warming and its effect of the environment. The support for conferences such as the Rio de Janeiro Earth Summit in 1992 and the creation of leading bodies such as the European Environment Agency in 1990 have highlighted the urgency and significance of combating the effects of climate change. More voluntary movements, such as the European Climate Alliance and the Clinton Large Cities Climate Initiative have also been successful at least in attracting promises for a sustainable future. Individual countries and cities have further promoted support for environmental

protection and public involvement. Although there have been setbacks, such as the United States' rejection of the Kyoto Protocol in 2001, overall there has been a growing demand for more sustainable cities and lifestyles.

As part of this increasing environmental awareness, there have also been attempts to measure the impact of humans on the environment. The most prominent of these is that of ecological footprints of nations and cities, developed by the Canadian ecologist William Rees and his colleague Mathis Wackernagel. These measurements are defined as 'the areas required to supply them [cities] with food and forest products and to absorb their output wastes, and particularly their output of carbon dioxide' (Girardet, 2008: 113-115). The proposed method calculates that if every person was a Londoner, we would need three planets, and if a Los Angelano, five to sustain their current lifestyles. In terms of land, Canadian, Australian and American cities require eight to ten hectares of productive land per person, far above what is available (Girardet, 2008: 113-115).

Therefore, it is no surprise that the building industry, responsible for approximately half of the world's energy use and forty to fifty percent of global carbon emissions (Battle in Gissen, 2002), among other damaging tendencies, has become more involved in reducing its negative environmental impact. International conferences, such as the Council on Tall Buildings and Urban Habitat's 2008 World Congress entitled 'Tall and Green', have focused on the sustainability of tall buildings, while architectural professional bodies such as the AIA and RIBA request that all new and refurbished buildings to comply with low-carbon targets. Voluntary architectural certification such as the LEED and BREEAM programs have proven popular and often financially beneficial.

Numerous arguments also exist for the health and economic benefits of sustainability, which are common and too abundant to expand on here, so a short summary is provided. Health benefits, such as improved indoor air quality and reduced occurrences of the Sick Building Syndrome are discussed in Edwards and du Plessis (2002), Gissen (2002), *American College of Allergists* (no date) and Yeang (1996). Economic benefits include a reduction in staff productivity losses due to the Sick Building Syndrome (*EHS Services* website, no date), decreased health care and sick leave costs (*U.S. Department of Energy* website, no date) and savings in energy cost. As Yeang (1996) argues, the operational and maintenance expenses make up more than two-thirds of the cost of the commercial skyscraper (Figure 1.2).

He estimates that as much as thirty to sixty percent savings could be made during the life cycle of such a building. Just one bioclimatic strategy, the use of vegetation, can lower wall surface temperature by about 17°C and reduce air conditioning costs by twenty-five to eighty percent (Yeang, 1996).

This is not to say that the tall building type is necessarily the solution for a sustainable future, as indeed convincing arguments against their credentials have been put forward numerous times by various authors. Susan Roaf of Heriot-Watt University, noted for the project and book entitled *Ecohouse* (2007), presents perhaps the strongest case against them in *Adapting Buildings and Cities for Climate Change* (Roaf et al., 2005). She provides a long list of issues that the skyscraper fails to adequately address: health, cost, social, overpopulation, security, solar, wind, light and energy security. Her skepticism is echoed by Peter Blake, whom she quotes (2005: 31):

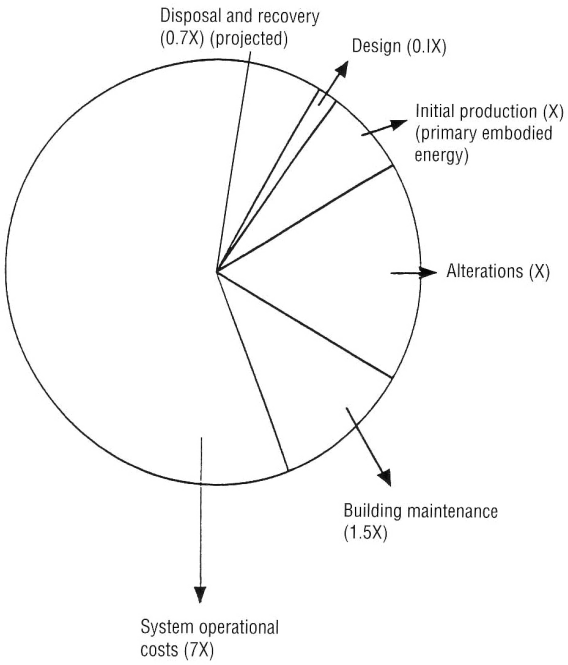


Figure 1.2: Energy costs of a commercial skyscraper (Yeang, 1996)

> The first alternative to Modern Dogma should obviously be a moratorium on high-rise construction. It is outrageous that towers more than a hundred storeys high are being built at a time when no honest engineer and no honest architect, anywhere on earth, can say for certain what these structures will do to the environment – in terms of monumental congestion of services (including roads and mass-transit lines), in terms of wind currents at sidewalk level, in terms of surrounding water tables, in terms of fire hazards, in terms of various sorts of interior traumata, in terms of despoiling the neighborhoods…'

Most of the criticism is on the non-sustainable approaches of typical modern towers, but the argument depicts the tall building as a whole in a negative light. Moreover, Roaf states that climate change is expected to speed up tall building deterioration due the type's exposure to climatic elements as well as poor construction techniques (2005: 249). In contrast, there is an assumption that six- to eight- story buildings are best adapted for dealing with these issues, but whether or not this is a good compromise is 'anybody's choice and anybody's guess' (2005: 259). What is conclusive is that Roaf hopes that 'Perhaps the days of size mattering are over and

our building choice in the future will be dominated by the desire to ensure that what we build from now on has the smallest impacts and lasts the longest time rather than making the biggest impression today' (2005: 260). Whether or not one expects the tall building to play a role in sustainability, this last point is a valuable one to remember in any design.

In contrast to the views of Roaf, the proponents of the tall building argue that a green tower can have many environmental, social, health and economic benefits, some of them discussed previously. However, there is a range of views within this group of supporters: some state that towers have a crucial role to play in building a sustainable future, while others accept them as a higher-energy type that will continue to be built nonetheless and therefore needs to be improved upon. The second of these opinions is common amongst even the most well known proponents of the green skyscraper, including Ken Yeang, who claims that 'Tall buildings, for instance, are particularly unecological and research has also shown that they take 30 per cent more embodied energy to build' (2006: 78). Furthermore, in *The Green Skyscraper*, he recognizes various criticisms of the tall building: 'The reasoning is that by virtue of their enormous size, skyscrapers consume huge amounts of energy and materials and make similarly extensive charges into the natural environment (a charge not denied here), and are inherently un-green' (1999: 18).

However, he states that such attitudes do not take into consideration the entire life cycle of a tall building, as its materials are more likely to be recycled and as it reduces the need for transportation (Yeang, 1999: 18-21). Furthermore, a tower's smaller building footprint is claimed to have a less disruptive effect on natural ecosystems than widespread low- or medium-rise developments (1999: 22-23). Indeed, many designers and researchers of sustainable tall buildings subscribe to Yeang's view, as it promotes the type without dismissing its problems. However, Yeang's commitment to sustainability is rare amongst skyscraper designers, and is nearly always referred to by those researching the type.

Much of the construction industry nonetheless argues that the initial cost of sustainable construction and technologies makes investment in such towers economically unfeasible, especially when their ownership is intended to last a short while. As pointed out in a paper 'The Economics of Sustainable Tall Buildings' (Collins et al. cited in Wood, 2008: 184), the problems that are faced in altering this perception include:

uncoordinated legislation that fails to clearly link cause and effect; insufficient incentives for developers; the fragmented nature of the property and construction industries; and the lack of coherent framework for all the issues that influence the sustainable credentials of a high rise (or other) scheme.

With such a perception, it is unsurprising that most approaches to green skyscrapers have been disjointed and only partially apply the range of sustainable strategies. Perhaps the most prominent trend is the move towards the 'energy efficient' skyscraper, which often focuses on the efficiency of a building's fabric and systems; this trend is discussed later in this chapter. Such buildings are prevalent in Europe and North America, as discussed in the case studies in Chapter 4, but non-Western cities have perhaps been most meticulous in their designs. The Pearl River Tower in Guangzhou exemplifies this concern, as a focus on its HVAC, lighting system and high-performance building envelope contribute to the majority of its energy reduction (Frechette and Gilchrist in Wood, 2008; Fortmeyer, 2008). Despite its innovations, the modernist aesthetic and the engineer's dominance in ensuring environmental performance remain intact.

The Pearl River Tower also represents a second prominent trend in tall building design, that of energy production. Like the DIFC Lighthouse Tower in Dubai (Atkins, no date) and Bahrain World Trade Center (Atkins, no date) and the more drastic Rotating Tower (Dynamic Architecture website, no date), the tower relies on renewable technologies for a further reduction in energy, in this case to a zero energy target; it should be noted, though, that these turbines have not yet been installed. Such buildings' forms are also often based on the expression and placement of the turbines or photovoltaic panels, in effect forming an updated version of the 'expression of technological innovation' found in early Chicago towers. At first confined to Middle East and Asia, the popularity of this approach is evidenced even in cities that are somewhat hesitant with skyscrapers, as illustrated by London's Strata Tower, considered the first skyscraper in the world to have integrated turbines.

However, both trends do not necessarily ensure that all of the primary, bioclimatic design methods are applied, methods which reduce an additional need for energy reduction in systems or energy production through renewables. These technologies at times merely end up 'fixing' the problems created by poor planning of floorplates and insufficient daylighting conditions that could have been prevented in earlier stages of design. Furthermore, the dominance of the engineer in ensuring sustainable design endures, and architects once again remain preoccupied with the

more stylistic elements of design; often, unsurprisingly, the conventional ‘purist’ model continues to be adopted.

These two types are found by the author to represent the most prevalent approaches to green towers. That is not to state that other approaches do not exist, but that they are in the minority, an outstanding example being that of Ken Yeang, whose methods form a starting point for this study an are examined later. Other categorizations of ‘green towers’ also exist, notably the one presented in ‘Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings’ (Oldfield et al., 2009). Summarized in Figure 1.3, the paper classifies a wide range of towers according to their energy consumption characteristics, specifically according to their ‘shape and form, facade, attitude to natural lighting, ventilation strategies, etc.’ Currently, most towers are classified under the ‘fourth’ generation, characterized by their high glazing percentages, lower U-values, a compact shape and a dependence on air-conditioning. ‘Fifth-generation’ towers are considered ‘still relatively rare, at least in completed form’, and described as having a high surface area to volume ratio, high levels of envelope transparency, natural or mixed-mode ventilation strategies and renewable technologies for generating energy. This paper provides a valuable historical evaluation, one that offers much data and support to the sources and discussions in this study’s survey, which was initially written prior to its publication. The ‘fourth-generation’ building in this sense is analogous to the ‘energy efficient’ tower, although it is argued in this thesis that the ‘on-site energy generation’ concept can be interpreted as an extension of the ‘energy efficient’ focus in that the emphasis remains on the performance of the façade and/or additional systems, rather than the building form. It would in any case be interesting to see how data specific to residential towers would compare to the general data presented, and to consider whether the residential type would benefit from earlier energy performance characteristics if a similar methodology was applied.

	1st energy generation	2nd energy generation	3rd energy generation	4th energy generation	5th energy generation
	From the birth of tall buildings in 1885, to the 1916 Zoning Law	From the 1916 Zoning Law to the development of the glazed curtain wall, 1951	From the development of the glazed curtain wall, 1951, to the 1973 energy crisis	From the energy crisis of 1973 to the present day	From the rise of an environmental consciousness in 1997 to the present day
Typical energy performance characteristics	- Compact shape (large volume vs. small façade area) - High levels of thermal mass in façade - Low percentage of façade transparency compared to modern tall buildings - Reliance on natural light penetration - Heating and lifts main consumers of primary energy	- Slender shape (small volume vs. large façade area) - High levels of thermal mass in façade - Low percentage of façade transparency compared to modern tall buildings - Greater levels of artificial lighting - The use of air-conditioning becoming more common	- Compact shape (large volume vs. small façade area) - Low performance, single-glazed curtain wall façade systems - High quantities of façade transparency with tinted glazing - Total reliance on mechanical conditioning and fluorescent lighting - Large quantity of 'black skyscrapers'	- Compact shape (large volume vs. small façade area) - Good performance, double-glazed curtain wall façade systems - High quantities of façade transparency with good solar transmittance - Total reliance on mechanical conditioning	- Slender shape (small volume vs. large façade area) - High performance double-skin & triple glazed curtain wall façade systems - High quantities of façade transparency with good solar transmittance - Natural ventilation possibilities exploited - On-site energy generation promoted

Figure 1.3: 'Five energy generations of tall buildings' (Oldfield et al., 2009)

1.8 Summary

This chapter provided an overview of the history of tall buildings and sustainability. The two concepts have always been linked, more often than not in negative terms. They may share a similar period of existence, but they often portray a very different approach to the built environment. During much of the twentieth century they were considered incompatible and mutually exclusive, but in the last decade a more cooperative vision has emerged. Yet even contemporary 'green towers' reveal an incomplete and early stage of sustainable design approaches. More research is needed for buildings with such ambitions to become the norm and so the next chapter will examine the ways in which such research is taking place.

2 LITERATURE REVIEW: RESEARCH AND FRAMEWORKS

This Literature Review consists of two parts. The first part is a review of research relating to sustainable tall buildings. While relatively little contemporary research exists in this field, the evaluation will include key investigations by researchers in academia, university-based design studios, practices and professional organizations. An effort is made to focus on research relating to residential towers in a temperate climate, although a more general view is at times presented as many of the groups discussed practice internationally. A review of design research and design frameworks follows, many of which are not as specific to building type but whose existence is significant in the study's formation. That section also includes a discussion on the differences between design tools of architects and those of engineers. Ken Yeang's more general framework is then presented and critiqued.

2.1 Research on tall buildings

Although the rate of research on sustainable tall buildings is increasing, the current amount of information is much lower than is common among more established areas of architecture. Much of what is available is of a descriptive, rather than analytical, nature and is often promotional of a specific building. Research on residential green towers is particularly lacking and often presented as only a side note to a commercial concern. Climate-specific information is just as rare; much of it also refers to national rating systems, such as LEED, rather than any particular climatic design influence. While there are a sufficient number of technical studies regarding certain building elements and, especially, technologies that can be used in the green tower, there is nevertheless minimal analysis of the design process specific for the sustainable tall building. Yet due to the increasing number of academics, institutions and practices that have shown interest in the sustainable tall building, more comprehensive research results can be expected in the near future. This section will demonstrate some of the more promising models in academia, higher education, practice and professional organizations.

2.1.1 Academic research

Only a small amount of sustainable tall building research from an architectural perspective exists, although abundant studies on various elements from an engineering point of view are available. This section will consider two types of

researcher, the specialist in sustainable tall buildings and the specialist in sustainability, who contribute to this discussion.

There is a scarcity of researchers, particularly those with architectural backgrounds, that have specialized in tall buildings in general and sustainable tall buildings specifically, although the number is growing. One of the first to specialize in this particular area is Joana Carla Soares Gonçalves from the University of São Paulo. Like Yeang, she emphasizes bioclimatic design and the inclusion of green spaces within the building, although she recognizes that currently only parts of Yeang's vision can be materialized (Umakoshi and Gonçalves, 2007: 230). She has examined many towers claiming to be sustainable, but is quick to point out that technologies such as the double-skin façade can also fail in negative conditions, such as high winds, and therefore should not be relied upon (Gonçalves, 2007 lecture). Much of the support for these findings stems from her 2003 PhD thesis, *The Sustainability of Tall Buildings*, which was published in 2010 as *The environmental performance of tall buildings* and which covers a range of tower functions and climatic conditions. As with much research on tall buildings, it is more qualitative than quantitative; in her case study section, Gonçalves is quick to point out that one of the reasons that the Commerzbank is important is 'because crucial data have been made available on the energy performance of the building since its completion; this is rare for most tall buildings, even for those claimed to be more environmentally responsive and, therefore, more energy efficient' (2010: 238). Expectedly, much of her work has been found useful in the design modules she leads and teaches.

The fact that her book is among the first to critically approach the green tower is telling of the field's nascent status, and a number of other research projects, often in the form of PhD theses, have followed suit. Puteri Shireen Jahn Kassim's thesis at the University of Brighton entitled *The bioclimatic skyscraper: a critical analysis of the theories and designs of Ken Yeang* (2004) examines a number of elements in Ken Keang's design for the hot climate in Malaysia and provides some post-occupancy studies and comparisons. PhD candidate Binh K. Nguyen's and his supervisor Hasim Altan propose a new rating system for the sustainability of tall buildings. Two other notable PhD theses, also published during the research period of this thesis are Philio Oldfield's *Tall Buildings and Sustainability* (2012), which considers sustainability in the broader economic, social and environmental sense, and Antony Wood's *Tall buildings: search for a new typology* (2010), which contributes to 'a new typology for tall buildings which are appropriate to the local, the global and the major

challenges of the age'; both are composed of published papers, some of which are referred to in this text. Such research is increasingly common, but still underrepresented in academia and often carried out by researchers with an engineering, rather than architectural, background. The design principles in the guidance, therefore, often are developed by papers presented in engineering journals or studies carried out by non-architects, but this is not problematic when the main aim is a transfer of information. It does present challenges, as described in Section 2.3.2, when engineering models are adopted to the process of design. It also illustrates the rift between the two professions as discussed in the last chapter.

Other than through collaboration with engineers and other consultants, perhaps the most accessible information on sustainable approaches to tall buildings for architects is more general texts relating to aspects of sustainability. One group, such as Kwok's and Grondzik's *The green studio handbook: environmental strategies* (2007) and Lechner's *Heating, cooling, lighting: sustainable design methods for architects* (2009) compile and translate research findings for general handbooks or textbooks, often intended for university design modules, that can be interpreted for tall buildings with much discernment. Another assumes a technical approach in a particular aspect of, or physical element in, sustainable architecture, such as natural ventilation or light shelves, that can be applied to the building type. These texts include Steemer's and Baker's *Daylight Design of Buildings* (2002) and Johnson's *Low-e glazing design guide* (1991). Again, due to a scarcity of data specific to the tall building, the principles developed in this study also include data from both of these types of sources.

What this section shows is that academic research on sustainable towers, as applicable to architects, is lacking and fragmented. These problems can be attributed partly to the lack of an emphasis on research and publication in many architectural courses, but the more significant reason for their incidence is the relatively recent emergence of the field. Therefore, when a publication capturing examples of notable critical analysis occurs, it is all the more remarkable. One such example is the 2007 Spring/Summer issue of the *Harvard Design Magazine* entitled *New Skyscrapers in Megacities on a Warming Globe*. It arguably serves as model for future discussions, and, as three of its essays are particularly relevant for this study, they are discussed here.

The first, ‘The Tower: An Anachronism Waiting Rebirth,’ is by the writer, curator and consultant Peter Buchanan. He argues that current high-energy tower designs embody a large range of defects, environmental, social and economic, but that ‘the green agenda and the quest for sustainability, the death knell of these kinds of towers, might reinvent and reinvigorate the tall building’ (2007: 5). He presents strong arguments against standard tower designs, before providing examples of towers he believes are more successful, such as the Commerzbank Headquarters, which actually outperformed its expectations in cutting energy consumption from 30% to 50% due to its provision of natural ventilation (2007: 10). Buchanan then suggests that the ‘next big step forward will be towers that generate all their own operational energy’ (2007: 13). Unlike most authors, who continue to focus on commercial towers, he also presents a case as to why residential towers may be the first to achieve such an aim:

> Although technically possible, that is not yet economically viable with office towers that require energy-intensive chilling because of heat produced by the electronic equipment and admitted through the fully glazed envelopes if the automatic controls of the sun-shading blinds are overridden. Office towers also need a lot of electricity for all the equipment they contain, the larger number and higher performance of elevators than residential blocks have, and myriad other electric motors powering various automated systems (2007: 13).

He then discusses Marks & Barfield’s *Sky House* and Bill Dunster Architects’ SkyZED ‘Flower Towers’ as examples. He also mentions the expectation that curved corners and other forms of ‘wind focusing’ are ‘certain to become common’ due to their ability to triple the energy output of turbines (2007: 13), something which is argued by architects elsewhere. Then, in a turn of events, and echoing Roaf (2005), he describes the cities of the future, the ‘Conceptual Age’ as he calls it, as being composed not defined by the high rise. Most people, he argues, would prefer a mid-rise urbanity, a ‘convivial city where community has a chance of being reestablished’ (2007: 14). He concludes:

> Sustainability requires not only that we lessen our ecological impacts, but also that we create the urban and cultural frameworks in which we can attain full humanity, in contact with self, others, and nature. This might be the reason that the tower seems an anachronism. There may be a few clusters of green towers here and there, but their presence might be limited in the compact and convivial cities of the future (2007: 14).

This forecast does not bode well for tall building designers, but nonetheless already holds true for cities such as London, where mid-rise buildings overwhelm permitted skyscraper clusters. What it can in fact suggest is that their designs will much be carefully deliberated, although whether or not they will be ‘green’ is debatable.

The second essay, ‘Truth in Tall Buildings’ is written by Guy Nordenson, a structural engineer and professor at Princeton University. He offers a critique of current practice regarding green tall buildings, arguing that ‘Modern building is not an experimental science. Cities may be laboratories, but the problem is that few scientists are watching the experiments’ (2007: 30). Buildings such as the Commerzbank and 30 St Mary Axe may be iconic, inspirational advocates of environmentally responsive design, ‘But who knows how well their green building systems work?’. He continues, ‘To my knowledge and that of colleagues involved in the designs, there have been no post-occupancy studies to test the original design’s energy consumption projections and natural ventilation simulations’ (2007: 31). Although this somewhat contradicts the previous essay’s statement about the Commerzbank, it is true in the context of the vast majority of tall buildings. Nordenson blames this lack of concern on ‘the clients, academies, and governments who commission, theorize, and legislate without much investment in empirical research’ (2007: 31). He proposes that selected groups of tall buildings follow the protocols of medical studies by establishing benchmark data sets and monitoring key factors. Control experiments and comparative studies between different city climates and tall building practices are encouraged. Whether or not Nordenson’s suggestions would be welcomed by architects is disputable, but Kassim’s (2004) and Nguyen’s and Atlan’s (2011) studies may provide an early, and here unacknowledged, start.

The third essay, ‘No Building is An Island: a look at the different scales of energy’ is written by Michelle Addington, an associate professor of architecture at Yale University. She presents a bleak picture of current design, pointing out that energy use in buildings continues to rise in new projects. More surprisingly, comparisons between buildings of a similar age and size show that those retrofitted with several energy-efficient features used more energy than those that had not been altered. Moreover, she states that:

> Buildings with daylight sensors used 40% more electricity than those without sensors: buildings with Energy Management and Control Systems (EMCS) used 25% more energy than buildings without these systems. Indeed, in every category of building size, buildings reporting any energy conservation feature, from advanced glazing to economizer cycles, consistently used more total energy per square foot than the average building of a comparable size (2007: 38).

She then argues that the ‘fundamental question that now emerges is not one of motivation, nor of practice, but of the determination of the domain of the problem’ (2007: 38). To address it, she uses a case of the high-rise building. According to the Department of Energy (DOE), buildings over ten stories or more have an energy

intensity approximately 50% higher than buildings of three or fewer floors; this is mirrored by statistics for the average electricity use per square foot (2007: 39-9). However, although assumed as true, such statistics can be misleading. An additional piece of data states that the average urban dweller uses less energy than the average rural dweller, and so this situation changes. The DOE database hence states that a typical high-rise building uses 50% to 70% less energy *per person* than a low-rise building. This takes into account only the building operational energy and not the allocations for transportation and infrastructure that is also available to the urban dweller. Consequently, 'basing comparisons on btu's per square feet rather than btu's per person clouds the analyses' (2007: 39). This conclusion questions current practice, including justifications for tall buildings on productivity grounds.

Another point Addington examines is that a building is only a consumer of its embodied energy: the occupants and the systems they rely on in fact consume all other energy types. Addressing this issue involves changing the perception of occupants towards spaces, and challenges two approaches common among green skyscraper proposals: performance-driven design and Zero Energy Building. Through an excessive reliance on technology-specific data, performance criteria 'simultaneously narrow the option, effectively preventing the very type of development and experimentation needed to make any significant headway (2007: 40). Likewise, the Zero Energy Building concept not only isolates the building from its infrastructure-rich urban environments, but also mistakenly views it as an energy producer. Producing energy at the scale of the building, she argues, is 'incredibly inefficient' compared to production in larger systems. Building occupants should instead focus on energy consumption, as this is where the building can have the most impact (2007: 42). The problems reviewed by Addington are also applicable to the 'zero carbon, zero net energy' approach adopted in an early thesis methodology, discussed in Chapter 3.

Addington also considers architectural elements linked with energy efficiency. The application of CHP systems is not regarded as efficient as reducing initial waste heat from equipment and humans, but is considered a 'step up' from other sources of energy generation, such as photovoltaics and biomass boilers. Photovoltaics' low efficiency requires more surface area for power generation; this choice then causes a situation where their poor reflectance, well below conventional curtain wall materials, leads to a higher surface temperature, exacerbating the heat island effect. As biomass and micro-turbines both require a combustion process, releasing heat, a

similar concern ensues (2007: 43-44). Such technologies are perhaps better placed outside of urban areas, as studies suggest their efficiency is higher there, for 'it is highly unlikely that a high-rise urban building would provide an appropriate site' (2007: 44). Addington continues:

> Instead of asking how we can use buildings as energy generators, we should be asking how to most effectively generate and distribute energy. Instead of asking how to design buildings that produce enough energy to cover their internal needs, we should be asking how we can eliminate points of consumption through rethinking our design process (2007: 44).

In essence, this leads back to the application of passive design principles and a greater knowledge of subjects as varied as neurobiology. She also points out that renewable energy systems should not be used to offset a new additional load, but to replace less efficient technologies (2007: 45). In these ways, she echoes the thoughts of bioclimatic designers such as Yeang. Finally, she criticizes the 'path of least resistance' towards green buildings that most designers have chosen, stating that:

> High-rise buildings in dense urban areas do have an important future, since they may well offer the best opportunity to consolidate services and interior spaces to most efficiently serve human needs. But the green skyscraper, as an idea and as a building, is a red herring, since it maintains the illusion of the building as an entity unto itself. Buildings will play an enormous role in the decoupled systems of the future, but it will be a subordinate role of facilitation and support for a populace beyond the walls of any given building, not the starring role in a one-man show (2007: 45).

These three essays represent a rare analytical view of existing green towers. They fail to agree at certain points, for example on the urban role of the tall building, but this diversity of views is often missing from the promotional characteristic of many sustainable tall building articles available. Issues such as the role of residential tall buildings, post-occupancy evaluations and renewable technologies are not questioned as much as they should to be elsewhere. These essays therefore present a critical perspective for an often-blind enthusiasm of tall buildings, and, in so doing, encourage more empirical research.

2.1.2 Research in university-based design studios

Considering the trend towards sustainability in tall buildings, the number of university-based design studios concentrating on the green tower is somewhat small. As their primary concern is often teaching rather than research, for the purpose of this chapter short summaries of two such groups are sufficient:

- The Tall Buildings Teaching and Research Group, is linked with the University of Nottingham's Institute of Architecture and the Illinois Institute of

Technology in Chicago, both of which run tall building modules with a environmental design focus (*TARG website*, no date). The University of Nottingham, as of 2009, has formed the first Masters course on green towers, the MArch in Sustainable Tall Buildings.

- Chris Abel, author of *Sky High: Vertical Architecture* (2003), established the Vertical Architecture Studio at the architecture departments of the University of Sydney, the University of New South Wales and the University of Nebraska. It aims to mark 'a departure from conventional high-rise studies,' and so 'focuses on alternative models of sustainable high-rise design, and new kinds of spatial and functional relationships between tall buildings' (CTBUH website, no date).

These are in addition to one-off projects and recent design studios, such as those carried out at Dessau Institute of Architecture, IUAV University of Venice, Kind Saud University, University of Calgary, University of Illinois Urbana-Champaign and others (CTBUH website, no date).

The work of such department-led, studio-based research groups contrasts with traditional academic, text-based research methods. A sense of experimentation that is often lacking in practice is also found there. The growth of such modules also points to the increasing responsibility of universities in promoting and developing sustainable approaches for tall buildings.

2.1.3 Research within practice

Despite the relatively slow uptake of bioclimatic strategies in some practices, 'sustainability' is now a ubiquitous term in office profiles, and internal 'sustainability teams' are not uncommon. This section will therefore consider the architectural practice, not to exhaust the ways in which the approach is implemented, but to offer a synopsis of its types as they relate to the tall building.

Architectural offices often adopt sustainability as an additional service, and the green towers form a subset of its research agenda. Nonetheless, there is much diversity in how they are organized, partly due to the constraints in office size. A few of the research groups or collaborations within offices include:

- Skidmore, Owings and Merrill (SOM) formed a partnership with Rensselaer Polytechnic Institute to host the Center for Architecture, Science and Ecology (CASE) with an agenda of 'pushing the boundaries of environmental

performance in urban building systems on a global scale, through actual building projects as research test beds' (CASE website, no date). In more detail, 'CASE aims to implement changes to building practices with international impact in three priority areas: energy consumption; sustainable resource management; and quality of access to essential resources: Fresh Air, Clean Water, Natural Daylight, and Plant and Animal Life.' Given the urban emphasis and SOM's association with tall buildings, unsurprisingly many of CASE's research projects, including those related to parametric modeling and building-integrated active phytoremediation systems, are applicable to the building type.

- Foster and Partners have established a Research and Development Group, which includes a Sustainability Forum, within its studio. 'The Forum was established to consolidate and develop the practice's knowledge base and has allowed us to develop better access to information on new products, materials, and research findings.' This research is then applied to various projects and the creation of new technologies. Like SOM, it claims that 'sustainability is an issue that has driven the work of the practice since early days,' although this once again is much more visible in recent projects (Foster and Partners website, no date).
- Aedas, likewise, hosts a Sustainability Team within its Research and Development Group. It has established projects such as CarbonBuzz, which 'provides a platform to benchmark and track project energy use from design to operation' and Green Book, an online Tool and Design Guides 'that assist designers in communicating sustainability and incorporating passive and active systems for sustainable design.' Although its projects thus far are not designed specifically for tall buildings, they are intended to be applied in all types of projects, including skyscrapers (Aedas website, no date).
- Llewelyn Davies Yeang is a further example of how a practice can evolve once a strong sustainable component is added. The office was established in 1960 as Llewelyn-Davies Weeks and became prominent through its masterplanning of Milton Keynes. In July 2005, Ken Yeang joined as a partner, making sustainability into one of the firm's foremost concerns. It is now, according to its website, mainly 'dedicated to being the world's leading architects, planners and designers delivering innovative signature deep green buildings, and ecodesign strategies.' It has furthermore added a new unit, Eco Systems, committed to 'providing innovative and sustainable solutions' for a wide range of users. The practice has authored numerous publications

and been involved in a large number of seminars (*Llewelyn Davies Yeang website*, no date).

- Arup Associates, though not a traditional architectural office, is Arup's subsidiary design unit that attempts to bridge the gap between architects and engineers (Arup Associates website, no date). The sharing of information and skills within the unit is complemented by input from Arup's services such as Sustainability Consulting and publications such as *It's Alive* (Hargrave, 2013) that considers the future of urban buildings in terms of technologies and material choices, though not specifically emphasizing form-making.

Further examples of approaches in practice can be found in the case studies and elsewhere, but the main concern here is to illustrate that much of the current research regarding tall buildings is of a non-traditional nature. Moreover, as environmental science appears to have been more of a concern of engineers than architects before sustainability became a popular issue, contemporary architects are increasingly involved in this type of research to meet the demand for environmentally-responsive buildings. What is important to note, then, is that research on the sustainability of tall buildings is often of a fragmented, but nevertheless multi-disciplinary, form. What constitutes 'research' in the traditional sense is therefore difficult to discern.

2.1.4 Research in organizations

There are increasing numbers of local, national and international organizations involved with urban buildings and/or sustainability, but perhaps the one most relevant to this study is the Council on Tall Buildings and Urban Habitat (CTBUH). Although not founded around the premise of sustainability, the organization has nevertheless in recent years become one of the most successful in terms of promoting environmental issues within tall buildings. Its 2008 *8th World Congress* exemplifies this direction, which was attended by nearly one thousand professionals and academics. The conference's theme was 'Tall and Green: Typology for a Sustainable Urban Future' and the event included over a hundred presentations and resulted in numerous published papers. Many of the sessions had a 'tall' focus, particularly as the Burj Dubai was of great interest at that time, but the 'green' message also produced many research-driven papers. Session topics ranged from 'Alternative Design Thinking' to 'Sustainable Structural Systems,' mostly of them admittedly technical, but it also effectively portrayed a wide variety of research under

development. The Congress was also a starting point for the establishment of, in 2010, the Council's Research, Academic and Postgraduate Working Group, which looks to promote networking and collaboration related to tall buildings. It forms part of the CTBUH Research Division, which 'provides support and advocacy for building research that promotes resilient and sustainable building development' (CTBUH website, no date).

Most architecture-based organizations, such as RIBA and the AIA, have also been involved in the research and promotion of research on sustainability at various levels. Sustainability-oriented organizations generally welcome the debate on tall buildings. A number of cities have also hosted numerous conferences on sustainable tall buildings. London exemplifies this trend. Within two years, it hosted a *Talking Tall* conference in 2006, organized by Taylor & Francis and the CTBUH and a *Designing Tall Buildings* conference in 2008, hosted by the *Architect's Journal*.

2.2 Design Research

Ken Yeang poses the questions: 'what is a tall building and is there a theory for the design of the tall building? But an even more niggling question is, can there be architectural theory at all? For architectural theory can be perceived as an admirable endeavour to make architecture theoretical rather than a body of theory that is architectural' (no date). His question, referring to a text by Mark Linder (1992), is a significant one, as it has yet to be addressed by most tall building designers in the context of sustainability. This section argues that a theory of design for the tall building can aid the transformation of the type towards a more environmentally-responsive approach.

Design research is a concept that can be traced back to the 1960s. It quickly gained interest amongst a range of academics and professionals, notably John Christopher Jones and Bruce Archer, culminating in the formation of the Design Research Society in 1966. Design research encompasses a wide range of design fields, such as industrial and graphic designs, and therefore it naturally incorporated ideas from fields unrelated to design, such as computer programming. An illustrative example of this convergence can be seen in *A Pattern Language* (1977) by Christopher Alexander, who developed a practical system consisting of 253 'patterns,' or design suggestions, for application in the varying scales of the built environment. This scale ranges from regions to interior fixtures, alongside 'patterns' for individual buildings.

The system assumes that only classical patterns, which have been tested successfully, are those that should be applied to certain circumstances. There is a strong link to mathematics and computer science, as the fields utilize the terms 'generative grammar' to describe a similar system. It is therefore unsurprising that the application of a 'pattern language' has been successful in fields such as engineering as much as architecture. In fact, the format of the proposed tall buildings guidance owes much to the theory and presentation format, based on extensive illustrations, of Alexander's book.

Over the last four decades, design research expanded as a field, producing specialists such as Jeremy Till, Murray Fraser and Herbert Simon. Publication such as Peter G. Rowe's *Design Thinking* (1991) have provided a generally creative field with more systematic processes of designing, while others, such as Brian Lawson's *What Designers Know* (2004) and *How Designers Think: The Design Process Demystified* (2006) consider the origins and applications of design knowledge and thinking. A summary of the types of research constituting design research can be seen in the timeline of Figure 2.1; 'Sustainability' here is included, but dated as staring some decades later than often assumed. The growing number of organizations and journals in the field of design research testify that it is now an established and complex field.

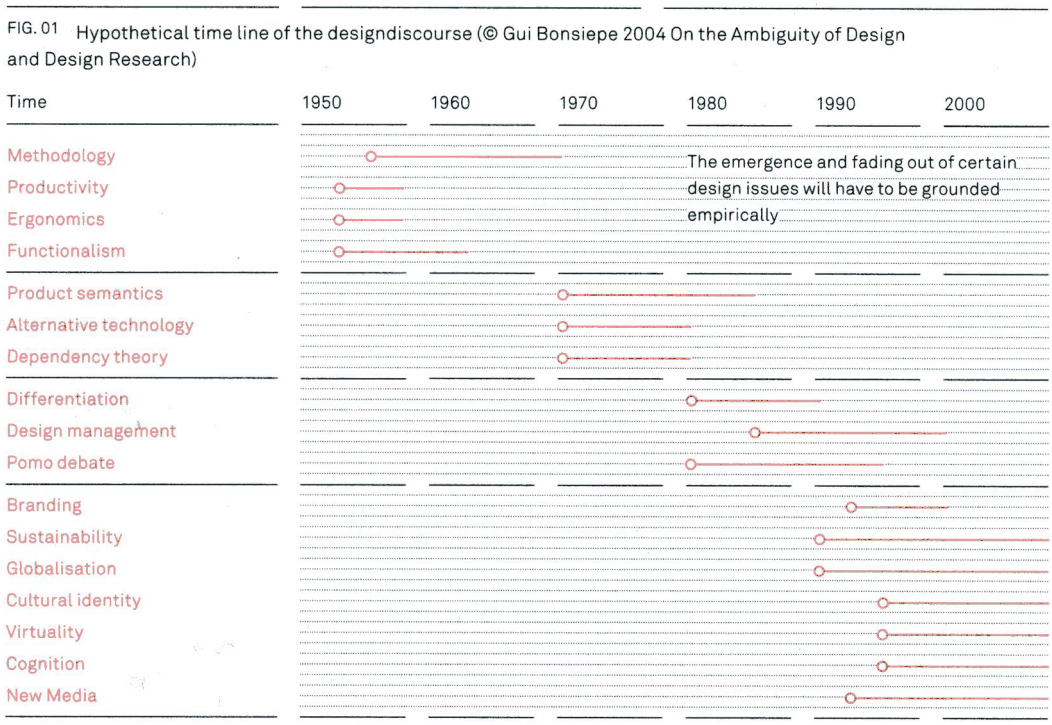


Figure 2.1: Timeline of Design Research (Bonsiepe in Michel, 2007: 33)

A useful place to begin a review of current practice is through a recent compilation of texts titled *Design Research Now* (Michel, 2007). Here the Board of International Research in Design (BIRD) presents a variety of contemporary positions and approaches relating to design research in order to illustrate the lack of any central themes behind the practice. Design here is not specific to architecture, but includes fields as varied as communication and photography and the essays presented have differing visions of the role of research in design.

Many of the essays approach similar problems and responses. One issue is the differentiation of design and scientific research as respectively non-cognitive (visual) and cognitive (research) activities. This argument is used to dismiss design research as a genuine field, but such a position fails to recognize the experimental nature of both design and science and the fact that the two fields are becoming less exclusive. As Gui Bonsiepe (2007: 29) illustrates:

> One example should make this clear: nowadays, when an industrial designer is commissioned to design sustainable packaging for a carton of milk for a client, she or he will need to access scientific information about energy profiles and *ecological footprints* and, if necessary, to systematic experiments on material combinations to place design activities on a scientific footing. It is no longer possible to tackle a task of this nature intuitively.

Like the milk carton analogy, tall building design now requires 'energy profiles' and 'ecological footprint' data, and, conversely, data for further research can be extrapolated from such resulting design experiments. The increasing dependence of architectural design on fields such as engineering and sociology further demonstrates this convergence and as ecology becomes a more prevalent driving force behind designs, the scientific base behind design research becomes more pressing.

There is some debate whether or not scientific research is actually beneficial for design. Klaus Krippendorff considers 'design research' as a 'debilitating oxymoron' as he views research as based on past realities whereas design aims to propose future ones. 'Science articulates the constructions that worked so far,' he states. 'Design articulates constructions that might work in the future – but not without human intervention.' If design were to follow science as practiced today, he argues, design would be limited to past models (Michel, 2007: 79). Similarly, it could be argued that most architects also have an approach that overlooks scientific research in fear that it might stifle creativity. This is particularly evident in contemporary architecture's lack of compatibility with the natural environment. Yet this disregard for

nature and the parameters it sets for built forms is what is needed today, as basing architecture on scientifically-verified principles and design processes may be the only way to mitigate the negative environmental influences of non-cognitive design practices. Looking into the future, then, requires research on existing bioclimatic parameters.

Beat Schneider points out that disciplines such as medicine, sociology and the engineering sciences began as practical professions that *applied* science before being classed *as a* science. The fact that design now requires progressively applying knowledge and meeting the standards for conducting research common to scientific fields can place it in the 'scientific' category (2007: 212). Architecture, specifically tall building design, has some distance to cover before this change takes place, but it appears to be moving in this direction. This is not to state that architecture should no longer be an 'art.' Indeed, much of the character of architecture, as opposed to that of engineering, stems from its artistic pursuits, but, as was discussed in the literature survey in Chapter 1, architecture and engineering need to find additional common ground if they are to result in more sustainable outcomes. This then also implies that science, for the same purpose, will have to be more inclusive of fields that seek to apply it.

There is certainly a history of architects claiming to have applied science as the basis for their design endeavors. Le Corbusier's 'machine for living' and much of the work of Buckminster Fuller exemplify this trend. Yeang's own focus on research and the application of bioclimatic and ecological principles to the built form qualifies as a recent illustration of this approach. As these architects also exemplify approaches that relate to the environment, it is perhaps not a coincidence then that sustainability may bring research and design closer together. Architecture in general, and tall buildings specifically, need to abandon the predominant value system that rates buildings on their potential as icons and instead create one that evaluates their impact on the earth's ecosystems. As the works of Corbusier, Fuller and Yeang portray, a more pragmatic approach is not necessarily limiting; their projects indeed show that such approaches can instead lead to some of the most memorable architecture ever constructed.

2.3 Design frameworks

This section will describe several approaches that are specific to sustainability, though general for building type, and that were influential in the development of the design process proposed in this thesis. It will first examine those approaches that are at times confused with a design process named as the 'framework' in this thesis. These include 'checklists', assessment tools and general design guides. The differing understandings of design tools by architects and engineers will also be considered.

2.3.1 Checklists, assessments tools and general design guides

As shown in section 2.1.3, a growing number of practices have embarked on research related to sustainability, and this concern has at times resulted in an adoption of certain design guidelines that are adopted in their projects. One of the most notable of these is Hellmuth, Obata + Kassabaum's 'experiment' that involved moving 'their projects and the profession as a whole towards sustainable design,' published as *The HOK Guidebook to Sustainable Design* (Mendler et al., 2006: xv). It arranges its guidance as 'Ten Key Steps' for the stages of the design process in the order of 'Project definition', 'Team building', 'Education and goal setting', 'Site evaluation', 'Baseline analysis', 'Design concept', 'Design optimization', 'Documents and specifications', 'Bidding and construction' and 'Postoccupancy' (2006: 17). A clear aim is to integrate the practice's design process with the requirements of the LEED Rating System, so unsurprisingly there is a focus on the sustainable use of materials and the reduction of waste (2006: 14). Like Arup Associates, the practice questions the 'traditional design process' in terms of limited team interaction, proposing instead a 'change from a serial collection of discrete tasks performed with little interaction between players to a collaborative and self-conscious effort to integrate design strategies between all disciplines and all players in the project delivery process' (2006: 16). This focus is evident in the presentation of the framework, which resembles a series of checklists for each key step and which are organized around LEED's own categories of sustainable sites, water efficiency, energy and atmosphere, materials and resources and indoor environmental quality. Every checklist recommendation specifies parties to be involved, including planners, architects, interior designers, engineers, landscape architects and owners. Although all parties are to be included, it is for the architects, often the clients' first point of contact, to ensure that such collaboration takes place.

The authors assert that 'LEED should be viewed as *a floor and not a ceiling*' (2006: 28). LEED, and the buildings produced with its application, are therefore not intended models of sustainability, but rather as steps towards that goal. Despite this statement, it is clear that LEED determines the hierarchy of design considerations, which are not necessarily established by the site's local climatic conditions and which may inhibit bioclimatic design. Furthermore, the 'checklist' nature of the recommendations mimics LEED's own 'checklist' approach, which is often criticized as limiting and not necessarily resulting in a comprehensively 'green' building; these critiques are further explored in Chapter 5. Therefore, although informative and offering design principles that are further explored in the proposed design process for tall buildings, HOK's 'checklist' approach was not adopted as a model.

Like the 'checklist', a 'framework' for design is at times confused with an assessment tool. An example of such a tool is Ove Arup Partners' SPeAR, developed to examine the London Bridge Tower and which aims to:

> assess the sustainability of projects, organizations, developments or buildings using four pillars of sustainable development. Environment, Natural Resources, Social and Economic. It calculates the relative impacts of a number of factors under each of these headings and represents them on a chart to enable visualization of where improvements can be made or to enable comparison of different options or projects' (Guthrie, 2008: 99).

The tool is in the form of a circle, meant to represent interdependency of impacts, and it also includes a social sustainability aspect. The four 'pillars', or segments, of the circle incorporate further sub-segments of specific strategies. The success of the tower is indicated by the proximity of colored markers to the circle's center, with the boundary of the circumference representing poor performance (Guthrie, 2008: 99). The London Bridge Tower's generally high score, some of which can be attributed to the central location of the building, is presented in Figure 2.2.

Therefore, this assessment tool is intended to evaluate, rather than guide, the design process. Although it can point out to inadequacies in the resulting building prior to construction, which may lead to some adjustments in the design, it nonetheless does not offer any specific guidance on design methodology and, as with 'checklists', does not offer a form of hierarchy that may, for example, highlight the need for bioclimatic approaches prior to inclusion of efficient technologies. This end-of-design focus also offers clues as to why it was developed by an engineering, rather than an architectural, practice and as to why architects are less likely to adopt it. The thesis' proposed design framework, on the other hand, intends to offer architects a methodology for the schematic design of sustainable tall buildings.

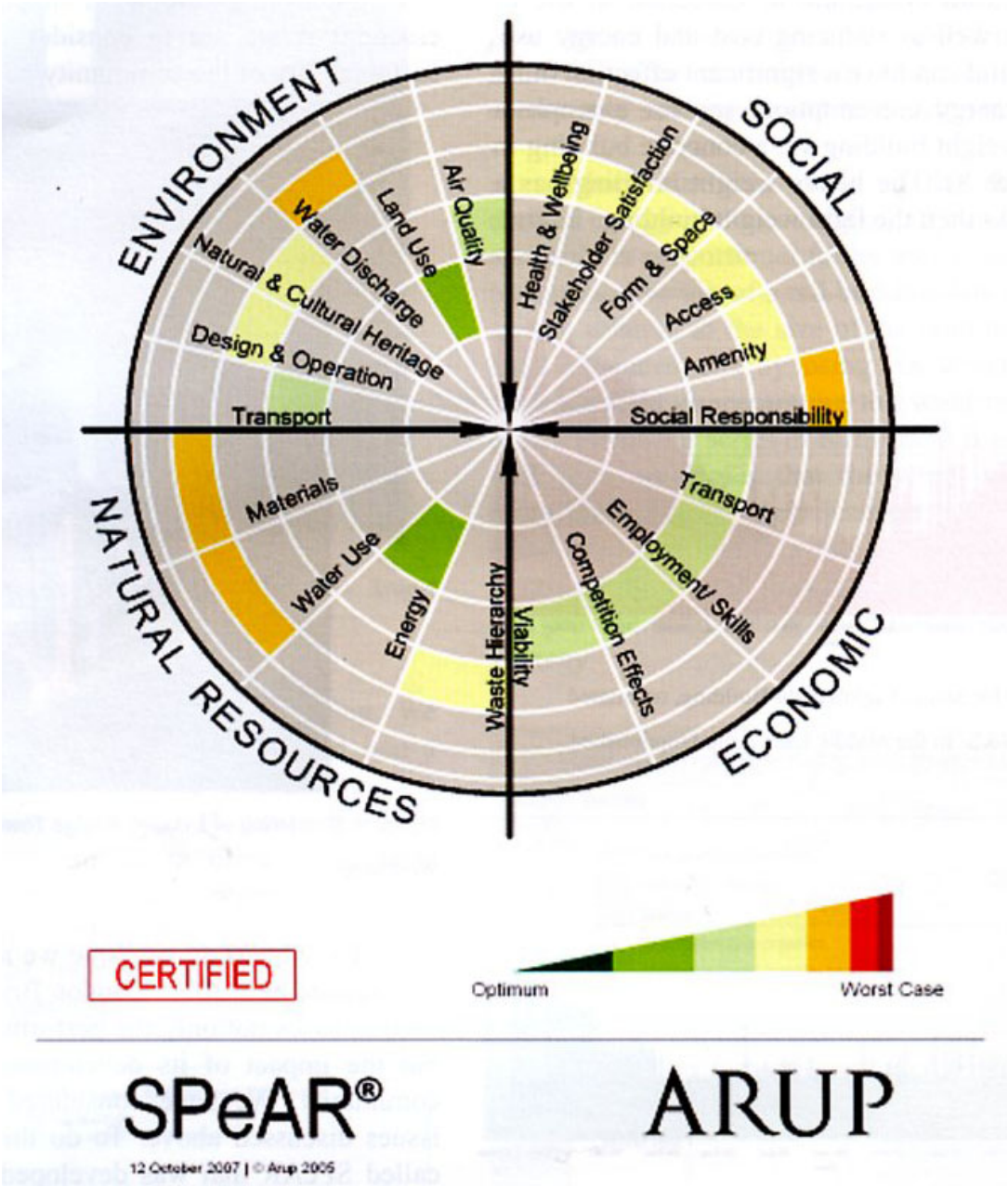


Figure 2.2: SPeAR Assessment Tool (Guthrie in Wood, 2008: 100)

Design guides, usually in the form of textbooks intended for students and practitioners, offer general guidance on various aspects of sustainable design. Some of these are also mentioned in Section 2.1.3 and include:

- Kwok's and Grondzik's *The Green Studio Handbook: Environmental Strategies* (2007);
- Lechner's *Heating, Cooling, Lighting: Sustainable Design Methods for Architects* (2009);
- Brown and DeKay's *Sun, Sind and Light: Architectural Design Strategies* (2001);

- Halliday's *Sustainable Construction* (2008)*;*
- Hausladen et al.'s *Climate Design: Solutions for Buildings That Can Do More with Less Technology* (2005);
- Olgyay's *Design with Climate* (1963);
- Sassi's *Strategies for Sustainable Architecture* (2006);
- Smith's *Architecture in a Climate of Change: A Guide to Sustainable Design* (2005); and
- Watson and Lab's *Climatic Building Design: Energy-Efficient Building Principles and Practice* (1983).

These guides, often presented as 'handbooks' or 'textbooks', usually present a variety of design principles, or elements, within broader categories, often either relating to climatic conditions, such as 'promoting solar gain' or general environmental concerns, such as 'recycling'. They are like 'checklists' in that the principles are usually presented with equal weight amongst them, but in this case are discussed much further, often with the support of recognized studies carried out by the authors or other researchers. They may also be linked with rating systems like LEED, as it the case with *The Green Studio Handbook* (2007), but their primary organization is based around themes that the authors consider as essential. They often include diagrams and illustrations, alongside charts and tables, which may be more inviting for architects. Case studies are prevalent, often showcasing projects that have applied some of these principles and serve as models for contemporary green design. All of these positive aspects have meant that these design guides have had a considerable influence on the development of the study, particularly its content.

However, design guides are not to be mistaken for a design process. Although the proposed study does include guidance for design, it also attempts to address some weaknesses in its unsystematic application. One is it 'generality' in terms of building type and climate; although some attempt to resolve this issue, often the specific guidance is embedded within a large volume of text. More importantly, though, is the common lack of a hierarchic, systematic approach to design. This shortfall excludes it from offering a design method that can be followed step-by-step through in schematic design, even when general categories such as 'orientation for solar gain' are included.

It should be noted, though, that the lack of a hierarchy, within both design guides and other texts, is sometimes rudimentarily approached in appendices. One of the most relevant examples for this study is one claiming to provide 'an overview of the importance of different measures – both passive and active – relating to eleven climate zones' and which is found in David Lloyd Jones' *Architecture and the Environment: Bioclimatic Building Design* (1998: 245). Represented as a chart in Figure 2.3, it rates design strategies, or design measures from 'No Importance' (0) to 'Very Important' (7) as they relate to a specific climate, and therefore infer a level of prioritization. The strategies include both passive an active comfort measures, such as natural and mechanical ventilation and are further defined in detail on a separate page. Embodied, grey and induced energy, comfort management and energy generation are not ranked as they are described as constant in any location (1998: 245).

Also noteworthy is that an accompanying climate zone map contrasts with the climate types defined in Chapter 3 that are used for this study, and so the most applicable climate types there are those labeled as 'Continental' and 'Temperate'. Nonetheless, both types share a similar ranking of priorities and strategies to avoid. There is a high priority placed on insulation, solar and free (geothermal) heating and a low one on artificial cooling, evaporative cooling and lightweight construction. There is a strong support for 'passive' measures, with 'active' methods used only to enhance them (1998: 244). Needless to say, its emphasis on bioclimatic design had a significant influence on the development of the research.

To conclude, there are several types of approaches towards sustainable design, which may be mislabeled as 'frameworks' when in fact they serve as 'checklists', assessment tools and design guides. Although they have contributed to the development of the framework, their aims and structure cannot be understood as determining its format. A notable omission in this section is the framework developed by Ken Yeang, which has been left to the end of this chapter as his work is has particular significance to this study. However, prior to that investigation, a theme has appeared in this and previous sections that requires further consideration, and that is the different approaches to design by architects and engineers.

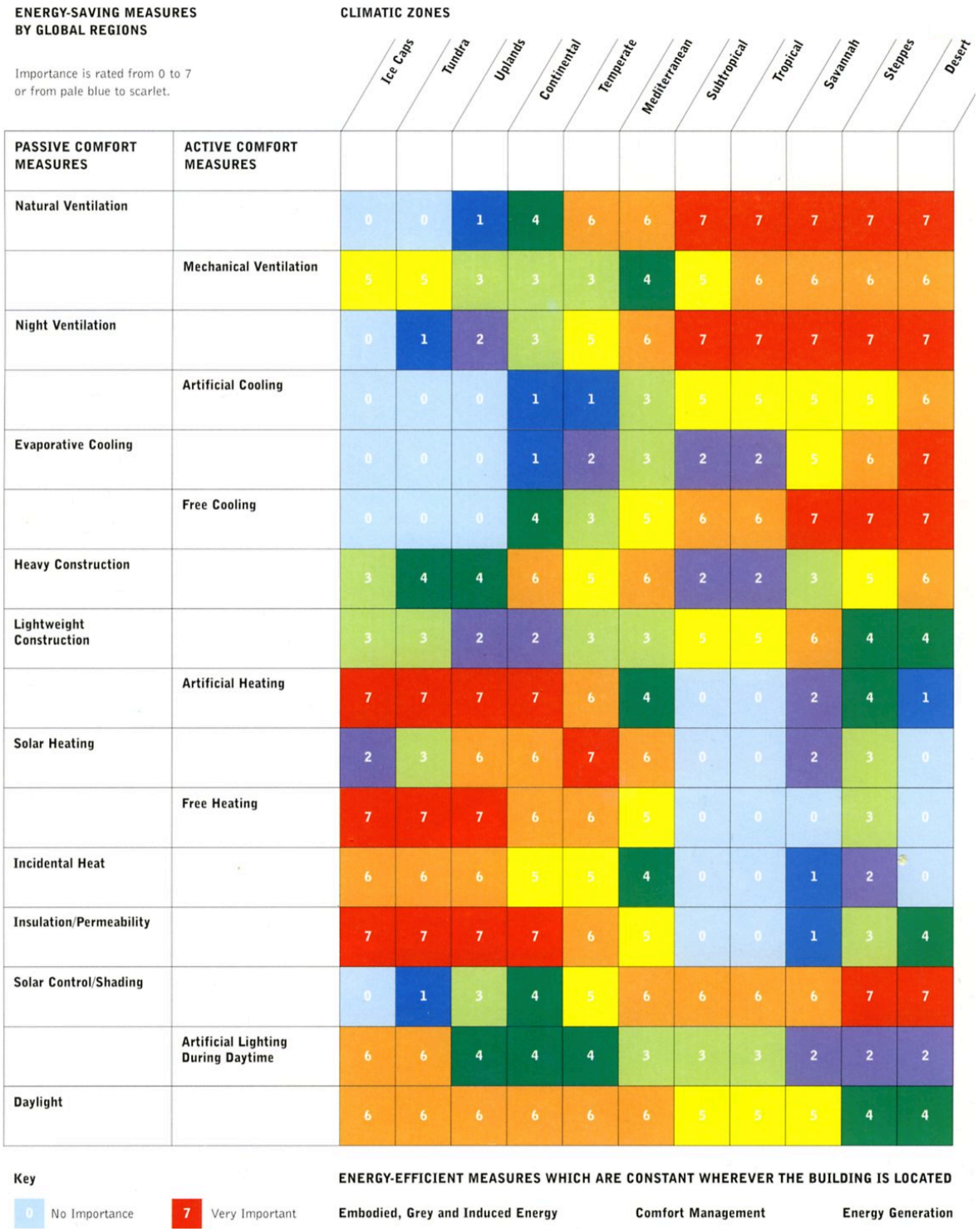


Figure 2.3: 'Energy Savings by Global Regions' (Jones, 1998: 245)

2.3.2 Differing approaches to design within professions

The modern disconnection between the roles of architects and engineers in aspects pertaining to sustainability has emerged as a theme in this research and warrants further mention as the proposed guidance is specifically intended for architects. An instructive example of these differences can be found in Balcomb's (1992) discussion on design tools, and so this discussion will begin with his observations.

In *Passive Solar Buildings* (1992), Balcomb, himself an engineer, begins his argument by noting that 'Many believe that a key factor in the transfer of passive solar technology from the research level to standard practice will be the development of suitable design tools' (1992: 16); this assumption, indeed, is one that the thesis supports. He then offers some connotations associated with the term and its advancement:

> The term "design tool" means different things to different people. Many architects think of a design tool as an aid in the design process, whereas many engineers (who usually are not designers) think of design tools as computer programs. A computer program can certainly be a design tool, but few are. Design tools sometimes evolved out of practical experience as a codification of conventional wisdom. This may come from an aggregation of experience in design offices or as a result of feedback from the field regarding successful applications of a particular design procedure. Some very effective design tools are simple graphical procedures. However, most of them originate from the repeated application of a complex analysis procedure.'

Balcomb's book focuses on the last noted origins; the guidance developed in this study can be held to have evolved from the Yeang's 'conventional wisdom' in the form of design principles to a more analytical and tested design procedure, as discussed in the Chapter 3. The term 'design tool' is loosely used by Balcomb, at times referring to a procedure relevant to one aspect of design, as opposed to the guidance's use to encompass the wider range of schematic design. Balcomb's 'design tools' are nonetheless useful and categorized into evaluation tools, i.e. 'energy-analysis computer programs', and guidance tools (1992: 21). As the former type is applied after, and the latter type before, a design step is taken, it is the latter that is of most interest to this research. However, in an uncommon critique of Balcomb's distinction, Reynolds (cited in Balcomb, 1992: 485) points out that guidance tools for many designers 'are only a guide as to where to start' and so implies some form of evaluation carried out by the designer. This is assumed particularly true for tall buildings, and so this study, while offering a guidance tool, nonetheless recognizes that some form of evaluation will be necessary, although in this case most likely by a specialist due to the type's complexity.

The way in which a design tool is developed forces further problems. There exists a contrast between the approach of the 'developer', who advances a 'complex analysis' into 'simplified techniques' often based on simulation, and the 'user', who 'wants simple techniques first, even if the results are approximate, and may use complex analysis later in the design process, if at all' (Balcomb, 1992: 17). Resulting design tools can then be indecipherable to the user as they may be presented as 'mathematical treatises' rather than simple guidelines. On the other hand, the users 'do not realize that although guidelines are the simplest to use, they can be the hardest to develop' and that the developer may not be familiar with design practice to understand and meet the users' needs (1992: 17-18). These difficulties quickly became apparent when the guidance's author, an architect, attempted to comprehend and translate such guidelines into a design-led process.

Furthermore, Balcomb (1992: 23) argues that 'design tools must be tailored to a particular class of user *and* to a particular phase of design'. As architects, builders and engineers 'speak different languages, take different approaches to the problem, and have different expectations', they therefore 'require different tools'. The guidance, likewise, offers a tool specifically for architects and the schematic design phase. The description of term 'schematic design' applied here is that of the AIA (AIA website, no date) as a the first phase of the design process in which the architect consults with the client and produces documents, in the form of site plans, floor plans, sections elevations, models, etc., that 'illustrate the concepts of the design and include spatial relationships, scale, and form' and 'include overall dimensions'. In other contexts, such as that of Kwok and Grondzik (2007), it also encompasses the 'conceptual design phase' that precedes schematic design and is not included in AIA's phases.

Balcomb (1992: 22-23) also offers a valuable critique of 'rules of thumb', the most common form of the guidance tool, as being too general and unrelated to climate; he points out that rules of thumb 'thus do not integrate the essence of bioclimatic design.' He uses as an example of 'The area of south-facing windows should be 10% of the floor area', which 'fails to account for climatic variations or other critical factors, such as building internal heat generation or the need for daylighting.' This problem, also discussed previously, is widespread in guidance either 'simplified' for, or written by, architects. The proposed framework therefore aims to provide guidance, when available, that relates to the specific climate and building type and which allows for links between the more specific 'rules of thumb'.

Balcomb's arguments are generally supported by John S. Reynolds, who, in a chapter of his book, 'presents a short but precise review of design tools from the perspective of an architect' (1992: 33). The summary of Reynolds's review, although dated from 1992, still appears accurate two decades later in many respects: 'Reynolds points out that in recent years we have seen a tendency toward sophisticated, numeric-based design tools that are strong on evaluation but weak on guidance' (1992: 33). He separates the design tools into 'conceptual', 'schematic' 'developmental' and 'final' tools, the last of which require detailed simulations and are often completed by consultants. The proposed framework is mainly a schematic tool in that it provides rules of thumb for the 'first sizing, shaping, and placement information for elements of a building at a specific site', although some conceptual tools, such as building orientation, are included (1992: 488). He then offers further details on various approaches to these categories, such as that of Olgyay (1963), which are too numerous to list here, but many of which are considered in the study.

Addressing all the shortcomings discussed in this section within the guidance is not a straightforward or simple task, as evidenced by the lack of existing tools. 'The challenge,' Balcomb writes, 'is to devise guidance tools that are simple enough to be employed early in the design process and yet comprehensive enough to be useful' (1992: 23). The proposed framework, though it will inevitably fall short in some respects, aspires to offer a structure to address that challenge.

2.4 Ken Yeang and his framework

A discussion on sustainable tall buildings and frameworks would not be complete without considering the work of Ken Yeang. A Malaysian architect, trained in the United Kingdom, Yeang is known widely as the 'father of the bioclimatic skyscraper.' Both his written and architectural works have had a great influence on the design of sustainable tall buildings. In fact, he is often considered not only the original advocate of green towers, but also the only architect that has consistently developed his tall building designs on the basis of climate. Notably as well, he is amongst a small number of practitioners who developed a theoretical framework encompassing sustainability. This section will offer a brief introduction to the background and development of his framework, both of which have had a great influence on this study. A critique of his approach will follow. It will not, however, consider his background in detail and will instead emphasize those aspects that have had most

influence one the thesis's framework development. A large number of descriptive books and articles, some referred to in this text, are available on his background and individual projects; a more succinct, but critical, overview is found in Kassim (2004). A small selection of his projects will be examined in the case study section in Chapter 4.

2.4.1 Ken Yeang introduction

Ken Yeang's first bioclimatic high-rises were located in, or nearby, Malaysia. His novel approach in country has been referred to as an expression of Malaysian independence and economic aspirations. He used, and continues to use, modernism without symbolic abstraction, showing an understanding of traditional values without the use of traditional forms and materials (Richards cited in Yeang, 1994). This method is exemplified by his extensive use of skyscraper skycourts, which serve the same function as traditional verandas. The application of native vegetation and the linking of building form and orientation with location replace the internationalist tendencies of the majority of skyscrapers. They instead intend to serve as steps towards an independent architectural style specific to one people and one locality.

This adaptation of regionalism was later translated into his western skyscrapers, where he continues his pursuit towards buildings of minimal environmental impact and with optimization of passive systems of operation. His designs are strongly linked to his research, which includes the use of wind power and biodegradable materials. His numerous works demonstrate his insistence on applying urban design principles vertically through such measures as skygardens as parks. Yet his most memorable contribution to skyscraper design remains the close relationship between a building and its local climate.

Yeang's interest in climate design is rooted in his PhD thesis, *Designing with Nature: The Ecological Basis for Architectural Design* (1995), which refers directly to the influential work of one of his former course professors, Ian McHarg (1969). McHarg's *Design with Nature* challenged urban and regional planners to consider ecology as a starting point. This was a new concept in 1967, four years before Yeang's postgraduate study began at the University of Cambridge. McHarg expressed the various aspects of ecological design – geology, hydrology, physiogeography, soil, vegetation – as a series of overlay maps and diagrams, a method and subject that resonates with Yeang's diagrammatic tall building illustrations. McHarg's (1969: 115)

descriptions of his maps are also just as interchangeable with those of Yeang's skyscrapers:

> The maps in this study are more like mosaics than posters—for good reason. They result from asking the land to display discrete attributes which, when superimposed reveal great complexity. But this is the real complexity of opportunity and constraint. Yet it may appear anarchic, but only because it we have become accustomed the dreary consistency of zoning, because we are unused to perceiving the real variabilities in the environment, and responding to this in our plans.

Yeang's own thesis was an attempt to develop 'a unifying theoretical basis and frame of reference for design.' Within, he provided a framework for integrating buildings with nature. A cyclical pattern of material use was promoted, one that encouraged designers to minimize the adverse ecological effects of their concepts. The resulting framework, relevant to the building's entire lifetime, provides links between ecological elements. It is to be applied both in research and design, as he considers it a holistic method.

Before describing the framework itself, it is worth noting that Ken Yeang considers his framework unique as both a definition of ecological design and as a 'satisfactorily formulated' theory of green design (Yeang, 2006: 59). In *Ecodesign*, he states that for the success and longevity of ecological design, 'it is essential that a fundamental "law"' of ecological design' be formulated. He then states that the Interactions Matrix of his initial framework is this 'law' and theory (2006: 60). He further explains that ecological design is for the most part 'certainly considerably more complex than is currently recognized by many ecological designers' and that most designers' theories fail to 'include and environmentally holistic property (e.g. 'connectedness')' that is inherent in his approach. (2006: 60). Through these statements, he reinforces both the uniqueness and longevity of his methods.

2.4.2 Ken Yeang's framework overview

Yeang's theoretical framework consists of the combination of two approaches: a General Systems Theory and a Partitioned Matrix. The General Systems Theory, depicted in Figure 2.4, considers the outcome of a design 'as a system…that exists in the environment' (Yeang, 2006: 61). It allows for a limitless number of variables in the design problem and is described as an 'open structure as a design map' (2006: 61). Key here are the 'transfer points,' or points where the designed system, i.e. the building, interacts with the surrounding ecosystem, as this is where most damage

results (2006: 62). These interactions are visualized in the General Systems Theory model, and grouped into four sets:

1. external interdependencies of the design system (system's relations to external environment);
2. internal interdependencies of the design system (system's internal relations);
3. external/internal exchanges of energy and materials (system inputs);
4. internal/external exchanges of energy and materials (system outputs) (Yeang, 2006: 64).

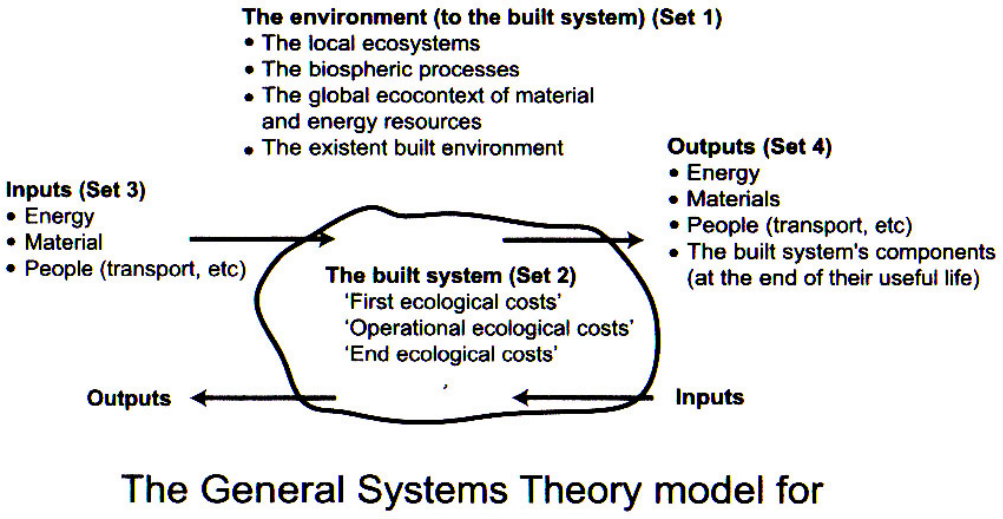


Figure 2.4: General Systems Theory (Yeang, 1996)

To 'unify' these sets of interactions into a 'single' symbolic form, Yeang uses the more regular structure of a Partitioned Matrix, depicted as figure 2.5 (Yeang, 2006: 64). He separates the design system (1) and the environment (2) and places them into a matrix in which L stands for the 'interdependencies within the framework' (Yeang: 2006: 64-5). Four types of interactions are also identified using this method, labelled as L11, L12, L21 and L22 (2006: 65). Yeang describes these in further detail in Figure 2.6. These interactions are effectively the same as those obtained in the General Systems Theory, although their representation in the Partitioned Matrix is more structured.

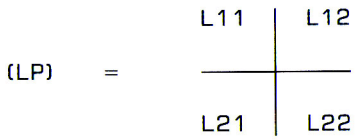


Figure 2.5: Partitioned Matrix (Yeang, 1996)

Interactions	Symbol	Description
The external inter-dependencies of the designed system (its external relations)	L22	This refers to the totality of the ecological processes of the surrounding ecosystems, which intersect with others which interact with other ecosystems elsewhere within the biosphere, and the totality of the earth's resources. It also includes the slow biospheric processes involved in the formation of fossil fuels and other non-renewable resources. These may influence the built environment's functioning and are in turn also influenced by the built environment. It is these elements that are either altered, depleted or added to by the built environment.
The internal inter-dependencies of the designed system (its internal relations)	L11	This refers to the sum of the activities and actions that take place in or are related to and associated with the built environment and its users. They include the operational functions of the built environment. These will directly affect the ecosystems of the location in which they take place spatially and the ecosystem elsewhere (systemically), as well as the earth's totality of resources. These can be considered in the pattern of a life cycle of the built environment.
The external/ internal exchanges of energy and matter (the system's inputs)	L21	This refers to the total inputs into the built environment. These consist of both the stock and the flow components of the built environment (or the energy and matter needed for the physical substance and form of the built environment and its attendant processes). The efforts taken to obtain these inputs from the earth's resources often result in considerable consequences to the ecosystems.
The internal/ external exchanges of energy and matter (the system's outputs)	L12	This refers to the total outputs of energy and matter that are discharged from the built environment into the ecosystems and into the earth. These outputs may include the built environment's own physical substance and form, which also may need to be disposed of at the end of its useful life. These outputs, if they are not assimilated by the ecosystems, result in environmental impairment.

Figure 2.6: Interaction descriptions (Yeang, 1996)

At this point it is worthwhile pointing out that, like his diagrammatic illustrations, Yeang's Partitioned Matrix also had a precedent. Although he does not often highlight the fact, his framework is a reinterpretation of the work of F. E. Emery and E.L. Trist, which applied a similar framework to sociological and organizational purposes (Emery, 1969). Their name of their text, *Systems Thinking*, is also a more general term for a process that views all systems as consisting of a number of inter-connected issues. Therefore, each system component cannot be understood in isolation from other components and systems, and so systems are inherently considered 'open'. *Systems Thinking* as a text represents a resource of significant papers related to the topic, gaining enough influence to be reprinted six times (Emery, 1969).

Undeniably, it also had an important impact on the work of Yeang. His Partitioned Matrix particularly resembles a framework presented in one of these papers. In 'The Causal Textures of Organisational Elements,' Emery and Trist present a set of interactions, nearly identical to Yeang's matrix:

$L_{1\,1}$, $L_{1\,2}$

$L_{2\,1}$, $L_{2\,2}$

This matrix is developed as 'a comprehensive understanding of organizational behaviour requires some knowledge of each member' of the set (1969: 242). The terminology used to describe the interactions likewise recalls that of Yeang, as Emery and Trist continue (1969: 243):

> $L_{1\,1}$ here refers to the processes within the organization – the area of internal interdependencies; $L_{1\,2}$ and $L_{2\,1}$ to exchanges between the organization and its environment – the area of transactional interdependencies, from either direction; and $L_{2\,2}$ to processes through which parts of the environment become related to each other (i.e. its causal texture) – the area of interdependencies that belong within the environment itself.

Yeang's framework, discussed previously in Chapter 5, therefore clearly adapts to and applies this earlier matrix to the built environment. Here, the term 'organization' is replaced by 'built system.' Yeang himself does not discuss the effectiveness or history of the original Systems Thinking framework, but nonetheless claims that his interpretation 'is itself a complete theoretical framework embodying all ecological design considerations' (2006: 65). Like its organizational counterpart, it also doesn't promote a specific method of design, but instead offers a way to analyze all variants within a system.

Yeang describes as the 'key feature' of his framework its 'comprehensiveness' (Yeang 206: 69). Many times in his texts, Yeang highlights the fact that all

interactions need to be accounted for if the design is to be truly ecological. He also describes the 'four prime functions' of the framework, summarized as follows:

1. a 'conceptual framework' for the designer in organizing and understanding the ecological impacts of the designed system
2. a 'common frame of reference' for the designer working with other disciplines
3. a 'common frame of reference' for further theoretical collaboration by various fields
4. a 'single, unifying theory to bring together under one umbrella aspects of environmental science and protection efforts that have in the past been uncoordinated' (Yeang, 2006: 69-70).

These functions are ambitious, and there is little evidence that they have achieved their intended purpose. They may have informed his projects and interaction with other practitioners, but there is little proof for this supposition in existing documents. In fact, Powell (cited in Kassim, 2004) restates a common view of his work: 'Yeang is often criticized for the apparent disparity between his theoretical writings and his buildings; it is difficult to juxtapose the theory alongside the built work.' He continues, 'Yeang readily agrees that he post-rationalises his actions'.

2.4.3 Ken Yeang's framework review

Although there has been some evaluation of Yeang's projects and theories in general (Kassim, 2004), his framework has not been subject to much analysis. This section will therefore analyze Ken Yeang's framework as it relates to the qualities of this study's proposed framework. However, as some further consideration has been included in the following chapters, this section will aim to be fairly succinct. Here, five characteristics of Yeang's approach are critiqued.

Scope

The scope of the framework provided by Yeang is too broad for application by architects, who have limited time and influence available for certain aspects of design. Examples of these aspects include the ecological analysis of the site and the choice of interior paints, which may be determined as decisions, respectively, for ecologists and interior designers. This is not to say that the designer is not to be ultimately responsible for a thorough consideration of all aspects of interactions presented in Yeang's matrix. As highlighted by Mendler et al. (2006), he or she must aim to facilitate the sustainability of the entire environment as well as the building's impacts throughout its life cycle. Yet the architect is usually hired to focus on a

specific aspect rather than all interactions, and that is namely the design of a built form. It would be unreasonable to state that the designer has equal influence of all quadrants of Yeang's Partitioned Matrix as this is clearly not the case. The proposed framework for tall buildings will therefore relate to the main aspect of bioclimatic design, namely L21, while acknowledging that the designer must be aware of the entire process as suggested by Yeang. It should be noted that the framework initially also aimed to include the interactions of L12, which relate to a wider range of sustainability, but due to the differing purposes of the two aspects and reasons discussed in Chapter 3, it has been omitted from the final version.

Climate

Although Yeang is among a few architects to portray climate as a primary determinant of form, the framework presented does not illustrate this concern. It instead encourages a general structure, applicable to a number of design climates without any reference to conditions specific to any locality. Yeang's published texts, specifically his books, also do not organize climate-specific design strategies into any related groups, even though he does often claim if a certain strategy is climate-specific within more general paragraphs. In order to fully apply climate as a determinant of form, the proposed design framework will therefore focus on the cool temperate climate.

Building type

As is the case with climate, Yeang's framework is not specific to a building type. He provides more information regarding the tall building than other authors, but the framework itself does not reflect his specialization. As his framework was developed before his practice as a high-rise designer, this is expected. However, as the tall building type interacts with the environment in a distinctly different way than low- and mid- rise structures do, a framework specific to its design can be justified. Furthermore, just as low- and mid- rise structures have varying users and spatial organization, so too do residential and commercial towers. Therefore, an even more particular guidance to their design is warranted.

Hierarchy

Yeang purposely avoids having a strict hierarchy, designing his framework as an 'open system.' However, he does suggest that the framework does have a loose structure, arguing that:

> The theoretical basis for ecological design must provide the designer with an easy-to-apply set of structuring and organising principles. This can be in the form of an open structure with which the selected and relevant design constraints (eg ecological considerations) can be holistically and simultaneously organised and identified. Furthermore, the open structure must facilitate the selection, consideration, and eventual incorporation of the design objectives in our subsequent design synthesis (2006: 60).

His Partitioned Matrix, though, does not imply any structure that can guide the process of design. Instead, he provides some basic instructions in his texts, summarized in *Ecodesign* (2006: 64):

> The first step is systematically to take account of the internal processes of the designed system (eg in B12 to B17). The second step is to measure, based on a thorough knowledge of the building's physical and functional requirements, its interactions with the earth's ecosystems in the form of the energy and resources removed from the environment by the construction and ongoing operation of the structure. Also to be measured are the amounts of matter and energy that are sent back into the natural environment as a result of the functioning of the building's internal systems (the 'metabolism' that makes it function as a built environment; see B4 to B11, and B18 to B29). In the case of a built structure this includes the transportation consequences of moving people and goods to and from the built structure.

These steps are expanded on in various chapters of *Ecodesign* (2006), but their links with the framework are somewhat irrelevant. The danger in having steps that are not linked in strong terms with his framework is demonstrated by the North American and European case studies. A lack of hierarchy elsewhere often leads to buildings that focus on energy-efficient systems, rather than bioclimatic suggestions. Such an order clearly is set against both the aims of Yeang and that of general sustainable design. Yeang is therefore correct in organizing much of his text based on the preferable stages of application, even if his framework lacks such a structure.

However, he does he caution that 'ecodesign is not sequential in application and that the order in which these instructions are followed may vary, depending on the design assignment at hand' (2006: 17). The argument presented by the proposed tall buildings framework is that although at times this may be the case, architects must be clearly aware of the sequential application of certain design principles ahead of others for maximum environmental benefit. A lack of emphasis on this point would only continue the focus on technology as a means to resolve issues stemming from poor orientation, form and fabric design. The proposed framework will therefore aim to create a hierarchy of design principles in order to reduce energy consumption through less active means. These suggestions can be overlooked at the designer's risk, but he or she must be aware of their importance within the design process.

Origin

As mentioned in a previously, Yeang's framework was developed ahead of his application of the design principles. Furthermore, the two appear to have advanced separately, as there are few textual and no visual links between them. Both strands can be observed in Yeang's projects, but their combination would prove difficult to accomplish by any architect unfamiliar with his work. From a practical point of view, most practicing architects would in all probability be inclined to apply Yeang's individual design principles rather than the framework itself. However, this would leave behind much of Yeang's primary contribution, likely leading to a design which would not consider any matrix quadrants in detail and not be sustainable on Yeang's terms.

Therefore, the proposed tall buildings framework will aim to combine the two aspects of overall structure and individual recommendation. In order to unite the aspects, the framework is to be developed from opposite starting points than those of Yeang. Whereas Yeang initially developed the framework and then established the design principles, here such design principles will be used to develop a new design process. This will ensure that the principles are effectively organized, as well as allowing the framework to serve a practical purpose. General categories relating to design principles are to be included, providing opportunities for additional design suggestions to be incorporated at a later stage.

In any case, it must be remembered that, although criticized here, Yeang's framework is amongst only a few fully developed by architects and is perhaps one of the best of those currently available in relating architecture to the environment. The aim of this section was therefore not to argue against its comprehensiveness, which Yeang describes as its key feature, but rather to suggest advances which would make it more understandable and applicable in specific areas of architectural design.

Yeang himself points out areas in which the framework needs to be further developed. For example, he claims that a 'more comprehensive feedback loop must be further developed from the framework as it now stands' (2006: 69). He further recognizes that sustainability as field is in its infancy, often mentioning that further research needs to take place. The proposed tall buildings framework therefore aims to expand on this research, providing specific design solutions that could be applied in certain circumstances. This is not to state other design solutions cannot exist, but only that most contemporary design methods for sustainable residential towers are

more detrimental than promising in terms of environment and so new ways of designing need to be developed.

2.5 Summary

Design research and design frameworks challenge the usually non-cognitive and unsystematic manners in which architects develop their environmentally-responsive building designs. They both encourage architects to rationally evaluate their design choices and reflect on ways in which to improve future schemes. This chapter considered some examples of such methods, beginning with a brief history and overview of contemporary issues that face design as a research method. There is much debate whether or not the design process should be scientifically based, but there is nonetheless an understanding that it must assimilate some scientific methods if it is to remain relevant in a time where climate change poses great risks. Architects have undeniably been inspired by nature; therefore an understanding of scientific findings and processes as they relate to the development of sustainable architecture may form a natural progression for the field. In the same way, design frameworks may offer opportunities for further reflection, particularly as sustainable design offers both possibilities and complexities of an unprecedented scale. This chapter examined several examples of systematic approaches, with a focus on the ways in which they informed the development of the proposed guidance. It then considered the framework developed by Ken Yeang, as well as approaches that influenced him. The chapter concluded with a concise yet critical analysis of Yeang's framework, linking it to the tall building guidance proposed in this thesis. As the last two chapters have provided an introduction and review to the contexts of this study, the following one will consider the methodology behind it in more detail.

3 METHODOLOGY

The Literature Review of Chapter 2 revealed a lack of specific guidance for the environmental design of residential tall buildings in the cool temperate climates. Moreover, the available guidance is often fragmented and incoherent and missing a hierarchy that emphasizes key decisions relating to passive design. However, sufficient information exists regarding individual strategies that can be applied to such towers and adequate evidence is accessible to rank some of these strategies in accordance to the specific climate type. This chapter will therefore introduce the methodology for the application of such information to this design framework. It will begin with a restatement of the research question and point out some of the outstanding definitions and limitations it implies. The overall approach of the research process will then be outlined, followed by a restatement of the research aims and objectives. The research methodology will then be discussed in more detail by linking its main stages to its objectives.

3.1 Research question and limitations

As discussed in the previous chapter, there is both a lack of research on and guidance for environmentally responsive tall buildings. The majority of available information on the topic is descriptive and overly general to be applicable for specific climates, and the research that has taken place in academia, design studios, practices and organizations is often under development and at times not widely accessible to architects. Design guidance, when not confused with other tools, is either vague in terms of climate and building type, or particular to a specific context or presented in an exceedingly complex manner to be of benefit for architects during the schematic design stage. Even the root of this research project, the work of Ken Yeang, is either too wide in scope, climate and building type or insufficient in hierarchy so as to form coherent design guidance. Nonetheless, all of these sources, in addition to providing valuable data and informing the design guidance, have helped to develop a research question that is both broad enough to be applicable for a variety of situations and focused enough to be relevant to the specificities of bioclimatic design.

The question the research intends to answer can thus be stated as: ‘Using the work of Ken Yeang as an initial reference, what principles of environmentally sustainable design can be found which would contribute to the design of residential tall buildings

in the cool temperate climates of Europe and North America and how can they be best organized to inform architects?'

Two determining elements of the research question, then, are building type and climate. The previous chapters touched on the differing spatial and energy needs of commercial and residential buildings; effective guidance therefore would need to distinguish between the two uses, or, as is the case here, consider only one. Although both types require further consideration, this research has focused on the residential one as the proportion of such towers is increasing, the amount of available research is especially lacking and the type is more adaptable for further uses, e.g. as a home office.

The second element, climate, is as relevant. Successful bioclimatic design is dependent on a suitable response to local climatic conditions; as the discussion on internationalist towers in previous chapters implies, the application of general guidelines from another climate type can be just as, if not more, detrimental than a non-environmental approach. The temperate climate is chosen as its seasonal variances present specific challenges not found elsewhere in terms of design, while Europe and North America are selected as the author is familiar with the cultural and spatial preferences found in those continents.

A definition of climate is here warranted. The Köppen System (*Survey of Meteorology*, no date) divides the earth's climate into five different regions, illustrated in Figure 3.2: tropical moist climates, dry climates, moist mid-latitude climates with mild winters, moist mid-latitude climates with severe winters and polar climates. The moist mid-latitude climates are commonly referred to as the temperate climate. This study will focus on two subsets of the temperate climate, which will be referred to as the cool temperate climate. These subsets can be defined as:

Marine (Cfb)
This major type occupies the western sides of continents from 40° to 60° latitude. Prevailing western winds moderate the climate near the coast. Winters are relatively mild, where the coldest month is below 18°C and above -3°C, and summers are cool. There are many low clouds, and much fog and drizzle, particularly during the non-summer seasons. There is little snow usually, except at higher mountain altitudes.

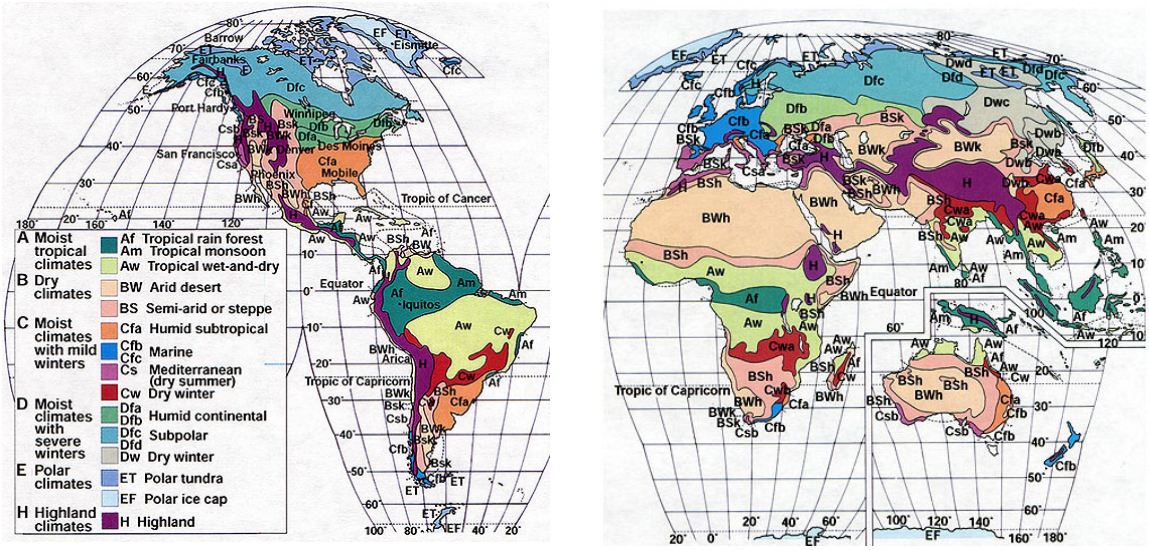


Figure 3.2: Köppen System classification of climate (*Survey of Meteorology*, no date)

Humid continental with hot summers (Dfa) or cool summers (Dfb)

Found between 40° and 60° latitude, this major type has uniformly dispersed precipitation of twenty to forty inches throughout the year. The area with hot summers (Dfa) differentiates itself from the other (Dfb) because of the season's high temperatures and warm, humid evenings, as well as a growing season extended by about two months. This area has cold winters, where the average temperature in the coldest month drops below -3°C, with snow cover expected.

These climate subsets are chosen for three reasons. First, although they share the same temperate climate category, their somewhat variant temperature ranges, particularly in winter, allow for a more clear analysis of the impact climatic deviations on tower design. Second, each subset corresponds generally to both Europe and North America, two continents that share as similar cultural and social background that affects their somewhat cautious outlook toward residential skyscrapers when compared to attitudes in Asia. Their cultural exchanges relating to sustainability and architectural ideas provide further reason that the two continents be seen together. Thirdly, the subsets transverse the locations of cities where the majority of Western skyscrapers are to be found, including:

Chicago:	Moist Climate with Severe Winters	Dfa	Humid Continental
Toronto:	Moist Climate with Severe Winters	Dfb	Humid Continental
New York:	Moist Climate with Severe Winters	Dfb	Humid Continental
Moscow:	Moist Climate with Severe Winters	Dfb	Humid Continental

London:	Moist Climate with Mild Winters	Cfb	Marine
Rotterdam:	Moist Climate with Mild Winters	Cfb	Marine
Frankfurt:	Moist Climate with Mild Winters	Cfb	Marine

In addition to these definitions, the research question also implies some limitations. The most apparent one is that the study will focus only on the environmental aspect of sustainability, not the economic and social ones that also make up the 'triple bottom line'; even that aspect would be eventually narrowed to 'bioclimatic'. In a wider sense, then, the research will not concern itself with the historic, societal, contextual, regulatory and legal aspects of tall building design. This is not because these are not considered as relevant or significant as the environmental aspect, but because they cannot be as systematically evaluated and applied as the former. In many cases, some are predetermined in the case of the tall building and so be outside of the scope of influence for the architect: for example, legal and regulatory demands often define suitable sites and the building's location on the site; building structure would also fall under that category. Other aspects involve the architect during the design process but are so specific to the site that they must be considered on an individual basis: historic, contextual and societal aspects require such attention.

As compared to such varying and mutable aspects, environmental, and in particular bioclimatic, design guidelines are much more static and can therefore be examined in a fairly systematic way. By not addressing other aspects, the research therefore has a greater general relevance in the climate type. However, it should be acknowledged that those aspects must be evaluated and their restrictions noted prior to and during the proposed design process; in some cases, they may encourage the use of a particular strategy, but may eliminate others. They would therefore need to be factored into the design process, as would any restraints on structure, aesthetics, etc.

3.2 Overall research process

The research can principally be described as a series of iterative trials, which are grouped into three stages. All stages share in common a model framework, or guidance, and its application in the context of a schematic design process on a specific site or sites. The model framework, referred to as a version correlating in number with each stage, is an improved adaptation based on the interim findings

from a previous stage. In this sense, that element is cumulative, as, for example, Version 3 includes amendments based on Stages 1 and 2. Version 4 is an exception to the series of trials, as, although it is an improvement based on earlier stages, it did not involve its application for a particular site. The application of a framework to a design process is also of a repetitive nature as each trial helps to refine the content and order of the information within the guidance. However, each stage also has an independent focus relating to framework: Stage 1 on the choice and organization of the principles, Stage 2 on assessment and climatic and urban variations and Stage 3 on usability.

The decision to structure the trials as a series of design processes is alluded to in the previous chapter. The use of design as a research tool had been applied on a number of occasions in academia and practice. The fact that design by architects would also inevitably have additional influences relating to aesthetics, economics, etc. could also be easier to discern and examine in a design process rather than by only evaluating resulting buildings or rationalizing the framework elements through academic texts. An initial design process would also inform subsequent attempts, highlighting further areas for examination and improvement. Furthermore, as the intention of this thesis was to have applicability in practice, trials that would mimic the schematic design stage were also determined to be the most adaptable for its transfer upon completion.

The concentrations of the three stages are discussed generally in the sections that follow and in more detail in the subsequent thesis chapters. It should be noted that many of the elements of this research, like the literature reviews and case studies, although presented in singular chapters in the thesis, in fact reemerge through the study. This varied structure is somewhat expected, as the iterative series of trials would ensure that certain elements were rejected while others re-emerged. At times, this means that data collected for a particular stage may not be included in an associated chapter but broadly summarized. For example, the review of existing literature relating to the principles is only depicted as an accumulation in the Annexe, rather than as an in-progress overview in each chapter. Likewise, although the initial case study reviews also occurred prior to the development of the trials, they are included in the chapter relating to the first stage and depicted in a manner relating to it. Figure 3.1 acts as an overall summary of stages and demonstrates some the open loops and dead-ends of the research process.

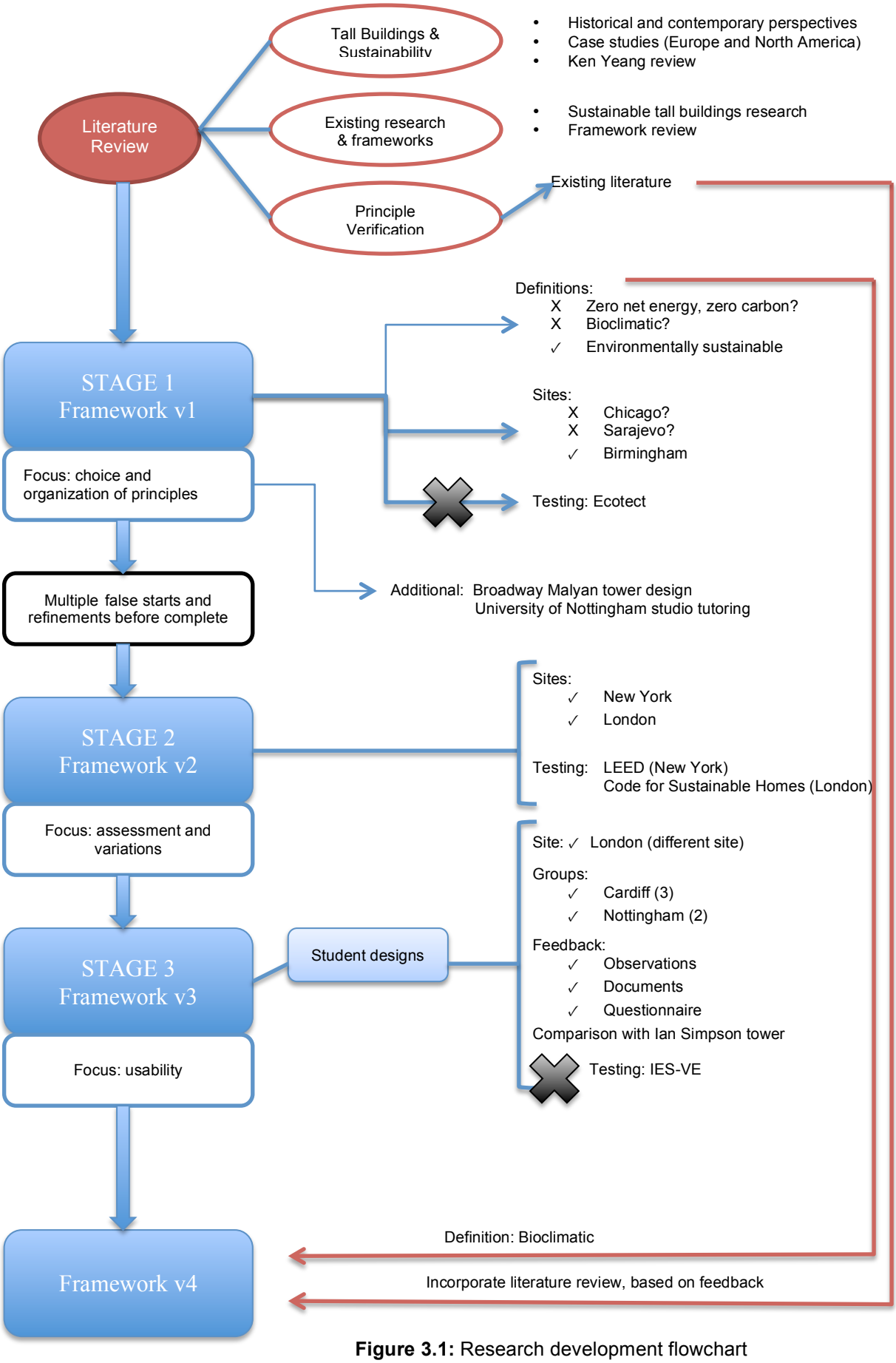


Figure 3.1: Research development flowchart

3.3 Research aim and objectives

In order to understand and present how the developments of the three stages relate to the purpose of the research, a restatement of the research aim and objectives is useful here. Analogous to the research question, the research aim can be summarized as:

> To determine the content and organization of environmental design principles to inform the design of residential tall buildings in the cool temperate climates of Europe and North America.

The objectives of this research are therefore as follows:

- To find principles of environmentally sustainable design which would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America;
- To organize these principles so that they can best inform architects during the schematic design stage.

For the rest of this chapter, these objectives, noted by numbers in each subsection title, will be linked with the tasks undertaken at each stage. This format helps to demonstrate when and how each one was approached individually, as well as where they interact and combine, usually when the framework as a whole is applied. The assumptions and limitations of each stage are also included.

3.4 Stage 1

The focus of Stage 1 was the choice and organization of principles into coherent design guidance, generally referred to as the 'framework'. The resulting Framework version 1 was then used to design a test tower on a Birmingham site. These and other themes, as well as the recommended changes for version 2, are discussed in the following subsection.

3.4.1 Extraction and presentation of principles from Ken Yeang's text (1)

Finding an initial starting point for the research was perhaps the most straightforward aspect of this research project. As discussed in the previous chapter, this study is rooted in the work of Ken Yeang, widely recognized as the first and most prominent

proponent of the climatic design of tall buildings. He is perhaps the only tall building architect that can claim to have dedicated over three decades of practice integrating sustainability with the built form. He is also the most prolific architect in this area in terms of published works and sustainable tower projects.

Ecodesign (2006), a compilation and expansion of his previous texts, was therefore examined more closely, as it provided numerous strategies for improving the sustainability of built forms. For the purpose of this study, these are referred to as 'design principles'. Yeang organizes them in themes, such as 'passive mode using building mass', within sections ranging from passive to full-mode design strategies. There is an emphasis on bioclimatic, or low-energy passive design, which is also reflected in the proposed framework. However, as much of Yeang's work is for commercial purposes and rooted in the hot and humid climates of Malaysia, only some of his principles, those that are valid for the residential function and the temperate climate, were extracted. His interest in the temperate climate is relatively recent, as he joined a London firm, now known as Llewelyn Davies Yeang, as a Design Director in 2005 and has proposed a small number of residential towers for the city since. Therefore, *Ecodesign*, published in 2006, includes a considerable number of design strategies for the climate. The principles he presents are generally those developed by other researchers and also utilized by other designers, but Yeang nevertheless also specifies a number of less common strategies, such as the use of a wing wall.

At times, these strategies are presented in a complex manner, so an effort is made to simplify them for use as individual steps, or 'rules of thumb'. As architects are generally regarded as visual learners, these principles were at first to be depicted as diagrams. Yeang's presentation style was also an influence, particularly as his early texts included numerous sketches of elements relating to specific building forms. His texts have recently become more text-based and often lack these images, which are more striking than his sometimes verbose written explanations. Therefore, the reintroduction of diagrams as design principles was aimed at producing more accessible and memorable design steps. However, once the framework was fully developed, as illustrated in the final version in the Annexe, it became apparent that the complexity of the design process could not be illustrated by these streamlined drawings. This finding, and a further recommendation, is discussed in Chapter 7, but the overall result is that the images consequently read as simplified 'snapshots' of

the progress of the design process, ones which could be advanced and integrated into future framework development.

3.4.2 Case study comparison with principles (1)

In relation to the design principles, the main purpose behind Stage 1 was therefore to extract and present Yeang's suggestions for the climate and building type. However, as Yeang did not have completed projects in the climate type, a case study comparison was set up to examine their suitability and application by other designers. An initial review of contemporary tall buildings found that seven European and North American cities were prominent in terms of skyscraper construction activity, numbers of residential buildings and policies promoting their future development. Upon further inspection, it became clear that not all of these places had examples of sustainable tall buildings to examine. Undeniably individual cities, such as London and New York, had by this time emerged as centers for green tower design. A number of them were also located in various subcategories of the temperate climate and would so allow for a more throughout examination of the effects of such variances in the climate type. For these reasons, a smaller number of cities were examined more fully, and eighteen case study towers, nine from each of the two continents considered, were chosen. As the number of green residential designs was very limited, commercial projects were also included to increase the variety and quality of case studies presented. For similar reasons, and to provide examples of more experimental towers, proposed projects were also incorporated into the review. In addition, one of Yeang's London proposals was included to compare his design work alongside his written one. The findings are discussed in Chapter 4, but the case studies confirmed the initial supposition that Yeang's focus on the range of sustainable strategies is wider than that of most other designers, particularly as they relate to bioclimatic design and thus furthermore justified the use of his written work as the basis of this research. Furthermore, the case studies, and their subsequent comparisons, supported the reasoning behind the creation of a design framework that would highlight the need for sustainable choices in the early stages of design.

3.4.3 Applications of principles in practice and teaching (1)

To further examine their application potential, many of the principles were initially utilized in a professional and academic setting. A temporary placement at Broadway Malyan Architects to develop a bioclimatic design for a 35-storey tower proposal in

Birmingham formed the professional setting. The principles not only proved helpful in determining much of the tower's built form, but also were useful in communicating the building's features to the developer and potential client. Furthermore, the exercise highlighted the need for a distinction between solar and airflow elements. The academic settings for their early application were design studio modules at the University of Nottingham and Cardiff University, and in this context they provided the students with segments of information that were easily comprehended and applied. The necessity of a gradual application of the principles was here noted.

3.4.4 Organization of principles (2)

Through these early examinations, it became apparent that the application of the design principles was at times indiscriminate and, at best, as in the case of Yeang, only loosely organized. To link them more strongly with both the schematic stage of design and climatic elements, a framework matrix was determined to be valuable. This would form the broadest and most hierarchical element of the framework's overall structure, determining the priority of interactions considered. The use of such a format is also based on Yeang's 'partitioned matrix', but that format, as discussed in the previous chapter, was determined to be too vague for the purposes of this research. A focus on one quadrant of that matrix, 'the external/internal exchanges of energy and matter (the system's inputs)' was therefore adopted as the most suitable starting point for this matrix. As Stage 1 advanced from bioclimatic to more general 'sustainable' design, a second interaction, 'the internal/external exchanges of energy and matter (the system's outputs)' was added. It should be noted that with a further focus on the bioclimatic aspect towards the end of the research process, the latter interaction was again omitted; this decision is discussed further in Chapter 7.

A series of attempts were made relating to the content and organization of this matrix and are outlined in Chapter 4. A number of false starts on a Birmingham test tower, which were expected as part of the research due to a lack of precedent and as part of the feedback cycle, also contributed to its structure at the end of Stage 1. All in all, a table format based on the interactions between climate influence and design stage was determined to be most advantageous. Climatic influences would form the row headings and elements of schematic design would form the column headings. As the temperate climate consists of significant differentiations of conditions, like temperature extremes between summer and winter months, the climatic influences were further subdivided into 'increase' and 'decrease' aspects. This format allowed for the building to be initially designed for the prevailing climatic concerns, such as

that of thermal radiation in winter, while allowing for secondary adjustments, mainly through fabric, to correct the negative impact of those conditions during other seasonal periods. The interactions between these parts would be depicted as boxes where the various design principles could be placed according to their function. The matrix was to be applied in series of columns, and so it gave an overall hierarchy and sequence for interactions. Certain interaction boxes are blacked out, so that those elements and climatic conditions that are prevalent are addressed first. In this way, the framework is climate-specific. The hierarchy was generally determined from a review of the literature, although some of the stages' trials also affected its overall format.

However, the framework matrix was not sufficient for determining how the design principles would be ordered within the interaction boxes and so a third element of the framework, the steps sequence, was required. Again, a number of attempts at a first version of the framework would inform this element, but the first trial in the form of a Birmingham test tower would both develop and test the validity of the sequence presented in forming a tower design. Each principle was therefore linked to a certain step, although eventually any principles with identical purposes but with different features for achieving them would be divided as options.

3.4.5 Birmingham test tower and required changes to framework (1) (2)

The option of a Birmingham site for the first trial stems from a period prior to the establishment of the particular research aim and objectives; there was a preliminary interest by the author in the wider concept of sustainability so that it would encompass social and cultural aspects. As the author had resided for some time in the cities of Sarajevo, Chicago and Birmingham, these were found to be suitable starting points for a cultural comparison. However, it was soon established that although both social and environmental aspects of sustainability require positive interaction, they are nonetheless separate fields with independent aims. A decision was thus made to focus only on the environmental aspect. As the Birmingham test site had already been researched and established, and as it provided a suitable location in terms of climate and urban context, it was chosen as an appropriate site for the first trial.

The resulting Birmingham test tower design process, and the subsequent building designed by the framework's author, therefore formed a preliminary approach for

creating and analyzing the framework's main elements. Although most of the principles were found to be suitable and organized adequately, there were a number that were not or lacked sufficient information. As all of the design principles at that point were rooted in Yeang's texts, this phase also helped to eliminate his irrelevant one and suggest supplementary information from other sources. Some minor restructuring of the matrix and steps sequence was also required. However, these issues were relatively easy to resolve. The larger concern at the end of this stage was of a different kind: the framework's success in its content and structure could not be said to lead to an environmentally improved building. The work in Stage 2 would therefore help to refine the principles and their organization and assess the framework's environmental credentials.

3.5 Stage 2

The focus of Stage 2 was the impact of climatic and urban variations on the resulting towers and the assessment of the framework and the buildings by prominent rating systems. The framework was adjusted on the basis of findings in the previous stage, and the resulting Framework version 2 was then used to design towers for London and New York sites. These and other themes, as well as the recommended changes for version 3, are discussed in the following subsection.

3.5.1 Climatic and urban variations (1) (2)

After the design guidance was adjusted from Stage 1, two test tower sites were specified in order to observe the impact of a pair of key variations for the generation of form. The first variation was a climatic one, as the cool temperate climate had encompassed a range of climate subtypes with differing temperature extremes and solar and wind conditions. The second variation was an urban one, as some tall buildings would undoubtedly be placed within high-rise clusters while others would act as prominent singular landmarks within low- to mid-rise cities. Sites in the cities of New York and London were chosen as they embodied these variations well. An equivalent application of the framework on both sites was used and differences in buildings were noted at each step. The effect of certain climatic aspects on discrepancies in form and fabric were noted.

3.5.2 Assessment with rating systems (1)

A number of approaches were considered in order to inspect the step sequence and the framework's overall organization in terms of environmental impact. Environmental modeling of the resulting buildings was first considered, but due to a variety of reasons, discussed later, it was found impractical and better suited for another stage. A more suitable option, and one that would place the framework in the context of leading appraisals of green design, was the use of building rating systems. Assessing both towers with a single environmental rating system, in this case initially EcoHomes and subsequently the Code for Sustainable Homes, would have been problematic. Many of the available systems had embedded assumptions regarding local climate and practices, making them difficult to apply in other countries. A dual solution was consequently adopted for assessment by the author: the LEED rating system for the New York tower and the Code for Sustainable Homes for the London tower. Not only did would this arrangement allow the towers' performance to be assessed in local terms, but it also allowed a more thorough comparison of the two rating systems. It furthermore created an opportunity for the comparisons of both systems with the framework, suggesting the benefits and drawbacks of each.

3.5.3 Required changes to framework (1) (2)

Again, the design principles required further refinement, including the addition of options and general links between them. The framework matrix and the steps sequence nonetheless remained for the most part the same, although a discrepancy in the organization of inexhaustible and exhaustible resources was noted. The framework still had a major flaw in that it could not claim to be applicable by architects as no one other than its author had used it. This question of usability and objectivity would lead to the establishment of Stage 3.

3.6 Stage 3

The primary focus of Stage 3 was to examine the usability of the framework in a design studio setting. Students applied the updated Framework version 3, this time notably based only on Yeang's work, in various degrees to design a test tower on a London site. This theme, as well as the recommended changes for version 4, is discussed in the following subsections.

3.6.1 Usability of framework on student test towers (1) (2)

Two groups, practicing architects and postgraduate architecture students, formed possible populations for this third trial as both had sufficient architectural training to be able to complete a design process and analyze the framework at that stage. Preliminary discussions with practicing architects determined that limitations in available time and resources meant that full participation was unfeasible. On the other hand, discussions with module leaders revealed three modules in which the study could be suitably completed. One module in a distance learning MSc Architecture course at the Centre for Alternative Technology proved to be impractical in terms of scheduling and digital reformatting of the documents. The trial would therefore include five teams of students, two from the University of Nottingham and three from Cardiff University. All were instructed to design a tower on the same site and both modules focused on environmental design, although agendas and functions of buildings varied between both institutions and teams. Of the five, three applied the framework to varying degrees, while two acted as control groups by designing their buildings independently. The author of the framework observed the groups' progress through attendance of their design modules and received further feedback through a questionnaire and student notes.

Upon completion of these tests, there was some consideration of further evaluation of the guidance and results through environmental modeling. As mentioned previously, the fact that the framework required further adjustments and therefore the buildings were not representative of a revised version meant that tests during those earlier stages would be premature. In any case, a building design and environmental analysis tool, Ecotect, was studied in preparation for a later stage where such testing may prove to be more suitable. However, based on later information and advice from a Computer Simulation of Buildings lecturer, it was argued that the thermal performance and ventilation of the building could be evaluated more accurately with IES-VE, and so the author undertook a series of training courses directly through IES, with the goal of evaluating the framework's corresponding visual radiation, thermal radiation and airflow aspects. The training was completed concurrently with the student tests.

However, with further consideration and through this training, the reasoning behind the evaluation of the designs in this manner proved to be less coherent than initially thought. At a practical level, the training, consisting of SketchUp into IES, ModelIT,

RadianceIES, MacroFlo and ApacheSim modules, suggested to the author that a thorough environmental testing of these buildings would in itself require significant input of time and additional experience beyond the limits of this research. In fact, an analogous thesis, that of Puteri Shireen Jahn Kassim (2004) at the University of Brighton, demonstrated the complexity of evaluating some of the elements of Ken Yeang's designs in the tropical climate with such software; even with her scientific background, significant technical assistance was required that was not accessible for the author's framework testing. In any case, the development of the framework as a design process and the inclusion of additional elements is in itself a further complication that made the use of such testing in the time scale available at best of a rudimentary quality.

On a more substantial level, the evaluation of the resulting designs was even more problematic. If the purpose of these evaluations was to test the environmental performance of the framework as a whole, the testing could not achieve that result. Instead, it would assess the performance of the resulting buildings, and partially at that, as the designers would inevitably add or subtract elements, related or unrelated to the framework advice. The additional factors could have a large impact on the designs, as would prior training in environmental design. In this sense, the student tests could be just as biased and unreliable as the author's. To obtain any form of reliable comparisons and statistical estimates, a large number of designers, perhaps with a large number of building designs, would be required. Again, such a task would go well beyond the scope of the thesis.

If the purpose of the evaluations was to examine the performance of the individual elements, in this case steps or design principles, initially there could have been an argument for a form of evaluative modelling. In fact, this has been done in the aforementioned thesis (Kassim, 2004), but with discouraging conclusions: 'based on a rigorous climatic analysis which he himself advocates, it is proposed that Yeang's designs should be evaluated in terms of their overall forms rather than separate components.' The 'components' in that case are fairly equivalent to some of the 'design principles' in the framework; they consist of 'core placement, skycourts, balconies, shading system and vegetation system.' Furthermore, they are often cumulative and sometimes prohibitive in relation to other principles, and so cannot always be assessed independently. Even so, as some of the steps eventually had options and the majority had other variations, a prototype model for testing might not be representative, even if it does suggest areas for improvement for that specific

building. What was found to be a much more effective use of resources for verifying the validity of the design principles, therefore, was a referencing of reliable sources, which were either in the form of environmental performance studies or information deduced from a number of such studies.

All in all, the performance assessments, of both the designs and elements, would yield a limited amount of information and influence in the framework as it stands. Moreover, as the framework is not, and not intended to be, complete, but adaptable and expandable, environmental assessments may be more suitable for instances where there is disagreement between studies or where insufficient data exists for a principle to be considered definitive. Both cases are referred to in the final framework version in the Annexe, and the best methods for advancing the framework are discussed in Chapter 7.

3.6.2 Required changes to framework (1) (2)

A thorough discussion of the improvements suggested by the students is included in later chapters; here, it is sufficient to state that the feedback, and the additional literature review that followed, substantially altered both the principles and their organization. As noticed by the students, and also as highlighted in the previous stage, the framework's strength and uniqueness was in bioclimatic design, so version 4 would focus solely on this aspect.

3.6 Summary

To reiterate, this research aims to find principles of environmentally sustainable design that would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America and organize them so that they can best inform architects. This chapter explored the methodology adopted and tasks undertaken to respond to its purpose, as organized into three key stages. The following chapters will consider a part of this methodology and its application in further detail. Stage 1, in which the principles were extracted from the work of Ken Yeang and where initial attempts were made in their organization, will be examined first.

4 STAGE 1: INITIAL DEVELOPMENT AND BIRMINGHAM TEST TOWER

Chapter 2 ended with a review of Ken Yeang's framework and so this one will begin with an introduction to his principles. As the choice and organization of his principles is the focus of Stage 1, this chapter starts out at with an overview of the design principles he sets out. Some of these are verified at this point by a small number of sources. The case studies, which examine the use of such principles in practice and point to any gaps, are then considered. Some observations from student work and from practice are also included so as to infer their applicability in those settings. Initial attempts at framework organization are presented, culminating in the first major version of the guidance, which is then applied to the design of a tower in Birmingham. The analysis considers the outcome of this test, mainly as it relates to the organization of the framework.

4.1 Ken Yeang design principles

The choice of the design principles is directly related to the first objective of this research, 'To find principles of environmentally sustainable design which would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America.' This section will therefore introduce a set of design principles, extracted from the work of Yeang, that were considered as applicable to building and climate type. Nonetheless, those not specific to any climate or building type were generally included, as much of his advice was applicable to a range of projects. It should be highlighted that at this stage the principles were not evaluated, but extracted for later examination. Some appraisal did inevitably take place early in the study, but the main goals initially were to extract them, organize them and point to any gaps.

Many of these design principles have been developed throughout Yeang's practical work. However, they are necessarily not his own ideas; one of the main inconveniences of his texts is the lack of proper referencing of his notes. What he instead provides is a large bibliography at the end of his books, consisting of hundreds of sources consulted throughout more than three decades of work. It is thus difficult to verify the source of his work, but as many of the suggested principles are common among other green architects and as Yeang himself is regarded as a leading expert in the field, they offer a valid starting point.

The principles have been simplified as individual steps and for the purposes of the framework accompanied by instructive diagrams. The diagrams have been created in order to abridge the complicated verbal descriptions characteristic of much of Yeang's written work. However, some principles are best described in words and therefore do not include these diagrams. These also have been generally summarized from Yeang's original statements.

These design principles are collected from a recent and extensive explanation of Yeang' approach as set out in *Ecodesign: A Manual for Ecological Design* (Yeang, 2006). Essentially, this book is a collection of his previous texts, though organized in a different manner. Unlike some of his earlier work, this book is not specific to the tall building, but it does reinstate previous work as part of a more general design approach. 'Despite the current plethora of literature on ecodesign,' he comments, 'none exists that provides a comprehensive set of fundamental considerations and criteria in an organised approach to design. This then is the objective and usefulness of this manual' (2006: 16). It is furthermore considered a 'comprehensive body of instructions that inform the reader of what constitutes ecodesign' (2006: 16).

Alongside these high expectations, however, Yeang also describes what the manual lacks, namely 'all the answers to ecological design' (2006: 16). He considers ecodesign 'still in its infancy,' and hopes that 'this groundwork will be augmented in the future and revised as the field advances and develops' (2006: 17). The designer is warned against the expectations that following the instructions in this manual will necessarily result in a successful design, as this is dependent entirely upon the 'design skills of the designer' (2006: 17). There is one final precaution as well, that of expecting that there is a set sequence to the instruction's application:

'Although the set of instructions for ecodesign provided here is set out in what is hoped is an orderly manner, we need to caution that ecodesign is not sequential in application and that the order in which these instructions are followed may vary, depending on the design assignment at hand' (2006: 17).

There are essentially three sections to this manual, 'General Premises and Strategies' (A), 'Design Instructions' (B) and 'Other Considerations' (C). The section on 'Design Instructions' (B) is of primary importance of this study. It begins with a set of general considerations 'to be taken into account in the initial approach to any design assignment'. However, as they are 'intended to assist the designer in writing the brief' (2006: 7) and are therefore less relevant to the development of the proposed design framework, they are disregarded here. Chapters B13 through B29

form the basis of the proposed design framework. Collectively, they are described as ‘considerations that need to be taken into account as the designer proceeds to articulate the design of the environmental or comfort-related systems of the built system or the designed product’ (Yeang, 2006: 8). In others words, these include the L21 and L12 interactions of Yeang’s matrix. If one recalls the discussion in the last chapter, the framework eventually focused on the former interaction, but as its earlier versions included both and as the case study reviews incorporate both, they are described in this chapter.

The principles were used to examine their application among other designers in the case study review and so, rather than repetitively list them out here, they are presented in the next section in Figures 4.1 and 4.2 and with reference to the final framework steps and options, found in Chapter 7. It should be noted that the terms used here are a summary of those used by Yeang, and may differ from those in the final framework. Their order in the table approximates that of their presentation in *Ecodesign* (2006), which does not always correlate with that of the sequential steps in the framework. They are nonetheless sufficiently similar for comparison; again, specific citations are found in Chapter 7. The legibility of the images is mostly irrelevant at this point as only the framework’s author applied the principles, and likewise the final images can be found in the final framework.

4.2 Case studies

As a further extension of the first objective of the research, this section presents eighteen case studies of sustainable tall buildings, one half from Europe and the other half from North America, as well as a Ken Yeang proposal for London, in an abbreviated format. It looks to provide an overview of the contemporary state of sustainable towers in the region, principally to determine which principles other designers applied in their projects; this approach would consider whether the choice of principles from Yeang was justifiable, how commonly they were applied elsewhere and whether any additional ones need to be included. Therefore the case studies, like the design principles at this point, are for demonstrative, not evaluative, purposes.

This section includes a brief textual summary of the individual case studies, each one followed by a diagram that more clearly points out which of the design principles was applied. A case study comparison, which will assess the overall degree of application

of these principles and provide a more general overview of the state of current design approaches, completes this section. In so doing, it will reinforce the applicability of some of Yeang's principles and highlight any gaps that require resolution in the framework.

The buildings examined here are intended to represent a variety of cool temperate climate types and design approaches currently utilized. However, in order to limit the amount of case studies considered, only those from four countries will be included. This number allows a sufficient variety of examples while permitting comparisons within local groups and climate types.

Ideally, the case studies would have consisted only of residential towers. Yet due to their relatively small number and for the benefits of variety and comparison, a decision was made to include towers with various functions. In this manner, issues separating residential and commercial towers are also made more apparent, although some rating systems, such as LEED, evaluate them jointly. For similar reasons of variety, proposed and planned towers are included alongside completed ones. Such towers also often represent a more advanced view of sustainability than their predecessors and provide inspiration for the development of a framework for future buildings.

It should be noted that the information for these case studies dates to August 2008. Given that the case studies nonetheless demonstrate the current range of design approaches, they remain a representative sample. Moreover, the global economic slowdown has had much impact on the construction and completion of tall buildings, and so the numbers of possible case studies has not risen at the same rate as in decades before.

Although an attempt was made to research all elements and strategies utilized by individual towers, at times all are not necessarily confirmed. Many of the buildings are in the design or construction stage and the strategies included are those that ideally would be incorporated, but this outcome is not guaranteed. Therefore, the data presented cannot be construed as entirely accurate. However, there was an effort to confirm and support the data through multiple sources. Additionally, sustainable design is something that architects tend to publicize to a great extent and so the probability of overlooking a strategy is greatly diminished.

Figures 4.1 and 4.2 respectively correspond to and list the design strategies extracted from Ken Yeang and adopted in more general terms by the case studies. Again, these form a starting point for the research, and so they were either eventually adopted, adjusted, expanded on or rejected in the final framework; for reference purposes, the steps and, where necessarily, options corresponding to this final version are provided in the table. An adoption of a strategy is linked with a highlighted corresponding box of Figure 4.1.

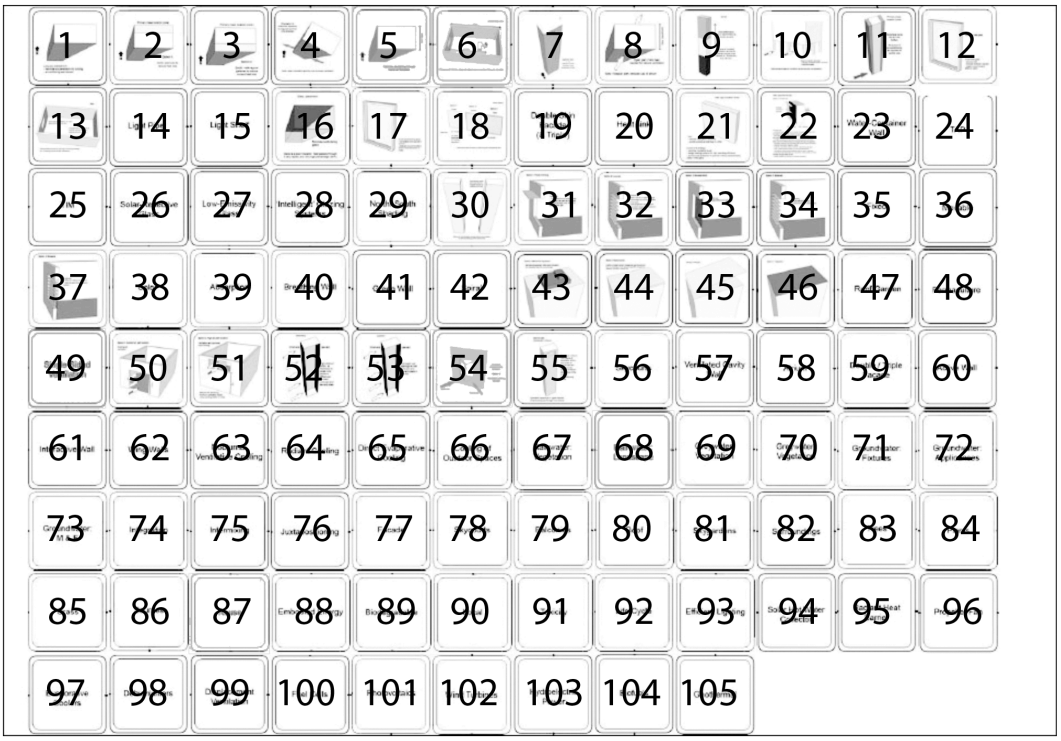


Figure 4.1: Design strategy identification within case studies.

Figure 4.2: List of design principles extracted from Yeang, and their correlation with the case study key and final framework.

No.	Name	Fwk	No.	Name	Fwk
1	Long axis oriented east-west	1	54	Adjustable or closing devices	27, 28, 29
2	Service core on north side to help reduce heat losses	2 (1)	55	Recessed windows	29
3	Walkway or gallery on south side to help reduce heat gain	2 (2)	56	Skycourts (ventilation)	-
4	Orientation towards summer wind	3	57	Ventilated cavity wall	-
5	Narrow-width floor plates at 14-16 m to optimize daylighting	7	58	Atrium (ventilation)	28
6	No more than 5-7.5 m distance from desk to outside wall	8	59	Double/triple façade (ventilation)	28
7	An optimal built form aspect ratio of 1:1.6	4	60	Active wall	28

8	Shallow floorplan of 14 m depth to facilitate cross-ventilation	9	61	Interactive Wall	28
9	Series of modified venting devices for different height zones	12	62	Wing walls	27, 29
10	Ground floor open to outside space, with care taken to avoid wind turbulence	12	63	Nocturnal cooling	27, 29
11	Double peripheral cores as opposed to a central core	2 (1)	64	Radiant cooling	25
12	Tinted glass to be avoided	24	65	Direct evaporative cooling	-
13	Glare control	8	66	Cooling of outdoor spaces	-
14	Light pipes	26 (1)	67	Rainwater: vegetation	-
15	Articulated light shelves	26 (2)	68	Rainwater: landscape	-
16	Minimal north-facing glass	5	69	Greywater: vegetation	-
17	Clear glass for solar gain	13	70	Greywater: landscape	-
18	Glazing layers	19	71	Groundwater: fixtures	-
19	Double/triple façade (radiation)	17 (1)	72	Groundwater: appliances	-
20	Heat sink materials	16	73	Groundwater: M&E	-
21	Increased insulation	23	74	Vegetation: integration	18
22	Trombe wall	15	75	Vegetation: intermixing	18
23	Water container wall	15	76	Vegetation: juxtapositioning	18
24	TAP	-	77	Façade planting	18
25	TIM	15	78	Skycourts (planting)	18
26	Solar-reflective glass	-	79	Balconies (vegetation)	18
27	Low-emissivity glass	21	80	Roof vegetation	18
28	‘Intelligent’ glazing systems	22	81	Skygardens	-
29	Shading on solar facades	17	82	Surrounding/context vegetation	-
30	Solar shading on ‘hot’ east and west sides	17	83	Vegetation: trees	18
31	External shading devices	17 (1,2)	84	Vegetation: plants	18
32	Mid-pane shading devices	17 (2)	85	Vegetation: grass	18
33	Internal shading devices	17 (3)	86	Materials: sources	-
34	External louvers	17 (1)	87	Materials: reuse	-
35	Fixed shading devices	17 (1,2)	88	Materials: embodied energy	-
36	Movable shading devices	17	89	Materials: biodegradable	-
37	Mid-pane louvers	17 (1)	90	Materials: local	-
38	Wall color	25	91	Materials: toxicity	-
39	Wall material absorption properties	25	92	Materials: lifecycle	-

40	Breathing wall	18	93	Efficient lighting	-
41	Green wall	18	94	Solar hot water	-
42	Vegetation placement	18	95	Radiant heat barrier	-
43	Roof insulation	23	96	Ceiling fans	-
44	Roof radiant barrier	-	97	Evaporative coolers	-
45	Roof canopy	-	98	Dehumidifiers	-
46	Roof vegetation	18	99	Displacement ventilation	-
47	Roof garden	18	100	Fuel cells	-
48	Roof permaculture	18	101	Photovoltaic panels	-
49	Single-sided ventilation	29	102	Wind turbines	-
50	High air path location	27, 29	103	Hydroelectric power	-
51	Low air path location	27, 29	104	Biofuels	-
52	Building geometry for (cross) ventilation	3, 27	105	Geothermal power	-
53	Opening location for (cross) ventilation	3, 27			

Although the individual design principles are considered in terms of if and how other designers apply them, the types or groups of strategies applied are also as significant, and at times are of a greater importance. So for example, the fact that a designer applied a strategy for solar shading is more important here than the detail that mid-pane adjustable louvers were chosen. The keys, in the form of Figures 4.3 and 4.4, are helpful for this purpose. The first signifies which general building element is involved, and the second which overall climatic or environmental influence is being addressed. Note that these categories were developed later in the framework, but are nonetheless illustrative of the types of strategies available.

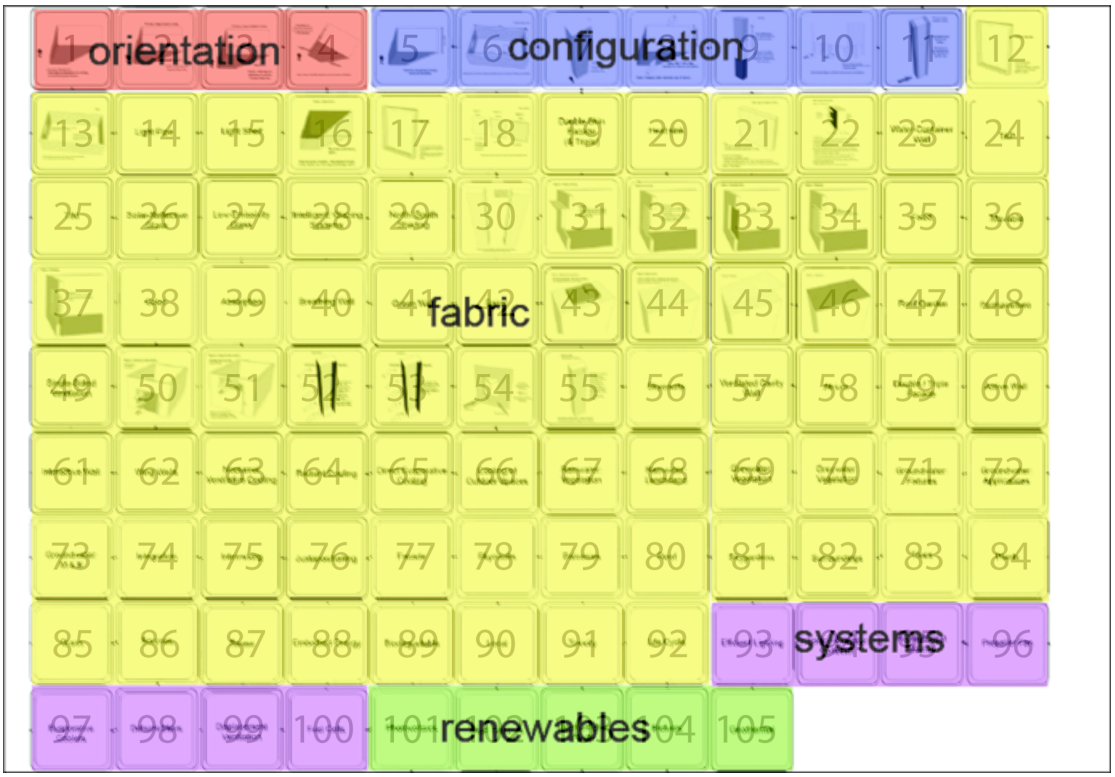


Figure 4.3: Categorization of building elements.

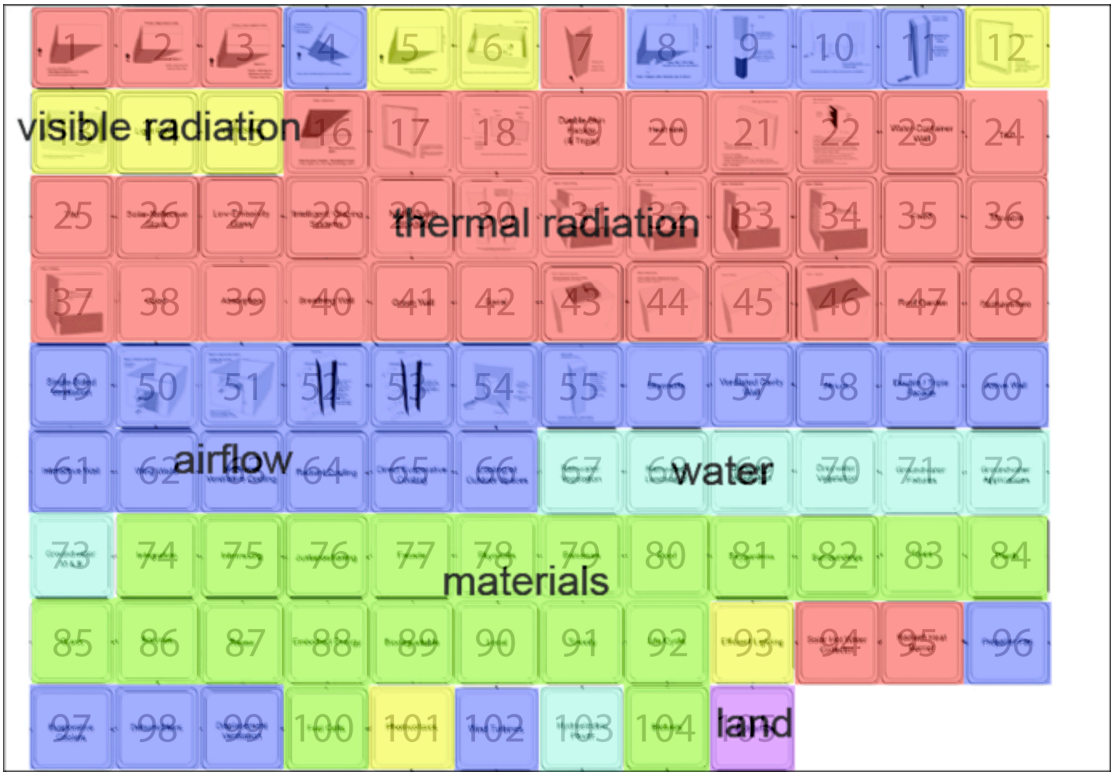


Figure 4.4: Categorization of climatic and environmental strategies.

4.2.1 North American towers

340 on the Park

Location: Chicago, USA
Climate: Humid Continental (Dfa)
Architect: Solomon Cordwell Buenz & Associates
Completed: 2007
Height: 205 m
Main Use: Residential



Figure 4.5: 340 on the Park (340 on the Park website, no date)

340 on the Park is the first residential high-rise in Chicago to meet LEED Silver certification standards. At the time of its completion, it was also the tallest residential tower in the city, although the Trump Tower soon challenged its title. It provides 344 condominiums and 471 parking spaces, which are supplemented by a more environmentally friendly 'I-GO' car service, a 343-bike room and access to local buses and trains (Lahey in Wood, 2008: 366).

Among its features are two green roofs. A highly reflective, lightly-colored roof is provided on the building top and a landscaped version on the second floor canopy that absorbs rainwater for irrigation (Lahey in Wood, 2008: 366). More vegetated space is also made available on the twenty fifth floor winter garden, with a southern, two-story terrace looks that looks over the city's new Millennium Park. This private social space is supplemented by a fitness room, two-lane lap pool and a lounge (2008: 356). As is the case with most residential towers, no public space exists.

This is an all-glass building, segmented by white 'frames,' but its floorplan is unusually narrow, presumably to provide the residences with adequate daylight. The core is located in the center, so is artificially lit. The north façade is 'prow-shaped' and oriented for optimum sightlines towards Lake Michigan (Lahey in Wood, 2008: 365). Other than daylighting, the building form and orientation are not based on climatic influences.

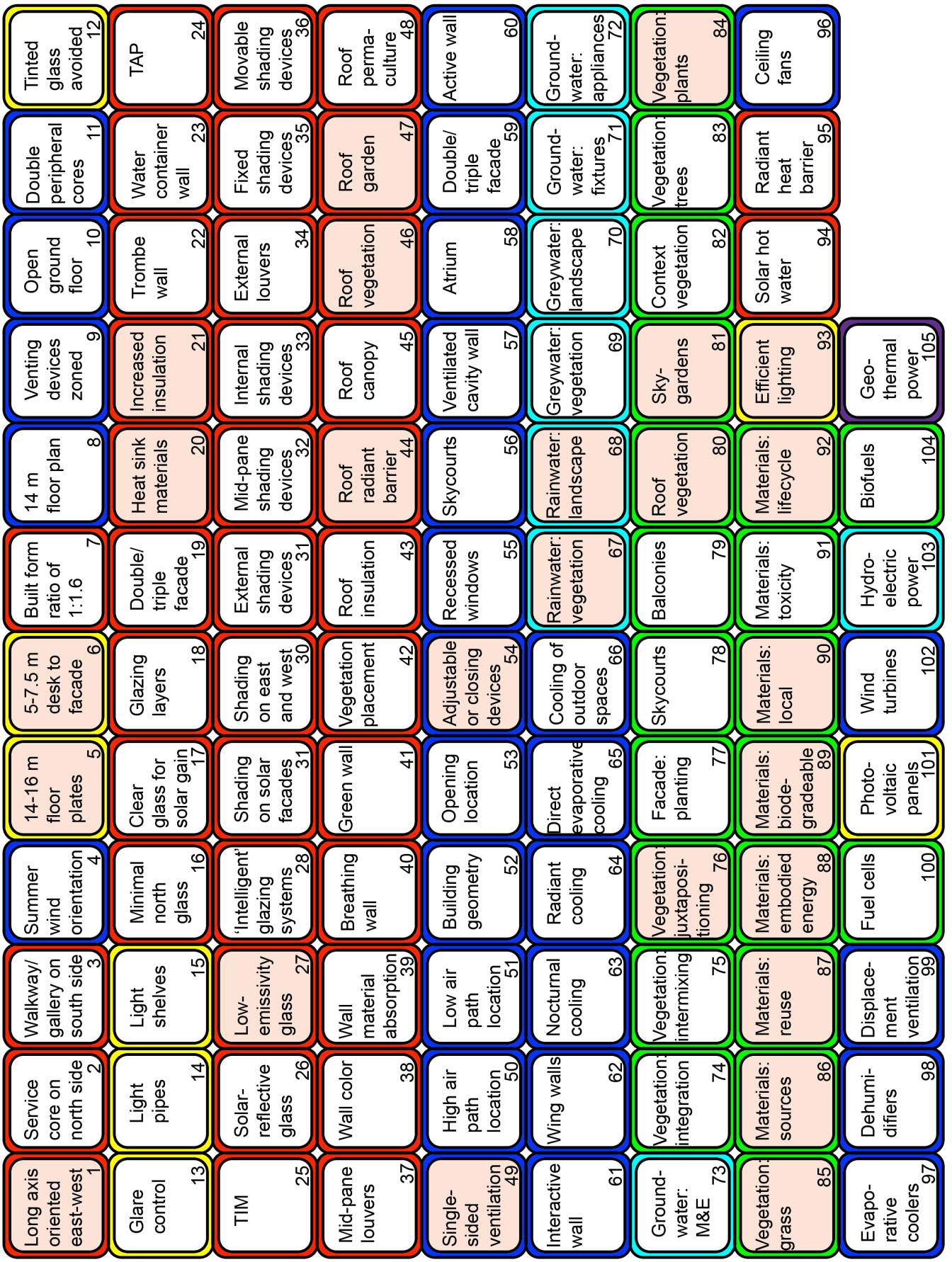
The façade is composed of low-e tinted glass and aluminum panels in a thermally broken aluminum frame in order to provide a high level of insulation and therefore conserve energy **(**'340 on the Park,' no date). High indoor air quality is provided with an energy-efficient ventilation system and localized sensors directing the exhaust fans and replacement air controls. The specification for low-VOC products and

strategies such as green methods of pest control also promotes this aim (Lahey in Wood, 2008: 366). The mechanical heating and cooling systems are energy-efficient and chilled water is delivered through pipes from a district cooling system. Air conditioning is deemed to be more efficient than would be expected with an on-site chilled water plant. As is the case with most North American towers, the focus of this building's energy strategy is on its engineering systems (2008: 366).

340 on the Park is also like other North American towers in that it has a comprehensive material and water conservation strategy that assumes minimal impact on its modern aesthetic. The materials used are described as eco-friendly, particularly due their high-recycled content: 100% concrete reinforcing steel, 99% typical interior drywall, 48% drywall used at perimeter walls and 90% other miscellaneous metals (Lahey in Wood, 2008: 366). 27% of building products were produced within a 500-mile radius, which in this case is considered 'local' by American standards, and further emphasis is placed on renewable materials with the use of bamboo flooring for all residential areas. Moreover, during the construction process, 82% of waste was recycled, which was estimated to have saved more than 2,800 tons of waste from a landfill (Lahey in Wood, 2008: 366). Rainwater is to be collected in 4,200-litre (11,000-gallon) storage tank in the garage for landscaping purposes. This is in addition to the mentioned green roofs, which help to minimize storm water runoff and reduce the heat island effect (Lahey in Wood, 2008: 366).

Overall, the architects project that the building consumes 10% less energy than a typical building of the same size (Lahey in Wood, 2008: 366. In comparison to other case studies, these claims may not seem like much. However, this building sets a precedent for other American residential towers in that its sustainability strategy focuses on the energy efficiency of advanced systems much more than through passive methods. It also shows the relatively simple and positive application of a winter garden and green roof, a strategy already strongly promoted by the city. The interaction between the LEED requirements and the city agenda is an interesting one to follow, as LEED becomes a more standard requirement and cities continue to compete for the title of 'American Greenest City.'

Figure 4.6: 340 on the Park strategies



Chicago Spire

Location: Chicago, USA
Climate: Humid continental (Dfa)
Architect: Santiago Calatrava
Architect of record: Perkins + Will
Completion: proposed
Height: 610 m
Floors: 150
Main Use: Residential

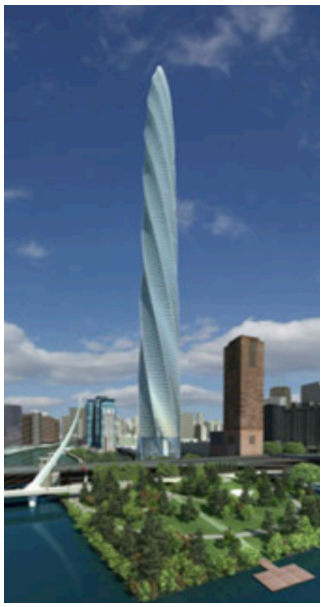


Figure 4.7: Chicago Spire (Chicago Architecture website, no date)

Once expected to become North America's tallest tower and the second tallest residential building in the world at the time of its completion, the 150-story Chicago Spire is designed to provide 1,193 luxury condominiums on a lakefront site in the neighborhood of Mies's Lake shore drive. The seven-sided corkscrew shape derives from Santiago Calatrava's interest in natural forms, such as the snail shell, and what he describes as his inspiration of the site:

> I know that Chicago is an Indian name, and I can imagine in the oldest time the Native Americans arriving at the lake and making a fire, with a tiny column of smoke going up in the air. With this simple gesture of turning one floor a little past another, you achieve this form ('The Chicago Spire,' no date).

Each of the tower's stories rotate on average 2.44 degrees adding up to a 360 degree rotation in total ('Chicago Spire,' no date). This curving is expected to add strength to the structure and to deflect wind ('Editor's Report,' 2007).

The shape, however, does not seem related much to its sustainability agenda and the pursuit of a LEED Gold rating. In fact, just as in 340 on the Park, the thinness of the tower can only be attributed to its need for the expected provision of daylight to each apartment. The core is therefore a central one, which does not benefit from natural daylight. The rest of its environmental strategy appears divided between its energy-efficient systems, water conservation and waste disposal strategy. Monitored outdoor air delivery, the use of river water for cooling and intelligent building and management systems make up the systems strategy. The water strategy consists of the planting and development of parkland around the building and the use of recycled water for landscaping treatments. There is a sustainable waste storage and recycling management system, although no specific figures are provided regarding this or material resourcing. The building also features glass designed to protect migratory birds ('The Chicago Spire - a closer look,' 2007).

Additionally, the building provides a bike storage system for approximately 400 bikes (‘The Chicago Spire - a closer look,’ 2007) and 1,500 underground parking spaces (‘The Chicago Spire,’ no date). As with other luxury developments, here condominiums costing up to $40 million each, there are expected to be no links to nearby train lines or public transportation. Undeniably, this building is much like a gated community in other ways as well. There is an observation deck on the top floor and a four-story lobby, but both of these are inaccessible to the public (‘Chicago Spire,’ no date). On the first seven floors, the residents are also provided a range of facilities**,** including a daycare, library, retail and office space, spas, pool and fitness center.

The engineering systems and construction systems may be some of the most advanced, but its environmental strategies do not present a novel model for future towers. Nonetheless, it is one of a small number of supertall residential towers that aims to increase its energy efficiency, in this case by 15% (‘The Chicago Spire - a closer look,’ 2007).

Figure 4.8: Chicago Spire strategies

Solstice on the Park

Location: Chicago, USA
Climate: Humid continental (Dfa)
Architect: Studio Gang
Completion: Planned
Height: 91 m
Floors: 26
Main Use: Residential



Figure 4.9: Solstice on the Park (Solstice on the Park website, no date)

Unlike most sustainable towers in America, Solstice on the Park is based on applying passive strategies to reduce energy consumption. Consisting of 145 dwellings and amenities, including a library in the lobby and fitness center, hospitality suite, pool and a 2023 m² (0.5 acre) roof garden on the fifth floor, this residential block is, as the architect states, 'literally shaped by solar access' ('Solstice on the Park,' no date). Its most unusual feature is the south façade, which is tilted back 71 degrees. While permitting sufficient daylight to enter the building, this angle allows the sun to enter the apartments during the winter for passive solar gain and to block it out during the summer in order to reduce the need for air conditioning ('Solstice on the Park,' no date). The angle is specific to Chicago and was determined using parametric modeling, a method the architect argues can be used for future green designs (Gang, 2008: 499). This alteration is visible in the top two-thirds of the building and grouped in four-floor segments, giving it a dramatic 'sawtooth' shape.

The north façade is kept plain for the most part and the east and west facades consist of shear walls, carved away where forces are low. The placement of apartments on the south, core on the north and insulation on the east and west is in itself an established passive mode of reducing energy consumption in residential buildings, an effective method that has often become overlooked. Yet it is just this simple strategy of building orientation and configuration that makes the block original in the city, rather than any advanced systems common in green tall buildings. Indeed, the building does boast a number of other significant environmental credentials, such the positive effects of titled glass on bird migration, dual-flush toilets, rainwater recycling, low-off gas carpet, recycled materials, energy efficient appliances, recycling 75% of construction debris, low-VOC materials and finishes, photovoltaics and wind turbines (Bowen, 2008; Becker, 2008; *Solstice on the Park* website, no date).

Solstice on the Park does, however, share some of the environmentally negative aspects of current contemporary towers, particularly in the provision of five hundred parking spaces in a neighboring garage for both its residents and surrounding area (Rossi, 2007). This is an issue in which commercial skyscrapers appear to be ahead of residential towers. There appear to be very few residential attempts in America that challenge this standard, and this building is of no exception.

However, Solstice on the Park is a distinctive building overall. It is the only building in this case study, and perhaps the first in America, to propose an alternate vision of sustainable design. As its architect states, 'By making latitude into a visible feature for the façade and its reason-to-be, the project challenges the current notion of pure iconography and symbolism in tall buildings' ('Solstice on the Park,' no date). This low-tech approach in green tower design is a rarity, perhaps best echoed in Europe by Ken Shuttleworth and Ken Yeang**,** but one that has gained much interest throughout the course of this research. Here the aim is not primarily LEED certification, although it targets to obtain a Silver rating, but the creation of a climate-responsive design. Although not as tall as Studio Gang's less bioclimatically designed 82-story Aquatower, Solstice's approach is likely to reemerge in the practice's future projects, continuing the tradition of Sullivan's theoretical approach to skyscraper forms.

Figure 4.10: Solstice on the Park strategies

Four Times Square

Location: New York City, USA
Climate: Humid Continental (Dfb)
Architect: Fox and Fowle
Completed: 1999
Height: 247 m
Floors: 48
Main Use: Office



Figure 4.11: Four Times Square (Gissen, 2002: 17)

Completed in 1999, Four Times Square is widely considered as America's first 'green' skyscraper. Although many of its features are standard today, the building's sustainability credentials were unique at the time and its emphasis on technology and materials continues to shape the approach to American green towers to this day. Although not LEED certified due to a non-smoking prerequisite (Fox in Wood, 2008: 357), it nevertheless shares a design methodology comparable to LEED-rated buildings.

Also known as the Condé Nast Building, the tower is placed on a major intersection, of Four Times Square, facing the Times Square entertainment area on the west and the Midtown commercial district on the east. Consequently, it has two distinct types of facades that relate to each area. The west and north are based on technology and glass and the east and south are more historical and opaque. As this building connects two streets, the lobby is open to the public (Höweler, 2003: 184). Because of its central location, it is also within walking distance to mass transportation systems.

Other than the structural steel hat truss, the building's overall form is that of a rectangular, bulky office building with a central core. It is only in the approach to building fabric that differences begin to appear. In particular, on the west and north orientations, the floor to ceiling heights are slightly expanded and enclosed by a low-e-coated glass curtain. This specification allows for natural light to infiltrate the perimeter areas of the building while filtering out unwanted ultraviolet light and minimizing heat loss and gain (Höweler, 2003: 184). The building is also fitted with energy-efficient lighting and occupancy sensors used in the central areas of the building during the day and throughout the night (National Renewable Energy Laboratory, 2001). Although the introduction of daylight into a tall office building is commendable, it would be safe to assume that the depth of the floorplan makes

daylighting as an effective strategy unachievable**.** It would be interesting to measure in practice what effect the differing facades have on daylight penetration, as well as insulation.

Solar radiation also powers the 18 meters of photovoltaic panels integrated in the spandrel glass of the top nine floors of the east and south façade (U.S. Department of Energy, 2002). Although they produce only up to 5% of required energy (Nash, 2005: 172), that is 15 kW of power, they form a key green approach in the tower's rare utilization of the technology and so play a highly symbolic role. They also function as part of the façade, saving materials and cost (National Renewable Energy Laboratory, 2001) and offering an alternative to conventional fabric choices.

Although the building does not rely on natural ventilation, its air delivery system provides 50% more fresh air than required by the New York City code, with the possibility of purging any three floors simultaneously with 100% outside air (U.S. Department of Energy, 2002). The air enters the building at high elevations and is 85% filtered and monitored (National Renewable Energy Laboratory, 2001). This high standard of air quality is considered one of the greatest advancements of this skyscraper, although this is achieved mostly through active means.

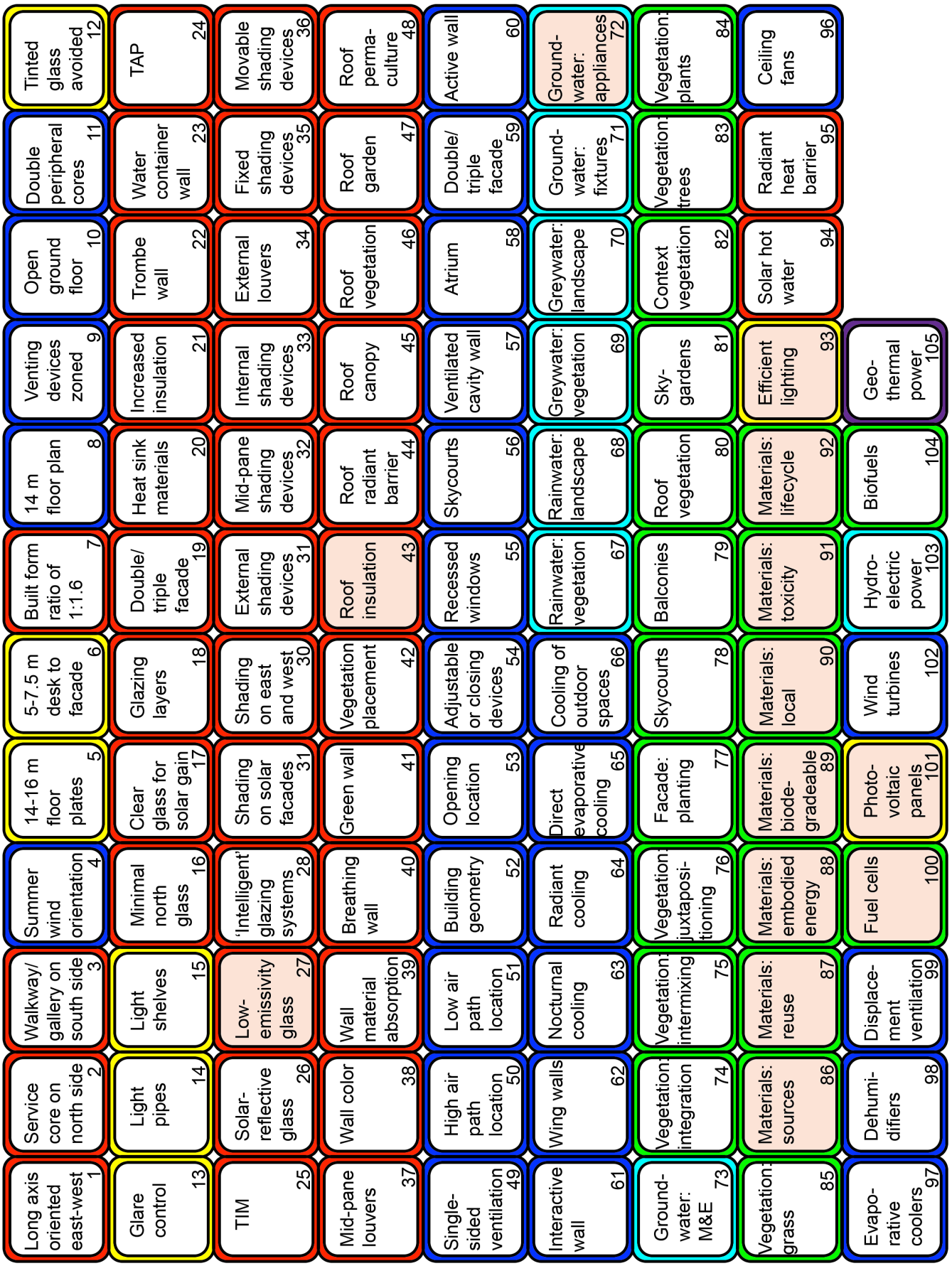
Four Times Square is also notable for two other systems. The first of these is the use of two 200-kW fuel cells, which generate power through a chemical reaction. Although natural gas is required for their operation, they produce 100% of the nighttime electric demand and about 5% of daytime demand without combustion, thus reducing waste heat (U.S. Department of Energy, 2002). Its by-products are hot water, used to help heat the building during winter and for domestic use, and, because of the fuel source, carbon dioxide, in effect making the system energy efficient but not completely environmentally neutral. The second notable system is also relies on natural gas. Absorption chillers/ heaters, placed on the roof, supply hot and cold water to heat and cool the building. They vary in size, so can be combined to suit the building's needs, and do no use ozone-depleting chlorofluorocarbons (CFCs). Additional systems, such as variable-speed pumps, fans and motors and individual floor fan units are also utilized to increase energy efficiency (National Renewable Energy Laboratory, 2001). As is the case with most strategies tested on this building, and as is the case of most contemporary green towers, the aim is not to reduce the need for technological solutions, but to make them more efficient.

Other than green technologies, Four Times Square was at its completion unique in its resource conservation strategies. In regard to materials, the structural steel hat that characterizes the building's top decreased the amount of steel used for the structure (Fox, 2008: 357). Concrete was also used as a structural element and existing footings also reused (National Renewable Energy Laboratory, 2001). Furthermore, more than a third of the structure is made from recycled materials (Battle McCarthy, no date) and the use of modular, renewable, and local/regional materials was encouraged (Gissen, 2002: 23). Approximately 65% of construction debris was recycled (Fox, 2008: 357). Inside, there is a network of recycling chutes (Gissen, 2002: 23) and an emphasis on non-toxic, biodegradable and sustainably sourced materials and equipment (National Renewable Energy Laboratory, 2001). The strategy water conservation is less advanced, although the low-flow water fixtures were specified (U.S. Department of Energy, 2002). The architects also provided a set of tenant guidelines to ensure that indoor air quality and sustainability credentials were maintained. These include information regarding lighting, power usage, interior furnishing and maintenance (Höweler, 2003: 184).

Notably, the tower initiated an experiment linking architectural and engineering fees to the measured level of energy efficiency. This involved multiple agencies and extensive modeling support. (Browning, in Gissen 2002: 179). If applied elsewhere, the system could present higher incentives for designers and developers than voluntary LEED certification. The fact that Four Times Square has been in full occupancy since its completion has a suspected occupier productivity increase by at least 10% (Hallowell, 1999) and lower overall operational costs by 10-15% (Battle McCarthy, no date) demonstrates that green strategies often have financial benefits. This health/economic benefit has since been widely used to justify more recent green towers, as is illustrated in further case studies. As Douglas Durst, the developer, states, productivity is 'the biggest argument for green buildings. If you can make people more efficient, that's a huge saving' (Hallowell, 1999).

Nonetheless, Four Times Square is not a model of sustainability. Its extensive animated lighting is often criticized and its energy efficiency is poor compared to towers completed in the following decade. Its focus on technology and energy efficiency at the expense of passive design methods continues to be emulated particularly in American green towers. Yet the fact that it is the first tower in North America to challenge the assumption that skyscrapers are incompatible with sustainability makes it a highly symbolic landmark in New York City.

Figure 4.12: Four Times Square strategies



The Solaire

Location: New York City, USA
Climate: Humid Continental (Dfb)
Design Architect: Pelli Clark Pelli Architects
Exec Architect: SLCE Architects
Completed: 2003
Height: 86 m
Floors: 27
Main Use: Residential



Figure 4.13: The Solaire (The Solaire website, no date)

The Solaire is considered the first green residential high-rise in America as it was the first to be designed by the LEED rating system. Although it faces west, an undesirable orientation environmentally but the best in this case for Hudson River views, the building fabric attempts to mitigate the problems this orientation causes. Its facade is mostly constructed of brick and so provides a much higher degree of insulation than the more typical curtain wall. The rooftop garden as well grants natural insulation. This focus on materials is apparent between apartments, where there is 33% more sheetrock for extra soundproofing and fire barriers (*The Solaire website*, no date). Continuous air barriers ensure that the envelope is sealed and that windows have low infiltration rates (Natural Resources Defense Council, no date).

The box-like windows themselves are not typical of a contemporary high-rise building. They are low-e rated and sized in association with high ceilings to allow for adequate levels of daylight without incurring unwanted heat gain and loss inherent in uniform curtain-wall designs (Natural Resources Defense Council, no date). The daylighting system also works alongside dimmable fluorescent lamp ballasts and occupancy and daylight sensors (Natural Resources Defense Council, no date). The windows are also openable, which is another uncommon feature and that allows for personalized natural ventilation (Gissen, 2002: 156). The ventilation system is enhanced through the use of a central air-filtration system, an air quality monitoring system, 24/7 exhausts in baths and kitchens, low or no off-gassing building materials and parking garage carbon monoxide monitoring (*The Solaire website*, 2007). Due to the use of both manual and mechanical window systems, the occupants can choose between fresh or conditioned air (Natural Resources Defense Council, no date). This level of preference is exceptionally rare in towers and assumes that inhabitants prefer the more natural forms of lighting and ventilation.

The Solaire uses the western orientation in a more positive way. The unshaded western façade and parts of the roof are covered with 316 square meters of photovoltaic panels, taking advantage of the strong westerly sun (*The Solaire website*, 2007). They operate at peak production on sunny summer days when demand on the local power grid is greatest (Natural Resources Defense Council, no date). Upon completion, they were expected to generate 5% of the building's energy at peak loading performance and estimated to have a payback period of about four years (*The Solaire website*, 2007). Thus, the usually negative western design orientation is utilized to form a sustainable design feature.

The building also has reserved a space and fuel connection for the installation of fuel-cell technology (Natural Resources Defense Council, no date). For now, the building's energy-efficiency is further enhanced through the use cooling towers of a digitally managed, gas-fired central heating and cooling system (Natural Resources Defense Council, no date). This reduces the electricity demand during peak periods when the New York City power grid cannot meet requirements and users generally rely on supplemental power provided by highly polluting generators (*The Solaire website*, 2007).

In regard to resource conservation, the Solaire is also a pioneer. Sixty-seven per cent of its materials were manufactured within a 500-mile radius of the site, and 50 percent of these materials were specified to contain raw resources from the local area (Zukowski and Thorne, 2000); the brick, cast stone, slate, granite and ceramic tile are of those produced locally (Natural Resources Defense Council, no date). There are also specifications for this use of recycled materials, which make up 19% of the materials. These include recycled-content gypsum board, mineral wool insulation, mineral-fiber ceiling panels and tiles, and slate roofing shingles. The photovoltaic cells in particular are emphasized as being composed of 100% recycled materials. All materials are further specified to be low- or no-emission and formaldehyde-free. The wood was sourced from sustainable forests, certified by the Forest Stewardship Council, and the ozone-depletion potential of refrigerants in cooling systems was minimized. The use of cement in concrete was also reduced by 30% through the use of fly ash. The construction waste generated on site was sorted and sold for re-use and 93% (by weight) was recycled (Natural Resources Defense Council, no date).

There is also an extensive strategy for water conservation. Other than energy-efficient fixtures, the building has a system to treat wastewater for use in toilets, cooling towers and landscape irrigation; in this manner, 100% of wastewater is recycled. Stormwater is also controlled through a system consisting of a water retention layer, subsurface infiltration basins and a roughly 38,000-litre (10,000-gallon) basement storage tank (*The Solaire website*, 2007). This system also complements a water conservation method that relies on vegetation. About 75% of the open roof area, and 57% of the site area, is vegetated by plants chosen for their visual interest, drought tolerance, wind resistance and adaptability to shallow soil (*The Solaire website*, 2007). These shrubs, perennials and bamboo utilize a water retention layer underneath them, which captures nearly 70% of rainwater for their use. The water that is not needed then flows to the stormwater retention system, where it is recycled and used in the landscape or the roof garden (*The Solaire website*, 2007). As a whole, the water conservation system is considered the most distinct passive design feature of the building.

The building also has a variety of other less visible green specifications, including the requirement for energy star appliances (Natural Resources Defense Council, no date). Other, more non-tectonic features, are also included. Less than 20 percent of residential units are provided with basement parking spaces, and the building owners have contracted with ZipCar to offer on-demand access to hybrid-technology vehicles. Provisions have been made for electric vehicle charging and storage has been granted for bicycles (Zukowski and Thorne, 2000).

All in all, the Solaire consumes 35% less energy than the New York State energy codes require and reduces peak demand for electricity by 65 percent and potable water by 50% than expected of its type (Zukowski and Thorne, 2000). Considering it is the first green residential high-rise in the city, it offers a model for the successful combination of passive and active design methods. Although not particularly innovative aesthetically, it is one of the only green towers to consider an opaque insulating façade as a solution to unwanted solar radiation. Furthermore, the narrow floor plates required for apartments necessarily enhance the possibilities for daylighting and natural ventilation, both of which more recent deep-plan commercial towers cannot achieve.

Figure 4.14: The Solaire strategies

Hearst Headquarters

Location: New York City, USA
Climate: Humid Continental (Dfb)
Design Architect: Foster and Partners
Associate Architect: Adamson Associates
Completed: 2006
Height: 182 m
Floors: 46
Main Use: Office

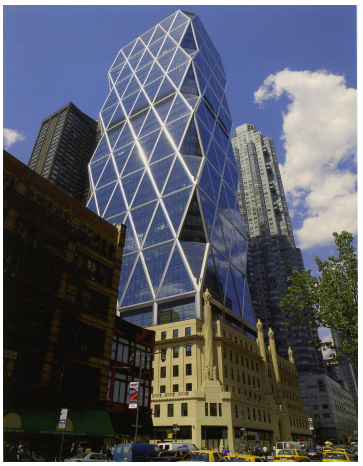


Figure 4.15: Hearst Headquarters (Gräwe and Schmal, 2006: 96)

Hearst Headquarters, the first office building in New York City to achieve a LEED Gold Rating, also departs from typical office towers in terms of structure and form. Hovering above a historic 1928 six-story masonry block, the contrasting steel and glass tower uses no vertical steel beams, a first for American office towers. Instead, a 'diagrid' system of four-story triangles defines the façade. This rigid appearance is furthermore emphasized through the use of chamfered corners. In terms of layout, the triangulated structure allows for flexible, uninterrupted floorplates. In regard to sustainability, the efficient structural system reduces the use of steel by twenty percent as compared to a typical office building, saving approximately 2,000 tons of the material (*Hearst Corporation website*, no date).

Although oriented to fit the New York grid like typical office towers, the Hearst Headquarters provides uncommon levels of daylight. The core is shifted west towards a neighboring building so that the east side is left as an open plan for areas. The other facades are reserved for senior editors, who are provided with cellular offices enclosed with glass-fronted interior walls. This layout is complemented by use of low-e glass curtain walls on the exterior, reducing the impact of solar gain while allowing for the transmission of natural light (Small in Millard, 2006). Yet although the typical floor-to-floor height is 4 m, the average 1,900 m² floor area makes a daylighting throughout impossible. The comprehensive use of light sensors that respond to daylight levels and task lighting, alongside occupancy sensors for enclosed offices, thus help to reduce the amount of artificial lighting requirements ('Hearst Tower,' no date). Also worth noting here is that the gap created between the original block and the new tower ensures that the lobby area benefits from daylighting as well.

It is interesting to note that, as is the case with many other daylit towers, this skyscraper promotes the use of this passive strategy more on grounds of health and economy rather than on environment. In promoting its energy strategy, the tower's website claims that the 'optimization of natural light has been demonstrated in recent studies to have important, positive effects on occupant health, quality of life and productivity' (*Hearst Corporation website*, no date). A case study on its lighting further reveals that it accounts for 13 percent of overall energy savings per $1,000 as compared to a standard design. More broadly, its lighting requirements account for 23% of total energy costs, as opposed to the more standard 30%. In this building, the lighting efficiency measures contribute to the entire strategy as follows: 76% from daylight savings, 2% from lower lighting power densities and 12% from occupancy sensors ('Hearst Tower,' no date). These figures illustrate the large impact that daylighting has on efficiency and present a strong case for the inclusion of the strategy in future towers.

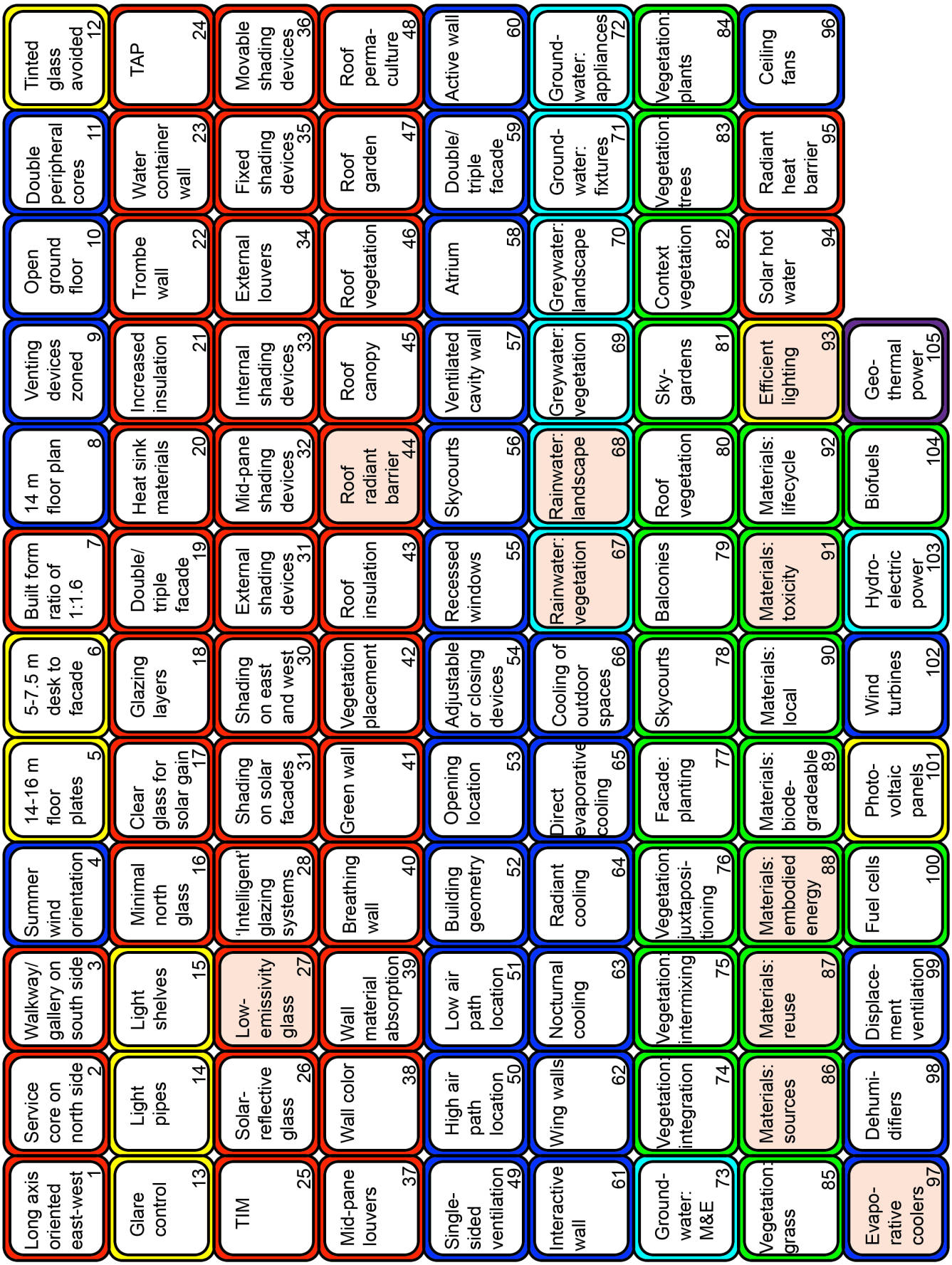
There is a claim that for most of the year natural ventilation is possible (Grave, 2006: 99), although it seems somewhat overstated as the building also boasts high efficiency HVAC systems. Here, air-conditioning equipment utilizes outdoor air for cooling and ventilation for 75% of the year (Laumer, 2006). Although this system is more efficient than usual, there is a disparity in the use of the terms 'natural lighting' and 'natural ventilation.' Often the partial use of these strategies qualifies them as naturally lit or ventilated buildings, but as these are not the primary factors determining building form, this cannot be considered their most comprehensive use. The Hearst Headquarters, therefore, may have some elements of natural ventilation and more of daylighting, but cannot be fully considered as a building based on these passive principles. Nonetheless, in terms of daylighting at least the building displays uncommon commitment to its implementation.

The Hearst Headquarters also displays a range of conservation strategies, including high specifications for material sourcing. Over 90% of structural steel is made from recycled material (*Hearst Corporation website*, no date). Ceiling tiles and carpets are made from recycled materials and sustainable woods are used throughout, including in workstations and an exercise-room sauna (Millard, 2006). The walls are coated with low-vapor paints and furnishings are specified formaldehyde-free (Laumer, 2006). To reduce the heat-island effect, the roof has high-reflectivity pavers, a simple, effective strategy often overlooked in tall building design (Millard, 2006).

Waste and water recycling schemes are also utilized. During the demolition of the original block's interior, 85% of materials were recycled for future use (*Hearst Corporation website*, no date). As of early 2006, the Hearst Corporation has implemented a 'target zero-waste' policy, which includes the composting of approximately 95% of food wastes and the recovery of all paper, metal, glass and plastic for future use. Rainwater collected from the roof is stored in 14,000-gallon tanks in the basement and used in the air-conditioning system and irrigation of plantings and trees within and outside of the building. This will provide about half of the watering needs. The harvested water will also used for 'Icefall,' a three-story water feature in the building's atrium. It cools and humidifies ambient air and is believed to be the country's largest sustainable water feature (*Hearst Corporation website*, no date).

All in all, the tower's energy efficiency programs were expected to save $420,000 and 900 tons of carbon dioxide each year ('Hearst Tower,' no date); this figure would make it 22% more efficient than a typical office building. The design process behind it is described well by Brian Schwagerl, Hearst's director of Corporate Real Estate & Facilities Planning: 'We started out the process just incrementally, seeing how green a project we could become, and by virtue of just following the LEED guidelines, all of a sudden we [went] beyond 'certified', and we became 'gold' (Millard, 2006).
Hence the tower is a good example of the features expected when designing for LEED certification. Here orientation and form are not as important as the highlighted systems and resource conservation strategies. Although it aesthetically does not relate to its sustainability agenda, the tower has nevertheless gained much international attention, setting a standard for future towers in the city.

Figure 4.16: Hearst Headquarters strategy



The New York Times Building

Location: New York City, USA
Climate: Humid Continental (Dfb)
Architect: Renzo Piano Building Workshop
Exec Architect: FXFOWLE Architects, PC
Completed: 2006
Height: 348m
Floors: 52
Main Use: Office



Figure 4.17: The New York Times Building (NYC Architecture website, no date)

The New York Times Company selected Renzo Piano's design for its headquarters as his design architecturally expressed the newspaper's values of 'clarity and transparency' (Höweler, 2003: 132). This brief had also asked for the tower to be 'explicitly European, stating that the manner in which the building met the street was a key consideration' (Gregory, 2008: 46). As a result, the ground floor is attached to a four-story building and includes an auditorium, restaurants, shops and internal garden, visible from the outside and open to the public (Höweler, 1003: 52). The glass-walled garden is located in an open-air courtyard and, due to its transparent enclosure, is also visible from the lobby, the building's offices and auditorium. Its simple design features a grove of paper birch trees, a ground covering of two types of moss and a wooded footbridge. (The New York Times Company, 2008). It should also be mentioned that the building has no on-site parking, although an indoor parking area for 20 bicycles is provided (Naparstek, 2007). The rest of the vertical zoning consists of twenty six floors owned by the *Times*, including a seven-story newsroom, twenty four floors owned by Forest City Ratner Companies, and a double-height cafeteria on the fourteenth and fifteenth floors. Above the top floor, Piano planned to have a private roof garden that will also feature trees discernible through the rods (Stephens, 2008: 101). The theme of transparency continues throughout the tower, as activities within it are visible from the street and as the open plan, low-level furniture interior layout allows for views to the outside (Gregory, 2008: 46).

The fact that this building is split between two main users is of importance here, as many of the interior energy-saving features found in *Times'* floors do not appear in the specifications of the FCRC levels. Consequently, the building owners did not pursue a LEED rating (Stephens, 2008: 98). Nevertheless, its main sustainable feature, the façade, remains throughout both parts.

This unique approach to the façade consists of two elements: a floor-to-ceiling screen of clear glass shaded by off-white ceramic rods held 0.6 m (2 feet) in front and allowing for increased vertical spacing towards the top (Höweler, 2003: 132) The aims of this system are also twofold: it allows for daylight to enter the building while also ensuring the deflection of solar gain. The glass is low-iron, double glazed and with a high performance e-coating (Stephens, 2008: 103). The use of the smaller windows or heavily coated glass was rejected, as they reduce views, light and transparency (Forest City Ratner Companies and The New York Times Company, 2007). The 170,000, 3-inch ceramic rods allow for city views while shading all orientations of the building and reduce the heat load by thirty percent and energy costs by thirteen percent, as compared to a non-daylit building. The corner glass areas that are not shaded by the rods are instead covered with a ceramic frit pattern (Stephens, 2008: 103). These rods also reflect the light and color changes throughout the day, adding visual interest to the otherwise uniform façade. (Forest City Ratner Companies and The New York Times Company, 2007)

To test the effectiveness of this system before investing in its actual construction, a nine-month monitored study consisting of full-scale mockups of various options was established. This involved numerous agencies, including the Lawrence Berkeley National Laboratory, and was used not only to create a competition between manufacturers but also to allow them to modify their designs. This process revealed that certain orientations were more successfully daylit, particularly the southwest corner, where conditions were sufficient enough to allow for lights to be turned off (The Lawrence Berkeley National Laboratory, 2007).

These mockups were comprehensive in that they also tested the effectiveness of automated shading, furniture design and interior finishes for the working environment (Chen, 2004). The automated roller shades complemented the façade system in managing daylight and glare. A manual override system was provided as well options for disabling the shades when the building was in shadow from urban obstructions (The Lawrence Berkeley National Laboratory, 2007). The 18,000 light fixtures can be individually controlled to further reduce consumption. The daylighting and shading system as a whole are calculated to provide an energy savings of over 50% than would be expected otherwise (The New York Times Company, 2008).

In terms of comfort and air quality, the building also features an underfloor air distribution system, carbon dioxide sensors, demand-controlled ventilation and a

100% outdoor air purge system. The underfloor air distribution system in particular has significant energy savings, as it is able to air condition at 68°F, 10 degrees warmer than a typical system. This effect occurs because it pumps chilled air from the floor rather than pushing it down from the ceiling. The building also benefits from free-air cooling from outdoor air during cool mornings. Waste heat produced by the co-generation plant is used heat the space during colder periods. The plant itself is an energy-efficient feature and provides 40% of the power required by the building (The New York Times Company, 2008).

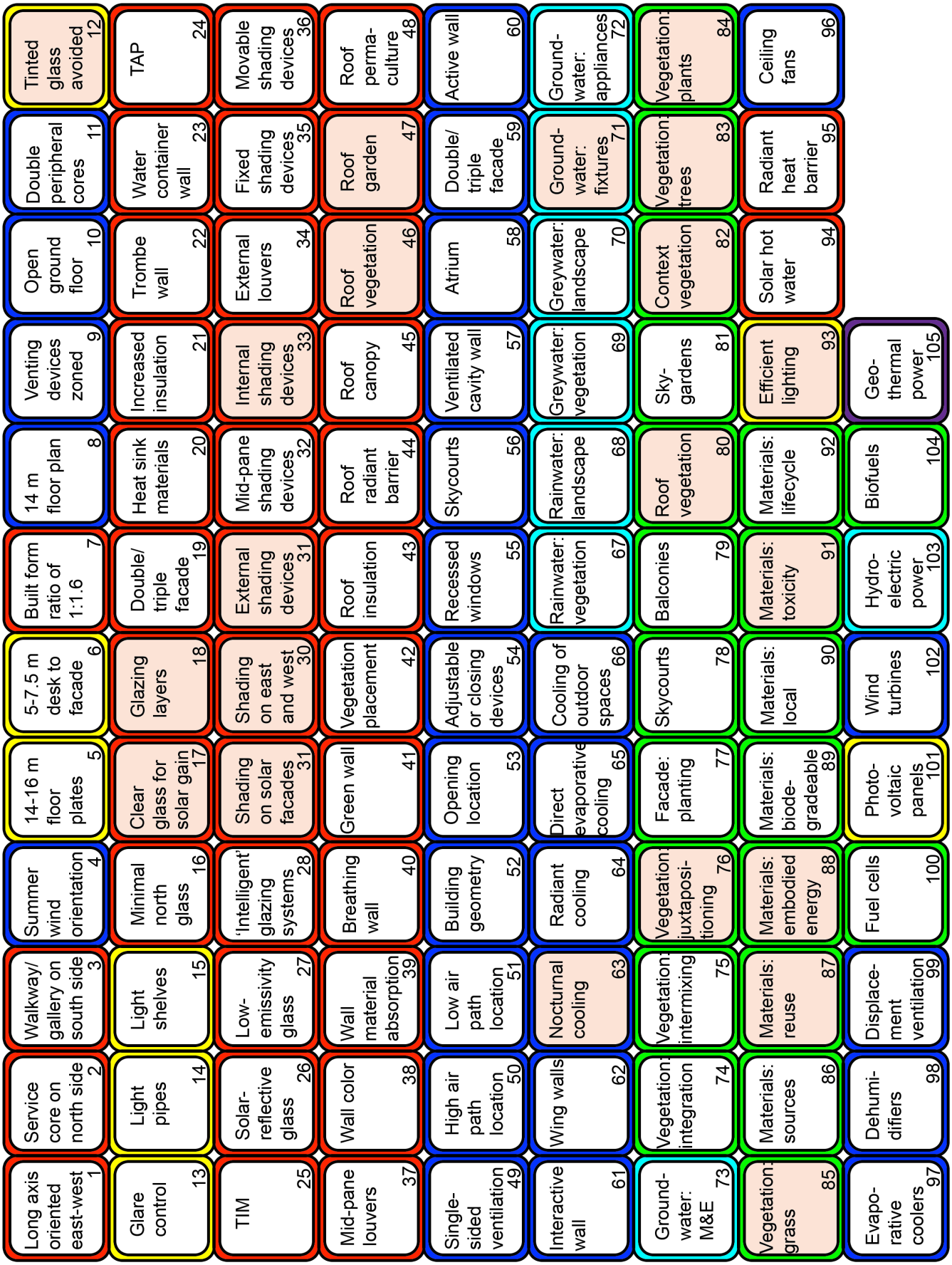
There is also an attempt to conserve materials, as more than 95% of the structural steel contains recycled material. The use of sustainable indoor materials is specified as well, including carpets, ceiling tile, workstations and fabrics (Forest City Ratner Companies and The New York Times Company, 2007). However, as a change to original plans, the contractors were instructed not to keep track of the amount of construction debris recycled. This would have required more time and investment, and, as it was abandoned, led to the decision not to become LEED certified (Stephens, 2008: 98). Other than the specification of high-performance water fixtures, there appears to be no major water conservation features either, making this building one of the less advanced American examples on those terms. The general indoor material decisions, however, also tie it to common commercial American concern for employee productivity ahead of environmental sustainability (The Lawrence Berkeley National Laboratory, 2007).

Even the tower's key feature, the shading system, may become dispensable. There are plans for new towers to the west and south, which will ultimately cut off some of the light the building faces. There are already difficulties with window washing, as they are only 18 inches behind the self-cleaning rods. Piano has also admitted the rods themselves should have been whiter, as the building's current appearance has earned it the nickname 'the gray lady' (Stephens, 2008: 104).

The architect has furthermore questioned its claim of sustainability: 'If you really want to be green, you shouldn't build a tall building in a city in the first place. But the Times wanted to be here, where it belongs, not in some new building on a greenfield site in New Jersey. So we can only do our best' (Glancey, 2007). He sees solar strategies as key, pointing out that 'the ceramic sunshade cools the building, so we need less air-conditioning; and daylight gets into most of the building, so we cut down on electricity' (Glancey, 2007). This building is therefore an example of both the positive

and negative aspects of green tower design. Its unique façade system encourages a more creative approach to the smooth, glass skin typical of most North American towers. Yet its use of the system is also its weakness, as simpler design features could have cost much less and been much more effective. The fact that the building's cruciform plan is 59 m X 48 m deep, with at times a 15 m distance from façade to central core, precludes it from fully taking advantage of daylighting *(The New York Times Building*, no date). Nonetheless, the attention to the façade and the testing of its effectiveness are rather unique in North American tower designs, and the direction towards more passive sustainable design features challenges the more typical system-oriented green designs.

Figure 4.18: The New York Times Building strategy



Bank of America Tower

Location: New York City, USA
Climate: Humid Continental (Dfb)
Architect: Cook+Fox Architects, LLP
Exec Architect: Adamson Associates Architects
Completed: 2009
Height: 377 m
Floors: 54
Main Use: Office



Figure 4.19 Bank of America Tower (Cook+Fox Architects website, no date)

The Bank of America Tower at One Bryant Park is America's first high-rise office to achieve LEED Platinum certification (Fox in Wood, 2008: 358). It is located on one of the city's busiest intersection hubs, where a dozen train lines link. It uses this arrangement to encourage more sustainable forms of travel by not providing parking for Banks of America's four thousand employees (Lepik, 2008: 154). It further integrates with pedestrian traffic by providing a public circulation space three times larger than expected from a similarly sized office building, including provisions for street furniture, widened sidewalks and a public garden room on the ground floor level (Fox in Wood, 2008: 358).

The base of the building is characterized by its incorporation of a listed façade from a theatre completed in 1918, but this purpose is delegated to an underground space seating one thousand guests (Lepik, 2008: 155). The contrasting new tower is inspired by the Crystal Palace, the country's first light-frame metal building, constructed in Bryant Park in 1853 (Fox in Wood, 2008: 358). It tapers upward, with a single layer of the glass façade extending above the structure and visually extending its height. There is no climate-based response in terms of orientation or form.

It can be argued that the bank is most concerned with the health benefits of sustainable design, particularly as they are linked to productivity (Lepik, 2008: 154). This concern has led to two key strategies: daylighting and natural ventilation. The passive strategy, daylighting, is achieved through the use of floor-to-ceiling windows, with low-e coating and a frit pattern to improve energy performance. The pattern, denser at ceiling and floor heights, consists of small ceramic dots silkscreened directly onto the glass curtain wall. These dots fade away to allow for a clear view in the center 1.5 m of each panel. They help to block unwanted solar gain, but are also

employed to provide a feeling of security and speckles of light and shadow into the interior, 'recalling the experience of being outdoors' (Fox in Wood, 2008: 358). Indeed, the architects often mention this connection between indoor and outdoor environments, in text referring to the psychological benefits of vegetation, although the building itself fails to provide any vegetated space above ground floor level. A more general criticism of its daylighting strategy can also be applied to the deep floorplan, which typically spans at least 12 m from exterior to central core (Mueller-Lust, 2008). This prevents most of its interiors from ever benefiting from sufficient natural light.

The second strategy, ventilation, relies on the use of a mechanical system to filter 95% percent of particulates, including ozone and VOCs, a figure that is 60% more than usually filtered by a typical NY office building. Through this system, air exhausted from the building is expected to be cleaner than the air coming in (Fox, 2008: 359). Furthermore, an under-floor air distribution system will allow for local air control through individual air diffusers, minimizing complaints and saving energy. The poor air quality in this area of New York City is assumed here to exclude the use of more natural ventilation systems, although the energy efficiency of this particular mechanical system is not further specified. What the architect instead points out is that if the impacts of a higher quality of indoor environment raise employee productivity by 1%, that is by five minutes per day, the Bank would save roughly $10 million a year (Fox in Wood, 2008: 359). The fact that Robert Fox, a former member of Fox & Fowle, the architects behind Four Times Square, has focused on Bank of America's productivity illustrates the importance of the tactic in promoting green design in the city.

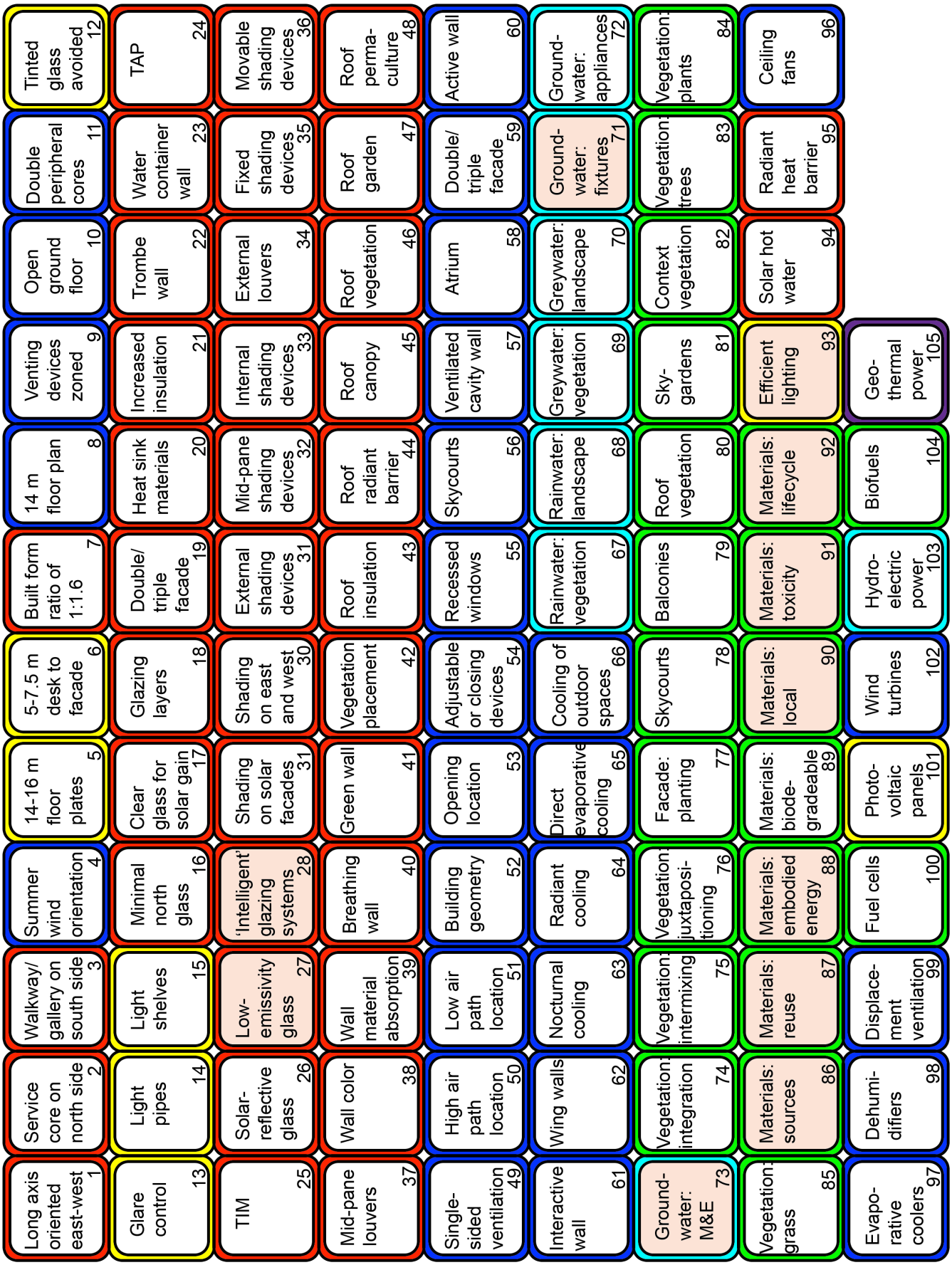
This focus on systems over more passive methods is also demonstrated by its heating and cooling strategy. Located entirely in the building's basement, the Combined Heat and Power plant is designed to provide the building with a third of its peak energy demand and almost 70% of its annual energy requirements (2008: 152). The waste heat from electricity production will be used to generate hot water for both heating and cooling, the latter through the use of an absorption chiller supplemented by a thermal storage plant (Fox, 2008: 358). Further energy savings will be achieved through the use of daylight dimming, carbon dioxide monitors and LED lights ('Bank of America,' no date).

The building also has a strong emphasis on material sourcing and recycling. Although constructed from glass, steel and aluminum, none particularly environmentally friendly, more than a third of the building's materials, including steel girders, are from recycled sources. (Lepik, 2008: 154). There is also a strong preference for local materials and a requirement for no VOC substances. The use of blast furnace slag, a waste product from the steel industry, instead of cement, is expected to prevent 56,000 tons of CO_2 particles from entering the atmosphere. Upon completion, 83% of construction and demolition debris is to be recycled (Fox in Wood, 2008: 359-60).

There is also an extensive water conservation strategy. Aside from extreme weather events, all stormwater and groundwater is to be collected and stored, alongside water from condensed steam and air conditioning equipment and lavatory sinks. This graywater is then used to flush toilets and supply the cooling tower, replacing the typical overdependence on clean drinking water. When combined with other water strategies, such as urinals that alone save over eleven million liters of water (three million gallons) per year, the building is to consume less than half of potable water than required by a more typical office building (Fox in Wood, 2008: 359).

Overall, green technologies and practices only represent about 2% of the $1.3 billion project budget, but save half of the energy and water consumed by a more typical building of its size (Fox in Wood, 2008: 360). Nevertheless, due to 'unreasonable payback periods,' more costly plans for photovoltaics and wind turbines were abandoned (2008: 258-60). The building, with its glass facade, thus lacks any visual green features. The fact that this tower is first to receive a LEED Platinum certification highlights the program's focus. Although the promotion of water and material conservation strategies is innovative, the building's reliance on highly engineered systems and façade treatments only partially remedies the ills created by a lack of concern for climate-based orientation and form. Like other 'energy-efficient' towers, it maintains corporate image and organization of less sustainable towers.

Figure 4.20: Bank of America Tower strategy



One World Trade Center (formerly Freedom Tower)

Location: New York City, USA
Climate: Humid Continental (Dfb)
Architect: Skidmore, Owings & Merrill LLP
Completion: 2013
Height: 541 m
Floors: 84
Main Use: Office

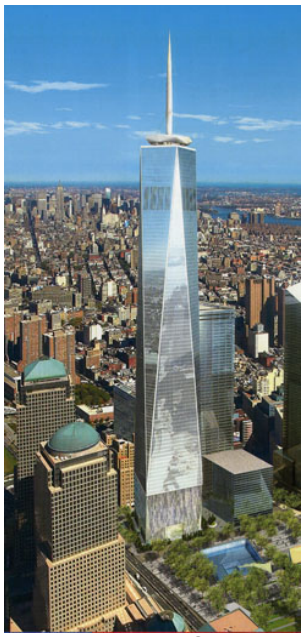


Figure 4.21: One World Trade Center (Gräwe and Schmal, 2006: 120)

Nearly a year after the destruction of the World Trade Center towers, an international competition, headed by the Lower Manhattan Development Corporation, was launched for the redevelopment of the area. Much debate followed, some groups calling for keeping the site as a memorial park and others wanting more prominent towers (Höweler, 2003: 204). Nonetheless, the competition attracted unprecedented worldwide attention, and after the reception of 406 entries, many with skyscrapers, seven architectural offices were later invited to resubmit their masterplans for further reconsideration (Lepik, 2008: 150). In the end, a decision was made to reserve the footprints of the destructed buildings for a memorial and Libeskind's plans that included an angular, spire-topped tower referencing the nearby Statue of Liberty and reaching to a symbolic height of 1,776 feet.

However, the plans for the site and particularly the tower have undergone much change and consequently the label of the most controversial building site in the world. By early 2008, Larry Siverstein, the developer, revealed that Libeskind would from then on play the role of a consultant in general planning, a role without a building contract. The executive architect, and hence the designer of One World Trade Center, would be David Childs of SOM, with whom Silverstein had entered discussions regarding refurbishment of the original twin towers prior to their destruction (Lepik 2008: 150). Much professional and public protest followed this decision, and so the construction of the building is still undergoing alterations as of October 2012. Meanwhile, Michael Arad and Peter Walker were chosen to design the memorial, Santiago Calatrava to restore the railway and underground stations and Fumiko Maki, Jean Nouvel Norman Foster to contrive neighboring office buildings (Lepik 2008: 150).

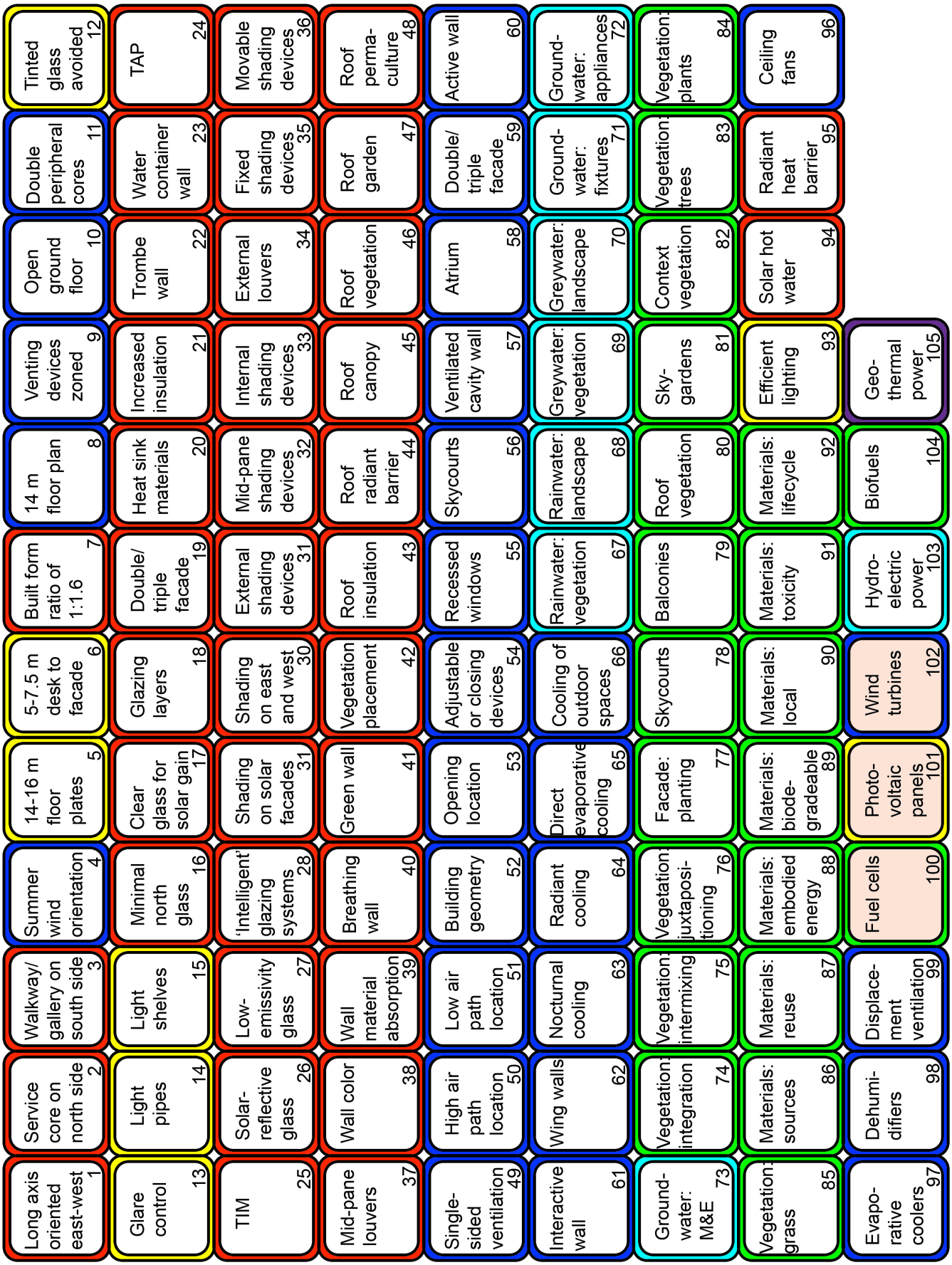
Daniel Libeskind's winning proposal also featured a garden, in fact the 'Gardens of the World' that would occupy the top third of the tower. Yet this, as well as the high

angularity of his proposal, was omitted from the current proposal for commercial reasons (Lepik, 2008: 151). Although undergoing some changes, the current tower's overall form has been resolved. The bulky base of the building is a square of 61 m by 61 m, the exact dimension of the former World Trade Center. There is a central concrete core and the façade consists of a steel and glass façade. The building is torqued so that from the twentieth floor the façade consists of eight equilateral triangles that form an octagon mid-height and taper at a forty-five degree angle at the top. Essentially an office tower, it does however provide public spaces and observation decks. The building is topped by a 123 m antenna, which would make the building as tall as Libeskind originally intended (Grawe and Schmal, 2007: 123)

The sustainable features of this tower are therefore not related to either the form or orientation, but are somewhat arbitrarily added on to the building. There is much emphasis on renewable resources, including solar panels and wind turbines, located at the building's crown (Murray, 2008). Additionally, there are plans for the use of twelve fuel cells to power its heating and cooling systems. This seems to be both an environmental and commercial decision, as the cost of the electricity produced is comparable to that available form the grid. The tower is expected to be 20% more energy efficient than required by New York Code and to meet the requirement for LEED's Gold Certification (Murray, 2008). Although the use of these may encourage the use of greener technologies, One World Trade Center's bulky form makes the use of cheaper and simpler environmental strategies, such as daylighting and natural ventilation, difficult if not impossible.

After the fall of the twin towers, many assumed that the era of the high-rise was over. Yet the interest generated by the competition, and the worldwide growth in tall buildings, have questioned that theory and shown that quite the opposite situation is occurring. In any case, as is seen in the final design, the influence of pragmatic, technology-generated sustainability has remained entrenched in American tower developments.

Figure 4.22: One World Trade Center strategy



4.2.2 European case studies

Commerzbank Headquarters

Location: Frankfurt, Germany
Climate: Marine (Cfb)
Architect: Foster and Partners
Completed: 1997
Height: 259 m
Floors: 58
Main Use: Office



Figure 4.23: Commerzbank (Jones, 1998: 229)

The Commerzbank Headquarters is widely considered the world's first green high-rise. Its design utilizes many of the passive design strategies found in the early modern skyscrapers, including natural daylighting and ventilation, but also introduces new characteristics of sustainability, such as skygardens, water conservation systems and foundation reuse. The existence of this building has brought the sustainability agenda forward for many architectural practices, especially those in Europe, and, because of its overall focus, it is to date still considered by many the most environmentally sensitive completed building.

The sixty-story building, the tallest in Europe upon completion, responds in plan German building regulations, demanding that all offices must have daylight and visual contact with the outside world (Lepik, 2008: 121). The result in plan is a hollow equilateral triangle with lifts, stairs and services at each corner. It is narrow, measuring less than 16m window to window at its widest, and so allows all building users how much natural daylight and views across each wing. Daylight, solar gain and glare are filtered through Venetian blinds, located within the double-skin façade enveloping the larger perimeter (Davies, 1997). As the atrium is covered from above and enclosed on all sides, it is of a single-layer glass construction.

The central atrium, partitioned by glass every twelve stories, also acts as a ventilation chimney for the offices inside and is surrounded by operable windows. It had also originally been a feature of a wind turbine, which was eventually rejected because of its noise and difficulty in control (Davies, 1997). The exterior double façade also enhances the prospects for natural ventilation. It consists of an interior openable glass window and an exterior glass pane, which has a gap above and below that allows for ventilation while blocking wind and rain. In the summer, cool air is drawn in at a faster rate when the temperature in the cavity between increases,

and in the winter the cavity acts as a kind of conservatory, improving the insulation by as much as twenty percent (Davies, 1997). Additionally, when external weather conditions are unfavorable, all windows can be closed and a central air-conditioning system is available (Jones, 1998: 228).

The vertical organization further enhances daylighting and natural ventilation. It is arranged so that a four-floor, single-pane winter garden interrupts eight floors of office space. The gardens spiral around the building, so that each floor has one garden level and two office ones. Other than its social benefits, which will be mentioned later, this arrangement enhances natural ventilation and allows for interior-facing offices to have sufficient daylighting (Jones, 1998: 228). This consideration exists in addition to its aim of providing a vegetated space to balance the inorganic mass of the structure.

The mechanical heating system is more conventional and made up of panel radiators. The air conditioning, however, is derived through an innovative system delivering coolness by water, not by air. Water has a higher specific heat capacity and pumping it uses less energy than blowing air. It can also be re-circulated, meaning that it is not wasted. The chilled-ceiling air conditioning is also separated from the ventilation system for efficiency and the two cannot be used concurrently. Here the building management system decides which system functions (Davies, 1997). The Commerzbank Tower also minimizes parking space, uses timers and movement detectors for artificial lighting and directs sludge water to the toilets (Jones, 1998: 228).

However, the building's most inventive sustainable element remains its winter gardens that divide it vertically into five twelve-story 'villages.' Each garden is assigned to about two hundred and forty workers and is laid out for each 'village' to see. In fact, the most popular offices are not by the exterior windows but by the atrium, signaling the importance of communal spaces, or social sustainability, of the building. Structurally, the gardens only have one exterior glazed curtain wall, set back from the surface and sloping outwards, to protect them. This allows room for an external terrace at garden level, makes the interior more visible from the outside by interrupting the pattern of reflections and breaks up the radar signature for air traffic controllers at the local airport. The gardens are connected to a hot-water system that reduces the risk of cold downdrafts and condensation and are always naturally ventilated because of a lack of atrium windows. Their contents represent three plant

ecologies: Asia to the east, North America to the west and the Mediterranean to the south (Davies, 1997). The Commerzbank is one of a few tall buildings in the temperate climate to include skygardens, even though this element has become a signifier of sustainability globally.

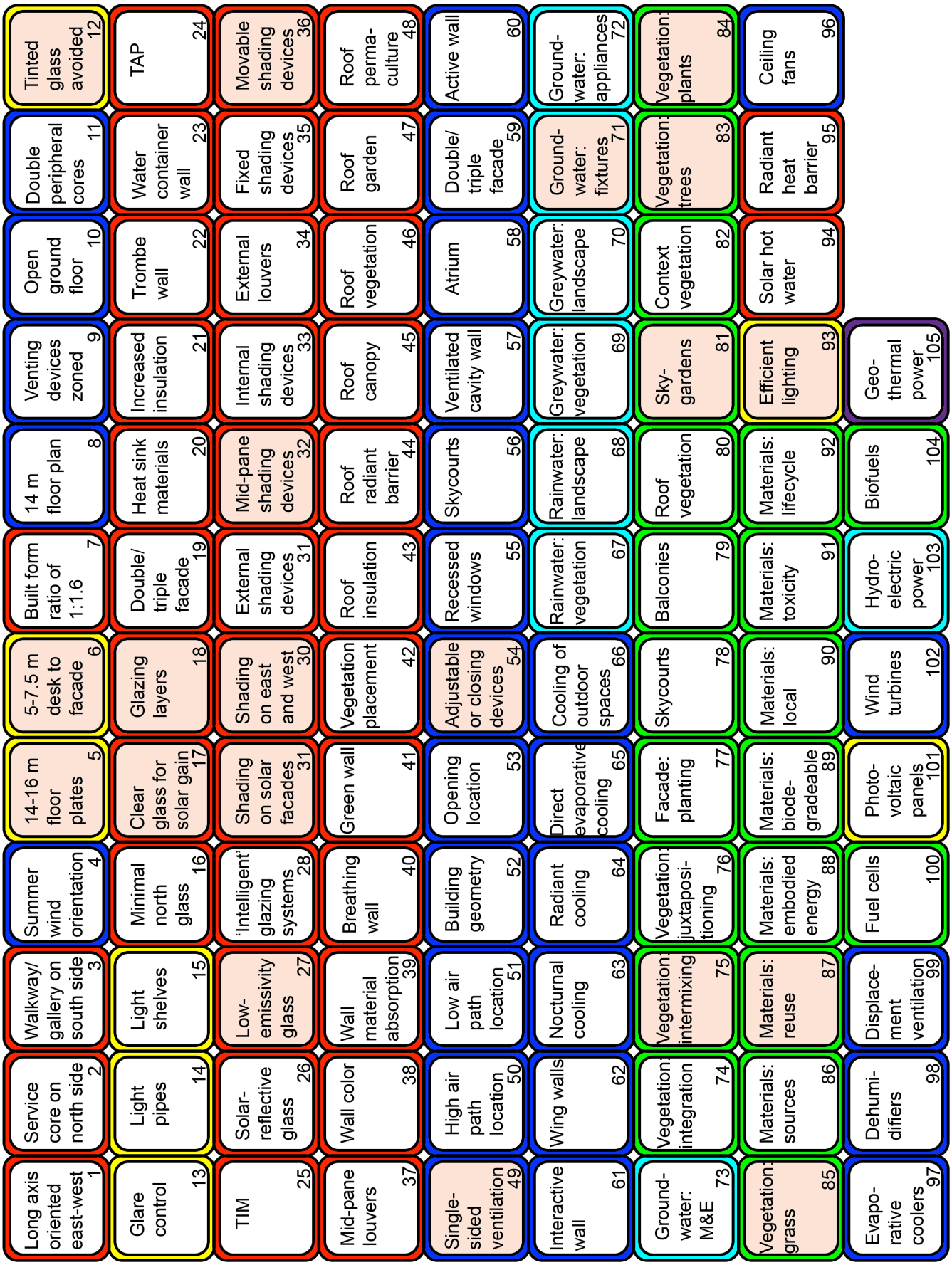
Although this tower is often still considered the best example of ecological design, it is not a model to be applied blindly. Critics often point to technical malfunctions of details such as motion sensors and larger issues such as the inefficient use of space due to its large core (*Sustaining: Tower Blocks*, 2004). Some of the harshest criticism comes unsurprisingly from the tower's competition runners-up, Ingenhoven Overdiek und Partner**.** Falk Jaeger, in a monograph on the firm's work, points out that the facades are extremely exposed to the wind and sun, that floor plans have a 'highly problematic ratio between circulation areas and areas for use' and that 'despite the proffered 'natural ventilation,' the daily operation runs on mechanical air-conditioning' (Feireiss, 2004: 209). Criticism abounds for even the gardens, where, 'incidentally, experts are still struggling to establish a thriving flora' and statistics are unavailable for their success (2004: 209). Jaeger continues (cited in Feireiss, 2004: 209):

'The building is its own water tower, fully automated right down to an electric motor for every opening wing, requires ambitious fire protection measures and expensive high-performance elevators, not to mention the fully electronic building management and faultless monitoring system. High-rises on this scale have become almost unjustifiable, at least from the perspective of society as a whole'.

What IOP proposed instead was a somewhat smaller skyscraper, which eventually took the form of the RWE tower in Essen, discussed in the next case study.

The most serious of criticisms, however, is in fact something that is becoming less overlooked in contemporary towers: the embodied energy of materials (Jones, 1998: 228). Unlike modern-day towers based on the LEED system, the Commerzbank does not focus on the sourcing or recyclability of the construction materials. The use of modular construction techniques and the use of timbers from managed sources are perhaps its most significant achievements in terms of material conservation. Despite all criticisms, however, the Commerzbank is one of the earliest, and still outstanding, examples of a modern tower that is for the most part daylit and naturally ventilated.

Figure 4.24: Commerzbank Headquarters strategy



RWE-Turm (RWE Tower)

Location: Essen, Germany
Climate: Marine (Cfb)
Architect: Ingenhoven Overdiek und Partner
Completed: 1996
Height: 120 m
Floors: 30
Main Use: Office



Figure 4.25 RWE Tower (Feireiss, 2003: 223)

The architects of the RWE Tower aim to distort the distinction between the engineer and architect, a distinction that, as previously discussed, defines modernist architecture. Martin Pawley describes this endeavor through the example of the building's skin:

> Though not the first building to be fitted with a double façade, the RWE tower was the first to incorporate climate control as an integral part of the architect designed building envelope – a venture into engineering design and machine production whose significance should not be underestimated, for it touches upon the demarcation of roles in the construction-related professions, and possibly marks the beginning of an architectural counter attack to recover much of the territory captured by structural engineers in the last century (Feireiss, 2004: 31).

As this tower represents the 'reclamation' of engineering as architecture, it is fitting that the RWE high-rise maintains the glass and steel purist aesthetic of most contemporary, highly engineered towers. However, unlike in most skyscrapers, engineering here is not just a way to enhance energy efficiency and increase productivity. It is also a contemporary re-interpretation of the Vitruvian model of design, where architecture acts as a mediator between the unpredictable environment and more stable human requirements. Technology here becomes architecture and therefore distinctions between passive and active methods of climate control also become less clear.

In terms of the most fundamental passive features, form and orientation, the building is designed as a cylinder so as to deliver 'the best ratio between area for use and envelope area with positive results for heating requirements' (Jaeger in Feireiss, 2004: 210). This form is generally considered the best solution for the problems of unwanted solar gain and loss and strong winds, although the diameter usually does not allow for daylighting or ventilating of the center, where the core is usually located. The RWE tower nevertheless does attempt to ameliorate the problems caused by this form through the use of an external elevator core (*Hochhaus einer Konzernverwaltung in Essen*, 1997: 358). The 32 m diameter interior floorplan is then designed as three layers: a core space for 'group and communicational uses,' a ring

access corridor and an outer office zone (*Hochhaus einer Konzernverwaltung in Essen*, 1997: 358).

Vertically, the building is divided like a classical Greek column, with a base, shaft and capital defined by the platform, uniform floors interrupted by a vented mechanical levels and a pillared disk on roof. This roof was originally designed as a heliport but not now acts as a platform for the maintenance system and a shading component. The shading component, consisting of aluminum louvers and photovoltaics, covers a top garden level (Meyer in Feireiss, 2004). An antenna is attached to the elevator core, bringing the total building height to 162 m.

A more complicated range of mechanical details accompanies this simple form. The most notable is the 'fish mouth' device, located within the double façade and between each floor, acting both as a sunshade and an air intake. The exterior end of the device can be opened to ventilate the double skin-façade or closed in order to enhance the building's insulation (Gissen, 2002: 52). It works in collaboration with an extensive building management system, which monitors temperature, rainfall and external wind forces (Höweler, 2003; Pehnt in Feireiss, 2004). When conditions are within an accepted range, the inhabitants of the building can regulate the office environment with small control switches and open the internal windows, though only 15 cm (Pehnt in Feireiss, 2004:26). When conditions are undesirable, the internal skin closes and an air-conditioning system mechanically ventilates the space (2004: 26). This combination of passive and active methods, technology and architecture, is further seen in other building features, such as thermal storage concrete floors and mechanized sunshades (Höweler, 2002: 186; Jaeger in Feireiss, 2004: 210). Each of the architect's ideas is described by Jaeger as 'hardly novel or sensational on its own, but the sum of these ideas achieves unprecedented results' (Jaeger 210).

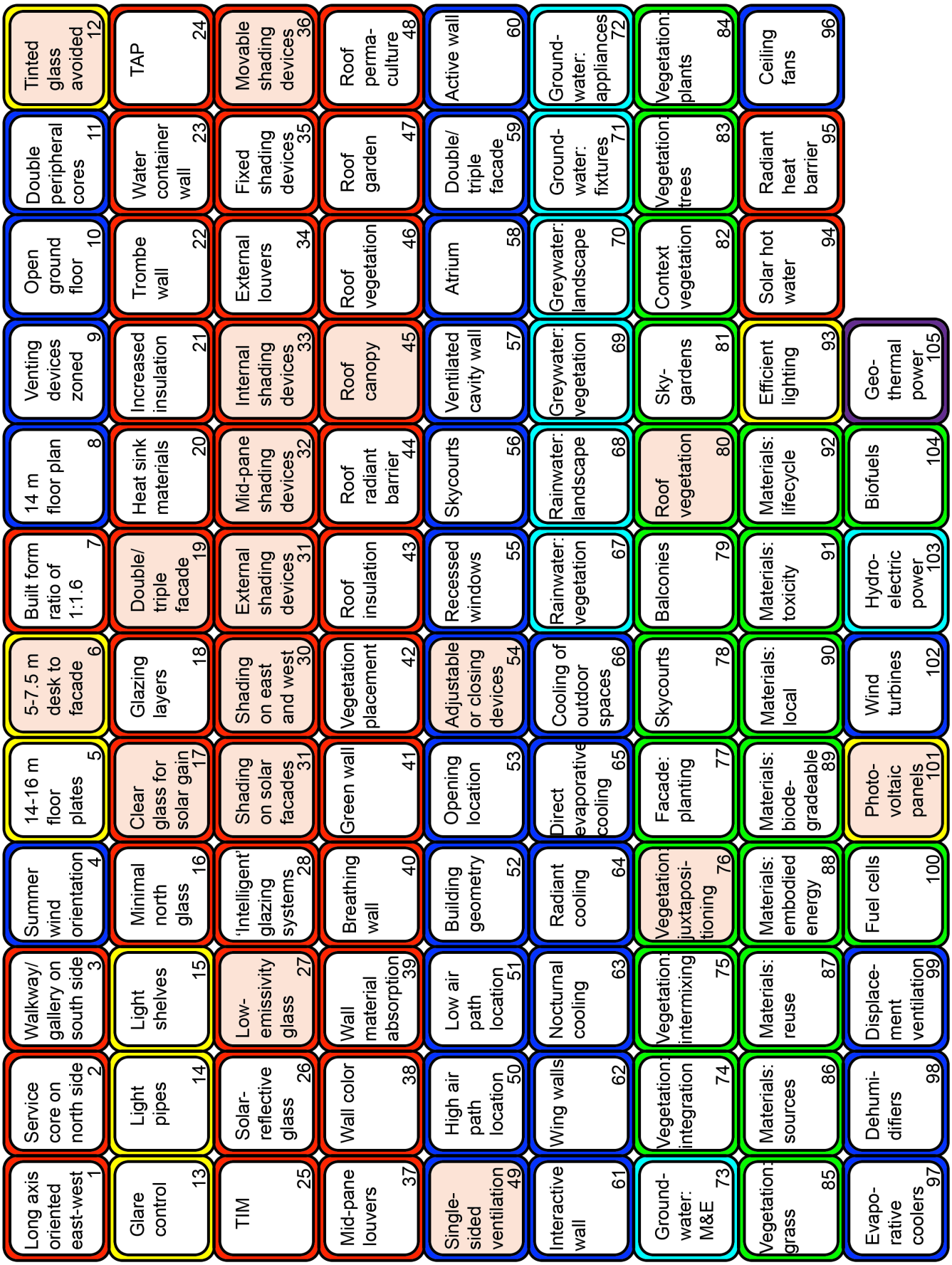
The RWE building, all in all, summarizes the outlook of the architects in terms of architecture and sustainability. As Wolfgang Pehnt states, 'Ecological architecture in the sense of Ingenhoven Overdiek und Partner is technologically clever architecture. They utilize the opportunities of advanced building technology and apply them to the current market climate' (cited in Feireiss, 2004: 26). However, despite this focus on technology, they do not consider themselves as part of Höweler's high-tech category: 'High-tech, it turns out,' Falk Jaeger criticizes, 'is susceptible to damage, expensive, high maintenance and user-unfriendly. The most recent trends are thus once again in the direction of simplification, self-regulation and take the psychology of the user into

account during the planning process' (Jaeger in Feireiss, 2004: 207). Convinced that the high-rise 'cannot be transformed into showcases of economical, sustainable building,' their sustainable tower goals are also less reliant on the imagery of the machine:

> Certain conditions that were once taken for granted are to be returned to the workplace. These are: natural light; a view of the outside through clear and uncoated panes; natural ventilation; and some acoustic contact with the outside world – the sound of cars far below, helicopters in the sky, and perhaps even the sound of a bird brave enough to fly to these lofty heights (Pehnt in Feireiss, 2004: 26).

To conclude, Ingenhoven Overdiek und Partner exhibits a specific approach to sustainable skyscraper design that embraces both the modernist aesthetic and rejects its separation of engineering and architecture. As a result, and as is the case with most North American towers, the German RWE Tower relies upon is technology as a measure of its success and its aesthetic conceals its environmental ingenuity. However, the fact that there is a strong sustainable logic behind the building form and that there is at least some form of individual control makes it more environmentally advanced than most American towers. The role of the German building regulations should not be underestimated, but the comprehensive ecological design philosophy of Ingenhoven Overdiek und Partner is in any case difficult to find among American practices. On the other hand, as the architects expect from a tall building, the RWE is not a 'showcase' example of sustainability; this is true particularly in terms of material choice. It also lacks the emphasis on water, waste and material recycling that American towers exhibit. Nonetheless, many of its more successful passive design strategies could without much difficulty be adapted to towers abroad.

Figure 4.26: RWE Tower strategy



SEG Apartment Tower

Location: Vienna, Austria
Climate: Marine (Cfb)
Architect: Coop Himmelb(l)au
Completed: 1998
Height: 82 m
Floors: 25
Main Use: Residential



Figure 4.27: SEG Apartment Tower (Binder, 2002:106)

The SEG Apartment Tower consists of seventy apartments, nine dining facilities, offices and practices. These are arranged essentially as two buildings, one commercial and one residential, stacked on top of each other. The space intersecting these 'buildings' is a 'sky lobby' that provides a playground, a 'teleworking café' and a sun deck. (Binder, 2002: 106; Höweler, 2003: 192). There is also a two-floor entrance, which includes a concierge service (Binder, 2002: 106). The apartments themselves are open-plan and contain no interior load-bearing walls, allowing for a greater flexibility of use (Binder, 2002: 106).

Despite the rarity of such flexible and social spaces in apartment buildings in general, what makes this skyscraper most unique is a second concept, referred to as the 'climate façade.' (Binder, 2002: 106) The concept has three purposes, the first which is described by Binder as 'the linking and surrounding element between the two components' (2002: 106). First, the climatic façade envelops the building with a unifying angular geometry, determining much of its sculptural form. Second**,** the spaces left between the internal and external façade form additional semi-public spaces, or loggias, two or three floors in height that can also be vegetated. The third purpose is to use the space between the outer and inner façade to act as a thermal buffer that, when combined with the 'air box' on the building's top and the 'heat accumulator' core, helps cool the apartments in the summer and heat them in the winter (Höweler, 2003: 192; Binder, 2002: 160; Zukowski and Thorne, 2000: 88). Thermal energy is also stored in a thermal reservoir located in the interior of the building, to be recirculated in all but the summer months (Höweler, 2003: 192). This external climate façade also has openable windows, which can be controlled by the residents (Höweler, 2003: 192).

Without this climatic façade and solar thermal systems, the high-rise would have unlikely have been an example of sustainability. With its bulky floorplan and a 45-

degree off-south orientation, the building may have required many technological interventions to reduce its energy use. However, the insertion of sky lobbies and the detailing of the façade have made it one of the most effective examples of sustainable residential high-rises. The simple addition of what is essentially an expanded and operable secondary skin reassesses the spatiality and function of what has become a standard component of green skyscrapers and offers a passive energy solution to problems that would usually have been resolved mechanically.

Figure 4.28: SEG Apartment Tower strategy

30 St Mary Axe

Location: London, UK
Climate: Marine (Cfb)
Architect: Foster and Partners
Completed: 2004
Height: 180 m
Floors: 40
Main Use: Office



Figure 4.29: 30 St Mary Axe (RIBA website, no date)

Considered London's first 'green' skyscraper, 30 St Mary Axe's publicity is largely responsible for current trends towards both new towers in the city as well as more environmentally sustainable buildings in general. The first tall building to be built in London since the completion of Tower 42 in 1980, 30 St Mary Axe sits on the site of the former Baltic Exchange, destroyed by the IRA in 1992 (Lepik, 2008: 132). The site had originally been reserved for the reconstruction of the original building, but after reconsideration, an invited competition was launched in 1996. The winner, Foster's 385-m Millennium Tower, was however in the end considered unsuitable for the site and rejected by the City of London Corporation. The Swiss Reinsurance Company then acquired the site in 1997 and commissioned Foster to build their London headquarters, with the provision that it be smaller than Tower 42. Originally known as the Swiss Re Tower, the building then changed its name to 30 St Mary Axe as a marketing tool to attract more tenants (Wright, 2006: 205) and was sold in 2008.

The tower is essentially a circular plan on a rectilinear site. The first two stories are open to public use as retail space, while the rest of the tower is reserved for the tenants; this consists of thirty-four floors of office space, three service stories and a top-floor restaurant, function room and bar (Lepik, 2008: 132; Nordenson and Riley, 2003: 72). The conical shape bulges from a 49 m diameter base to a maximum of 56 m the 17th floor, before tapering at the crown, treating restaurant visitors to 360 degree views of the city (Nordenson and Riley, 2003: 72). To achieve such an unprecedented tower form, a new structural system, consisting of a central circular core and a 'diagrid' of diagonally interlocking steel elements, was created, allowing for an open plan throughout the office space (2003: 72).

30 St Mary Axe's aerodynamic shape had been the result of the a series of experiments aiming to reduce its resistance to wind. Through the use of computational fluid dynamics, described as a 'computerized wind tunnel test,' it was

found that the final form ‘produced around 40% of the downdraught of a square building of equivalent size’ (Powell, 2006: 98-100). That result in turn led to a reduction of downward winds at the base and of pressure on the load-bearing structure (Lepik, 2008: 132). In terms of internal comfort, the shape was also successful in promoting natural ventilation:

> Instead of wind forces being pushed downwards, as in the rectangular high-rises of an earlier generation, wind would flow around the tower, producing positive pressures on the windward aspect with negative pressures on the sides of the building, a perfect driving force for cross-flow natural ventilation (Powell, 2006: 80).

This benefit would be enhanced through its internal layout, particularly with light wells.

Before considering the interiors, though, it is worth noting that the form was also useful in terms of two solar influences that are particularly troublesome in office buildings. The first, solar gain, was reduced by the circular plan which led to the building requiring ‘up to 25% less external surface area than a rectangular block of equivalent size.’ This characteristic would also help in the elimination of heat loss during winter months (Powell, 2006: 98). The second influence, that of daylighting, was addressed through the vertically tapering shape. Although the maximum distance from the core to the inner façade is 14 m (Powell, 2006: 78), as a result of the tapering shape for much of the tower this closer to the 7 m ideal.

As is the case with natural ventilation, daylighting is enhanced through the use of light wells. The light wells, like the conical shape, were a result of a process involving the use of a series of physical models (Powell, 2006: 78). Here it is important to mention that the design process of this tower, although developed with the environment in mind, was nevertheless initially driven by the desire to build an iconic architectural form. Environmental benefits, particularly those of natural ventilation, cannot quite be described as coincidental, but neither were they essential to the tower’s purpose. As described by Paul Scott, a member of the Foster team, ‘we developed the architecture first, then set about making it work practically. There was a certain amount of post-rationalization.’ (Powell, 2006: 78). The light wells exemplify this process, as they were first proposed as straight lines down the building, then envisioned as spirals to give the tower a ‘dynamic push’ and finally adjusted to allow for natural ventilation (Powell, 2006: 78-79).

Also referred to as atria, the light wells serrate the circular floorplan as six identical wedges. Each floor rotates 5° from the plan below, leaving five-story spiraling atria

stretching the full height of the building. To adjust to the tapering form, the atria, like the floor plan, reduce in size accordingly (Lepik, 2008: 132; Nordenson and Riley, 2003: 72). In terms of spatial planning, their inclusion helps to reconcile the circular floorplate with the rectangular office floors and allows for visual communication between floors (Nordenson and Riley, 2003: 72; Powell, 2006: 78).

Environmentally, the atria are designed both to encourage daylighting and to allow for natural ventilation. The daylighting strategy is simple: they allow more office spaces to benefit from daylight by reducing floor depth. The natural ventilation strategy is somewhat more complicated and works in conjunction with the building façade. For 40% of the year, the air pressure differentials created by the conical form help to move the air upward, allowing for a stack effect at each spiral (Nordenson and Riley, 2003: 72). External air is drawn into the light wells through motorized perimeter windows in each atrium (Powell, 2006: 100). As is the case in the Commerzbank, the windows help to control excessive draughts, while allowing sufficient fresh air to reach the office floors (Powell, 2006: 80, 100). As natural ventilation is practical for 40% of the year, much of the energy savings of the building relates to this system (Powell, 2006: 104). When external conditions are detrimental, the windows shut and conventional air conditioning helps to cool the interiors. The exception to this mixed-mode system is the top three floors, as they are not connected to the light wells and are thus entirely air-conditioned (Powell, 2006: 80).

Before considering the rest of the facade in detail, there are two alterations in the current light well design that were not part of the original scheme. Due to fire safety concerns, the atria needed to be sealed every six floors (Wright, 2006: 206). The atria were also originally envisioned as sky gardens with cascading vegetation (Wright, 2006: 206; Powell, 2006: 83). However, despite Foster's protests, the suggestion was rejected. Sara Fox (cited in Powell, 2006: 83), the project manager, defends this decision:

> The practical problems were too great. The maintenance burden was potentially huge. Anyway it became clear that the spaces were not going to support more than a small range of plants. They had to be shaded in some way, to combat glare, so the plants wouldn't get much light. And the opening windows would produce variable climatic conditions that were again not going to encourage plant growth.

Considering the overall positive reputation of Commerzbank's skygardens, this outcome is perhaps another 'post-rationalization' based on economic concerns. As they stand, the atria spaces are visible as black diagonal glass bands, quite the

opposite of those in Foster's early sketches. External glass louvers were considered, but found difficult to clean, and so shading relies on a dark tint (Powell, 2006: 83).

The remaining exterior cladding also plays an important role in both solar control and in assisting natural ventilation. It consists of five-and-a-half thousand flat triangular and diamond-shaped glass panels with horizontal openings that form a double skin (Barker, 2005). The outer skin comprises of a low-e, double-glazed openable unit and the inner of a single-glazed layer. They are separated by a cavity measuring between 1 and 1.4m in depth and equipped with metallic Venetian blinds to reflect heat (Powell, 2006: 80). In the summer, cool fresh air is vented into the cavity at floor level, cooling the glass and blinds, and then extracted at ceiling level through fan-assisted ducts. Solar gain is thus reduced by 85%. In the winter, warm air from the offices has the opposite function, helping to reduce the effects of the cold glass façade (Powell, 2006: 100).

In addition to the buffering effect, this 'active ventilated façade' works in partnership with the tower's form to extract used office air to the cavity, assisting in natural ventilation (Powell, 2006: 80-81). The slots in the façade can alternatively also draw air in through the concrete floors to the air-conditioning machinery (Wright, 2006: 206). However, 30 St Mary Axe does not aim to provide the same natural ventilation and cooling standards as the Commerzbank. As Paul Scott (cited in Powell, 2006: 78), the project director at one point, states:

> Given the office culture of London, somewhere between that of Europe and North America, there had to be an element of choice. So there was conventional air conditioning alongside natural ventilation. The building was to be highly progressive for London – that didn't necessarily mean embracing standards that would be acceptable in, say, Zurich or Frankfurt.

Due to the air conditioning option, the amount of machinery required to run the tower is considerable. Alongside the heavy plant equipment located in the tower's basement and the three-story high cooling towers located near the top, four gas boilers were located in the top floors of a neighboring building (Powell, 2006: 81, 101). The design team nevertheless specified that the air conditioning plant be decentralized, operating on a floor-by floor basis in hopes of reducing energy usage (2006: 81). Additionally, the cooling towers are said to have been 'chosen for their efficiency and reduced consumption of water and chemicals' (2006: 101).

Yet it is important to point out that the aspirations for the tower's ventilation strategy have been compromised since its completion. According to a 2008 article, many of

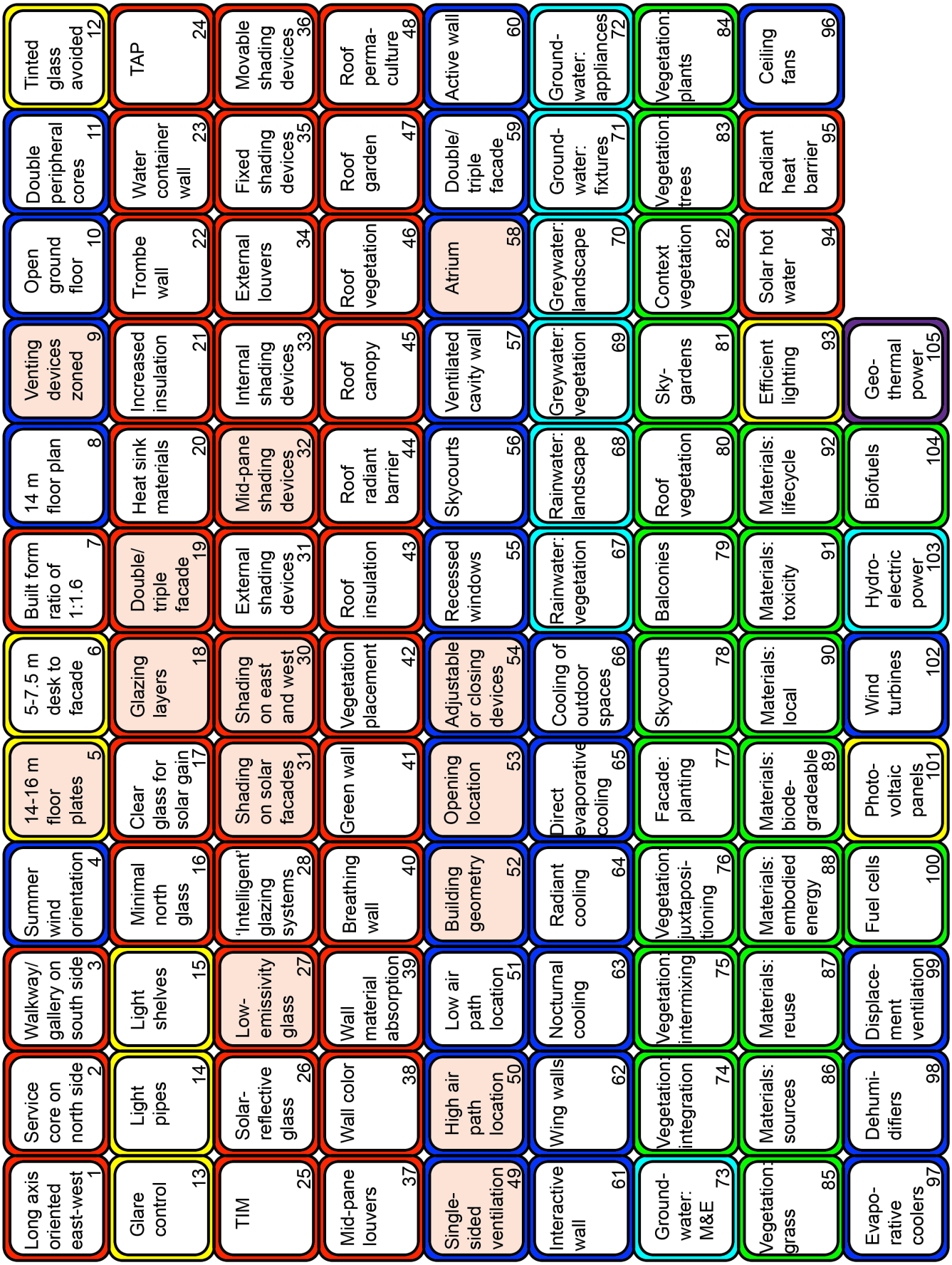
the building's new tenants are law firms, which have fitted the rectangular floorplate 'fingers' with cellular office spaces due to privacy requirements. This partitioning however prevents air from flowing throughout the building as originally planned. The largest of these firms has even added a four-story stairwell within one light well, further altering the initial building concept. Moreover, Swiss Re is the only tenant not to have rejected the fresh air option, although it also has had to curtail its availability 'after staff complained of stuffiness' (Spring, 2008). As Martin Spring (2008) illustrates, even the building's digital programs have been adjusted:

> Originally, the internal temperature was set to rise to 26°C before the windows would close and air-conditioning take over. This has now been lowered to 24°C, which is the top temperature recommended by the British Council for Offices for air-conditioned, but not naturally ventilated, offices.

Richard Stead (cited in Spring, 2008), the building's property services director, points out that such changes have made the '50% less energy' aim 'a bit over-ambitious' as Swiss Re is the only tenant to refuse internal partitions and to utilize the opening windows for ventilation. All other tenants are provided with year-round air-conditioning.

Other than the use of modular construction techniques and unspecified water conservation and reuse methods, 30 St Mary Axe is not particularly concerned with the source or recyclability of its materials (Gissen, 2002: 92). Alongside this common environmental concern, the tower has also been criticized for its over-reliance on the inefficient glass façade, most notably by one of its chief architects, Ken Shuttleworth. Yet for the most part it has been well received, both by the public and bodies such as English Heritage (Wright, 2006: 205).

Figure 4.30: 30 St Mary Axe strategy



The Leadenhall Building (122 Leadenhall Street)

Location: London
Climate: Marine (Cfb)
Architect: Richard Rogers Partnership (now Roger Stirk Harbour +Partners)
Completion: 2014
Height: 225 m
Floors: 50
Main Use: Office

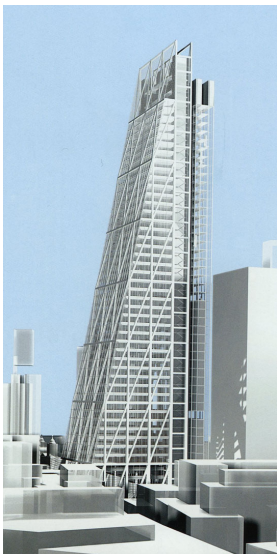
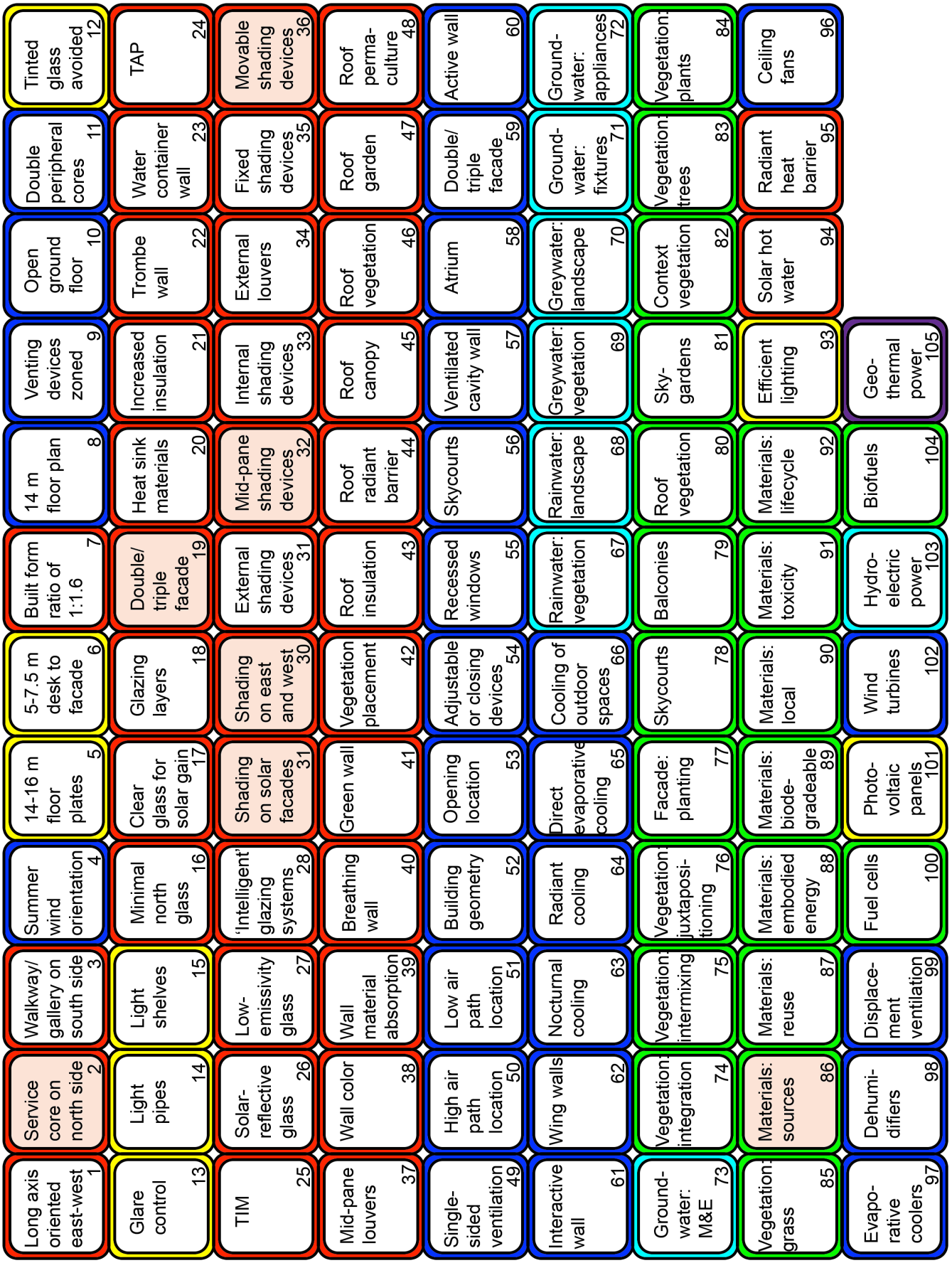


Figure 4.31: The Leadenhall Building (Powell, 2006)

The Leadenhall Building was one of the first towers in London to feature sustainable strategies. However, its primary concern in planning was the requirement that that it did not intrude into the sightline of St. Paul's Cathedral. The resulting building design therefore has a triangular profile, tapering away from the south cathedral view, all the while maintaining rectangular floorplates. This allows for the attachment of a circulation and service tower on the north façade. The base of the building is reserved for a seven-story public space, which is to include a restaurant, bar and entertainment venues amongst mature trees (Powell, 2006: 218). The building's overall structure is an innovative truss system, which allows for column-free floors (2006: 218).

Although the form was designed to suit the zoning requirements and express the architect's high-tech aesthetic, it nevertheless results in some sustainable features that perhaps would not have existed otherwise. The designers furthermore enhance the performance of the features. The building thus has a preferred south orientation and all but the North orientations have a ventilated façade that minimizes glare and solar gain. The double skin is also designed to increase air flow, consisting of a double glazed internal glass panel and a glazed outer panel with air openings every seven floors. A stack of decks supporting the elevations also acts as an internal brise soleil. The tapering of the deep lower-level floorplan also ensures what at least the upper parts of the building will enjoy sunlight, as will the open public space. The northern detached core is to lower energy consumption because of a lack of ventilated system. These passive systems are also to be enhanced thought the use of a 'sophisticated comfort cooling system with heat recovery technology' (Greater London Authority, 2004). Furthermore, the building also is to be made of 'environmentally sound materials' and with modular construction, but as the building construction had not begun at the time of this review, the results of this promise remain to be seen (Di Carlo in Nordenson and Riley, 2003: 98).

Figure 4.32: The Leadenhall Building strategy



The Shard (formerly London Bridge Tower)

Location: London, UK
Climate: Marine (Cfb)
Architect: Renzo Piano Building Workshop
Completed: 2012
Height: 306 m
Floors: 87
Main Use: Office (mixed-use)

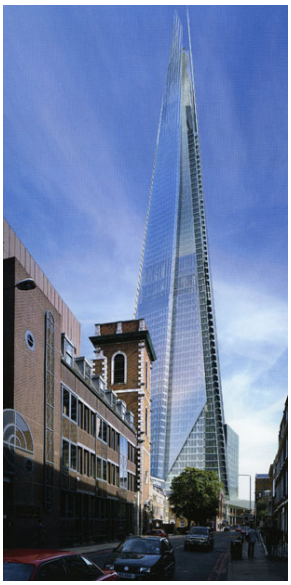


Figure 4.33: London Bridge Tower (Nordenson and Riley, 2003: 123)

Rebranded as 'the Shard' due to its angular façade, the tower is described by its architect, Renzo Piano (cited in Wright, 2006: 225-227), as 'a vertical town for about seven thousand people and for hundreds of thousands to visit'. It incorporates a three-level public space with retail and restaurants, forty-eight floors of office space in the lower levels, followed by a three-level public internal piazza, a twenty-seven-floor, 195-room five-star hotel, thirteen floors of apartments and a public observation deck above all ('London Bridge Quarter,' 2008).

The tower is envisioned as a pyramid, a shape that responds to the context of church spires and ship masts that have defined the city's skyline. This relationship with the Thames is key, as Piano (cited in Finch, 2000: 11) states: 'The building should belong to the river, like a mast, like a sail…the top part must be slim and light, we will not go up in the air with a big strong volume.' It should be said that this form is the result of a longer process, as the tower changed shapes early on, at one point featuring an upright side like the Leadenhall Building (Wright, 2006: 225).

Also like Roger's tower, the Shard's existence is strongly influenced by the presence of St. Paul's Cathedral. In fact, the greatest objections from the English Heritage and a subsequent public enquiry were based on its impact on two of the ten protected views of the historic landmark. Unlike the formal geometric response of the Leadenhall Building, though, the Shard's reaction focused on the building fabric. The 'shards' consist of different shapes that reach, but do not join, the apex while creating shadows and gaps within the fabric (Wright, 2006: 225). Yet the choice of a low-iron glass, similar to that of Piano's New York Times Building, is meant to create an impression of a building that reflects the clouds and disappears into the sky, rather than one that boasts of its great height (2006: 225).

The glass also forms part of the tower's approach to 'ecology, sustainability and environmental design' (Finch, 2000: 11). The façade consists of an externally-ventilated triple skin with an excellent thermal performance in both summer and winter seasons. The glass is clear**,** allowing for sufficient daylight penetration at least on the shallower floors. An extensive use of shading also reduces solar gain, leading to greater comfort (Guthrie, 2008: 100). Piano originally envisioned winter gardens on each floor, but as of 2008 they are to be included at least in the office areas ('London Bridge Quarter,' 2008: 52). They nonetheless are enclosed by operable louvers, providing occupants with fresh air and connections with the outdoors (2008: 52).

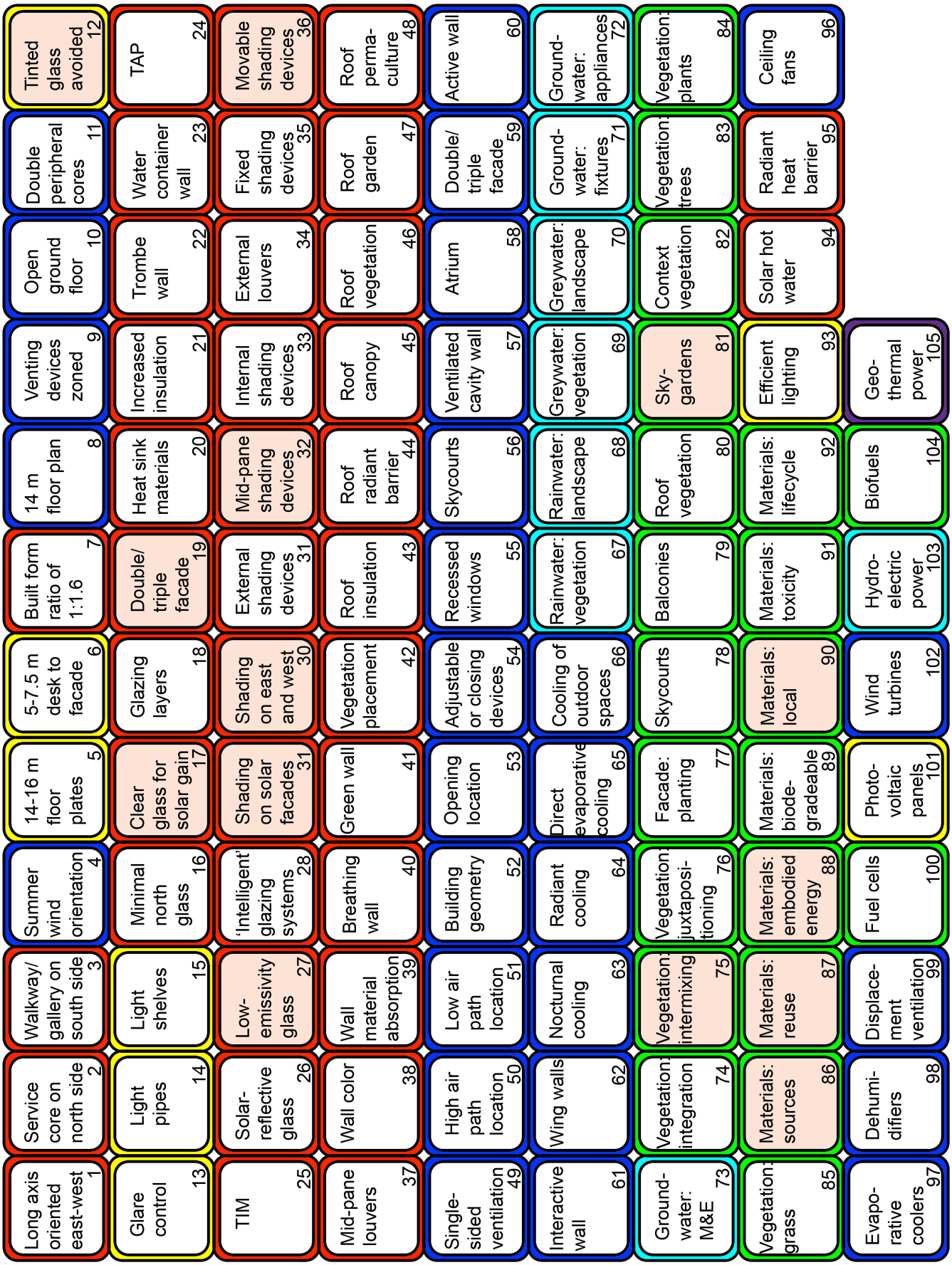
The most innovative of its environmental features is one that has been removed, its heat transfer system. Essentially, a naturally driven stack effect would have pulled excess heat from the offices upward and used to heat the hotel and apartments above. At the top heights of the structure, a **'**radiator' of finned tubes would have naturally dispersed excess heat and use the thirty-five mile-per-hour winds to cool the building when needed (Wright, 2006: 225; *Emporis*, 2005). Apparently, advances in cooling systems have made the system redundant, although it is unclear how the energy savings would have compared.

The tower design also considers new forms of air-conditioning with chilled ceilings and the use of boreholes in the London Aquifer to further regulate the internal climate. In terms of conservation, it promises the use of local, recycled or low embodied energy materials (Wright, 2006: 225). However, it has been criticized for its lack of a more targeted policy on sustainable materials and for not having plans for the on-site recycling of most of the demolition material from the existing 1970s high-rise (Guthrie, 2008: 101). There are also critiques of its abandonment of a water recycling strategy due to the easy availability and low cost of municipal water (2008: 101).

Yet perhaps its strongest green selling point is its close proximity to a major public transportation hub. As part of its urban planning, the Shard offers a new railway station concourse, a relocated bus station and an external public square (Powell, 2001: 226). Less than fifty parking spaces are provided in total. The building is not only enhanced by the transport links, but, as Piano states (cited in Finch, 2000: 11), 'it would be impossible to achieve the scheme except next to a major transportation interchange.' The use of the transportation system represents what appears to be

the Shard's environmental design philosophy as a whole. Here, environmental features do not determine the architecture, but rather adapt to it. They are not an indispensable part of its design process, as the tower could have just as easily have been a more energy-intensive building. The danger for this design and others lies in that features that determine sustainability could be discarded without having much of an impact on its ability to be built. They could easily be misused to gain planning permission but, as is the case here with the rainwater system and presumably many of the gardens, omitted for financial reasons. Nonetheless, the fact they are initially included and publicized emphasizes the desirability of sustainable approaches in contemporary design.

Figure 4.34: London Bridge tower strategy



CityZED

Location: London, UK
Climate: Marine (Cfb)
Architect: Bill Dunster Architects ZEDfactory Ltd
Completion: Proposed
Height: NA
Floors: 35
Main Use: Residential

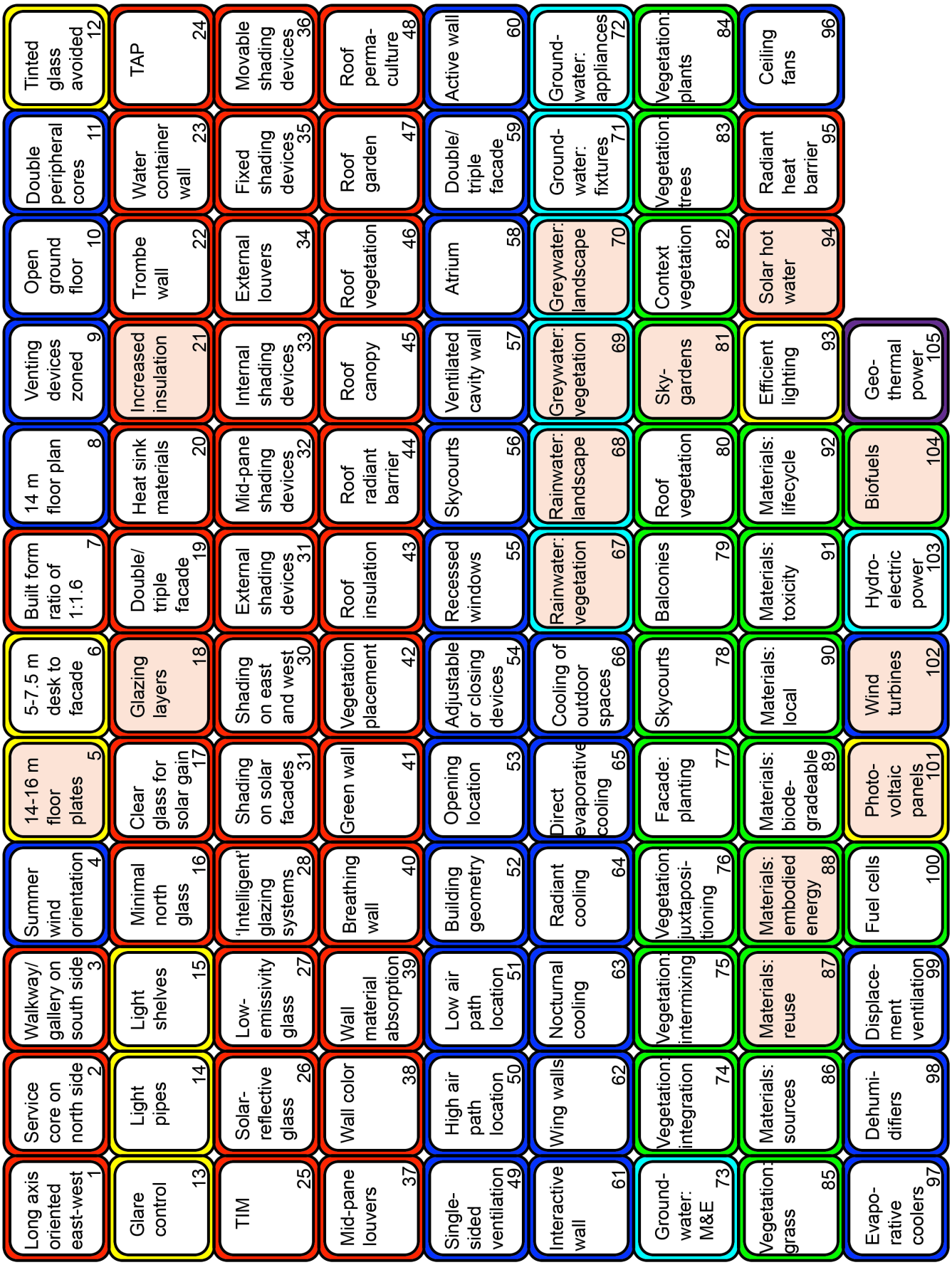


Figure 4.35: CityZED (Dunster et al., 2008: 236)

After the successful completion of UK's largest carbon-neutral community, BedZED, in 2001 Bill Dunster suggested CityZED (Zero-Energy-Development) for a London roundabout. According to the architects (Dunster et al., 2008: 236), this high-density, mixed-use tower aims to provide 326 flats and a variety of social amenities, including aerial herb gardens on every fourth floor. These gardens also form glazed bridges that link two 'aerodynamic blades' of the tower, giving it a convex H-shaped plan. The shape helps to channel wind to a series of 15 kW turbines, supported by the bridges. These turbines, when combined with solar thermal collectors on each floor, photovoltaic cladding and a biomass CHP on the plinth, are expected to ensure that the tower remains carbon-neutral and zero-energy.

However, it also utilizes passive strategies, including high levels of insulation and narrow floorplates, although such strategies are not as widely promoted as the wind turbines. Yet one can tell from its renderings that this building, unlike most green towers, radically departs from conventions in its aesthetic. 'Superinsulated' solid walls and triple-glazed punctured windows replace the more typical glass facade and the monochrome nature of modern facades is challenged by the use of an array of bold colors (Dunster et al., 2008: 236). The building is to be made of reclaimed materials: slip-formed Ground Granulated Blast Slag concrete and recycled timber stressed-skin panels, with new ply and glulam (*Zedfactory website*, no date). The tower is envisioned as an 'urban village' and is also expected to include a 'living machine', black and grey water treatment system for an entire urban block (*Zedfactory website*, no date). Here environmental sustainability creates a new architectural style, one that rejects the glass and sleekness of modernism. It furthermore outlines a vision of social sustainability where affordable homes, high density and the provision of extensive communal space combine to form a direction rarely explored in contemporary tower design.

Figure 4.36: CityZED strategy



Skyhouse

Location: London, UK
Climate: Marine (Cfb)
Architect: Marks Barfield
Completion: Proposed
Height: 189 m
Floors: 50
Main Use: Residential

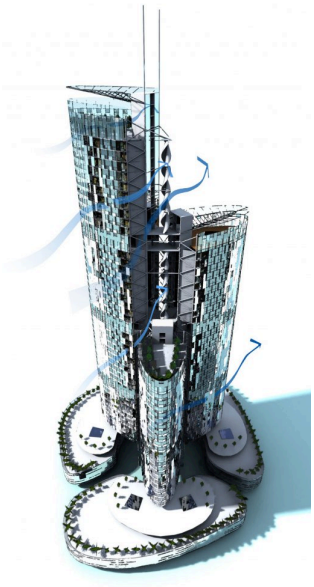


Figure 4.37: Skyhouse (Marks Barfield Architects website, no date)

Best known for its design of the London Eye, Marks Barfield Architects also initially envisioned a dozen of 50-story Skyhouses along the Greenwich peninsula and surrounded by parkland (*Skyscrapernews*, no date). However, the project was not considered commercially viable enough, and so was reduced in both number and height to a 189 m single tower (*Skyscrapernews*, no date). It remains to date without a site, although the architects had searched for developers throughout the city.

Even though the tower does specify high insulation materials and the provision of daylight to the residences, the main concept behind its architecture is the inclusion of helical turbine. The tower consists of three oval components of different heights that meet at and channel the wind to an open center, where the helical turbines rise to the top floor (Pearman, 2004: 38-39) This renewable strategy is also complemented by the use of photovoltaics within the glass façade (2004: 38-39). When combined, these strategies would provide enough energy to run communal areas (*Sustaining: Tower Blocks*, 2004). The architects also mention the inclusion of a recycling system, but as this is a proposed project, no further information is provided.

However, it is one of the first sustainable residential proposals for London, and, unlike the vast majority of such proposals worldwide, it has a high concern with social sustainability that makes green towers more than designs for a privileged lifestyle. Even unlike most new typical residential towers of London, a quarter of the apartments would be reserved for key workers such as nurses and teachers (Abel, 2003: 89). The apartments and penthouses on the higher levels would be set aside for wealthier inhabitants, but the very tops of the building would be turned into gardens or other open places for all to share. More double-height skygardens would be provided within the building as part of the recreational space. Alongside the rooftops, and because of the compact three hundred square meter size, the tower

would leave sixty-five percent of a one-hectare urban plot for green space (Pearman, 2004: 38-39). Research revealed what people wanted in high-rise residences: space, light, security, concierge, health clubs, access to transport links, laundry facilities, shops, modern design and excellent views; these were to be provided. Parking was included, which goes against the trend of building at public transport intersections (*Skyhouse website*, no date) Other provisions include crèches and libraries at ground and top levels (Pearman, 2004: 38-39).

All in all, this project is unusual in linking the bioclimatic approach with social inclusiveness, which is something that green campaigners promote but skyscraper designers and investors have thus far avoided. In a sense this concern for social sustainability overshadows the environmental strategy of the tower, although the design of a form to suit wind turbines is critical. The building's environmental strategy is not without its faults, for example the lack of façade differentiation on varying orientations, but such faults and the social concern are very reminiscent of an early green skyscraper, the Unité d'Habitation in Marseilles.

Figure 4.38: Skyhouse strategy

Kite Tower

Location: Leeds, UK
Climate: Marine (Cfb)
Architect: Make Architects
Completion: Proposed
Height: 90 m
Floors: 28
Main Use: Residential



Figure 4.39: Kite Tower (Make Architects, no date)

Established in January 2004, Make is headed by Ken Shuttleworth, often acknowledged as Foster's lead designer of 30 St Mary Axe. The new practice, however, radically rejects that tower's glass aesthetic, primarily due to the negative environmental impacts of excess solar gain in summer, loss of heat in winter and reliance on energy-consuming mechanical conditioning. It is nevertheless also dismissive of other practices' 'green' approaches, such as elaborate shading devices, ventilated cavities and double facades, all of which are considered to make a façade 'both complicated and expensive' (Shuttleworth in Wood, 2008: 482). Instead, Shuttleworth proclaims (cited in Wood, 2008: 484):

> The design of the tall building facade is at the forefront of a change. The fully glazed, totally transparent office block is dead, a thing from the past when regulations were more lenient and our attitude to the environment more naive. The design of the tall building façade needs to incorporate more opacity, more solidity and more insulation, with windows strategically located where natural light penetration is actually required, as opposed to simply wrapping every inch of the building skin in glazing.

Although the inclusion of such levels of opacity requires a major stylistic shift, the inclusion of the less transparent building skin is promoted under an environmental agenda so as to improve energy performance and arguably reduce the building's embodied energy. There is also the benefit of reduced cost, but this is also secondary to the green aim (Shuttleworth in Wood, 2008: 484). To achieve a higher performance, a recommendation for an approximately 50% solid skin is suggested. The resulting buildings are not to be reduced to 'dull, monotonous boxes with repetitive square punctured windows,' however, and it is under these guidelines that this case study, the Kite Tower in Leeds, is designed (2008: 483).

The Kite Tower was proposed as part of a large mixed-use development site in Leeds, and although the original bid was not successful, Make still hopes to construct the building in the city (*Skyscrapernews*, no date). It is to consist mostly of residential accommodation, supplemented by a hotel, office space and conference facilities

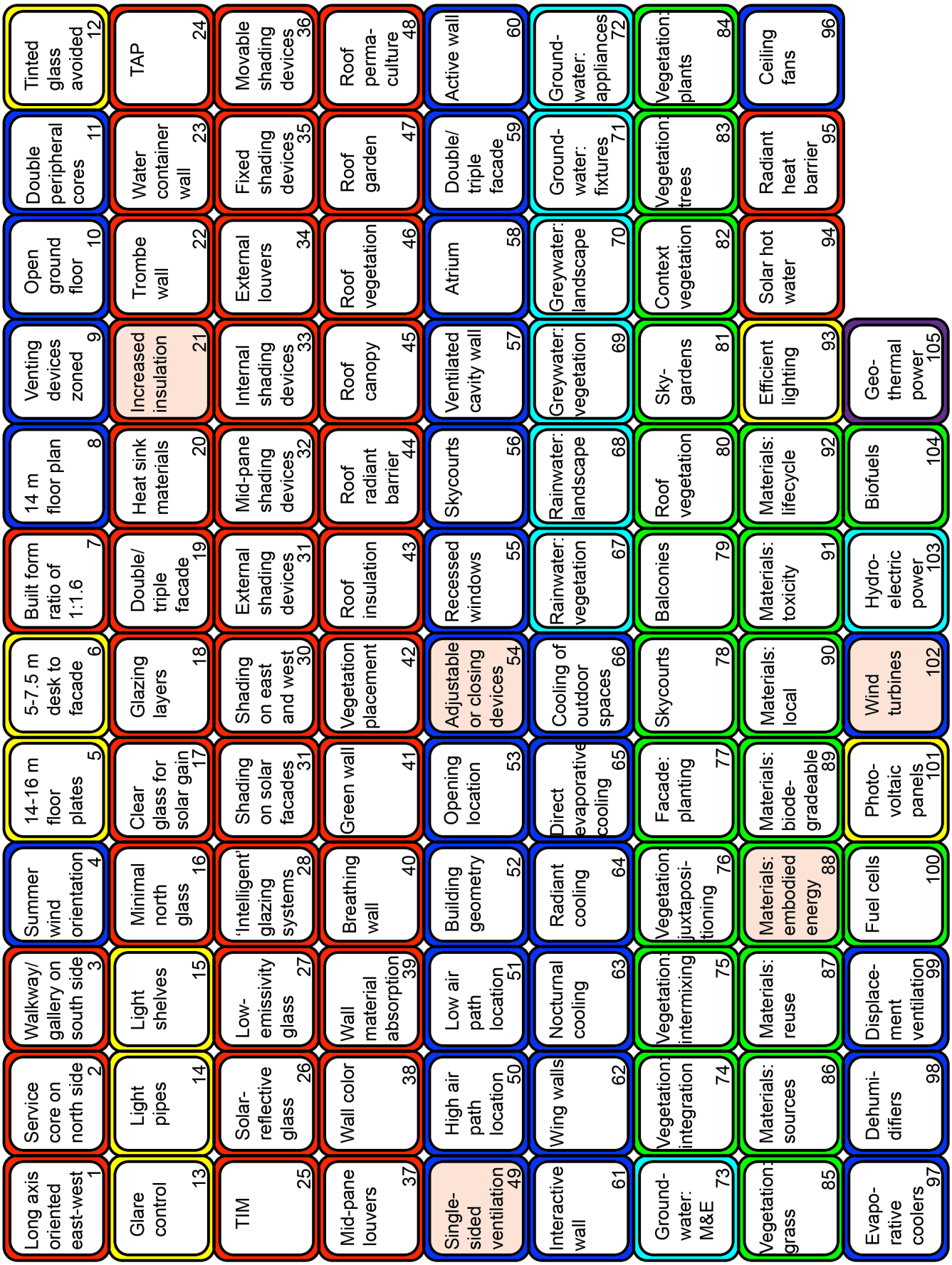
(*Make Architects*, no date). However, as this is a speculative building, further detail regarding the placement of these facilities is unspecified (*Skyscrapernews*, no date).

The building takes its unusual shape from six tall triangles that alternate in direction. This leads to triangular floor plates at the base and top of the building, with varying plans in between (*Make Architects*, no date). However, its overall shape and orientation are not specific to climatic requirements, and thus most of its environmental success relies on the efficacy of the façade. The tower is to be constructed with approximately 50% glazing, as limited by the guidelines, and the windows, at times shown as rectangles and at others narrow slits, are placed irregularly across the façade. Furthermore, there are three pairs of circular windows at the highest levels, contrasting with the tower's angular geometry. The high level of insulation is 'to give the best balance between view, daylight and heat loss and heat gain' and the tower is furthermore to be naturally ventilated (*Make Architects*, no date). To complement this range of passive methods, three vertical-axis wind turbines are to be located at roof level (*Make Architects*, no date).

Although Make is genuinely more sustainable in their approach than most architectural practices, there are still some issues that need to be resolved if Make's towers are to reduce their impact on the environment to the greatest extent. One of these issues is Make's preference for metals such as stainless steel, aluminum or zinc. The use of such metals demands much embodied energy, which counteracts much of the benefits of a more solid façade (Wright, 2006: 218). Make is involved in research on new façade materials, such as highly insulating translucent Nanogel panels and vacuum-sealed cladding and glazing, but the use of such materials is limited at the present time (Shuttleworth, 2008: 484).

Another issue with Make's approach, and one that is seen in nearly every one of the case studies, is the lack of concern for building orientation; the fact that all facades are the same does not reflect a local climatic response, a prerequisite if contextual sustainable skyscrapers are to replace unsustainable internationalist towers. Nevertheless, Make does attempt what few architects in Europe have done: question the validity of glass as the de-facto façade material of high-rises. By questioning the uniformity of the building fabric, he reconsiders the climatic design principles of early American skyscrapers without necessarily adopting their design aesthetic.

Figure 4.40: Kite Tower strategy



4.2.3 Case study comparison results

Ken Yeang case study
Elephant and Castle Eco-Tower

Location: London, UK
Climate: Marine (Cfb)
Architect: T.R. Hamzah and Yeang International
Completion: Proposed
Height: 140 m
Floors: 35
Main Use: Residential

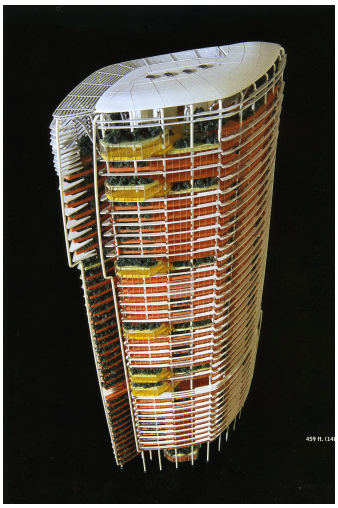


Figure 4.41: Elephant and Castle Eco-Tower Riley and Nordenson, 2003: 47)

Three towers, one thirty stories tall and shown in Figure 4.41, and the others twelve, are part of Ken Yeang's proposal for a 180-acre regeneration project for the Elephant and Castle area (Richards, 2001). The compact cores here are placed in a central location and surrounded by a ventilated and vegetated internal circulation ramp. The apartments are located along the perimeter of the plan, an irregular southeast oriented oval with a corner protrusion in the north-east façade that deflects undesired winter wind. The plan is also centrally cut through along the southeast direction to allow for the summer wind to cool the interior of the building (Richards, 2007: 73). The orientation is also chosen to allow for the greatest amount of apartments to benefit from solar gain in the winter (2007: 76). The narrowness of the floorplan allows sufficient daylight for all apartments.

To increase the social sustainability of the tower, 'sky pods' are inserted into the built form (Richards, 2007: 73). These are inserted as undefined communal spaces and at times also provide recessed shading in the summer (2007: 75). Often, they are vegetated, absorbing and reflecting much of the undesired summer solar radiation. These spaces are complemented by private gardens, arranged as terraces and courtyards. The courtyards open in the summer, allowing for cross ventilation to cool the apartments, and closed in the winter, so as to act as greenhouses (2007: 76). The apartments are further provided with adjustable solar shading, which blocks out sun along the south façade in the summer and permits solar radiation in the winter. Operable shutters along the plan openings also serve this function, as well as to control natural ventilation within the core (2007: 76). As discussed before, Yeang here is not averse to supplementing these passive strategies with mechanical ventilation and heating in colder months, although air conditioning does not appear to be an option during the summer (2007: 76).

These towers also specify the use of materials that have a low embodied energy and come from sustainable resources (Richards, 2001). No further information is provided regarding rainwater and waste recycling, but considering the extent of Yeang's involvement in other towers, this is less likely to be an omission than an undeveloped plan. What can be expected is that rainwater will likely be incorporated into the vegetation maintenance strategy and that waste would be sorted through a comprehensive recycling system. What is emphasized is that the towers aim to generate zero CO_2 emissions (Richards, 2001), an improbable feat for what is at the moment a mixed-mode building with no renewable energy strategies.

Figure 4.42: Elephant and Castle Eco-Tower strategy

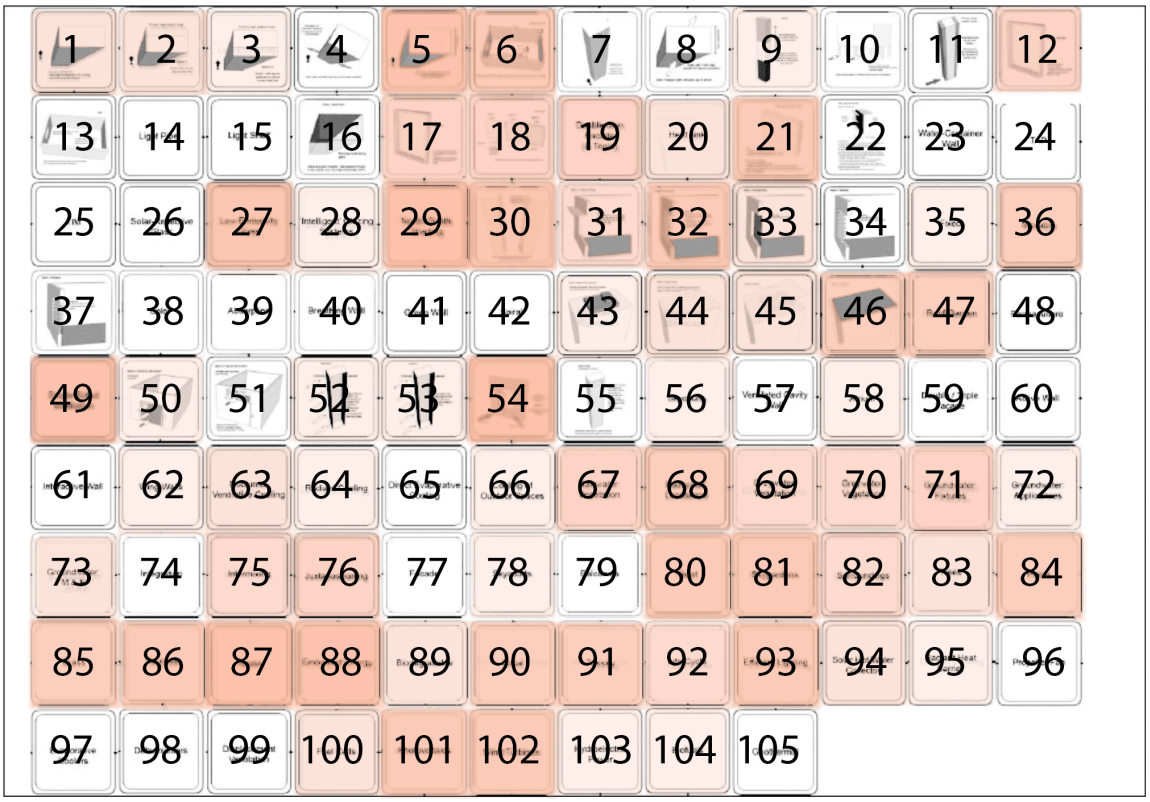


Figure 4.43: Overlay of case study strategies, numbers refer to no. column in Fig. 4.2.

Having reviewed each of the case studies individually, this subsection will consider the case study results. Perhaps the most informative way to begin is to consider the overall application of certain principles. As the number of case studies is arbitrary and the information available inexact, the most basic approximation of the principles' prevalence among the case studies is depicted through the overlay in Figure 4.43. This first part of the comparison will not include the case study of Yeang's tower, which is discussed towards the end.

The most popular design principles, in the darkest shade, are those relating to narrow floor plates, double facades, insulation, glass type, shading devices, roof vegetation and single-sided natural ventilation through openable windows. Those relating to rainwater, materials and efficient and renewable technologies closely follow the application of these strategies. This variety of principles is a promising sign, but it must be remembered that the case studies are unrepresentative of the general state of tall buildings as those buildings are considered amongst the leaders in terms of sustainability. On the other hand, strategies such as light pipes and light

shelves, thermal walls and wing walls, commonly examined in Yeang's work, are not represented.

When compared to the image in Figure 4.3, the categorization of building elements, there does not appear to be a preference for any building element group. Nonetheless, some impressions result within the groups. 'Orientation' is not as common as other groups, and for the most part the principles used relate to solar radiation, rather than airflow. The most popular 'configuration' elements are those for daylighting, as opposed to those relating to solar gain or airflow. 'Fabric' elements are varied, forming no strong discernible pattern. Other than efficient lighting, which is common amongst many case studies, there is no consistency among application of principles. The most popular 'renewables' are photovoltaics and turbines.

When compared to Figure 4.4, the categorization of climatic and environmental strategies, more details are collected. 'Visible radiation' is a prevalent strategy, with the exception of the devices mentioned previously. 'Thermal radiation' is approached mostly with an aim of solar shading, although the lack of solar gain applications is perhaps a result of the commercial nature of many buildings rather than the fault of the principles themselves. 'Airflow', when natural, is predominantly single sided, and openable windows again emerge as a preference. Strategies relating to 'water' are applied often, and each principle is accounted for. Likewise, strategies relating to 'materials' are common, although strategies linking vegetation of façade planting and balconies are not applied; as the end of this chapter will show, this appears to be a direct result of a mismatch between the principles applied by Yeang and those applied by other designers.

What the results so far reveal, then, is that a wide variety of environmental strategies are applied in the range of case studies examined. It also shows though that Yeang is unique in some respects, and so the applicability of those strategies needs further consideration. However, it does not provide a comparative view of the various building functions, climate subsets and regional characteristics, which are next considered in more detail. Furthermore, the various marketing and regulatory influences are not discussed here as they vary significantly between cities and are beyond the scope of the thesis.

The contrast between commercial and residential buildings is most evident in the building form. The residential case studies share strategies for daylighting, resulting

in narrow building forms, which are more rare amongst commercial examples. In some cases, such as the Chicago Spire, the resulting form is a ‘point tower,’ while in others, such as 340 on the Park, the it resembles a thin slab. On the other hand, a majority of commercial buildings are less inclined to desert the typical deep floorplate, leading to spaces without adequate daylighting and ventilation. As residential towers are more likely to accept the limits of dimensions promoting daylighting, it could be argued that they are generally more sustainable at the outset.

In terms of climate, an instructive example of the different approaches is the use natural ventilation, which is utilized much more in the designs of European towers than those of North America. The presence of mild winters in many European cities as opposed to severe winters in American ones is the climatic variance that appears to have the strongest impact on the application of the strategy. This difference could lead to a conclusion that the extent of uncomfortable climatic conditions in North America justifies the small proportion of naturally ventilated towers there when compared to Europe. However, the presence of natural ventilation in towers such as the Solaire refutes this presumption. The method of naturally ventilation may be limited, for example, due to snow loads on facades and the length of the application of such strategies may be defined by the climate, but that building demonstrates that natural ventilation is applicable in the coldest regions of the climate type.

The exclusion of certain individual methods or elements is also apparent within the climate subtypes. The climate of Chicago, Dfa, is cooler than that of New York, Dfb, but the climatic influence that is of more concern than winter conditions is humidity. Chicago is noted for its humid summers and so naturally ventilating the building is much more indirect than in New York. Yet as natural ventilation is common amongst low-rise residences in the city, the strategy can presumably be applied to high-rise projects in the city for much of the year. What is lacking amongst many architectural practices in America is the experimentation common amongst European, particularly German, designers. The sustainable tall building has yet to be defined, so the availability of a greater number of design approaches, developed by local practices, can only enhance the variety and quality of architecture within American cities.

The most prominent difference, and therefore comparison, relates to the types of green features emphasized. North American towers tend to focus on three areas: materials, water and systems. It can be argued that these result from the continent’s LEED rating system, which will be discussed in Chapter 5. In terms of materials, their

local sourcing, recycling and disposal are the top priorities. The embodied energy is sometimes considered, particularly in the use of recycled steel and interior furnishings, but the choice for structure and façade is seldom based on overall environmental impact. Water conservation and reuse is the second chief concern, and the vast majority of towers on the continent have rainwater and graywater recycling systems, often related to the landscaping strategy. Thirdly, the use of energy-efficient mechanical systems is persistent in all of the American case studies with the exception of the Solstice on the Park. At times these supplement the passive strategy, as is commonly the case with daylighting, but for the most part the technology's energy efficiency is its only link with sustainability. It is often used to 'fix' many of the problems associated with environmentally negligent spatial planning.

The main environmental concerns of European sustainable towers generally relate to building form, the potential use of renewable technology and once again systems, albeit in a different manner. The variety of forms present in European case studies demonstrates the range of approaches to skyscraper design. Sometimes, as in the London Bridge Tower, they result from the architect's aesthetic approach, while at other times, as in the RWE Headquarters, they are the direct consequence of an environmental concern. However, even from the non-climatic preferences, the towers' forms are manipulated to enhance the environmental function; in the London Bridge Tower, this is seen in the interaction of the form with the heat transfer system.

Although often not apparent in completed buildings, the focus on renewable technology application is also evident in many of the proposed towers. The use of wind turbines is a helpful example. From the original design for the Commerzbank Headquarters, to the proposed Skyhouse, SkyZED and Kite Tower, there is a much more common consideration of wind turbines than in most North American towers. They are available in some North American towers, such as the One World Trade Center, but their presence there is hidden or incorporated into the architecture. In Europe, however, they are much more visually apparent, often determining much of the architecture.

The use of efficient mechanical systems, however, is just as prevalent in European as in North American towers, but its application is often very different. Whereas North American towers are often reliant on the technology, European towers see these systems as complementary to other more passive methods of climate control. For example, the use of mechanical ventilation is applied frequently in skyscrapers on

both continents, but the inclusion of openable windows is rare in American towers. A case in point here is the RWE Tower, whose design is very much directed towards environmental engineering, but which nonetheless allows for the opening of windows at least to a slight extent. In most European towers, the systems are generally meant to improve, not replace, passive design methods.

The difference in environmental focus between North American and European Towers can be described in more general terms as well. North American Towers usually focus on efficiency, in terms of energy, materials and water, whereas European towers focus more on architectonic approaches to sustainable design. The form of the European skyscraper is adjusted to suit climatic influences. Often, it is further shaped to allow for passive methods to fully function alongside the mechanical strategies. The configuration of towers, such as Skyhouse, to enhance the output of renewable technologies further demonstrates the connection between architecture and sustainability rarely seen in American examples. There is also a more socially sustainable approach in European towers than in American towers, but as this is often separate from its environmental aims, it will not be further discussed here.

In a way this discussion links back to Goldberger's description of Chicago and New York towers, except that at this period, it appears as though both American cities have adopted the same style. In a more recent description of American architecture, Goldberger states, 'I don't see the regional differences that were apparent in the past. Trends today are national or even global' (cited in Pearson, 2008: 90). In terms of approach, American towers are closer to the 'historic' than the 'theoretical' in that the common modernist aesthetic is applied to a newer sustainable trend in architecture in order to justify its continued use.

Chicago, for the most part, seems to have abandoned its reputation as the re-inventor of the tall building. There is much criticism in current literature on the quality of Chicago towers, much of it well founded. As usual, there are exceptions to this, as illustrated by the case studies. However, New York's conservatism has received more widespread criticism, including that from Goldberger. 'I'm fascinated by the extent to which provincial places in the country are willing to take more risks than cities like New York and L.A.,' he claims. Fortmeyer shares a similar opinion: 'Market and regulatory demands have become so perilous for skyscraper interests in the States – epitomized by the flawed process at the WTC site – that many domestic

observers and fans of the typology have given up expecting anything more than mediocrity' (2007: 40).

When examining the case studies, it also becomes apparent that less conventional skyscraper forms in the city in fact generally stem from European 'starchitects,' as exemplified by Foster's Hearst Tower. In total, the common American approach to tall buildings can be summarized in the paraphrased words of David Scott (cited in Fortmeyer, 2008: 137), the former Chairman of the Council on Tall Buildings and Urban Habitat: 'Too often,' he says, architects apply sustainable concepts to the existing skyscraper typology, without questioning the typology itself'.

Europe, on the other hand, appears to have become the new home of a more experimental, theoretical approach, often based on the requirements of sustainability. The case studies illustrate the variety of tall buildings on the continent, most displaying the investigational approach common in early Chicago skyscrapers. This design-oriented approach contrasts highly with the American focus on practicality. Describing this disparity, Larry Malcic (cited in Powell, 2008: 84), design director of HOK's London office, observes: 'European architects see themselves as artists in a way many Americans don't. Maybe it's a reflection of the way the USA received the ideas of the Bauhaus from people like Groupius, Mies and Breuer – there is an emphasis on practical utility in the Bauhaus philosophy.

Kenneth Powell (2008: 85), in a discussion of the cultural differences between the continents, points out that European nations after World War II had a 'statist ethos' while America had already developed its free enterprise and big business characteristics. It can be argued that the latter was more conductive to the proliferation of tall buildings, even though the same may not be true today as evidenced in the developing Asian economies. In any case, the varying cultural approaches influenced the design and number of towers during the last half of the 20th century. Although much of such a difference is attributed to the shortage of tall building archetypes on the continent, World War II and the subsequent reconstruction effort also played a significant role. The dramatic destruction of populated European cities and the need to quickly rebuilt them led to poor construction practices or the replication of poor designs (Power, 1997: 93). Often little attention was paid to the location and amenities provided for such buildings, leading to additional social problems. Unsurprisingly, the public, and consequently the state, turned away from their initial enthusiasm for the building type. Architects

building towers decades later, aware of the continuing negative perception, had to adopt a more precautionary approach to their design, and arguably a more 'artistic' direction to change their image.

Although the The United Kingdom faced many of the same challenges as the rest of Europe, it is today somewhat of an exceptional place. Powell points out that although in the 1950s and 1960s, 'the London City Council ran what was arguably Britain's most significant practice,' political change and the growth of Britain as a global financial capital accompanied 'the adoption of American norms in office design that have not found acceptance in, say, Germany or the Netherlands.' He continues, 'Fast-track construction and the use of standardized components have revolutionised the British scene in the last 20 years' (2008: 85). Although his last comments bring to mind the post war reconstruction scene, there is now a much more 'American', i.e. 'big business', approach to tall buildings, reflected in the buildings' roles and layouts. The commercial skyscrapers of Canary Wharf are an iconic example of this, but many 'sustainable' towers, such as the Leadenhall Building, London Bridge Tower and 30 St Mary Axe. also demonstrate the vertical scale and deep floorplans reminiscent of American models.

In spite of the differences, however, European architects have been playing an increasingly influential role in American tall building design. This is seen both directly in the iconic towers designed by European architects in American cities, as well as the indirect influence from American architects that have trained or worked abroad. The unusually European form and approach of Chicago's Solstice on the Park demonstrates this subtle influence, as its architect Jeanne Gang notes 'significant experience as a senior designer' at Rem Koolhaas's Office Metropolitan Architecture in Rotterdam' in her website biography (Studio Gang website, no date). Perhaps, as Powell (2008: 4) states:

> Only by challenging existing notions of pre-packaged design, unimaginative construction techniques and complacent attitudes to sustainability, can things hope to move forward, and maybe outsiders are the right people to shake things up. As Paul Finch notes, it is a tribute to America's political and cultural maturity that it can entertain and encourage architects from Europe and Japan, but it must also be hoped that beyond the sparkling of superstar fairydust, this reciprocity has more profound repercussions.

As a final point, a brief comparison between the preceding case studies and the work of Yeang merits attention. Yeang's work portrays a fundamentally different approach to the sustainable tall building than that of the majority of architects named in this chapter, namely in that there is a predominance of passive architectural strategies. It

is evident that his primary focus is the relationship between the building, its site and climate. Unlike most other high-rise architects, there is an abundant display of wind and sun roses to describe local conditions, followed by a series of diagrams explaining the tower's reaction. The only other architectural practice in the case study group that utilizes such diagrams is Studio Gang, and this is perhaps why the building is noticeably different from other American examples. Yet the amount and variety Yeang utilizes is unique, particularly in his consistent application of sunpath and windrose images.

Furthermore, unlike the other architects, Yeang's descriptions are not overly concerned with efficient systems, or renewable energy sources for that matter. This was clearly evident during the process of compiling data for other studies, in which system-specific information was often more accessible than that of passive design strategies. Although some of the proposed case studies also do not focus much on systems, this character can be attributed more to the early stages of design rather than any particular partiality for their exclusion. The fact that many are concerned with renewables, essentially advanced mechanical systems, indicates this preference. In contrast, even Yeang's completed non-Western projects provide minimal information regarding their systems and much more on the shaping of form and fabric based on the use of passive design strategies. Once again, towers such as Solstice on the Park and the Kite Tower also display concern for passive strategies, but the number and extent to which such strategies are explored is more developed by Yeang.

However, the specific case study used here, one of four considered for the climate type, and included in Appendix A, shows a disparity between Yeang's design and theory. The Elephant and Castle Eco-Tower resulting review in Figure 4.42 does not compare well to other towers nor does it show a thorough application of his design principles. It appears to confirm the critique stated in the previous chapter. However, some recognition must be given that the project is incomplete and so much of the relevant data unavailable. It also highlights the need for a broader consideration of strategies employed by other architects, particularly those with completed or more developed proposals.

4.3 Observations and applications in education and practice

Two opportunities arose during the author's research period that allowed for the observation and application of the design principles in education and practice. One involved creating a proposed sustainable tower in Birmingham with Broadway Malyan Architects. The other was based at Nottingham University's tall building design studio that encouraged students to create new models for green towers. Like the case studies, this approach was related to the first thesis objective of finding suitable principles in that it helped to inform which ones can be applied in teaching and practice and how they are best constructed and presented. Furthermore, it would also suggest initial ways in which they could be organized, although the first objective is here more pertinent.

4.3.1 Broadway Malyan Birmingham proposal

The framework's author was hired on a temporary basis at Broadway Malyan Architects to create a bioclimatic strategy for a proposed tower. The building was to be placed inside the triangular courtyard of a listed Birmingham building and segmented into commercial purposes at the base, a hotel along the middle levels and residential apartments at the top. The design team also consisted of a Part II Architect, a 3D rendering specialist and an office Director who provided supervision through the process. The Birmingham City Council had aims of providing an iconic tower for the prominent site, asserting that it should stand as the 'Shard' of Birmingham, in reference to the London Bridge Tower. Broadway Malyan interpreted this aim as a tower of a crystalline form, with jagged edges and slants reflecting the angular nature of the site. This requirement would demand the use of a fully-glazed façade.

The author's period of employment started after the form's and façade's prerequisites were set, and when the design was initially a vertical extrusion of the site. An initial flat roof had been replaced by one tilted 45 degrees facing south. At the time of hiring, a decision was made to fully optimize environmental strategies, which would in the end be represented as solar and wind strategies. A shadow analysis was also carried out, which revealed that the new tower would have minimal impact on the solar access of nearby buildings.

The site layout was also inherently beneficial for ventilation, as the local wind rose confirmed that the wind would not have much impact on the building facades, particularly in the winter period as it ran parallel or at a highly oblique angle to the glass walls. During the summer period, on the other hand, both the primary and secondary wind directions were more perpendicular to the façade and were thus used as part of the natural ventilation strategy, specifically on the west and north-east facades. The shallow floor plans worked alongside this aim.

The winter wind conditions required that windows be closed and that low-level inlets and high-level exhaust openings be used for the ventilation strategy. Yet the winter wind's parallel direction to the south-east façade was used as a positive feature. The wind was to be channeled to a series of vertical turbines, located on the northernmost corner of the wing. An angular metallic 'fin' was also added to the building's side, enhancing the channeling force. Like the façade serration for western skygardens, this increased the angular aesthetic of the built form. The building is also provided with further vegetation on the northeast wing's slanting north-facing balconies and at the highest levels of the building below the slanted roofs. It acts both as a thermal buffer and as a private screen.

The solar strategy was of primary concern, as the depth of the building would not allow sufficient access to daylight. A triangular central hole was introduced, so that each wing of the tower would form a completely daylit slab. The solar strategy also included the changing of the roof slant to approximately 30 degrees east of south, as this allowed more daylight and useful winter gain to penetrate the tall northeast wing by lowering the heights of the southern ends. To allow for sufficient gross area, the tower height was therefore raised to a maximum of thirty-seven stories on the northeast edge.

As it was to be an all-glass building, the tower also needed extensive solar protection. This was provided by horizontal louvers on the southeast façade and vertical ones on the western wing. All louvers were sized and angled to reflect the summer sun while allowing sufficient solar penetration in winter. The louvers were also closeable at night, to reduce heat loss through the building skin. To add variety, as well as biomass to the building, skygardens with trees were added to the lobby and communal sections on the west façade and emphasized with an angular cut through the building skin. The three wings now each had their own characteristic

facades, helping to both avoid a monotonous glass skin as well as to visually demonstrate the significance of building orientation in bioclimatic design.

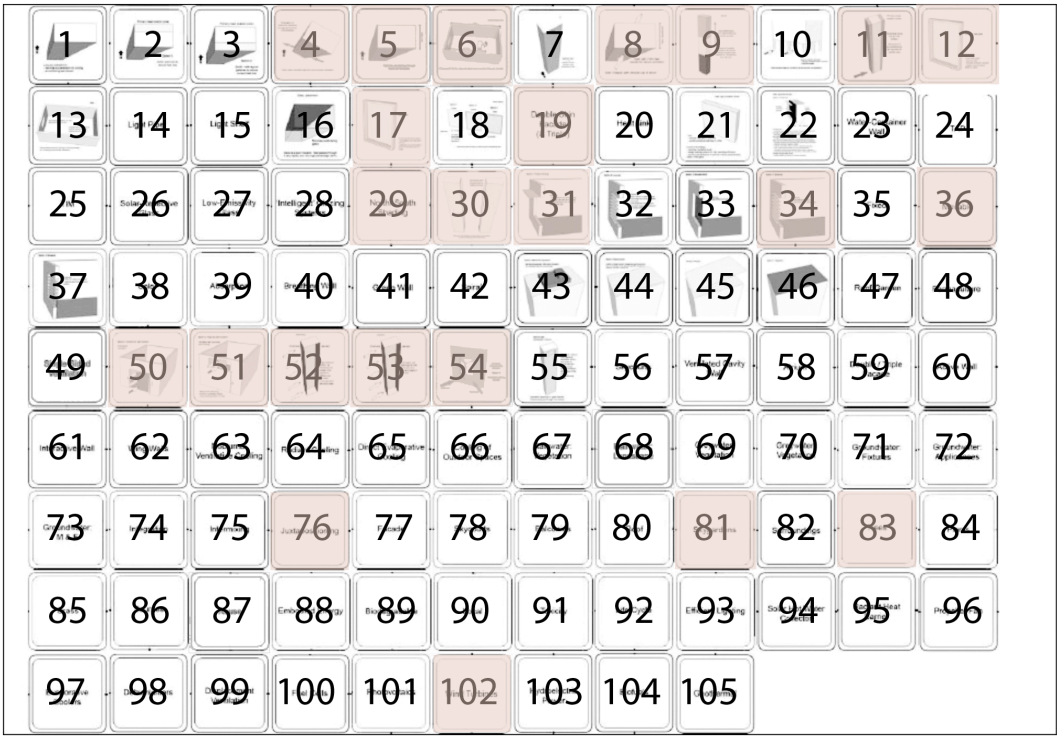


Figure 4.44: Broadway Malyan proposal strategies, numbers refer to no. column in Fig. 4.2.

Therefore, as supposed for the case studies as well, some of this tower's strategies were chosen for commercial as well as environmental reasons. Yet the variety of design principles, as noted in Figure 4.44, demonstrate that they can be integrated into a design process fairly easily; this schematic design's environmental strategy was developed in three weeks, showing that this is the case even with severe time restrictions. The rate of application is particularly true for bioclimatic strategies. On the other hand, the time limit also restricted some of the more complex and specific strategies, such as the type of glass specified, which would require further consideration later. The specification of an 'all-glass' façade and predetermination of the overall form of the building restricted the strategies that could be used. However, there was also much enthusiasm by the team and developer in the adoption of many of these design principles, and indeed many of the environmental features, particularly the trees, became the building's defining qualities. The building is depicted in Figure 4.45 and its bioclimatic strategies summarized in Figures 4.46 and 4.47.

The project also had some impact on the framework. In addition to refining the clarity and guidance of the design principles, it also supported their grouping into certain environmental influences. Bioclimatic principles particularly benefited from being separated into those relating to a ‘solar strategy’ and a ‘wind strategy’, which would later be developed into visual radiation, thermal radiation and airflow. It also supported the prioritization of solar strategies over those relating to airflow, which would later be reflected in the framework’s hierarchy.



Figure 4.45: Birmingham tower rendering

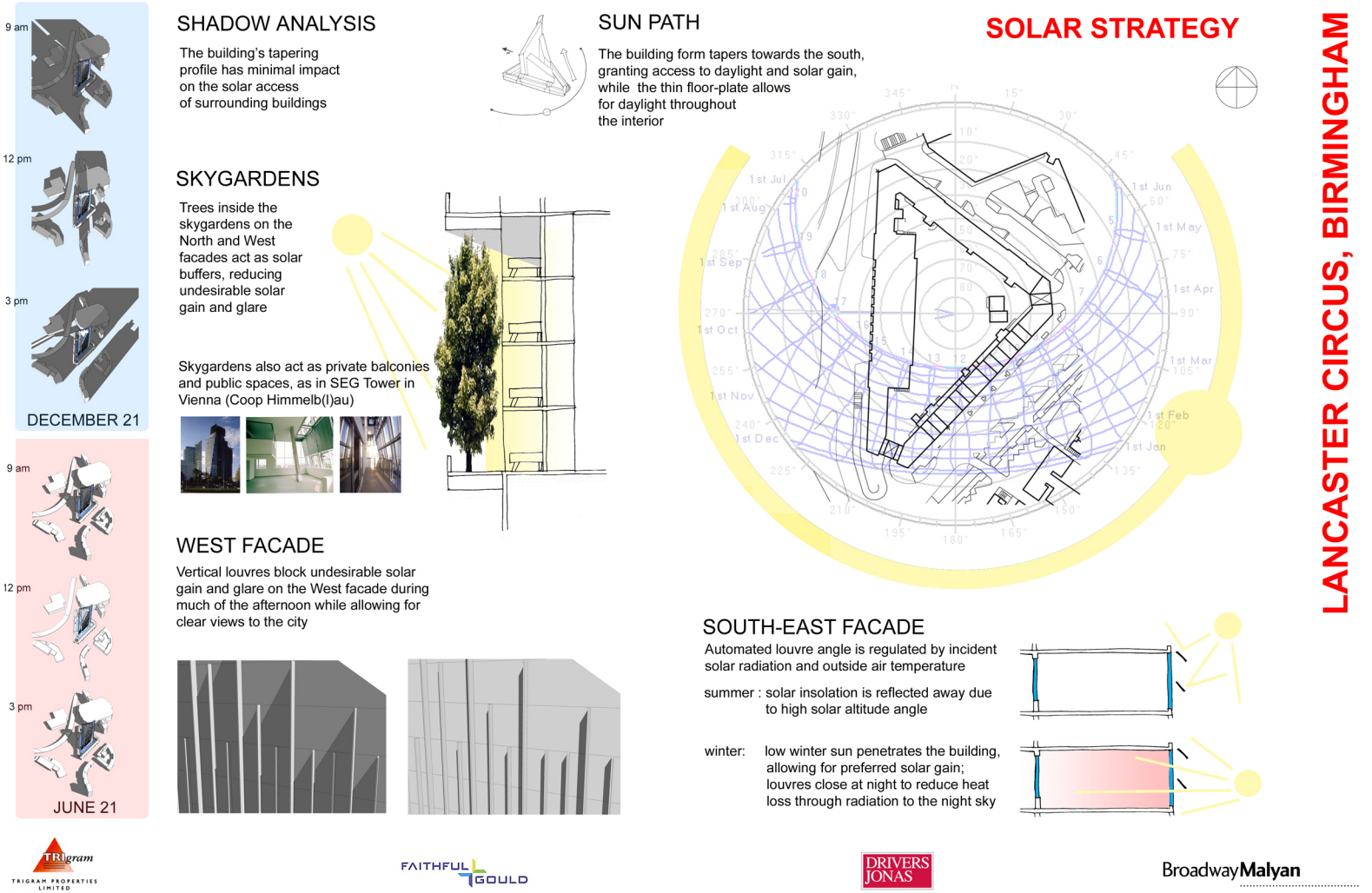


Figure 4.46: Birmingham tower solar strategy

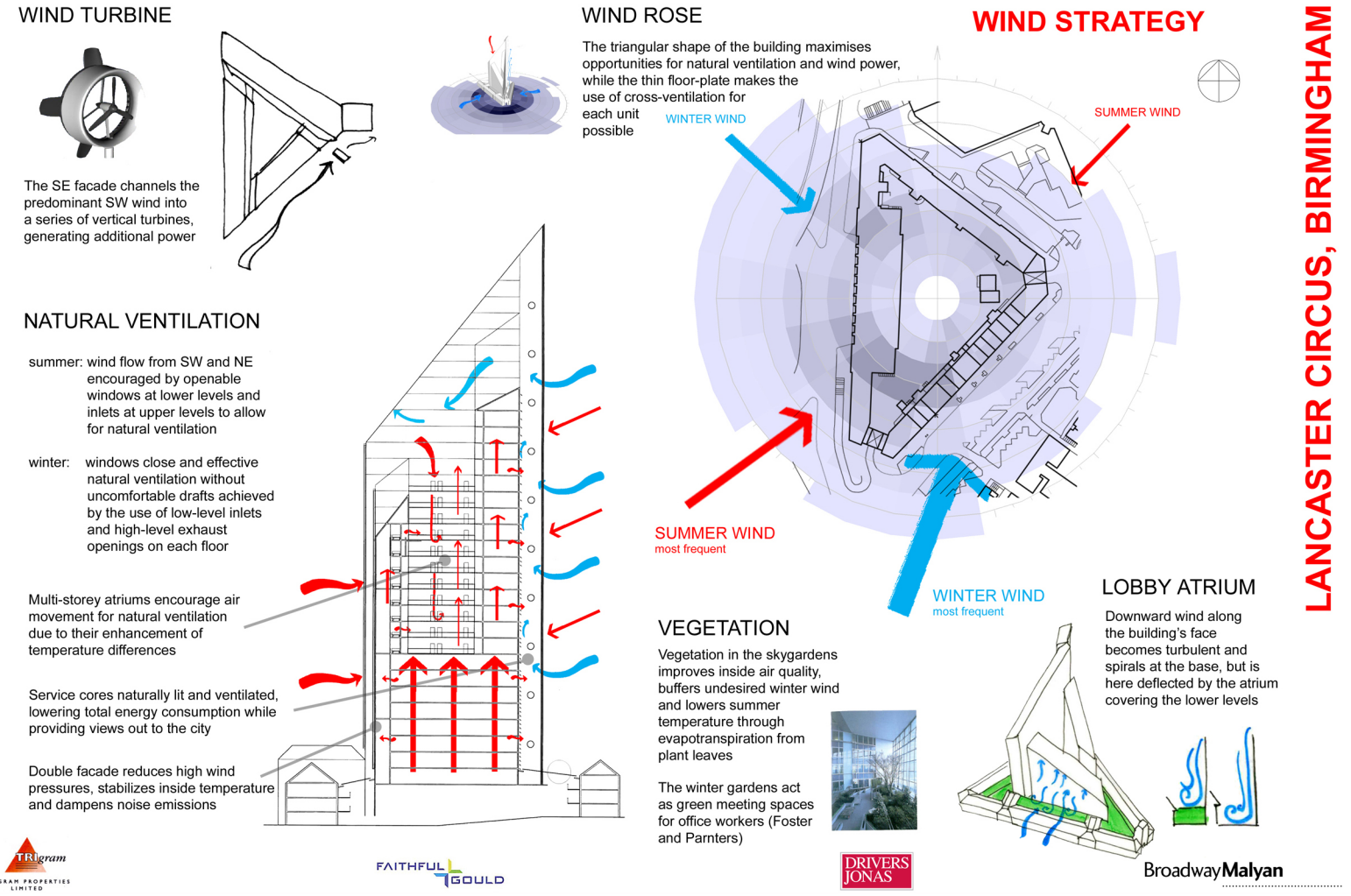


Figure 4.47: Birmingham tower wind strategy

4.3.2 Nottingham design studio observation

The author's first encounter with the tall buildings design studio at the University of Nottingham was as a visiting tutor in 2007 and 2008 while the initial framework was being developed; that role was different to the one adopted in the student test towers of Chapter 6. However, as many of the aims of the course have remained consistent, here it is sufficient to say that the groups of students involved in this earlier period, consisting of two semesters, had a different site of Canary Wharf, London, and that the theme of the course at that moment was 'Bioclimatic Skyscrapers', although a wider range of sustainable approaches was also encouraged. As many of the observations from these early groups compare well with those of the student testing in Chapter 6, an observation of two contrasting approaches from 2007 and some general reflections are sufficient as they relate to the early framework development.

As the principles were well developed at that point, the author's tutoring role involved encouraging their application as well as a more general observation of the students' process of design. As there was no precedent of a design course on bioclimatic towers, the students were understandably somewhat confused at the beginning as to what strategies to adopt. One group decided to mimic Foster's Commerzbank, which in the beginning proved useful in educational terms. However, as they were unable to propose a different form towards the end of the course, the emphasis on the existing tower proved detrimental. Another group was more formal in their approach, proposing a 'sail-shaped' tower for a waterfront site, which in itself was not unique and which appeared to be unrelated to any bioclimatic principles.

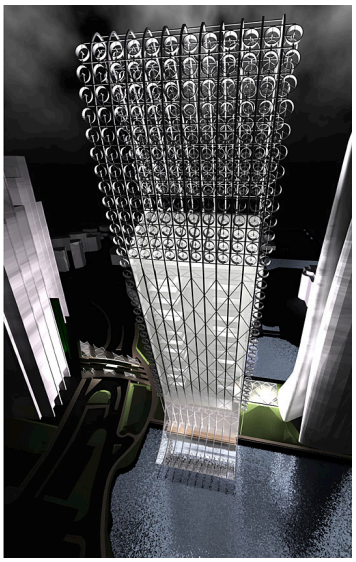
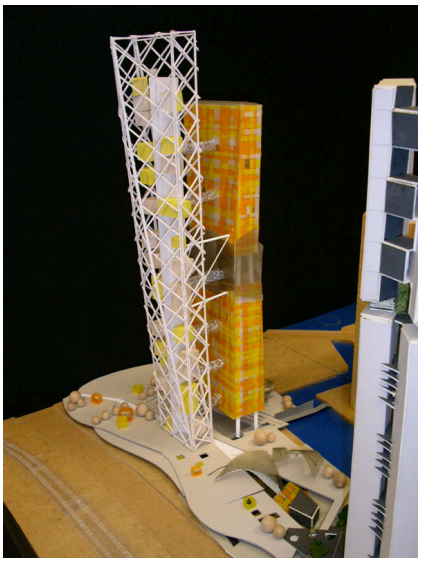
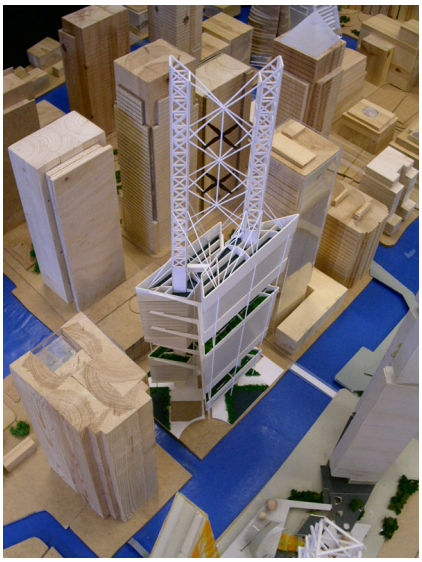
The difference between the two groups' projects at the end of the semester was vast. Whereas the former was somewhat unwilling to adopt design principles other than those found in the Commerzbank, the latter consistently applied and developed their project, which in the final reviews did not resemble their original idea. The latter project resulted in two towers, one of a residential function and other acting as 'a street in the sky.' Both were oriented and sized to encourage solar gain and airflow. Due to its innovative application of bioclimatic strategies, as well as a strong urban concept, this project in the end was considered by the team of tutors to be one of the most environmentally responsive. This project, alongside others, is illustrated in Figure 4.48 at end of this subsection.

Yet, as mentioned, this second project had a less than promising start. The students were, like the Commerzbank group, reluctant for a long time to change what they felt was a strong design idea. The original project, and one that remained undeveloped for some weeks, was of a tower held up by two main posts, with slots for air and light, many of them sized unfittingly. A major issue with the early design was that its south-facing orientation, although ideal for solar gain, did not correspond to the southwest wind force needed to run the large turbine topping the building. After a sustained period of critique, the students decided to abandon the single-orientation of the structure. Two sustainability principles, relating to an allowance solar radiation on the south façade and orienting the form to enhance wind turbine performance, were then considered separately. A suggestion was quickly adopted to split the structure in two, one element to hold the building mass in a south-facing direction and the other to orient the turbine at a 45-degree angle. This solved not only the bioclimatic problem but also the early building's lack of urban consideration, as removing supporting corner columns would invite Canary Wharf visitors to the public plaza at the base of the site. After this point, the group quickly adopted other bioclimatic design strategies, adjusting the floorplate and vertical zoning to suit local climatic conditions. The example of this group ties in well with the aim to introduce the solar and airflow strategies separately, as was done in the Broadway Malyan proposal. Furthermore, it urged the author to make the bioclimatic design principles simple and therefore easy to apply. Like this group, other groups that progressively adjusted their towers to climate, rather than suppose that one approach would suit all conditions, appeared to have a much higher success rate. This observation suggests that there is a danger of green towers serving as icons, rather than instructive prototypes. Given some students' insistence on replicating the towers' forms without critically evaluating their performance or suitability, design guidance and knowledge of design processes may be more beneficial for generating more environmentally responsive and original buildings.

This may further suggest the unsuitability of using existing case studies as models for sustainable design, rather than relying on design guidance and design processes to inform it.

Overall in the course, as some of the teams were apprehensive about applying the preliminary bioclimatic strategies of orientation and configuration to their initial design concepts, there was much focus on building fabric and, particularly, on wind turbines. A case in point is the 'Wind and Water Tower,' whose deep floorplate and inefficient

spatial organization prevented it from being particularly sustainable in terms of ventilation and daylighting. However, in contrast with this author's evaluation of the project as lacking a regard for bioclimatic principles, the tower, upon assessment by other examiners, received the Canary Wharf plc. prize as a 'best design', notably for its crown of dozens of turbines that provided a strong aesthetic indication for the future of green skyscrapers. Although one cannot argue regarding the strength of the unique imagery it proposes, the group's win raises questions whether passive, bioclimatic towers are likely to obtain the recognition that more technologically-focused towers receive. Given the results, it appears as though in terms of marketability bioclimatic principles are essential or only supplementary for future tall building designs.

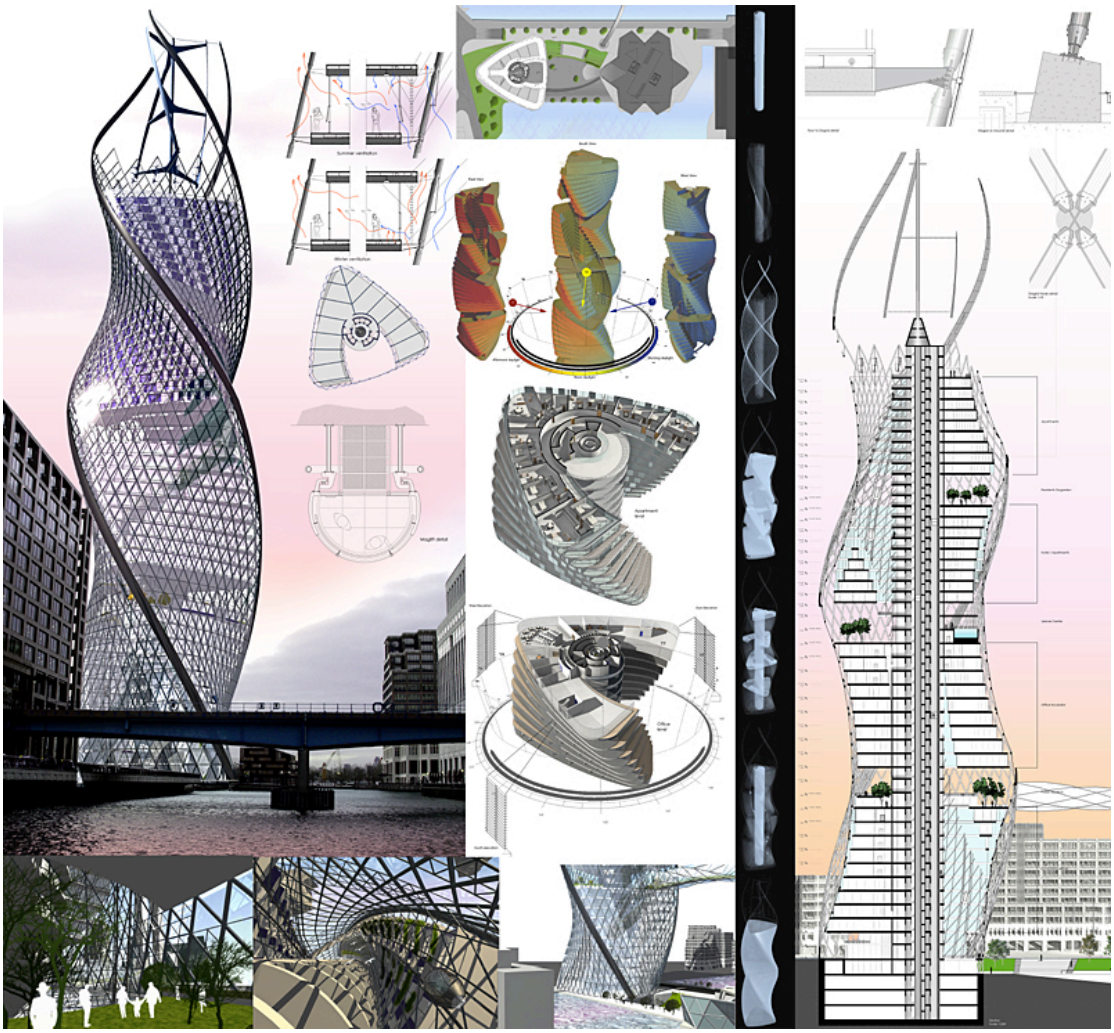


Figure 4,48: 2007 Nottingham projects (SBE website)

4.4 Framework attempts prior to version 1

Having already examined the source and applications of the design principles, this section will consider the response to second research objective, the organization of those principles to best inform architects during the schematic design stage. It will discuss the early development of the sequence of the proposed framework and attempts at a broader level of organization. The inclusion and development of functional category labels will be considered and the framework's response to climate type will be specified.

4.4.1 Early attempts at organization

As mentioned previously, the framework's focus varied through its development, from bioclimatic to sustainable to bioclimatic again; in this first stage, it would begin as

bioclimatic and end as sustainable. In any case, initial problems were rooted in bioclimatic design's necessary link with the varied conditions in the cool temperate climate. The four bioclimatic concerns of daylighting, ventilation, heating and cooling through natural means often contradicted each other. Solar gain, for example, posed a particular problem, as it was to be encouraged during cooler periods and discouraged during warmer ones. Ventilation, too, would be encouraged during warmer seasons but limited during the cooler ones. A way of representing such complex relationships soon became the main concern of the framework.

One of the early ways of illustrating this dichotomy of climatic requirement was attempted through an early 'iconic' framework, as seen is Figure 4.49. Here, the building and climatic aspects were represented respectively as a square within a circle. The climatic components consisted of solar and airflow influences, and so were subdivided into the four quadrants of daylight, heating ventilation and cooling. Within these quadrants, the square was placed, and then split into orientation and configuration. As the framework initially assumed that it would lead to a morphosis of a building's form, the configuration category was provided with additional subcategories of 'extrusions' and 'reductions'. Examples of such elements included solar shading under 'extrusions' and window openings under 'reductions'.

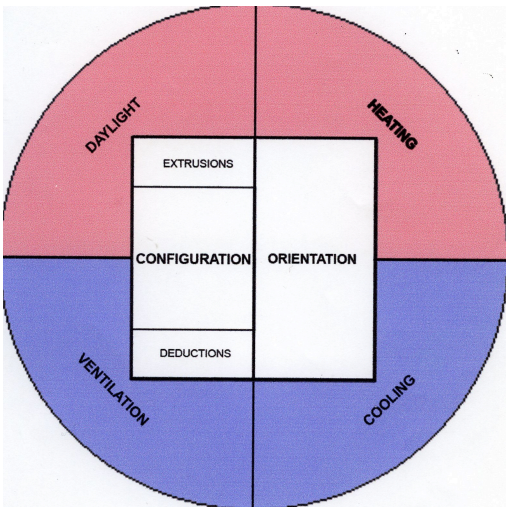


Figure 4.49: An early graphic representation

However, this format, like other early attempts, proved to be too simplistic and lacked the hierarchy the framework intended. Although heating, cooling, ventilation and daylight could be approached individually, an assumption that certain elements were linked only to a specific influence proved misleading at the outset. The use of absolute forms such as circles was also shown to be somewhat irrelevant to the framework's purpose, detracting from the generally sequential nature of design. This representation was therefore abandoned early on.

Afterwards, organization attempts were to take the form of a table, here referred to as a matrix. This would allow the dual aspects of building design elements and

climatic strategies to be represented in columns and rows while allowing them visually to interact within cells. The first tables, such as the one in Figure 4.50, were designed to reconcile the organization of labels in the circle chart. However, as they proved troublesome in relation to the established design principles, there were attempts to expand the labels by including categories, such as solar orientation as additional cells. In spite of these adjustments, the categories presented too many problems in terms of hierarchy and principle inclusion, and so the categorizes needed to be rethought.

A decision was soon made to label aspects relating to the building as site, configuration, orientation, fabric and renewables. Site was included to recommend a site analysis and fabric to encompass the previous extrusion/reduction categories. As the research aim at this point was still based around the concept of a zero carbon, zero energy building, it became apparent that bioclimatic strategies alone could not achieve this result. Renewable sources of energy were therefore added as a category, although systems were still considered as avoidable 'additional inputs.' Yeang's chapter and section titles were then inserted within the matrix. Figure 5.1 displays an example of this option. 0_{CE} represented the zero carbon aim.

Figure 4.50: Early attempt at a table format

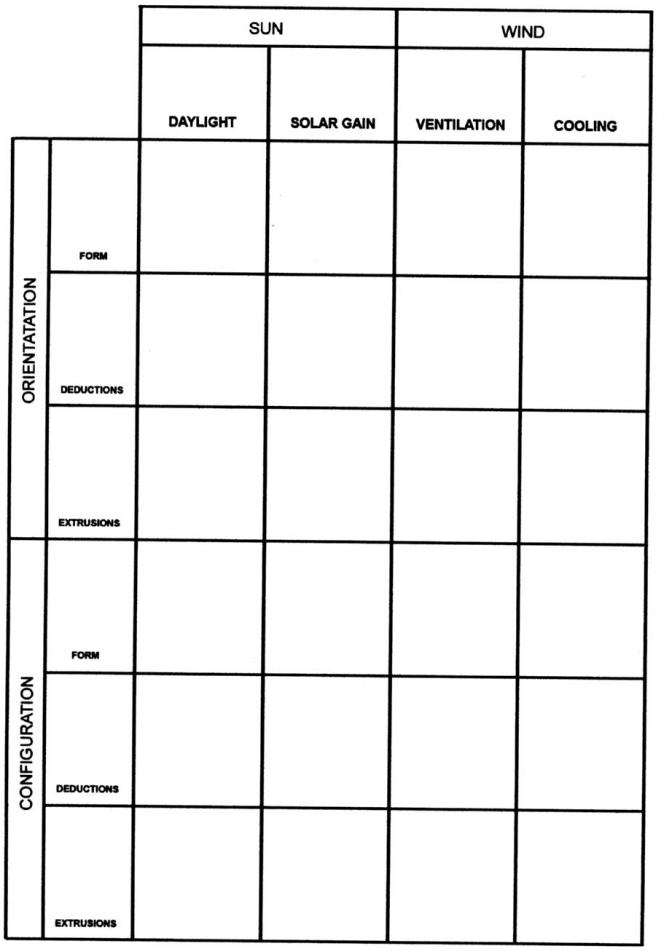


Figure 4.51: Table with improved building element categories

Site	Orientation	Configuration	Fabric	Renewable	0_{CE}	Additional ?
A. City	A. Built Form	A. Built Form	A. Enclosure and Façade Design			
B. City Block	B. Floorplate	B. Floorplate	B. Solar Control Devices			
C. Street	C. Core / Build. Mass	C. Core / Build. Mass	C. Passive Daylight			
D. Pedestrian			D. Wind and Natural Ventilation			
			E. Roofscape			
			F. Color			
			G. Landscape			
			H. Passive Cooling			
			I. Building Mass			
Site	**Orientation**	**Configuration**	**Fabric**	**Renewable**	**0_{CE}**	**Additional ?**
A. City	A. Built Form	A. Built Form	A. Enclosure and Façade Design			
B. City Block	B. Floorplate	B. Floorplate	B. Solar Control Devices			
C. Street	C. Core / Build. Mass	C. Core / Build. Mass	C. Passive Daylight			
D. Pedestrian			D. Wind and Natural Ventilation			
			E. Roofscape			
			F. Color			
			G. Landscape			
			H. Passive Cooling			
			I. Building Mass			

This format, however, relegated many of the climatic issues to the fabric column, and so the matrix would read as unrelated to climate in terms of site, orientation and configuration. This result in fact contradicted the initial intention of the matrix to emphasize interactions of the climate and the building, and so was a step away from some earlier framework attempts. An effort was then made include, within each cell, eight aspects of environmental design: daylighting, solar gain, solar protection, natural ventilation, passive cooling, wind protection, health and conservation. The resulting format, depicted in Figure 4.52 was more comprehensive but also more difficult to follow. Many of the cell interactions were redundant, while others, such as health, were outside of the aims of environmental sustainability. The framework version at the end of Stage 1 would therefore aim to resolve these issues, and the first six numbered issues and column categories would set a precedent.

Figure 4.52: Expanded table with eight subcategories per cell

SITE	CONFIGURATION	ORIENTATION	FABRIC	RENEWABLE
CITY 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	BIUILT FORM 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	BUILT FORM 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	ENCLOSURE/ FAÇADE DESIGN 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	PHOTOVOLTAICS 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
CITY BLOCK 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	FLOORPLATE 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	FLOORPLATE 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	SOLAR CONTROL DEVICES 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	HYDROELECTRIC POWER 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
STREET 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	CORE / MASS 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	CORE / MASS 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	PASSIVE DAYLIGHT 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	GEOTHERMAL ENERGY 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
PEDESTRIAN 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation			WIND & NATURAL VENTILATION 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	BIOMASS ENERGY 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
			ROOFSCAPE 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	HYDROGEN 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
			COLOR 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	WIND GENERATORS 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation
			LANDSCAPE 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health	
			PASSIVE COOLING 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	
			BUILDING MASS 1. Daylighting 2. Solar gain 3. Solar protection 4. Natural ventilation 5. Passive cooling 6. Wind protection 7. Health 8. Conservation	

4.4.2 Labeling of categories

As a basic table structure had been created, the final framework's matrix development progressed more steadily from this point. First, there emerged recognition that the site column was outside the scope of bioclimatic design. Originally, it aimed to highlight the need for a climatic evaluation of a site, but this was judged to belong to a stage preceding design. As design would focus on the building itself, there was no need to involve the architect in the planning of the city, city block and street, as these were usually pre-existing conditions. The architect instead would use existing urban patterns and climatic site evaluations to create a specific building, and so any examinations of these aspects would have been completed at an earlier stage. The inclusion of site also created confusion in relation to the column of orientation as the two in some ways could appear to coincide in purpose. However, as the site was usually a pre-existing condition and could therefore not be shaped, the orientation category proved sufficient for the time being in determining the placement and orientation of the building form. The issue of site would reemerge in later discussions, including those of Chapter 6.

A second improvement would rely on the sequential application of certain cells. There was an early recognition that the framework matrix should be read as a newspaper page, with the top left cell representing the starting point and the bottom right the end. Therefore, the order of the column and row labels was key. Birmingham tower trial runs and previous hierarchy suggestions, such as that of David Lloyd Jones (1998), helped to determine the organization of the rows, representing environmental inputs. Those inputs with a particular importance in the cool temperate climate were placed as priorities, towards the top. This order ensured that building would focus on the most significant inputs, while the overall framework matrix guaranteed that all influences would be reconsidered multiple times. Visual radiation, or daylighting, was initially seen as a primary concern, followed by thermal radiation and airflow. This order would remain until the final version, where it would undergo a larger change. These specific terms themselves were thought to better represent climatic conditions, and therefore resolved additional issues related to natural ventilation and passive cooling by placing them into one category.

The columns, or building design elements, remained related to the design process in a similar manner as in previous attempts. An addition here is the column of systems, which was included as there was a particular focus on this category in the case study

literature. However, as mechanical systems are often overly emphasized in sustainable towers, the principles included focused on providing suggestions for their efficient application. The inclusion of systems would therefore recognize the 'energy-efficient' concern of many designs, while identifying it as separate from bioclimatic design and only as a part of general sustainability. Although renewables and systems often serve the same purpose, due to a common inefficiency and high dependence on certain climatic conditions, renewables are the last to be considered. The framework does not prohibit a building from focusing on energy generation, but it does expect that in that case it is a pre-design decision as it can determine much of a building's orientation and configuration.

As the framework was at this point moving from 'bioclimatic' to 'sustainable', an additional category of resources was also added. The manner in which resources were to be included was somewhat debatable. Initial frameworks by the author included subcategories such as water, flora and fauna, their relationship with the design principles needed to be resolved. A solution to this problem was also researched in *Ecodesign*, which offered a categorization of resources as inexhaustible and exhaustible. As inexhaustible resources, such as air and solar energy, had already been categorized in the framework matrix, there was a need to label the exhaustible resources. Yeang separated these into replaceable (and maintainable) resources and irreplaceable resources. Replaceable resources included water, flora and fauna, whereas irreplaceable resources consisted of soil, fossil fuels, land and the landscape itself. He further classified irreplaceable resources into four subcategories. However, this level of categorization was too extensive for the purpose of this framework matrix, although the initial exhaustible and inexhaustible resource categories justified a level of separation in terms of approach. This version would eventually include three broad irreplaceable resource categories of water, materials and land, which could be expanded on by the cells and principles within the matrix.

4.4.3 Climate specificity

There were two further steps to the completion of the framework, ones that would help to increase its climate-specific aims. As the temperate climate consists of two climatic extremes, such as summer and winter solar conditions, the framework matrix was adjusted to display this fact. Subcategories of 'increase' and 'decrease' were added to the categories of visible radiation, thermal radiation and airflow to highlight

these variations. A second step of blocking out certain interactions, or cells, related these variations to the design process, as the framework then required that certain measures of primary climatic concern were considered before others. For example, bioclimatic design recognizes that residential buildings in the temperate climate overall benefit from an increase in thermal radiation, or solar gain, than its decrease. Through the blocking out of the 'decrease' thermal radiation cell corresponding to orientation, the designer would be encouraged to first utilize those strategies increasing the input. Secondary concerns, such as the decrease of thermal radiation, would then be considered in subsequent steps and used to adjust the building so that it reflected the dual nature of the temperate climate. Blocking out was furthermore used when an interaction was determined to be unnecessary. It should be noted here this increase/decrease split does not apply to renewables, which generally require the maximization of environmental inputs.

4.5 Stage 1 final framework matrix

This section will therefore provide a brief summary of the final Stage 1 framework matrix, presented in Figure 4.53. Its rows represent the energy and materials flowing through the building and are split into inexhaustible and exhaustible resources, together referred to as environmental inputs. The inexhaustible resources include visible radiation, solar radiation and airflow. The designer is provided with a choice of either increasing or decreasing their effect according to the season. The exhaustible resources, consisting of water, materials and land are meant at best to be conserved or at worst to be recycled. The preferred order of application here is from top to bottom, with a clear distinction between inexhaustible and exhaustible.

The columns are the design elements of a building. They consist of orientation, configuration, fabric, system and renewables. The preference of application here is from left to right, as orienting a tower is much less energy intensive than applying an optimal building system. The application of the columns on their own leads to a design that lacks any coherent organization, and therefore they function together with the rows. To achieve the greatest effect, the designer should consider the top left corner interaction, the orientation and visible radiation, apply as many principles as possible, before examining the next row down. In this way the bioclimatic approach is examined before any active mode approaches can be made. However, not every interaction will need to be considered, as certain environmental inputs are not affected by the building's design elements. For example, building orientation does

not influence an input as much as visible radiation and so the interaction is omitted and blocked out in the diagram. This omission also occurs when an input, such as the decrease of airflow, is counterproductive in a stage of design, here orientation, and better approached elsewhere, such as configuration. Orientation therefore applies the main considerations of the climate's design; the following rows then handle secondary and subsequent considerations. This makes this version of the framework matrix specific to the cool temperate climate, as a different set of interactions would be prioritized in other climates.

The interactions between the rows and columns are connected to a separate set of design principles, which consist of a series of simple, individual steps related to the combination. For example, one of the principles for the interaction between visible radiation and fabric includes louvers, which are explained in a series of steps with individual options for size, angle, etc. These principles are presented as annotated visual images to allow for ease of use and are linked with each other, both in the same interaction and with others. Due to their presentation as individual images, rather than as one large principle, the framework is designed to be adaptable and expandable, so that that any future additions or corrections can be included with ease and without changing the framework structure. Furthermore, the principles' simplicity aids in their memorization, so that the framework with each application becomes easier to use.

The next section will consider an initial test of this framework in the form of the Birmingham test tower. The Birmingham site had already been used to help develop certain aspects of this framework, but the next step would actually test its coherence as a whole, as well as develop its third element, the steps sequence.

			Orientation	Configuration	Fabric	System	Renewables
Inexhaustible Resources	Visible Radiation	Increase					
		Decrease					
	Thermal Radiation	Increase					
		Decrease					
	Airflow	Increase					
		Decrease					
Exhaustible Resources	Water						
	Materials						
	Land						

Figure 4.53: Framework matrix Stage 1

4.6 Birmingham test tower

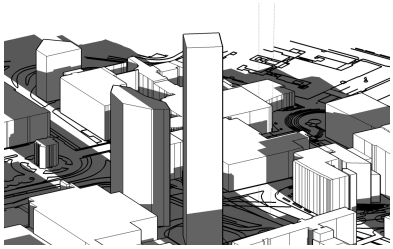


Figure 4.54: Site building cluster

To ascertain whether the principles could inform architects' design processes, a series of iterative trials was organized. As mentioned in the previous chapter, the purpose of each trial was to refine the framework, but each stage also had a particular focus. As the earliest version of a framework structure had been created but not yet applied, Stage 1's test had a broader focus on the choice and organization of principles into coherent design guidance. Any adequacies and inconsistencies in the framework during the design process would be noted; they would furthermore be resolved in the next version of the framework for the subsequent stage.

The Birmingham site in Figure 4.54 is one of tall building locations specified by the City Council. At the time of this trial a parking space, the site is bordered on the north by the 28-story Alpha Tower and on the west by a mid-rise hotel. Nearby on the south is another mid-rise building, the Axis, serving a commercial purpose. A large city road stands to the east. The test tower therefore forms part of a building cluster at the edge of the city center, as shown in Figure 4.55**.**



Figure 4.55: Birmingham aerial view of site (Google Earth image)

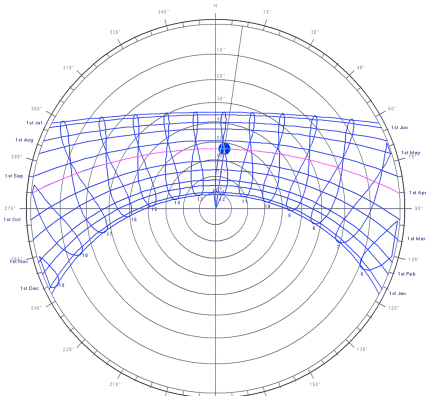


Figure 4.56: Sunpath diagram (in Ecotect)

In terms of climate, the city has a Marine (Cfb) climate type, and so the temperature differences between seasons are not as extreme as in other parts of the temperate climate. The city is located at 52° 30' N, and so the angle and amount of solar radiation varies greatly between the summer and winter months, as is illustrated by the sunpath in Figure 4.56. As is typical of other UK cities, much of the time the sky is overcast and light rainfall is frequent. The airflow conditions, seen in Figures 4.57 and 4.58 are also typical for much of the UK, with the prevailing winds generally coming from the southwest direction. During the summer, additional currents from the northwest direction are also common.

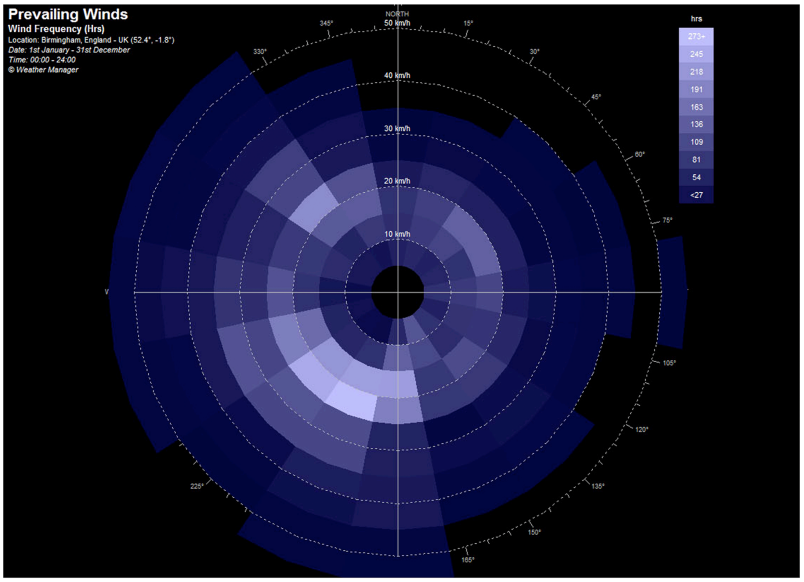
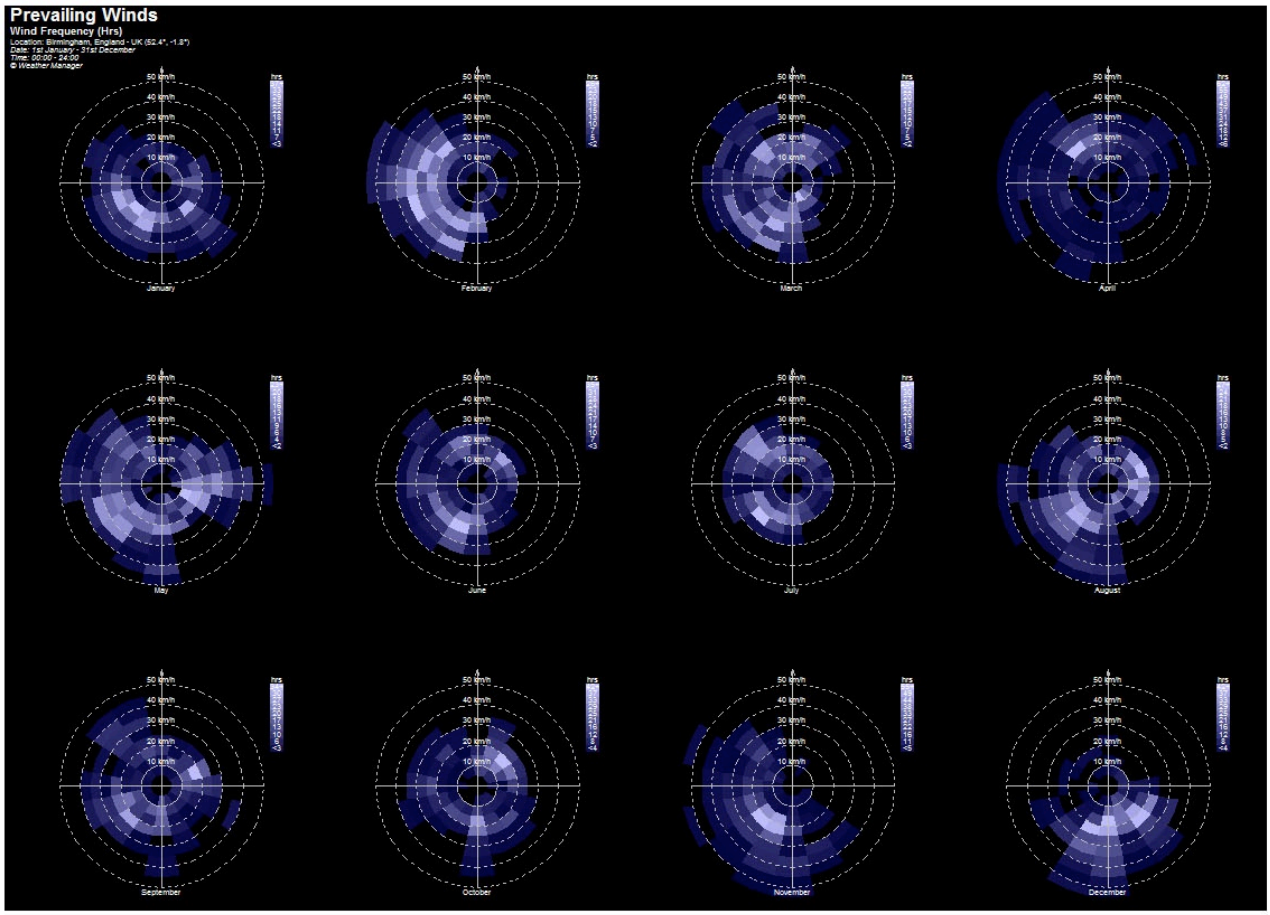


Figure 4.57: Annual average prevailing wind directions (in Ecotect)

Figure 4.58: Monthly average wind directions (in Ecotect)



The building program, detailed on the next page, had changed from one encompassing social sustainability to one concerned mainly with the residential aspect of tall buildings. Therefore, although it requests some public and commercial services, only the tower's residential floors were to be designed in detail. Birmingham City Council confirmed that there was no planning requirement for parking spaces in tall buildings: public transport is instead encouraged. Therefore, the Birmingham tower does not include any parking, although the underground area can be used for that purpose.

It should also be noted that the garden requirement of 20% resulted from a review of the work of Ken Yeang, which discussed several recommendations for green space. According to Ebenezer Howard's garden city, as Yeang describes, the ratio of city to green is 1:6; according to the World Health Organization, 25 square meters of greenery per resident in an urban development are recommended.

Yeang then calculates that, in an office tower, 20% of gross floor area should be added for landscaped sky courts, which is appropriate for general town planning standards obliging 10-15% of gross planning area for parks. ‘However,’ Yeang states, ‘as built systems are mostly inorganic, it is preferred that the organic mass be equivalent to, or more than, the inorganic, and a more desirable ratio of between inorganic areas to organic landscaped areas might be 1:1’ (2002: 132-133). This ratio arguably also applies to residential towers, as no further ratios are provided. Although this is a desirable aim, the more widely recommended figure of 20% was applied to this test tower. Considering that current towers usually have no landscaped areas, this figure is itself a radical proposal for standard practice.

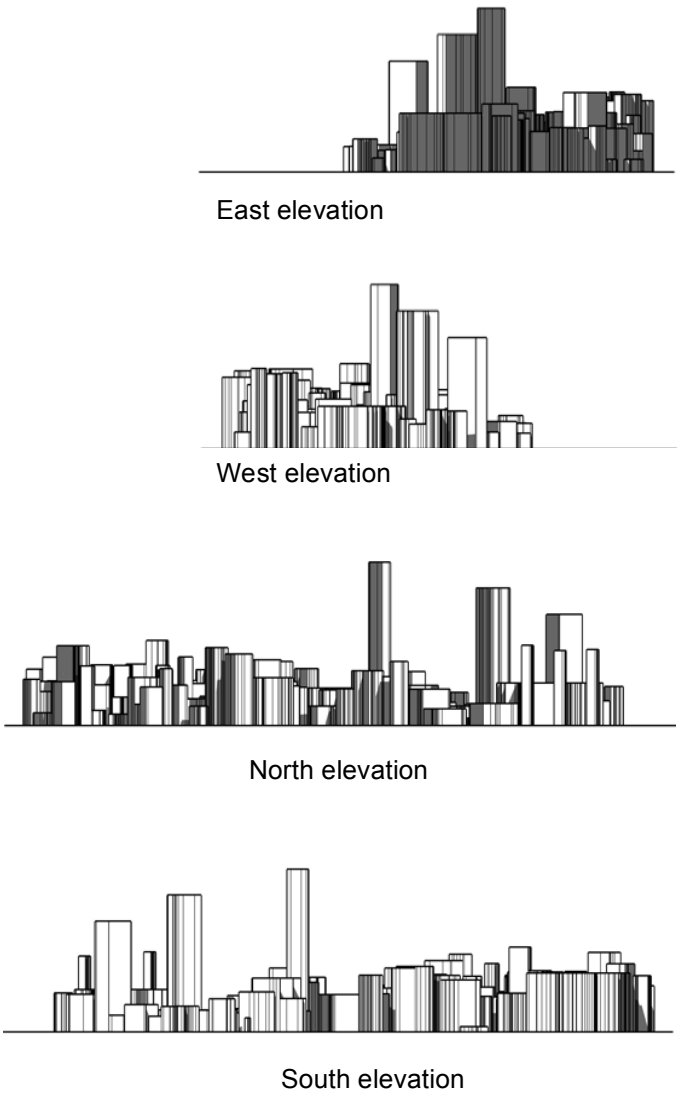
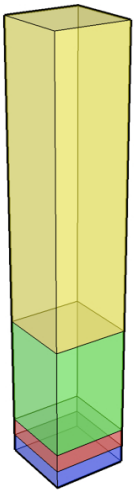


Figure 4.59: View of tower from various directions (in SketchUp)

The building height was determined through a study of current towers in the city and abroad. The 150 m figure was considered to be satisfactory for both established and emerging high-rise cities. This height was found acceptable for the New York and London sites and did not pose any particular structural problems that might discourage certain types of interior planning. In Birmingham, studies displaying the visual and shadowing impacts of the tower were completed, represented in diagrams such as Figure 4.59, where the test tower acts as the highest building.

Birmingham Tower Program



BUILDING HEIGHT			150 m (50 floors)
SITE DIMENSION			25 m X 25 m
SITE AREA			625 m²
FLOOR SPACE			31,250 m² *
Residential	32	70%	21,875 m²
Garden	12	20%	6,250 m²
Public	3	5%	1,563 m²
Commercial	3	5%	1,563 m²
Parking	0	0%	underground

Residential

As this is mainly a residential building, it is expected that apartments will occupy at least 70% of the floor plate. The total number of apartments will depend on the final configuration of the building according to environmental principles, but will number no less than 150. These will consist of:

- Studio apartments
- One bedroom
- Two bedroom

The number of apartments from each category is unspecified, but a variety of types is expected.

Garden

The 20% figure of garden space is based on Yeang's recommendation for the ratio of vegetated to built-up area. This amounts to a double-height garden every five stories. Because of the need for vertical space, the floor area is exaggerated, although the volume of building dedicated to garden space remains proportional. These areas include both public and semi-private gardens and this figure does not include the addition of individual, private garden spaces such as balconies.

Public

The public spaces consist of service areas for the tower's inhabitants that are not of a commercial nature. These include:

- Local medical and dental practices
- Local information services, including libraries
- Local educational facilities, including schools and nurseries
- Recreational facilities such as swimming pools and leisure centers
- General services, such as waste and recycling centers

Commercial

Retail and office space comprise the commercial space, which are expected to benefit the local community and participate in the environmental program of the tower. This space is suitable for activities such as:

- Local grocery shops
- Small businesses run by residents
- Restaurants

Parking

Parking has been minimized to encourage more sustainable forms of transportation. Some private parking spaces will remain, although they will be limited in number. Instead, an adequate provision of bicycle spaces below ground as well as an encouragement of (electrical) car hire / carpooling will be provided.

* The floor space is calculated using the average site area. As the building configuration is likely to change to accommodate climatic conditions, the floor area is likely to decrease. Therefore, the quantities below are the maximum floor areas, although the percentages will nevertheless remain similar.

As the program was established, the Birmingham test tower entered its design phase. As it was focused on a residential function, it was assumed that the building's bottom floors, skygardens and top two levels would provide sufficient public and commercial functions and were thus not designed in more detail. The tower as a whole was to be of a generic, orthogonal appearance, in order to visually illustrate the effects of the proposed framework on a basic form.

At this point the steps sequence of the framework began to be formed, not in advance but through the early attempts at the tower design. Some of these attempts had failed at various points, but each helped contribute to the final sequence. As mentioned in the Methodology, the order was determined primarily by the framework matrix, but at this stage the design principles were further organized according to their application in the design process, with some placed ahead of others when specified as preferred by Yeang. An example of the latter case is the placement of louvers ahead of blinds, as louvers are more effective in blocking out solar gain.

The process of designing this tower was ultimately recorded in a flowchart, minimized in Figure 4.60. Although illegible due to the limitations of the thesis format, it is briefly described here and notes of the design process are available in Appendix A. As this design process is an interim solution and not representative of the organization of the final framework sequence, details of the design process are included from Stage 2 onwards. The columns correlate to the framework matrix's columns, but here, in order to conserve space, fabric has been split into two long columns, situated in the middle. The flowchart also has visual symbols: circles represent interactions; diamonds, principles; ovals, options/steps; rectangles, considerations/subcategories. Furthermore, it indicates where the design could be tested using external tools (trapezoid), such as environmental software, as well as where a visual preview is preferred at point where choices may have a large aesthetic effect (rounded tag). Although the figure shown here has illegible text, these symbols help to show the route of this building's creation as well an array of options available, in this example only from principles extracted from Ken Yeang's work. A visual representation of the building's gradual evolution, using SketchUp software, is included Figure 4.61. A basic illustration of the resulting tower is available at the end of the chapter, as Figure 4.62.

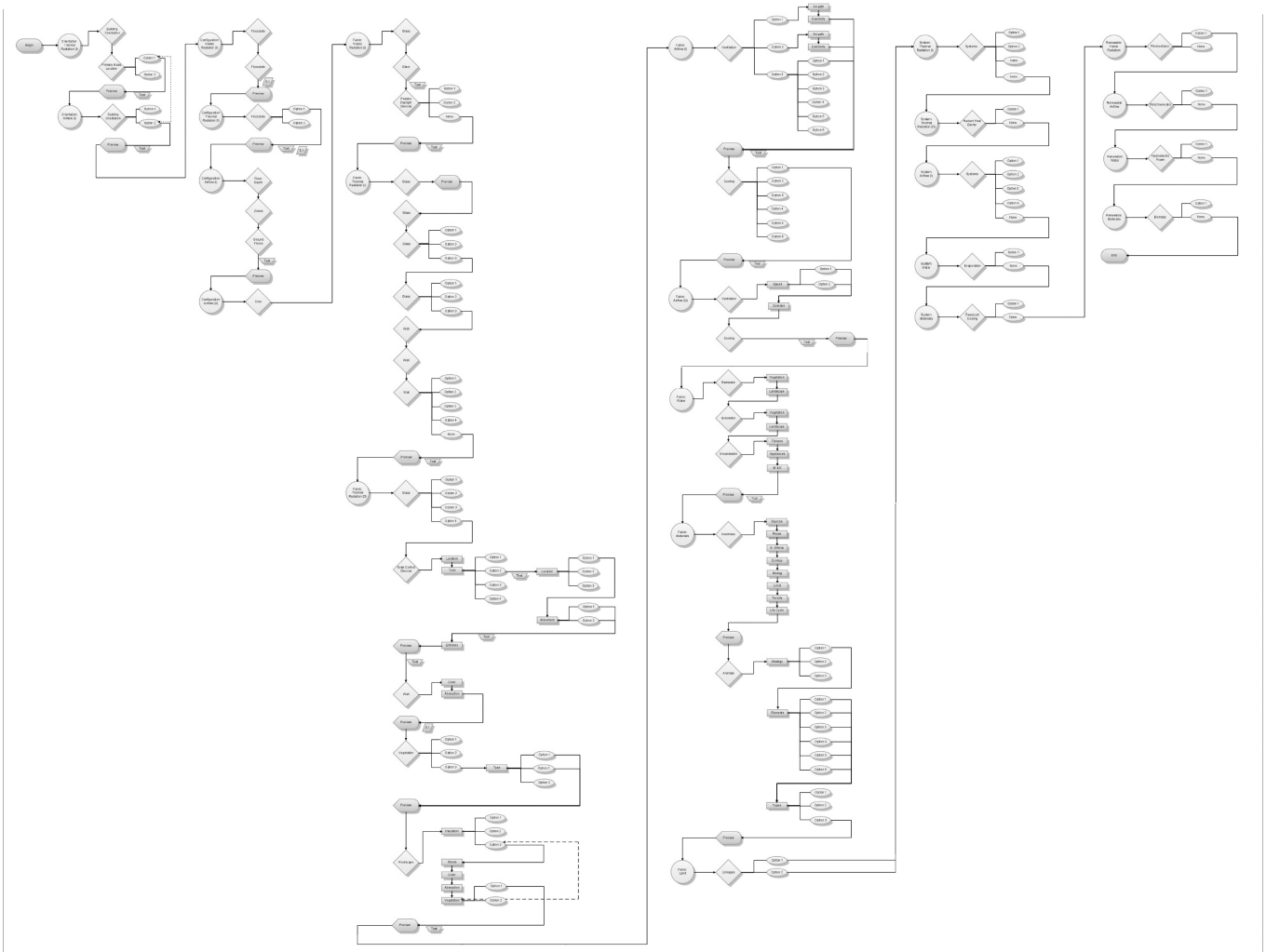
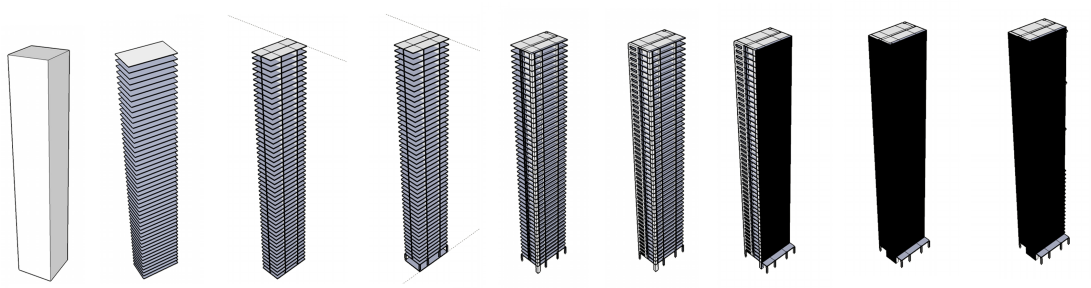
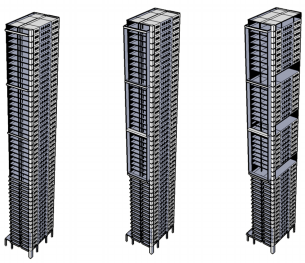


Figure 10.7: Flowchart of design decisions (details available in Appendix A)



SW Facade development



NE Facade development

Figure 4.61: Evolution of building form

4.7 Stage 1 framework and tower analysis

The final tower, although not designed to have a varied aesthetic, nevertheless demonstrates that the proposed framework leads to a building whose facades respond to, and therefore differ on, each orientation. Although its aesthetic and a comparison with Yeang and other designers are interesting, they are not a main subject of this research and are so discussed in Appendix A. What is more crucial is the result's affect on the framework, which is considered here.

As referred to before, alongside the framework chart, notes were taken to highlight any problems encountered in the design process. These are also available in Appendix A, but their findings are summarized here. There were two aspects considered as they related to the thesis objectives, namely the finding of suitable design principles and their organizations for use in the schematic design stage.

Relating to the first objective, it was determined that the principles were most useful if formatted as simplified and illustrated 'rules of thumb' based on the work of Yeang. The earlier literature review and case studies had already determined that the range of principles discussed in his texts was beyond that applied in practice, and so in this sense the use of his text as a starting point was also justified. Furthermore, the earliest applications to practice and teaching also justified the formatting of the principles as a series of steps, further recommending that they be grouped into solar and airflow aspects and gradually applied.

The Birmingham tower test, however, did point out some problems. A main concern was the inclusion of some principles under the categorization of environmental sustainability, as exemplified by glare. Initially glare control was included as a step as this had been the case in Yeang's texts. However, further consideration of the term, and problems categorizing it within the framework, determined that glare was more related to occupant comfort than environmental sustainability. Like other safety and comfort elements, although it forms an important design component to be considered, it was omitted from this framework as it did not relate to its specific purpose. In this way the logic behind the decision was similar to the one regarding the exclusion of structure.

A second type of problem that emerged during the tower design process was a lack of sufficient information in Yeang's texts on some principles. Whereas he was shown

to have included the vast majority of environmental design strategies available, his texts at times necessarily lacked the depth of detail required to apply them directly during schematic design. Solar shading exemplifies this, as Yeang's description does not specify dimensions or angles for particular elements. Other sources needed to be consulted, and here a useful source for this strategy *Sun, Wind and Light* (2001) as it provided additional data and charts that would make Yeang's principles applicable: it provided guidelines for the length, depth and angle of shading devices. Such resources were therefore addition to the principles, and their ease of inclusion suggested that other data could be added without difficulty.

In terms of the second objective, as much time had already been devoted to the development of the framework organization, including through earlier attempts at a Birmingham tower, at the end of Stage 1 the overall structure did not cause any major problems in its application. The organization of steps into a table, known as the framework matrix, based on the interactions between climate influence and design stage was found to be generally successful in the schematic design process, and the steps sequence, which helped to organize the various principles sharing an interaction and which was further developed during the Birmingham tower test, helped to ensure that the steps were logically and inclusively applied. Likewise, only a minor restructuring of the sequence was required as a result of the test.

The various types of changes discussed in this section were therefore applied in a second trial, that of Stage 2. The matrix itself proved sufficient as a whole, although some problems in prioritizing and structuring principles relating to natural resources were noted. As the framework had performed well overall, the second stage would also consider the framework's response to specific climatic and environmental conditions, and place it in the wider context of environmental rating systems.

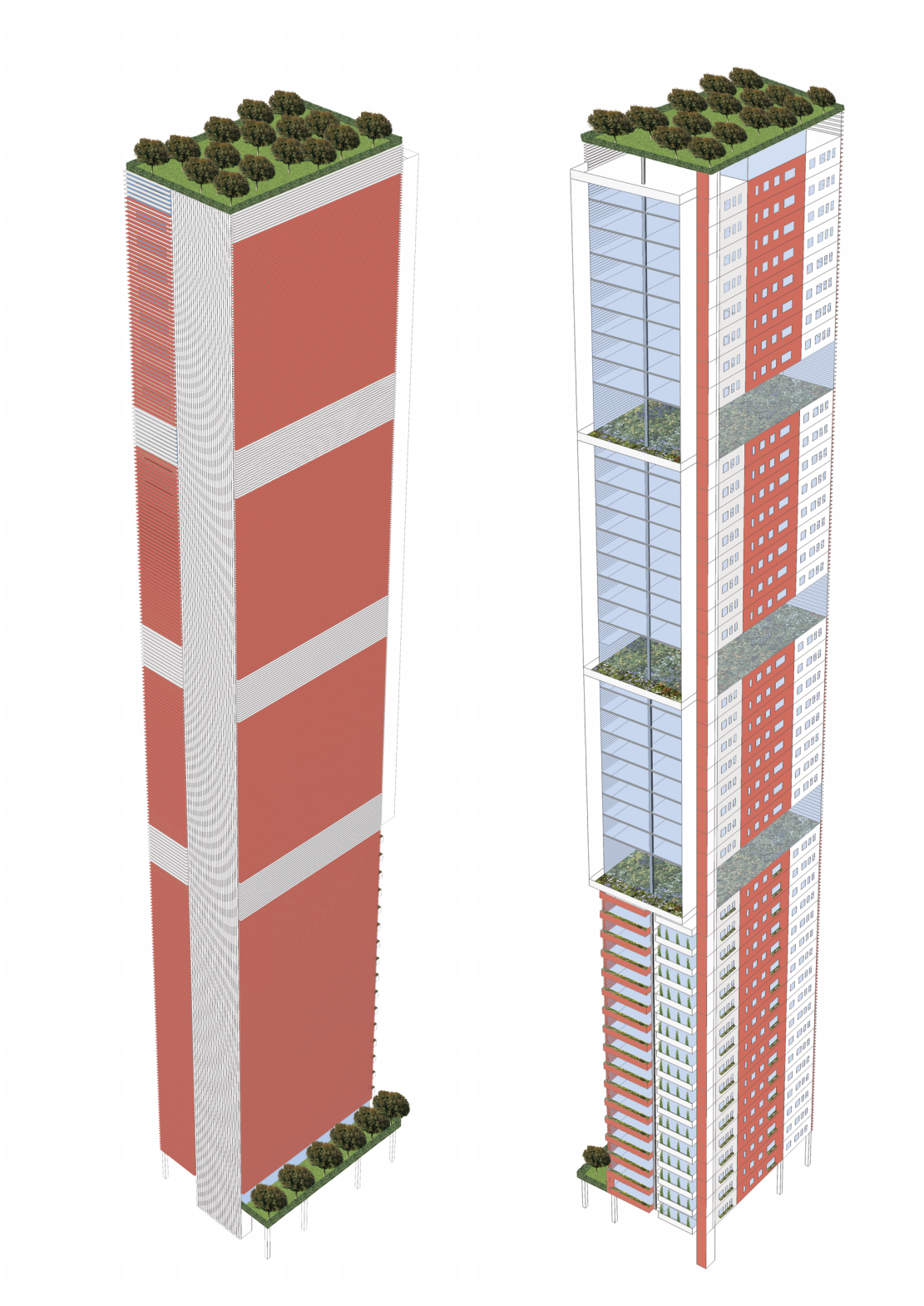


Figure 4.62: Birmingham tower final illustration

5 STAGE 2: NEW YORK AND LONDON TEST TOWERS

As the last chapter considered the first stage of the framework's development, this one will consider the ways in which it was applied and assessed in Stage 2. It will involve two further test towers, in London and New York which will relate it to prominent environmental assessments and determine the effects of local climate and urban conditions the design process and results. The environmental assessments relate to the first objective of the framework, that of finding suitable principles for the building and climate type. The variations in climate and urban conditions relate to that objective and the second one, that of organizing the principles so that they best inform architects in the schematic design stage. The results of this trial will thereafter help to further develop the choice and organization of the principles.

This chapter will begin with a restatement of the choice of cities for these test towers, as well as the their program. Thereafter, the process and results of those trials will be examined. As part of this consideration, a comparison with the LEED and Code for Sustainable Homes rating systems will be provided. It should be emphasized here that this stage was completed at the start of 2009, so the text used to inform and evaluate it is accurate only as of that period.

5.1 Test tower city choice

The case studies chapter established that London and New York had a significant number of tall buildings when compared to most other European and North American cities. It could be argued that they act as representative cities in their respective continents in terms of both number and variety of tower proposals. Despite this similarity of interest, however, the cities were also chosen for their different approaches to urban planning and local climate. Whereas London is a generally low- to mid-rise city, New York has a historical dependence on tall buildings. In London, tall buildings therefore either stand alone or form clusters contrasting with the overall fabric of the city, while in New York the type is integral to its character. As discussed in the case study comparison, London is located in a milder 'Marine' type of the temperate climate, while New York's 'Humid Continental' climate has greater seasonal temperature extremes. Furthermore, whereas London's airstream comes primarily from the southwest direction, New York's main wind direction from the south is often negated seasonally by varying directions. A visual description of these differences is depicted in Figure 5.1. The climatic and urban differences of the cities

will be discussed in more detail throughout this chapter, but here their main characteristics are sufficient in justifying their use as examples of climatic variations available in the cool temperate climate. It should be noted, however, as with many of the images in this chapter, the figures were initially designed at a much larger scale as posters for presentation; a closer view is available in the digital format of this thesis.

5.2 Building program

The building program is the same as that of the Birmingham test tower, with one large exception. The building footprint is again dimensioned as 25 m by 25 m and the height limited to 150 m at roof level. The building has a residential focus, so although some variety of use is expected, the design will only concentrate on its overall form and apartment layout. The main exception, therefore, is that a preference for vegetation as a design element is specified. The purpose of this is direction is to observe the effects of a certain design outlook, attributed to Yeang, on the resulting tower. In turn, this allows an analysis of the extent to which the appearance of his buildings is determined by bioclimatic strategies rather than a general preference for vegetated space.

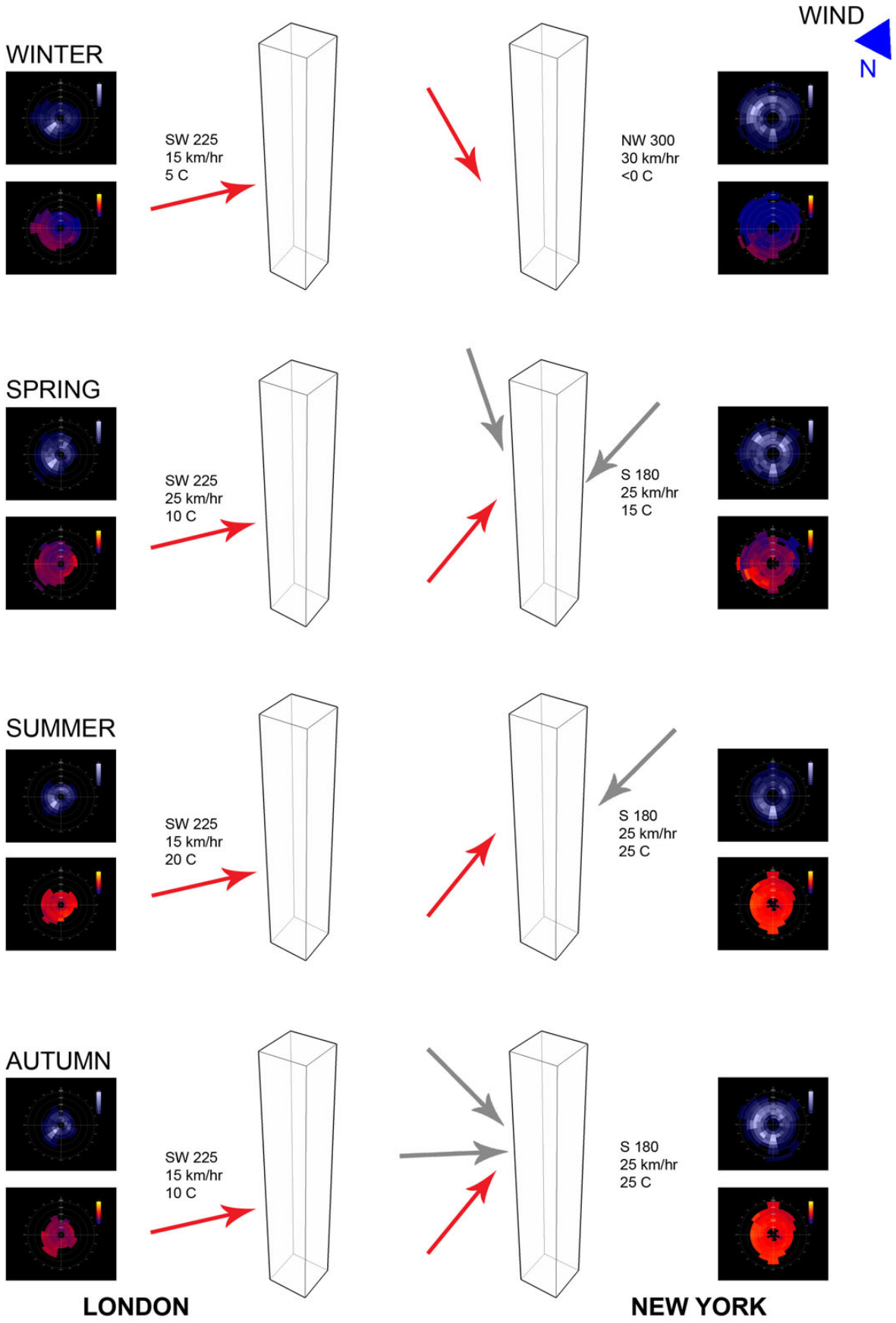


Figure 5.1: Climatic comparison between London and New York (diagrams based on data from Ecotect)

5.3 London: context

This section will aim to provide contextual information for the London test tower. A brief statement on the city's general character will be followed by a discussion on its relationship with the tall building. Examples of such buildings are discussed amongst the case studies in Chapter 4, so will not be repeated in detail here.



Figure 5.2: Urban density map of London
(Burdett and Sudjic, 2007:140)

Despite its considerable population of 7.5 million, London generally continues to remain a low- to medium-rise city. Its average density is a low 4,795 people per square kilometer, which is achieved by its relatively large urban area of 1,600 km^2, when compared to other world cities (Burdett and Sudjic, 2007: 140). Described as the 'capital of suburbia' in an essay by Ricky Burdett, London is essentially a collection of urban villages located around public-transport hubs. These villages, punctuated by large parks, organically radiate from the commercial center. Therefore, the most dense part of the city is concentrated just outside a central core, as seen in Figure 5.2. Although the River Thames splits this metropolitan area, the flat character of the landscape allows urban sprawl to occur relatively equally in all directions.

The city's central core is of key concern here. Although there are exceptions, as is the case with Renzo Piano's London Bridge tower, most contemporary tall buildings are located in these small areas, described well in character by Burdett (Burdett and Sudjic, 2007: 147):

> Pockets of taller buildings (not really skyscrapers by international standards) mark the city's old and new financial centres, clustering around the City of London – with Norman Foster's distinctive curved 'Gherkin' at the epicenter of a new generation of highly sculpted vertical monuments – and Canary Wharf, marked by an ever-growing series of undistinguished corporate boxes.

Unlike in New York, these clusters, constructed in the last few decades, contrast with their mid-rise surroundings, which tend to vary in terms of periods and styles under which they were constructed. They were particularly encouraged by Ken Livingstone,

the city's former mayor, in what is described, by Deyan Sudjic, as his 'enthusiasm for creating Europe's first skyline to aspire the model of Shanghai rather than Manhattan' (Burdett and Sudjic, 2007: 142). The towers are of a commercial nature, signifying London's presence as the world's leading financial center.

Residential tall buildings, on the other hand, are generally stand-alone objects, although some residential clusters are emerging in areas such as Leamouth, where SOM had proposed a number of mid-rise towers no more than 85 m high. As in Birmingham, London planners historically had a dislike of towers as a reaction to 1960s and 1970s projects. As mentioned in a previous chapter, many of these buildings had been designed as a result of post-war building programs, which encouraged a repetition of designs and construction practices, at a great speed and often at the cost of quality. Although they initially received positive reviews, after a relatively short period of time incidents relating to problems with building maintenance and social isolation re-branded these towers in a more negative light. Incidents, such as the Ronan Point collapse of 1968, also raised questions on the structural integrity of such towers and added to this disapproving public image. These issues, and a defense of these early tower blocks, were perhaps best described in Miles Glendinning and Stefan Muthesius historical overview, *Tower Block* (1994). Some of their arguments against the denigration of residential high-rises have indeed been proven by a recent trend in the refurbishment of many of these towers, including the previously maligned Trellick Tower.

Newer residential buildings, often designed exclusively for the upper class, nevertheless are subject to standards similar to those required by commercial buildings. Notably, and unlike New York, there is much emphasis on the buildings' relationships to city views in general and the view of St Paul's Cathedral in particular. In June 2003, and with additions in later years, English Heritage and the Commission for Architecture and the Built Environment (CABE) published *Guidance on Tall Buildings* (2007), a consultation document that details these specific requirements. Alongside general concerns for architectural quality, the guidance often mentions appropriate tower locations as they relate to the urban fabric and views from and towards them. More specific guidance included a report, commissioned by the Greater London Authority, called *London's Skyline, Views and High Buildings* (DEGW, 2002). Supportive of tall buildings in general, it argued that the City needed a more comprehensive strategy for their location and that this should more clearly be based on the protection of views. Some of these protected views can be seen in

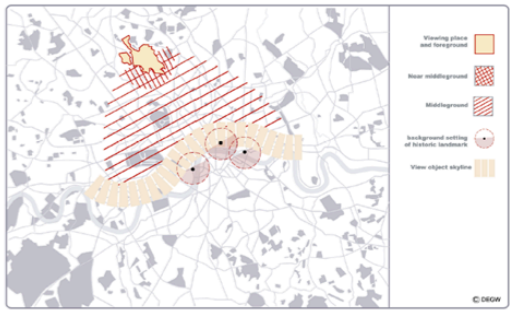
Figure 5.3, as well as a larger site analysis that includes Canary Wharf and the City. As the proposed tower falls somewhat outside these view corridors, it is assumed that its 150 m height does not pose any particular problems in this regard.



London's Strategic View Corrdors



Monument views over 360 degrees and extents of St Paul's heights



Components of the View Experience

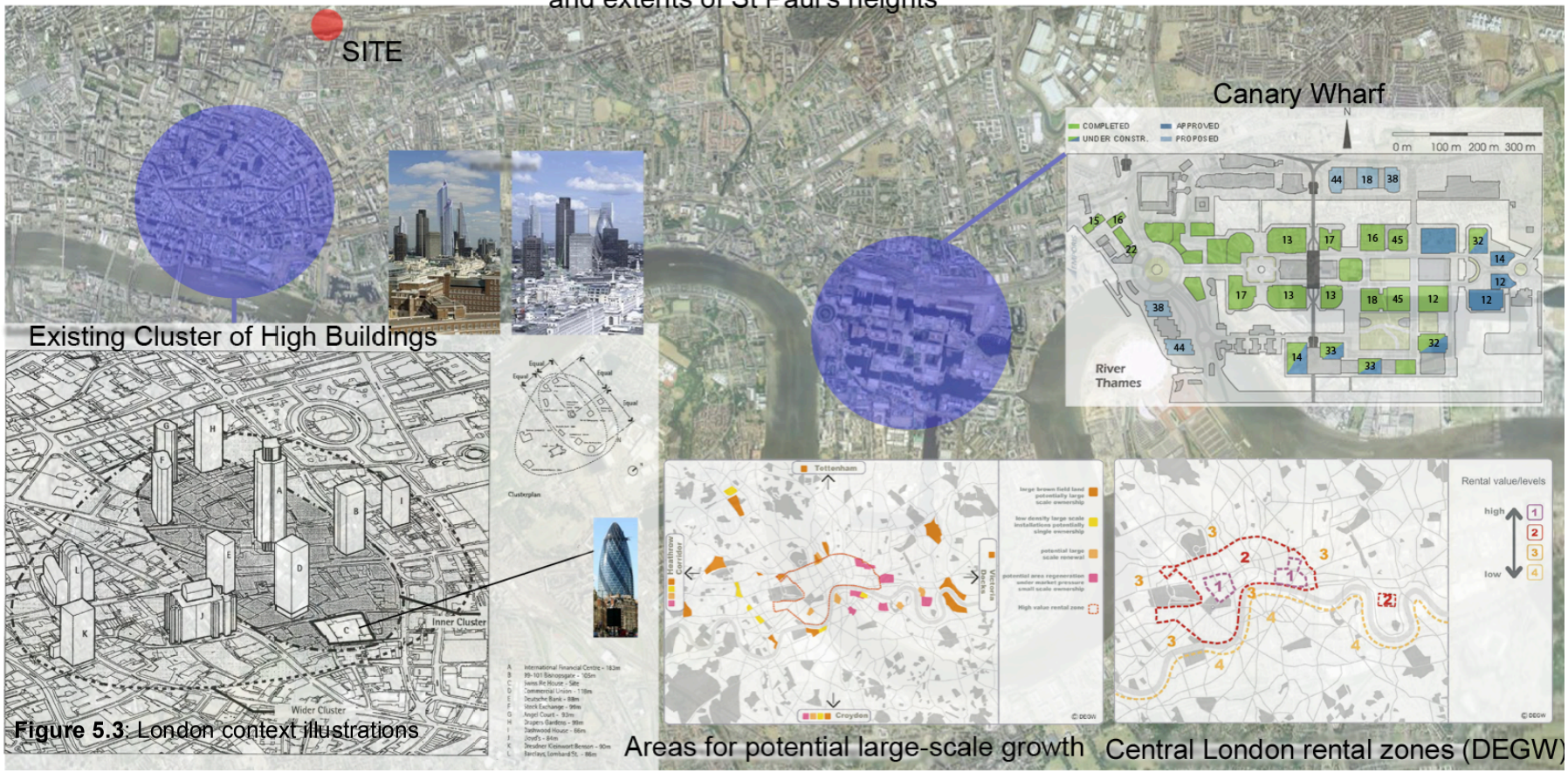


Figure 5.3: London context illustrations

5.4 London: test tower site

The London site, as seen in Figure 5.4, sits slightly northeast of the City of London, within walking distance and with a view of the existing towers. Although it is of an irregular shape, it borders can generally be named as follows:

Site boundaries

N Bethnal Green Road (E) – Scalter Street

S Quaker Street (train tracks come before)

E Brick Lane

W Shoreditch High Street

1 km^2 radius boundaries (major streets)

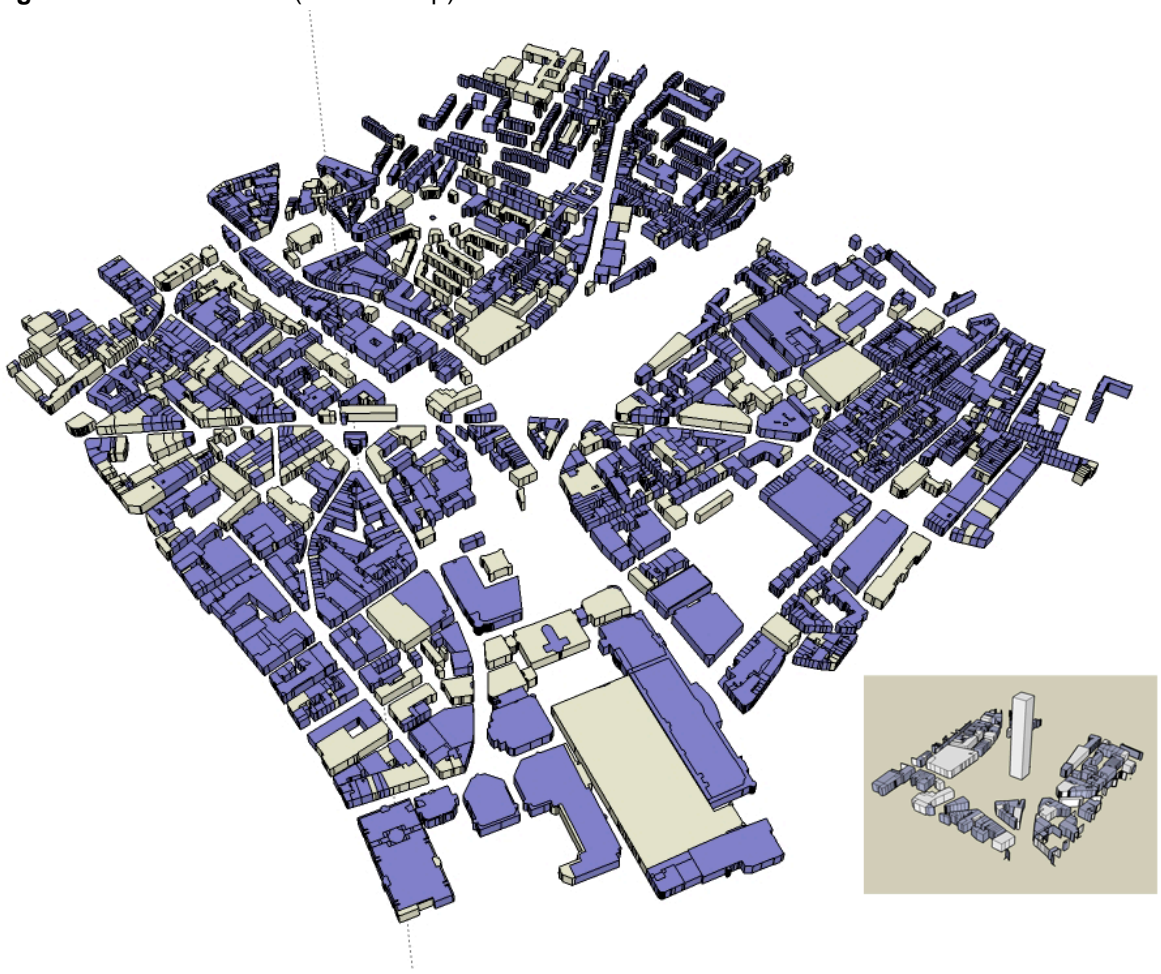
N Old Street (E) – Gosset Street

S Whitechapel High Street (E) – Whitechapel Road

E Vallance Road

W City Road

Figure 5.4: London site (in SketchUp)



Known as the Bishopsgate Goods Yard, the site is a large brownfield site that featured in the 'Living in the City' international competition in 1999. Organized by the Architecture Foundation, the brief followed from the 'idea that high density mixed tenure housing is the most effective way to revitalize our cities, being environmentally, socially and economically positive' (Weinstock and Woodgate, 2000: 8). Therefore, it is unsurprising that, given the site's central location and access to public transportation, many of the proposals include tall buildings. Skylab, shown in Figure 5.5, includes residential buildings up to seventeen stories high and green features such as external shades and sky gardens (2000: 32-35). Renzo Piano's 'A Home in the City' proposal, shown in Figure 5.6, aims to crate a 'vision of lightness and transparency' through the vertical placement of homes within a skeletal tower (2000: 68-71). Yeang, as mentioned in an earlier chapter, also has a proposal for this site, although the one included in the catalogue is of a slightly different character than the case study included in the previous chapter. The tower, as shown in Figure 5.7, is nevertheless characteristic of much of his recent work, focusing on vegetation, water collection, waste recycling systems and alternative forms of energy generation (2000: 52-55).

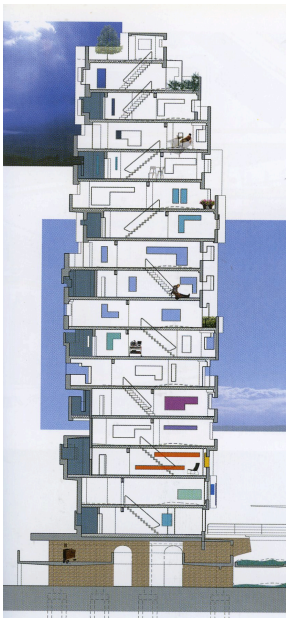


Figure 5.5: 'Skylab' (2000: 69)

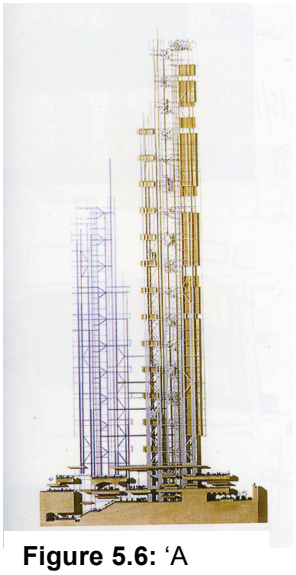


Figure 5.6: 'A Home in the City' (2000: 69)

As the competition already established it as a potential location for high-rise living, the site was chosen for the purpose of this study. Furthermore, as it is isolated from the building cluster and not significantly overshadowed by any surrounding buildings, it provides a considerable contrast to the dense urban surroundings of the New York test tower. This difference would allow for a helpful comparison on the effect of urban context on the buildings' forms.

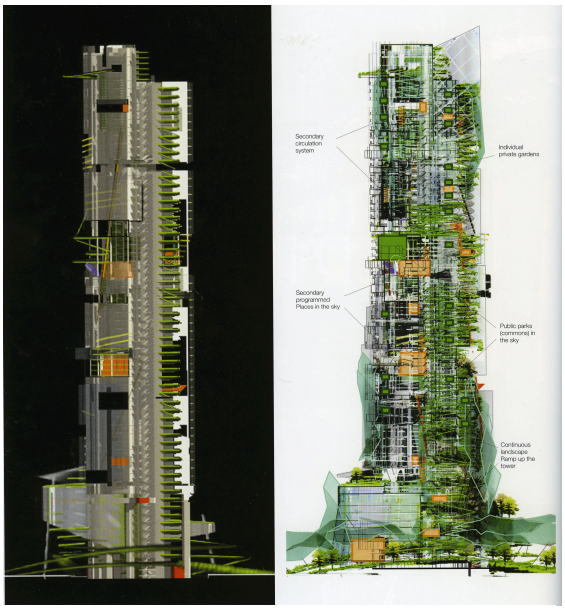


Figure 5.7: Yeang's proposal (2000: 52)

The local climate was evaluated, using data from Ecotect and shown in Figure 5.8. As the site's latitude is 51.4°N, the winter sun is at a relatively low angle and so any shading provided could be designed to be effective solely during brief summer periods. Solar radiation data also suggested that the quality of daylight in this climate is somewhat poor. The wind direction was relatively stable throughout the year, arriving from the southwest, although changes could be expected occasionally. As the main concern in this climate for most of the year is preventing heat loss, this singular wind direction meant that the tower would block out undesirable excessive airflow perhaps at the expense of natural cooling through ventilation.

5.5 London: test tower steps

Having examined urban and climatic conditions, this section will now aim to present the sequential application of design steps generated by the framework as they relate to the London tower. Although sufficiently extensive for its purpose, this section does not intended to highlight each detail regarding every step. Appendix B will provide additional commentary on individual steps. Instead, it will focus on the tower's evolution as it relates to sustainability and architectural form. This is represented in an annotated table format, referred to as Figure 5.9. The process has a total of 93 steps, which are based on the previous design principles and organized according to the framework introduced in the last chapter. The principles are therefore listed, as are their architectural implications on the particular building. For further reference, the correlating framework steps and options are given. The views of the building in the images are from the southwest direction unless specified otherwise.

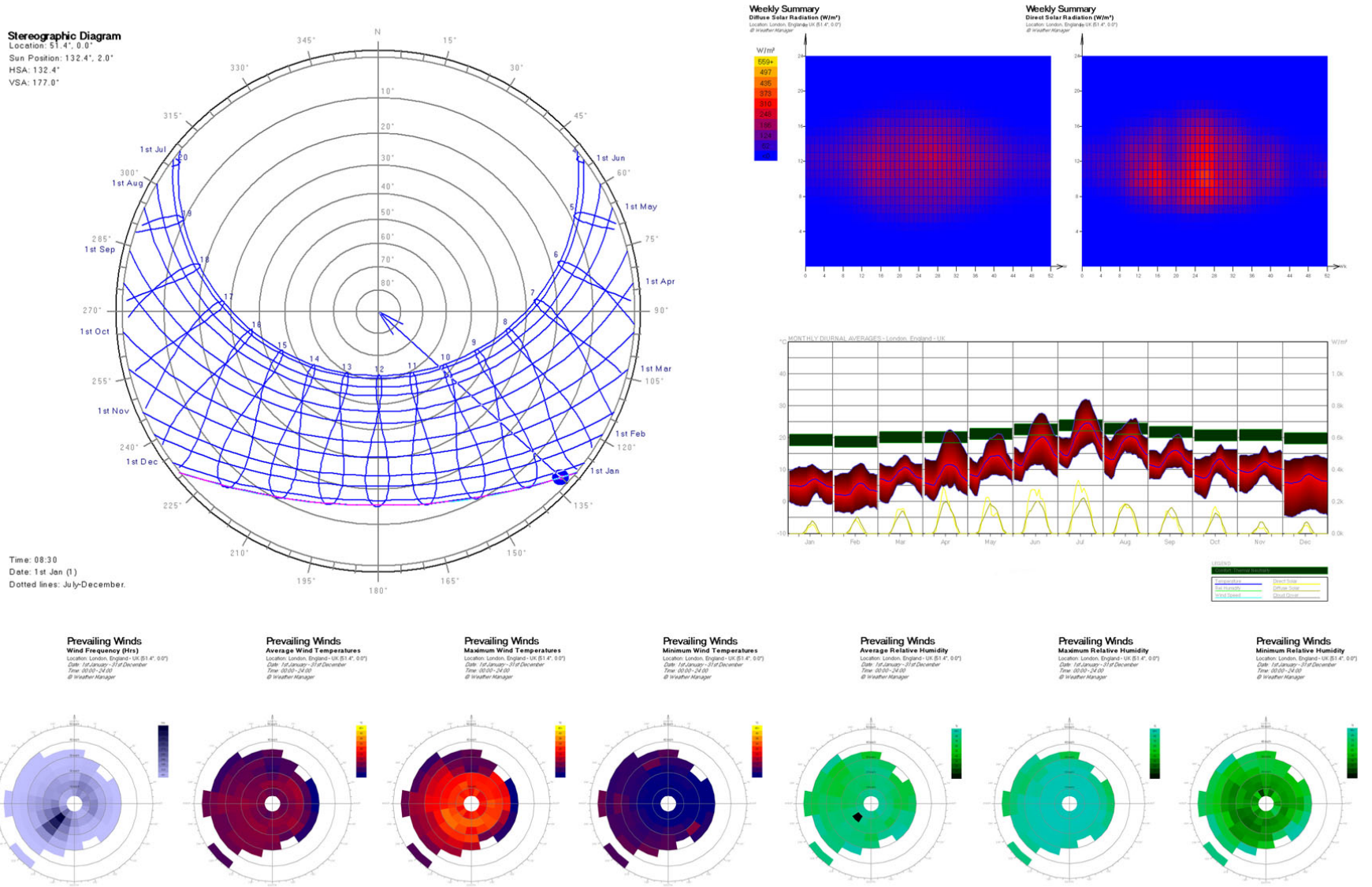
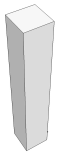
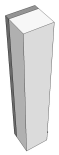
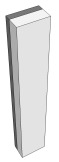
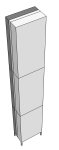
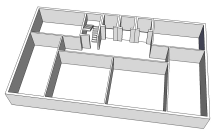


Figure 5.8: London climatic site analysis (in Ecotect)

Figure 5.9: London tower steps

Step	Design Principle	Architecture	Image	Fwk
1	Starting point; no axis	Building as square		-
2	Core to reduce heat loss	Core elements (stairs, elevators) to be placed on north		2 (1)
4	Floorplate optimized for daylighting	Floorplate narrowed from 25 m to 15 m		7
5	Room depths of 7.5 m max for daylighting	Apartment depths limited to 7.5 m		8
8	Vertical zoning for wind	Future effect on ventilation devices		12
9	Naturally ventilated ground space in summer	Ground floor open, with option of devices for control of wind and rain		12
		Typical floorplan		-
13	Horizontal light pipe for additional of daylight	Little effect on architecture		26 (1)
15-18	Clear glass for daylighting, minimized on north to reduce heat loss	Differentiation between opaque north façade and transparent south façade; skygardens (as decided in program) visible due to fabric choice		5, 24
20	Highly insulated walls for avoid excessive heat loss in winter and solar gain in summer	North facade altered in depth in relation to building material		23
26-29	Solar control devices on south, east and west facades; fixed in east and west living rooms and adjustable in other spaces; mid-pane	Fixed shading acts as covered balconies on south; louvers provide texture on facades		17 (1,2)

30	Light-colored walls to reflect sunlight and reduce peak cooling	White exterior walls		25
31	Light concrete to reflect radiation and release absorbed heat as thermal radiation; link with materials for choice	Wall texture		16, 25
32	Vegetation on east and west facades to act as shading	Vegetated east and west facades		16
33-34	Vegetated roof garden to reduce undesired heat gain	Vegetated roof		18
35	Single-sided ventilation at two levels in living rooms for ventilation, cooling and night cooling options; one level in other locations for ventilation and cooling only	An inlet above 2 m and an inlet below 2 m in living rooms; inlet below 2 meters in other locations		18
38	Openable windows for natural ventilation	Openable windows		27, 28, 29
45	Skycourts to ventilate inner parts of building, including corridors and protect 'hot' east and west sides of building	Skycourts on east and west façade of building		-
57-58	Rainwater recycling for vegetation and landscape	Provision of rainwater catchment scallops and storage		-
59-60	Greywater recycling for vegetation and landscape	Specification of greywater recycling systems; little architectural influence		-
61-63	Conservation of groundwater	Specification of groundwater recycling systems; little architectural influence		-
64	Integration as vegetation strategy to encourage species interaction and migration, creating more diverse and stable ecosystems	Addition of vegetation to encourage visual integration of building and biomass		18
66	Vegetation on skycourts for reasons above	Further 'greening' of facade		18
67	Addition of plants to balconies for reasons above	Further 'greening' of facade		18
69	Vegetated skygardens for reasons above and to increase interior biomass	Vegetated skygardens		18

71	Trees to decrease ambient air temperature, provide fresh air and create shade	Trees in skygardens		18
72	Plants for similar reasons as above	Plants in skygardens and balconies		18
74	Grass to reduce solar heat gain and increase biomass	Grass as floor and roof covering		18
75	Specification of recycled materials	Visual quality of building material affected		-
75	Specification of the reuse of materials	Little effect on architecture		-
76	Specification of low embodied energy materials	Visual quality of building material affected		-
77	Specification of biodegradeable materials	Visual quality of building material affected		-
78	Specification of local sourcing of materials	Little effect on architecture		-
79	Specification of low-toxicity materials	Little effect on architecture		-
80	Specification for positive consideration of material lifecycle	Little effect on architecture		-
81	Specification of low-energy lighting	Little effect on architecture		-
89	Photovoltaics on south façade to provide additional energy	Photovoltaics integrated into south balcony as fence, altering fabric		-
90	Wind turbines on top of building to provide additional turbines	Wind turbines on top of building, adding an additional feature / height		-

5.6 London test tower flowchart

Before describing the resulting building, a method in addition to a table for displaying the progressive development of the tower was considered. To fully consider the decisions available to the user, a flowchart was created. Such a format would also allow for a visual representation in which the interactions between the environment and building elements occured. Unfortunately, the limitations of the thesis format again prevent a more legible view, and so the description here is brief. Furthermore, this flowchart, like the one presented in the previous chapter, was abandoned in the final version of the framework. Nonetheless, as it illustrates the grouping of the principles at second stage of framework development, it is included here.

The flowchart, depicted in Figure 5.10, consisted of boxes representing principles, connected to each other in a sequential manner. At certain points, such as shading devices, there is more than one option and so the architect can chose one path, or more for varying orientations, but always necessarily converging where an interaction within the framework or a secondary strategy related to the same interaction takes place. Thus, for example, a decision of fixed external overhang instead of mid-pane louvers as a solar shading device would nevertheless lead to the next strategy related to that interaction, that of external wall color. In case of the London test tower, the decisions taken are shown as red box outlines.

The flowchart is in effect a more detailed account of the steps sequence in that it takes into consideration individual design principles. As it stands in Figure 5.8, it is difficult to decipher exactly how the two relate, but when color-coded to reflect the interactions it represents, as in Figure 5.11, this becomes clearer. Therefore, whereas the step sequence in the framework is implied, in the flowchart it becomes integral.

It reveals that out of the 115 choices or design principles, about half, 51, were applied. As an intention at this stage was to apply as many principles as possible, this result suggests that the framework self-regulates against the application of redundant steps, while allowing for a variety of options to yield varied results. Here, the first option was chosen, but it could be assumed that an adoption of a second or third option would have resulted in a very different building. Furthermore, in the color-coded flowchart some categories were more inclusive of a greater variety of design principles than others. Those related to exhaustible resources were especially

inclusive, and this can be interpreted as partly due to a lack of options and partly due to their independence from a specific stage. This last point would later affect the narrowing focus of the framework back to bioclimatic design.

To put the Stage 2 framework into context then, it is composed of three components. The first is the table format of Figure 5.9 of design steps. These describe the choices taken which are individual to each test tower, and so vary in application and number. The second is the steps sequence, depicted as a flowchart, which demonstrates the relationships between the design decisions, including design options. Unlike the table in Figure 5.9, this is a universal format as it depicts the total amount of design options available. Only the outlining of certain decisions, or boxes, signifies a specific route of decisions. The third, the framework matrix, also universal, differs from the flowchart as a sequence is implied but not specified. Consideration of all three aspects is meant to clarify the application of the design process.

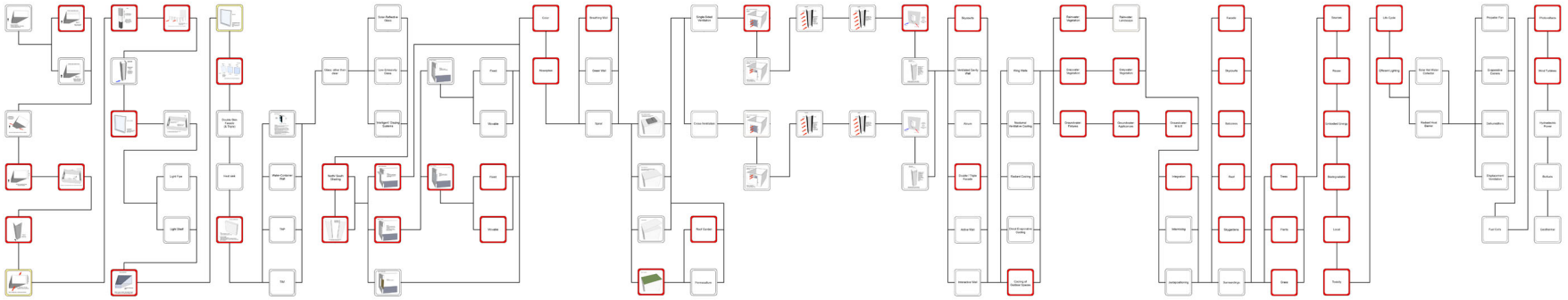


Figure 5.10: London flowchart

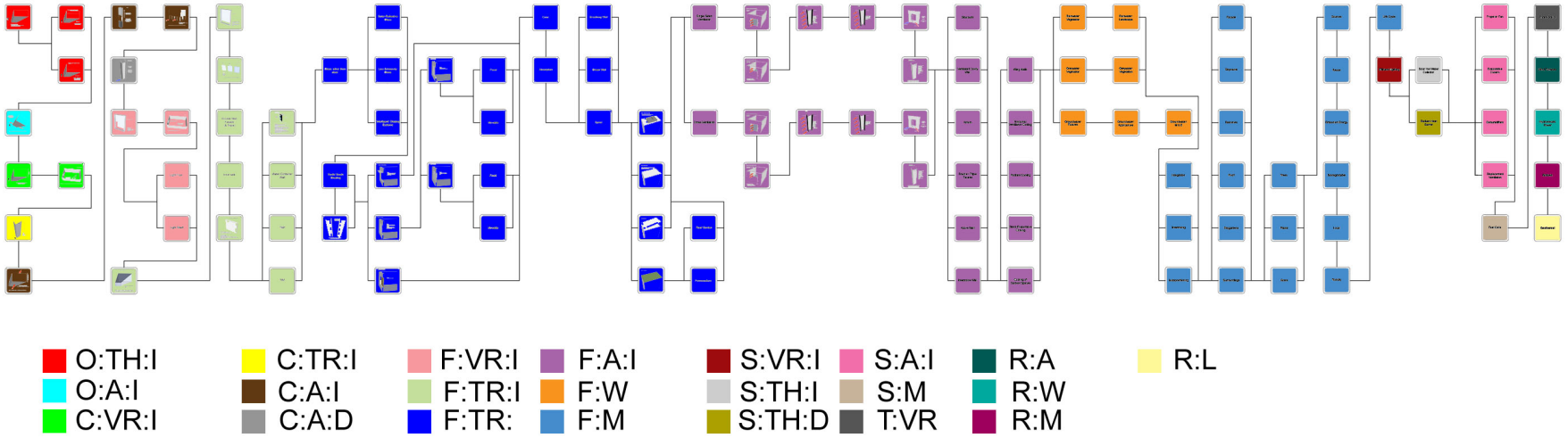


Figure 5.11: Flowchart/framework relation

5.7 Resulting London test tower

The resulting tower, seen in Figure 5.12 and its typical floorplan in 5.13, will be evaluated later; here a brief description is sufficient. Like the Birmingham test tower, it is of a segmented nature, following the same ratio and configuration of garden space, and of a similar rectangular shape. The four facades are clearly distinct as well, in terms of both fenestration and shading elements. What is certain, though, is that the emphasis on strategies involving vegetation creates a much 'greener' tower visually, although not to the same extent as Yeang's projects. This result suggests that Yeang's predominant 'vegetated' aesthetic may be more based on a design preference than on a specific environmental advantage; neither he, nor the literature in this thesis, are able to verify the superiority of vegetation in terms of building performance. A later section will add to this this argument on vegetation, but in a different climatic and urban setting.

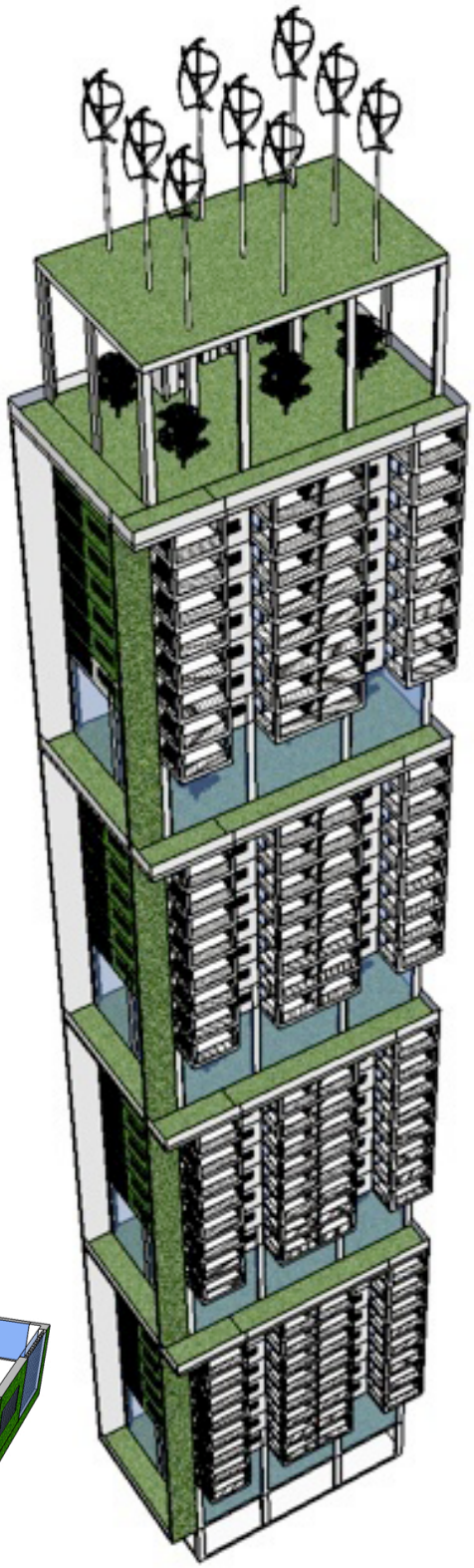


Figure 5.12: Birmingham test tower south facade

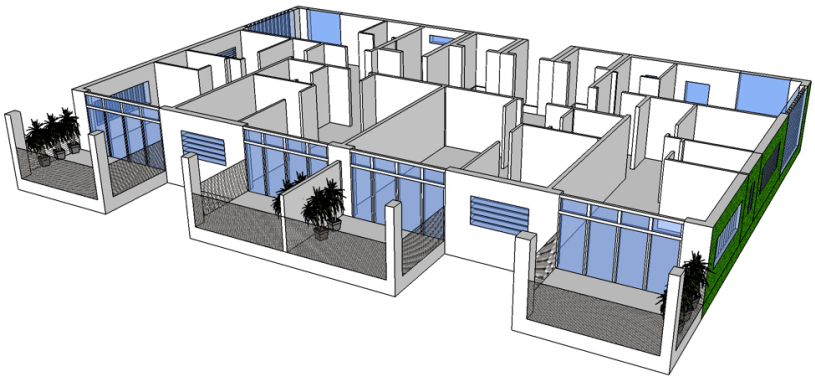


Figure 5.13: Typical residential floor

5.8 New York: context

As in a Section 5.3, this part of the chapter will provide some contextual information for the test tower. However, as the tall buildings of New York were discussed to a greater extent in earlier chapters, it will be more concise than the London section. An urban and climatic analysis of the site will follow.

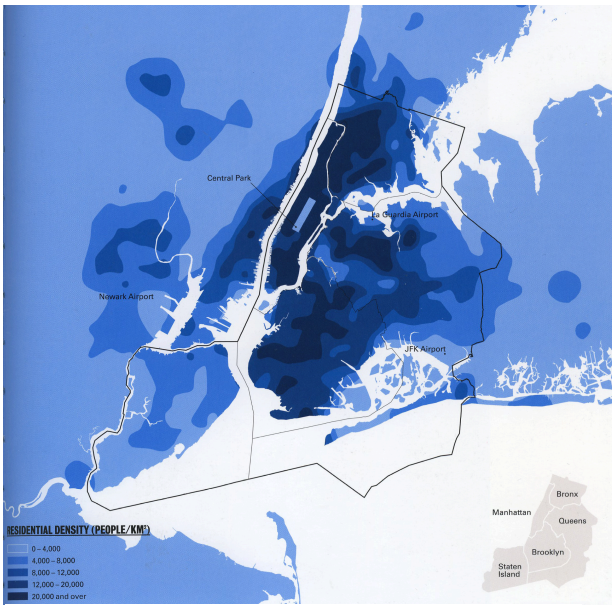


Figure 5.14: Urban density map of New York City (Burdett and Sudjic, 2007:78)

New York City is home to 8 million people, a figure that rises to 21 million when the Metropolitan region is included. Hence, the population of its central area is comparable to that of Greater London, which is only smaller by half a million. However, when compared in terms of density, the contrast could hardly be larger. Whereas London's density is 4,795 people/km^2, New York's is approximately five times that number at 24,000 people/km^2 (Burdett and Sudjic, 2007: 76). Figure 5.14 illustrates the form of this density. The two cities also have differing approaches to the key subject of this study, the tall building, alongside major differences in their approaches to political and social issues. Whereas London remains somewhat hesitant to the tower's presence, its continued advance defines New York.

An interesting account of the growth of this skyscraper city is expressed in *Delirious New York* by Rem Koolhaas (1978). He celebrates the spontaneity and chaos of the city, proclaiming 'Manhattan is a counter-Paris, and anti-London' (1978: 20). All things here are based on economy and megalomania, as the limited city blocks push architects and clients to promote their ideologies vertically. Despite the euphoria this image represents, there is a more negative result that has become more visible in the decades following the book's publication. Koolhaas indeed alludes to this problem (1978: 20):

> In spite of its apparent neutrality, it implies an intellectual program for the island: in its indifference to topography, to what exists, it claims the superiority of mental construction over reality…The plotting of its streets and blocks announces that the subjugation, if not obliteration, of nature is its true ambition.

He argues that even the city's Central Park, proposed in the mid-nineteenth century due to the its rapid growth, is manipulated for this aim, despite its attempts to look natural (1978: 23). The environmental problems facing New York, alongside the rest of the planet, expose the lack of farsightedness in continuing with such an approach. Unfortunately, this 'obliteration of nature' remains standard as cities hastily grow to serve an increasingly urban population. Yet there have been some promising recent initiatives, such as 'PlanNYC 2030' in general city planning, and some of the more experimental case studies suggest a way forward for towers in particular.

5.9 New York: test tower site

The New York site is located in the lower half of Manhattan, south of the World Trade Center development, and in an area increasingly known for its new residential tall buildings. The site is of a roughly rectangular shape, as shown in Figures 5.15 and 5.16, and named as follows:

<u>Site boundaries</u>

N Rector Street (building exists south)
S Edgar Street (extension of street to be built)
E Greenwich Street
W Washington Street

<u>1 km^2 radius boundaries (major streets)</u>

N Ann Street (crossing at Trinity Place)
S Water Street
E Nassau Street
W South Cove edge

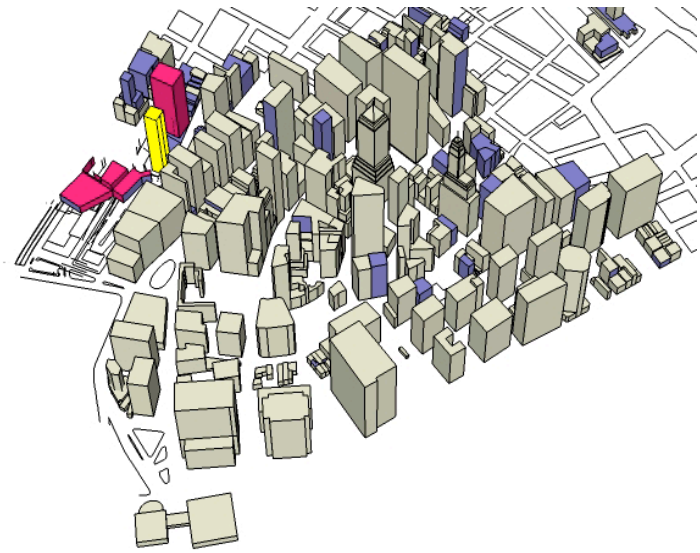


Figure 5.15: New York site model (in SketchUp)



Figure 5.16: New York context illustrations

The site is part of the Greenwich Street South redevelopment area that, despite a concrete proposal in 2005, had not been developed as of early 2009 when this trial commenced. According to the Lower Manhattan Development Corporation and the City of New York, who jointly prepared the document, the site 'has the potential to be brought back as a thriving residential neighborhood that links Tribeca – one of New York's most desirable residential neighborhoods – to Battery Park' (2005). They therefore stipulate that 2.7 million square feet of residential development be created as part of its 'six goals' for the area. There is no specific environmental strategy mentioned, but images produced by the group, such as Figure 5.17 and 5.18, portray a landscaped, pedestrian-oriented area. Site B in the redevelopment plan is adopted for the New York test tower.

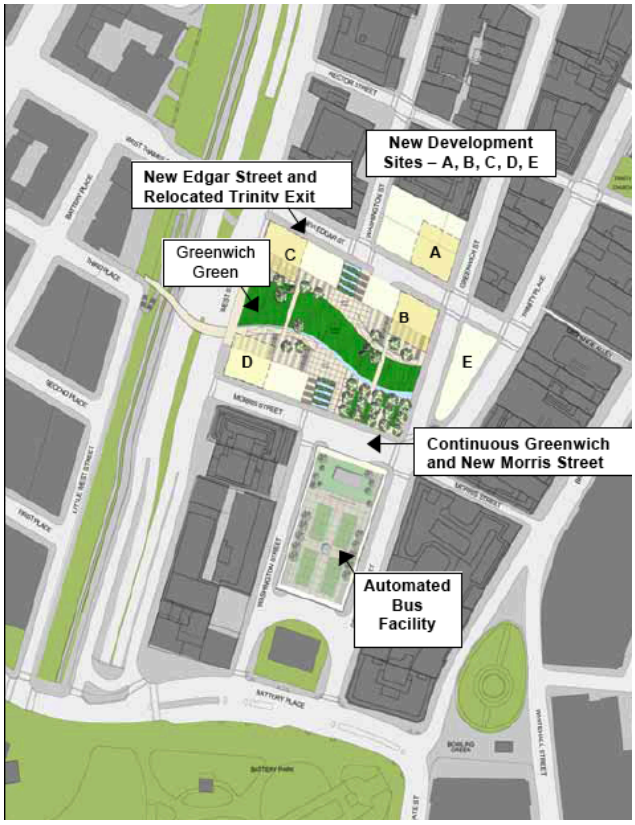


Figure 5.17: Greenwich Street South redevelopment plan (LMDC et al., 2005)



Figure 5.18: Artist's impression of park adjacent to tower (LMDC et al., 2005:1)

As it forms part of a building cluster, this residential site permits an analysis of a common urban context on environmental design to a greater extent than is possible in London. Although it is not significantly overshadowed from the south as is common amongst high-density city sites, there is sufficient overshadowing from surrounding areas to disregard the need for shading devices on the bottom 24 m on the western facade and the bottom 100 m on the eastern. The orientation angle of the site, discussed in the next paragraph, minimizes any negative overshadowing on the building behind. This type of urban analysis is meant to precede environmental strategies and so this influence is marked in the first step model.

Another significant difference with the New York site is the relevance of an urban grid. Whereas London in general and the test tower site in particular are not subject to a grid pattern, with the exception of Canary Wharf, New York follows traditional American standards of urban planning. However, unlike most America cities, the grid in Manhattan is rotated 29 degrees east from the north-south axis. This is a result of the Commissioner's Plan of 1811, which arranged avenues to run along the existing spine of Manhattan, calculated at 29 degrees from true north (Roberts, 2006). As the site is large enough for the building to change orientation, it does not affect it much environmentally but rather questions the common approach of utilizing the site as the basis for a building footprint.

As the site's latitude is 40.7°N, the sun is at a much higher angle than in London. This fact, as well as the less frequent occurrence of cloudy days as compared to London, helps to explain its higher measure of solar radiation. There is however a longer period in the summer where forms of cooling are needed for comfort. Nevertheless, heating again is the primary concern so solar gain is encouraged throughout most of the year. Due to greater seasonal temperature variations, the New York test tower is likely to require solar shading to a larger extent than the London building. Figure 5.19 illustrates the solar influences, as well as those relating to wind.

The site also has greater variations in wind direction. This allows the building to be oriented for natural cooling during the summer as the condition of protection from the cold winds during winter periods can be fulfilled by other means.

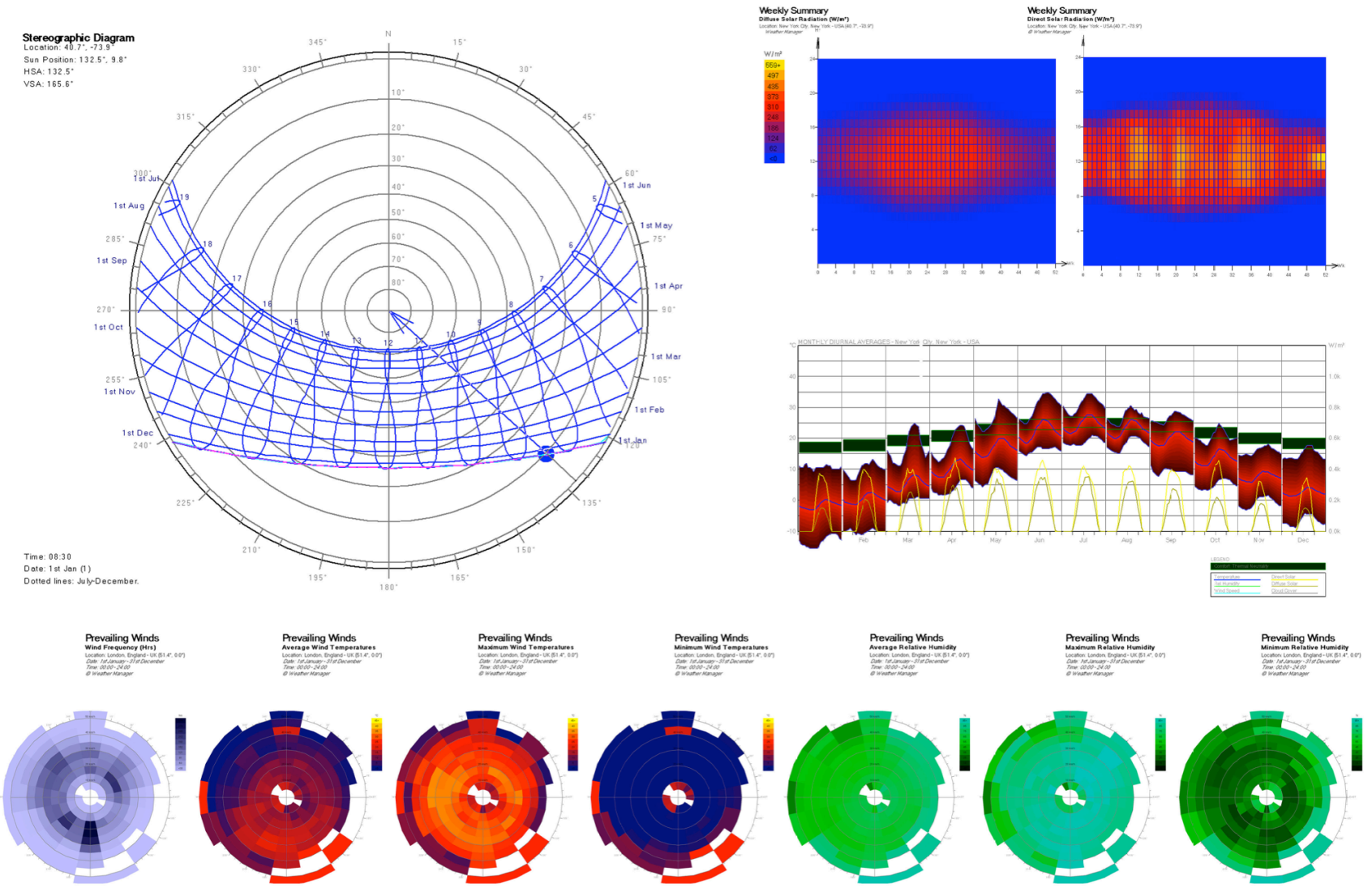
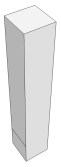
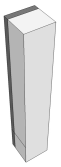
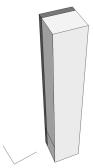
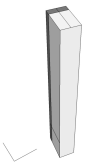
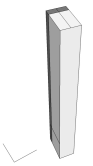
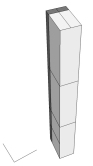
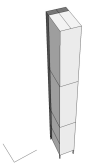


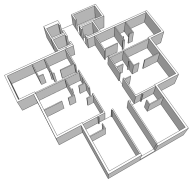
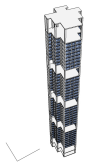
Figure 5.19: New York climatic site analysis (in Ecotect)

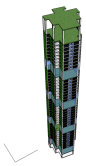
5.10 New York: test tower steps

As the New York test tower was to be designed in the same manner as the London building, the number of steps is the same. The results then should report on the effects of climate and urban planning on the building rather than any additional design strategy of choice. Figure 5.20 will present significant steps in table format. More details can be found in Appendix B.

Figure 5.20: New York tower steps

Step	Sustainability	Architecture	Image	Fwk
1	Starting point; no axis	Building as square		-
2	Core to reduce heat loss	Core elements (stairs, elevators) to be placed on north		2 (1)
3	Orient building to maximize exposure to summer wind; wind to enter building on east and west sides	Building rotated 29 degrees to face south		3
4	Floorplate optimized for daylighting	Floorplate narrowed from 25 m to 15 m		7
5	Room depths of 7.5 m max for daylighting	Apartment depths limited to 7.5 m, 2.5 m corridor		8
8	Vertical zoning for wind	Future effect on ventilation devices		12
9	Naturally ventilated ground space in summer	Ground floor open, with option of devices for control of wind and rain; addition of apartments, corridors		12

		Addition of apartments, corridors		-
		Typical floorplan; all apartments to have access to south		-
15-18	Clear glass for daylighting, minimized on north to reduce heat loss	Differentiation between opaque north façade and transparent south façade; skygardens (as decided in program) visible due to fabric choice		5
20	Highly insulated walls for avoid excessive heat loss in winter and solar gain in summer	North facade altered in depth in relation to building material		23
26-29	Solar control devices on south, east and west facades; combination of fixed, louvers and blinds	Fixed shading acts as covered balconies on south; louvers provide texture on facades		17
30	Light-colored walls to reflect sunlight and reduce peak cooling	White exterior walls		25
31	Light concrete to reflect radiation and release absorbed heat as thermal radiation; link with materials for choice	Wall texture		25
32	Vegetation on east and west facades to act as shading	Vegetated east and west facades		18
33-34	Vegetated roof garden to reduce undesired heat gain	Vegetated roof		18
35	Single-sided ventilation in bedrooms and bathrooms	Inlet below 2 m		29
38	Openable windows for natural ventilation	Openable windows		29
40	Cross-ventilation in living room, particularly during summer	Inlet below 2 m		27
43	Openable windows for natural ventilation	Openable windows		27
53	Nocturnal cooling in corridor	Openable windows in corridor		27, 29
57-58	Rainwater recycling for vegetation and landscape	Provision of rainwater catchment scallops and storage		-
59-60	Greywater recycling for vegetation and landscape	Specification of greywater recycling systems; little		-

		architectural influence		
61-63	Conservation of groundwater	Specification of groundwater recycling systems; little architectural influence		-
64	Integration as vegetation strategy to encourage species interaction and migration, creating more diverse and stable ecosystems	Addition of vegetation to encourage visual integration of building and biomass		18
69	Vegetated skygardens for reasons above and to increase interior biomass	Vegetated skygardens		18
71	Trees to decrease ambient air temperature, provide fresh air and create shade	Trees in skygardens		18
72	Plants for similar reasons as above	Plants in skygardens and balconies		18
74	Grass to reduce solar heat gain and increase biomass	Grass as floor and roof covering		18
75	Specification of recycled materials	Visual quality of building material affected		-
75	Specification of the reuse of materials	Little effect on architecture		-
76	Specification of low embodied energy materials	Visual quality of building material affected		-
77	Specification of biodegradeable materials	Visual quality of building material affected		-
78	Specification of local sourcing of materials	Little effect on architecture		-
79	Specification of low-toxicity materials	Little effect on architecture		-
80	Specification for positive consideration of material lifecycle	Little effect on architecture		-
81	Specification of low-energy lighting	Little effect on architecture		-
89	Photovoltaics on south façade to provide additional energy	Photovoltaics integrated into south balcony as fence, altering fabric		-
90	Wind turbines on top of building to provide additional turbines	Wind turbines on top of building, adding an additional feature / height		-

5.11 New York: test tower flowchart

The flowchart depicted in Figure 5.21 represents the design decisions available and those selected for the New York test tower. It is apparent that the majority of the choices were similar for both test towers. Other than the lack of light pipes and skycourts, there were only two additional steps that contrasted with the London building. Nonetheless, the incorporation of building orientation for maximum summer wind exposure and of cross-ventilation in certain areas had a noticeable effect on the building. Clearly local climate has much influence on the design process, as it can significantly alter a basic design. The two buildings will be further compared in the next section, but it can be seen here that an application of the framework at that stage was able to produce varying buildings without aesthetic influence from the designer.

At this point it would be helpful to display the links involved in the framework flowchart, as illustrated in Figure 5.22 and specified as thick lines. They serve as reminders for the designer to check that the decision taken does not negatively affect any past decisions. The framework was designed to minimize such occurrences, but the fact that the temperate climate requires two sets of climatic reactions for warmer and cooler periods ensures that, at certain points, checks may be necessary. The recommended checks occurred at the last design strategies within an interaction cell; this placement would eventually be challenged by input from students and a more comprehensive literature review.

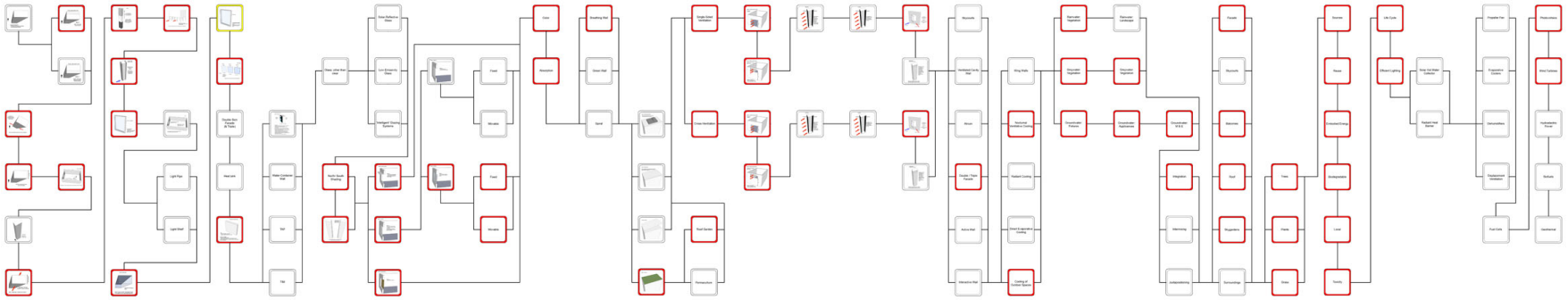


Figure 5.21: New York flowchart

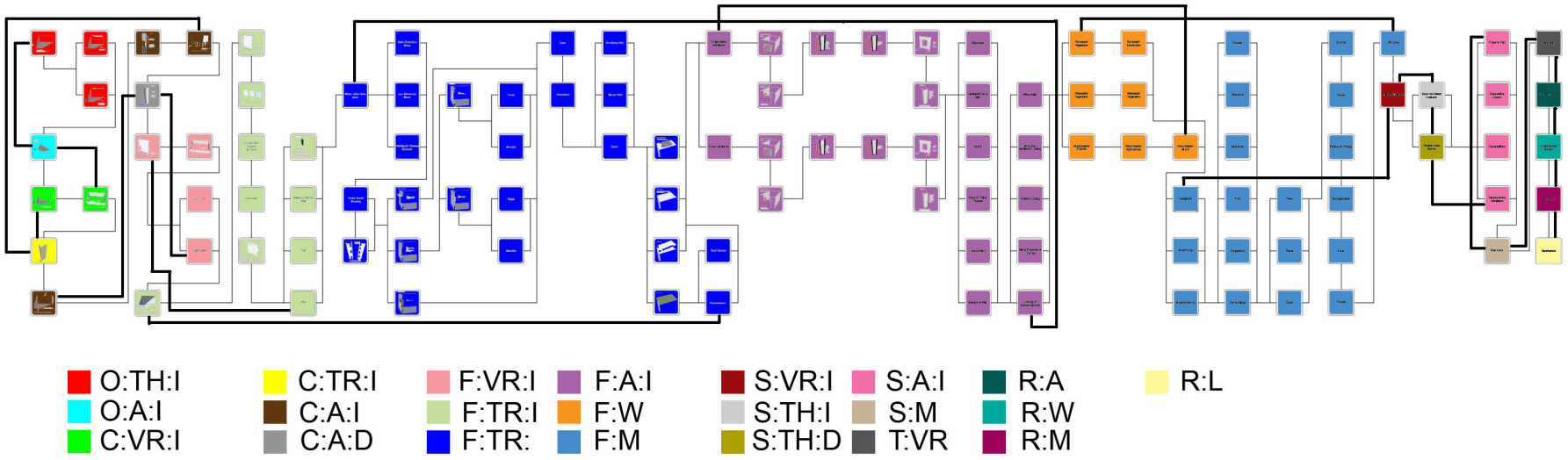


Figure 5.22: Principle links

5.12 Resulting New York test tower

The New York test tower, depicted in Figures 5.23 and 5.24, is formally vertically segmented like the London building. However, it has a much more serrated appearance in plan as the differing types of apartments line up against a central corridor, as seen in Figure 5.25. Again, the north façade is much more opaque than the southern façade, and the building as a whole has high amounts of vegetation. The next sections will consider its aesthetics and environmental performance in more detail.



Figure 5.23: North/east facades

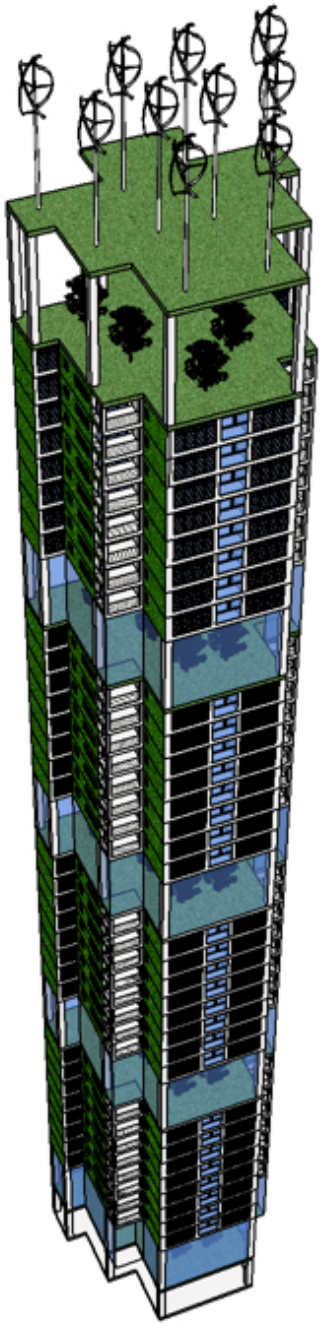


Figure 5.24: South/west facades

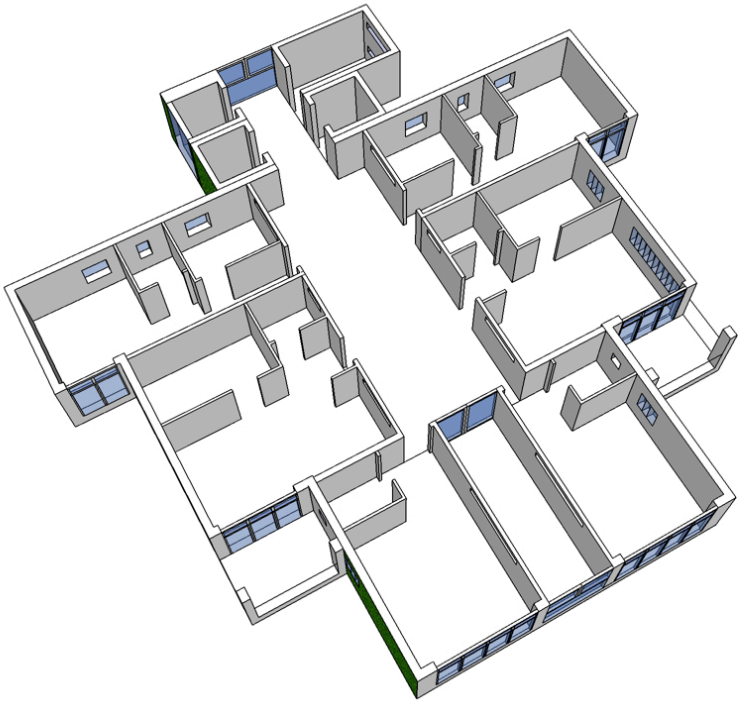


Figure 5.25: Floorplan

5.13 London and New York Test towers: comparative analysis

A more analytical review of the design processes and the resulting towers will be provided in this section. It will first briefly consider the effect of climatic and urban variations through a spatial and aesthetic comparison of the resulting buildings. An evaluation through standard forms of environmental assessment will then be outlined so as to place the framework in a larger context and highlight its particular strengths and weaknesses. As the Code for Sustainable Homes and LEED are the most recognized systems of assessment, they will be further discussed in section 5.13.2 and utilized to evaluate the towers. Again, as the tests in this chapter were completed in early 2009, the discussion relates to the versions of ratings available at that time.

5.13.1 Climatic and urban variations

As mentioned in previous descriptions, the buildings, despite their identical program and equal dependence on the framework, display differing traits in overall form and plan. Also as discussed previously, only a small number of alternate design decisions occurred due to local influences, but the results are fairly varied. This infers that the

framework would necessarily lead to varying results on differing sites, rather than a standard model to be replicated throughout the climate type.

The London tower, in much the same way as the earlier Birmingham test tower, has a more uniform, rectangular appearance than its stepped New York counterpart. Judging from the sequence of steps, this is a direct result of a response to airflow surrounding the building, as it is both oriented and configured to maximize its exposure to the wind during warmer seasonal periods. Although nothing could be claimed as conclusive from such a small number of test towers, these results suggest that in this climate type the direction of airflow has a larger impact on differences in buildings in terms of spatial organization than solar radiation.

In contrast, as visual radiation is generally received from a similar set of orientations in the climate, albeit at different angles of incidence, it does not encourage strong deviations in the building forms. However, as the incident angle varies within the climate, it allows for a great number of disparities in the building fabric. The angle of the louvers and the depth of overhangs are locally established and act as visual reminders of a building's climate and site conditions. Likewise, the location of sustainable towers can be 'read' through their relationship with wind and details of building fabric.

The observations above, of course, are most visible where there are little, if any, obstructions: therefore the influence of urban conditions on the resulting buildings requires further assessment. As seen most strikingly in the New York test tower's lack of shading devices on most of the east façade, the urban influence is interconnected with climatic strategies, in this case negating their necessity at certain levels. Depending on the location, the urban condition could theoretically have more impact on the environmental design of a building than its local climate and should therefore be carefully considered in an early stage. This is why assessment of the site, although preceding the stage of schematic design and not as systematically straightforward as bioclimatic design, requires much thought. Therefore, there is an interactive characted between a number of buildings: just as one could infer the local climate from form and fabric, a tower's neighbors could be envisioned if an approach conscious to the urban condition is applied.

5.13.2 LEED and Code for Sustainable Homes assessment systems

Having evaluated the impact of climatic and urban influences, this subsection will now consider the framework's relationship with environmental assessments. It is hoped that through this method the framework and its resulting buildings can be put into the larger context of contemporary green design, allowing for further analysis in terms of its strengths and weaknesses. As those assessment systems are not particular processes of design, the analysis will relate most directly to the fist objective of the research, namely the choice of the design principles available. Before comparing the research results with the assessments systems, a useful reintroduction of the systems and some of their specific characteristics is through a comparison of two prominent ones, the Code for Sustainable Homes and LEED rating.

The Code for Sustainable Homes was introduced in April 2007 on a voluntary basis and as a replacement of the Ecohomes method, established in 2000. Like its predecessor, it is a version of the Building Research Establishment's (BRE) assessment method for new, renovated and converted apartments, houses and flats (*BREEAM* website, no date). BRE's office version, BREEAM, has been available since 1990, making it the oldest and most widely used national assessment method worldwide (*BRE* website, no date). The Code already plays a particularly important role in England and Wales, as all new homes have been necessarily rated against it since May 2008. The Code is composed of six levels, from 'Pass' to 'Outstanding,' each one setting out minimum standards. Within these levels, there are seven key areas that are mandatory:

- Energy efficiency /CO_2
- Water efficiency
- Surface water management
- Site Waste Management
- Household Waste Management
- Use of Materials
- Lifetime homes (applies to Code Level 6 only).

Alongside these obligatory requirements, there are also 'flexible,' or optional credits. Energy and CO_2 emissions, calculated with the aid of national Building Regulations Part L1 (2006), are of key concern. The weighing categories and their factors are represented in Figure 5.26.

Table 1.4: Total Credits available, Weighting Factors and Points			
Categories of Environmental Impact	Total credits in each category	Weighting factor (% points contribution)	Approximate weighted value of each credit
Category 1 Energy and CO_2 Emissions	29	36.4%	1.26
Category 2 Water	6	9.0%	1.50
Category 3 Materials	24	7.2%	0.30
Category 4 Surface Water Run-off	4	2.2%	0.55
Category 5 Waste	7	6.4%	0.91
Category 6 Pollution	4	2.8%	0.70
Category 7 Health and Wellbeing	12	14.0%	1.17
Category 8 Management	9	10.0%	1.11
Category 9 Ecology	9	12.0%	1.33
Total	–	**100.0%**	–

Figure 5.26: Categories and weightings in the Code

The Leadership in Energy and Environmental Design (LEED) rating system was established by the U.S. Green Building Council in 1998. Like BREEAM, it has been used extensively in the US, as well as in at least forty other countries. It was developed mainly for commercial and institutional projects, although high-rise residential buildings are specified under this category as well. There are four levels of certification, ascending in prestige: Certified, Silver, Gold and Platinum. LEED is based on five key areas (US Green Building Council website, no date):

- sustainable site development
- water savings
- energy efficiency
- materials selection
- indoor environmental quality.

Like the Code, LEED also has minimum prerequisites and is a points-based system. Unlike its competitor, however, there seems to be no weighting of points, a decision

that has often been criticized. In opposition to the Code as well, it is not as reliant on local climatic conditions, covering non-temperate climates as well without any adjustments. Here, LEED's strong dependence on the technical ASHRAE standards should also be mentioned, as this can be linked to the 'systems' preference in terms of design. This affiliation also leads to somewhat less adaptable rating system, as given by the example of car parking: whereas BREEAM awards credits for the minimization of car parking, LEED awards it existence (Parker, no date).

In terms of a more general comparison, Aurore Julien, an expert in both systems, summarizes: 'Overall, the weightings are comparable, but the detail of the criteria differs significantly' (2008: 31). This leads her to conclude that 'the criteria from BREEAM UK may be slightly more onerous than that of LEED' (2008: 32). This is a charge repeated elsewhere. Eszter Gulacsy, a sustainability consultant from MTT/Sustain, also argues that LEED is simpler, whereas BREEAM is more rigorous and academic (cited in Parker, no date**)**. While BREEAM is based on very exact requirements embedded in a complex weighting system, LEED relies on percentage thresholds to determine a building's rating (Parker, no date). This discrepancy is also exemplified by their international projects: while BREEAM International (Bespoke) adjusts its assessment criteria with each locality, at the time of the towers' assessment LEED's US criteria remained unaltered in other regions (Julien, 2008; Parker, no date). However, LEED has changed in its third version with the introduction of regional bonus credits, shortly after this stage was completed . Such changes could presumably then be applied to international projects. What is somewhat paradoxical regarding the specificity of the two systems is that LEED appears both to require more extensive documentation and provides more information than BREEAM (Parker, no date).

Julien also compares the focus of the two systems: 'LEED gives slightly more importance to the occupant's health and comfort, while BREEAM UK and Bespoke Checklists would tend to be more focused around environmental impacts (2008: 31). The case study comparison confirms this as well, as many American towers justified the use of environmental strategies on productivity grounds. Furthermore, as productivity was often linked with economics, it is not surprising that LEED is based on US Dollars, in contrast to carbon dioxide measurements for BREEAM (Parker, no date). Clients therefore often choose LEED over BREEAM due to its link with a global corporate policy. Nevertheless, this financial focus can at times backfire, as was the case of the New York Times Building's abandonment of the rating system

due to the time and financial costs associated with keeping track of the construction debris (Stephens, 2008: 98).

It should be noted that as of 2008, BREEAM had been involved in a greater number of certifications, at over 100,000, than LEED, at just under 2,000 (Parker, no date). However, as LEED was established nearly a decade after BREEAM, this result is somewhat expected. As seen throughout the case studies, LEED however does appear to have a greater number of assessments in tall buildings, but this is also anticipated as America has a much higher number of skyscrapers. Nevertheless, both systems are at an early stage and therefore are not expected to be fully developed. Residential tall buildings, in particular, pose a problem as they are in both systems somewhat of an anomaly. As their numbers grow perhaps a new assessment method will have to be developed, just as BREEAM has developed bespoke versions for international projects.

5.13.3 Environmental assessments of test towers

Before detailing each building's assessment, it should be stated that the environmental approach applied here is a comparison of each building with standards rather than buildings. This is a deliberate choice, as an analysis based on building comparison would pose several problems. Currently, and as discussed in Chapter 2, the vast majority of 'green' towers generally do not effectively monitor their outputs, either in terms of energy use of carbon dioxide emissions. The application of a theoretical baseline model can be a more promising approach, but again an improvement on current standards does not necessarily indicate a truly sustainable building. Chapter 3 discusses further relevant issues with relying on evaluative models. Therefore, although by no means perfect, a decision was made to compare the buildings with generally accepted and applied standards such as the Code for Sustainable Homes and LEED.

As mentioned in the methodology chapter, the initial intention was to assess both buildings with the Code. Yet the rating system proved inflexible for use in North America and so the buildings are assessed according to their local standards. This scenario does have an advantage in that the two systems can be compared with each other, the buildings and therefore indirectly the framework. The assessment would also determine if the framework could be adapted to include already existing standards, therefore contributing to the critique and development of those systems.

5.13.4 London test tower: Code for Sustainable Homes analysis

The London tower was assessed in accordance with the 'Design Stage' criteria set out in the documents *Code for Sustainable Homes: Setting the standard in sustainability for new homes* (2008) and *Code for Sustainable Homes: Technical Guide* (2008). It should be mentioned at this point, as this is a purely theoretical exercise, any additional documents and checklists required for an official Code rating are not included. This omission includes third-party involvement, such as the Considerate Contractors Scheme, and specific percentages associated with individual credits. This assessment instead aims to determine whether the buildings resulting from the framework can be rated and whether or not the framework is compatible with the rating system. Therefore the approach adopted here is, where applicable, to associate the credits with design principles.

The Code has a prerequisite dwelling emission rate requirement, which aims to reduce the carbon dioxide produced by individual dwellings. The percentage of reduction is linked with the number of credits that can be gained as well as the overall rating of a building from one to six star levels. To determine the emission rate, the Code relies on the Standard Assessment Procedure (SAP) currently recommended by the UK government to measure the energy and carbon dioxide emissions rating of residences. As the Code is primarily used in the context of low-rise homes, the manner in which it measures energy and emissions in high-rise buildings relies on treating each apartment type as an individual building. For the London test tower this involved the examination of all six apartments on a typical floor, as the SAP rating is sensitive to orientation as well as floor area. A SAP worksheet was then used to assess these apartments, which corresponds to the numbers in Figure 5.27. Each apartment was then given a number of ratings: standard (without renewables), with wind turbines, with photovoltaics and with wind turbines and photovoltaics. The calculations are provided in Appendix B, but a summary of the calculations is available in Figure 5.28.

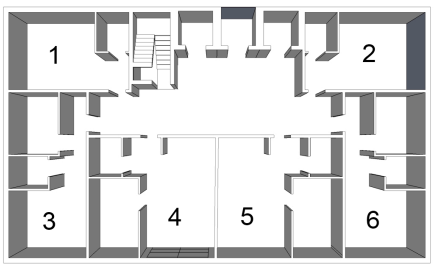


Figure 5.27: London apartment numbers relating to SAP rating

With the bioclimatic strategies alone, all apartments performed better than the minimum target, reaching level three in terms of star rating. The south-facing middle apartments rated considerably well, suggesting that residential tall buildings are perhaps more efficient when design as slab, as opposed

to point, towers. The nine turbines, which could produce only 52 kWh per annum, per apartment, as opposed to the photovoltaics' 6,000 kWh, did not enhance the rating. The extensive use of photovoltaics along all southern-facing balconies made each apartment carbon negative to a great extent, confirming that carbon neutral tall buildings could be designed, though with the supplementary use of renewable technologies. Nonetheless, it should be remembered that in the Code the definition of 'carbon neutral' does not include the measurement of embodied energy, which is a significant source of carbon in itself, and so the overall carbon savings may be much lower.

In addition to the SAP rating, the Code for Sustainable Homes includes a checklist of weighted credits that are arguably less difficult to obtain than an efficiency rating. Many of them are not necessarily linked to the architecture or environmental concerns. Some concerns, like laundry drying space and the provision of a home office, rely on the participation of building inhabitants than any particular design option. Others, like those relating to security lighting and white goods, are efficiency measures that may not involve the architect. Some, like flood risk analysis, are aspects that would be considered often before the architect is summoned. The category 'Health & Wellbeing' mostly concerns social issues beyond the scope of this study. Figure 5.29 further illustrates the variety of credit options, which for the purpose of this study are categorized as pre-requisite (blue), non-framework (yellow) and those similar to the strategies in the framework (white). Even the 'sustainable' version of the framework here, at Stage 2, does not consider most of these categories. More importantly, though, none of these credits contradict the framework and could easily be incorporated into its design process. All in all, a top Code rating is achievable with an application of the framework, although it would require a checklist approach dependent on other practitioners and building users.

	Standard	**Turbines**	**PVs**	**Turb+PVs**	**Target**
1	18.60 (3)	17.92 (3)	- 60.33 (6)	- 61.02 (6)	29.07
2	18.60 (3)	17.92 (3)	- 60.33 (6)	- 61.02 (6)	29.07
3	14.49 (3)	14.46 (3)	- 41.27 (6)	- 41.76 (6)	23.46
4	12.12 (3)	11.71 (3)	- 35.39 (6)	- 35.81 (6)	19.05
5	12.12 (3)	11.71 (3)	- 35.39 (6)	- 35.81 (6)	19.05
6	14.49 (3)	14.46 (3)	- 41.27 (6)	- 41.76 (6)	23.46

Figure 5.28: Summary of SAP calculations

Code Categories	Expected Credits	Category Weighting Factor
Energy and CO_2 Emissions		
Dwelling Emission Rate	15	
Building Fabric	2	
Internal Lighting	2	
Drying Space	1	
Energy Labelled White Goods	2	
External Lighting	2	
Low or Zero Carbon (LZC) Energy Technologies	2	
Cycle Storage	2	
Home Office	1	
Category Total	**29**	**36.40**
Water		
Indoor Potable Water Use	5	
External Water Use	1	
Category Total	**6**	**9.00**
Materials		
Environmental Impact of Materials	15	
Responsible Sourcing of Materials – Basic Building Elements	6	
Responsible Sourcing of Materials – Finishing Elements	3	
Category Total	**24**	**7.20**
Surface Water Run-off		
Management of surface water run-off from developments	2	
Flood Risk	2	
Category Total	**4**	**2.20**
Waste		
Storage of non-recyclable waste and recyclable household waste	4	
Construction Site Waste Management	2	
Composting	1	
Category Total	**7**	**6.40**
Pollution		
Global Warming Potential (GWP) of insulants	1	

NOx Emissions	3	
Category Total	**4**	**2.80**
Health & Wellbeing		
Daylighting	3	
Sound Insulation	4	
Private Space	1	
Lifetime Homes	4	
Category Total	**12**	**14.00**
Management		
Home User Guide	3	
Considerate Constructors Scheme	2	
Construction Site Impacts	2	
Security	2	
Category Total	**9**	**10.00**
Ecology		
Ecological value of site	1	
Ecological enhancement	1	
Protection of ecological features	1	
Change in ecological value of site	4	
Building footprint	2	
Category Total	**9**	**12.00**
Total	**104**	**100.00**

Figure 5.29: Code for Sustainable Homes credit checklist based on documents

5.13.5 New York Test tower: LEED analysis

Like the Code for Sustainable Homes, the LEED Rating System has both a component of energy efficiency testing as well as checklist of supplementary demands. However, the energy efficiency of the New York Tower was not determined, mainly as it requires the project to comply with provisions set in ASHRAE 90.1-2004. This essentially necessitates a whole energy building simulation which encompasses process energy, a term referring to equipment such as computers, washing machines and refrigerators (USGBC, 2005: 34). This mechanical focus and level of detail is beyond the scope of this framework and so any attempt to quantify such data for the New York tower at this point would be an inaccurate presumption. Furthermore, as this research was conducted in the United Kingdom, technical support for the application of the Code was available, whereas support, including verification of results, relating to the LEED system was more difficult to obtain. However, as both New York and London towers are located in the cool temperate climate and designed using the same standards, it is cautiously assumed that the New York tower's energy performance would be comparable to that of London. This section will therefore focus on the LEED checklist.

Like the Code, many of the credits provided are of a greater scope than the environmental framework. Some, like brownfield development, would be considered prior to the building's design, while others, such as controllability of lighting systems, are more related to social and technical issues than architectural design. These are again highlighted in yellow in a checklist document, here as Figure 5.30, provided by the USGBC website (2008). As was the case with the Code, the framework did not contradict, and could be expanded to incorporate, all of the LEED credits. The New York building would be able to include all but three of these credits, arguably accomplishing less than its London counterpart. The three credits that it could not possibly include are Credits 1.1, 1.2, 1.3 of the Materials & Resources category, which are concerned with the reuse of existing walls, floors, roofs and interior non-structural elements that an unoccupied site could not acquire. Nevertheless, the building compares well with the checklist, reaching a Silver status without any of the yellow issues and a Platinum rating with them.

LEED for New Construction v 2.2
Registered Project Checklist

Project Name: _____

Project Address: _____

Yes	?	No		
			Project Totals (Pre-Certification Estimates)	69 Points
			Certified: 26-32 points **Silver**: 33-38 points **Gold**: 39-51 points **Platinum**: 52-69 points	

Yes	?	No			
			Sustainable Sites		14 Points
Yes			Prereq 1	**Construction Activity Pollution Prevention**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density & Community Connectivity**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel Efficient Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity	1
			Credit 5.1	**Site Development**, Protect or Restore Habitat	1
			Credit 5.2	**Site Development**, Maximize Open Space	1
			Credit 6.1	**Stormwater Design**, Quantity Control	1
			Credit 6.2	**Stormwater Design**, Quality Control	1
			Credit 7.1	**Heat Island Effect**, Non-Roof	1
			Credit 7.2	**Heat Island Effect**, Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
			Water Efficiency		5 Points
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Powered by Adobe® LiveCycle™

LEED for New Construction v 2.2
Registered Project Checklist

Yes	?	No			
			Energy & Atmosphere		**17 Points**
Yes			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Yes			Prereq 1	**Minimum Energy Performance**	Required
Yes			Prereq 1	**Fundamental Refrigerant Management**	Required

***Note for EAc1:** All LEED for New Construction projects registered after June 26, 2007 are required to achieve at least two (2) points.

			Credit 1	**Optimize Energy Performance**	1 to 10
				Credit 1.1 10.5% New Buildings / 3.5% Existing Building Renovations	1
				Credit 1.2 14% New Buildings / 7% Existing Building Renovations	2
				Credit 1.3 17.5% New Buildings / 10.5% Existing Building Renovations	3
				Credit 1.4 21% New Buildings / 14% Existing Building Renovations	4
				Credit 1.5 24.5% New Buildings / 17.5% Existing Building Renovations	5
				Credit 1.6 28% New Buildings / 21% Existing Building Renovations	6
				Credit 1.7 31.5% New Buildings / 24.5% Existing Building Renovations	7
				Credit 1.8 35% New Buildings / 28% Existing Building Renovations	8
				Credit 1.9 38.5% New Buildings / 31.5% Existing Building Renovations	9
				Credit 1.10 42% New Buildings / 35% Existing Building Renovations	10
			Credit 2	**On-Site Renewable Energy**	1 to 3
				Credit 2.1 2.5% Renewable Energy	1
				Credit 2.2 7.5% Renewable Energy	2
				Credit 2.3 12.5% Renewable Energy	3
			Credit 3	**Enhanced Commissioning**	1
			Credit 4	**Enhanced Refrigerant Management**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

LEED for New Construction v 2.2
Registered Project Checklist

Yes	?	No	Materials & Resources	13 Points

Yes					
Yes			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse,** Maintain 75% of Existing Walls, Floors & Roof	1
			Credit 1.2	**Building Reuse,** Maintain 95% of Existing Walls, Floors & Roof	1
			Credit 1.3	**Building Reuse,** Maintain 50% of Interior Non-Structural Elements	1
			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
			Credit 3.1	**Materials Reuse**, 5%	1
			Credit 3.2	**Materials Reuse**, 10%	1
			Credit 4.1	**Recycled Content**, 10% (post-consumer + 1/2 pre-consumer)	1
			Credit 4.2	**Recycled Content**, 20% (post-consumer + 1/2 pre-consumer)	1
			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured	1
			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No	Indoor Environmental Quality	15 Points

Yes					
Yes			Prereq 1	**Minimum IAQ Performance**	Required
Yes			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
			Credit 1	**Outdoor Air Delivery Monitoring**	1
			Credit 2	**Increased Ventilation**	1
			Credit 3.1	**Construction IAQ Management Plan,** During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Lighting	1
			Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
			Credit 7.1	**Thermal Comfort,** Design	1
			Credit 7.2	**Thermal Comfort,** Verification	1
			Credit 8.1	**Daylight & Views,** Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views,** Views for 90% of Spaces	1

Powered by Adobe® LiveCycle™



LEED for New Construction v 2.2
Registered Project Checklist

Yes	?	No			
			Innovation & Design Process		5 Points
			Credit 1.1	**Innovation in Design:** Provide Specific Title	1
			Credit 1.2	**Innovation in Design:** Provide Specific Title	1
			Credit 1.3	**Innovation in Design:** Provide Specific Title	1
			Credit 1.4	**Innovation in Design:** Provide Specific Title	1
			Credit 2	**LEED® Accredited Professional**	1

Figure 5.30: LEED Checklist with additional credits highlighted.

5.13.6 Design framework: LEED and Code for Sustainable Homes analysis

This section will now provide a comparison between the rating systems and the design framework. This analysis will evaluate the systems individually, suggesting areas where the framework differs from them. It will help to place the framework in the context of current assessments.

The scope of the Code for Sustainable Homes, like LEED, is presumed to be too broad for the focus of environmental sustainability as defined by the framework. Although both systems claim to be based on the design of environmentally sustainable architecture, credits issued for issues such as access to public transportation and the protection of ecological features on the site are often quite unrelated to actual building design. The Code has a particularly European inclination towards aspects of social sustainability, with 'Health and Wellbeing' forming a category, allowing credits for social agendas for Lifetime Homes and the provision of sound insulation. Therefore, it could be argued that the Code, particularly the checklist segment, is in many ways more concerned with changing user patterns than altering the qualities of the building itself. An illustration of the way in which the credits fit into the Code, in Figure 5.31, illustrates the different focus. This is in contrast with both LEED, which focuses on materials, water and energy efficiency, and the framework, which highlights the importance of bioclimatic design.

Additionally, although the Code's SAP rating provides a useful measure of energy consumption and carbon emissions, it can be argued that it does not consider seasonal variations enough. For example, it generalizes overhangs by assuming they always provide the same amount of shade throughout the year. Nevertheless, it

is based on the Marine climate prevalent in the UK, and so more advanced in this respect than LEED, which can indiscriminately be applied to any of the climate types located in the United States. As these types encompass variations from the climate from Florida to Alaska, it could not be labeled a climatic system in the same way as the Code. Again, the updated version, subsequent to this study, has rectified this issue to some extent with the introduction of regional credits.

The strength of both LEED and the Code, as compared to the framework, appears to be particularly related to the specificity of guidance regarding materials. While the framework does include sufficient information regarding their use, LEED and the Code are more specific in requiring that certain percentages of materials embody a range of sustainable qualities. The framework could be enhanced with such figures, which would make the resources category more relevant to current standards. The same could be said regarding the variety of building management and assessment plans the two rating systems encourage, and so framework at points could label where long-term monitoring would need to be incorporated. On the other hand, the assessment systems' strengths may justify a more bioclimatic focus in the framework, which was adopted in the final version.

In the same respect, both rating systems' lack of focus on bioclimatic design strategies could allow for poorly configured, but technologically advanced, buildings to gain a relatively high rating in terms of energy, despite being at high risk of environmental failure if such renewable systems were to malfunction or if unexpected climatic changes or changes in urban surroundings emerged. Such an approach would also disregard embodied energy, which is inevitably increased with additional renewable technologies. The early stages of design are recognized as key determinants of a sustainable outcome and so the prioritization of passive, bioclimatic strategies deserves more attention.

As discussed in previous sections, the framework is more focused on design aspects that are relevant to the architect. Issues such as transportation, site ecology and mechanical systems rarely involve much specific input from the architect. The framework thus affirms that the architect's time and talent is better spent focusing on those issues where he or she has the most impact and control, namely those aspects involving the environmental design of the building. The framework thus allows for a reasonably direct design process to be incorporated into the schematic design phase.

			Orientation	Configuration	Fabric	System	Renewables
Inexhaustible Resources	**Visible Radiation**	**Increase**		Hea 1 Daylighting	*Hea 1 Daylighting*		Ene 7 Low or Zero Carbon (LZC) Technologies
		Decrease					
	Thermal Radiation	**Increase**			Ene 2 Build Fabric		
		Decrease			*Ene 2 Build Fabric*		
	Airflow	**Increase**					*Ene 7 Low or Zero Carbon (LZC) Technologies*
		Decrease					
Exhaustible Resources	**Water**				Wat 1 Internal Potable Water Use Sur 1 Water Run-off		*Ene 7 Low or Zero Carbon (LZC) Technologies*
	Materials				Mat 1 Env. Impact Mat 2 Sourcing (Basic Mat 3 Sourcing (Finish) Pol 1 (GWP) of Insulants Eco 1 – 4		*Ene 7 Low or Zero Carbon (LZC) Technologies*
	Land						*Ene 7 Low or Zero Carbon (LZC) Technologies*

Figure 5.31: Code for Sustainable Homes within the framework

5.13.7 Stage 2 framework analysis summary

The New York and London trials found that the framework encouraged variations in design in response to climatic or urban demands, despite a consistent application. The results suggested that airflow had the greatest effect on differences in form and solar radiation in fabric, but, as this is a small study, they are not definitive. Urban conditions were found to have much of an impact on the application of certain principles, and so would need to be considered in detail prior to design.

The Code for Sustainable Homes and LEED rating systems, although different in their emphases, were found to point out several areas where the framework is successful. SAP calculations demonstrated that the London building could theoretically exceed the target rating through passive technologies only; a carbon-neutral building would furthermore be possible with the application of renewable technologies, particularly phovoltaics. Both rating systems were much broader in their categories than the framework, but there were no inconsistencies that would prevent the resulting buildings from achieving a top rating if those categories were also included. Information and targets relating to materials and water use were especially more prominent in the rating systems. The framework, on the other hand, was more advanced in terms of bioclimatic and schematic design guidelines.

More generally, the framework at this stage more fully met the requirements of the research as set out in the objectives. Most of the principles chosen had contributed to the design of the two tall buildings. However, some, such as thermal walls, need further explanation. As the framework is based around the extensive work of Ken Yeang and a specific interpretation of sustainable design, some areas therefore require further explanation and evaluation through the use of other resources.

The second objective's requirement, the organization of those principles so as to best inform architects during the schematic design stage, was also more successfully resolved. The framework matrix and sequence had been applied without the need for major changes, and so the second version's overall structure would remain the same. However, two weaknesses were noted that would require resolution. The first weakness relates to the step sequence. Although the format is on the whole necessarily sequential, more focus needs to be placed on links between certain strategies that may affect each other. The links at this stage are shown within the descriptions of specific design principles, which may have a tendency to be

overlooked, and so a new system is needed. A more pressing weakness is the somewhat loose organization of exhaustible resource interactions, as they are not as sequentially related as the inexhaustible resource interactions. The manner in which principles within the cells are organized is based on Yeang's texts, which were often assessed as lacking a strong hierarchy, and so more independent work into sequencing is required.

The assessments carried out thus far were meant to be objective, but it was acknowledged that the author was too involved in the framework's development to guarantee full impartiality. Therefore, student tests in the next stages were introduced partly to substantiate the issues discussed here, and more so in order to offer an alternative evaluation. Those tests did not require substantial changes to the framework at the outset as much of the structure and guidance was assumed to be valid, and as some of these issues were left unresolved to gain from student input. The framework at the end of Stage 2 consequently did not differ as much from that of Stage 1 as it would from its final version.

6 STAGE 3: STUDENT TESTING

As the framework lacked application by users other than the author, a series of student trials was organized. This chapter will detail the methodology behind them and provide an analysis of their results. Observations of student work during teaching sessions and reviews, student notes in the framework document and, especially, a questionnaire provided the data with which to evaluate them. Given the broad range of topics covered through these trials, they relate to both objectives of the research. Additionally, a brief comparison with the approach of Ian Simpson Architects, who had developed a tower for the site, is provided.

6.1 Student groups

This section will provide further detail on the composition of student groups, their familiarity with environmental design, the site, resources, design briefs and the groups' notions of environmental design prior to testing. These elements help to point not only to the background of the testing, but also any related assumptions and limitations that may have affected the outcome. References to the questionnaire, included in Appendix C, are referred to in parentheses as questions.

6.1.1 Composition

The student tests involved the voluntary participation of five groups of students from two postgraduate architecture courses. Two groups of students contributed from the High Rise Architecture Design Research Studio module at the Department of the Built Environment, University of Nottingham. One group, here referred to as NF, consisted of three students that had agreed to use the framework fully, and continued to do so to some extent throughout the design process. One of the group's members later referred to consulting 30-40% of the framework during the development of the design (Question 5). This can be considered as a full adoption of the framework as the number and organization of options available precludes an application of all the steps and so this is a high percentage. The group especially focused on the thermal guidance (Question 6). A second group of two students, NN, also agreed to apply the framework at the outset but did not carry out this intention, partly due to a late start in examining the framework and partly due to a very early focus on building structure rather than environmental concerns. This second group will therefore be considered as not applying the framework. It is also worth noting

here that this was the only group with no responses to the questionnaire, so all reactions from it are based on observations from visits to Nottingham.

Three groups, one with three students and two with two, participated from the Environmental Design Application module from the Welsh School of Architecture, Cardiff University. The first group, CF, agreed to use the framework fully, and provided an assessment of it as part of its coursework. This group later indicated consulting the framework '100%' (Question 5). This can here be interpreted as the framework guiding its design process fully, rather than all options being applied. This understanding is supported by responses stating 'Our aim was to apply as much as we could'. When questioned specifically which parts of the framework were applied, one of the members affirmed: 'The parts that were adequately and thoroughly analysed, in particular the first steps' (Question 6). The second group, CP, used the framework partially, if and when it found it useful, and so its notes are mainly based on the areas it found helpful. It indicated consulting 50% of the framework (Question 5), especially steps 1- 29 (Question 6), relating to orientation, configuration and some aspects of fabric design. In this sense, it considered more steps than any of the Nottingham groups, but in terms of the design process specified by the framework, the Nottingham group NF had been more dependent on its organization and so in that manner more fully reflects its application. The third group, CN, did not apply the framework, although it did have access to it for comments. It outlined its own method of design as part of the final presentation.

Both modules, aimed at an MSc level, also included a number of other student groups examining either different sites or following an alternate brief. The groups mentioned thus far therefore do not represent the modules in their totality. At times, the notes placed these groups, particularly the Nottingham ones, into the context of the courses as a whole.

Environmental design foundations

Based on the student questionnaire and discussions in person, all students had a level of previous education in environmental design. This response was anticipated, as both courses specialized in environmental design, that of Nottingham in areas relating to tall buildings and that of Cardiff in more general terms. In the questionnaire responses (Question 1), they described their knowledge of environmental design prior to using the framework as 'good', 'very good' or 'basic'.

However, at the outset of the design process and during initial visits, it became clear that the knowledge of environmental design was often acutely limited, especially in the case of the Nottingham students. This was true despite the fact that four of the students, now in mixed groups, had enrolled in a separate environmental design module and one was enrolled in a MArch degree in Environmental Deign. This discrepancy can be attributed partly to a restricted number, if any, of environmental design modules in previous courses, and perhaps partly due to the fact that all students had come to study from countries with a warmer climate where the focus in undergraduate environmental courses was likely to have been on a different set of bioclimatic strategies. It is notable here too that no student had had any education or professional experience in tall building design prior to the start of the course, though the Nottingham groups were concurrently involved in a parallel seminar course concentrating on tall building case studies and a research report.

6.1.2 Resources

In addition to consultation with supervisors and recommended course readings, the students also carried out their own research. All but one group noted the use of Internet websites and relevant books (Question 7). The Nottingham groups, as part of their course, also examined a number of tall building case studies and a Cardiff group identified the use of journal articles. Markedly, there was reference to Yeang's texts in groups in which the framework was not consulted. This brings into question how much influence his texts had on all groups, and how different the designs would have been if they were not a main resource. However, this fact does offer a benefit regarding the evaluation of the framework in that the force of hierarchy proposed, more so than the individual principles presented, becomes more apparent than it would have been if the principles varied vastly.

The group that differed from the rest in not using additional resources, other than for clarification of terms or details of some techniques and technologies through the Internet, was the group using the framework most fully (CF). It should be noted nonetheless that all groups, upon requests from a number of individuals, received a copy of detailed notes from Ken Yeang's texts relating to the specific steps and options and a reading list of eleven key texts that were advised by the framework author as further resources. These requests highlighted the need to include a wider variety of resources than the information provided by Yeang. A number of such texts had been included in earlier versions of the framework, but omitted from the

students' framework version in order to clarify and underline areas in which the guidance provided in Yeang's texts was insufficient. It became evident that these resources, as well as a number of others, needed to be placed back into the framework in its revised version.

6.1.3 Design Briefs

The design brief of the two modules varied in emphasis, but nonetheless had similarities in the tall building elements. All students involved with the framework study created a tall building on a London site. This section will therefore discuss the similarities and differences between the groups participating in the framework study, but it should be stressed that majority of the design conditions were essentially the same.

Nottingham Brief

The design brief at Nottingham (Nicholson-Cole and Oldfield, 2011) was entitled 'Tall Buildings: Climate, Culture, Context' and students were required to respond to all three of these aspects. A main argument running throughout the project was that the tall building as a typology needed to be updated so that it responds to place more distinctly, and therefore innovative approaches were encouraged. To allow for this to occur, all students were required to propose a specific agenda that the projects would address, which resulted from an examination of some or all of the aforementioned aspects in an early site study. Other than these prerequisites, the groups were unrestricted in their approaches to the size, height, responsibilities and function of their buildings.

Groups had a choice of three sites: Abu Dhabi, London and Singapore. As the framework study only focused on the London site, any reference to the Nottingham groups will only indicate the two groups designing on that site. It is worth noting, for comparison, that the other sites involved many more groups than the London site and that the London groups generally progressed more slowly than the others. It appeared as though the cosmopolitan character of the city and the temperate climate itself made agendas applicable to all residents more difficult to develop and the approach to the climate more complicated. Nonetheless, the groups did develop two distinct agendas, one of a 'food tower' (NF), related to the need for local food and popularity of gardening, and another of a 'flooding tower' (NN), referring to the site's

and city's vulnerability as a flood plane during a period of climate change. All groups designed mixed-use towers, with a residential aspect occupying approximately half of the building.

Cardiff Brief

The Environmental Design Application module at Cardiff University had allowed the students to apply in practice information gained through parallel modules (Fedeski, 2011). The project took the form of an in-depth design study of a chosen environmental aspect of design. Having a substantial research element, the project's final submission was to be composed of a 'problem, proposition and proof' and to be supported by computer simulations when possible.

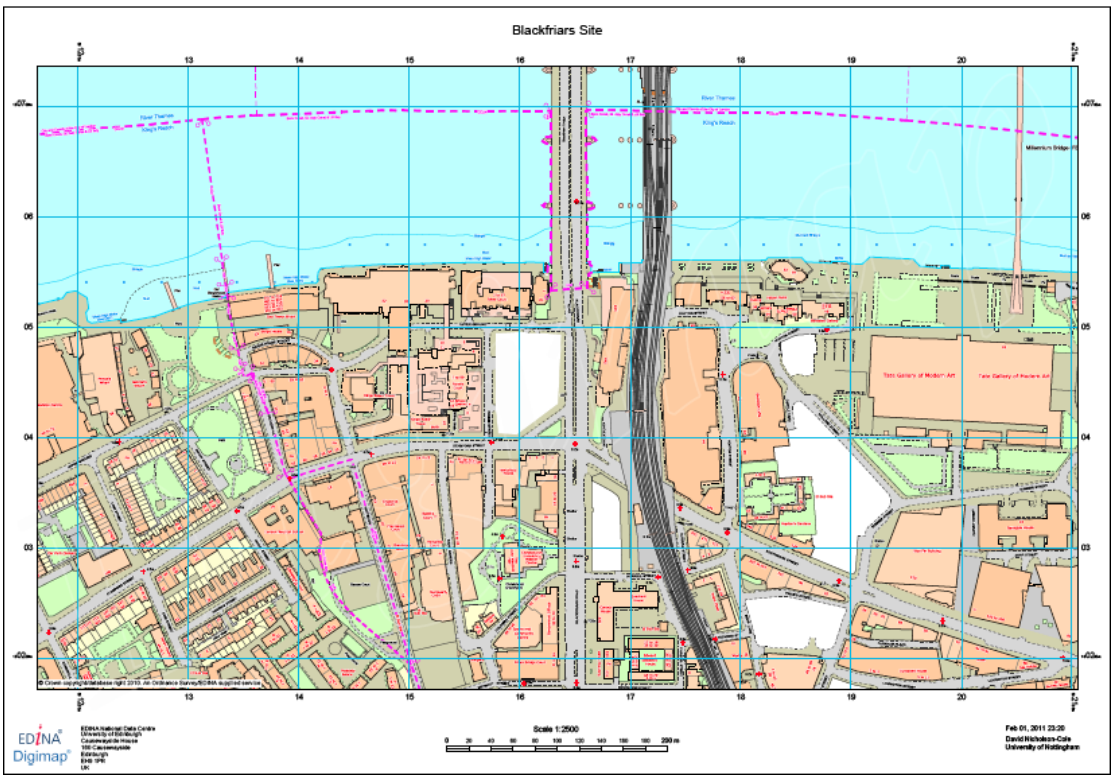
Like the Nottingham students, the Cardiff students also had to set their own design briefs. In this case, they were to state the context, the feature to be explored and the objectives against which success could be measured, usually in the form of an environmental performance target. The project could be of two categories: a building type or a feature of a building design. The London tall buildings option falls under the first category.

The three groups of two students that volunteered for the tall building option were asked to have a critical approach to the design guide, in keeping with the more general objectives. More exclusively, they were asked to present what they believed were 'the essential issues in the sustainable design of residential towers,' to give their 'own advice on these issues to supplement that offered by the tool' and 'to have a view on the effectiveness of the design tool, and tools of its type' (Fedeski, 2011). They were allocated a broadened version of the Nottingham brief, and so focused less on the contextual and cultural aspects of the design and more on the environmental ones. These students were also not asked to produce an additional agenda like the Nottingham students, but were asked more directly to include a substantial amount of residential accommodation. As only the tall building groups were seen during observation visits to Cardiff, comparisons with other groups are unavailable.

6.1.4 Site

All groups were asked to design for a central London site, known as 1 Blackfriars Road or Bridge, located south of the river Thames and in the vicinity of Tate modern. As Figure 6.1 shows, although typical of urban London in that low- to mid-rise buildings surround it, the site is nevertheless large enough, at 4800 sq. m, to allow for a number of building placement options. Most groups chose a central placement and a number consequently generated a large building footprint. Parking was assumed to be underground.

Figure 6.1: Blackfriars Road site plan



Given its height, any tower was negligibly affected by overshadowing from nearby buildings as compared to its impact on neighboring low-rise buildings to its north and west. Most groups, however, considered the impact of the former more relevant and supported the central location of their towers with this logic.

The prevailing wind direction on the site is from the southwest, particularly during the summer and winter. There is occasional wind from the northeast during the summer and winter periods and from the southeast during autumn. There were little obstructions to airflow on the sites from adjacent buildings. As London's climate is a

Maritime Temperate (Cfb) one, the winters are cold and summers warm, but without the extreme seasonal discrepancies found in other regions in the cool temperate range. More information on the London climate can be found in Chapter 5.

As of 2011, a 170 m, 50 story residential and hotel tower was planned for the site and designed by Ian Simpson Architects. This design will be discussed more in later chapters, but it is sufficient to say here that most groups eventually proposed a tower of a similar height.

6.1.5 Approaches to environmental design prior to testing

Responses relating to a particular method of work towards environmental design before starting on the project (Question 2) indicated that all students had some form of individual approach. Other than the two groups using the framework fully and one (CN) that outlined its design progress, the approaches employed were more generic in this project. More decidedly, the majority of groups directly specified daylight as a main driver of design (Question 3). One student indicated more generally 'sustainability' as a driver, while another stated building function as well as the ability of 'being able to grow the fruit and vegetables in the area' (NF). All responses therefore include elements of daylighting as a main driver. Thermal performance was also stated alongside daylighting as a secondary priority, and equal in significance to daylighting in one group (CN). This focus on visible radiation, followed by thermal radiation, was validated by observations of student work. Airflow, specifically natural ventilation, emerged as an issue of importance often only after radiation was addressed extensively. Other bioclimatic issues, such as water use and material selection, were much less pressing concerns throughout the design process.

The project aims for environmental performance (Question 4) were similar to the main drivers and not quantified at the outset. Again, there was a focus on daylight, with responses, such as 'allow as much sunlight in and retain as much heat as possible without the building getting over heated' and 'daylight performance', signifying its importance. One group (CN) had provided a hierarchy of aims, with 'thermal comfort of occupants' as the main priority, followed by 'optimization of daylight availability into all spaces', 'natural ventilation' and 'social issues'. One group (CF) had conflicting responses, with one student having no specific aims and another having some, although unspecified, ones.

All in all, it is apparent that there was an early emphasis on bioclimatic designs by all groups questioned, particularly on the visible radiation aspect. Only one group (CN) had indicated thermal radiation as the main priority at the start of the project, and this was notably a group not using the framework. The framework groups, inevitably, altered their focus to thermal performance once the design process commenced.

6.2 Design process

This section will provide a brief overview of the design process and observations of the project development in the two courses, especially for those groups applying the framework. These notes will focus on stating the effect of the content and sequencing of the Stage 2 version of the framework on the designs. In order to remain objective, advice was offered by the author only as requested by the tutors and students, particularly in Nottingham. The design process was usually not commented on, unless clarification was required on the framework for the project to continue. Any such suggestions have been noted here.

6.2.1 Nottingham

The Nottingham module leaders had agreed that the students could voluntarily apply the framework, as long as it would not 'dominate their design process.' Both London groups decided to apply it, but, perhaps partially because of this condition, it was not as weightily enforced by either as it had been by one Cardiff group.

The Nottingham module began on 3 February 2011 with a field visit and ended on 1 June 2011 with final reviews. There were two additional interim reviews and an Easter break of approximately four weeks. The framework author attended one tutorial based on a review of a presentation, one general tutorial, two interim reviews and the final review. Each of these reviews was led by the module leaders and often attended by a number of other tall building specialists. Note that only the NF group provided copies of presentations for all visits, with NN only contributing the first and last visit.

Visit 1: 10 March 2011, presentation tutorial.

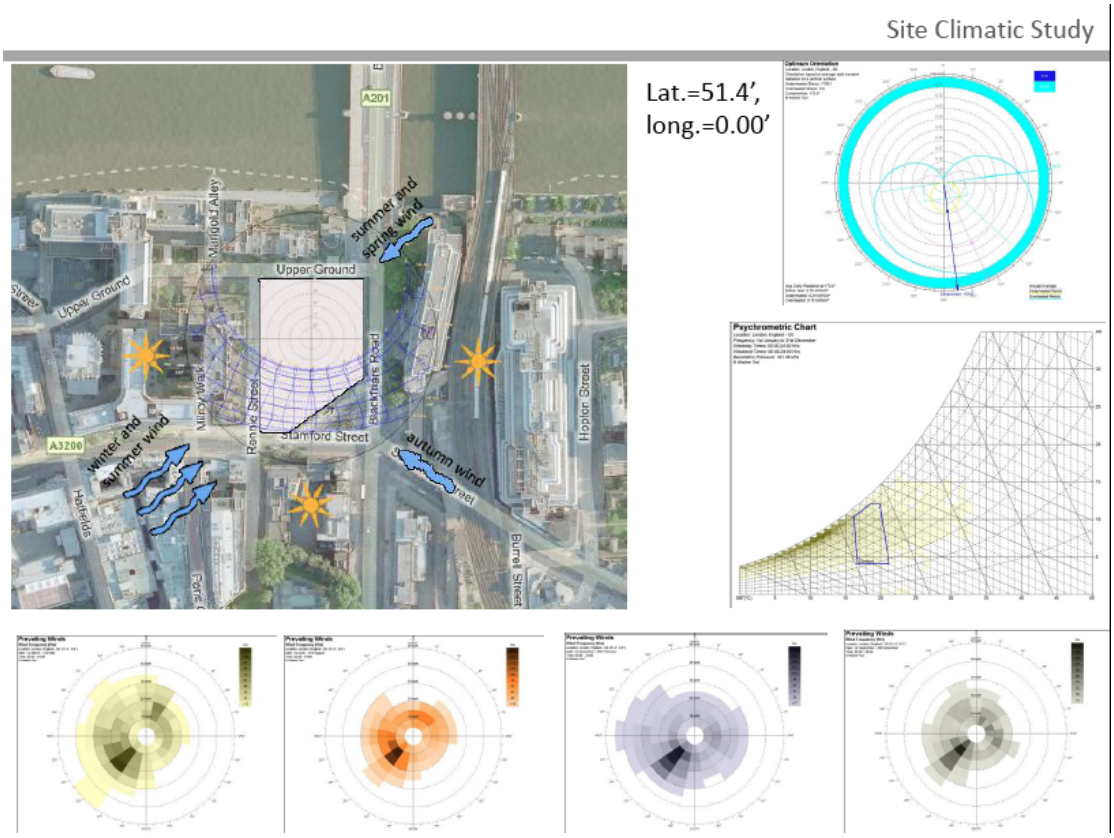
After presenting a joint site study, of which the climatic portion is included in Figure 6.2, the London students were introduced to the design framework. They were asked

to use it as a reference guide, without it impeding any conceptual or aesthetic ideals. They had already chosen a previous design concept as a design agenda.

The group using the framework (NF) proposed a ‘food tower’ that later developed into a ‘vertical farming’ tower. It did not have a fully developed shape and at that point had consisted of stacked rigid planes. Planning needed to be advanced further, as did the building function. Preliminary research had been completed on edible plants in general and climbing plants in particular.

The group that eventually did not apply the framework (NN) proposed three schemes, all based on the high risk of flooding in the area as it related to climate change scenarios. All schemes presented were for a mixed-use building, with the residential aspects oriented north rather than south, the environmental preference. The students were asked to reorient their towers to respond to this advice.

Figure 6.2: Nottingham students’ site study



Visit 2: 17 March 2011, tutorial.

The groups presented advanced versions of their agendas and forms. NF had now settled on designing a building with a triangular plan, part of it which is presented in Figure 6.3, in which its two sides acted as residential volumes and one as a farming area. It had, however, oriented the building in an environmentally detrimental manner, with the gardens facing north and a poor quality of sunlight available to residences. After critiques from all present, the tower was turned by 180°. The south-facing garden would then act as a buffer both in the summer and the winter and the residences would have solar access from the south, east and/or west. The placement of the core and ground floor needed resolving, and more systematic aspects of food production were to be researched. NF stated that it had not applied the framework yet, understandably somewhat due the conceptual stage of their design. However, it had commented that it found the introduction and some of its early step guidance helpful in determining the 'measurements' of building element placement it had been considering.

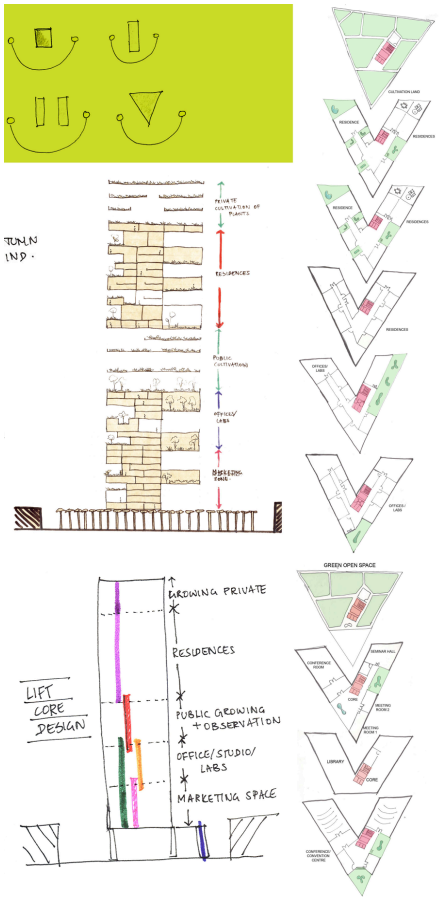


Figure 6.3: NF Visit 2 proposal

NN had continued with the 'flooding tower' concept, now adding a 'vertical city' aspect as well due to its mixed-use nature. The form was at the moment much more regular and stable than the one presented previously and included two cores serving either office or residential purposes. Again, though, the building orientation did not suit the site either environmentally or contextually. It had been oriented 45° from north so that the prevailing southwest wind would allow for cross-ventilation, which may have been beneficial in some areas during the summer but was unfavorable during the winter. A reorientation to south-facing residences and north-facing offices was recommended once more. The ground floor of building, lifted high off the street level, needed redesign, as did the function of the building in the near future, rather than during flooding periods only. Like the first group, NN had not applied the framework, although it still expressed interest in using the document.

Visit 3: 31 March 2011, interim review.

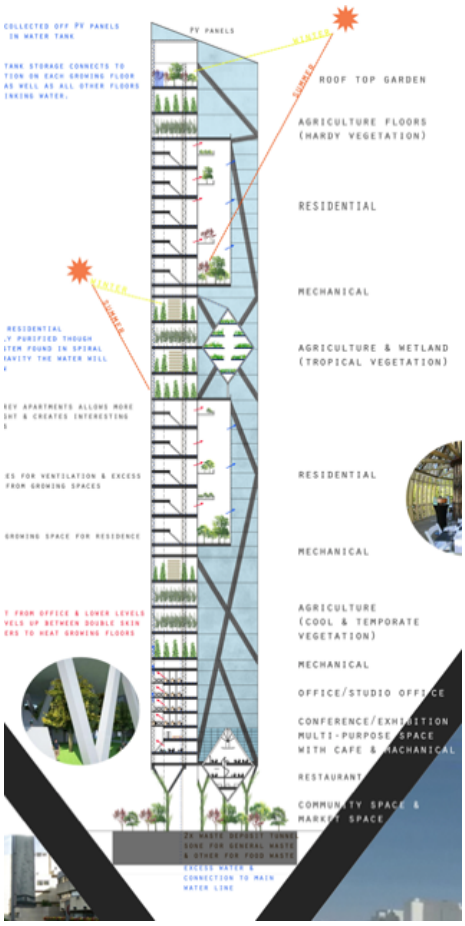


Figure 6.4: NF Visit 3 proposal

NF had maintained the same building shape but had attempted applying an irregular exoskeleton around it for contrast. The building, at 242 m tall, had remained similar in plan, although additional growing spaces inside its corners and cuts along its sides, purportedly for ventilation, were now included. These changes are illustrated roughly in Figure 6.4. A number of elements, such as a 'wetland' space and a 'hanging pods' restaurant were proposed, only to be abandoned in subsequent presentations. PV panels were also introduced to the roof and south façade, with some concerns as to their tilt and efficiency. Native crops were to be grown in three types of gardens, but the form and façade of the building had not been adjusted to allow for such growing conditions. The residences were arranged as 'villages' of one to three bedroom apartments, some of them duplexes, served by south-facing 3.5 m corridors on every two floors. The apartments had been designed at 7.5 m in depth and 3.5 m in height with the advice of the framework.

Consequently, the group again commented on the helpfulness of the suggestions in the framework relating to the dimensioning of space in accordance with environmental limitations. It had clearly been applying the framework, with markings throughout the text, until the middle of the façade section. It was also pleased that the guidance could be directly applied into the designs. On the other hand, the group found that there was a lack of 'tips' on where to find further information on specific topics. Reputable websites were suggested as sufficient for this purpose.

NN had concentrated on the building's structure, particularly in considering ways to make the building more laterally stable. A change occurred in the building form in that the large north-facing offices' plan reduced in depth from 10 m to 7.5 m and the residences' plans also reduced from 10-14 m to 7.5-10 m. This difference appears to be mostly for structural reasons, although there were indications that daylighting had

played a role as well. The residential areas consisted mostly of large studio apartments and the base of the building had been developed to some extent. NN had not used the framework, citing a lack of time as the main challenge, but had read some of it anecdotally. With façade studies as the next step, it was becoming clear that the group would be unable to apply the framework fully.

Visit 4: 12 May 2011, interim review.

NF had abandoned the irregular exoskeleton and continued to advance its building plans and sections, the latter being illustrated in Figure 6.5. The planting area's façade acted as a greenhouse, while the residential facades were a combination of white structural elements and more transparent, openable windows, at times with PV panels. The windows were to form a double-façade and punctured by a planted balcony. The two functions were also distinguished by the choice of fixed louvres in the south facade, with the residential ones vertical and those signifying agricultural spaces horizontal in axis. It was pointed out that the use of vertical louvres was not beneficial on the south façade, and that the framework indicated their use on the east and west areas only.

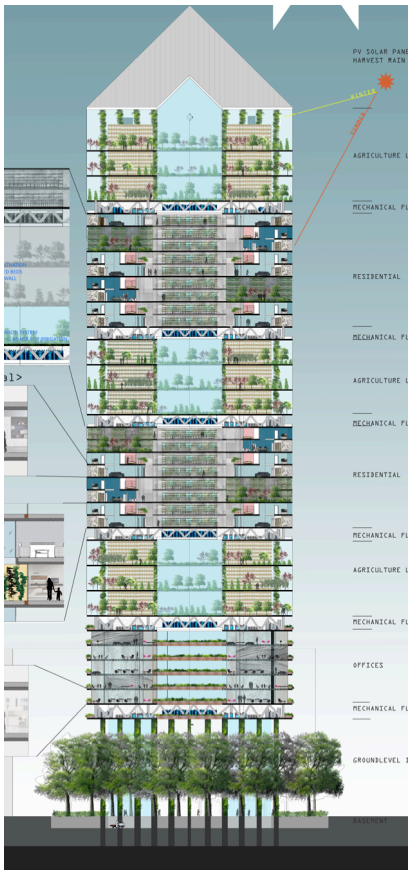


Figure 6.5: NF Visit 4 proposal

Furthermore, although designed for natural ventilation, the triangular configuration of the building and the humidity levels from the nearby gardens makes sufficient airflow unlikely. The group stated that the ventilation strategy was both natural and mechanical, but the use of a mechanical ventilation system was unspecified. The 'village' grouping of the residences with the vegetated atriums was a challenge for heating, as they were to be heated as one unit rather than individually. Other issues needing resolving included circulation, social sustainability and the ground floors. There was some progress on the rainwater collection system and slanting of the roof southward for greater PV output. All in all, NF had continued to apply the framework until the vegetation section, where it found sufficient information lacking.

NN yet again focused on structure, regressing to an earlier option. Progress had also been made on the circulation strategy and ground floor. The residences were still expected to have sufficient daylighting, but the ventilation strategy was unclear and the group did not present a strong argument that it would function. The shading system was also unusual, as it had been developed as part of a related façade technologies module. It consisted of movable horizontal and vertical louvres of 3 m in length and it did not appear to work well in this scheme. The group had also overestimated the amount of shading that a floor slab could provide for the story beneath it. All facades, residential and office, had double-glazed glass and a low air inlet and high exhaust outlet, but questions were raised as to the suitability of the high amounts of glazing and lack of opaque elements for the residential areas. There were some balconies in the residential areas. The core had yet to be resolved, and some options were discussed concerning the use of daylighting and stack effect within it. The flat roof served as a community space. The necessity of some renewable technologies for a self-sufficient building was discussed. Other than some basic dimensioning advice, NN had not used the framework as it had assumed that the environmental strategy would follow a structural solution.

Visit 5: 1 June 2011, final review.

The ‘vertical farming’ tower presented by NF, seen in Figure 6.6, was a refined version of earlier attempts. It consisted of a ‘market’ ground floor, raised 20 m above ground, offices in the form of labs and researcher space, gardens and residential ‘villages’. All spaces were set in an 8 m by 10 m grid. Most of the feedback from tutors and visitors present there did not center on its environmental strategies, as they had been resolved to a significant extent.

NF’s presentation of the ‘flooding tower’, seen in Figure 6.7, emphasized the building’s structure and the ‘flooding’ function of the raised ground floor. Feedback mostly focused on the design’s lack of flexibility and contemporary function, with some comments given on the façade’s absence of environmental responsiveness. It was agreed by the reviewers that it had not been a resolved project at that point.



Figure 6.6: NF Final Review poster

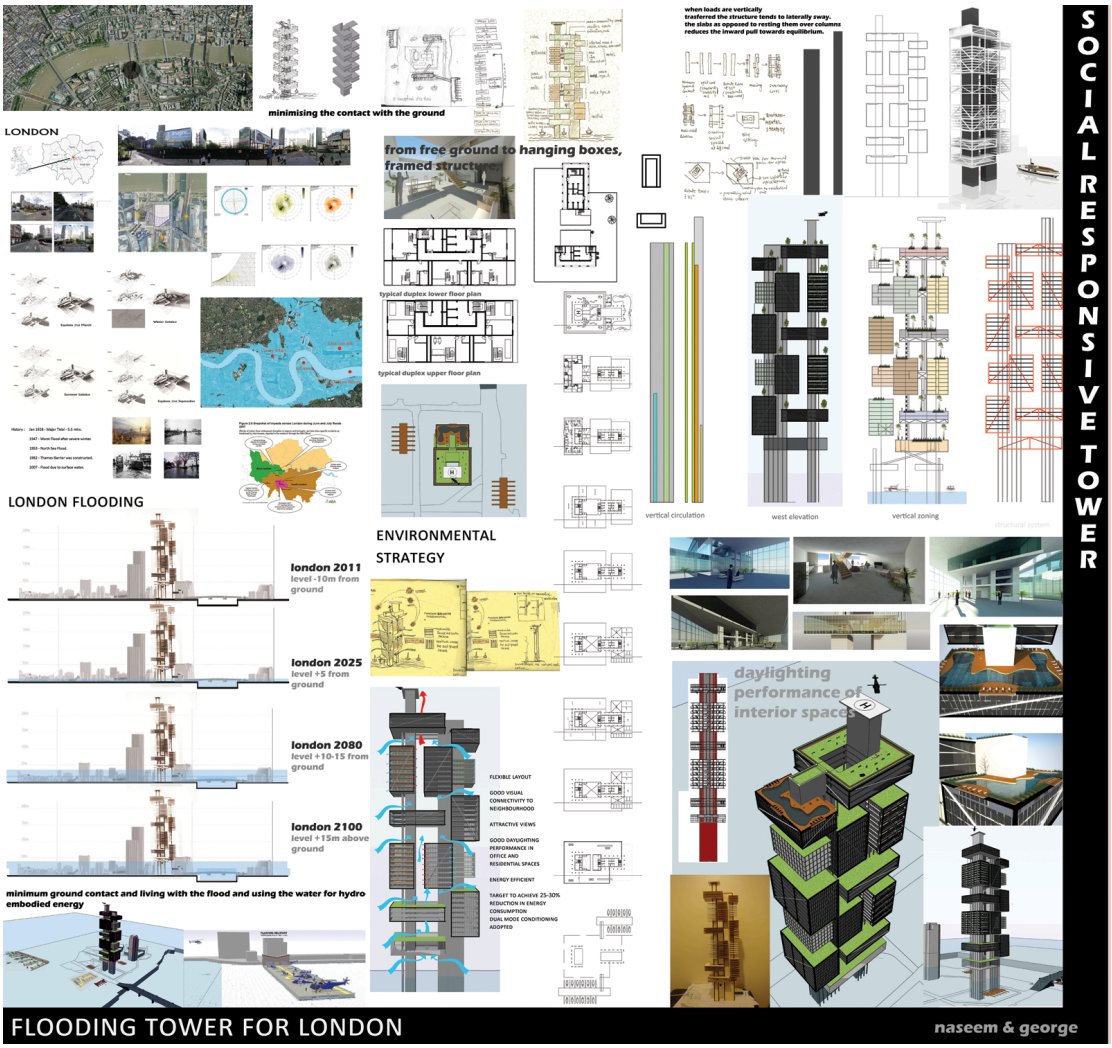


Figure 6.7: NN Final Review poster

6.2.2 Cardiff

The Cardiff module leaders had agreed that the students could voluntarily apply the framework fully or to any extent they judged suitable, with no specific conditions as in Nottingham. The fact that the Cardiff students focused on the environmental, rather than any additional design approaches, made the framework testing particularly suitable. Three groups therefore participated to various extents, ranging from no application of the recommended design process to its full use.

The Cardiff module began on 28 March 2011 with an introduction to the project and ended on 6 June 2011 with a final review for the tall buildings option. There were no interim reviews scheduled as in Nottingham, but regular weekly tutorials, interrupted again by the Easter break. The framework's author attended four sessions, including the introduction and the final review. As the final presentations consisted of multiple sequential posters that related to the framework, they are presented in full in Appendix C, and so here only the final design solutions are illustrated.

Visit 1: 7 April 2011, tutorial.

The students were introduced to the framework and encouraged to ask any questions related to its application. Most of the resulting questions related to information gaps found in the guide document, such as the zoning of the building in response to wind conditions. They asked for additional resources to fill these gaps, and were subsequently emailed a brief 'recommended reading' list of key texts and a copy of an early thesis literature review with details of Yeang's suggested strategies. As the first had been intentionally omitted from this version of the framework to test the limitations of Yeang's advice, it became clear, as with the Nottingham groups, that further advice should be reincorporated in any future framework revisions.

Additional questions were asked about the site, including the provision of parking for the building. Unlike the Nottingham groups, parking was considered to be necessary, but, like those groups, it didn't affect the building form as it was placed underground. Some discussion took place on the possibility of collaboration with the Nottingham group, but due to time and financial constraints this did not occur, with the exception of a Nottingham tutor's visit to the Cardiff final review.

After this meeting, the students developed ‘tall building manifestos’ with the main tutor. These would clarify and reinforce the design paths they were to take. CF agreed that ‘We will consider all the options offered in the framework, and we will respond to them as directed. If we find something difficult to understand, we will respond as best we can rather than consult the author. If an aspect of design is not mentioned, this allows us the freedom to do whatever we think best with respect to that.’ CP stated that ‘We will consider all the options offered in the framework, but will respond to them as we think best. This will allow us the freedom to [:] explore more complex resolutions of issues [and] give greater weight to non-environmental factors [.] If we find something difficult to understand, we will respond as best we can rather than consult the author.’ CF affirmed that ‘We have read the framework, but are not following its procedure. We will draw up our own framework for use in developing strategies. This allows us the freedom to consider our own design options, which may include or exclude options from the framework, and include additional options, both environmental and non-environmental.’

Visit 2: 13 May 2011, tutorial.

Unlike other tutorials, this one was based around a student critique of Nottingham groups’ work. The projects shown were those of NF and NN from the interim review of 12 May 2011. NN’s tower was assessed as having ‘unrealistic’ ventilation, and NF’s tower was found to adversely avoid the use of south-facing residences. All in all, both presentations were found to be well composed but lacking in environmental emphasis, when compared to the requirements in the Cardiff module, although NN’s project was found to be somewhat more favorably evaluated than it had been during the Nottingham interim review.

At this tutorial, the groups did not present the progress of their projects. Instead, they provided a confirmation that they had progressed as planned and added some general comments on the framework. Their key points were that the framework had an assumption of a compact south-facing building and that there was a focus on vegetated space. Both of these evaluations were correct, particularly as there was, respectively, a focus on bioclimatic principles and the work of Ken Yeang, but nonetheless this preference was to be noted in any future framework revisions and alternative options provided where appropriate.

Visit 3: 23 May 2011, tutorial.

Two of the three groups were present and discussed their progress and early tower designs. The group using the framework fully (CF) had spent some time contemplating the placement of its building on the site, as the framework did not provide guidance on this, and settled near the northern edge to reduce other buildings' shading effects on the tower's lower floors. The students commented that the framework would benefit from including guidance on this aspect.

CF had also considered its form, resulting in two typologies. The first, referred to as the 'Dummy's Box', was based on what it interpreted as 'using the framework strictly.' This was essentially a thin rectangular box in the center of the site. The second, 'Bottle', attempted to 'divert from such a simple and compact form' and consisted of floors decreasing in size according to height. The reasoning behind this form was the promotion of the southwest winds and the provision of a comfortable environment for pedestrians at the base level. The group had developed three options for this form. The highest one, 44 stories tall, with the smallest maximum plan area for access throughout the site, was chosen as the basis of the tower design. There are two observations to note here. First, the students had a very limited interpretation of 'using the framework strictly' in this respect. The framework did not prohibit the use of alternative forms, and in fact suggested a more balanced rectangular plan with a ratio of 1:1.6. The fact that the students did not fully comprehend the flexibility of the framework and could not view, and therefore apply, the ratio guideline image suggested that the framework needed further clarification and editing. Second, even with a severe interpretation, the students decided to adopt a building shape not specified in the framework, bringing into question their perception of applying the framework '100%'.

CF further discussed the use of window and shading steps, which it found helpful, and requested more information on ventilation, vegetation, specific wall types, balconies and systems. Despite the literature review and reading list, in which some books may have been difficult to locate, this request advocated the need for more direct information in the steps themselves. Due to time constraints, additional information was not sent and the students later indicated that a small number of additional resources were consulted.

CF's building plan needed further development as there was only one elevator serving the entire tower. It had also been based around the placement of living rooms along the north or south façade, the former for reasons related to view and the latter for environmental purposes. Views also were cited as the reasons behind the inclusion of extensive north and west glazing, which was not encouraged by the framework. In elevation, the lowest floors had a single glazing and the upper ones were double glazed, purportedly based on wind conditions. As these decisions were either not included in the framework or only weakly mentioned but had a significant impact on the building design, some discussion on their influence is warranted in the guidance.

CF also mentioned what was perceived to be randomness in choosing options, such as one type of glass over the other. It found this open approach had advantages and disadvantages, but in the end further stratification of the framework was felt to be beneficial. The organization of the shading steps was mentioned as a good model for a stronger hierarchy.

The group not using the framework (CN) had also started out its design with four typologies, but this time in apartment plans rather than elevation. The building had two service cores around which they experimented moving the residential modules. The group spoke of designing 'in three dimensions' rather that in '2 dimensions' that CF felt it was limited to, and so suggested it had more freedom than other groups in their design. This was an interesting observation in that it is true that the design guidance steps usually focus on the horizontal or vertical plane and rarely both. As including further '3D' steps in the framework would complicate its guidance and therefore bring into question its purpose, there are two options for responding to this criticism. The first is to acknowledge that the framework does have this restrictive element as it responds to climate-responsive design, which is in itself necessarily limiting when compared to more typical non-environmental design. The second is to revise the framework so that its organization makes clear when each dimension is being approached and therefore allows its users to more easily recognize that all dimensions are considered, albeit separately. Both were applied in the revised framework.

Visit 4: 6 June 2011, final review.

CF presented an instructive set of posters outlining its design process and evaluation of the framework; these are included in Appendix C. In the interest of brevity, these posters, as well as those of the other groups, will be discussed as part of the feedback Section 6.3 as they were evaluated fully afterwards. However, a few features stood out initially in the final review that are worthwhile mentioning here. Most noticeably, the framework matrix and steps had been color-coded to simplify their complexity. This was a fairly straightforward change that could be included in a revised document. There was also much solar radiation analysis presented through Ecotect models, which will be discussed in a later section. There were four detailed sheets on the choices made in the design process, alongside a table summary on a separate poster. Some of notes pointed out steps where the advice was vague or in conflict with other advice, as well as where links could be made. All of these points are to be addressed in a revised framework. The overall judgment on the design guide was that it was helpful but constraining. This was judged especially true if attempting to design in a non-orthogonal manner. More 'loops' linking steps were requested and also perhaps some summaries of sections. The steps were also expected to benefit from a weighing factor reflecting their significance.

The resulting design was critiqued by those present as posing some structural problems, in that the building was too narrow to have sufficient lateral support. Plans, with at most three residences per level, were too unrealistic, as was the use of some steps, such as the single glazing option, for certain areas. It was clear that the framework was for the most part followed extensively, sometimes at the expense of structural, planning and aesthetic requirements. As it is based entirely on environmental sustainability, this is to be expected of a literal application. However, this result was shown to have caused the framework to be regarded as restrictive and at times detrimental to the overall design. Therefore, stronger acknowledgement of its limitations is required, as well as further qualifications.

The group partially using the framework (CP) presented a tower with a plan splayed in order to increase the south-facing surface area. Like CF, it had also included some elementary building simulations, but this time of both radiation and airflow. Whereas the first group had analyzed their building at the end of the design process, CP had tested it during the process of design. The question of modeling would suggest that this was a weakness in the framework, but as the framework is not an evaluative

tool, it can be argued that guidance on modeling is beyond its scope. In any case, future versions would point out any critical steps that require modeling.

CP had decided to increase the use of glazing to 40% from the recommended 20%, even with an increase in floor-to-floor heights. This was felt to improve daylighting and the view north, although it would undeniably have an affect on the building's thermal performance. This was in sharp contrast to CF's decision to decrease northern glazing to 15%, signifying the two groups' varying priorities. As they had partially used the framework, CP students commented that contextual advice should be included in the framework and that it would benefit from certain quantifications and guidelines.

The group not applying the framework (CN) presented an orthogonal U-shaped tower, based on the placement of four apartment typologies and solar access. Like CP, it had simulated radiation and airflow, but had further quantified the majority of their design options and decisions. CN's presentation was based around a flowchart illustrating their design process, which was, according to the group members, based on previous experience. The diagram consisted of four stages: 'Inception', 'Design Parameters', 'Building Design' and 'Evaluation of the Design'. The first two stages could be considered 'pre-design' stages in that the first analyzed the brief's contextual, social and environmental requirements and the second appeared to act as a sort of compilation of 'notes' from which the design should develop. In fact, many of these notes had similarities with the framework steps in that they provided advice such as building orientation and inclusion of skycourts. Furthermore, if the framework were to be applied as a checklist, as one group, CF, commented, it would function much like this 'design parameters' section of CN's flowchart; it should be remembered, though, that the framework is not designed to be a checklist in any case. This section of the flowchart also included 'Surroundings and Buildings' as one of the two main 'Design Parameters', once again highlighting the importance of site guidance for the Cardiff groups in particular. The 'Building Design' section started out with a 'Configuration of Form' that was based as much on a logical arrangement of apartment typologies as environmental responses.

The second step, relating to the layout of the typologies in accordance with passive design requirements, was not illustrated in the presentation. It nonetheless was apparent that this part, applying design principles such as shading and material selection, concerned itself more with apartment typologies rather than the building as

a whole. There were exceptions to this focus, such as the placement of the core, but this emphasis on individual apartments was also true of the visual and thermal radiation analysis. This way of approaching design contrasts with the framework in that the building is oriented and configured to a great extent around the apartments. This design method attempts to insure that the main concerns of design, the residences, are environmentally responsive, which could be at the expense of subordinate spaces like the core. There is also a risk that the residences, while functioning well on their own, might not act as well when arranged adjacently. This does not seem to be the case here, however, and the design process presented offered some questions and ideas for the framework revision.

6.3 Questionnaire

In addition to observations of the design process, the guidance aspect of the student trials took the form of notes on a framework document, for those groups using it, and a questionnaire for all at the end of the design process. The notes on the framework were submitted in a PDF version of the document by NF and as part of the final presentation by CF. As NF provided feedback specific to each step and the general conclusions of CF were presented in the final review and mostly repeated in the questionnaire, their findings will not be reiterated here and can be found in detail in Appendix C. This section will instead concentrate on the feedback questionnaire as it provides a more general review. All individual responses to the questionnaire can also be found in Appendix C.

Due to the scope and depth of questions covered, the questionnaire formed one of the primary elements of this research. It consisted of 25 questions categorized according to the students' design foundations, framework application, the framework's effect, utility and areas for improvement, tall building design challenges and design guidance in general. The groups using the framework fully or partially (NF, CF and CP) provided responses to all questions, while those not using the framework (NN and CN) were asked to provide answers to questions 2, 3, 4, 7 and 20 through 25.

One student from NF provided an individual response. Individual responses were received from each CF member, here referred to as CF1 and CF2. CN and CP provided group responses. No response was received from NN and will therefore be discounted in this section. The responses relating to design foundations and

framework application have been discussed in the sections above. Questions relating to design guidance in general are included in Chapter 7.

6.3.1 Effect of the framework on design assumptions

Question 8. In what ways did you find the framework supported your assumptions about environmental design?

All responding students agreed that the framework supported their assumptions about environmental design, particularly as it related to radiation. Two students (CF2 and NF) referred specifically to thermal radiation and two students (CF1 and CP) indicated daylighting. One student (CF1) found that the framework provided 'several more specific guidelines', such as room depth specifications for one-sided daylighting. CF2 commented that basic approaches, such as thermal performance and ventilation, were supported, but that there were still 'gaps that needed extra time to reflect on that we didn't have.' In this sense, the framework went beyond basic bioclimatic advice and added further approaches and aspects to consider.

Question 9. In what ways did you find the framework added to your assumptions about environmental design?

One student (CF2) could not remember the ways in which the framework added to assumptions about environmental design and one student (CF1) had a more general answer of 'illuminated interesting points'. Two other students responded with specific steps, one (CP) on zoning airflow according to building height (Step 8) and another (NF) on determining the depth of the building and rooms in response to radiation and airflow conditions (Steps 4, 5 and 7). As in the observations, the student from NF found that the measurements provided there useful. The response to this, and the previous, question indicates that the framework supports already existing instruction in environmental design and expands on the knowledge gained in relevant courses.

Question 10. In what ways did you find the framework conflicted with your assumptions about environmental design?

One student using the framework (NF) stated that the framework didn't conflict with any assumptions about environmental design. The two students from Cardiff using the framework (CF1 and CF2) both responded that the framework was difficult to

follow at times and that some steps contradicted others. CF2 expressly stated that 'It was not easy to follow a one-way route towards the last step. Most times we had to go back and review previous assumptions.' This problem was mentioned in the Cardiff final review as well, and so additional information was provided on each step separately in the final version. In general, the main ways of addressing this inadequacy are through extra information and links to other steps being included in each step. Although the groups in Nottingham and Cardiff had different responses, from other comments it can be assumed that all groups would welcome additional information and clarity in a revised version of the framework.

CP responded with a wide-ranging comment that 'The framework needs to address the main environmental aspects (lighting, thermal analysis, ventilation) in a more holistic way.' How it would do so was unspecified, but again the inclusion of links could make the relationship between the steps more apparent. CP also responded with a specific comment that the 15-20% glazing to wall ratio was 'something that didn't work for our design', as was noted in their reviews.

All in all, although the framework as a whole did not appear to conflict with assumptions about environmental design, there are some internal conflicts within it that need to be addressed in its revision.

6.3.2 Framework utility

Question 11. How helpful was this particular design framework for you as an educational tool for the environmental design of tall buildings?

All groups, to varying degrees, found the framework to be a helpful tool. NF stated that, for a first tall building design project, 'it was a good starting point'. CP found that it was 'Very useful.' CF1 stated 'Very helpful, especially if you have few knowledge on environmental design. Valuable when complete and when treated as a guidelines tool instead of a step-by-step process to be followed.' CF 2 commented:

> It was helpful in terms that it sets the base and can be subjected to improvements. I also realized how many considerations one should have in mind when forming this sort of framework and in general how difficult is to develop a 100% accurate and complete framework.

This feedback therefore concludes that, at least among students interested in environmental tall building design, the framework was a useful educational design tool. CF1, as echoed in other comments, felt that the tool could be further developed

and that it needed to be used as a guideline rather than a restrictive process. The revised framework consequently is to provide additional information for each step and to discuss in an introduction its purpose as a guide.

Question 12. Which parts of the framework did you find most useful?

All students found the first half of the framework most useful. CF1 referred to the 'core of the framework, especially the window shading devices part', CF2 to the 'first parts that had the most details', CP to 'Steps 1 -29' and NF to 'floorplate depths and floorplate configurations.' This is unsurprising, at this half had included the greatest amount of information and its structure had been most fully tested and developed. A similar approach would be needed for revision of the second half of the framework, but, as discussed in other sections, a choice was made to focus on the bioclimatic elements in the final version.

The groups using the framework had throughout the progress pointed to the Fabric: Thermal Radiation (Decrease), or shading, section as the best organized. CF, in their final presentation posters, stated that this section was the 'Ideal presentation.' Where it differed from some other sections was in its specificity of elements and the clarity of its hierarchy. Therefore, although its exact format was not adopted in the final framework version, as it would overcomplicate the structure at other points, its hierarchy would inform the later revision.

Question 13. Which parts of the framework did you find least useful?

As anticipated in the responses for Question 12, the second half of the framework was found to be least useful. CF1 found that the 'last part about services' was least useful and CF2 echoed that analysis by referring to 'Some parts at the end,' due to a lack of information available. This summary also reflects posters from the Cardiff presentations, where the CF group commented on the 'predominant phenomenon' of 'blank pages' towards the end, especially in the systems and renewables section. Again, as the final framework would emphasize passive approaches and as renewable and system technologies become outdated relatively quickly, the final framework would not include them.

Like the Cardiff framework group, a Nottingham student using the framework (NF) commented on steps lacking information, particularly those 'parts without pictures.' This critique nonetheless supports a basic premise of the framework, that it should

be illustrated, as architects prefer information presented visually. An initial attempt was therefore made in the final framework to include more images, although the complexity of the advice later suggested that such images would likely be inaccurate or unrepresentative of the entire step or option and so the images serve an illustrative point only. The popularity of the images among the test students reflects the popularity of illustrated books among architecture students in general**;** in the North American context, for example**,** the popular illustrated works of Francis D. K. Ching have remained in publication for decades: *Architectural Graphics* (2009) is now in its fifth edition, *Architecture: From Space and Order* (2007) is in its third and *Building Construction Illustrated* (2003) in its third, all being initially published in 1975. With further resources, an expansion of the guidance and a different digital format, it could be argued that the framework could eventually reintroduce this type of guidance.

NF also stated that that parts that repeated and had unconventional numbering were confusing. This problem was resolved in a restructuring of the final framework so that options were limited in number and links made more apparent.

Question 14. Based on your experience of using the framework to guide your decision-making in the design of a specific building, how do you think its use influenced the following aspects of your design:

a) Overall building form:

strongly/slightly/not at all beneficially/adversely

The Cardiff students responding to this question (CF1, CF2, CP) all felt that the framework 'strongly' influenced their building form. This was in direct opposition to NF's response, which stated that it did not influence the design at all. It is clear that the Nottingham student had a much more liberal approach to its application than the Cardiff students. In one way, this was beneficial, in that the framework was not meant to be restrictive in creative decisions. However, the fact that the building form has much higher proportion of influence on the environmental performance than later decisions brings into question if there should be areas where the framework needs to be restrictive. In their presentation poster, the Cardiff framework students likewise stated that 'There should be some indication on important steps that they should better not be rejected' and that

'…the factors to been taken into account, are highlighted but they haven't been given an importance factor. Is this because the editor considers that it is subjective or varies for

different sites or it was just neglected? Someone will need some guideline about this, for the framework to work as a tool, since some contradicting choices depend upon this.'

Note here that because of this lack of preference indication, the students sometimes felt the options were contradictory. The final guidelines and links should improve the next revision, as should the bioclimatic focus.

There were also a variety of responses relating to the type of influence the framework had on the building design. Both students using the framework in Cardiff (CF1 and CF2) indicated that the framework 'adversely' affected their design, whereas the Cardiff group partially using the framework (CP) stated that the influence was 'beneficial'. NF did not respond to this part, as it related to the 'not at all' response in the first part of the question. Again, given the other feedback in the presentations and within the questionnaire, CF students strongly felt that a rectangular plan needed to be assumed. The revised Framework Introduction therefore needs to discuss these (incorrect) assumptions, highlighting the fact that the rectangular plan images are for illustrative purposes only, and additional options in the early steps of Configuration: Visible Radiation (Increase), Configuration: Thermal Radiation (Increase) and Airflow (Increase) should be offered.

b) Structure of the building:

strongly/slightly/not at all beneficially/adversely

As in Question 14a, the groups fully using the framework vastly differed in their responses. NF stated that the framework 'slightly' influenced the structure of the building, whereas CF1 and CF2 both claimed that it 'strongly' influenced it. Furthermore, NF found that it 'beneficially' did so, while CF2 stated it did so 'adversely' and CF1 felt that this part of the question was not applicable. As structure is most dependent on early design choices, these responses correlate to previous replies, particularly interpretations of restrictiveness. However, as the framework itself does not provide any direct guidelines on building structure, this question highlights that bioclimatic design inadvertently has much impact on its development. Therefore some guidance should perhaps be provided, although in this case it should be supplementary to the actual framework guidelines and perhaps be offered by engineers or consultants.

Illogically, CP found that the framework did not influence the building form at all, but that it nonetheless did so adversely. It is unclear why both responses would be

applicable. This finding is also difficult to put into the context of other responses, as these students felt that it had a 'beneficial' influence on the building design. In any case, it highlights a need for the clarification point mentioned previously.

c) Outer building envelope:

strongly/slightly/not at all beneficially/adversely

The responses to this part of the question were more consistent. CF1 and CF2 found that the framework influenced their building envelope 'strongly' and CP and NF felt it did so 'slightly'. As the 38 of the 61 steps/options in the framework related to the building fabric and as elements of the fabric steps were found to be most useful, this is not an unanticipated reply.

Three of the four responses stated that the framework's effect was 'beneficial'. However, there was a disagreement between the two members of the CF group, with CF1 claiming that it 'beneficially' influenced the building envelope and CF2 stating it did so 'adversely'. However, judging by comments during the observation process and the notes from the final presentation, the framework had a more positive influence than a negative one in this regard. Although some students felt that it limited the overall building form, and hence the overall envelope options, many of the options available, such as shading, were seen as beneficial contributions.

d) Thermal design:

strongly/slightly/not at all beneficially/adversely

All groups stated that the framework 'beneficially' influenced their buildings' performance. This suggests that the framework's hierarchy had a positive effect on improving and encouraging thermal design. The first step, in fact, was part of the Configuration: Thermal Radiation (Increase) interaction, and all other design phases, with the exception of renewables, included a consideration of options relating to thermal radiation.

CF1 and CF2 found that it 'strongly' influenced thermal design, whereas CP and NF found that it did so 'slightly'. This is expected as the CF students had decided to use the framework fully and most restrictively.

e) Lighting design:

strongly/slightly/not at all beneficially/adversely

All students did not see lighting design being influenced by the framework to the same extent. CF1 and CF2 both felt that it 'strongly' influenced it, as did CP. NF, on the other hand, stated that it did not influence it at all. However, this last response does not match the other comments from this student, including the statement that some of the most useful parts of the framework were 'measurement' options such as steps 4 and 5, both of which relate to visible radiation. There is a possibility that the student misunderstood this question as referring to the 'systems' lighting design aspects.

Nonetheless, all students did respond that the framework 'beneficially' influenced the lighting design. As much of the guidance on visible radiation was provided in the first part of the document, these responses correlate well to previous comment on the first half of the framework being the most useful. This impression is echoed in the bioclimatic focus of the guidance.

f) Ventilation design:

strongly/slightly/not at all beneficially/adversely

Three of the four responding students (CF1, CF2 and CP) found that the framework 'beneficially' influenced ventilation design, while on (NF) did not offer a reply to this part of the question. Again, given the framework's emphasis on bioclimatic design, this positive response was intended. As in part *e)*, CF1 and CF2 felt it influenced their ventilation design 'strongly', while CP and NF did so 'slightly'. As before, these responses relate well to the extent to which the framework was applied.

g) Internal planning:

strongly/slightly/not at all beneficially/adversely

The groups using the framework fully (CF1, CF2 and NF) stated that the framework 'strongly' affected their internal planning. However, NF stated it did so 'beneficially', CF2 'adversely' and CF1 added a response option of 'not applicable'. Once more, this could be related to an interpretation of its use, but it should be noted that the framework at that point offered little advice on internal planning, outside of the 'measurement' aspects discussed previously. It did not examine the placement of rooms in respect to one another, the placement of specific types of rooms towards

certain orientations, the location of internal hallways, etc. Although this guidance was not emphasized much by the groups, upon a review of the framework, the author has decided that they would add some beneficial direction for the building design.

CP, who stated that the framework did not influence their internal planning at all, did nonetheless find it 'adversely' would do so otherwise. This response, as well as review of the final presentations, supports the point above on including some basic guidance on internal planning within the revised framework.

h) Water use:

strongly/slightly/not at all beneficially/adversely

Three of the four responding students (CF1, CF2 and NF) claimed that the framework did not influence their water use at all. One (CP) did not offer a response. There was no response also from three students on the type of effect it had, with the remaining one (CF1) stating that it did so 'adversely'.

The replies here are less consistent with other comments in the framework and during presentations. CF had, according to the presentation document, applied all steps relating to water, and NF had done in the majority of the cases according to the annotated framework. NF also commented that 'water recycling played a major role in our design' and provided a booklet detailing its use. This disparity between the questionnaire comments and those in other documents and observations can be attributed to two factors. In the case of CF, although they did apply the guidance, they did not appear to find it fully developed, as was the case at times with the second half of the framework steps. This would explain both it 'adversely' and influencing their design by one student and a lack of response by the other. Equally, NF had not relied on the framework much for providing water use guidance, and instead referred to other more detailed resources. Nonetheless, both groups appear to have found that the framework did not provide guidance required for their differing levels of interest in the subject.

i) Material selection:

strongly/slightly/not at all beneficially/adversely

Two of the students stated that the guidance influenced their material selection process 'beneficially', one (CF1) stating it did so 'slightly' and the other (CF2)

'strongly'. NF found that it did not affect material selection at all, although the annotated framework does imply that some of the steps were applied. CP did not offer a response to this question.

j) Renewable technologies:

strongly/slightly/not at all beneficially/adversely

As in part *j)*, CF1 found that the framework 'slightly' and 'beneficially' influenced the application of renewable technologies, whereas CF2 though it did so 'strongly' and 'beneficially'. Again, CP found it did not have any influence, even though there was a clear use of elements such as photovoltaics and biofuels in the design. CN did not offer a response for this part of the question.

In addition to the recommendations of additional information by the CF group, the fact that the NF group did not feel that the framework affected their use of renewable technologies while such technologies were applied in any case brings into question again if the location of renewable technologies within the framework is appropriate. Intentionally, the framework in this stage exhausted all bioclimatic options before introducing renewable technologies; the literature review shows that it is often not the case in current practice, with detrimental results. This feedback further supported the omission of non-bioclimatic elements.

6.3.3 Areas for improvement

As stated previously, a more detailed listing of action steps relating to areas of improvement specified by the students can be found in Appendix C. The subsection here will iterate and analyze questionnaire responses in the wider context of structure, clarity, guidance, the path the framework suggests for the design process and its relationship with non-environmental aspects of design.

Question 15. In what ways can the framework be improved with respect to:

a) Its structure?

The Cardiff framework students (CF1 and CF2) did not comment on any possible improvements to structure. Instead, CF1 stated that 'The section of the window shading devices was the best structured part'. CF2 also wrote 'I think the process

with the steps was helpful enough so as to decide if you are going right to the next step or you have to jump some steps according to your assumptions.' As they were the students using the framework to the greatest extent, these comments suggest that the framework's overall structure, in the form of the matrix, does not need major alterations.

CP's improvement idea, 'Back and forth between different aspects', related to the aforementioned necessity for further links between steps. This is to be included in the framework revision. NF indicated that 'sometimes when the yes and no next step was the same it was confusing to understand what difference it made,' but this is more of an issue of clarity and therefore improved in a revised version.

All in all, compared to the major changes to the framework the author had undertaken before, the changes suggested by the students are minor and do not impact on its main structure.

b) Its clarity?

CP commented that the framework, generally, 'was clear'. NF suggested that 'maybe colour images would be helpful,' a slight, but noteworthy, change to make. CF1 and CF had more substantial recommendations. CF1 stated that 'Some steps are confusing and other even controversial' and therefore there is a need to 'Set priorities.' This comment corresponds with comments from CF observations and the presentation poster, and so needs addressing. Additional information and further editing is needed for the steps. Although the framework avoided adding any 'controversial' suggestions, such comments nonetheless justify the inclusion of additional references and a brief literature review for each step to moderate this perception.

CF2 likewise pointed out that 'More details can be provided in the parts that contain terms and techniques/technologies difficult to understand.' This is a point also mentioned by NF in the annotated framework as 'did not really understand what leeward was'. Furthermore, CF2 pointed out that 'blank pages' 'should be definitely filled with relevant information.' Therefore, the reintroduction of resources omitted from this version of the framework will be supplemented by other texts.

c) The guidance it gives?

CF1's comment mirrored that of CF2 on clarity, in that it suggested the framework 'needs to be complete and corrected at some points. The last part gives very limited guidance' and that some steps were blank. CF2 continued along the same lines as before, stating that 'There could be more details in some steps. It should be noted that the first steps are more than adequately explained.'

Similarly, CP commented that 'It would be useful if references were provided or additional information to explain some aspects to a greater depth (eg step 29)'. NF added a need for 'more information or consistant amount of information per page'. These suggestions have been noted previously and are therefore to be included in the revised framework.

d) The path it suggests for the design process?

There was no response from NF on this part of the question. CP commented positively with 'It was quite clear' and CF1 with 'It is an interesting and helpful path'. CF2 provided a more substantial response, but one relating to guidance in general. Noting that 'I am quite certain' that much research had informed that path, the respondent continued:

However, from my point of view (and as long as I was involved in this project), I believe that it is very difficult to follow a one-way route towards the end. There are so many considerations relating to every single step and so many interactions and relationships among the distinct parts (e.g. thermal performance, lighting design, ventilation etc.) that you will always have to do turn-overs and go back and forth again.

The framework did attempt to 'simplify' the route towards environmental design by adding a series of steps within a hierarchical structure. Nonetheless, links to other steps, admittedly only to those following them, are included in order to present a more 'holistic', as CP had requested, form of guidance. Nonetheless, it is clear from this response, and some others, that the framework should incorporate some links to previous steps as well. This inclusion would benefit not only students in 'checking' their design's progress and changes, but also in giving them the impression of a more interconnected series of steps. Therefore, the steps template in the revised framework is to include both a 'future links' element and a 'past links' one.

e) Its relationship to non-environmental aspects of design?

NF and CP did not offer a response to this part of the question. CF2 stated 'No idea.' CF1, on the other hand, replied 'It has very limited reference to non-environmental aspects. Structure, aesthetics and other aspects could be added.' This evaluation is true of the framework, as it had a singular, environmental emphasis. The inclusion of other aspects, such as structure and aesthetics, at best, 'could' be added, but this seems by no means compulsive. Planning, on the other hand, had been commented earlier as being helpful, and so has a greater reasoning for a presence. Nonetheless, it was clear from some of the presentations that all of these types of guidance were at times deficient, as noted in the observations, despite tutors' efforts and students' own research. The fact too that the students did have guidance on these aspects also suggests that such circumstances may not be the same in other institutions/practices and argues for the addition of some supplementary guidance. Therefore, although the revised framework will not aim to provide any detailed guidance on non-environmental aspects of design, its Introduction will highlight these limitations.

6.3.4 Restrictions

16. Did you find the recommendations in the framework or its structure restrictive? If so, please list the restrictive elements.

The main area of restriction as noted by the students was the rectangular form. CF1, in response to the question, stated that 'At some points yes; e.g. the first references to the orientation of the building restricted the building shape we could create to be able to follow the next steps.' Given other comments by this student, this relates directly to CF2's response of 'Yes. For example, the plan of each floor of the building cannot be other than rectangular. This was a major constraint. You don't have many choices and you cannot be really creative within this context.' CP, too, commented, 'It was restrictive in the process to choose a building form (only a rectangular form was considered in the framework)'. Even though the group avoided the rectangular plan, NF's response was essentially the same: 'it was unadaptable for a building not in the form of a rectangle but that was mainly in regards to core placement'.

As mentioned previously, this was not the intention of the framework, but clearly the impression it gave. The decision of a rectangular plan in the first and subsequent steps was based more on orientation than form making. A rectangular image was in part chosen as it allowed a most clear demonstration of north/south/east/west

orientations. It is true that Yeang's advice recommended a rectangular building for this climate type, but this suggestion related to Step 6, which apparently no student applied. Therefore, there was perhaps an assumption by the students that such a plan was necessary for a design following this framework. Furthermore, there was an intuitive assumption by the author that most students would begin with a standard, rectangular plan as it would allow for a building with more advantageous orientations. It is clear though that these assumptions were disadvantageous, and so the revised framework is to include both a discussion on why the rectangular plan may be beneficial in this climate as well as options for other building forms that may be suitable.

6.3.5 Strengths

17. Please list the strengths of the framework that you have not already mentioned.

NF offered no response to this question, and CF2 replied with 'N/A'. CF1 stated 'It has a summary of the aspects that need to be taken into consideration. It pretty much makes sure nothing is left out.' CP responded with 'The framework helps especially inexperienced designers to take into account all the necessary steps for a successful design'. It is evident from these and other comments that the students found the inclusion of simple steps within the framework a strong point. The variety of steps, including both common and less usual options, was noted as helpful and comprehensive. Consequently, the revised framework is to maintain the 'step' structure.

6.3.6 Weaknesses

18. Please list the weaknesses of the framework that you have not already mentioned.

CF1 responded with 'Connection of framework to matrix not obvious, several errors and gaps, sometimes un-clear instructions.' The first of these weaknesses is to be addressed in a revised Introduction, and the others through further editing.

CP was more specific, with a number of suggestions. Although both Step 2 and Step 10 relate to the building core, the student noted that the 'possibility of locating the core in the west or east side of the building is examined in step 10 where it can be

very late.' This can be explained as the preferred core placement is on the north side for thermal radiation purposes (Step 2), while the east and west sides are more applicable as core placements for airflow obstruction (Step 10). Nevertheless, there could be a secondary reasoning for east and west placement for the core for the reduction of solar radiation during summer periods. Although this is not part of the reasoning behind Step 2, it needs to be accounted for. This step therefore needs to at least raise this possibility and link it to subsequent steps where appropriate.

CP added, 'The location of the building within the site it is not examined at all.' Furthermore, the group stated 'No specific guidance is provided in order to reduce glare. We suggest that the contrast between the two halves of the room does not exceed the value of 1/3.' Step 12 provides guidance on glare, but it relates to glazing/external wall ratios and the daylight factors at the back of the room. However, as glare, like view, is outside of environmental sustainability, it does not affect the function of the building and so this step will be omitted in the revised framework. Instead, some guidance will be provided in steps relating to daylighting. Lastly, CP commented 'Only horizontal shading devices are considered.' This observation is a valid one, even though this was not the intention of the framework. The inclusion of vertical shading devices is not apparent in the guide as it stands, so a separate option is to be included.

19. Please list any errors you may have found in the framework document.

NF offered no response. CF1 and CF2 referred to the final presentation poster, which can be found in Appendix C, and C2 added that 'Some steps were kind of misplaced.' CP again provided specific notes. 'Steps 4 and 7 suggest different maximum values for the maximum allowable floor depth.' As Step 4 refers to visible radiation and Step 7 to airflow, this discrepancy is logical. In any case, the recommended depths overlap and so should not cause problems during the design process. However, an improved Introduction will highlight this organization and discuss the arrangement of complimentary steps. CP added 'The framework provides exactly the same guidelines for both side and cross ventilation.' This is true, and unfavorable. Therefore, this section is to be restructured and supported by additional resources.

6.3.7 Design challenges

22. What environmental aspects of the design of tall buildings did you find most challenging?

There was a range of answers from all four responses. CF1, surprisingly, mentioned 'The effect of the urban heat island phenomenon.' This aspect is something that is outside of the framework scope. CF2 was less specific, stating 'It depends on the surroundings. Natural ventilation against wind protection especially on the top floors.' The zoning of the building and recessed windows are included respectively in Step 8 and in number of options in Step 29. Since the organization of the natural ventilation section is to be reformatted, these steps are to be expanded on and further references provided.

CP, echoing earlier comments, referred to 'Site analysis and designing for the wind.' NF indicated 'the sun penetration and retaining heat gains, the wind tunnel effect at groundlevel'. CP's and NF's comments are to be addressed with the airflow reorganization and additional information.

23. What non-environmental aspects of the design of tall buildings did you find most challenging?

CP did not respond to this question and CF2 could not recall anything. CF1 mentioned 'The interaction with the surrounding buildings', which falls under the 'pre-design' context revision. CN mentioned 'aesthetics', which as mentioned is outside of the framework but is to be discussed in the Introduction. NF mentioned 'circulation', which certainly was a major issue throughout the design process due to the building's triangular plan. Some reference to circulation, as it relates to planning for sufficient daylighting and ventilation, is to be included in the revised framework.

24. What non-environmental aspects of the design of tall buildings would the framework benefit from including?

CF2 and CP offered no response. CF1 replied with 'The interaction with the surrounding buildings', using 'right to light' as an example to consider. CN mentioned 'Social issues' and NF 'circulation'. Again, many of these issues go beyond the scope of the framework, and would be difficult to address in such a systematic manner.

6.3.8 Student questionnaire results summary

In Stage 3 the questionnaire served as a primary research method to evaluate the usability of the framework by other designers. By providing a series of questions that encouraged the students to both rate certain elements of the framework and to provide additional comments, the answers could compare the usefulness of certain elements within the framework and point to areas previously not considered. Some of the strengths and weaknesses were discussed throughout this chapter, but here it is helpful to highlight some of the outputs as they relate to the research objectives.

To begin with, the students found that the framework was not only a useful tool that supported existing assumptions relating to environmental design, but also one that offered new strategies and more details for strategies they had previously encountered. This inclusion of a variety of principles and detailed guidelines, especially the 'dimensions' often referred to positively, are one of the framework's more prevalent strengths and are to be maintained, and expanded on, in future versions. Few areas, such as internal planning, required further guidance, and no specific strategies relating to 'environmental design' as defined in this research were omitted. In this sense, this trial had positive feedback regarding the first research objective, that of finding principles of environmentally sustainable design.

The most consistent critique in terms of individual steps was a lack of information and illustrations, especially in the second half of the guidance. As the information included in this stage was only from Yeang's text and as some of the strategies were more experimental, especially for tall buildings, this outcome suggested that further resources would need to be consulted and discussed. Furthermore, the students often requested information that was not central to the application of the principles but that would discuss their origins and highlight relevant research. By also considering alternatives that were not recommended as viable options but that could override the framework preferences, these discussions could additionally help to lessen the perception that the framework was restrictive. A method for including such information without interfering with the key facts in the steps would therefore need to be developed.

More broadly, bioclimatic principles were found to be the most developed and most beneficial. Given the roots of the framework in Yeang's texts and the main concerns of the schematic design stage, this result was somewhat expected. That outcome,

and the relative strength of information on renewable resources in the assessment systems considered in Stage 2, argues for the framework's focus on bioclimatic design as originally intended.

The second objective, organizing these principles so that they best inform architects during the schematic stage of design, had also received encouraging feedback. The overall organization of the framework matrix and sequence was found to have been mostly useful and positively influential; again, this result was especially true in terms of bioclimatic strategies. Overall, the students preferred a more hierarchical form of step sequencing, as evidenced in Fabric: Thermal Radiation (Decrease). However, such a structure was not applied consistently through the sequencing, leading to unnecessary repetition, retrogression and confusion. The links between the framework matrix and sequencing would also required

A major weakness in the framework's organization concerned the relationships between the various steps. Although there had been an attempt to provide links between them, these were often not prominent enough and led to some students retrogressing to earlier steps when a conflict appeared. To remedy this, the aforementioned hierarchy in the sequencing of the steps would need to be expanded and made more plainly visible, and information on when a previous step choice would either encourage or limit the use of subsequent steps, and vice versa, would need to be highlighted. Likewise, the relationship between the three major elements comprising the framework would need to be further discussed in its introduction.

6.3.9 Critique of questionnaire design

All in all, the questionnaire feedback had led to insights and suggestions that most likely may not have emerged otherwise. The range of questions asked both filled the gaps in the author's observations and students' framework notes and highlighted the various assumptions the students and author had made prior to this trial. In tandem, specific questions allowed for a more straightforward rating and focused responses to particular themes and framework elements. In this sense, the questionnaire's design was successful in encouraging the students to provide data that would determine it as a main element of the research. Nonetheless, as with the framework itself, after the student feedback was collated, some areas for further improvement in its design became apparent.

First, although the scope had been sufficiently broad to capture responses to a range of issues, the questionnaire would have benefitted from a structure that related more directly to the research objectives. As it stood, it consisted of nine sections for discussion, which were organized logically but which were not presented as specific to any particular objective. Direct references to the design principles and their organization would have allowed for more relevant feedback in some sections and hence a less complicated evaluation. However, some of the benefits of the current format, namely the range of issues that emerged, may have lessened if the questions had been more limited in that respect. A compromise, perhaps, would have been to restructure the 'Areas for improvement' or 'Strengths' and 'Weaknesses' sections to directly refer the objectives, while allowing other sections to contain more open-ended questions.

Likewise, Question 14 in particular would have benefitted from a more structured format. At times, the student responses indicated that 'strongly', 'slightly' and 'not at all' could be interpreted differently amongst individuals. A scale, for example of 0-10, with 10 indicating the strongest influence, may have remedied this inconsistency. Furthermore, at times illogical combinations of responses, for example 'not at all' and 'adversely', occurred, so the questionnaire should have made it clear that a 'none at all' response necessarily precluded a response to the second part of the question. This second part of the question, 'beneficially/adversely', also would also have benefitted from a scale; in this case, if 0 represented 'netural', -5 'adversely' and 5 'beneficially', then the product of the two parts would have allowed for a more comparative and quantifiable result, especially if the questionnaire were to be used again with a larger number of groups.

Third, the comments sections, too, could have encouraged alternative sources to be named, both when the framework had and had not been used. This inclusion would have allowed the framework's author to more directly consider alternative presentations of and information regarding design principles and framework structures. Such information could then have been included in the revised framework. It should be noted that some specific resources were included as recommended by students, but this was done in a more informal manner and could have been more extensive if encouraged in the questionnaire.

Lastly, the questionnaire would have greatly benefitted from a checklist for noting the steps and options used, including an indication if they were used because of the

framework or because of other sources. Such a document would have made the recording of design principles used by students more straightforward and transparent, as opposed to the current reliance on students' notes in the framework documents and the author's observation and design evaluations. This last issue is particularly relevant to the next section, and is discussed more there.

6.4 Design principles applied by students

This section will consider the use of the design principles in more detail. As mentioned previously, all participating students were given an identical copy of the design guidance. As that version of the principles and their sequence differs only slightly from that of the New York and London assessments but significantly from that of the final framework, Figure 6.8 acts as a summary of its status at the start of the student test. As in other chapters, links to the final framework document are provided.

Figure 6.8: Student test steps and principles.

Step	Position	Title	Option	Option name	Fwk
1	O: TR (I)	Building Orientation	-	-	1
2	O: TR (I)	Primary Mass location	1	Solid north core	1 (1)
			2	South walkways/galleries	1 (2)
3	O: A (I)	Building Orientation	-	-	3
4	C: VR (I)	Floorplate Configuration [building]	-	-	7
5	C: VR (I)	Floorplate Configuration [rooms]	-	-	8
6	C: TR (I)	Built Form Ratio	-	-	4
7	C: A (I)	Floor Depth	-	-	6
8	C: A (I)	Height Zones	-	-	12
9	C: A (I)	Ground Floor	-	-	12
10	C: A (D)	Building Core	-	-	-
11	F: VR (I)	Glass [clear]	-	-	24
12	F: VR (I)	Glare	-	-	24
13	F: VR (I)	Passive Daylight Devices	1	Light pipe	26
			2	Light shelf	26
14	F: TR (I)	Glass [placement]	-	-	5
15	F: TR (I)	Glass [clear]	-	-	-
16	F: TR (I)	Glazing	-	-	19
17	F: TR (I)	Double and triple façade	-	-	28
18	F: TR (I)	Heat Sink Materials	-	-	25
19	F: TR (I)	Wall Insulation	-	-	23
20	F: TR (I)	Glazed Thermal Walls	1	Trombe wall	15

			2	Water-container wall	15
			3	Thermosiphon air panel	15
			4	Transparent insulation material	15
21	F: TR (D)	Glass [non-clear]	1	Solar-reflective glass	-
			2	Low-emissivity glass	21
			3	'Intelligent' glazing systems	22
22	F: TR (D)	Solar Control Devices [E, W orientation]	-	-	17
23	F: TR (D)	Solar Control Devices [N, S orientation]	-	-	17
24	F: TR (D)	Solar Control Devices [elements]	1	Fixed overhang	17 (2)
			2	Louvres	17 (1)
			2A	External louvres	17 (1)
			2Ai	Fixed external louvres	17 (1)
			2Aii	Movable external louvres	17 (1)
			2B	Mid-pane louvres	17 (1)
			2Bi	Fixed mid-pane louvres	17 (1)
			2Bii	Movable mid-pane louvres	17 (1)
			3	Movable blind (internal)	17 (3)
25	F: TR (D)	Wall Material Color	-	-	25
26	F: TR (D)	Wall Material Absorption Properties	-	-	25
27	F: TR (D)	Vegetation	1	Integrating	18
			2	Intermixing	18
			3	Juxtapositioning	18
28	F: TR (D)	Roof	1	Insulation	23
			2	Radiant barrier	-
			3	Canopy or pergola	-
			4	Vegetation	18
			4A	Roof garden	18
			4B	Permaculture	18
29	F: A (I)	Ventilation	1	Single-sided ventilation	29
			1A	Comfort air path location	29
			1B	High air path location	29
			[1]*	Geometry	29
			[2]*	Location	29
			[3]*	Windows (adjustable/closing)	29
			[4]*	Windows (recessed)	29
			2	Cross-ventilation	29

			2A	Comfort air path location	29
			2B	High air path location	29
30	F: A (I)	Stack Ventilation	1	Skycourts	-
			2	Ventilated cavity wall	-
			3	Atrium	28
			4	Double façade	28
			5	Triple-skin	28
			6	Active wall	-
31	F: A (I)	Comfort Ventilation	1	Wing walls	27, 29
			2	Nocturnal ventilative cooling	27, 28
			3	Radiant cooling	-
			4	Direct evaporative cooling	-
			5	Cooling of outdoor spaces	-
32	F: W	Rainwater [vegetation]	-	-	-
33	F: W	Rainwater [landscape]	-	-	-
34	F: W	Greywater [vegetation]	-	-	-
35	F: W	Greywater [landscape]	-	-	-
36	F: W	Groundwater [fixtures]	-	-	-
37	F: W	Groundwater [appliances]	-	-	-
38	F: W	Groundwater [M&E]	-	-	-
39	F: M	Vegetation	1	Integration	18
			2	Intermixing	18
			3	Juxtapositioning	18
40	F: M	Vegetation Elements	1	Façade	18
			2	Skycourts	18
			3	Balconies	18
			4	Roof	18
			5	Skygardens	18
			6	Surroundings/context	-
41	F: M	Vegetation Types	1	Trees	18
			2	Plants	18
			3	Grass/turf (small scale)	18
42	F: M	Inanimate Materials (sourcing)	-	-	-
43	F: M	Inanimate Materials (reuse)	-	-	-
44	F: M	Inanimate Materials (embodied energy)	-	-	-
45	F: M	Inanimate Materials (biodegradability)	-	-	-
46	F: M	Inanimate Materials (local)	-	-	-
47	F: M	Inanimate Materials (toxicity)	-	-	-

48	F: M	Inanimate Materials (life cycle)	-	-	-
49	S: VR (I)	Efficient Lighting	-	-	-
50	S: TR (I)	Solar Hot Water	-	-	-
51	S: TR (D)	Radiant Heat Barrier	-	-	-
52	S: A (I)	Propeller Fans	-	-	-
53	S: A (I)	Evaporative Coolers	-	-	-
54	S: A (I)	Dehumidifiers	-	-	-
55	S: A (I)	Displacement Ventilation	-	-	-
56	S: M	Fuel Cells	-	-	-
57	R: VR	Photovoltaics	-	-	-
58	R: A	Wind Turbines	-	-	-
59	R: W	Hydroelectric Power	-	-	-
60	R: M	Biofuels	-	-	-
61	R: L	Geothermal	-	-	-

To understand the application of both categories of steps and individual steps by the students, an overview, in the form of Figure 6.9, is presented here. It highlights which steps and options each group applied; those not utilized are blacked out. As stated previously, groups NF and CF agreed to follow the framework most fully, and are here signified in white. These groups stated directly which steps were applied, and so determining their use was fairly straightforward. Groups NN, CN and CP followed the framework to a lesser extent, and are highlighted in yellow. These groups either did not indicate specific steps at all or they indicated their use in a more general manner, and so their statements, design drawings and the author's group observations were used to extract this information.

Figure 6.9: Steps applied by student groups

STEP	CF	CP	CN	NF	NN
1	Y	Y	Y	Y	Y
2	Y (O2)	Y (O1)	Y (O1)	Y (O2)	
3				Y	
4	Y	Y	Y	Y	Y
5	Y	Y	Y		Y
6					
7	Y	Y	Y	Y	Y
8	Y			Y	
9	Y		Y	Y	Y
10				Y	
11	Y	Y	Y		Y
12	Y				
13					

14	Y	Y	Y		
15	Y	Y	Y		Y
16	Y (O1, O2)	Y	Y (O1, O2, O3)	Y	Y (O1?)
17			Y	Y	
18					
19	Y	Y	Y	Y	
20	Y (O4)				
21	Y (O3)		Y (O2)		
22	Y	Y	Y	Y	
23	Y	Y	Y		
24	Y (O2Aii)	Y (O1, O2Ai, O2Aii)	Y (O1, O2Ai, O2Bii)	Y (O2Ai)	
25		Y	Y	Y	
26					
27	Y (O?)		Y (O2?)	Y (O?)	Y (O2?)
28	Y (O4A)		Y (04A)	Y (O3)	Y (O4A)
29	Y (O1A[3,4], O2A[1,3,4])	Y (O2A[1,3,4])	Y (02A[1,2]	Y (O1A, O1B, O2A, O2B)	Y (O?)
30			Y (O1, 04?)	Y (O1, O3)	
31	Y (O2)	Y (O2)		Y (O5)	
32	Y		Y?		
33	Y			Y	
34	Y		Y?	Y	
35	Y			Y	
36	Y				
37	Y				
38	Y				
39	Y (O2)		Y (O2)	Y (O2)	Y (O2)
40	Y (O1, O4, O6)		Y (O2, O3, O4, O5, O6)	Y (O3, O5)	Y (O4, O5?)
41	Y (O2, O3)		Y (O1, O2)	Y (O1, O2, O3)	Y (O1, O3)
42	Y	Y			
43	Y				
44	Y				
45	Y				
46	Y				
47	Y				
48	Y				
49	Y		Y		
50	Y			Y	
51					
52	Y	Y			
53					

54	Y		
55			
56	Y		
57	Y	Y?	Y
58		Y?	
59			
60			Y
61	Y		

It would be inaccurate to suggest that the percentage of steps taken reflects the extent to which the framework was applied, as the percentage would not reveal the importance of specific guidance. For example, because of its origins, the framework has much emphasis on vegetation, and so many steps, some of them interrelated, refer to it. However, vegetation comes much later in the hierarchy than building orientation, which is determined generally in one step and early in the design process. Moreover, the fact that a step is included does not denote that it was adopted because of a reference to the framework; in fact, it would be impossible, without overly extensive student feedback and monitoring, to tell which strategies were obtained from the framework and which were found independently. Note, too, that some steps have a number of 'options' that could be interpreted as individual steps, whereas others are more limited or less developed.

Nonetheless, it is interesting to note the number, and percentage, of steps taken by each group, as it very generally signifies the percentage of common environmental strategies that were applied. To summarize:

CF:	46 / 61	75.4%
CP:	18 / 61	29.5%
CN:	29 / 61	47.5%
NF:	28 / 61	45.9%
NN:	14 / 61	23.0%

These figures show that there is a range of emphasis on environmental strategies, but that their number and interactions are so vast that it is impossible to exhaust them fully in one design. Even the group claiming to use the framework fully, CF, managed to apply only 75% of the possible steps. This does not discredit their intentions, but instead emphasizes the flexibility and number of choices offered in the framework. On the other hand, while it is theoretically possible to design a tower with no environmental strategies, the group using the framework least, NN, still managed

to apply about a quarter of the major strategies discussed in the framework document. As mentioned previously, this group had nonetheless been required by the brief, and advised by the tutors, to respond with some elements of environmental design. However, as is expected by the low percentage here, that tower was judged to be the least environmentally responsive of the ones available.

Interesting to note, though, is that the percentages of strategy use are otherwise inconsistent with the framework application. CP should arguably have applied more of the framework than CN, but the reverse is the case, with CP only marginally improving upon the percentage of NN. Likewise, NF would have been expected to apply more of the steps than CP and CN, but this figure is approximately equal to that of CN. Therefore, the arbitrariness of these percentages supports the statement that the percentage of steps taken does not reflect the extent to which the framework was applied.

A more useful comparison is one that compares the popularity of steps/strategies within all groups. It highlights which environmental strategies the students are most familiar with and most likely to apply. Likewise, it shows which strategies are underutilized, and, in the case of those students using the framework, perhaps also those misunderstood or lacking information. The percentages of individual step applications, here numbered and organized by design elements, are shown in Figure 6.10.

Figure 6.10: Percentages of steps applied.

Number of Applications	Orientation	Configuration	Fabric	System	Renewable	**Total**
5	1	4, 7	16, 29	-	-	**5 (8.2%)**
4	2	5, 9	11, 15, 19, 22, 24, 27, 28, 39, 40, 41	-	-	**13 (21.3%)**
3	-	-	14, 23, 25, 31, 34	-	57	**6 (9.8%)**
2	-	8	17, 21, 30, 32, 33, 35, 42	49, 50	-	**10 (16.4%)**
1	3	10	12, 20, 36, 37, 38, 43,	52, 54, 56	58, 60, 61	**19 (31.1%)**

			44, 45, 46, 47, 48			
0	-	6	13, 18, 26	51, 53, 55	59	**8 (13.1%)**

It is apparent that very few steps, 5 or 8.2 per cent of all available steps, were applied by all five groups. As all course modules related to environmental design, it is unsurprising that some of the principal bioclimatic strategies, such as building orientation and the use of clear glass are among the most accepted choices. There are exceptions to this perception of popularity; Step 16 offers glazing options, one of which will necessarily be chosen if clear glass is an option, and so it doesn't truly represent a 'choice'. Nonetheless, those steps that are applied most are generally those that emphasize basic, early environmental strategies.

The least applied steps fall into three categories. The first are those that require the design to be well resolved, and so generally do not fall under the 'bioclimatic design' category. Steps relating to system and renewable strategies are therefore not applied by at least half of the groups. Likewise, CF is the only group to apply the majority of the later 'Fabric' steps that relate to material choices (Steps 43-48).

A second category of least applied strategies is defined by steps that are less practical to apply. Thus, for example, there is no group applying evaporative coolers (Step 53), displacement ventilation (Step 55) or hydroelectric (Step 59) or geothermal (Step 61) power. These options are neither standard in tall building design, nor are there precedents for their use. It could be argued that their current inclusion in the framework is questionable, and indeed they are later omitted.

The third category of infrequent strategies is those that are misunderstood. Some steps, like passive daylight devices (Step 13) and wall material absorption properties (Step 26) could be considered highly practical, but the students either did not feel that they would enhance their design or misunderstood their purpose. For example, from observations of these and other course modules, the use of horizontal light pipes was misinterpreted as a way to bring daylight into unlit spaces, rather than as a way to enhance low levels of existing daylight. Their lack of application suggests that the framework text needs to include further clarification and information. Other steps, and in particular the one discussing the built form ratio (Step 6) are incomplete in the framework and need even more clarification and information. The key image in Step

6 had been a corrupted file and thus not printed out in the student's framework version, and the lack of this strategy's application demonstrates how much impact such an error makes.

6.5 Additional areas of misunderstanding and assumptions

When compiling data for the tables in this chapter, a number of additional areas of confusion were evident and are worthwhile mentioning. Many of them do not relate to the framework use itself, but do affect assumptions taken when compiling the data. As they are addressed in the revised framework, and in the interest of brevity, the key ones are briefly listed.

6.5.1 Visible radiation

NN had stated in its environmental strategy that vertical louvres are included in the east and west facades and horizontal louvres in the south. These are not shown in the drawings and, unlike the water and renewable systems, have a major influence on the environmental performance of the building for both radiation and airflow. Therefore, their application is omitted in Figure 6.10. In the final presentation NN had also stated that the floor slabs are to act as overhangs, which is a major misinterpretation of their capabilities as shading devices.

6.5.2 Ventilation

There is much confusion in NF's approach to ventilation. It had combined both single-sided ventilation, a low and high air inlet, without specifying how they would be applied so as though they do not contradict each other. Its approach to stack ventilation is similarly undeveloped. There is also a lack of sequential application of certain steps or strategies, which brings into question the effectiveness of the ventilation design as a whole.

NN's ventilation strategy is also not resolved. The plans of the apartments prohibit cross ventilation due to partitioning, but the diagram refers to cross ventilation. Although single-sided ventilation is possible with this arrangement, the reference of a double skin excludes it. To complicate the situation further, although mentioned in sketches and statements, the double façade is not illustrated in the final drawings. It is therefore unclear if it is intended for office or residential space. There is also some

reference to ‘two modes of mechanical ventilation’ in the final presentation drawings, but again it is unclear where this is applied. Although the ventilation system is not developed, for the purposes of the testing a single skin will be assumed as it correlates most closely with the drawings and observations.

CN has applied the double skin primarily as a protection from high wind speeds. However, there is no indication on any variance in its design vertically, even though CN has evaluated the building height’s effect on airflow. More contradictory is its use of the double skin and cross ventilation concurrently.

6.5.3 Non-bioclimatic strategies

CF and NF both specified vegetation in their towers, but no specific option was chosen between intermixing, integration and juxtapositioning. This again could partly due to a printing fault, and the most likely choice obtained from their drawings is included.

NF’s uncertainty in the meaning of some terms suggests that a glossary would be beneficial. In a key instance, it had indicated using a skycourt in the design, when in fact the design drawings show a skygarden. Likewise, CN indicated using skycourts, whereas skygardens were implied. The correct interpretation of skygarden is signified in Figure 6.10.

CN has specified the use of rainwater and graywater in its ‘design strategy’, but its application or location is not apparent in the drawings and final building. Nonetheless, it has been assumed as applied in Figure 6.10. This disparity is also the case for photovoltaics and wind turbines, which are again assumed in the table.

6.6 Design evaluations by students

The design questionnaire included two questions about design evaluation. These questions confirmed the types of environmental evaluation undertaken by the students, and are supported by findings within the their presentation documents. As is the case with the rest of the questionnaire, the responses are categorized from CF1, CF2, CP, CN and NF. Again, there were no responses from NN.

20. How did you evaluate the building resulting from the design process, especially in regards to its environmental responses?

Although CF2 misunderstood the question with a response of 'Fair', CF1 pointed out that the group had tested the building for thermal and lighting performance. Although not mentioned in the response, it was clear from the presentation documents that Ecotect had been used. CP responded with 'software like Ecotect, Radiance and Daysim'. CN stated 'advanced simulation programs', particularly Ecotect, Radiance and Winair'. Like CF2, NF had misread the question, offering an evaluation of the building's performance. When asked for clarification, NF had mentioned using Ecotect at an early stage of the process. Even though NN had not responded to this questionnaire, it was apparent that the building had not been evaluated with any environmental software, despite the application of rendering software for its interiors.

21. What were the results of these evaluations? If available, please also attach the results of these evaluations separately.

CF1 referred to the presentation, noting that 'Interesting conclusions were made', while CF stated: 'The lighting levels were not as expected. The thermal performance could not be actually simulated in Ecotect, as the building contained new technologies which could not be 100% integrated in the simulations.' This correlates with the feedback comments, in that the tutors noted that the daylighting analysis looked to be miscalculated. CP offered no response. NF referred to the previous analysis. CN noted:

Firstly, annual and seasonal energy demands were calculated. Secondly, modifications were made mostly to the fabric of the building in order to improve the thermal performance of the flats. (Results shown in posters). Thirdly, same process was followed for visual performance and for natural ventilation.

The analyses carried out by the students varied in scope and software available. As the framework was applied differently by each group and as the results are not verified by further tests, they are not discussed more here. Attempts to relate them to the framework steps or sequence were also problematic due to site constraints and building function. In any case, CP's approach, that of evaluating the design at major decision points, does seem to have been productive in determining which design options were most suitable; if translated into the framework, such an analysis would be helpful in refining the advice of steps for the specific building. Further discussion on this aspect is available in Chapter 7.

6.7 Ian Simpson Architects comparison

During the process of student testing, an interview was arranged with Christian Male of Ian Simpson Architects on the 18 April 2011. The initial intention was to gather information for a comparison of design principles, in a similar manner as the case studies, and design processes. However, as further required information, particularly the Environmental Impact Assessment, was not available, presumably due to the undetermined status of the building, this was not possible and only a brief comparison of the building, shown in Figure 6.11**,** with the framework will be provided here.



Figure 6.11 1 Blackfriars Road proposal (Ian Simpson Architects, no date).

The interview consisted of questions relating to the general approach of Ian Simpson Architects, general questions on 1 Blackfriars Road, questions relating to the design process on 1 Blackfriars Road and those relating to the applicability of the framework. A copy of the interview questions and interview protocol is provided in Appendix C, although the answers are contained in a recording and within unstructured notes.

In terms of the first part, the definition of environmental sustainability that Ian Simpsons provided was a broad one, which considered it 'integral' at the 'fundamental level' of design, and inclusive of form and layout. There was no particular systematic approach in the office to ensuring a level of sustainability was met, so legislation, Greater London Authority guidelines and the Code for Sustainable homes provided direction in this respect. The main challenges of sustainability were deemed to be related to the overall cityscape, particularly density requirements, the discrepancy between maximization of floorplate dimensions versus environmental limitations in depth, façade design, thermal requirement and daylight. Generally, then these included not only the bioclimatic aspects but also financial ones, and so the focus on that aspect was also determined to be crucial in the inclusion of hotels within their towers.

Regarding the second part of questions, although 1 Blackfriars road was at that moment ‘on hold’, the building was designed at a schematic level. At about 170 m tall and fifty stories high, the lower half of the building was reserved for a hotel and the upper half for residences. The most important criteria were determined to be urban response and building performance, with the latter evident though the various design iterations for the tower’s base. Twenty consultants, including those for the façade and building services engineering, and twelve architects were involved. For this building specifically, the environmental design guidance that was used, for the energy strategy particularly, included the Mayor’s guidelines for the city, the Code for Sustainable Homes and a BREEAM Assessment for the hotel, which rated it ‘good.’ These documents, as well as the building’s Environmental Impact Assessment, were referred to and requested for further examination but never received, but in any case the interview did provide some interesting approaches worth mentioning. There was mention of a biomass boiler as a strategy and double skin facades that varied from 600 mm in depth for the hotel and 1800 mm for residences, but it was the residential screen, which could be closed so as to provide 30% of the glazing with additional thermal insulation, that the author found most innovative. Again, though, further details on its environmental performance were not available to the author, some supporting documentation, created for a planning application, were provided and showed these elements. However, due to this limitation, the third part of the interview, relating the design principles and process of the building to that proposed in the framework at Stage 3, did not yield any reportable results.

The fourth part found that the architect interviewed felt that the office would benefit from a framework or guide for the design of residential tall buildings. This had confirmed earlier optimism by other offices approached. However, like the CF group, there was a preference for the guidance to be in the form of a ‘checklist’ and, notably, to function as a ‘conscience’. The checklist was envisioned as a form of an audit at certain stages, particularly conceptual ones, and preferably presented in a sequential manner. The format expected to be most beneficial was one that could be integrated into software such as CAD.

This last section therefore points to mixed results for the framework at Stage 3. Although the sequential and conceptual aspect is integral to it, the reference to a ‘checklist’ is less encouraging. Issues relating to checklists were discussed in Chapter 2, but here it is worth emphasizing that a checklist approach would be detrimental to the aims of this research. Unless weighted sufficiently, an option that

would undoubtedly be debatable and perhaps impossible due to site variations, a checklist could take away the focus from early elements of bioclimatic design that may be most significant in terms of energy savings. It would also place the framework amongst other checklist approaches, like LEED and BREEAM, which would both complicate the process of design and likely limit the framework's application. It would, perhaps most significantly, then label the framework as an evaluative tool rather than a design tool. Such a move would then certainly negate the premise of the research, which argues that evaluative tools, although useful, are nonetheless insufficient for providing guidance for environmental design.

The recommended format of the design guidance, as integrated into an existing software, both questioned the current format of the framework but pointed a way into greater levels of adoption. Indeed, the framework's author at this stage had similar thoughts, which are expanded on in the following chapter. Although the student testing did not at this stage find the printed document format detrimental, this comment may better reflect professional practice, but such integration may soon be inevitable in the former setting as well. In any case, even if the designer is familiar with the framework in its current format, it can be cumbersome to flip through pages in search of a related strategy, particularly when links are involved. Integration into a software program could recommend a design principle prior to the drawing of a design. These, and other benefits, are discussed further in Chapter 7.

6.8 Summary

This chapter provided a brief summary and analysis of the student trials of Stage 3. In so doing, the framework's usability by architects during the schematic design stage was replicated and tested. All in all, the composition of the design principles and their organization was found to be effective, although specific areas required further input and restructuring. In that sense, both research objectives, and hence the research aim, had been broadly met. After this evaluation, and once supplemental information was obtained, the framework was adjusted to form version 4, available in the Annexe. The next chapter therefore offers a summary of those changes, as well an evaluation of the research process in its totality.

7 CONCLUSION

The literature review for this research revealed a lack of information and guidance for the design of environmentally sustainable tall buildings. Information that did exist was generally incomplete, and design guidance incoherent, leaving architects with inadequate material for systematically approaching schematic design. Furthermore, that which was available was often not specific to the building function and climate type that this research considered. This study therefore aimed to address these concerns by determining the content and organization of environmental principles to best inform the design of residential tall buildings in the cool temperate climates of Europe and North America. It was completed in three stages, subject of the three previous chapters, each with a common goal of addressing the research aim and objectives but each also with differing methods of approaching them. This chapter will summarize the methods and findings of that study, its limitations, implications and areas for further research.

7.1 Summary of findings

The aim of this research project was 'To determine the content and organization of environmental design principles to inform the design of residential tall buildings in the cool temperate climates of Europe and North America.' This aim can be distributed into two objectives: first, 'To find principles of environmentally sustainable design which would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America' and, second, 'To organize these principles so that they can best inform architects during the schematic design stage'. This section will first reexamine the suitability and validity of the methods used in the general research process and specifically in each stage, followed by a discussion of the research results in terms of overall findings and achievements.

7.1.1 Research process

To address its aim, the research was separated into three key stages, forming an iterative series of trials that act in effect as the overarching methodology. Each trial would share in common a procedure that would integrate the elements of a proposed design guidance, known as the framework, into a schematic design process for the creation of one or more 'test' towers. The research objectives of finding and organizing the principles of environmental design would be embodied in the

framework and be advanced through the findings of the design process. The repetition of the design trials would therefore lead to cumulative results, and could continue indefinitely. Hence, although the overall methodology was suitable in replicating the conditions in which the design principles and their organization would be used and improved, the fact that the process can be repeated further, perhaps suggesting other changes, makes the results of this research non-definitive. Nonetheless, the three stages and their results point to a reasonably valid choice of principles and their organization, particularly when the time and resource limitations of this type of research project are taken into account.

Furthermore, this overarching research methodology was supplemented by a specific focus in each stage. The choice of the focus was often determined as a gap in the research that emerged in previous stages. Stage 1 here was the exception, as it represented the first instance in which the framework was applied and therefore the choice and organization of the steps was the only major concern.

As the framework had performed well overall in Stage 1, Stage 2 would additionally consider the framework's response to specific climatic and environmental conditions, and place it in the wider context of environmental rating systems. These two foci presumably could have been separated into two stages, but as both would take advantage from two sites in which to compare the framework application and resulting buildings, and as the analyses were not competing or conflicting, they were combined into one stage.

The method used for addressing the first focus of stage 2 was fairly straightforward: trials on two sites with varying climatic and urban conditions would be carried out. Again, these could have been separated into two stages, one for climatic variations and one for urban ones, but the fact that two sites existed that held both of these qualities, and again given the research limitations, made their combination complimentary. It was also clear in each case where a climatic, as opposed to an urban, variation impacted the design, thus avoiding conflicts in analysis. In any case, although the findings suggested that the framework was suitable and responsive to various climatic and urban inputs, they did not point out to any major improvements to its content and organization and so this method had not proven as productive in advancing the research objectives as the ones used in later stages.

As the literature review in Chapter 2 had demonstrated that the available frameworks often were lacking a specificity the research project required or were not applied by multiple designers, the use of two extensive and common rating systems, LEED and the Code for Sustainable Homes, were chosen as an alternative for the second focus. As these systems were nationally rather than climatically developed, both needed to be used. Nonetheless, the assessment of the resulting buildings did confirm that the application of the framework would lead to buildings that would likely meet their standards and so fitted well in the wider context of environmental design. Once again, though, the fact that they did not particularly challenge the choice or organization of the design principles meant that this method, and focus, did not initially advance much the design aim objectives, although the assessments' relative strengths in terms of exhaustible resource guidelines would later be used to support the framework's focus on bioclimatic design.

With the framework's content and structure stable, Stage 3 would have a focus on a recurring gap in the research, one that was especially relevant to the second objective's requirement that the principles 'best inform architects' during the schematic design stage. As discussed in Chapter 6, the method that was found to be most suitable for this end involved a number of student groups applying the framework and providing feedback on their experience and results. Although these students were architects in that they had already completed an undergraduate degree in architecture, which often also required some time in practice, it would have been helpful to see the impacts the various constraints in practice and further experience would have had on the framework application.

Notwithstanding, the results of the student tests were some of the most productive. The students' feedback during design studios, on framework documents and, most significantly, in response to the questionnaire resulted in an extensive reevaluation of the principles and their organization. Particularly, their insistence on more information required the author to change the framework's contents most substantially. The involvement of other designers, the inclusion of a feedback mechanism such as the questionnaire and an extensive and continuing process of literature review could therefore be argued to be the most effective methods of advancing the framework.

Acting as a link between this and the next section, Figure 7.1 is a summary of the stages and framework elements in each stage. Version 4, a response to Stage 3, stands alone, as it was not tested subsequently with a 'trail' like other stages.

Figure 7.1: Summary of changes to framework elements

Stage (and fwk version)	Design Principles	Step Sequence	Framework Matrix
Stage 1: Initial development / Birmingham tower test (Version 1)	Only Yeang's original principles included in guidance. References to other sources noted for Birmingham trial, so some principles verified and developed further to a limited extent for future versions. At the end of the trial, decision to remove non-environmental concerns as principles.	Initial sequence based on organization in Yeang's text. Sequence changed based on early Birmingham tower tests.	Early unsuccessful attempts at various forms of organization. Early attempts at Birmingham tower lead to first framework matrix. Decision to remove non-environmental aspects from framework. Initial bioclimatic focus, but at time of tower trial focus extended to environmental sustainability. Framework matrix, Version 1, used for full Birmingham tower trial.
Stage 2: Environmental Assessment / New York and London test towers (Version 2)	Only Yeang's original principles as guidance, but references to other sources required for design.	Stage 1 final version applied, with minor changes. Some links added to steps, mainly at the end of major interactions. Attempt at visual representation of sequence application, abandoned.	Stage 1 final version applied.
Stage 3: Student test / student test towers (Version 3)	Only Yeang's original principles included in guidance. Verification and development of Yeang's principles not included at start of trial. During the trial, as a student request, additional sources listed for reference. Students request further information to be incorporated into principles in Version 4. Students note gaps and discrepancies noted in design principles in Version 4.	Stage 2 final version applied, with minor changes. Students given a second version of visual representation of sequence application. Students request simplified sequencing and stronger hierarchy in Version 4. Less linear sequence requested by students in Version 4.	Stage 1 final version applied.
Version 4	Majority of Yeang's principles verified and expanded on by additional sources. Some of Yeang's principles removed based on verification. Further design principles added from other sources. Removal of all non-bioclimatic principles.	Major changes in terms of sequencing due to verification of principles, changes in matrix and analysis of process. Sequencing simplified and stronger hierarchy applied from Stage 3. Further links added at each step.	Major changes in terms of order and application of key interactions, based on verification of principles and analysis of process. Focus on bioclimatic design.

7.1.2 Research results

As opposed to the last subsection's focus on methods in the differing stages, this subsection will discuss the findings and achievements of the research process as they relate to its main objectives. The first objective of the research, that of finding principles of environmentally sustainable design for the specific building and climate type, initially involved the extraction of suitable principles from Yeang's texts and a comparison with existing practices from case studies. This process indicated that Yeang's texts were a valid starting point for finding most principles, mainly due to the range of strategies covered. Figure 7.2 demonstrates this finding by summarizing the derivation of the final design principles. It should be kept in mind that Yeang's work could not be determined as the original source of these principles, only the first source for this study. Yeang did acknowledge the work of other authors through his bibliography, but a lack of citations in the text made it excessively difficult, if not impossible, to link each principle with a specific source.

Figure 7.2: Origin of principles

S #	Step	O #	Option	Origin
1	Building Orientation			Yeang
2	Core Location	1	North	Yeang
		2	South Walkway	Yeang
3	Building Orientation			Yeang
4	Built Form Ratio			Yeang
5	Glazing Placement			Yeang
6	Floor Plan			Goulding et al.
7	Floor Plate Depth			Yeang
8	Room Plan			Yeang
9	Floor Plate Depth			Yeang
10	Apartment Plan			Watson and Labs
11	Double Height Apartments			Santamouris and Asimakopoulos
12	Building Height Zones			Yeang
13	Glass Coating: High SHG			Yeang
14	Solar Reflectors			Watson and Labs
15	Thermal Storage Walls			Yeang
16	Thermal Mass			Yeang
17	Shading Devices	1	Louvers	Yeang
		2	Overhangs	Yeang
		3	Blinds	Yeang
18	Vegetation			Yeang
19	Glass Glazing	1	Triple	Yeang
		2	Double	Yeang
20	Glass Infill Gases			Hausladen et al.
21	Low-E Coating			Yeang
22	Variable Trans. Glass			Yeang
23	Thermal Insulation			Yeang
24	High Vis. Trans. Glazing			Yeang
25	Material Reflectivity			Yeang
26	Reflector Systems	1	Light Pipe	Yeang
		2	Light Shelf	Yeang
27	Cross-Ventilation			Yeang
28	Stack Ventilation			Yeang
29	Single-Sided Ventilation			Yeang

However, the trials in Stages 1, 2 and, especially, 3 pointed to deficiencies in Yeang's descriptions of the principles, namely insufficient amounts of information for their application in a design process. This finding led to a verification, expansion and elimination of some of those principles through an extended literature review of other sources. The presentation of those principles changed considerably as well. In Yeang's work, it most often consisted of a brief description, sometimes accompanied by diagrams or sketches. This format was maintained for the most part until the fourth version of the framework, in which principles are presented with qualifications, details, limitations and links. This change was partly a result of student requests and partly due to a subsequent literature review.
The second objective of the research, organizing the principles to best inform architects during the schematic design stage, involved ordering them sequentially and within an overall framework matrix. Although there were some changes in this respect at each stage, a hierarchy based on the interaction of environmental impact and the stage of schematic design was maintained from the beginning.

The framework matrix provides the broadest, most visible and most fixed element of this organization. Its overall structure has several advantages. To start with, the principles are categorized according to both environmental priorities and the chronology of the design process. As the interactions are ordered in a hierarchal order, with the table to be 'read' in columns, and as those of less primary importance are blocked out, the matrix ensures that preliminary principles with a high impact are not overlooked and applied at the earliest phases of schematic design. The 'increase' and 'decrease' subcategories within each interaction also allow for a more focused response to the various conditions in the cool temperate climate.

The major changes that occurred to the framework matrix are worth noting here as they also impacted the order of the steps sequence, principles included and hence the overall research scope. Considering its form at the end of Stage 1, as Version 1 in Figure 7.3, versus Version 4 in Figure 7.4, there are a number of alterations. In the latter, visible radiation is placed after thermal radiation, as a result of an analysis of student feedback and an additional literature review. Likewise, both sources pointed out some inconsistencies in the matrix, leading to a reevaluation of some 'blocked' interactions.

However, the most visible change is the omission of non-bioclimatic aspects in Figure 7.4. Although much of the research had been concerned with more general

'environmental' design strategies, upon examination of student feedback, as well as a reevaluation of previous stages, the author decided to focus only on bioclimatic design strategies. Specifically, Yeang's definition of bioclimatic design was reconsidered – 'to seek by design a *low-energy*, *passive building* and *better occupant comfort'* (1996) – with passive building of most concern. The findings of Stage 1 had pointed out that practitioners often overlooked such passive strategies for more active ones, thus compromising the performance potential of the building at the outset and subsequently leading to less climate-specific solutions. The findings of stage 2 showed that information involving exhaustible resources was already more developed in the existing rating systems; furthermore, such resources require conservation, not maximum application as inexhaustible ones, and their suitability is often linked with local availability. The student responses highlighted the usefulness and clarity of bioclimatic strategies for their design projects. By eliminating guidance on exhaustible resources, and by extension systems and renewable technologies, and therefore by focusing on bioclimatic design, the research could both contribute to a less applied aspect of tall building design and provide more detailed guidance for its related principles. In this way, the research parts with Yeang's emerging interest in 'ecological' design and provides further depth to his earlier bioclimatic focus.

The step sequence further refined the structure of the framework matrix by placing the principles into a series of steps. As opposed to the matrix, expected to remain static from Version 4, this element is more dynamic as the number of steps can be increased, or decreased, as new data or solutions become available. Furthermore, options are be provided for steps that had two or more strategies with the same function, e.g. light pipes and light shelves for increasing visible radiation through fabric.

Figure 7.3: Framework matrix Version 1

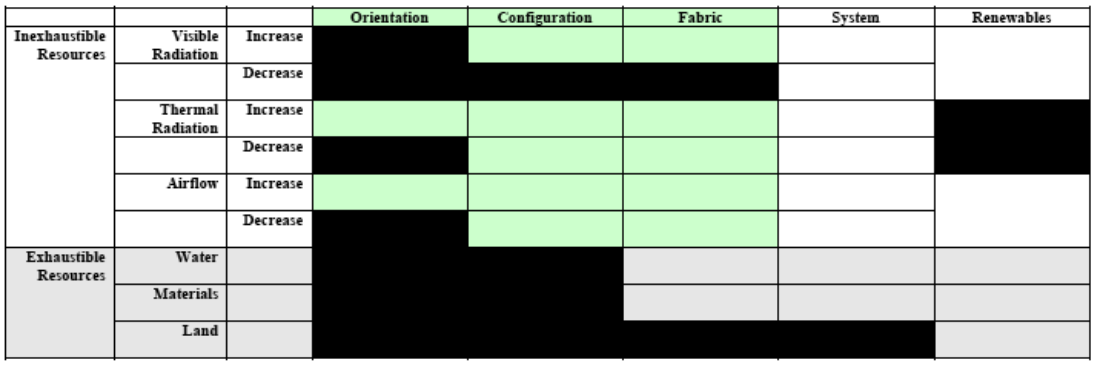
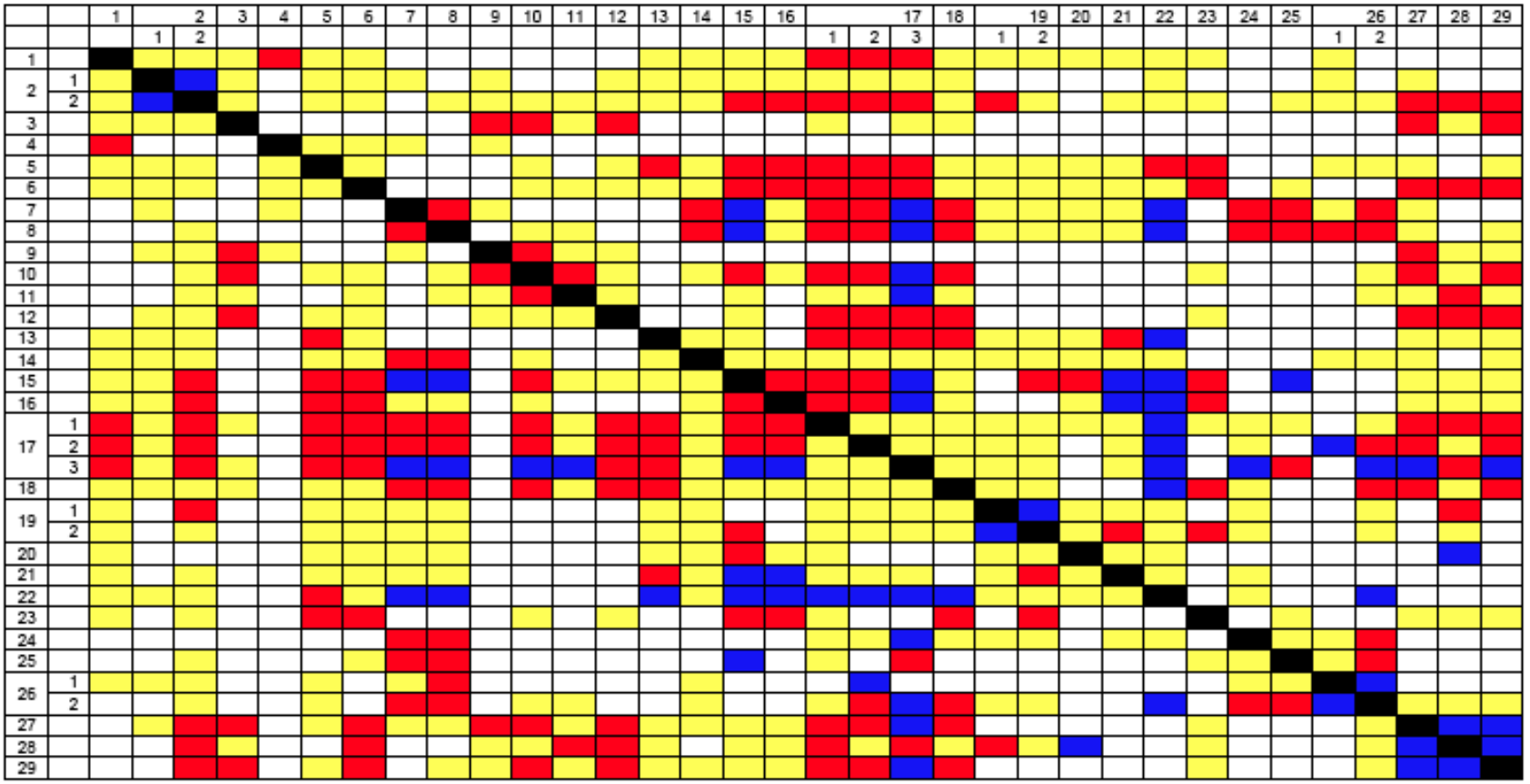


Figure 7.4: Framework matrix Version 4

		Orientation	Configuration	Fabric
Thermal Radiation	Increase			
	Decrease			
Visible Radiation	Increase			
	Decrease			
Airflow	Increase			
	Decrease			

As the temperate climate's range of conditions encourages the use of differing strategies for opposing seasons, links between steps were included to avoid conflict and point to particular compatibilities. These links were introduced in Stage 2 but expanded on Stage 3 as encouraged by student feedback. Figure 7.5 summarizes their frequent occurrence and compatibilities in Version 4. Interactions with no direct links between two steps/options are shown in white, those with weak links that may require coordination when both are used are in yellow, those with strong and direct links that are complimentary and should be used together are in red and those that have strong and direct links that are contradictory and should not be used together are in blue. These links, including the color-coding, and further discussions on some interactions are available in the Annexe document.

Worthy of note at this point, and relevant to both objectives, is that the connection between the student feedback and literature review findings was not as direct as expected. While the students provided exceptionally helpful advice relating to specific aspects of the guidance, one of their most common suggestions, the request for more information, lead to changes they had not foreseen in terms of principles included and their organization. As discussed in Chapter 6, the students found the overall structure of the framework matrix sufficient and the step sequence, although lacking information, for the most part adequate. The literature review, however, found that there existed variations and preexisting criteria for some of the principles and introduced a small number of additional steps. This information subsequently impacted the order of the principles within the steps sequence, and at times the broader level of the matrix.



	No direct link		Strong direct link, complementary, coordination required
	Weak direct link, coordination may be required		Strong direct link, conflicting, coordination/omission required

Figure 7.5: Step links.

At this point, a statement is required regarding the designs that result from the application of the framework. Unlike some projects in practice and research, the research here did not aim to create a ‘zero energy’, ‘zero carbon’ or other such building prototype, although it did initially consider such a concept. It instead aimed to find and organize existing environmental design principles so that they could inform the schematic design processes for a wider number of tall buildings within the cool temperate climate. In this sense, the framework is there to influence, but not determine, the final designs. The architect is expected to use his or her critical judgment throughout the process, as well as input from other professionals and evaluative tools, as at times specified in the Annexe. As discussed in other chapters, rigid, deterministic guidance would not be acceptable to architects, which would almost certainly lead to a greater disregard for green design. By allowing for the application of numerous principles in various combinations, the guidance encourages a diversity of designs.

7.2 Limitations of research

Many of the limitations of this research were discussed in further detail in earlier chapters, including the Methodology. This section will therefore restate those with the greatest overall impact. Some of them are also referred to in the areas for further research.

The most primary limitation of this research is the infancy of the field. As discussed in the Introduction chapter, the contemporary environmental concern of tall buildings is often traced to the 1970s, although earlier precedents exist. Even so, the number of tall buildings designed with an environmental approach, although growing, remains small and unrepresentative of skyscraper design at large. It is thus unsurprising that little information is available regarding environmental design principles for building and climate type, and even less regarding their suitable forms of organization. The problem is compounded when residential towers are considered, as office towers currently outnumber residential ones. Therefore many of the principles, including those adopted from Yeang, were those initially developed for smaller buildings. The lack of models of design guidance for such towers is even more problematic, consequently necessitating the iterative series of trials used in this study.

Time and financial constraints meant that the number of these trials was restricted, and so the last version of the framework was not applied to a design process like

previous versions. Students or practitioners could have further tested it, although the later group would likely face the same constraints as discussed in the methodology. The tests that were completed also depended on the availability of information from students, and, as discussed in Chapter 6, not all groups provided the same level of feedback. Likewise, evaluation of a sufficient number of resulting buildings through an environmental analysis tool could not be achievable within the time frame, and sufficient expertise required for such testing was not available at that time.

As discussed previously, the research was limited to environmental sustainability, with a final focus on bioclimatic design. Therefore aesthetic, urban, structural and social concerns were not examined. However, the flexibility of the guidance allows for such input, and so the obligation falls on the architect to consider it.

7.3 Implications of research

The study suggests that the application of design principles on an individual basis may overlook high impact strategies in favor of those that are most easily integrated into a predetermined form. Bioclimatic principles, in particular, are often neglected, despite their advantages even if more technology-based ones are included later. The links between principles are also lost if applied arbitrarily, possibly leading to competing strategies within the same project. The student tests of Chapter 6 demonstrate the hazards of applying environmental principles randomly and during the later stages of the design process only, as well as the benefits of having a systematic approach to design. This suggests that environmental principles should be integrated in the early stages of design in both education and practice, prior to any major aesthetic decisions that predetermine the orientation and configuration of the building.

The student tests also suggest that design principles as simple rules of thumb are not sufficient guidance; this confirms Balcomb's (1992) critique of rules of thumb and adds to the argument that strong links between principles are needed. The most common request by far from the students was for 'more information', and so even the most developed principles of Yeang were found to be lacking in this respect. Therefore, the final version of the framework not only added criteria, limitations, links and details to the more limited guidance, but also provided references for further study. This suggests that research studies could perhaps be more fully integrated into design modules, rather than forming separate or parallel modules. Such an

arrangement would address some of the debates regarding the compatibility of scientific/non-cognitive and design/cognitive activities discussed in Chapter 2. This request also implies that students not only want guidance, but sufficient information to make their own decisions, which may in turn lead to more critical and comprehensive environmental design.

Particularly for practice, this study suggests that the design of environmentally tall buildings cannot depend on rating systems as design guidance. Although some elements of the rating systems, such as SAP assessments, are valuable in evaluating designs at a later stage, they cannot act as guidance. The finding of the New York and London test studies suggest that often the rating systems act mostly as checklists, therefore ensuring that any elements of design principles contained therein are not applied in a systematic and critical way. As discussed in Chapter 2, a design tool is not an evaluative tool, and so environmental design for residential tall buildings requires the application and development of a design tool suitable for the building and climate type.

By implementing a systematic and critical bioclimatic approach, the domains of architects and engineers are no longer separated, respectively, into stylistic and environmental concerns. Architects once again hold some responsibility for the environmental performance of buildings, leaving room for more meaningful and creative collaborations between the two fields. The building fabric, in this sense, once again can become a ‘mediator of’, rather than a ‘barrier to’, environmental influences. Such an approach would help ensure a move beyond current ‘energy-efficiency’ and ‘power generation’ emphases in green buildings towards a more extensive sustainable approach.

7.4 Areas for future research

Some of the areas for further research are inferred from the limitations. The lack of information available on environmentally sustainable residential tall buildings clearly points to a large area in which much contribution is possible, even at the most basic level; for conciseness, though, this section will only consider those aspects that relate specifically to the design principles, their organization and methods of their application by architects. Chapter 2 offers a review of more general areas for future research, particularly those stressed by other authors.

Although verified and developed with a variety of sources, the process of finding suitable principles highlighted a lack of precedents for tall buildings. As discussed, Yeang's guidance was an exception rather than the norm, but even it was based on more general strategies rather than studies relating to tall buildings. Some strategies, such as solar orientation, can undoubtedly be adopted for skyscrapers, but others, such as ventilation openings and roof insulation, require much more critical evaluation and adaptation, and are at times inappropriate for the building type. Specific guidance relating to the climate and building type was also lacking, and so environmental strategies that apply to the buildings in this research require further examination. Given the lack of existing research, most types of studies can be recommended, including simulation-based models and post-occupancy evaluations of building performance.

The order of the design principles, as stated in the final version of the framework, would also consequently benefit from further studies, but even more so from further application in design processes. These could be established as a further series of trials, completed by architects in training or practice, or preferably both groups. Feedback from these groups could be incorporated in manner similar to that of Stage 3. Additionally, as mentioned in the Methodology, environmental performance evaluations of a large number of designs could suggest improvements in the sequence, although the number of such designs at the moment is prohibitive. More focused evaluations, of certain interactions of the matrix perhaps, could yield quantitative data with which to judge the energy saving, carbon emission, etc. impact of specific suggestions, but such evaluations would be only applicable for a specific context. This limitation suggests that evaluation tools are more suitable for integration within software. As such evaluative tools are already compatible with existing software, as is the case with Ecotect and Autodesk products, a methodical evaluation of certain elements is plausible for a specific context.

Another area for further development, if not study, concerns the presentation of the resulting framework. Its format as a printed document is problematic for a variety of reasons. First and foremost, its current size makes it cumbersome to find specific strategies and, especially, links. Given the established and increasing role of software in education and practice, the paper document fails to fully assimilate into the design process. Its updating is even more troublesome, as an addition of steps or changes to the sequence make a framework version instantly obsolete; the cross-referenced and extended final version would make changes even more challenging.

A digital document, on the other hand, would resolve many of these issues, particularly if integrated as an extension to existing design software. It would make updating the principles and sequencing faster and less complicated. The links could be automatically updated; those that are incompatible removed and those compatible highlighted. The dimensional limitations of certain steps, which were highlighted as highly beneficial by the architecture students, could be automatically signaled, forming a visual reminder. In practical terms, the integration with software would allow for more detailed organization, as in the current format only two layers of 'step' and 'option' are workable. The methods of including the guidance within software therefore require further research.

Information in the framework document, and especially the annotations, could also be shared as an open-source document, perhaps in the form of a textbook. Researchers and practitioners could modify such a document, allowing for more resources and feedback to inform the updated guidance. This collaborative model would encourage input from engineers, consultants, interior designers and other professionals. The author, or, more likely, a group of authors, could occasionally manage and review the guidance. The textbook format would be particularly useful for discussions relating to the references, thereby also permitting any related software applications to hide these discussions and allow for more abridged guidance. The document could then inform new versions of the software at regular intervals, while avoiding extensive disruptions to the design process.

The participation of other professionals can be extended to the industry, and so further exploration would need to occur in determining the best way to introduce and encourage new products that respond to the requirements of the principles. Furthermore, further research would be required in the implications of the suggested guidance on rating systems, as well as its bearings on the economic and social aspects of sustainability.

The research process and resulting framework could also be modified to provide guidance for other regions and climate types. It could perhaps most straightforwardly be applied to the cool temperate climates of other continents. For other climate types, some of the same principles can apply, albeit in a different sequence, although most would be expected to be specifically developed.

7.5 Conclusions

This research aimed to answer the question: ‘Using the work of Ken Yeang as an initial reference, what principles of environmentally sustainable design can be found which would contribute to the design of residential tall buildings in the cool temperate climates of Europe and North America and how can they be best organized to inform architects?' Given relative infancy of this field and the urgency of action on climate change, this study hopes to have advanced and expanded on existing information and practices in order to provide structured and verifiable guidance for architects during the schematic design stage. By focusing on bioclimatic design, it reinforces the role of the architect as a key contributor to a positive environmental performance of a building. A more profound collaboration with other professionals is then possible, as are more formative models for sustainable design.

WORKS CITED

340 on the Park. [Online]. Available at: http://www.lakeshoreeast.com/340-on-thepark.html [Accessible on 15 March 2009].

Abel, C. 2003. *Sky high: vertical architecture*. London: Royal Academy of Arts.

Abwi, H. 2010. Basic concepts for natural ventilation in buildings. CIBSE BSG Seminar: Natural and Mixed-Mode Ventilation Modelling.

Adrian Smith and Gordon Gill. [Online]. Available at: http://www.smithgill.com [Accessible on 15 March 2009].

AEDAS [Online]. Available at: http://www.aedas.com/Research [Accessible on 1 March 2013].

Aldersey-Williams, H. 2003. *Zoomorphic: new animal architecture*. London: Laurence King Pub. in association with Harper Design International.

Alexander, C. 1977. *A pattern language: towns, buildings, construction*. New York, Oxford University Press.

Ali, M. et al. (ed.) 1995. *Architecture of tall buildings*. Council on Tall Buildings and Urban Habitat Committee 30 (Architecture). New York: McGraw-Hill.

American Institute of Architects. [Online]. Available at: http://www.aia.org [Accessible on 15 March 2009].

Anink, D., Boonstra, C. and Mak, J. 1996. *Handbook of sustainable building: an environmental preference method for selection of materials for use in construction and refurbishment*. London: James and James (Science Publishers) Limited.

Arup Associates [Online]. Available at: http://www.arupassociates.com/en/approach [Accessible on 1 March 2013].

Ascher, K. 2011. *The heights: anatomy of a skyscraper*. New York: Penguin.

ASHRAE. 2003. ASHRAE's Green Tips. Reprinted from *ASHRAE GreenGuide*. Available at www.ashrae.org [Accessible 9 April 2012].

Baird, G. 2001. *The architectural expression of environmental control systems*. London: Spon Press.

Baker, N., Fanchiotti, A. and Steemers, K. (eds). 1993. *Daylighting in architecture: a European reference book*. London: James and James for the Commission of the European Communities.

Baker, N. and Steemers, K. 2002. *Daylight design of buildings*. London: James & James.

Balcomb, D. (ed). 1992. *Passive solar buildings*. Cambridge, Massachusetts: The MIT Press.

Barker, D. 2005. Swiss Re Tower by Foster and Partners. *Architecture Week* [Online]. Available at: http://www.architectureweek.com/2005/0504/design_1-3.html [Accessible on 10 March 2009].

Battle McCarthy. Sustainable towers: state of the art survey. [Online]. Available at: http://www.battlemccarthy.com/external%20site_sustainable%20towers%20website/SOA.htm [Accessible on 15 March 2009].

Binder, G. (ed.) 2002. *Sky high living: contemporary high-rise apartment buildings and mixed-use buildings*. Mulgrave, Vic.: Images.

Birmingham City Council. 2003. *High places: a planning policy framework for tall buildings*. Birmingham: Birmingham City Council.

Boake, T. [Online]. The tectonics of the double skin: green building or just more hi-tech hi-jinx? Available at: http://www.architecture.uwaterloo.ca/faculty_projects/terri/ds/tectonic.pdf. [Accessible on 20 August 2012].

Bowen, T. 2008. Form Follows Feathers: Bird-Friendly Architecture. *Architectural Record.* [Online]. Available at: http://archrecord.construction.com/news/daily/archives/080110feathers.asp [Accessible on 15 March 2009].

Brass, K., Wood, A. and Carver, M. 2012 [Online]. *Year in review: tall trends of 2012.* Available at: http://www.ctbuh.org/TallBuildings/HeightStatistics/AnnualBuildingReview/Trendsof2012/tabid/4212/language/en-US/Default.aspx [Accessible on 3 March 2013].

Broadway Malyan. [Online]. Available at: http://www.broadwaymalyan.com [Accessible on 15 March 2009].

Brown, G.Z. and DeKay, M. 2001. *Sun, wind & light: architectural design strategies*. 2nd ed. New York: John Wiley.

Brown, P. An unnatural disaster. *The Guardian*. 8 Jan 2004, pp. 1-2.

Burdett, R. and Sudjic, D. (ed.) 2007. *The endless city: the Urban Age project by the London School of Economics and Deutsche Bank's Alfred Herrhausen Society*. London: Phaidon.

Can do, will do: overseas architects are helping turn America' construction industry from can't do to can do. 2008. *Architectural Review*. April, p. 40.

Capeluto, I.G. 2003. Energy performance of the self-shading building envelope. *Energy and Buildings*. 35, pp. 327–336.

Carson, R. 1965. *Silent Spring*. Harmondsworth: Penguin Books.

Castleton, H.F., Stovin, V. Beck, S.B.M. and Davison, J.B. 2010. Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings.* 42, pp. 1582-1591.

Center for Architecture, Science and Ecology [Online]. Available at: http://www.case.rpi.edu/CASE.html [Accessible on 1 March 2013].

Cervera & Pioz. [Online]. Available at: http://www.cerveraandpioz.com/bionic_megacities_v.htm [Accessible on 15 March 2009].

Cheung, J.O.H and Liu, C.-H. 2011. CFD simulations of natural ventilation behaviour in high-rise buildings in regular and staggered arrangements at various spacings. *Energy and Buildings*. 43, pp. 1149–1158.

Chicago architecture info. [online]. http://www.chicagoarchitecture.info/ [Accessible on 15 March 2009].

Ching, Francis D.K. 2003. *Building construction illustrated*. 3rd ed. New York: John Wiley.

Ching, Francis D.K. 2007. *Architecture: form, space and order*. 3rd ed. Hoboken: John Wiley.

Ching, Francis D.K. 2009. *Architectural graphics.* New York: John Wiley.

Choi, Y., Cho, S.H. and Kim, J.T. 2012. Energy consumption characteristics of high-rise apartment buildings according to building shape and mixed-use development. *Energy and Buildings.* 46, pp. 123-131.

CIBSE. 2004. *Energy efficiency in buildings: CIBSE Guide F*. 2nd ed. London: Chartered Institution of Building Services Engineers.

CIBSE. 2006. *Environmental Design: CIBSE Guide A*. 7th ed. London: Chartered Institution of Building Services Engineers.

CIBSE. 2007. *Sustainability: CIBSE Guide L*. London: Chartered Institution of Building Services Engineers.

City of Chicago Department of Planning and Development, Landmarks Division. 2003. *Chicago Landmarks website*. Available at: http://egov.cityofchicago.org/Landmarks [Accessible on 15 March 2009].

Clarke, K. 2007. *WS Atkins plc Sustainability Policy Statement*. Available at: http://www.atkinsglobal.com.

Cofaigh, E., Olley, J. and Lewis, O. 1996. *The climatic dwelling: an introduction to climate-responsive residential architecture*. London: James and James on behalf of the European Commission.

Commission for Architecture and the Built Environment. 2007. *Guidance on tall buildings*. London : CABE & English Heritage.

Council on Tall Buildings and Urban Habitat website. 2009. Available at: http://www.ctbuh.org [Accessible on 10 March 2009].

Crosbie, M. 2000. Norman Foster: Analog and Digital Ecology. *Architecture Week* [Online]. Available at: http://www.architectureweek.com/2000/0920/news_1-1.html

Davies, C. 1997. *Commerzbank Frankfurt: prototype of an ecological high-rise*. Haselmere, Surrey, UK: Watermark Basel; Boston: Birkhauser.

DEGW. 2002. *London's Skyline, Views and High Buildings*. SDS Technical Report 19 to the Greater London Authority. August 2002. London: DEGW.

Dunnett, J. 2008. L'Homme Vert. *Architectural Review.* no. 1332, February, pp. 66-69.

Dunster, B. et al. 2008. *The ZEDbook*. Oxon: Taylor and Francis.

Dynamic Architecture. [Online]. Available at: http://www.dynamicarchitecture.net/ [Accessible on 15 June 2008].

Edwards, B. and du Plessis, C. 2000. 'Green Architecture.' *Architectural Design* in 'Today,' *BBC Radio 4*, 12 August 2000.

Eisele, J. and Kloft, E. 2002. *High-rise manual: typology and design, construction and technology*. Translated from German by E. Shwaiger, R. Benson and D. Henderson. Basel: Birkhäuser.

Emery, F. 1969. *Systems thinking: selected readings*. Harmondsworth : Penguin.

Emporis. [Online]. Available at: http://www.emporis.com/ [Accessible on 15 March 2009].

Evans, M. 1980. *Housing, climate and comfort.* London: The Architectural Press.

Fedeski, M. 2011. *ART032 Project Module Syllabus*.

Feireiss, K. 2003. *Ingenhoven Overdiek und Partner: energies*. Basel: Birkhäuser.

Finch, P. 2000. *Renzo Piano goes sky high with Europe's tallest building*. *Architects' Journal* [Online]. 20 July, 2000. Available at: http://www.architectsjournal.co.uk/home/renzo-piano-goes-sky-high-with-europes-tallest-building/191842.article [Accessible on 10 March 2009].

Fletcher, T. 2009. *New York architecture*. [Online]. Available at: http://www.nycarchitecture.
com/index.html [Accessible on 15 March 2009].

Forest City Enterprises. [Online]. Available at: http://www.forestcity.net/OFFICES/NEW_YORK/Pages/default.aspx.

Fortmeyer, R. SOM's Pearl River Tower. [Online]. *Architectural Record*. Available at: http://archrecord.construction.com/features/digital/archives/0612casestudy-1.asp [Acessible on 10 June 2008].

Foster + Partners. [Online]. Available at: http://www.fosterandpartners.com/ [Accessible on 15 March 2009].

Foster, A. 2005. *Birmingham*. New Haven, CT: Yale University Press.

Foster, N. 2008. Sustainable architecture of the future. *World Future Energy Summit 2008*. 21-23 January, 2008. Abu Dhabi.

Franzoni, E. 2011. Materials selection for green buildings: which tools for engineers and architects? *Procedia Engineering*. 21, pp. 883-890.

Gallo, C., Sala, M. and Sayigh A.A.M. (eds.) 1998. *Architecture: comfort and energy*. Oxford: Elsevier Science Ltd.
Ghisi, E. and Tinker, J.A. 2005. An Ideal Window Area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment.* 40, pp. 51-61.

Girardet, H.2008. *Cities, people, planet: urban development and climate change*. Chichester: Wiley.

Gissen, D. 2002. *Big & Green: toward sustainable architecture in the 21st century*. New York: Princeton Architectural Press; Washington, DC: National Building Museum.

Givoni, B. 1976. *Man, climate and architecture*. 2nd ed. London: Applied Science Publishers Ltd.

Glancey, J. 2007. The power of the tower. *The Guardian.* [Online]. 25 November 2007. Available at: http://www.theguardian.com/world/2007/nov/26/usa.architecture [Accessible on 10 March 2009].

Glendinning, M. and Muthesius, S. 1994. *Tower block: modern public housing in England, Scotland, Wales and Northern Ireland*. New Haven: Published for the Paul Mellon Centre for Studies in British Art by Yale University Press.

Goldberger, P. 1981. *The Skyscraper*. London: Allan Lane.

Gonçalves, J.S. 2010. *The environmental performance of tall buildings*. London: Earthscan.

Goulding, J.R., Lewis, J.O. and Steemers, T.C. (eds.). 1994. *Energy in architecture: the European passive solar handbook*. London: Batsford for the Commission of the European Communities.

Gräwe, C. and Schmal, P. (ed.) 2006. *High society: contemporary highrise architecture and the international highrise award 2006*. Berlin: Jovis.

Greater London Authority. 2004. *122 Leadenhall Street.* Available at: http://legacy.london.gov.uk/mayor/planning_decisions/strategic_dev/2004/sept0204/122_leadenhall_street_report.pdf [Accessible on 10 March 2010].

Gregory, B. 2008. The Gray Lady. *Architectural Review*. April, pp. 42-51.

Halliday, S. 2008. *Sustainable construction*. Burlington, MA, USA: Butterworth-Heinemann (imprint of Elsevier).

Hallowell, C. 1999. Douglas Durst: Can a Times Square Disaster Be an Inspiration? *Time Magazine* [Online]. 18 October 1999. Available at: http://content.time.com/time/magazine/article/0,9171,992295,00.html [Accessed on 10 March 2009].

Hargrave, J. 2013. *It's alive: can you imagine the urban building of the future?* January 2013. London: Arup Foresight & Innovation.

Hausladen, G., de Saldanha, M., Liedl, P. and Sager, C. 2005. *Climate design: solutions for buildings that can do more with less technology*. Basel: Birkhäuser.

Hawkes, D. and Forster, W. 2002. *Architecture, engineering and environment*. London: Laurence King.

Hearst Coporation. [Online]. Available at: http://www.hearst.com/ [Accessible on 15 March 2009].

Hochhaus einer Konzernverwaltung in Essen. 1997. *Detail*. München: Institut für internationale Architektur-Dokumentation.

Höweler, E. 2003. *Skyscraper***:** *designs of the recent past and for the near future*. London: Thames & Hudson.

Ip, K., Lam, M. and Miller, A. 2010. Shading performance of a vertical deciduous climbing plan canopy. *Building and Environment.* 45, pp. 81-88.

Irving, M. (ed.). 2007. *1001 buildings you must see before you die.* London: Quintessence.

Jenkins, D. 1993. *Unité d'Habitation Marseilles: Le Corbusier*. London: Phaidon.

Johnson, T. 1991. *Low-e glazing design guide*. Boston: Butterworth Architecture.

Jones, D. 1998. *Architecture and the environment: bioclimatic building design*. London: Laurence King.

Julien, A. Assessing the Assessor: BREEAM vs. LEED. *Sustain Magazine*. v. 9, i. 6, pp. 30-33.

Kassim, P.S.J. 2004. *The bioclimatic skyscraper: a critical analysis of the theories and designs of Ken Yeang.* PhD Thesis. The University of Brighton.

Kontoleon, K.J. and Eumorfopoulou, E.A. 2010. The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and Environment.* 45, pp. 1287–1303.

Koolhaas, R. 1978. *Delirious New York: a retroactive manifesto for Manhattan*. London: Thames and Hudson.

Kotani, H., Narasaki, M., Sato, R. and Yamanaka, T. 2003. Environmental assessment of light well in high-rise apartment building. *Building and Environment.* 38, pp. 283-289.

Kwok, A. and Grondzik, W. 2007. *The green studio handbook: environmental strategies for schematic design*. Oxford: Architectural Press.

Lambertini, A. 2007. Vertical gardens: bringing the city to life. London: Thames & Hudson.

Laumer, J. 2006. Hearst Tower Leed Certified in "Gold" [Online]. Available at: http://www.treehugger.com/sustainable-product-design/hearst-tower-leed-certified-in-agolda.html [Accessible on 10 March 2010].
Lawson, B. 2004. *What designers know*. Oxford: Architectural Press.

Lawson, B. 2006. *How designers think: the design process demystified.* 4th ed. Amsterdam : Elsevier/Architectural Press.

Lechner, R. 2009. *Heating, cooling, lighting: sustainable design methods for architects.* 3rd ed. Hoboken, New Jersey: John Wiley and Sons, Inc.

Lepik, A. 2008. *Skyscrapers*. Munich: Prestel.

Leslie, R.P. 2003. Capturing the daylight dividend in buildings: why and how? *Building and Environment*. 38, pp. 381-385.

Li, D.H.W. 2010. A review of daylight illuminance determinations and energy implications. *Applied Energy*. 87, pp. 2109-2118.

Li, D.H.W., Cheung, G.H.W., and Lau, C.C.S. 2006. A simplified procedure for determining indoor daylight illuminance using daylight coefficient concept. *Building and Environment*. 41, pp. 578-589.

Linder, M. 1992. Architectural Theory is No Discipline. In: Whiteman, J. et al. *Strategies in Architectural Thinking*. Cambridge, Mass: MIT Press.

Littlefair, P. 2001. Daylight, sunlight and solar gain in the urban environment. *Solar Energy.* 70 (3), pp. 177–185.

Littlefair, P. 2002. Daylight prediction in atrium buildings. *Solar Energy.* 73 (2), pp. 105-109.

Llewelyn Davies Yeang. [Online]. Available at: http://www.llewelyn-davies-ltd.com. [Accessible on 15 March 2009].

London Bridge Quarter. [Online]. Available at: http://www.shardlondonbridge.com/ [Accessible on 15 March 2009].

London School of Economics and Political Science. 2002. *Tall buildings: vision of the future or victims of the past?* London: Development Securities PLC.

Lyndon State College. *Survey of Meteorology Class Notes*. [Online]. Available at: http://apollo.lsc.vsc.edu/classes/met130/notes/ [Accessible on 15 March 2009].

Make Architects. [Online]. Available at: http://www.makearchitects.com [Accessible on 15 March 2009].

Manz, H. and Menti, U.-P. 2012. Energy performance of glazings in European climates. *Renewable Energy*. 37, pp. 226-232.

Marks Barkfield Architects. [Online]. Accessible at: http://www.marksbarfield.com [Accessible on 15 March 2009].

Mayor of London. 2004. The London plan: spatial development strategy for Greater London. London: Greater London Authority.

McHarg, I. 1969. *Design with nature*. Garden City, N.Y.: Natural History Press for the American Museum of Natural History.

McKee, Bradford. Raw materials: vinyl. *Architect Magazine*. [Online]. Available at: http://www.architectmagazine.com/magazine.asp?sectionID=1007 [Acessible on 15 March 2009].

McMullan, R. 2007. *Environmental Science in Building*. 6th ed. Basingstoke, Hampshire: Palgrave MacMillan.

Melvin, J. 2008. Height: between possibility and responsibility. *Architectural Review*. no. 1340, pp. 38-83.

Mendler, S., et al. 2006. *The HOK guidebook to sustainable design*. 2nd edition. Hoboken, N.J.: J. Wiley.

Michel, R. 2007. *Design research now: essays and selected projects*. Basel: Birkhäuser.

Millard, B. 2006. Hearst tower, New York by Foster and Partners. *Building Design* [Online]. November 2006. Available at: http://www.bdonline.co.uk/hearst-tower-new-york-by-foster-and-partners/3077506.article [Accessible on: 10 March 2009].

MoMA. *Exhibitions and the Collection*. Available at: http://www.moma.org/explore/collection/index. [Accessible on 15 March 2009].

Morrissey, J., Moore, T. and Horne, R.E. 2001. Affordable passive solar design in a temperate climate: an experiment in residential building orientation. *Renewable Energy*. 36, pp. 568-577.

Mueller-Lust, A. 2008. Growing up in Manhattan: Well-studied use of structural steel allows Bank of America Tower to rise in New York City. *Modern Steel Construction* [Online]. October 2008. Available at: http://www.modernsteel.com/uploads/issues/october_2008/102008_30782_bank_america_web.pdf [Accessible on 10 March 2009].

Naparstek, A. 2007. New York Times Employees Say Renzo Forgot the Bike Parking. *StreetsBlog.org* [Online]. 6 December 2009. Available at: http://www.streetsblog.org/2007/12/06/new-york-times-employees-say-renzo-forgot-the-bike-parking [Accessible on 10 March 2009].

National Renewable Energy Laboratory. [Online]. 2001. Available at: http://www.nrel.gov [Accessible on 10 March 2009].

NYC Architecture website. [Online]. Available at: http://www.newyorkarchitecture.info [Accessible on 10 March 2009].

Nicholson-Cole, D. and Oldfield, P. 2011. *Tall Buildings: Climate, Culture, Context*. Design brief.

Nguyen, B. and Altan, H. 2011. TPSI: Tall-building project sustainability indicator. *Procedia Engineering*. 21, pp. 387-394.

Nordenson, G. and Riley, T. 2003. *Tall buildings*. New York: Museum of Modern Art.

Offiong, A. and Ukpoho, A.U. 2004. An analysis of solar gain through externally shaded window of buildings. *Renewable Energy*. 29, pp. 131–150.

Oldfield, P. 2012. *Tall buildings and sustainability*. PhD Thesis. University of Nottingham.

Oldfield, P., Trabucco, D. and Wood, A. 2009. Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings. *The Journal of Architecture*. 14, no. 5, pp. 591-613.

Olgyay, A. and Olgyay V. 1957. *Solar control and shading devices*. Princeton, New Jersey: Princeton University Press.

Olgyay, V. 1963. *Design with climate: bioclimatic approach to architectural regionalism*. Princeton, N.J : Princeton University Press.

Parker, J. 2009. BREEAM or LEED - strengths and weaknesses of the two main environmental assessment methods. *BSRIA* [Online]. Available at: http://www.bsria.co.uk/news/breeam-or-leed/ [Accessible on 15 March 2009].

Pearman, H. 2004. The only way is up: high-rise hits Britain, and this time they mean it. *The Sunday Times* magazine. 2 May 2004.

Powell, K. 1994. *Richard Rogers*. London: Artemis London.

Powell, K. 2001. *New London architecture*. London: Merrell.

Powell, K. 2006. *30 St Mary Axe: a tower for London*. London: Merrell.

Powell, K. 2008. American Connection. *Architectural Review*. April, pp. 84-85.

Powell, R. 1999. *Rethinking the Skyscraper: the complete architecture of Ken Yeang*. London: Thames & Hudson.

Power, A. 1997. *Estates on the Edge*. London: McMillan.

Quesada, G., Rousse, D., Dutil, Y., Badache, M. and Hallé, S. 2012. A comprehensive review of solar facades. Transparent and translucent solar facades. *Renewable and Sustainable Energy Reviews*. 16, pp. 2643– 2651.

Ralegaonkar, R. V. and Gupta R. 2010. Review of intelligent building construction: A passive solar architecture approach. *Renewable and Sustainable Energy Reviews.* 14, pp. 2238–2242.

Richards, I. 2001. *T.R. Hamzah & Yeang: ecology of the sky*. Victoria, Australia: Images Publishing Group.

Richards, I. 2007. *Eco Skyscrapers*. Victoria, Australia: Images Publishing Group.

Roaf, S., et al. 2005. *Adapting buildings and cities for climate change: a 21st century survival guide*. Oxford: Elsevier/Architectural Press.

Roaf, S., et al. 2007. *Ecohouse: a design guide*. London: Elsevier/Architectural Press.

Roberts, S. 2006. Urban Tactics; City of Angles. *The New York Times*. [Online]. 2 July 2006. Available at: http://query.nytimes.com/gst/fullpage.html?res=9B04E0DF1530F931A35754C0A960

9C8B63&sec=&spon=&partner=permalink&exprod=permalink [Accessible on 15 March 2009].

Rowe, P. 1987. *Design thinking*. Cambridge, Mass.: MIT Press.

Royal Institute of British Architects. [Online]. Available at: www.architecture.com [Accessible on 15 March 2009].

Sadineni, S.B., Madala, S. and Boehm, R.F. 2011. Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews*. 15, pp. 3617–3631.

Santamouris, M. and Asimakopoulos, D. (eds.) 1996. *Passive cooling of buildings*. London: James & James (Science Publishers) Ltd.

Santamouris, M. (ed.) 2006. *Environmental design of urban buildings: an integrated approach.* London: Earthscan.

Sassi, P. 2006. *Strategies for sustainable architecture*. Oxon: Taylor & Francis.

Saunders, W. ed. 2007. *Harvard Design Magazine: new skyscrapers in megacities on a warming globe*. Cambridge: Harvard University Graduate School of Design. No. 26, Spring/Summer issue.

Scott, A. (ed.) 1998. *Dimensions of sustainability: architecture, form, technology, environment, culture*. London: E&FN Spon.

Sharp, D. 2002. *Kisho Kurokawa: eco-architecture, eco-cities*. London: Book Art.

Skyscraperlife. [Online]. Available at: http://www.skyscraperlife.com [Accessible on 15 March 2009].

Skyscrapernews. [Online]. Available at: http://www.skyscrapernews.com [Accessible on 15 March 2009].

Skyhouse. *Marks Barfield* [Online]. Available at: http://www.marksbarfield.com/#/projects/skyhouse/ [Accessed on 10 March 2009].

Smith, P. 2005. *Architecture in a climate of change: a guide to sustainable design*. 2nd ed. Oxford: Architectural Press.

Solstice on the Park [Online]. http://www.solsticeonthepark.com [Accessible on 15 March 2009].

SOM. [Online]. Available at: http://www.som.com [Accessible on 15 March 2009].

Stephens, S. 2000. Four Times Square. *Architectural Record*. March, pp. 90-97.

Stephens, S. 2008. The New York Times Building. *Architectural Record*. February, pp. 94-104.

Sullivan, L. 2012. [Online]. *The RIBA guide to sustainability in practice*. March 2012. Available at: http://www.architecture.com/Files/RIBAProfessionalServices/RIBAGuidetoSustainabilityinPractice.pdf. [Accessible on 3 March 2013].

Sustaining: tower blocks. [Online]. Available at: http://sustainingtowers.org/ [Accessible on 15 March 2009].

Tall Buildings Teaching and Research Group. [Online] Available at: http://www.tallbuildingstarg.com [Accessible on 15 March 2009].

The Architecture Foundation. 2000. *Living in the City: an urban renaissance.* London: The Architecture Foundation.

The Bionic Tower: a vertical city. [Online]. Available at: http://mc2000.arch.hku.hk/Bionic_Tower/Bionic_Tower.html [Accessible on 15 March 2009].

The Chicago Spire. [Online]. Available at: http://www.thechicagospire.com [Accessible on 15 March 2009].

The Chicago Spire – a closer look. Overseas Property Mall. [Online]. Available at: http://www.overseaspropertymall.com/press-releases/the-chicago-spire-a-closer-look [Accessible on 15 March 2009].

The City of New York. 2007. *PlaNYC: a greener, greater New York*. New York: The City of New York.

The Code for Sustainable Homes: setting the standard in sustainability for new homes. 2008. London: Department for Communities and Local Government.

The Code for Sustainable Homes: Technical Guide. 2008. London: Department for Communities and Local Government.

The Lawrence Berkeley National Laboratory. [Online]. Available at: http://www.lbl.gov [Accessible on 10 March 2009].

The Lower Manhattan Development Corporation et al. 2005. *The Greenwich Street South redevelopment study: creating new neighborhoods downtown*. New York: Environmental Simulation Center. March 2005.

The New York Times Company. [Online]. 2008. Available at: http://www.nytco.com [Accessible on 10 March 2009].

The Solaire. [Online]. Available at http://www.thesolaire.com/ [Accessible on 15 March 2009].

T.R. Hamzah & Yeang: selected works. 1998. Mulgrave, Vic: Images Publishing Group.

Torcellini, P., Pless, S., Deru, M. and Crawley, D. 2006. Zero Energy Buildings: a critical look at the definition.' ACEEE Conference Paper. Available at: http://www.nrel.gov/docs/fy06osti/39833.pdf [Accessible on 20 March 2009].

Tsui Design Research Ltd. 2005. *The 'Ultima' Tower, two-mile high sky city*. Available at: http://www.tdrinc.com/ultima.html [Accessible on 15 March 2009].

Umakoshi, E. and Gonçalves. J. 2007. The tall building and the architectural utopians: the role of environmental issues and the challenge of a design exercise in São Paolo. In: Wittkopf, S. and Kiang, B. eds. *Sun, wind and architecture: the*

proceedings of the 24th International Conference on Passive and Low Energy Architecture. Singapore, 22-24 November, 2007. Singapore: Research Publishing Services.

Urban Task Force, chaired by Lord Rogers of Riverside. 1999. *Towards and Urban Renaissance*. London: the Department.

U.S. Department of Energy. [Online]. Available at: http://www.energy.gov. [Accessible on 15 March 2009].

US Green Building Council. 2005. *LEED for New Construction & Major Renovations*. Version 2.2. October 2005.

US Green Building Council. [Online]. Available at: http://www.usgbc.org [Accessible on 15 March 2008].

V Building Vision Brochure. [Online]. Available at: http://www.thevbuilding.com. [Accessible on 15 March 2009].

Van Schaik, L. 2002. *Ecocells: landscapes and masterplans by Hamzah & Yeang*. Chichester: Wiley-Academy.

Watson, D. and Labs, K. 1983. *Climatic building design: energy-efficient building principles and practice.* New York: Mc-Graw-Hill Book, Inc.

Willis, C. 1995. *Form follows finance: skyscrapers and skylines in New York and Chicago*. New York : Princeton Architectural Press.

Willoughby, M. 2008. Darling reveals 2019 zero-carbon timeline for non-domestic buildings. *Building Design*. [Online]. 12 March 2008. Available at: http://www.bdonline.co.uk/sustain_story.asp?storycode=3108617 [Accessible on 15 March 2009].

Wolf, A. Sustainability Driven Trends and Innovation in Glass and Glazing. [Online]. Available at: http://www.dowcorning.com/content/publishedlit/sustainability_driven_trends_and_innovation_in_glass_and_glazing.pdf. [Accessible on 10 August 2012].

Wood, A. 2007. Sustainability: a new high-rise vernacular? *The structural design of tall and special buildings*. Wiley Interscience [Online]. Available at: www.interscience.wiley.com [Accessible on 15 March 2008].

Wood, A. (ed.) 2008. *Tall and green: typology for a sustainable urban future; proceedings of the CTBUH 8th World Congress.* Dubai, 3-5 March 2008. Chicago: Council on Tall Buildings and Urban Habitat.

Wood, A. 2010. *Tall buildings: search for a new typology*. PhD Thesis. University of Nottingham.

Wright, H. 2006. *London high*. London: Frances Lincoln Ltd.

Yeang, K. 1994. *Bioclimatic Skyscrapers*. London: Artemis London.

Yeang. K. 1995. *Bioclimatic Theory*. Available at: http://www.ellipsis.com/yeang/theory/032.000.html [accessible on 15 March 2009].

Yeang, K. 1995. *Designing with nature: the ecological basis for architectural design*. New York : McGraw-Hill.

Yeang, K. 1996. *The Skyscraper Bioclimatically Considered: a design primer*. London: Academy Editions.

Yeang, K. 1999. *The green skyscraper: the basis for designing sustainable intensive buildings*. New York: Prestel.

Yeang, K. 2000. *Service cores*. London: Academy Editions.

Yeang, K. 2002. *Reinventing the skyscraper: a vertical theory of urban design*. Chichester: Wiley-Academy.

Yeang, K. 2006. *Designing for Survival: a manual for ecological design*. London: Hoboken, NJ: Wiley-Academy.

Yeang, K. 2006. *Ecodesign: a manual for ecological design*. London: Wiley-Academy.

ZEDFactory. [Online]. Available at: //www.zedfactory.com/ [Accessible as of 15 March 2009].

Zukowski, J. and Thorne, M. (ed.) 2000. *Skyscrapers: The New Millennium*. Munich; London: Prestel.

Design Framework:

Environmentally Sustainable Residential Tall Buildings in the Cool Temperate Climates of Europe and North America

Version 4

Introduction

The framework is a design guide for environmentally sustainable residential towers in the cool temperate climates of Europe and North America. It focuses on the bioclimatic, or passive, design of such buildings, and does not offer advice on active systems or renewable sources of energy. Furthermore, as the design guide is intended for the schematic stage of design and intended for architects, certain bioclimatic strategies will require further evaluation by and consultation with other building professionals. Individual site conditions and building placement need to be evaluated and determined prior to the application of this guidance.

The framework is composed of three elements: design principles, step sequence and framework matrix. The design principles in this document form the steps and options, which are placed in a recommended sequential order. Not all steps can or need to be applied, but their order is hierarchical, as specified by the framework matrix, and so unnecessarily omission, particularly in relation to orientation and configuration, is likely to have a negative impact on the building's performance as a whole. The architect involved in the design need not be concerned with the matrix during the process of design, but it is provided below in case additional principles require categorization or if he or she would like to provide further feedback on the organization of steps. The table presented is meant to be read as a series of columns, with the top left hand corner first for consideration and the bottom right last. Certain interaction boxes are blocked out, so that those elements and climatic conditions that are prioritized are addressed first. The following page provides further detail on the organization of pages outlining the steps; such pages are followed reference pages which provide further discussion and sources relating to the guidance.

		Orientation	Configuration	Fabric
Thermal Radiation	Increase			
	Decrease			
Visible Radiation	Increase			
	Decrease			
Airflow	Increase			
	Decrease			

Design Stage: Environmental Influence (Task)

Step #

Step Name

Option #

Option name

Image

Orientation:
Relevant orientations listed, key ones in bold.

Season:
Relevant seasons listed, key ones in bold.

DESIGN PRINCIPLE SUMMARY
Explanation of design principle function.

Notes:
- Qualifications and details for the application of design principle.

Links:
Links between steps color-coded according to strength and compatibility:
Strong direct link, complementary, coordination required, Weak direct link, coordination may be required, Strong direct link, conflicting, coordination/omission required.

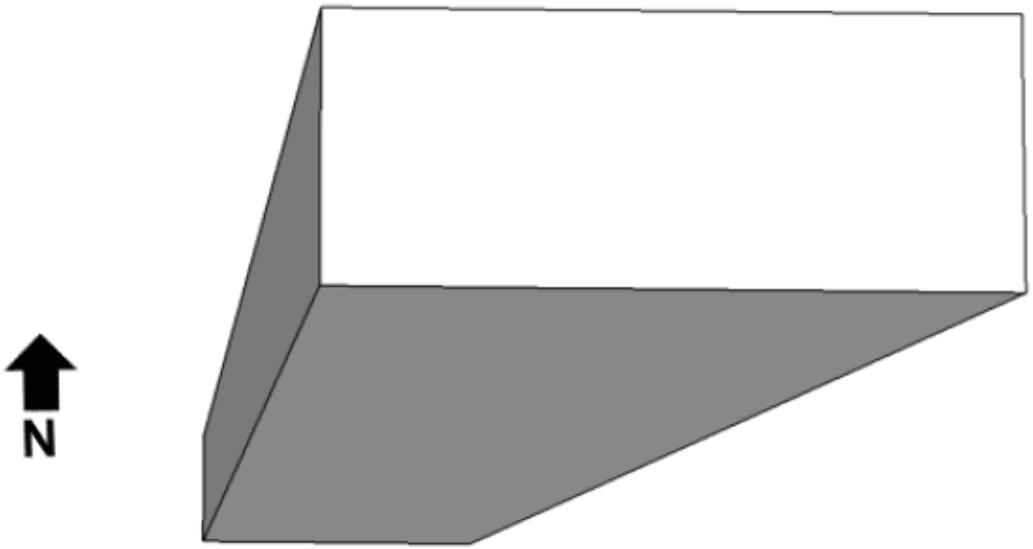
Limitations:
Limitations relating to site and key strategies.

_ YES, GO TO STEP X
_ NO, GO TO STEP Y

Orientation: Thermal Radiation (Increase)

Step 1

Building Orientation



Season:
Autumn
Winter
Spring

FACE BUILDING SOUTH (LONG AXIS ALONG E-W)

A south-facing orientation maximizes the amount of solar radiation penetrating the building, and thus has the greatest potential for solar gain in winter [1].

Notes:

- If constraints prevent exact orientation, limit off-south orientation to ± 15° in cold, cloudy climates and ± 40° in those with long, cloudy heating seasons with a higher proportion of diffuse radiation [2].
- Orientation can be shifted ± 10° to account for local climatic conditions related to morning or afternoon cloudiness [3].

Links:

2, O1; 2, O2; 3; 4; 5; 6; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19; 20; 21; 22; 23; 26, O1

Limitations:

If there are obstructions present near the site, the building orientation will need adjustment. In dense urban areas, this may mean that this strategy may not be possible for parts or all of the building [4]. Some shading may be required, and may present additional concerns for the east and west facades [5].

_ YES, GO TO STEP 2, O1
_ NO, GO TO STEP 2, O1

Step 1: REFERENCES

[1] Support for a south orientation is available from numerous sources, including Watson and Labs (1983: 101), CIBSE (2004: 4.1.3, 2007: 3.1.5.3) and Yeang (2006: 197). Lechner (2009: 198) quantifies the benefits by stating that 'In winter, south glazing collects about three times the solar radiation that east and west glazing collects, and in summer, south glazing collects only about one-third the radiation that east or west collects. With shading, the benefits of south glazing are even better.'

[2] This recommendation is based on Brown and DeKay (2001: 153, 168). They note that climates 'with long cloudy heating seasons, such as Seattle, are less sensitive to orientation because they have a higher proportion of diffuse radiation' and so the 15° rule can be relaxed. Lechner (2009: 168), gives a more lenient range, stating that solar glazing works 'well' if oriented ± 15° from south and 'fairly well' at ± 45°. Kwok and Grondzik (2007: 114) narrow the deviation: 5° off true south has 'no substantial performance penalty' and 45° off incurs a performance reduction of more than 30%; according to them, a 15° off south aperture will receive 'within 90% of optimal winter solar gains' (2007: 101). Smith (2005: 56) suggests an orientation +/- 30° off south and Goulding et al. (1994; 72) agrees. Littlefair (2001: 182) states that a south orientation is recommended by most passive solar guide books (Goulding et al., 1992, Littlefair, 1991, Yannas, 1994 and Brown, 1985 in Littlefair, 2001: 182), and that a 'consensus seems to be that within 20–30° of due south is best'. Olgyay (1963: 54), in his overview of previous studies, finds similar variations as those already mentioned (e.g. G. Bardet with +/- 30° off south).

A debate also exists on whether solar-heated buildings perform best with a slight shift of orientation eastwards or westwards. An east of south orientation (typically 15°) is exposes the building to more morning sun, enabling it to heat up earlier in the day (Watson and Labs, 1983: 101). A west of south orientation, on the other hand, allows the building to retain afternoon heat into the evening (Watson and Labs, 1983: 101; Brown and DeKay, 2001: 168). However, there is an increased risk of overheating during summer in these conditions, partly due to difficulties in shading east- and west-facing facades (Goudling et al., 1992: 72). Olgyay (1963: 54) provides an overview of orientation studies until the early 1960s, which include a variety of orientation recommendations: Rey, Pidoux and C. Bardet with 19° east of north, Marboutin with a general preference for south, G. Bardet with south, Lebreton with south to 25° east of south, Hilberseimer with south and Wright with 25° west of south (for New York specifically, and which Olgyay finds unreliable). Olgyay does not endorse a true south orientation, as although it 'undoubtedly does yield the greatest amount of radiation at the winter solstice and the least amount of insolation at the summer solstice,' the theories behind this orientation 'do not consider daily temperature variations which make solar heat more necessary in the early morning and sometimes more undesirable in the late afternoon' (1963: 54). Instead, he suggests a 'Sol-Air' approach which combines the effects of air temperature with solar radiation in order to maintain temperature levels in the 'comfort zone' (1963: 55). Thus, for the New York, New Jersey area, 17.5° east of south is considered the optimum orientation (1963: 59). However, Reynolds in Balcomb (1992: 491) suggests that Olgyay's recommendations are somewhat dated in that they assumed a low contribution of internal heat sources, which was typical of residences, and 1960s levels of insulation. The framework recommends the widely accepted orientation of south, with possibilities of adjustments, due to the general consensus and shading issues with off-south orientations.

[3] This recommendation is based on Brown and DeKay (2001: 168). Lechner (2009: 168) supports a shift of 10° towards west of south in residences used only at night and a more general west of south orientation in areas of morning cloudiness or fog. Both sources support reorienting as needed in case of general obstructions.

Step 1: REFERENCES

[4] All guidelines presented assume that the winter sun is unobstructed (Brown and DeKay, 2001: 168; Lechner, 2009: 168). When an obstruction is present, a particularly disadvantageous scenario would entail a higher south-facing obstruction that blocks out winter sun but allows for the high-angle sun to lead to unwanted solar gain in the summer (Littlefair, 2001: 182). In that case, clearly solar gain is undesired and so this step should be avoided.

[5] CIBSE (2004: 4.1.3; 2007: 3.1.5.3.) points out that the south orientation allows for the most effective control of solar gains in summer, as east and west-facing facades have low sun angles during some periods. Hausladen et al. (2005: 42) further explains that such problems in east-west orientations lead to a full closure of horizontal louvers, resulting in obstructed views, lack of natural light and an increase in electricity demand and internal loads. LIttlefair (2001: 182) refers to a NBA Tectonics study of solar houses, which found that west and east glazing loses solar gain while causing problems with shading.

CORE LOCATION

Hierarchy:

1. Option 1: North

2. Option 2: South Walkway

Orientation: Thermal Radiation (Increase)

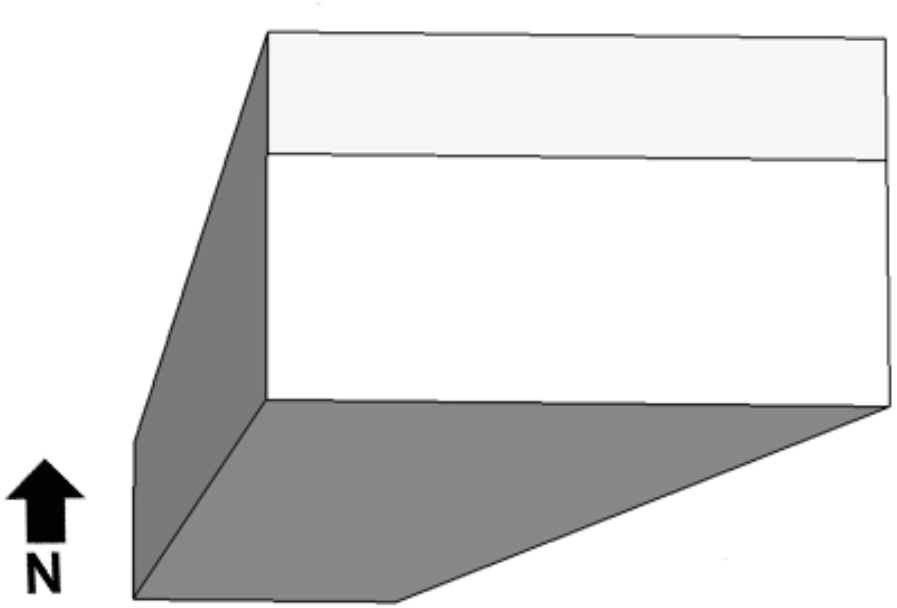
Step 2

Core Location

Option 1

North

Season:
Autumn
Winter
Spring



PLACE THE PRIMARY MASS (CORE) ON THE NORTH SIDE

A solid core on the north reduces heat losses on non-solar facades while increasing areas for solar gain [1].

Notes:

- The placement applies not only to the main core elements such as stairs and lifts, but also as for closets, service spaces and bathrooms [2].

Links:

1; 2, O2; 3; 5; 6; 7; 9; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 22; 26, O1; 27

Limitations:

Due to safety regulations, there may be a need for a secondary core on the south section of the building; in this case, the step still applies for those areas of the south facade that are not obstructed. An option in this case is to move the core to the east and/or west sides of the building [3].

_ YES, GO TO STEP 3
_ NO, GO TO STEP 2, O2

Step 2, Option 1: REFERENCES

[1] This is a strategy encouraged by Yeang (2006: 201) for tall buildings. Gonçalves (2010: 174) refers to it as ‘common feature’ of most recent ‘environmentally responsive’ skyscrapers and whose purpose is to move the mass away form the central position. She highlights, though, that it is not a precondition for daylighting and natural ventilation, but that it does allow for further functional zones within the building and its core.

[2] The aim is to place unheated spaces and those used less frequently on external walls as buffers between the outside and heated spaces (Cofaigh et al., 1996: 62; Kwok and Grondzik, 2007: 107).

[3] Double peripheral cores on the east and west sides are recommended by Yeang (2006: 197-8; 214) primarily to act as solar buffers on ‘hot’ sides of the buildings. They are therefore more suitable for non-residential towers in hot climates, rather than the temperate one where a main objective is to prevent heat losses and increase solar gain during cold periods. If they are placed on those sides, the building nonetheless benefits from daylighting and less complicated shading systems during the summer period.

Orientation: Thermal Radiation (Increase)

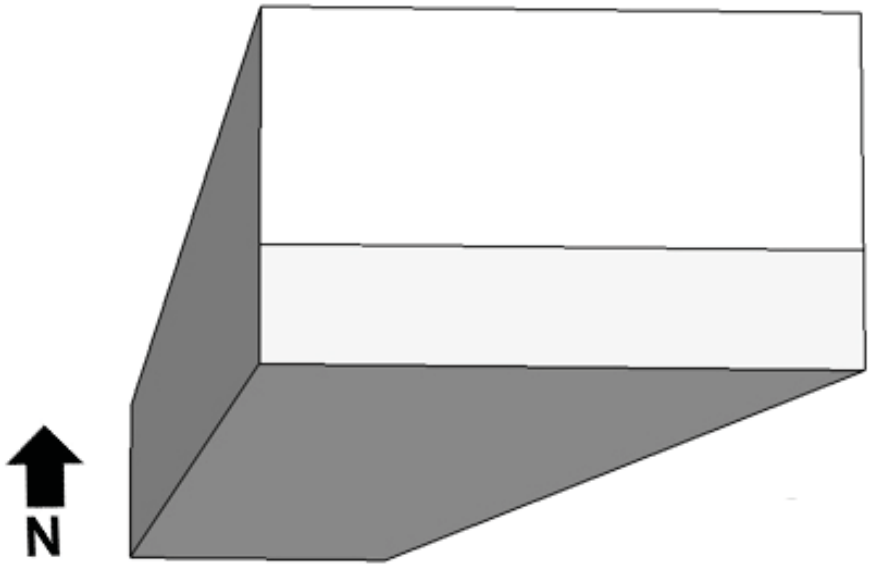
Step 2

Core Location

Option 2

South Walkway

Season:
Autumn
Winter
Spring



DESIGN SOUTH CORE ELEMENTS AS A WALKWAY OR GALLERY

A walkway or gallery that includes some of the core functions, such as stairs, can be designed as a sun-space to collect and pre-heat air for adjacent apartments [1].

Notes:

- Due to wide temperature swings, a sunspace needs to be designed as a thermal zone isolated from the rest of the building, although it should allow for some heat transfer in colder periods [2].
- The mass to glazing area for the purposes of heat storage is to be proportioned as at least 3:1 [3].
- Sunspaces should be well ventilated and shaded during the summer to prevent excessive heat gains [4].
- During the winter, the spaces should not be heated and will rely on thermal mass to keep from freezing [5].

Limitations:

Due to safety regulations, there may be a need for an enclosed core elsewhere; in this case, the mass should be placed north, or east/west if not feasible. Indoor vegetation may require further adjustments [7]. The dark walls usually recommended for heat storage may be in conflict with daylighting purposes [8].

Links:

1; 2, O1; 3; 5; 6; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 21; 22; 23; 25; 26, O1; 26, O2; 27; 28; 29

_ YES, GO TO STEP 3
_ NO, GO TO STEP 3

Step 2, Option 2: REFERENCES

[1] Sunspaces exist in smaller buildings as rooms to collect heat, reduce winter heat loss and act as secondary living areas (Watson and Labs 1983: 113, 127; Cofaigh et al., 1996: 88-90; Lechner, 2009: 163; Goulding et al., 1994: 70). A small number of towers in the temperate climate, notably the SEG Apartment Building in Vienna, have used sunspaces as a way to increase thermal radiation. Marcondes (cited in Gonçalves, 2010: 156) confirms this approaches' suitability for the that climate type in the context of tall buildings.

In line with the building orientation advice, sunspace glazing is considered most effective when oriented south, up to 15° off south deviation with a performance penalty of up to 5%.; at 45° off south, the penalty ranges from 10% to 30% (Jones, cited in Balcomb, 1992: 278); this range of orientation is also recommended by Kwok and Grondzik (2007: 120), although they also point to the more complicated option of orienting for morning or afternoon heat gains. Cofaigh et al. (1996: 88) gives a more general orientation of 30° off south.

[2] Tight-fitting doors and windows are used to separate the sunspaces from the main building, and are beneficial in that they allow for both isolation during hot periods and heat convection during cooler periods (Goulding et al., 1994: 161; Lechner, 2009: 163-164). Lechner (2009: 163-164) points out that even if isolated, there is an expectation that much of the heat will be transferred to the main part of the building through the facade elements. He (2009: 167-8) further recommends a common thermal-storage wall, possibly of water or a phase-changing material, for temperate climates as a way to avoid total isolation.

Lechner also discusses opportunities for spaces attached to, semi-enclosed by and enclosed by the building, but in the case of the skyscraper and this framework the attached and semi-enclosed options are assumed: an atrium would act as an enclosed space. If the sunspace does not act as a circulation space, advice is provided in the section on double facades. It is worth noting, as Goulding (1994: 70) points out, that these spaces can cover part of or the whole width of the building and can be multiple stories high (Goulding et al., 1994: 70).

[3] This recommendation is based on Brown and DeKay (2001: 172). Separating walls and floors do not necessarily have to be massive, but should allow for some insulation to reduce night-time losses; for quicker heat transfer, the separating walls can be glazed, although this will limit the net solar gain (Watson and Labs 1983: 127; Goulding et al., 1994: 161; Cofaigh et al., 1996: 90). Lechner (2009: 167) also points out that vertical glazing offers most benefits but that little, if any, glazing should be used on the east and west walls as it acts as a thermal liability. Balcomb (1992: 15) supports this view. Nonetheless, he states that the issue of overheating in sunspaces has much less of an impact on the main building than the overheating of direct-gain or Trombe walls. It is also worth noting that thermal energy is delivered to the building as warm air, and is therefore more difficult to store than energy stored directly in mass from solar radiation (Goulding et al., 1994: 71). See Step 16 for more information on thermal mass.

Step 2, Option 2: REFERENCES

[4] The majority of sources highlight this point, and a number provide further guidance on design details that are beyond the schematic stage of design. They include Balcomb et al. (1984), Brown and DeKay (2001: 172) and Lechner (2009: 166-167) on the sizing of wall vents. Jones and McFarland (cited in Balcomb, 1992: 270), discuss the amount of natural ventilation required to maintained various sunspace temperatures. Internal elements, such as furniture and flooring, have much impact on the effectiveness of sunspaces and are discussed in a number of sources, including Cofaigh et al. (1996: 57). Shading is often mentioned as especially important, as sunspaces often include increased areas of glazing (Goulding et al., 1994: 70; Kwok and Grondzik, 2007: 120). Many sources also refer to tilted glazing, and this aspect is discussed in Step 5, Note 4.

An additional method for the reduction of overheating in all seasons is presented by Balcomb (1992: 15). It suggests a limit of the solar gain collection area to one which would result in a temperature of no more than 22°C on a clear January day and a sizing of the thermal storage to result in a temperature swing of no more than (6°C) during the same period. He offers further percentages for areas of direct gain, but given the complexity of tall building facades, may not be suitable in this context.

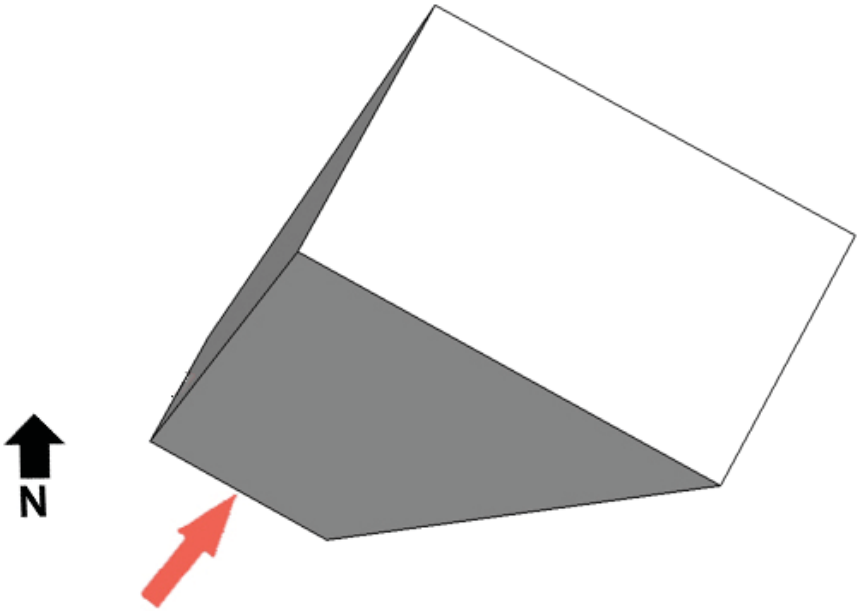
[5] This recommendation is based on Goulding et al. (1994: 70), Cofaigh et al. (1996: 90) and Lechner (2009: 163). Goulding et al. (1994: 161) state that the energy consumption of a building in northern Europe can double if heating is used. Lechner (2009: 164) also refers to the space having to be abandoned during extreme temperatures, but as the main purpose of the space here is as a building circulation area, this is not as large an issue.

[6] If the sunspace is to feature vegetation, auxiliary heating and humidity control may be required at times (Goulding et al., 1994: 70). The choice of plants therefore needs special attention. Goulding et al. (1994: 161) suggests that the external glazing should be doubled to reduce problems with condensation.

[7] For heat storage purposes, the color of the floor and walls should be dark (Goulding et al., 1994: 161). This may conflict with daylighting, so needs to be noted in advance.

Orientation: Airflow (Increase)

Season:
Spring
Summer



ORIENT BUILDING TO MAXIMIZE EXPOSURE TO SUMMER WIND DIRECTION

An orientation of the building so that the summer wind is perpendicular to the long surface allows for maximum wind pressure. Note, however, that a wide range of deviations are often suitable for this purpose [1].

Links:

1; 2, O1; 2, O2; 9; 10; 11; 12; 17, O1; 17, O3; 18; 27; 28; 29

Notes:

- This step is not intended to override Step 1, but complement it: orientation for solar gain is of priority [2].
- If there is no prevailing direction of wind, the building should be designed so that ventilation is possible along both axes. Here, a square-shaped building with windows on windward and leeward sides is suitable, although again a range of deviations could be considered [3].

Limitations:

A variation in seasonal winds is expected; if all are similar, ventilation is difficult to control. There may be conflict with performance of structural elements [4]. A chance of wind interference caused by surrounding buildings exists [5]. Air pollution is a risk [6]. In all cases, further evaluation and input is needed [7].

_ YES, GO TO STEP 4
_ NO, GO TO STEP 4

Step 3: REFERENCES

[1] Notable improvements in natural ventilation through the use of appropriate orientation were found by Ayata and Yıldız (2006) (cited in Cheung and Liu, 2011: 1149). It is generally assumed that winds exert maximum pressure when perpendicular to a surface (Lechner, 2009: 272; Watson and Labs, 1983: 111, 191). However, such an orientation is not compulsory. Brown and DeKay (2001: 167) state that variations up to 40° from perpendicular to the prevailing wind 'do not significantly reduce ventilation'. Givoni extends one step further in claiming that 'it is apparently unnecessary to orientate the main facades of a long building so that the wind enters perpendicular to the windows' and so a wide range of orientations, with appropriate openings, is satisfactory (1976: 230). Similarly, Lechner (2009: 272) states that 'Winds exert maximum pressure when they are perpendicular to a surface, and the pressure is reduced by about 50 percent when the wind is at an oblique angle of about 45°' but qualifies this statement by pointing out that indoor ventilation is better when turbulence is present from oblique winds, meaning that a range of wind directions would function. This framework assumes that changes in wind velocity will occur in most cases, and so the recommendation stands as an initial suggestion. Watson and Labs (1983: 111) support this stance, stating that 'the fact that the breeze may deviate from its prevailing direction justifies the general rule of facing squarely into the breeze.'

[2] As larger deviations in orientation are generally more acceptable for ventilation than for solar gain, and as heating is a higher priority than cooling in the temperate climate, solar gain takes precedence. Therefore, the building should not be reoriented from south, but can be adjusted if solar access is poor.

[3] This recommendation is based on Watson and Labs (1983: 111).

[4] In terms of structural concerns, Ascher (2011: 58) offers a number of suggestions to minimize vortex shedding: orienting the building so that the longer face of the structure is parallel to prevailing winds, chopping or rounding off corners to make it more aerodynamic, roughing up corners through placement of balconies or stepped corners, twisting the building, rotating it and punctuating its surface with an opening. Many of these are clearly relevant to environmental schematic design, and so should be considered and discussed with structural engineers. Watson and Labs (1983: 103), likewise, state that the building can be streamlined if winter winds come from a predictable direction with an idealized form of a teardrop or low-rise dome. The aim is to minimize the pressure differential between windward and leeward sides, in which case rounded corners or smooth surfaces promote the flow of wind. They also point out that a 'knife edge' corner is counterproductive, as it leads to a larger suction and driving force of the indoor air movement.

Cheung and Liu (2011: 1149) validly point out that there has been a bias towards structural issues, such as the wind load and moment, in tall building research, although recently some studies have emerged focusing on ventilation.

[5] Using CFD methods, Cheung and Liu (2011: 1149) found that the optimum building separation for ventilation was about five times the building width, but could be reduced to three times if a suitable building disposition was adopted. As with ventilation, Cheung and Liu (2011: 1149) call attention to the fact that little research has been completed on adjacent buildings' interference on natural ventilation in tall buildings, nor do existent guidelines provide adequate information.

Step 3: REFERENCES

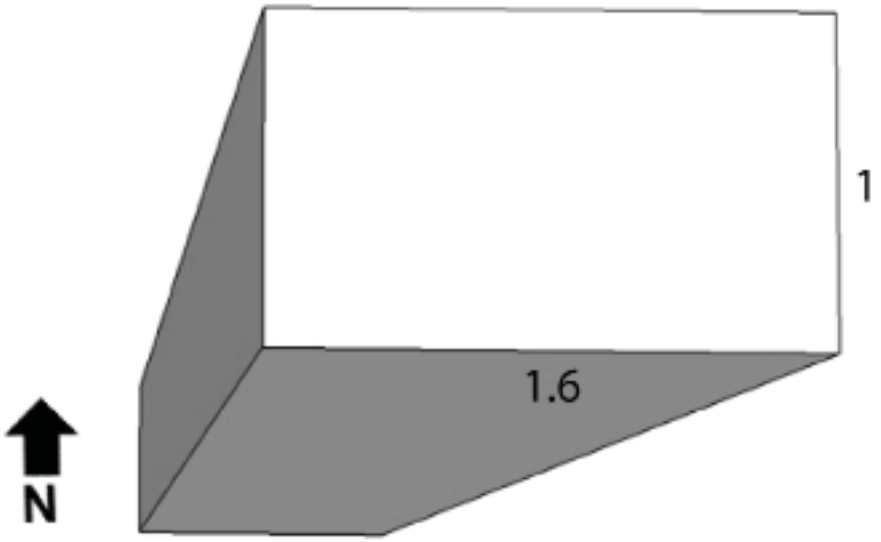
[6] CIBSE (AM10- section 2.2 in CIBSE Sustainability Tool, no date) suggests that air intakes or openable windows be minimally 20 m away from sources of external pollution, including roads.

[7] Evaluation options include wind tunnel testing and CFD analysis.

Configuration: Thermal Radiation (Increase)

Step 4

Built Form Ratio



Season:
Autumn
Winter
Spring
Summer

DESIGN FOR A BUILT FORM ASPECT RATIO OF 1:1.6

A built form ratio at about 1:1.6 allows for an optimal balance between solar penetration and insulation in the temperate climate [1].

Links:

1; 5; 6; 7; 9

Notes:

- The rectangular shape is considered better for solar control than the circular floor plate and is thus recommended for residential buildings in the temperate climate [2].

Limitations:

These recommendations are based on the assumption that the building faces south. In case of diagonal orientations, the most suitable plan is a square one [3].

_ YES, GO TO STEP 5
_ NO, GO TO STEP 5

Step 4: REFERENCES

[1] This recommendation is stated in Yeang (2006: 197-8). Although not referred to directly, it may have originated with the work of Olgyay (1963: 88), which encourages elongated forms along the east-west orientation. His optimal ratio for New York is 1:1.56 for winter conditions and 1:1.63 for summer, with an overall 'adopted index' of 1:1.6. Olgyay's ratio recommendations, as is the case with all other sources here, are based on houses rather than tall buildings, but have been adapted by Yeang and other practitioners. Watson and Labs (1983: 107-108) discuss variances of this ratio with latitude, with an inclination towards more square plans in northern latitudes; thus, for example the optimum ratio for Miami is assumed to be 1:1.64 and 1:1.30 for Glasgow. Having a compact form reduces the area of the outside wall per heated volume, resulting in a smaller energy requirement (Goulding et al., 1994: 3). It is from this benefit that Goulding (1994: 3) attributes the higher energy savings in apartments over detached dwellings. Cofaigh et al. (1996: 57) also refers to the increased energy efficiency of apartments over other types of housing.

It is worth noting, though, as Olgyay (1963: 90) states for large buildings, 'In the temperate zone there is the least stress from any specific direction. The smallest penalty is received from this climate, allowing considerable freedom in form; however, shapes on the east-west axis are preferable.' Thus the ratio seems to be more of an issue in other climates. There appear to have been more studies carried out in other climates in terms of tall buildings, including one study in Korea that found 'plate-type' buildings consumed less energy and were found to be more comfortable than 'tower-type' ones (Choi et al., 2012).

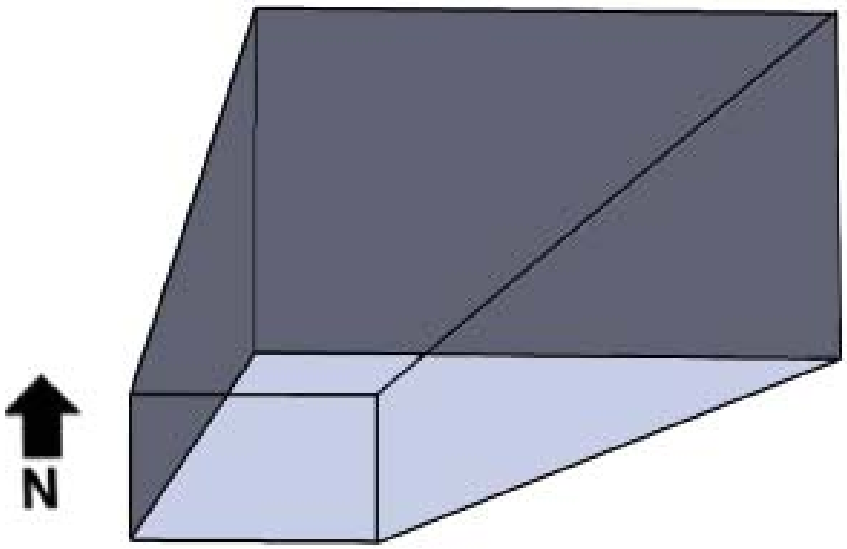
[2] The circular floor plate is considered as providing the least surface exposure to the sun, thus reducing air-conditioning loads, and is often recommended for office buildings in a cold/cool climate. Yeang acknowledges the benefits, but bases his preference for the rectangular floor plate on the shape's ability to control solar gain, particularly in buildings with low occupant density, such as residences, where solar gains can be used to offset heating requirements (Yeang, 2006: 199-200). Gonçalves (2010: 170), referring specifically to tall buildings, further states that a south facing slab building can avoid the negative implications of shading east and west orientations, even though she notes that a square or circular floor plan may be suitable if other preferences, for example heat transfer through the envelope area, are priorities. Olgyay (1963: 87) is less encouraging of the square shape, stating that the supposition of its preference is based on older buildings with small window openings, as opposed to more contemporary buildings with large openings, in which case 'this concept becomes a fallacy.' In more general terms, Lechner (2009: 467-469) points out that compact designs are less sustainable when natural ventilation is the dominant cooling strategy, especially in a climate with mild winters, and, in reference to multistory buildings, he states that more spread-out plans may also be preferred when daylighting is a high priority. Hausladen et al. (2005: 133), however, finds that a more compact plan reduces the area and depth of insulation required. Because of these conclusions, the diagrams presented in the framework represent the building as rectangular, although the designer may chose to omit this recommendation and align suggestions to specific building orientations.

[3] This recommendation is based on Watson and Labs (1983: 107-108), referring to 1977 data by Kasuda.

Configuration: Thermal Radiation (Increase)

Step 5

Glazing placement



Orientation:	*Season:*
North	Autumn
East	**Winter**
South	Spring
West	Summer

PLACE GLAZING ON SOUTH AND MINIMIZE GLAZING ON OTHER FACADES

Assigning the glazing area to the south side of the building increases opportunities for solar gain while minimizing glazing on other facades ensures that excessive heat is not dissipated during cold periods [1].

Notes:

- The south-facing area should be limited to around 20% of the total floor area [2] or 50% of wall area [3].
- North-facing orientations are not generally considered net energy providers, so to conserve energy glazing is generally minimized to form about 10-15% of the total glazed area, if sufficient for daylighting and cross-ventilation [4]. A possible exception is the highly insulated window, e.g. aerogel [5].
- East or west windows should be limited to form about 10% of the total glazed area [6].
- Tilting the glazing towards the sky can also increase solar gain by 30% [7].

Limitations:

The overall building performance is highly dependent on balancing the need for solar gain during heating periods with its reduction during cooling periods, and so this step must be combined with some form of shading, as outlined in the section Fabric: Thermal Radiation (Increase) [8].

Links:

1; 2, O1; 2, O2; 4; 6; 10; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 23; 26, O1; 26, O2; 27; 29

_ YES, GO TO STEP 6
_ NO, GO TO STEP 6

Step 5: REFERENCES

[1] This recommendation is based on Yeang (2006: 201-202), although other sources concur. It may be worth noting that the amount of glass proposed in the framework is much less than current standard practice. As Ascher (2011: 161) points out, at mid-century, the percentage of glass on building facades rose from 25% to 50-75%, which led to in what she terms ‘a dramatic fall in internal performance - i.e. heat losses in winter and excess solar gain in summer.’

In the framework, a distinction between the openable and glazed area of a window should be made, as set out well by Evans (1980: 109): ‘In many climates the terms window and glazed area will not necessarily be synonymous. In temperate climate windows will be fully glazed and partially openable.’ Baker et al. also illustrate the distinction in functions: ‘If the most important function of the window is illumination, it is usually best to locate it in a high position and size it to optimize the entry of natural light. If the ventilation aspect is to be favoured, its position in the wall is more important than its size. For a better exterior view, the size of the window and the height of the sill from the floor are extremely important. The lower the window, the more favourable it will be for views. In practice these three functions are combined in the most common types of window.’ Such varying window functions are further discussed in CIBSE (2004: 4.2.4.1), although the term ‘window/glazing systems’ is used interchangeably. The steps of the framework will therefore avoid using the general term ‘window’, and specify glazing or opening as required; however, the reference notes will use all terms as intended by the sources, although effort is made to distinguish functions.

[2] This recommendation is based on Cofaigh et al. (1996: 84). Goulding et al. (1994: 160) recommends limiting glazing to around 20% of the floor area in northern Europe, although it can be argued that more recent advancements in glazing technology could increase this percentage significantly. Lechner (2009: 397-398) also recommends a figure of 20%, but adds that in cloudy climates optimum window area can be increased with high performance windows and movable shading systems. Johnson (1991: 105), furthermore, warns of potential wintertime overheating if the area is greater than 7% to 10% of the floor area ‘that “sees” the window’, and so shading is crucial. CIBSE (2004: 4.2.6.4) provides percentages for glazing facing only one orientation, but its guidelines here are applicable only to office spaces; nonetheless, information in a similar format for tall residential buildings would be useful.

[3] This recommendation is based on a limitation of 30-50% in Hausladen et al. (2005: 133). They further state that ‘Extensive passive use of solar radiation is possible at a glazing fraction of 40%’ (2005: 132), but it is unclear if this refers to office buildings only. Goulding et al. (1994: 160) suggests a 60-70% area for south-facing solar glazing, as do Cofaigh et al. (1996: 84). In practice, Shuttleworth mentions a 50% solidity ‘staring point for most high-rise projects’ with no particular orientation is specified (Shuttleworth, 2008: 2). Likewise, Daniels (cited in Eisele and Kloft, 2002: 165) states that windows should ‘make up at least 50 percent of the facade’ without referring to an orientation. In any case, these percentages are notably less than currently seen in tall buildings; current standards lead to major problems, as discussed in Gonçalves (2010: 176-177).

Step 5: REFERENCES

[4] This recommendation is based on Goulding et al. (1992: 160) and Brown and DeKay (2001: 244), with daylighting and cross-ventilation preferences set by Goulding et al. (1994: 99). Johnson (1991: 100) points out that 'The amount of solar heat in north light on the equinox at mid latitudes is about 15% of the heat falling on a south-facing window at the same location on a clear day.' Nonetheless, Lechner (2009: 153; 484) states that, like east and west windows, north windows lose more heat than they gain in winter, although high-performance windows may change this suggestion. Watson and Labs (1983: 175) also point to the usual northerly direction of winter winds as a reason to minimize.

[5] Wolf (no date) argues: 'Even the solar energy available on the north façade is more than sufficient to counter small daytime losses and turn the window into a net energy provider.' This approach is highly dependent on window performance, as exemplified by vacuum windows, aerogel windows and gas-filled, triple-glazed units. However, this statement is based on calculations rather than measurements, and as the performance and application of window types varies and as insulated walls on the whole perform better than most glazing systems, Wolf's suggestion here is included as an exception rather than the rule.

[6] This recommendation is based on Goulding et al. (1994: 160). East and west windows are considered equivalent in this respect, as both are thought to have a high energy gain in summer and a low one in winter and present difficulties in shading (Baker et al., 1993: sec. 5.8; Santamouris and Asimakopoulos, 1996: 330-1).

[7] Brown and DeKay (2001: 168) infer that this maximum is best achieved by tilting the glazing 'at an angle above horizontal equal to the site's latitude plus 15°.' Goulding et al. (1994: 72) outlines the benefits of a reduction in the slope of a vertical south-oriented facade, including greater solar energy during the heating period, but warns that it could also cause more overheating problems during the summer and issues with horizontal shading application. Due to these concerns, and as the strategy is not commonly used in tall buildings and is perhaps better applied for solar shading purposes, here it is presented as a possibility rather than an individual step. Capeluto (2002: 327), basing his advice on a computer model, suggests that self shading, here tilted the opposite direction to that required for increased solar gain, works best with internal blinds and for east and west orientations; however, given the concerns of the temperate climate, other shading elements are usually more useful, although approaches such as that used in the Solstice on the Park building may point a way forward.

[8] Santamouris and Asimakopoulos (1996: 343) and Halliday (2008: 230) highlight this concern, while also referring to the importance of daylighting in the temperate climate.

Configuration: Thermal Radiation (Increase)

Step 6

Floor Plan

Orientation:	*Season:*
North	Autumn
East	**Winter**
South	Spring
West	

ARRANGE ROOMS TO RESPOND TO HEATING REQUIREMENTS

Energy use is maximized by placing rooms according to their heating requirements [1].

Notes:

- Spaces with the greatest heating need should be placed closest to solar facades and those used less frequently, such as stairs and utility rooms, on the north facade [2].
- Rooms placed in a long east-west arrangement also lower unwanted solar gain in summer [3].
- Apartments with more than one external wall have more heat loss than those with one [4].

Links:

1; 2, O1; 2, O2; 4; 5; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 23; 25; 27; 28; 29

Limitations:

Room placement is dependent on apartment placement, which should inevitably be arranged mainly along the south facade if previous steps are followed; if otherwise, this step still applies, although the benefits of solar gain are smaller.

_ YES, GO TO STEP 7
_ NO, GO TO STEP 7

Step 6: REFERENCES

[1] This recommendation is based on Goulding et al. (1994: 160) and Smith (2005: 56). Cofaigh et al. (1996: 56) provide some examples of this, in which living spaces and balconies face south and circulation spaces face north. They also note that an east-west layout section can be more evenly balanced.

[2] This recommendation is based on Goulding et al. (1994: 160). He offers two further actions, which are less applicable to tall buildings and so omitted here. Zoning could include: ‘an east- or southeast-facing window for bedrooms, kitchen and breakfast area to benefit from the earliest winter morning sunshine; a south orientation for daytime living areas; a southwest orientation for sunspaces or other indirect solar gain elements’ (Watson and Labs, 1983: 129).

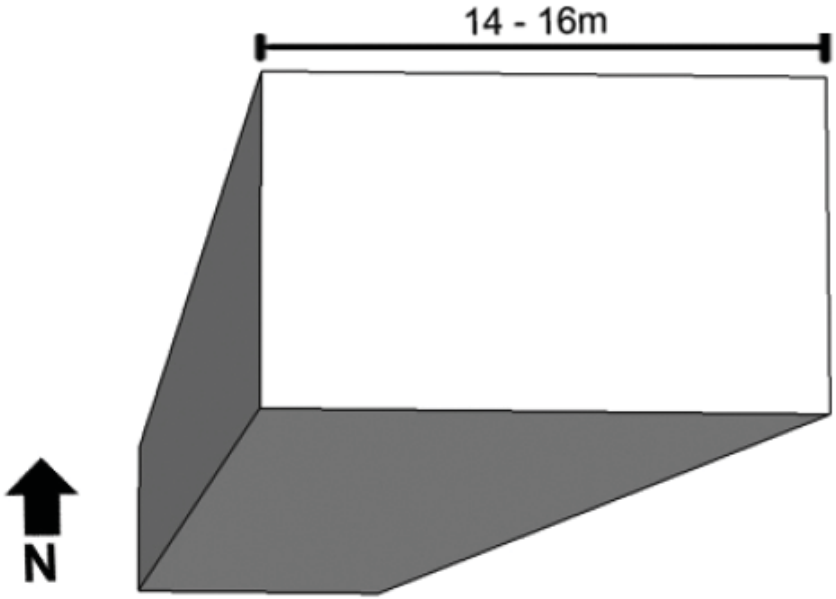
[3] This placement is noted in Brown and DeKay (2001: 153), due to the sun rising further east and setting further west in the summer.

[4] This fact is noted by Goulding et al. (1994: 159). Furthermore, there are differences in apartment placement and orientation: ‘The losses from an apartment situated at the northwest corner of the top floor of a conventional block can be up to twice those of an apartment in the middle of the south façade.’ No height is stated here, and no further data is referenced relating to specific heights. He also points out that increased insulation will be required to offset the losses.

Configuration: Visible Radiation (Increase)

Step 7

Floor Plate Depth



Orientation:	*Season:*
North	**Autumn**
East	**Winter**
South	**Spring**
West	**Summer**

LIMIT FLOORPLATE DEPTH TO 14-16 METERS

A limited floorplate depth optimizes opportunities for daylighting [1].

Notes:

- As daylighting is dependent on location and diurnal and seasonal variations, evaluations of daylight performance are recommended early in the schematic design process [2]
- Consider the use of an atrium if building form requirements prohibit a narrow floorplate. Attention should be paid to its configuration and internal obstructions [3].

Links:

2, O1; 4; 8; 9; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 24; 25; 26, O1; 26, O2; 27

Limitations:

Surrounding buildings have a significant impact on the availability of daylight, so in urban areas some facades may rely partly or entirely on reflected light [4].

_ YES, GO TO STEP 8
_ NO, GO TO STEP 8

Step 7: REFERENCES

[1] This recommendation is based on Yeang (2006: 210), but similar suggestions are common amongst general environmental design guides. Goulding et al. (1994: 124) and Leslie (2003: 383) advise a slightly smaller distance, based on a 6 m and 5 m light permeation range, respectively. Lechner (2009: 395), referring specifically to multistory buildings, gives a higher distance: 'a 15-ft (4.5 m) perimeter zone can be fully daylit and another 15 ft (4.5 m) beyond that can be partially daylit.' The main aim, in all cases, is to ensure that sufficient light is available on overcast days (Evans, 1980: 117; Müller and Schmitz in Eisele and Kloft, 2002: 154), which account for two thirds of all daytime periods in most European countries (Müller and Schmitz in Eisele and Kloft, 2002: 153).

[2] Goulding et al. (1994: 118) offers a number of limitations of daylighting and offers some relevant conclusions: due to a lack of visible radiation during half of the year, daylighting has a limited use above 55°N; around noon, a typical overcast sky in summer can often be twice as bright as that in winter; and daylighting levels at the start and end of days are too low to allow for useful daylighting. Although some of these restrictions cannot be overcome, the use of additional strategies in the framework, e.g. light shelves, can help diminish their effects.

Evaluation options include simplified tools as presented in Brown and DeKay (2001: 247) and Li et al. (2006), physical models available in Moore (1991) and Evans (1981) (cited in DeKay, 2001: 247), and computer simulation.

[3] As atria are primarily challenged by, and designed around, ventilation requirements, a more extensive discussion is available in that respect in Step 28, Note 6. Here atria serve as enclosed and covered internal spaces with the function of bringing daylighting into deep plan buildings (Baker et al., 1993: sec. 5.11; LG10 - Section 1.2.2.3 in CIBSE Sustainability Tool, no date). Significantly, atria provide decreased light levels, as compared to standard daylighting, to the adjacent spaces, in part because of the glazing and in part due to the structure supporting the glazing (Baker et al., 1993: sec. 5.11). Baker (1993: sec. 5.46, 5.48-5.49), Goulding et al. (1994: 149, 150) and CIBSE (2004: 4.2.1.2) furthermore point out that the depths and heights of spaces further down the atrium may be affected due to decreasing light levels, as may be window sizes. Both scenarios require some form of environmental modelling.

Square atria are recommended for higher height to width ratios: 'At low height to width ratios (1:1) atrium plan geometry is not very significant. Square and rectangular atria perform similarly. At higher ratios (2:1) square atria provide 7-10% more light to the atrium floor than rectangular atria with a 1:2 plan aspect' (Goulding et al., 1992 and Willbold-Lohr, 1989, cited in Brown and DeKay, 2001: 198). Goulding et al. (1994: 147) also suggest that a 'quadrangular atrium provides four sides with roughly equal illumination whereas the rectangular atrium provides two different levels of façade illumination.' CIBSE (2004: 4.2.1.2) concurs. Littlefair (2001: 105) also suggests splaying atria, so that the bottom is narrower than the top.

A width to height ratio of 1:1 is recommended as 'the ideal value to ensure good lighting' by Hausladen et al. (2005: 101). However, such a figure is unlikely in tall buildings, and so additional strategies, such as sidelighting or solar reflectors, are often required if sufficient levels of light are to be expected naturally. In any case, high reflectances are required when the height is greater than the width (Baker et al., 1993: sec. 5.45). More information on color, and reflective surfaces, can be found in Step 25.

Step 7: REFERENCES

Internal obstructions can significantly block out light: Littlefair and Aizlewood (1998, cited in Littlefair, 2001: 105) state that measurements in atria show that at least half of the light can be blocked by them. They include walkways, galleries and other circulation systems.

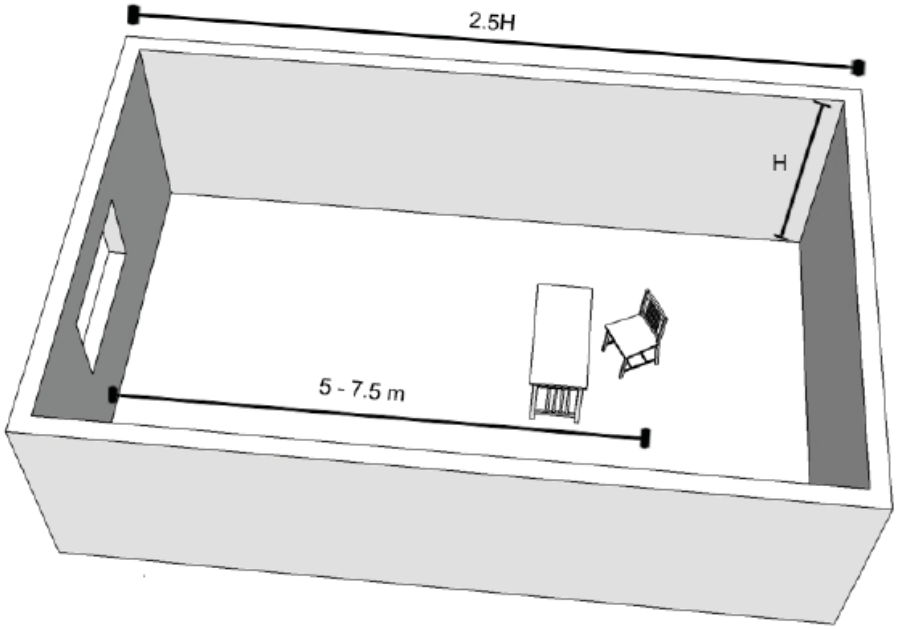
Generally, covered atria are more advantageous than open courtyards in the temperate climate, and the variety of reasons for this preference is set out in Goulding et al. (1994: 139).

[4] High room surface reflectance is recommended to promote the distribution of daylight (CIBSE, 2004: 4.2.6.2). Li (2010: 2115) summarizes that ‘Most useful light entering the glazing into building interior comes from a cone of light 100° centred to the normal of the glazing. The amount of this reflected light is dependent on how well these surrounding surfaces are illuminated and the reflectance of these surfaces.’ As Gonçalves (2010: 197) calls to attention, daylight in tall buildings is not particularly affected by height, other than the influence by the immediate surroundings. In this sense, different levels of a tall building may have different daylighting strategies as a response to context. However, as light reflected from vertical walls remains constant throughout much of the day, shaded windows facing streets with buildings benefit from a constant illumination source (Brown and DeKay, 2001: 246). Furthermore, Johnson (1991: 131) highlights the fact that a decrease in indoor reflectance has a greater effect in the back of a room than an equal drop in outdoor reflectance.

Configuration: Visible Radiation (Increase)

Step 8

Room Plan



Orientation:	*Season:*
North	**Autumn**
East	**Winter**
South	**Spring**
West	**Summer**

LIMIT ROOM DEPTHS TO 5-7.5 METERS AND 2.5 TIMES THE GLAZING HEIGHT

Limited room depths optimize opportunities for daylighting [1].

Notes:

- Rooms requiring high lighting requirements and frequent use should be nearest to glazing [2].
- Limit glazing area to that specified for solar gain, i.e. 25%, although orientation is not critical [3].
- Glazing placed in a high location is preferred to one placed in a low location [4].
- Glazing spread along the facade improves light distribution; if an individual element is used, a central placement is preferred to a corner one [5].
- Horizontal glazing formats are preferable to vertical ones [6].
- Glazing width in living rooms should be at least 65% of room width [7].

Links:

2, O2; 7; 10; 11; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 24; 25; 26, O1; 26, O2; 27; 29

Limitations:

Additional strategies may be required for sufficient lighting levels in deep plans [8]. Light-colored walls and ceilings and cloudy day illumination are assumed [9]. For daylighting, a common room suggestion is a width greater than the depth. However, for energy savings, narrower rooms are best, and should be prioritized [10].

_ YES, GO TO STEP 9
_ NO, GO TO STEP 9

Step 8: REFERENCES

[1] This 5-7.5 meter depth limit is based on Yeang (2006: 216) and encompasses a range of recommendations found elsewhere. CIBSE (2004: 4.2.1.1) points out that energy efficiency benefits from daylighting, as well as natural ventilation, are most beneficial up to 6 metres from windows. For multistory buildings, Kwok and Grondzik (2007: 65), refer to a '15/30 guideline' that states that a zone depth of about 15 ft (4.64 m) from the window can be illuminated by daylighting and that one of 30 ft (9.1 m) can be lit by a combination of daylighting and electric lighting. Most local regulations for tall building depth relate to office spaces located in European cities. Gonçalves (2010: 170-171) mentions the stipulations for a 7 m distance limit from a window in Germany and Holland, as opposed to the 12-13 m US market standards.

The 1:2.5 ratio is based on Yeang (2006: 16), but is supported by multiple sources. Johnson (1991: 131) finds that it provides adequate residential lighting levels, as opposed to office requirements of 1.5 times the window height. Hausladen et al.'s multiple of 1.5 (2005: 50) can therefore be assumed to be based on the office setting. Kwok and Grondzik (2007: 64) support the 1:2.5 ratio and Smith (2008: 58) confirms it, adding that glazing area should be 25-35% of the floor area. Brown and DeKay (2001: 201) support it also due the perception of lighting gradients by the eye. Baker et al. (1993: sec. 5.49) also refer to an 'optimum visual environment' to further justify the ratio. However, this proportion is not universal, and Lechner (2009: 397-398) claims that the 'useful depth' of daylit space is approximately 1.5 times the window height, so, on the side of caution, it is recommended that those areas requiring high levels of light are assigned to the front of the room.

In more general terms, Brown and DeKay (2001: 251) refer to work by Hopkinson et al. (1996) that suggests that 'For a room with average proportions and surface reflectances of approximately 40%, the average amount of light in the space is directly proportional to the area of the glazing.'

The recommendation applies to rooms adjacent to atria, as Goulding et al. (1994: 146) recommend a depth of about 6 m for a 50% glazed facade. This of course assumes that the atria allow in adequate light levels initially.

Note that for daylighting purposes, the guidelines refer to rooms rather than apartments, as light is blocked by room partitioning.

[2] Kwok and Grondzik (2007: 63) list that daylight zoning can be developed based on function, usage schedule, location and orientation. Rooms that need less light can therefore be placed away from the facade (Olgyay, 1963: 62; Brown and DeKay, 2001: 166). The application of this strategy correlates with the use of solar energy for heating, as described in Appendix X.

[3] Fenestration, or 'total window surface in relation to the area of the room which is illuminated by the window, expressed as a percentage' (Baker et al., 1993: sec. 5.7), is critical in influencing the amount and distribution of light. Baker et al. (1993: sec. 5.7) recommends that low fenestration, at 0-4%, should be avoided, but a high or a very high one, at 10-25%, may present problems with thermal control and glare and so requires some form of 'control elements.' The placement for solar gain, outlined in Step 5, still applies.

Step 8: REFERENCES

[4] According to Johnson (1991: 131), ‘High windows allow for much better light penetration than low windows’ and improve uniformity of light. Lechner (2009: 397-398) and Baker et al. (1993: sec. 5.7) concur. Hausladen et al. (2005: 46) qualifies this advice, arguing that the spandrel zone is ‘of little significance’ for working height light levels, in reference to offices; it should be noted that working heights and daylighting functions differ in residential buildings, so a high glazing height is still valid usually.

[5] The first part of this recommendation is based on Lechner (2009: 397-398). However, there is a disagreement between Lechner and Baker et al. (1993), as the former advises off-center window placement generally, while the latter recommends a central one for better light distribution and an off-center one for better glare control. Watson and Labs (1983: 176) agree with Lechner, stating that a ‘Corner location washes wall with light, makes window seem larger, reduces glare.’ Hausladen et al. (2005: 46) side with Baker et al., claiming that ‘If the glazing fraction is kept small then two narrower windows are preferable to a single, centrally positioned window’; they also recommend extending the glazing area over the facade width. As the framework recommends some form of shading, it is assumed that those elements will also reduce glare, and so a light distribution emphasis is followed.

[6] Lechner (2009: 397-398) claims that daylight is distributed better in horizontal windows, which correlates with the advice for openings for ventilation, as outlined in Step 17 and Step 29.

[7] This recommendation is based on Müller and Schmitz, cited in Eisele and Kloft (2002: 154). In the case of obstructions, they suggest that a width of 100% may not be sufficient.

[8] Methods of addressing this issue include avoiding partitions, the use of double-height spaces and multistory side-lit rooms (Brown and DeKay, 2001: 159) and placement of spaces such as closets and bathrooms in darker areas.

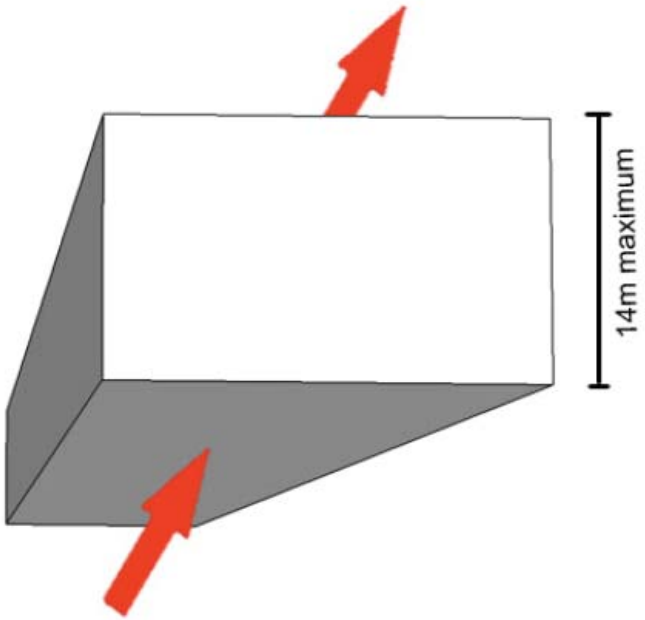
[9] High, light-colored ceilings help with lighting distribution (Johnson, 1991: 127, 131). He points out that daylight factors in the rear of dark-colored rooms are three to four times smaller than in light-colored rooms.

[10] In a study based on conditions in Leeds and Florianopolis, Ghisi and Tinker (2005: 59-60) found that smaller rooms and rooms with greater widths than depths have a greater potential for lighting energy savings as the former have a larger window-to-floor ratio and as the latter tend to provide more energy savings when daylight and artificial light are integrated. However, narrower rooms are found to have lower energy consumption ‘due to the lower solar heat gains or losses through windows.’ As the framework prioritizes solar gain over daylighting, the preference then is for narrow rooms, with the exception of orientations that do not allow for solar gain, e.g. north, in which case daylighting can be the main concern.

Configuration: Airflow (Increase)

Step 9

Floor Plate Depth



Season:
Autumn
Winter
Spring
Summer

LIMIT FLOOR PLAN DEPTH TO 14 METERS

A narrow floorplate depth optimizes opportunities for cross-ventilation [1].

Links:

2, O1; 2, O2; 3; 4; 7; 10; 11; 12; 27; 28; 29

Notes

- 14 m is considered a limit for cross ventilation of a single space [2].
- Single-sided ventilation is usually limited to 6 m, so the recommendation assumes 2 apartments and a corridor are included within the 14 m depth [3].

Limitations:

A continuous air path is required between the inlet and outlet, so cross-ventilation will not work between apartments. This recommendation is intended to maximize natural ventilation during the summer, so winter winds should be avoided preferably through orientation or otherwise opening placement [4].

_ YES, GO TO STEP 10
_ NO, GO TO STEP 10

Step 9: REFERENCES

[1] This recommendation is based on Yeang (2006: 217). Halliday (2008: 258) adds that cross-ventilation functions at a depth of up to 5 times the floor-to-ceiling height, and this can be adapted where non-typical ceiling heights are designed [2].

[2] This limitation is stated by Yeang (2006: 217).

For atria, a 15 m depth has been suggested by Halliday (2008: 260) as a limit for cross-ventilation.

[3] This limit is specified by CIBSE (2004: 4.2.1.1, 4.2.5.2). However, there is an argument that single-sided ventilation may be effective up to 10 m in low-heat gain spaces (CIBSE, 2004: 4.2.5.2), but as daylighting would be negatively affected, an extension is not advised.

[4] Watson and Labs (1983: 103) summarize: ‘This technique is the opposite of that recommended to capture the flow of summer breezes: the façade of the smallest area should face into the direction of prevailing winter winds, and windows and doors (openings vulnerable to infiltration) should be located in zones of minimum pressure.’

Configuration: Airflow (Increase)

Step 10

Apartment Plan

Season:
Autumn
Winter
Spring
Summer

DESIGN NARROW DEPTH, OPEN PLAN APARTMENTS

Narrow depth and open plan spaces promote internal air flow by allowing uninterrupted air streams to flow throughout rooms [1].

Notes:

- For single-sided ventilation, limit room depths to 6 m; for cross-ventilation, limit to 14 m [2].
- If an open plan is not suitable, partitioning should be adjustable and located to provide least resistance for desired airflow [3].
- If partitions are included, they can also be positioned to channel air movement through spaces where it is most needed [4].
- If cross-ventilation is not possible in all areas, preference should be given to living areas [5].

Limitations:

Although this framework does not consider later aspects of design, such as interior design, it is worth noting that devices exist that allow for visual privacy while providing for air movement, although an open plan is still deemed the best option [6]. Daylighting limitations must still apply for partitioning.

Links:

2, O2; 3; 5; 6; 8; 9; 11; 12; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 23; 26, O2; 27; 28; 29

_ YES, GO TO STEP 11
_ NO, GO TO STEP 11

Step 10: REFERENCES

[1] Watson and Labs (1983: 26) point out that any partitions between the inlets and outlets will impede ventilation. The best method of achieving good air movement is considered a partitionless interior. However, they point out, 'this design strategy is usually only applicable in small apartments and portions of the house where privacy is not necessary.'

[2] CIBSE (2004: 4.2.5.2) refers to BRE research titled *Natural ventilation in non-domestic buildings* to justify a 10 m depth for low-heat gain offices. Abwi (cited in Gallo et al., 1998: 174), likewise, refers to the same report in recommending a maximum room depth of 2.5 times the ceiling height. If the two recommendations are considered together, however, the ceiling height in such an area would need to be 4 m, much more than is typically permitted. In any case, as residential plans usually include much smaller spaces and as daylighting is limited to 5-7 m, a 6 m plan is nonetheless recommended.

[3] This recommendation is based on Watson and Labs (1983: 26) and should be applied to those periods of the year when ventilative cooling is preferred.

[4] This solution would need to be evaluated at this stage through modelling, as poor positioning can cut off air flow completely (Watson and Labs, 1983: 26).

[5] Stale air from living areas can also be vented trough bathrooms and kitchens grouped around the building core (Eisele and Kloft, 2002: 174).

[6] These devices include louvered doors and walls (Watson and Labs, 1983: 26).

Season:
Autumn
Winter
Spring
Summer

DESIGN DUPLEX APARTMENTS

Multiple-story residences, such as maisonettes, allow for vertical air movement due to the stack effect alongside the wind pressure formed at openings [1].

Notes:

- Corridors placed on every second or third floor, when combined with duplex apartments with openings to the opposite sides of a building, improve the possibility of cross-ventilation [2].
- Although there is some debate, in cooler climates the effects of high ceilings are negligible or negative. In any case, as a rule of thumb, the depth of single-sided ventilation is limited to 2 times the floor-to-ceiling height for a single opening and 2.5 times for a double opening arrangement; for cross ventilation, it is effective up to 5 times; for stack effect, it functions up to 5 times the height from the inlet to the exhaust [3].

Limitations:

Due to the complexities of ventilation design, some form of computational fluid dynamics modelling will likely be required towards the end of the schematic design stage. This is in addition to earlier, more simplified, estimations, such as those through airflow diagrams or calculations [4].

Links:

2, O2; 3; 6; 8; 9; 10; 12; 15; 17, O1; 17, O2; 17, O3; 18; 26, O2; 27; 28; 29

_ YES, GO TO STEP 12
_ NO, GO TO STEP 12

Step 11: REFERENCES

[1] This recommendation is advocated for multi-story buildings by Santamouris and Asimakopoulos (1996: 121). Watson and Labs (1983: 111) support this statement. More information on the stack effect is included in Step 28.

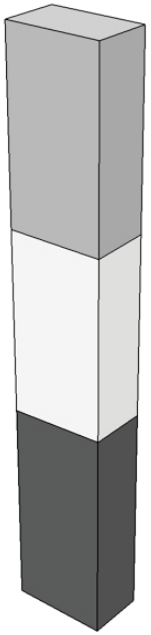
[2] Lechner (2009: 278) discusses Le Corbusier's Unite as an example of this approach.

[3] In a number of studies in hot climates, rooms with high ceilings were not found to be significantly more comfortable than those with 2.7 m or 2.5 m heights; in cold climates, however, 'distinct thermal advantages in lower ceiling heights of 2.3-2.4m' were found (Evans, 1980: 61). Evans also highlights that as most arguments for high ceilings assume high heat gain through the roof, they will only be applicable in top floors of tall buildings (1980: 61-62). Gonçalves (2010: 191), on the other hand, argues that higher ceiling heights allow for more air flow through the interior and allow for placement of openings at different heights. She cites the *British Council for Offices Guide* (BC0, 2000) for the recommended ceiling height of 3 m, but as this is based on office buildings and the framework encourages heat conservation over cooling, a lower height may be more suitable.

The ratios presented are based on Abwi (2010: 19) and Halliday (2008: 258).

[4] Santamouris and Asimakopoulos (1996: 247) offer calculations. Lechner (2009: 278-279) discusses air-flow diagrams and testing though a water table apparatus.

Configuration: Airflow (Decrease)



Step 12

Building Height Zones

Season:
Autumn
Winter
Spring
Summer

SEPARATE THE BUILDING HEIGHT INTO VARIOUS ZONES

Zoning the building according to varying heights allows for a series of modified ventilation devices that respond to wind conditions at various levels. There is a limit of about 300 m for openable windows [1].

Notes:

- The ground floor plan design is of particular importance. It is recommended that it be as open to outside space as possible, with precautions taken to avoid turbulence. A number of options exist for preventing such conditions, including the use of vestibules and canopies [2].
- The design of the roof has much less of an impact in taller buildings than lower ones as it generally affects only the uppermost floors. Roofs are nonetheless subject to suction and so are good locations for exhaust vents [3].

Links:

2, O1; 2, O2; 3; 5; 6; 9; 10; 11; 15; 17, O1; 17, O2; 17, O3; 18; 23; 27; 28; 29

Limitations:

The vertical zoning of a building is sensitive to the surrounding context, and so its design will often depend on some form of modelling of the building within the context. If turbulence is especially problematic, preventing natural ventilation entirely, the building shape could be adjusted [4].

_ YES, GO TO STEP 13, O1
_ NO, GO TO STEP 13, O1

Step 12: REFERENCES

[1] This recommendation is based on Yeang (2006: 215), although he does not provide further details as to how the building should be stratified. The 300 meter limit for calm days comes from Gonçalves (2010: 193), and she further recommends that windows below that height be closed in stages, starting from the top floors downward, when wind speeds increase.

[2] This recommendation is based on Yeang (2006: 212), as guidance apparently for skyscrapers in most climate types. McMullan (2007: 285) highlights the problem of tall buildings in that 'A typical value of wind speed ratio around low buildings is 0.5, while around tall buildings the ratio might be as high as 2', and recommends a maximum wind speed of 5 m/s at pedestrian level. Gunnarsson (cited in Eisele and Kloft, 2002: 127) estimates that up to half of the building height 40% of wind flows downwards, overlapping with wind load already at the base of building and possibly leading to wind loads the same or greater at the skyscraper entrance than at 100 m in height. This Downward Vortex Effect is acutely problematic in cool climates during the winter (Davies and Lambot, 1997 cited in Eisele and Kloft, 2002).

Watson and Labs (1983: 131) discuss vestibules in general, stating that they are most beneficial on facades exposed to winter winds. They refer to ASHRAE *Fundamentals* (1981) in that 'the use of a vestibule can reduce infiltration amounts from 900 to 550 cubic feet per door opening when compared to a single outside swinging door'.

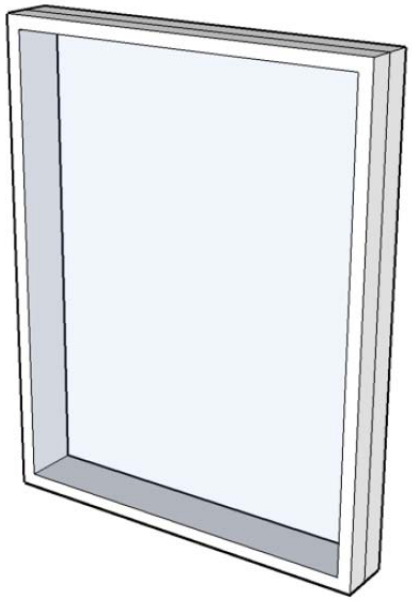
[3] Watson and Labs (1983: 111) also point out that steep roofs, despite receiving pressure on the windward plane, are not as effective for ventilation as openings in the windward side of the building. Perhaps the situation where the roof will have the greatest effect on ventilation is when the stack effect is utilized, but even in this case some controls will necessarily decrease its influence.

[4] A rounded and concave building diverts the air around it and a convex face creates stronger flows upward and downward (Davies and Lambot, 1997 in Eisele and Kloft, 2002). To reduce wind speeds and improve the local microclimate, a number of strategies can be applied, including a rounded aerodynamic profile, turning the narrow face to the wind and, if the building is significantly taller than the upwind neighbors, the inclusion of projections and setback facades. More information on the Downward Vortex Effect, Corner Effect, Wake Effect and Gap Effect can be found in Eisele and Kloft (2002).

Fabric: Thermal Radiation (Increase)

Step 13

Glass Coating: High SHG



Orientation:	*Season:*
North	Autumn
East	**Winter**
South	Spring
West	

USE GLAZING WITH A HIGH SOLAR GAIN COEFFICIENT ON SOUTH, NORTH

Glazing with a high solar gain coefficient enhances solar gain in winter [1].

Notes:

- For best performance, combine with a ‘hard-coat’ low-e coating [2].
- This glazing type is most advantageous for south facades, but can be used on north facades also [3].
- It may not be as beneficial on east and west facades due to shading concerns [4].
- The suggestion applies to horizontal glazing [5].

Links:

1; 2, O1; 2, O2; 5; 6; 14; 15; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 27; 28; 29

Limitations:

The overall building performance is highly dependent on balancing the need for solar gain during heating periods with its reduction during cooling periods, and so this step must be combined with some form of shading, as outlined in Step 19 and Step 20 or through ventilative openings [6].

_ YES, GO TO STEP 14
_ NO, GO TO STEP 14

Step 13: REFERENCES

[1] This step is recommended by Hanam in the *Green Building Advisor* (?). He claims that 'In Canada, even if windows are evenly distributed between the north and south, it's still worth putting in high-solar-gain windows on all sides', a statement he supports with RESFEN modelling software. Brown and DeKay (2001: 274) also argue for a high solar heat gain coefficient, of 0.40-0.60, 'to capture as much heat as possible'.

Most recommendations for tall buildings currently are based on office buildings, where high internal heat loads justify the use of low solar gain windows, but as the framework is based on residences, high solar gain glazing has been adopted. Definitive research findings are lacking for this issue.

[2] A type of low-e coating, hard coatings have a somewhat higher solar heat transmission than soft coatings (Santamouris and Asimakopoulos, 1996: 340). Low-e coating is discussed in Step 21.

[3] The recommendation for south facades is based on Hanam (?) and supported by Lechner (2009: 407). Lechner (2009: 407) supports the north facade suggestion. Brown and DeKay (2001: 274) suggest that care should be taken during the summer against overheating in north facades also, as 'all light, including diffuse sky light, carries heat with it.'

[4] This suggestion is based on an adaptation of earlier concerns for east and west facades (Baker et al., 1993: sec. 5.8; Santamouris and Asimakopoulos, 1996: 330-1). Brown and DeKay (2001: 274) add that, in any case, these glazing orientations do not provide significant heat gains in the winter.

[5] This recommendation is based on Lechner (2009: 407) for colder climates.

[6] Santamouris and Asimakopoulos (1996: 343) and Halliday (2008: 230) highlight this concern.

Orientation:
South

Season:
Autumn
Winter
Spring

ADD SOLAR REFLECTORS TO SOUTH FACADE

Solar reflectors enhance the effects of solar gain [1].

Notes:

- The reflector length should be 1-2 times the height of the opening and the same width as the opening. The angle between them should be within 5° of 90° [2].
- The reflector surface should generally be specular, rather than textured or matte [3].
- For windows beyond 30° from south, reflectors can be oriented in a vertical position [4].
- Reflectors can be moved or rotated during the summer to reduce unwanted gain [5].

Links:

1; 2, O1; 2, O2; 5; 6; 7; 8; 10; 13; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 26, O1; 26, O2; 27; 29

Limitations:

Solar reflectors can effect daylighting, so their impact should be modelled prior to inclusion [6]. Glare can also be an issue [7]. Like overhangs, they can also affect airflow.

_ YES, GO TO STEP 15
_ NO, GO TO STEP 15

Step 14: REFERENCES

[1] This recommendation is based on Watson and Labs (1983: 179), who note ‘Although the intensity of direct solar radiation itself cannot be increased, irradiation received by surrounding surfaces can be reflected into the opening, thereby increasing the effective collecting area of the window.’

[2] This specification is based on Mazria (1979: 241) and Brown and DeKay (2001: 228). Santamouris and Asimakopoulos (1996: 337) state that reflectivity ‘sharply decreases above an angle of about 60°’.

[3] Brown and DeKay (2001: 228) suggest a specular material so that the angle of incidence is equal to that of reflection, rather than diffusely reflected in many directions. Goulding et al. (1994: 73) support this statement. Lechner (2009: 171), on the other hand, suggests that diffusing/ white reflectors can be beneficial, although they need to be larger.

[4] Brown and DeKay (2001: 228) mention this recommendation, but warn that vertical reflectors are ‘ineffective’ at increasing solar gain to a south window. Watson and Labs (1983: 180) also note that vertical reflectors are more effective when sun angles are low in mornings and afternoons, especially in northern latitudes.

[5] This advice stems from Lechner (2009: 170), Goulding et al. (1994: 73) and Watson and Labs (1983: 179).

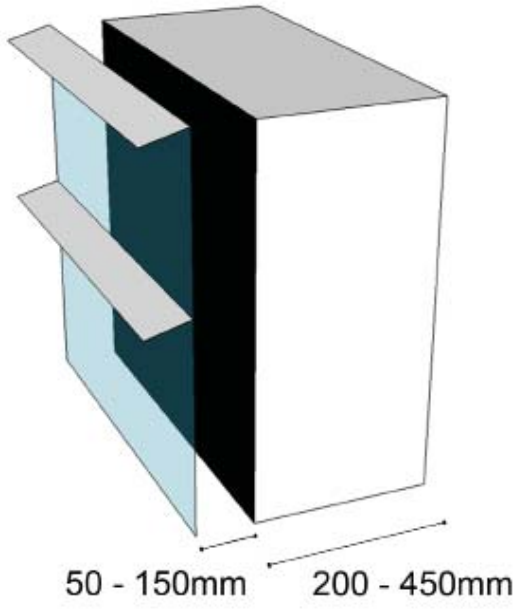
[6] Although solar reflectors can clearly reduce daylighting by acting as obstructions to the spaces below them, there is support for the assumption that they can increase daylighting in much the same way as light shelves, if designed to do so. If curved, Brown and DeKay (2001: 256) point out that they can increase the daylit zone to about 9 to 11 meters, and, if sun-tracking, up to 14 meters, as noted in Place & Howard (1990: 17-18).

[7] Glare concerns are noted in Brown and DeKay (2001: 256) and Goulding et al. (1994: 73), and should be especially noted for east or west facades and where reflectors are placed below eye-level.

Fabric: Thermal Radiation (Increase)

Step 15

Thermal Storage Walls



Orientation:
South

Season:
Autumn
Winter
Spring

USE A THERMAL STORAGE WALL ON THE SOUTH FACADE

Also known as glazed thermal walls, thermal storage walls collect and store solar gain in order to enforce a time delay for heating the living space [1].

Notes:

- In indirect gain systems, solar gain is captured by the thermal mass, which is located between the sun and the living space [2]. There are three main types of indirect gain systems: Trombe walls [3], water-container walls [4] and transparent insulation systems (TIM) [5].
- In isolated gain systems, a spatially and thermally isolated element collects solar gain. The sunspace is the most common example [6].

Links:

1, 2, O1; 2, O2; 5; 6; 7; 8; 10; 11; 12; 13; 14; 16; 17, O1; 17, O2; 17, O3; 18; 19, O2; 20; 21; 22; 23; 25; 27; 28; 29

Limitations:

Isolated gain systems strongly affect the building form, as well as daylighting and airflow [7]. Thermal storage walls may inhibit airflow [8] and require sufficient solar energy to function [9]. Shading or extra ventilation is required during the summer [10]. Thermal storage walls cannot be used if the south facade is overshadowed.

_ YES, GO TO STEP 16
_ NO, GO TO STEP 16

Step 15: REFERENCES

[1] This recommendation is based on a number of sources (Watson and Labs, 1983; Balcomb 1992: 267; Goulding et al., 1994; Brown and DeKay, 2001; Smith, 2005; Yeang, 2006; Kwok and Grondzik, 2007; Lechner, 2009). However, not all of them are specific to tall building design, and so further research is required for the building type. Therefore, the different types of systems are not discussed in detail here, although they are envisioned as separate options once sufficient resources are available.

The time lag is found to be 'approximately 18 minutes for 10 mm for concrete' by Goulding et al. (1994: 68), and thicknesses greater than 100 mm are not any more beneficial. Brown and DeKay (2001: 174) claim that the 'optimum thickness' of a Trombe wall is 300-400 mm with vents, or 250-350 mm without them, which is somewhat more than 200-300 mm recommended by Goulding et al. (1994: 68) and Yeang (2006: 232) for a 6-8 hour time lag, and in line with the 300-460 mm described by Lechner for a 8 to 12 hour time lag (2009: 158-159). The gap between the glass and wall is estimated at about 50-100 mm (Awbi in Gallo et al., 1998: 178). It is also worth noting that time lag requirements differ with orientations; as Santamouris and Asimakopoulos (1996: 194) suggest, north orientations require no time lag, east orientations need at least a 14 hour time lag and south and west orientations function best with a time lag of approximately 8 hours. In any case, these widths, and weights, are often impractical for tall buildings, and so alternative systems/materials may be required. Transparent insulation materials are thought to be suitable applications for a Trombe wall (Goulding et al., 1994: 68); they may be particularly applicable to tall buildings.

[2] The main elements of indirect systems are summarized by Smith (2005: 59): a high thermal mass element placed between the sun and internal spaces so that heat absorbed there is released later, materials and wall thicknesses based on modifying heat flow, glazing acting as insulation against heat loss and retaining solar gain through the greenhouse effect and an area of thermal storage wall approximately 15-20% of floor area of the space requiring heating. It should be noted that Thermosiphon Air Panels (TAP) have not been included here as they generally require sufficient solar radiation and a lack of low outdoor temperatures, which are more in line with warmer climates (Kwok, 2007: 125).

[3] Jones in Balcomb (1992: 235) states that Trombe walls can be either vented or unvented, and Brown and DeKay (2001: 174; 231), Awbi (cited in Gallo et al., 1998: 179) and Yeang (2006: 227) all agree, with Brown and DeKay stating that unvented Trombe walls work well with direct gain as they deliver heat later in the day. Goulding et al. (1994: 68), on the other hand, differentiate between thermal mass and a Trombe wall as the latter has 'vents top and bottom to allow air to circulate thorough the heated space.' Saadineni et al. (2011: 3619-3620) provide a review of literature relating to these and other types of Trombe walls and examine the use of shading and integration with PV panels. All resources mentioned agree on a south-facing glazed collection area and a thermal mass wall, painted a dark color or covered with a selective coating, of heavy material such as concrete and masonry. See STEP 16 for more on materials. Studies on the use of phase change materials in Trombe walls have also been reviewed in Sadineni et al. (2011: 3619-3620), suggesting that 'PCM Trombe walls were thinner and also performed better than concrete walls' A 'fluidized Trombe wall', in which the gap between the wall and glass is fluidized with highly-absorbing particles, showed similar benefits. There is some discussion available by Jones (cited in Balcomb, 1992: 266) regarding the influence of glazing layers and night insulation, but this is perhaps best tested individually; Kwok and Gronzik (2007: 116) generally suggest double glazing. Goulding et al. (1994: 68-69) lists the advantages and disadvantages of the Trombe wall. Advantages relating to environmental performance are lower temperature swings in living spaces than with direct gain systems and better night-time heating. See the 'Limitations' section for disadvantages.

Step 15: REFERENCES

[4] The water-container wall is briefly mentioned in Yeang (2006: 227) and examined further in Brown and DeKay (2001), Goulding (1994) and Lechner (2009). It functions similarly as a Trombe wall, but the water-container wall replaces the thermal wall. Goulding (1994: 69) estimates that it works more efficiently too, and lists a reduced temperature of the external surface and reduced temperature swings in the living space as additional advantages. Lecher (2009: 171) agrees, restating that water has 'the highest heat capacity of any material' and a 'very high heat-absorption rate.' Watson and Labs (1983: 123) agree also. There are a number of estimates of minimum thicknesses, with a 150 mm minimum supported by Jones (cited in Balcomb, 1992: 273) and 230-305 thickness outlined by Brown and De Kay (2001: 231). Unlike Trombe walls, water-container walls cannot be used as bearing walls, and so, in addition to a general facade structure, the water needs to be contained with rectangular steel tanks or vertical tubes. These tubes, Lechner (2009: 159) points out, can be painted in a dark color on the glazing side or be constructed of translucent/transparent plastic so that light can pass through, with similar results. Goulding et al. (1994: 69) also mention water-filled concrete walls as an option and Sadineni et al. (2011: 3620) consider the Transwall system. They also states that, due to a much shorter time lag for solar energy distribution, if heat is desired later in the evening, then some form of distribution control, such as insulation between the storage and living space, may be necessary.

[5] Transparent insulation materials are fitted behind external glass in order to reduce heat loss while enhancing solar gain (Smith, 2005: 77; Yeang, 2006: 227; Quesada et al., 2012: 2645). 'Transparent' here in reality refers mainly to 'translucent' materials, such as aerogels, which allow for some daylight to enter the building and so can, to some extent, replace windows where light, but not vision, is needed (Goulding et al., 1994: 74). Goulding et al. (1994: 75-76) suggest they complement direct solar heat systems, which can be interpreted as a more suitable strategy for residential buildings. Goulding et al. (1994: 75) also list four categories of TIM, relating to material structures, but it is the aerogels subgroup that appear to have most interest in tall buildings. Aerogels, which are 99% air by volume, can be fabricated from a range of materials and act as 'excellent' insulators as they have only one hundredth the thermal conductivity of glass (Smith, 2005: 77). The latter fact means that they could, on their own, decrease solar heat gain, and so here it is recommended that they are utilized within a Trombe wall or similar system, where solar radiation is trapped before it is stored. Sadineni et al. (2011: 3621) and Baker et al. (1993: 4.16) further discuss their properties, as does Wolf (no date). Although the framework concentrates on passive systems, a review of studies relating to both active, including PV, and passive systems can be found in Quesada et al. (2012) and Hausladen, et al. (2005: 142).

[6] The distinction between indirect and isolated systems is based on Kwok and Grondzik (2007: 114), Goulding et al. (1994: 70) and Yeang (2006). Some, generally older, resources categorize the wall systems differently: Jones (cited in Balcomb, 1992: 267) refers to sunspaces as 'indirect passive systems', as do Watson and Labs (1983: 123-124, 129), although Jones at a later point discusses 'direct-gain, thermal-storage walls, and sunspace systems' as categories (cited in Balcomb, 1992: 235) . In any case, isolated systems in the framework are distinguished from indirect systems by the presence of a thermally and spatially isolated element; another way to differentiate them is the inclusion of a space that can be occupied occasionally. They also imply dark surface finishes (Cofaigh et al., 1996:89), and so, alongside restrictions on view and position, are 'often viewed as being the least aesthetically pleasing of the passive solar options' (Smith, 2005: 59). Brown and DeKay (2001:231) point out that the floor and side walls, in addition to the main wall, should be thermally massive and offer optimum thicknesses for masonry. An option discussed by Jones (cited Balcomb, 1992: 273) is the use of water container walls with the sunspace.

Step 15: REFERENCES

[7] Kwok and Grondzik (2007: 118) mention that the separation of functions in isolated gain systems has a strong influence on the form of the building, although specifics for residential tall buildings are not discussed in this or other references. A walkway/gallery on the south side could act as a type of isolated gain system, but with a risk of it being uninhabitable during the warmest periods of the day. Alternatively, enclosed balconies or sun rooms could be included within apartment designs, but this complicates ventilation and daylighting and so should be examined on an individual basis.

[8] Smith (2005: 59) points out that in countries such as the UK, where inconsistent levels of solar radiation occur throughout the day, circulating air may be more beneficial than waiting for it to pass through a thermal storage wall.

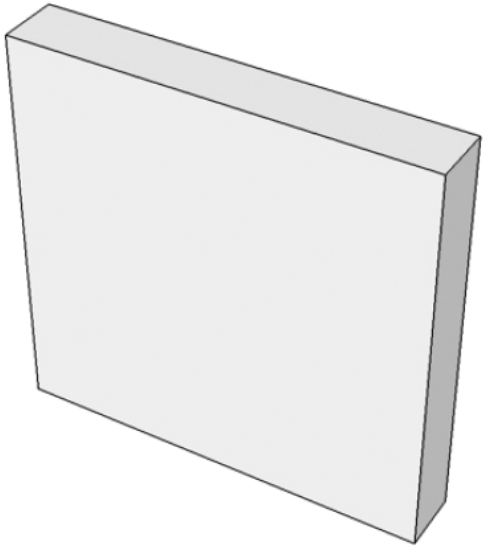
[9] Goulding et al. (1994: 68) states that 'In Northern European climates in mid-winter, where there is insufficient solar energy during the day to heat the wall, the high U-value of the Trombe or mass wall can be a heating burden.' Yeang (2006: 226-7) agrees.

[10] Goulding et al. (1994: 68) lists control 'by means of overhangs, closing external insulation or by the use of external opening vents'. Smith (2005: 59) refers to systems where air circulation is vented directly to the outside during times of excessive heat gain, while drawing in cooler outside air, and the inclusion of heat reflecting blinds between the glazing and thermal wall. In this case though, Goulding et al.'s advice of vents controllable by dampers 'to prevent reverse circulation at night which can reduce the effectiveness of the Trombe wall by about 10 per cent' is prudent (1994: 68). Awbi (cited in Gallo et al., 1998: 179) similarly suggests high-level external openings for cooling. On the other hand, Lechner (2009: 162) suggests screens for summer shading, in combination with direct gain windows, so as to avoid the use of seasonal outdoor and indoor vents as he finds they don't work well in any situation. In contrast, Sebald and Philips (cited in Balcomb: 1992: 260) claim that 'shading and ventilation have no effect on auxiliary heat consumption because a Trombe wall has very little tendency to overheat' while studies carried out by Balcomb and McFarland in 1977 (cited in Balcomb, 1992: 261) found that vents are only better in severe climates where dampers prevent reverse flow.'

Fabric: Thermal Radiation (Decrease)

Step 16

Thermal Mass



Orientation:	*Season:*
East	Autumn
South	**Winter**
West	Spring

SPECIFY WALLS AND FLOORS WITH THERMAL MASS ON SUNLIT SPACES

Walls and floors with thermal mass collect and store solar gain in order to enforce a time delay for heating the living space [1].

Notes:

- Facades receiving sufficient solar energy are suitable, but the south facade is the most effective location [2]. Solar gain can also be collected in internal partitions, floors and walls, as well as sunspaces [3].
- Materials with thermal mass should absorb and release heat in step with the diurnal cycle, during which heat is released at night [4].
- In winter, thermal mass also stabilizes internal temperature by releasing heat from internal loads [5].
- Although functioning differently than insulation, the two can at times complement each other [6].

Limitations:

In summer, shading or additional ventilation may be required [7]. Carpeting should be avoided [8].Thermal mass cannot be used on facades that are overshadowed.

Links:

1; 2, O1; 2, O2; 5; 6; 7; 8; 10; 14; 15; 17, O1; 17, O2; 17, O3; 18; 20; 21; 22; 23; 27; 28; 29

_ YES, GO TO STEP 17, O1
_ NO, GO TO STEP 17, O1

Step 16: REFERENCES

[1] Thermal mass and its benefits are discussed by Mazria (1979), Watson and Labs (1983), Cofaigh et al. (1996), Brown and DeKay (2001), CIBSE (2004), Smith (2005), Lechner (2009) and Sadineni et al. (2011). Although it is considered most effective in buildings that are unoccupied during the night (Sadineni et al. 2011: 3626), if sufficient daytime shading or ventilation is provided during the summer, the strategy can be adapted to residential buildings to mitigate daytime peak temperatures. In summary, the benefits of thermal mass, as compiled by Lecher (2009: 489), are the storage of passive solar gain, the possibility of its use as a heat sink for night cooling, the elimination of peak demand due to air conditioning and the reduction of solar heat gain. Although thermal mass has been found on a number of occasions to result in energy savings in housing, further testing and data is needed for residential tall buildings.

Like thermal storage walls, thermal mass often relies on wall thicknesses that may be unusual in tall buildings. However, Smith (2005: 56) points out that thicknesses of no more than 100 mm are sufficient, beyond which the improvements are only marginal. Jones (cited in Balcomb, 1992: 255) refers to tests that conclude that most of the benefit of mass thickness, at a density comparable to that of heavyweight concrete, is obtained in the fist 5 cm and that thicknesses above 10 cm ‘provide little additional benefit’. The ratio of surface area of the mass to the floor area and the weight of thermal storage walls has been discussed elsewhere, such as the two to one ratio and 24000 kg/m3 recommended by Lechner (2009: 238), but as there are difficult to correlate with tall building planning and structural requirements, a more suitable ratio needs to be presented.

Also see the related discussion on time lags in Step 15, Note 1.

[2] This recommendation stems from other recommendations for direct solar gain, such as those in Step 5 and Step 13, as thermal mass relies on direct solar gain. There is no available ‘rule of thumb’ for minimum solar radiation required, as it depends on the space and material properties that require modelling at this point. It should be noted that materials with high insulation levels, rather than thermal mass, are recommended on those facades receiving insufficient solar radiation, such as the north facade. Insulation is discussed in STEP 23.

[3] Lechner (2009: 154) declares that the floor is ‘the ideal and the most convenient location for thermal mass’, as it receives the most direct sunlight and as he finds floor heating the most comfortable type. He therefore recommends a concrete floor slab. CIBSE (2007: 3.10.2.2) quantifies this claim, stating that ‘Based on environmental profiles in the *Green Building Guide to Specification*, high thermal mass concrete is a poor performer in environmental terms’, presumably due to its high embodied energy. Cofaigh et al. (1996: 60) are more relaxed in their recommendation, not specifying direct or indirect storage as preferential. Although thermal mass functions well as part of the interior design strategy, it is noted by Watson and Labs (1983: 123) that four times as much storage capacity is required by materials not directly exposed to the sun as those that receive solar gain directly. In any case, they recommend a combination of directly and indirectly exposed materials. On the other hand, As Sadineni et al. (2011: 3626) refer to studies based on computer simulations, which conclude that energy savings in high rises in cold climates is not influenced by the position and distribution of thermal mass; given the specificities of the residential high rises, similar simulations can be recommended as further research.

Step 16: REFERENCES

Also notable here is CIBSE's (2004: 4.2.2) observation that 'cellular buildings often have thermal mass, regardless of the admittance of the materials used, as the extra surface area increases the thermal response.' CIBSE then suggests ways to mitigate this effect, but for the residential building this can be an advantage.

[4] As noted by Sadineni et al. (2011: 3626), the diurnal ambient temperature variation should be more than 10 K. The most referred to material by the sources, and perhaps the most suitable for tall buildings, is concrete. Alternatively, Sadineni et al. (2011: 3626) discusses phase change materials, which he states 'basically function as thermal mass', and Watson and Labs (1983: 123) and Lechner (2009: 172) confirm their suitability and efficiency. Lecher there also compares the volume requirements, for equal amounts of heat storage, of water, concrete and phase-change materials, and the last are found to be most efficient spatially as well. Although they cannot be used for structural purposes, Hausladen et al., (2005: 143) and Sadineni et al. (2011: 3621) provide a more thorough discussion, with Hausladen et al. adding that the translucent character is beneficial for daylighting, and so further endorses their use. Thermal mass of materials is measured by heat capacity Cp, rather than U- or R- values as for insulation, and sample material performance can be found in Lechner (2009: 171). In basic terms, a good storage material needs to have both a high conductance and high heat capacity (Lechner, 2009: 171). CIBSE'S Guide L (2007) also provides a section on 'choice of materials and thermal mass' that can be considered for various options.

[5] More information is available in CIBSE's guide F (2004).

[6] In his 'Rules for Thermal Mass', Lechner advises as his first rule 'Never use thermal mass without insulation', followed by instructions that mass should always be placed on the indoor side of the insulation (2009: 491). CIBSE (2007: 3.10.2.2) agrees, also adding additional measures to reduce its concrete's environmental impact. However, as it can also reduce the ability of materials to absorb solar gain, insulation may be detrimental where solar gain is desired, such as floors in sunspaces, and when thermal mass may be beneficial in absorbing internal heat gain, for example during the daytime in the summer period. There is also the possibility of adding movable insulation to the outside surface during periods of high solar gain, particularly the summer, and removing it during cooler seasons. In any case, there is some disagreement as to the benefits of combining thermal mass and insulation, and very little information relating to tall buildings, so it is advised that individual modelling is carried out until more conclusive studies are available. As noted by Balcomb, J. and R. Jones (1988, cited in Santamouris and Asimakopoulos, 1996: 195) the analysis of thermal mass is much more difficult than that of insulation.

[7] CIBSE (2004: 4.2.2) states that night insulation is 'critical to avoiding summer overheating,' suggesting that lower thermal mass may be more appropriate if it cannot be assured. An alternative, albeit less effective, option is to minimize solar and internal gains and maximize daytime ventilation. Nonetheless, it should be kept in mind that CIBSE's advice is generally oriented to office spaces, and this step assumes that solar gain is beneficial. Shading, specifically occupant-controlled shading, is encouraged by Kwok and Grondzik (2007: 108). See also the discussion on a variant of shading, movable insulation, in Note 6, as well as Step 23.

Step 16: REFERENCES

[8] Carpeting reduces the effectiveness of thermal mass, including that required for sunspaces, and so should be replaced with heat absorbing material such as tile (Cofaigh et al., 1996: 80; Kwok and Grondzik, 2007: 108). Lechner (2009: 155) points out that all contents within the building act as thermal mass, but they are not sufficient unless an exposed concrete slab is included. Alternatives include masonry, water or phase-changing materials. Furthermore, dark colors, with an absorbance of 0.5-0.8 are recommended for thermal mass, as opposed to a lighter color for low-thermal mass surfaces (Kwok and Grondzik, 2007: 108)

SHADING DEVICES

Hierarchy:

1.Option 1: Louvers

2. Option 2: Overhangs

3. Option 3: Blinds

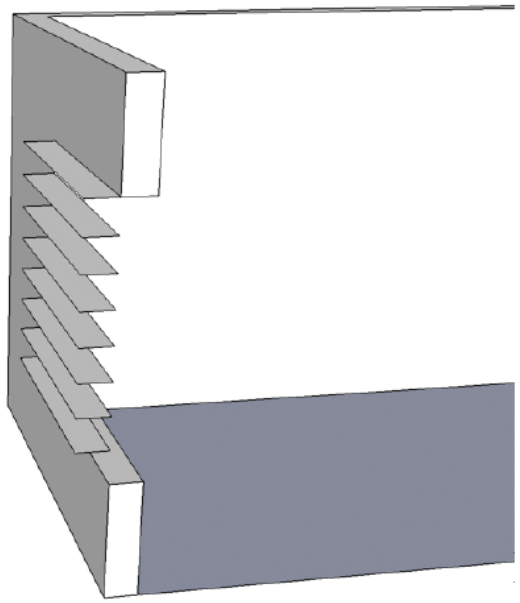
Fabric: Thermal Radiation (D)

Step 17

Shading Devices

Option 1

Louvers



Orientation:
East
South
West

Season:
Spring
Summer

ADD LOUVERS ON SOLAR FACADES

Louvers reduce solar gain on non-north facades, while permitting for solar gain in the winter [1].

Notes:

- Louvers can be either fixed or movable. Fixed louvers may be more effective, but may also block desirable solar gain during the winter season [2]. Movable louvers are more versatile in protecting from excessive heat gain in summer and reducing heat loss during winter, when they are closed at night [3].
- Louvers can either be external or mid-pane, with the former being the most effective option and the latter most suitable in double facades where wind speeds or snow loads are concerns [4].
- Horizontal louvers are suitable for all facades, while vertical ones may benefit east and west sides [5].
- Louvers can be applied to thermal storage walls and thermal mass [6] and atria [7].

Links:

1; 2, O1; 2, O2; 3; 5; 6; 7; 8; 10; 11; 12; 13; 14; 15; 16; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 22; 23; 24; 25; 26, O2; 27; 28; 29

Limitations:

Louvers have an effect on airflow, and vice versa [8]. They can interfere with daylighting [9]. At times, they can increase solar gain [10]. Certain materials and colors can be sources of glare [11]. Overshadowed facades, or facade portions, may not require louvers when overshadowing during cooling seasons occurs [12].

_ YES, GO TO STEP 17, O3
_ NO, GO TO STEP 17, O2

Step 17, Option 1: REFERENCES

[1] This recommendation is based on Yeang (2006: 205-207), although it is commonly found elsewhere (Olgyay & Olgyay, 1957; Givoni, 1976; Evans, 1980; Goulding et al., 1994; Santamouris and Asimakopoulos, 1996; Cofaigh et al., 1996; Brown and DeKay, 2001; Eisele and Kloft, 2002; CIBSE, 2004; Hausladen et al., 2005; Kwok and Grondzik, 2007; Lechner, 2009). However, Olgyay & Olgyay (1957: 71) notably point out that solar radiation can never be eliminated fully in a glazed facade as 'Even if the glazing is totally shaded, diffused light from the sky, ground, and reflection and radiation from the shading elements will contribute 20% of the total exterior solar radiation to the space in the form of light and heat'. It should be kept in mind too that louvers may interfere with other key aspects of the design like view, which is why sources like Lechner (2009: 217) prefer overhangs rather than louvers.

There are numerous ways of designing louvers, based on shading coefficients, indoor air temperatures, 'coolnex' indices, etc. (Santamouris and Asimakopoulos, 1996: 333). Brown and DeKay (2001: 264-267) offer a simple chart-based method as a quick reference for deciding whether louvers are spatially suitable and their basic dimensioning, although computer simulations may be more suitable for deciding the impacts of both radiation and airflow on their performance in tall buildings. There is also a concern that graphical approaches may yield inaccurate results, such as the 10% margin of error of a nomogram discussed by Ralegaonkar and Gupta (2010: 2241).

[2] A number of advantages listed within the sources include their simplicity of use, low cost, minimum maintenance and limitations for human error or misuse. However, even a good design will have the major disadvantage of blocking off solar gain when it may be desired. As Watson and Labs (1983: 190) point out, there is a delay of one and a half months between the peak of the overheated season in late July through August and the period of maximum insolation in June. If a louvre, or other type of shade, is designed to provide shading from June to September, it will also block desirable solar gain from March to June. They, like Yeang (2006: 207) suggest 'as a compromise' the use of fixed devices for the late summer months only, indicating that they would have to be removed seasonally. Lechner (2009: 220) offers a similar discussion, using the same reasoning to encourage movable shading devices. Note that fixed external structures are often referred to as brise-soleil, as defined by Baker et al. (1993: sec. 5.25).

[3] Yeang (2006: 207) supports movable louvers in most situations, and the majority of sources agree (Milne in Givoni, 1976: 184; Müller and Schmitz, cited in Eisele and Kloft 2002: 159; CIBSE, 2004: 4.2.6.5). Advantages listed by these sources include louvers' protection from glare and excessive solar heat gain, and, in winter, the ability to be closed to reduce heat loss from the building. 'Movable' here may mean adjustable seasonally or throughout the day, or removable altogether during heating periods. Movable louvers may be controlled manually or with a network of sensors centering around optimal conditions (Awbi in Gallo et al., 1998: 221). It should be kept in mind that occupants usually prefer individual control, so overrides should be allowed for automatic devices (CIBSE, 2004: 4.2.6.5).

It should be noted though that Yeang (2006: 2007) states that fixed shading is suitable for the south facade, agreeing with Lechner (2009: 215) that the south orientation is generally easier to shade than others.

Step 17, Option 1: REFERENCES

[4] A number of the sources mentioned in Note 3, including Yeang (2006: 207) support external devices, mainly based on their effectiveness at stopping radiation from reaching the building skin. Hausladen et al. (2005: 146) cite this as a main advantage, with the disadvantages including exposure to weather and inability to operate in strong winds. Kwok and Grondzik (2007: 94) present a hierarchy for shading device glazing as 'external to the glazing, integral with the glazing, and then internal to the glazing.' Santamouris and Asimakopoulos (1996: 334), citing a number of texts, quantify the effectiveness of external over internal shading elements at 35%, but this is understood to refer to blinds rather than mid-pane systems. Similarly, Hausladen et al. (2005:42) state that the shading factor is 3 to 5 times more effective if shading is external. Relating to tall buildings specifically, Gonçalves (2010: 182), referring to tall buildings, states that 'Despite the fact that blinds are placed in most cases within the cavity due to issues of structure and maintenance, the performance of external blinds is still far superior when compared to internal and mid-pane blinds.' Boake (no date) agrees.

Brown and DeKay's (2001: 270) offer an argument for mid-pane louvers over external ones, in that the former also protect shading from pollution and harsh weather conditions and reduce maintenance requirements. Lechner (2009: 401) supports this claim. Müller and Schmitz (cited in Eisele and Kloft, 2002: 159) also point out that, due to high wind velocities, louvers are frequently installed within a double skin facade or laminate glass panes. Hausladen et al. (2005: 146) concur with these analyses, adding that fixed systems reduce daylighting and visibility. Cofaigh et al. (1996: 94), though, notes that there are issues with thermal stresses and breakages in these units, requiring extra care in design.

[5] Horizontal louvers are often accepted as suitable for all solar facades, and are usually the only option recommended for the southern orientation. At times, though, they are overlooked on the east and west facades by those supporting vertical louvers, and so sometimes described as a 'south option', as is the case with Baker et al. (1993: sec. 5.25). Although less effective on the east and west facades due to the angle of the sun (CIBSE, 2004: 4.2.6.5), horizontal louvers are considered the best option on the south as they can 'block the high-angle summer sun but admit the low-angled winter sun' (Cofaigh et al, 1996: 92).

Before examining east and west shading, it should be kept in mind, despite their symmetry from a solar perspective, the two nonetheless usually require a different solution. As Lechner (2009: 253) points out, 'They differ because afternoon temperatures are much higher than morning temperatures and because site conditions are rarely the same.'

Vertical louvers, including fins, are more contested. Brown and DeKay (2001: 266) support their use, claiming that 'Slanted vertical fins are more effective at shading than fins perpendicular to an east or west-facing window, which will allow full sun penetration when the sun is shining due east or west (perpendicular to the glass).' Hausladen et al. (2005: 42) agree, referring to the low position of the sun, meaning that horizontal louvers would need to be almost fully closed to be effective, leading to additional problems. Other supporters include Cofaigh et al. (1996: 92), Milne (cited in Givoni, 1976: 208) and Goulding et al. (1994: 100, 162). Evans (1980: 117) takes a more limited view, suggesting that 'closely spaced vertical louvres' may be the best option for western windows only. The possibility of adjustment is notably key to Hausladen et al. (2005: 42). Note also the possibility of using a singular fin per window, at a 0.3 m to 1.2 m projection and as tall as the glazing, as a variant (Baker et al., 1993: sec. 5.23).

Step 17, Option 1: REFERENCES

The strongest opposition to vertical fins comes from Lechner (2009: 233-234) as he claims 'they shade no better than horizontal overhangs, but they obstruct the view much more… there is a time every morning and afternoon when the sun shines directly at the east and west facades of a building during the summer six months of the year (March 21 to September 21). Therefore, vertical fins that face directly east or west will allow some sun penetration every day during the worst six months of the year. To minimize this solar penetration, we need to minimize the "exposure angle"… We can accomplish this by decreasing the spacing of the fins, by making the fins deeper, or both. To be highly effective, the fins must be so deep and so closely spaced that a view through them becomes almost impossible.' The key to his opposition is the view, but he concedes, where view is not important or where there is a need to control its direction, then fins slanted either south for more winter sun or to the north for more cool daylight, and both if adjustable, are appropriate (2009: 234). An intermediate option, but perhaps one leading to other issues such as increased loads and maintenance, is 'egg crate' shading, although it is mainly used in hot climates (Evans, 1980: 117; Lechner, 2009: 237). Santamouris and Asimakopoulos (1996: 335) argue that it is especially effective if inclined 45° southwards. A form of egg crate shading linked to tall buildings is one formed of floor-height elements (Milne, cited in Givoni 1976: 208); in terms of this framework, though, such a form would be a combination of a vertical fin and horizontal overhang.

As discussed in Step 5, it is important to note that controlling solar gain on east and west facades is critical due to low summer sun angles (Cofaigh et al., 1996: 64; CIBSE 2007:3.1.5.3). Referring to a 42° latitude on June 21, Lechner (2009: 214) states that east and west windows collect twice as much, and a skylight about four times more, solar radiation than a south window. The shading of skylights is discussed further as relating to atria, but generally skylights are not recommended, as discussed in Step 21, Note 4.

In cases where the glazing faces southeast or southwest, the framework's prioritization of solar gain over shading is still in effect, and so the more rigorous shading requirements for east and west facades may be less appropriate than those for the south. This concurs with the assertion of Santamouris and Asimakopoulos (1996: 335-336) that 'Horizontal shading elements are more effective than vertical ones in the south-east and south-west orientations', although he adds that egg-crate elements are even better; however, this advice is generally specific to hot climates and so not the basis of this hierarchy. Movable devices appear to be especially advantageous in those situations. It should also be kept in mind, as discussed in Step 1, that the southeast orientation is preferred over the southwest in residential buildings, and therefore southeast facades may need considerably less shading as compared to southwest ones.

All in all, the designer's intention and some form of computer modelling are to be considered. In any case, this debate on the suitability of east and west vertical shading, as well as the difficulties related to designing any form of shading on this facade, highlight the recommendation in Step 5 that glazing is to be minimized in those orientations, taking into consideration daylighting and ventilation.

[6] The same rules for shading apply as for glazing intended for solar gain, although movable or removable devices may be most efficient. Watson and Labs (1983: 159) go so far as to suggest that shading devices can be applied to building walls in general, although more recent insulation qualities may make that recommendation impractical and obsolete.

Step 17, Option 1: REFERENCES

[7] All types of atria, whether internal or open to one, two or three sides, require some form of shading for summer conditions (Goulding et al., 1994: 123, 142; Hausladen et al., 2005: 104) . Although shading may not only be necessarily be provided by louvers, their benefits in terms of ventilation, as discussed in Step 28, mean that they are often the preferred form of shading as well. As even ‘any kind of glazing system’ reduces daylight levels in an atrium by 20% or more (Baker et al.,1993: secs. 5.44-5.45; CIBSE, 2004: 4.2.1.2), Baker et al. (1993: secs. 5.44-5.45) and Goulding et al. (1994: 142) recommend that shading devices are movable rather than fixed; Baker et al. (1993: secs. 5.48-5.49) and CIBSE (2004: 4.2.1.2) also recommend a distancing from the roof and the wall so that light reaches the walls more effectively.

Louvers as shading devices for atria are discussed in Johnson (1991: 145). He states that fixed louvers only function in atria of buildings with long axes that run either north-south or east-west. In the first case, the louvers are to run from north to south and be perpendicular to the floor. In the second, louvers are to run along the length of the atrium and also be perpendicular to the floor.

[8] Further modelling is required. The impact need not be always negative, as Goulding et al. (1994: 100) point out. Referring to tall buildings, Müller and Schmitz (cited in Eisele and Kloft, 2002: 159) state that room temperatures usually remain acceptable, but that limiting ventilation during peak temperature periods helps to reduce the amount of heat reaching the interior. Furthermore, partial shading can lead to thermal stresses across the shadow-line, and so a ventilation gap between the louvers and glazing is recommended, as is the use of ‘toughened or laminated glasses’ (Cofaigh et al.: 1996: 93). More information on ventilation in double facades can be found in Step 28, Note 5.

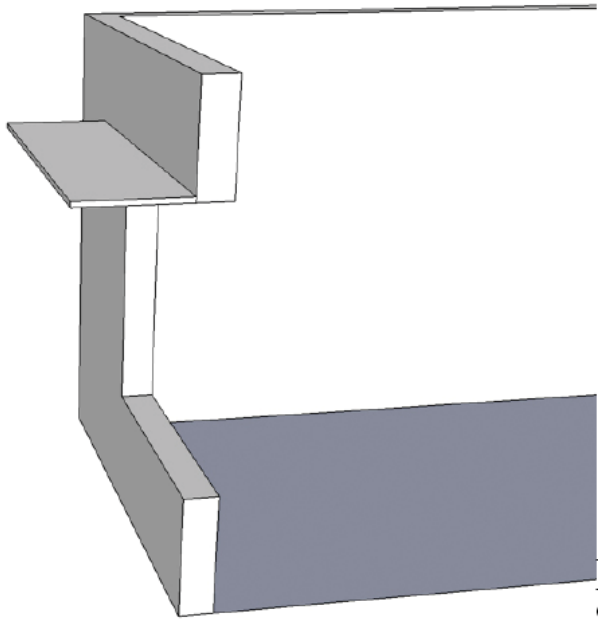
[9] Ander and Navvab (1983, cited in Brown and DeKay, 2001: 260) further present studies that ‘predict reductions in illumination of 50% from exterior verticals fins at 45° to the building surface’. However, as Lechner (2009: 401-404) argues, they can also be ‘one of the most effective strategies for reflecting light into the ceiling’ if they are properly designed and if the ceiling acts as a diffuse reflector; he specifically recommends external louvers. Design options he mentions are louvers with a specular finish and those curved to avoid excessively bright patches or matte reflectors generally; modelling is recommended to choose between the two.

[10] Brown and DeKay (2001: 260) point out that ‘it is important to distinguish those which reflect light but not heat, such as white paint, from those which reflect both light and heat, such as polished metals’ when selecting materials, in that solar reflectors are not recommended and louvers should be light in color, especially on the underside, for daylight reflection in any case.

[11] Brown and DeKay (2001: 260) advise that louvers should be placed to avoid the residents’ field of view. Müller and Schmitz (cited in Eisele and Kloft, 2002: 161) point out that concave louvers are more effective than convex louvers in preventing glare.

[12] Although adjacent buildings or structures may provide sufficient shading, often the window must also be shaded from the diffuse sky and reflected components (Lechner, 2009: 215). Again, due to the variety of contexts possible, ‘rules of thumb’ are inapplicable and additional modelling is required.

Fabric: Thermal Radiation (D)



Orientation:
East
South
West

Season:
Spring
Summer

ADD OVERHANGS ON SOLAR FACADES

Overhangs reduce solar gain on non-north facing facades, while permitting for solar gain in the winter [1].

Notes:

- Overhangs can be either fixed or movable. For increased gain, the movable type is recommended [2].
- They are accepted for south facades, but there is debate regarding other solar orientations [3].
- They should generally be wider than windows, although strip windows are less affected [4].
- The category of overhangs here includes elements such as balconies, skycourts and light shelves. Recesses, an opposite of overhangs spatially, perform on the same principle of reducing direct solar radiation at the window, but have less impact on daylighting [5].
- Overhangs can be applied to thermal storage walls and thermal mass [6].

Limitations:

Overhangs have an effect on airflow, and vice versa [6]. Overhangs can interfere with daylighting [7]. Snow loads are problematic [8]. Certain materials and colors can be source of glare [9]. Overshadowed facades, or portions of facades, may not require shading when overshadowing during cooling seasons exists [10].

Links:

1; 2, O1; 2, O2; 5; 6; 7; 8; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O3; 18; 19, O1; 19, O2; 21; 22; 24; 26, O1; 26, O2; 27; 28; 29

_ YES, GO TO STEP 17, O3
_ NO, GO TO STEP 17, O3

Step 17, Option 2: REFERENCES

[1] Lechner (2009) is the most steadfast proponent of horizontal overhangs, but this stance is related more to his prioritization of view than their performance when compared to louvers. Goulding et al. (1994: 162) also state that overhangs 'provide the best shade to south facades', as do Offiong and Ukpoho (2004). Santamouris and Asimakopoulos (1996: 335), likewise, refer to them as 'effective for south-facing windows'. As with all shading devices, overhangs often block out some solar gain in winter, although this can be minimized with good design. Typical sizings usually vary between 0.4 m and 1 m in depth (Baker et al., 1993: sec. 5.21).

There are a number of ways to design overhangs, such as the use of overlay shading mask protractors discussed by Milne (cited in Givoni, 1976: 205-208) and outlined in Lechner (2009: 228). Brown and DeKay (2001: 264-256) offer a quick reference for deciding whether overhangs are spatially suitable, as well as their basic dimensioning, although computer simulations may be preferable for deciding the impacts of both radiation and airflow on their performance in tall buildings. Lechner (2009: 230) also recommends the use of modelling even when design guidelines are used.

It should be highlighted here that 'overhang' refers to a singular shading device, per window and of any direction, as apposed to the dichotomy of 'vertical shading elements called fins, and horizontal shading elements called overhangs' referred to by the Olgyay brothers (Milne, cited in Givoni, 1976: 205). Unlike louvers, overhangs can be thought of as being a 'part of the building itself' (Baker et al., 1993: sec. 5.21), particularly in tall buildings, where supplementary structural support may be required. Note also that many of the same studies discussed in Step 17, Option 1 apply to this step.

[2] Whereas fixed overhangs are suitable when passive heating is not required, Lechner (2009: 230) argues, 'If both passive heating and shading are important (long over- and under-heated periods), then a movable overhang should be used.'

[3] Since the view is a very high priority for windows, Lechner (2009: 217, 223) believes that horizontal overhangs offer the best combination of view and shade for the east and west facades, and those of intermediate orientations as well. 'However,' he states 'the horizontal overhangs must be much longer on the east and west than on the south, and they need to be backed up with another shading device such as venetian blinds' (2009: 223). CIBSE (2004: 4.2.6.5) argues that they are not as effective on east or west facades, 'where reveals are more suitable'. Baker et al. (1993: sec. 5.21) also note that overhangs will not provide shading in the early morning or late afternoon. A more definitive argument for the application of overhangs on east and west facades is presented by Offiong and Ukpoho (2004: 141-142), where, based on computer models, they state: 'It is seen that in every case, over-hangs are much more effective in shading than vertical side-fins. This is quite contrary to widely held views that vertical sidefins are more effective in the temperate zones, while overhangs are useful only in the tropics.' Nonetheless, without much measured in-use feedback, it is difficult to prioritize one option over another.

[4] This recommendation is based on Lechner (2009: 227), due to the southeast and southwest angles of the sun in the morning and evening, respectively. He suggests 'a very wide overhang' or additional vertical fins for narrow windows.

Step 17, Option 2: REFERENCES

[5] This classification is based on the framework's hierarchy, although other sources, notably CIBSE (2004: 4.2.6.5) also include the various elements in this category. Note though that reveals, in addition to providing horizontal shading effects on the south facade, offer vertical shading on the east or west sides (CIBSE, 2004: 4.2.6.5). Offiong and Ukpoho (2004: 141-142), in their analysis of reveals, vertical fins and overhangs, in fact argue that 'Reveals are by far the most effective window external shading treatment since they combine the effects of vertical side-fins and overhangs'. In the northern hemisphere, they specify that a 400 mm deep reveal, for a 1 m by 1 m window, gives 'reasonable' shading, although their depth requirements in various window shapes may place limitations on their use. Balconies are discussed in Evans (1980: 66) as 'the most practical building form' for higher densities.

[6] The same rules for shading apply as for glazing intended for solar gain, although movable or removable devices may be most efficient. Watson and Labs (1983: 159) go so far as to suggest that shading devices can be applied to building walls in general, although more recent insulation qualities may make that recommendation impractical and obsolete.

[7] Lechner (2009: 227) points out that louvers may be beneficial in minimizing hot air collection under an overhang. Goulding et al. (1994: 162) likewise warn that all fixed horizontal shading devices should be separated from the facade by a minimum 100 mm ventilation gap.

[8] Baker et al. (1993: sec. 5.21) definitively state that overhangs result 'in a lower interior light level'. Daylighting requires further modelling at this point, and perhaps additions of daylighting devices or adjustments to apartment configurations.

[9] Lechner (2009: 227), even with all his enthusiasm for overhangs, concedes that this can be an issue, as can the more constant structural and wind loads. However, as Baker et al. (1993: sec. 5.21) points out, overhangs provide partial protection from the rain; this can be interpreted as a benefit for natural ventilation as it increases its availability.

[10] Brown and DeKay's (2001: 260) discussion on louvers in Step 17, Option 1 is applicable here.

[11] Although adjacent buildings or structures may provide sufficient shading, often the window must also be shaded from the diffuse sky and reflected components (Lechner, 2009: 215).

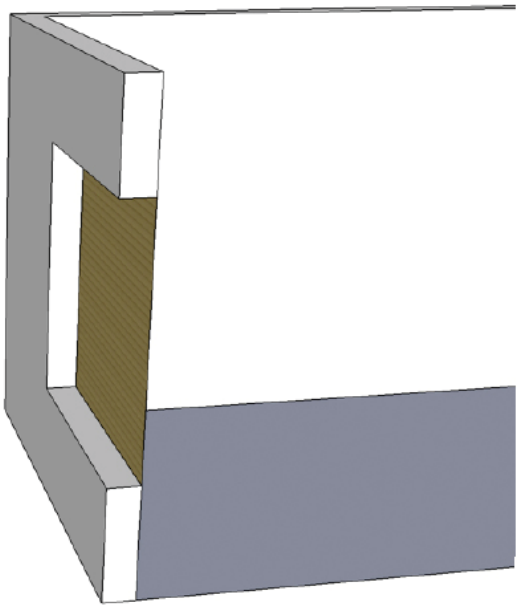
Fabric: Thermal Radiation (D)

Step 17

Shading Devices

Option 3

Blinds



Orientation:
East
South
West

Season:
Spring
Summer

ADD BLINDS INSIDE SOLAR FACADES

Blinds reduce solar gain on non-north facing facades, while permitting solar gain in the winter [1].

Notes:

- Indoor blinds can be used in addition to louvers and overhangs, where they can provide supplementary protection from solar gain and glare [2].
- The category of blinds here refers to internal devices and includes venetian blinds, curtains, roller blinds, etc., but not internal insulation [3].

Links:

1; 2, O1; 2, O2; 3; 5; 6; 7; 8; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 18; 19; 21; 22; 24; 25; 26, O2; 27; 28; 29

Limitations:

Due to their positioning inside the glazing, much of the heat remains indoors [4]. Blinds considerably block out the view while blocking out solar gain [5]. Certain colors increase solar gain and can be source of glare [6]. They cannot be used with low-e or high solar gain glazing [7]. When closed, they block airflow.

_ YES, GO TO STEP 18
_ NO, GO TO STEP 18

Step 17, Option 3: REFERENCES

[1] Blinds perform significantly worse, at about a 30% estimate by Goulding et al. (1994: 100), than either louvers or overhangs, and are here recommended as a supplementary approach or a weaker option where neither of the previous steps is available or where they interfere with other environmental aspects, such as ventilation. Hausladen et al. (2005: 146) cites protection from the weather, operation in all wind conditions and antiglare protection as the main advantages of internal shading. Its disadvantages are noted in the limitations section.

[2] When used alongside overhangs, Lechner (2009: 249) recommends that blinds move up from the base of the window as the lower portion of the window needs more shading than the upper. It should be added that in this case, they act to repair inadequacies in the design, and so more consideration is recommended on the amount of glazing area included. Also see Step 5.

[3] Internal insulation is discussed in Step 23.

[4] This limitation is noted in Lechner (2009: 249), Goulding et al. (1994: 100), Watson and Labs (1983: 189) and Hausladen et al. (2005: 146).

[5] This limitation is noted in Lechner (2009: 249-250). He adds that blinds with small perforations are available so as to increase the amount of light and view.

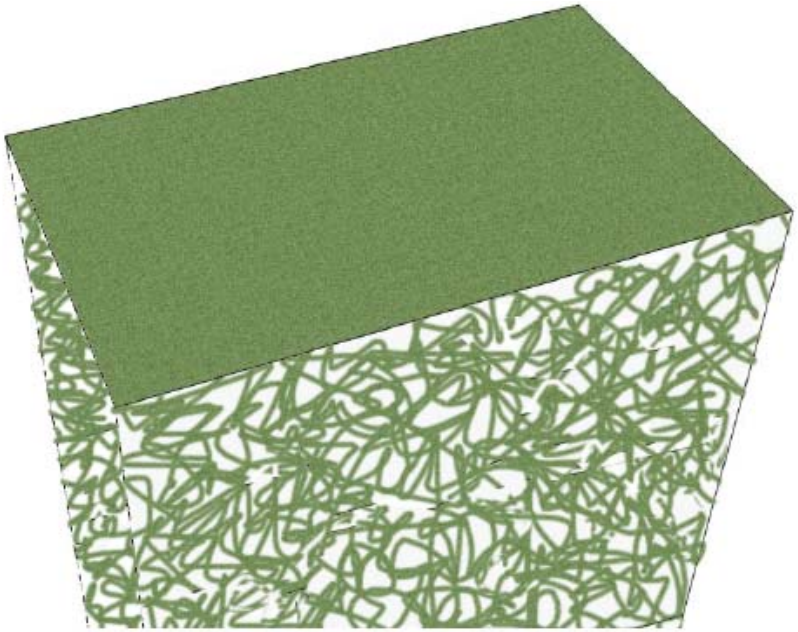
[6] Lechner (2009: 249-250) recommends white, or very light, blinds to maximize the solar radiation reflected back through the glass; likewise, he mentions the mirrored option. Santamouris and Asimakopoulos (1996: 335) concur, citing a Yannas 1990 study that indicates that off-white venetian blinds give 20% more shade protection than dark ones and roller blinds 40% more; aluminum blinds are also found to be more effective by 10% over colored ones. They also add that for curtains, ‘the differences are less, as light coloured ones are likely only 18% more effective than dark ones’. Evans (1980: 117) offers a similar argument. However, Santamouris and Asimakopoulos (1996: 343), referring to Givoni (1976), warn that this relationship between color and efficiency is superseded by the effects of airflow in open windows. Brown and DeKay’s (2001: 260) discussion on louvers in Step 17, Option 1 is also is applicable here.

[7] This limitation is noted in Goulding et al. (1994: 100).

Fabric: Thermal Radiation (D)

Step 18

Vegetation



Orientation:	*Season:*
North	Winter
East	Autumn
South	Spring
West	**Summer**

SPECIFY DECIDUOUS VEGETATION ON FACADES AND ROOF

Vegetation increases thermal insulation and deciduous planting prevents solar gain in winter [1].

Notes:

- Vegetation can be placed on all orientations, although more species grow on solar facades and northern orientations are not susceptible to solar gains [2].
- Vegetation can be positioned on, or within, glazing systems or on walls, as well as within skycourts, balconies, atria and roofs [3].
- Deciduous plants are recommended on southern facades and evergreens on others [4].

Links:

1; 2, O1; 2, O2; 3; 5; 6; 7; 8; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 19, O1; 19, O2; 22; 23; 24; 26, O2; 27; 28; 29

Limitations:

Significant solar gain is blocked in winter [5]. Plant choice may depend on available soil depths [6]. Daylighting, view and airflow are affected [7]. Sufficient light is required by the plants [8]. Alternative or interim devices may be needed [9]. Overshadowing by adjacent buildings may affect growth and reduce shading [10].

_ YES, GO TO STEP 19
_ NO, GO TO STEP 19

Step 18: REFERENCES

[1] Yeang (2006) is the most enthusiastic proponent of vegetation in tall buildings, so this recommendation is primarily based on his approach. He states that large shade trees around a building can reduce peak cooling loads by up to 30% and that vertical plant cover on exposed walls can reduce energy efficiency by 8% (2006: 223-224). Furthermore, in winter, he claims that facade planting can reduce heat loss by as much as 30%, and snow cover and frozen plant fibers can act as insulation (Yeang, 2006: 141).

All in all, other sources support his claims, albeit not always specifically referring to tall buildings. Brown and DeKay (2001: 267-268) add that leaves usually absorb 60% to 90% of incident sunlight, most of which is converted into local heat before being lost. They also outline the three ways that vegetation reduces heat gain, namely 'by reducing radiation transmitted through windows, by reducing the load on opaque surfaces, and by lowering via evapotranspiration the outdoor air temperature near building surfaces.' Milne (cited in Givoni, 1976: 210) also refers to deciduous trees as 'the most responsive shading devices', due to their leaf growth and loss at optimum times and their effectiveness in 'extremely' low-altitude sun. Lechner (2009: 211) echoes this sentiment, stating: 'In many ways, the best shading devices are the deciduous plants, most of which are in phase with the thermal year because they gain and lose their leaves in response to temperature changes', although he acknowledges some weaknesses. Watson and Labs (1983: 164) discuss their advantages, citing the example of a 50% reduction in solar radiation during summer by an ivy cover. Ip et al. (2010: 81) provide an examination of benefits from a number of studies.

Other than the solar gain, Yeang (2006) and other sources highlight that vegetation also provides organic counterbalancing of inanimate materials, a reduction in overall heat island effect, a control and regulation of humidity, a reduction of runoff, a windbreak for winter winds, green corridors, food production and removal of airborne toxins. It should be noted here that Yeang presents three strategies for the integration of biomass, juxtapositioning, intermixing and integration, with the last the preferred choice (2006: 137), which are unrelated to solar gain but would benefit from some planning at this point if they are to be included in the design. Likewise, he differentiates between green walls, which include a 'cascade' of planted terracotta basins, and breathing walls, which are totally vegetated facades; this distinction is worth noticing at this point. Further information on green walls, including additional distinctions between green facades and living walls, as well as a confirmation of many of the benefits discussed in this step, can be found in Kontoleon and Eumorfopoulou (2010). Ecocells, or large vertical slots and incisions of vegetation, can be integrated into the configuration of the building as well.

Although the framework presents vegetation after fixed shading devices, mainly due to the limitations listed here and lack of common application in tall buildings, it does have some advantages over more typical shading devices. Brown and DeKay (2001: 268), in fact, claim that it can 'outperform fixed shading' as temperature, rather than sun position, triggers its shading ability and as deciduous plants respond to seasonal variation, as opposed to a design based on long-term average temperatures.

Step 18: REFERENCES

[2] Yeang (2006: 138) states that planting zones should be placed on the south, southeast and southwest facades, but that occasionally north-facing species can be included on the north orientation. Santamouris and Asimakopoulos (1996: 336) concur with him on the first part of that statement, claiming that 'The position and orientation of vegetation follows the basic principles of shading design'. They furthermore suggest that horizontal overhangs, such as pergolas, be placed on the south side and that trees, bushes and climbing plants be positioned on the east and west orientations; creepers are considered as useful in all orientations on the building envelope (1996: 336). Milne (cited in Givoni, 1976: 210) also commends the effectiveness of trees nearby west windows for controlling afternoon heat loads. Olgyay (1963: 76) claims they perform best on eastern and western facades. Trees are not, however, recommended on the south facade (Lechner, 2009: 221) and Olgyay (1963: 76) suggests that an overhang is much more effective. Overall, Kontoleon and Eumorfopoulou (2010: 1302) find that the east and west facades benefit most from vegetation. More information on suitable species, and solar requirements, can be found in Brown and DeKay (2001: 269).

[3] Universal energy saving figures are discussed in Note 1, so more specific ones are presented here. Within double skin facades, Ip et al. (2010: 81) cite a study that indicates a reduction of cooling load by up to 20%. On attached walls, Yeang (2006: 224-225) claims that vines on a trellis are found to reduce surface temperature by 4˚C. Yeang (2006: 222-223) also states that roof gardens or permaculture decrease solar gains and provide insulation, in addition to other advantages, discussed elsewhere in the framework, among them reductions in rainwater runoff, reductions in the heat-island phenomena, creation of wildlife habitats, an extension to the lifetime of the waterproofing membrane and increased biodiversity. CIBSE (2007: 3.7.3- 3.7.4) provides a thorough discussion of the two basic living roof systems, intensive and extensive, as well as overviews of studies confirming their positive performance in both summer and winter. Lechner (2009: 330), Sassi (2006: 42) and Kwok and Grondzik (2007: 49) also discuss the advantages mentioned by Yeang and the roof systems examined by CIBSE. Lechner (2009: 330-331) furthermore highlights the fact that 'green roofs need just as much insulation as regular roofs for reducing heat loss in the winter' as wet soil does not reduce heat loss. He especially encourages the use of sod roofs, in part as they can dissipate 80% of incident radiation during summer months and provide some benefits of thermal mass. Ascher (2011: 163) refers to an even greater performance of green roofs, stating that soil and vegetation reduce solar gain by 'almost' 100%, although this statement does not appear to be supported by any specific data. A more detailed paper on green roofs by Castleton et al. (2010: 1583-1584) points to a study by Liu and Minor (2005) where heat gain through a green roof was reduced by 70% to 90% in the summer and heat loss by 10% to 30% in the winter as compared to a reference roof of steel deck with thermal insulation; Sadineni et al. (2011: 3623) also refer to this study, adding that the measurements were carried out In Toronto. They notably point out that all studies should be taken as case-specific and in fact buildings with U-values required by 2006 UK building regulations will save little, or no, energy (Castleton et al., 2010: 1590). This highlights the importance of insulation in roofs. In general terms, ground-cover plants, either within the building's flat surfaces or in the surrounding landscape, reduce reflected solar radiation in the summer (Yeang, 2006: 141). Facade planting, likewise, is thought to lower ambient temperatures by up to 5°C (Yeang, 2006: 141).

The significance of facade planting in tall buildings should be stressed here, as the facade area is much larger than any of the other elements discussed in this note. Sadineni et al. (2011: 3623) refer to a study in a 'multi-story residential building', in Madrid, that found the reduction in energy from a green roof was most high in the floor below and negligible for more than three floors below. Sheweka and Magdi (2011: 594) also discuss the importance of vegetation via the facade, referring to Yeang (1988) and a number of other studies.

Step 18: REFERENCES

[4] As planting on northern facades serves as additional insulation, an evergreen type is recommended. Watson and Labs (1983: 165) recommend it on east and west facades as well. Deciduous plants are advantageous elsewhere as their foliation is activated by outdoor temperature, rather than sun position, and respond to variations in average seasonal conditions (Brown and DeKay, 2001: 268). Those that have a dense canopy and a foliation period matching the building's overheated times should be chosen (2001: 268).

On solar facades, Yeang (2006: 224-225) refers specifically to the performance of deciduous trees, claiming that they allow maximum solar heat gain in the winter, particularly on the south facade. He encourages species with high canopies and pergolas to reduce heat gain and provide shade, without blocking much wind at lower heights; vines and shrubs, on the other hand, provide similar benefits relating to radiation but reduce wind speeds (2009: 140). Watson and Labs (1983: 165) advise a deciduous, perennial ivy on south orientations. Ip et al. (2010) recommends the Virginia Creeper as a suitable plant in the UK climate, as well as proposing a Bioshading Coefficient Function for quantifying the shading performance of plants in general.

[5] Brown and DeKay (2001: 268) point out that even bare branches of most trees block out approximately 30% to 60% of sunlight. This would significantly affect solar gain, requiring special attention to location, plant selection and possibly additional areas for solar gain. They recommend plants with an open branching structure and an avoidance of vegetation for shading solar collector apertures, unless they can be seasonally removed (2001: 268). Johnson (1991: 106) discusses this disadvantage, but also cites a 1979 study by Holzberlein that claims species such oak or ash transmit 70% to 80% of winter solar radiation. He also suggests that trees can be positioned closely to the windows so that the sun's rays pass underneath the canopy between September 21 and March 21 (1991: 106). Lechner (2009: 221) points out this disadvantage among plants in general.

[6] Yeang (2006: 141) lists general guidelines for soil depths: unspecified 'plants' require 7 cm, grasses 15-300 mm, vines 300 mm, low and medium shrubs 600-750 mm, large shrubs and trees 600-1050 mm and most vegetables 200 mm. Alternatively, a system without soil and with low light, and consisting of a metal frame and a PVC layer, can be integrated into facades, lowering the weight to around 30 kg per meter (Strongman, 2008: 26-27). Olgyay (1963: 75) suggests that trees should be approximately 4.5 m to 6 m when planted, although generally a fast-growing tree takes only five years to grow to have 80% of its full shading effect.

[7] The effects on daylighting, view and airflow are similar to those of other shading devices. Special attention should be paid to larger plants, such as trees, to ensure that ventilation is not blocked (Brown and DeKay, 2001: 269). Watson and Labs (1983: 165) cite as a main disadvantage of planting the trapping of heat near the surface of the building in summer, although breezes strong enough to move the leaves and water evaporation from leaf surfaces counteract this problem. On the other hand, care must be taken in the design of roofs, especially if they are to be inhabitable, for wind protection.

Step 18: REFERENCES

[8] Johnson (1991: 134) states that 800 to 1000 lux as the required lighting level for plants, and warns that ‘It can take up to two sunny days to make up for one day of insufficient daylight, so any space that supports plant growth must provide maintenance daylighting levels on cloudy days’.

[9] As Brown and DeKay (2001: 268) point out, shade plants need to be either grown before the facade is constructed or an interim shading strategy is required while the plants mature if planted after construction. Lechner (2009: 221) also mentions slow growth rates and diseases among disadvantages of plant shading, while adding that vines can overcome many of them.

[10] As with all shading devices, overshadowing by adjacent buildings can negate any benefits from the shading devices. Vegetation, too, depends on sufficient solar access, so the placement and choice of planting needs particular consideration if overshadowing is an issue at any point. This advice applies to roofs as well, as mentioned in Kwok and Grondzik (2007: 51).

GLASS GLAZING

Hierarchy:

1. Option 1: Triple

2. Option 2: Double

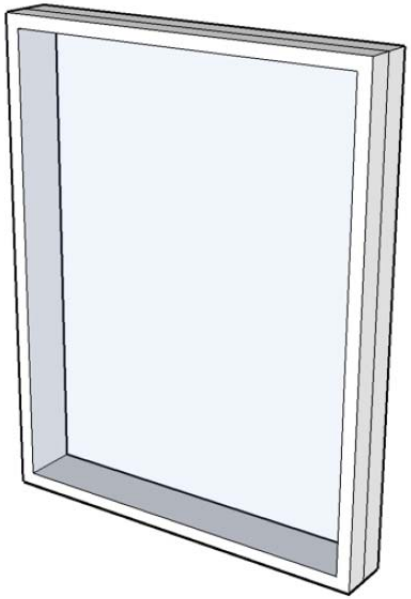
Fabric: Thermal Radiation (I)

Step 19

Glass Glazing

Option 1

Triple



Orientation:
North
East
South
West

Season:
Autumn
Winter
Spring

SPECIFY TRIPLE GLAZING ON FACADES

Triple glazing reduces internal heat losses by increasing thermal insulation [1].

Notes:

- To obtain a U-value below 1.0 W/m2K, triple glazing is recommended [2].
- It should be noted that window frames are of particular concern, so those of a low U-value should be specified if the unit is to function well in its entirety [3].
- It is estimated that low-e double glazing has a heat loss equivalent to that of triple glazing [4].
- In double facades the inner facade is usually double glazed and the outer one single glazed, effectively making it a triple glazed system. Likewise, triple facades, including sunspaces, are also triple glazed [5].
- Triple glazing is not recommended for atria roofs or glazing facing atria [6].

Links:

1; 2, O2; 5; 6; 7; 8; 13; 14; 17, O1; 17, O2; 17, O3; 18; 19, O2; 20; 21; 22; 24; 26, O2; 28

Limitations:

Triple glazing lowers natural light transmittance, so its effects should be modelled and taken into account [7].
If night insulation is used for the glazed area, then double glazing is encouraged instead [8].

_ YES, GO TO STEP 20
_ NO, GO TO STEP 19, O2

Step 19, Option 1: REFERENCES

[1] Gonçalves (2010: 178) relays this information as relevant to tall buildings in cold and temperate climates. According to Jones (cited in Balcomb, 1992: 257), triple glazing is considered a 'substantial improvement over double glazing' in cold, cloudy climates if the LCR is smaller than 30. Similarly, Watson and Labs (1983: 174) point out that 'triple glazing should be utilized in regions of more than 4500 heating degree days (average winter temperature below 30°F).' Hausladen et al. (2005: 133) states that U-values below 1.0 W/m2K require triple glazing.

[2] This recommendation is based on Hauseladen et al.'s guidance for tall buildings (2005: 133).

[3] Hausladen et al. (2005: 133) mention this aspect, adding that U-values should be calculated by taking into account the frame and glass.

[4] This finding is stated in Halliday (2008: 175) and CIBSE (2004: 4.2.4.1). Johnson (1991: 4) challenges it, stating that 'Triple glazing is no longer a viable alternative because it almost always costs more than low-e double coated glazing, and it doesn't perform as well.' He is most concerned with residential work, and as the statement isn't supported further, additional modelling and product information are required before concluding. Triple glazing and a low-e coating can be used concurrently, however, as discussed by Sadineni et al. (2011: 3621).

[5] Kwok and Grondzik (2007: 43) point out this fact, stating that it allows the inner facade to act 'as an optimum thermal barrier' for most climates and the outer facade to act as a buffer space. In sunspaces, the external envelope should be single glazed and internal one double glazed; an exception is where there is much planting, in which case double glazing should be used externally to reduce condensation (Cofaigh et al., 1996: 89).

[6] The performance of atria is highly dependent on daylight transmission, so lower levels of glazing are often recommended (Baker et al., 1993: sec. 5.46; Goulding et al., 1994: 149). Baker et al. (1993: secs. 5.48-5.49) and Goulding et al. (1994: 149) suggest that single-pane glazing would be best for this purpose.

[7] This limitation is referred to by Hausladen et al. (2005: 133), although no specific values are stated.

[8] Jones (cited in Balcomb, 1992: 257) states: 'If there is night insulation, triple glazing is never a substantial improvement over double glazing, and, in mild sunny climates, double glazing is not an improvement over single glazing'; this stipulation includes sunspaces (1992: 276). Watson and Labs (1983: 174) agree, stating that 'If operable insulating devices are used, only double or even single glazing need to be used on solar-oriented windows, so as to take advantage of their higher solar transmittance.' However, they warn that the effectiveness of night insulation will depend on its effective use, and so triple glazing, even if it reduces solar transmission and has poor R value, may at times be preferred.

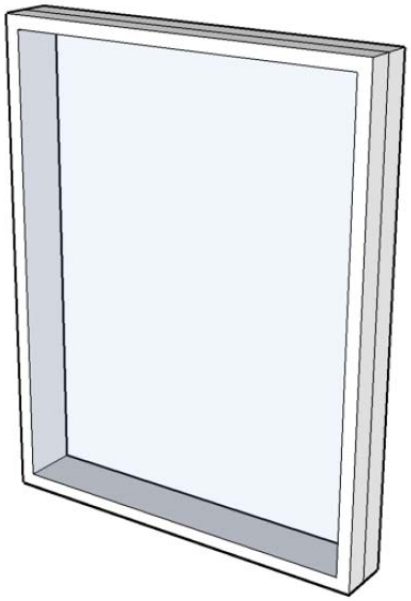
Fabric: Thermal Radiation (I)

Step 19

Glass Glazing

Option 2

Double



Orientation:
North
East
South
West

Season:
Autumn
Winter
Spring

SPECIFY DOUBLE GLAZING ON FACADES

Double glazing reduces internal heat losses by increasing thermal insulation [1].

Notes:

- As with triple glazing, window frames are of particular concern, so those of a low U-value should be specified if the unit is to function well in its entirety [2].
- Double glazing is considered to be most effective when combined with a low-e coating [3].
- It is more effective on south facades than others [4].
- Night insulation is recommended [5].
- Double glazing may not be suitable for atria [6].

Links:

1; 2, O2; 5; 6; 7; 8; 13; 14; 15; 17, O1; 17, O2; 17, O3; 18; 19, O1; 20; 21; 22; 23; 24; 26, O2; 28

Limitations:

Double glazing lowers natural light transmittance, so its effects should be modelled and taken into account [7].

_ YES, GO TO STEP 20
_ NO, GO TO STEP 20

Step 19, Option 2: REFERENCES

[1] Yeang's 'environmentally responsive approach tends to encourage use of clear or low-emissivity glass, in high-quality double- or triple-glazed units, wherever possible with solar shading provided' (2006: 205). Goulding et al. (1994: 160) recommends gas-filled, double glazed units with low-e coatings to minimize heat loss in buildings situated in the northern half of Europe.

[2] Hausladen et al. (2005: 133) mention this aspect, adding that U-values should be calculated by taking into account the frame and glass.

[3] For direct gain, Smith (2005: 56) specifies low-e, double glazed windows as a minimum requirement.

[4] Manz and Menti (2012: 231) discuss a study that suggests that triple glazing is the best choice overall for energy performance, but that double glazing is mainly effective on south facades.

[5] Night insulation is encouraged by Brown and DeKay (2001: 249) and discussed further in Step 23.

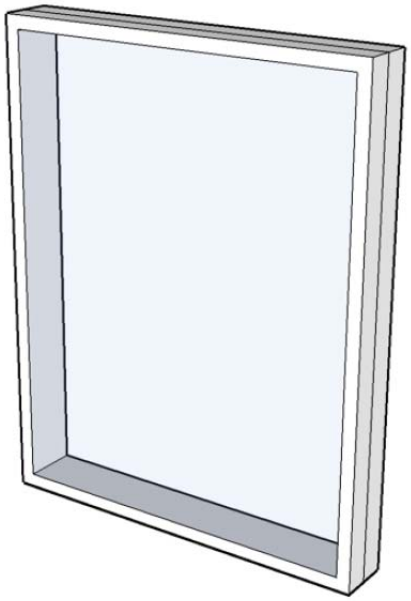
[6] The performance of atria is highly dependent on daylight transmission, so lower levels of glazing are often recommended (Baker et al., 1993: sec. 5.46; Goulding et al., 1994: 149). Baker et al. (1993: secs. 5.48-5.49) and Goulding et al. (1994: 149) suggest that single-pane glazing would be best for this purpose.

[7] CIBSE (2004: 4.2.4.1) points out that the greater the number of glazing layers, the smaller the light transmittance.

Fabric: Thermal Radiation (Increase)

Step 20

Glass Infill Gases



Orientation:
North
East
South
West

Season:
Autumn
Winter
Spring

SPECIFY INSULATIVE INFILL GASES IN GLAZING

Insulative gases mediate low external temperatures by preventing heat exchange through conduction [1].

Notes:

- Argon, Krypton or Xenon are commonly used; they are also colorless and have no impact on light transmission [2].
- Vacuum windows can perform to a similar standard as infill gases [3].
- Aerogel has similar benefits, but is included in the discussion on as thermal storage walls.
- Increasing the number of glazing layers increases the insulation value [4].

Links:

1; 5; 6; 7; 8; 13; 14; 15; 16; 17, O1; 19, O1; 19, O2; 21; 22; 28

Limitations:

Insulative infill gases cannot be used in double facades.

_ YES, GO TO STEP 21
_ NO, GO TO STEP 21

Step 20: REFERENCES

[1] This recommendation is based on a number of sources, including Goulding et al. (1994: 73-74), CIBSE (2004: 4.2.4.1), Hausladen et al. (2005: 144) and Wolf (no date), who explain the benefits of these gases. Wolf (no date) argues that 'Even the solar energy available on the north façade is more than sufficient to counter small daytime losses and turn the window into a net energy provider' but this isn't supported by measured data and so a reduction in glass area is still advised, as supported by most other sources, on non-south facades. Nonetheless, the heavy gas fill is recommended on all orientations to prevent heat loss in winter.

[2] Wolf (no date) examines the various gases in detail. Although krypton (3.71 kg/m3) and xenon (5.86 kg/m3) gave higher densities than argon (1.78 kg/m3), argon is the cheapest option, with the lowest payback periods, and therefore the most commonly used one. He also accepts that triple-glazed, argon- or krypton- filed, low-e units 'will outperform an insulated wall in winter, even when oriented to the north in a cold U.S. climate'; this finding, however, is based on another source, and the particularities of high-rise facade systems may offer other results.

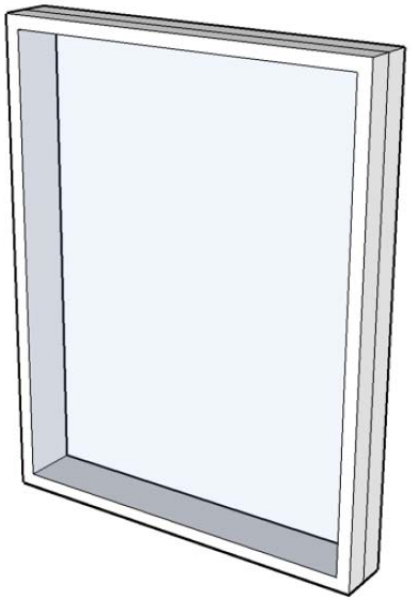
[3] This claim is made by Wolf (no date), who refers to other studies while stating 'A viable vacuum window or aerogel window could provide equivalent thermal conductance values to triple-glazed, gas-filled IG units with somewhat higher solar gain values, thus providing an even greater energy saving benefit.'

[4] This advice is provided by Wolf (no date); he gives the example: 'a doubling of the gas layers from double- to triple-glazing for argon- or krypton-filled, low-E coated IG units roughly cuts the U-value into half.' Goulding et al. (1994: 73-74) supports this advice.

Fabric: Thermal Radiation (Decrease)

Step 21

Glass Coating: Low-e



Orientation:
North
East
South
West

Season:
Autumn
Winter
Spring

USE A LOW-EMISSIVITY COATING ON GLASS

Glazing with a low-emissivity coating improves thermal insulation and prevents solar gain in summer [1].

Notes:

- The coating can be applied on any orientation [2].
- It can be applied to one side or both sides of a film, and in single, double and triple skin systems [3].
- It is beneficial for skylights, although skylights are generally not recommended [4].
- Additional benefits of low-e glazing include its ability to prevent fading of interior materials and to increase window size for admitting daylight [5].

Links:

1; 2, O2; 5; 6; 7; 8; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 19, O1; 19, O2; 20; 22; 24

Limitations:

There are some concerns regarding the daylight transmission properties of low-e glazing, specifically its effect on plants; a non-tinted type glass type should in any case be specified [6].

_ YES, GO TO STEP 22
_ NO, GO TO STEP 22

Step 21: REFERENCES

[1] Yeang (2006: 220) supports the use of low-e glass in for a variety of climates. Santamouris and Asimakopoulos (1996: 340) concur and offer a more thorough technical discussion, as do Hausladen et al. (2005: 144) and Johnson (1991: 25-28). Johnson (1991: 100) even states that 'better low-e glazings have nearly 2.5 times the thermal resistance of clear double glazing, at nearly the same solar transmission, so losses are more than halved while solar gains remain nearly the same.' Lechner (2009: 249) also suggests its use, but more specifically for conditions where 'solar heat gain must be minimized by daylighting is still desired and the use of external shading devices is not an option.' McMullan (2007: 18) furthermore states that, in addition to rejecting the maximum amount of solar energy while allowing for maximum amount of visible light, low-e glazing also reflects the 'maximum amount of room temperature back into the room.' Capeluto (2002: 327) finds that, based on computer modelling, high-performance, low-e windows yield the same energy performance as a self-shading envelope.

[2] Lechner (2009: 406-407) advises low-e glazing , different variations, on all facades. Johnson (1991: 100-103), one of the strongest proponents of low-e technology, supports the use of low-e glazing on the south facade over reduced glazing areas and exterior shading devices, namely based on concerns regarding views and cost. East and west facades are found to be just as suitable for low-e clear glazing. He even goes so far as to suggest that north-facing windows may 'draw a slight heating profit... in benign winter climates', but that it unfortunately doesn't compensate for heating losses, such as infiltration through joints and that due to cloud cover. Nonetheless, although northern walls lose heat during the winter, 'a north-facing low-e window with a high shading coefficient can replace much of that lost heat with the heat gained through the window as diffuse light.' This debate of windows versus walls is further discussed in Step 5.

[3] Wold (no date) provides details on the application of low-e coatings for a variety of systems, including specialized systems such as vacuum units. Sadineni et al. (2011: 3621), referring to other studies, notes that the coating, in any case, is placed on 'the inside surface of the outermost pane.'

[4] Johnson (1991: 134) claims that a clear, low-e glazed skylight of 5% to 9% of the floor area can lower solar gains down to the levels which would have been incurred by more typical lighting. Johnson (1991: 4) further states that low-e sloped glazing 'is now the cheapest way of controlling the always excessive solar gains in top-lit spaces such as atria', but this statement may be somewhat dated.

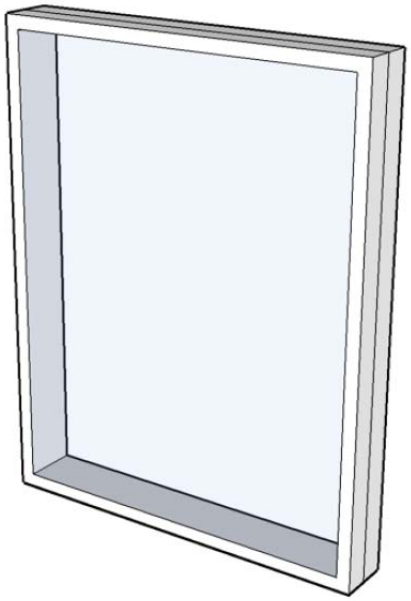
[5] As it filters infrared and ultraviolet radiation, Lechner (2009: 393) suggests low-e glazing would be beneficial in preventing fading. Lechner's statement could also infer that low-e coating may be more suitable than shading devices if material fading is of great concern. Yeang mentions that low-emissivity glass 'usually allows' the use of larger windows for daylighting.

[6] Johnson (1991: 145) questions these claims, and refers to experiments at MIT which he claims 'showed that neutral-colored low-e products do not seriously influence yields, plant health, or growth rates if the plants are kept near room temperature.' Tinted glass is discouraged by most sources, as it interferes with daylighting, increases cooling load in summer and are not as effective at reducing solar heat gain as other methods (CIBSE, 2004: 4.2.4.1; Yeang, 2006: 206; Lechner, 2009: 247). Lechner (2009: 249, 407) recommends clear glazing on all orientations other than horizontal glazing/skylights and clerestory windows, where translucent glazing may be more suitable.

Fabric: Thermal Radiation (Decrease)

Step 22

Variable Transmittance Glass



Orientation:
East
South
West

Season:
Spring
Summer

USE VARIABLE TRANSMISSION GLASSES ON SOLAR FACADES

Variable transmission glasses prevent solar heat gain during summer peak cooling periods by changing their transmission properties in response to radiation levels [1].

Notes:

- Variable transmission glasses can be photochromic, or light-sensitive, and thermochromic, or heat-sensitive. However, only the latter controls heat gain. A related option is fritted glass [2].
- Electrochromic, gasochromic and dispersed particle glazing are considered active as they require a power source, and electrochromic glazing is sometimes considered most suitable [3].
- As they are usually sandwiched between panels of glass, they can often be combined with technologies such as photovoltaics and low-emissivity coatings. Application on external shading is also an option [4].

Limitations:

All systems, if used during peak periods, interfere with daylighting [5]. Like all tinted glasses, they may have problems such as insufficient or excessive solar gain [6]. There may be interference from internal gains [7]. Overshadowed facades, or parts of facades, may not benefit from their application.

Links:

1; 2, O1; 2, O2; 5; 6; 7; 8; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 21; 24; 26, O2

_ YES, GO TO STEP 23
_ NO, GO TO STEP 23

Step 22: REFERENCES

[1] Variable transmission systems are recommended by Yeang (2006) and discussed in Baker et al. (1993), Santamouris and Asimakopoulos (1996), Eisele and Kloft (2002), Hausladen et al. (2005), Smith (2005), Lechner (2009), Sadineni et al. (2011) and Wolf (no date). They may also be referred to as ‘switchable,’ ‘smart’ or ‘intelligent’ glazings. It is envisioned, when sufficient information and testing is available, that this step could be divided into various options. Given the lack of adoption in the building industry, and tall buildings specifically, as well as the drawbacks discussed here, variable transmission systems are recommended as a secondary option to more traditional shading devices. Exceptions to this suggestion include conditions where high wind velocities exist (Müller and Schmitz, cited in Eisele and Kloft, 2002: 159).

[2] Thermochromic glazing is currently the only passive option available for controlling solar gain. It automatically changes its transparency in response to temperature so that it turns more transparent when cold (Lechner, 2009: 249), allowing for direct solar gain to occur during winter. Likewise, it becomes opaque, usually white, at about 30°C, meaning that it can block out insolation in the summer by about 70%. However, as Smith (2005: 67) points out, the possibility that it may react to internal gains means that it may not be very suitable for windows. Baker et al. (1993: sec. 4.17) also warn that it may possibly block useful solar radiation during the heating season.

Photochromic glazing is categorically not suitable for controlling solar gain; it would darken more during the winter when light strikes the window more directly but when solar gain would be beneficial. It is therefore generally considered as an option only for glare and daylighting control. It changes its transmission properties in response to visible radiation levels (Smith, 2005: 66). Although considered passive coatings, they nonetheless require an external voltage to de-colorize from a usually blue hue or prevent colorization in winter (Hausladen et al., 2005: 145). There are technical difficulties in scaling this technology to window size, as it was first designed for smaller applications (Smith, 2005: 66).

Fritted glass, also referred to as enamelled glass, includes a pattern fired into a glass surface so as to reflect solar gain. It is claimed that it can ‘reduce solar transmittance without blocking the sun or exposed faces of the building’ (Ascher, 2011: 71). Glare and view are concerns.

[3] Electrochromic glazing appears to be the most developed option, and is often considered the most suitable. Its mechanics are discussed in Smith (2005: 67), but it fundamentally relies on an externally-applied low electrical voltage, located between two laminated glass sheets, in order to change its solar and light absorption levels (Baker et al., 1993: sec. 4.16; Santamouris and Asimakopoulos, 1996: 340; Hausladen et al., 2005: 145). It can be controlled via a computer, photocell, thermostat or occupant (Lechner, 2009: 249). It has a slightly blue tint when operating (Hausladen et al., 2005: 145). Baker et al. (1993: sec. 4.16) give the solar radiation transmission range as between 15% and 70%, Lechner (2009: 249) widens it to 10% to 70% and Smith (2005: 67) refers to a type with under 20%. Sadineni et al. (2011: 3621-3622) refer to a study in Greece where an energy reduction of 54% was found when compared to a standard window, although its more difficult to say how it would relate to a temperate climate. They also list switching time, glare and color rendering issues among the current disadvantages of this glazing type. Nonetheless, Lechner (2009: 249) states that electrochromic glazing is ‘the most promising material for shading’ due to its transparency range and ease of control, and Santamouris and Asimakopoulos (1996: 340) declare it appears ‘to offer the best potential for use’. Wolf (no date) claims that it, and other actively controllable options, are ‘likely to be the preferred choice.

Step 22: REFERENCES

Gasochromic glazing functions much like electrochromic glazing, with the main difference being that the applied voltage is replaced with a small amount of hydrogen (Hausladen et al., 2005: 145; Wolf, no date). Again, there is a slightly blue coloration.

In suspended particle glazing systems, a film laminate of light-absorbing particles, suspended in a fluid, is placed between two layers of glass and activated by voltage. Unlike other systems, the default appearance is opaque. Although suitable for reducing solar gain, there are a number of unresolved issues, including those relating to radiant temperature and glare (Sadineni et al., 2011: 3622).

Liquid crystal glazing systems are also considered active variable transmission glasses, but as they are intended mainly for privacy purposes and have no energy savings, are not further discussed here.

[4] Due to view concerns, Smith (2005: 67) argues that variable transmission glasses may not be the most appropriate application for windows, stating that they are more suitable as external solar shading; this advice echoes Johnson's (1991: 168) recommendation in overhangs. Santamouris and Asimakopoulos (1996: 342) share the concerns, adding that they may be suitable for atria or skylights. It may also be worthwhile examining its performance in double facades.

[5] As some level of solar protection is needed during the daytime hours of cooling periods, view is necessarily compromised. Lechner (2009: 249) suggests that variable transmission glasses can be used in skylights, for example, where view may not be an issue. In tall buildings with curtain walls, therefore, they could be recommended on glazing sections where view is not required.

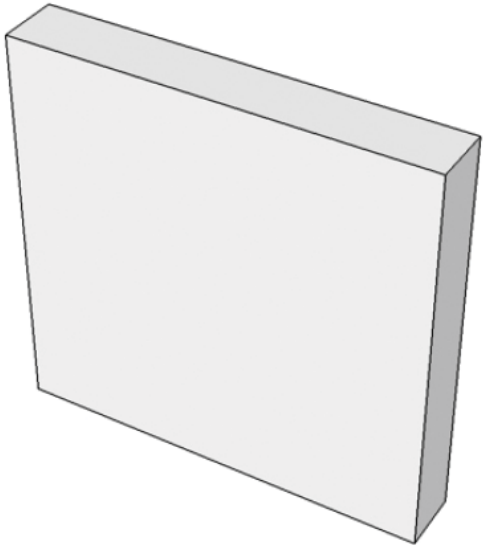
[6] As switchable glazing is considered as 'essentially a variable tint glazing' (Sadineni et al., 2011: 3621-3622), it may at times cause problems with solar gain, alongside daylight distortion, that is more pronounced in traditional tinted glass and discussed here and in Step 24, Note 2.

[7] This limitation is discussed in Note 2.

Fabric: Thermal Radiation (Decrease)

Step 23

Thermal Insulation



Orientation:
North
East
South
West

Season:
Autumn
Winter
Spring
Summer

SPECIFY WALL, FLOOR AND ROOF INSULATION WITH HIGH R-VALUES

Insulation with high R-values can prevent undesirable heat gain on solar walls in summer and reduces heat loss on all facades during winter [1].

Notes:

- On the north, east and west facades, insulation is recommended as a primary strategy. On the south facade, insulation is recommended only as a supplementary or secondary strategy [2].
- Internal insulation is recommended over external insulation; the roof is an exception [3].
- Removable insulation is recommended on facades utilizing thermal mass or glazed thermal walls and for double-glazed elements [4].
- Insulation is also recommended for floors, internal walls and the roof [5].

Limitations:

Without adequate ventilation, overheating can occur during warmer periods [6].

Links:

1; 2, O2; 5; 6; 10; 12; 15; 16; 17, O1; 18; 19, O2; 25; 27; 28; 29

_ YES, GO TO STEP 24
_ NO, GO TO STEP 24

Step 23: REFERENCES

[1] Insulation with high R-values can prevent undesirable heat gain on solar walls in summer and reduces heat loss on all facades during winter. Yeang (2006: 202) recommends high insulation levels, although he does not offer further details. Insulation is generally thought of as beneficial whenever heating is required for comfort, when mechanical cooling is used in summer periods and to keep interior wall surfaces at a higher temperature for both comfort and prevention of condensation (Watson and Labs, 1983: 145). The R-value and its reciprocal U-value are measurements of a material's thermal resistance; their extents and other charecteristics in common insulating materials are listed in various souces, including McMullan (2007: 17), Lechner (2009: 171) and Brown and DeKay (2001: 217).

The forms and categories of thermal insulation are numerous and covered by Hausladen et al. (2005: 141), Smith (2005: 68-79), Kwok and Grondzik (2007: 25-6), McMullan (2007: 15), Lechner (2009: 471-5) and Sadineni et al. (2011: 3625-3626). As a guideline for schematic design, the framework will not discuss these options in detail; in fact, the bespoke options for tall buildings would make that attempt futile. Nonetheless, the sources listed here offer some basic guidelines on R-values and thicknesses, appropriate for more conventionally-constructed tall buildings. In terms of design temperature, Evans (1980: 92) suggests that the average monthly minimum of the coldest month should be used.

Sadineni et al. (2011: 3625-3626) states that, in addition to the most important factors of thermal conductivity and thermal inertia, environmental and health impacts should be considered and then offers some examples of detrimental materials. McMullan (2007: 15) concurs, adding additional design criteria such as fire and pest resistance. Kwok and Grondzik (2007: 38) also mention recycling and disassembly, particularly of SIP. Some guidelines on these issues are summarized in Appendix X.

[2] The specification of high insulation on certain walls and not others is not a universal approach, but one that fits with the priorities set out in this framework. There are practitioners that argue for high levels of thermal insulation throughout, often allowing for the collection of solar gains only through glazed areas. This framework, on the other hand, suggests the use of walls and glazed areas for solar gain, meaning that insulation is not suitable for the south facade during colder periods. This argument is specific for residential tall buildings and therefore different from that for commercial skyscrapers, as summarized by Gonçalves (2010: 177): 'In general, in sealed buildings insulation should be high (meaning that U values should be low) including opaque and glazed areas, especially of the internal surfaces, while in naturally ventilated buildings, a lower degree of insulation is better, as the internal air temperatures tend to be slightly higher than the external, and therefore higher U values increase the heat losses from inside to the outside.' Kwok and Grondzik (2007: 115) recommend insulation on non-south facades as a 'most important' step, and most of the sources consulted assume its inclusion in at least those orientations. On the south facade, precedence is given to thermal mass, so insulation is recommended only as a supplementary or secondary strategy. 'Supplementary' here refers especially to forms of night-time or seasonal insulation, which are discussed in Note 4.

Step 23: REFERENCES

[3] It should first be stated that the choice of internal or external insulation may be non-existent or predetermined by the accessibility of cladding systems, in which case a type with a high R-value should generally be applied. In terms of preference of internal over external, Sadineni et al. (2011: 3625) points out that thermal insulation performs best when it is placed close to the surface of heat entry. Therefore, in heating dominated regions such as the cool temperate climate, it should be placed close to the inner surface of the buildings. CIBSE (2004: 4.2.3) also claims that internal insulation is preferable for intermittently heated buildings, but care needs to be taken regarding overheating if heat gains change rapidly.

On the other hand, Halliday (2008: 174), echoing Goulding et al. (1994: 76), states that condensation and frost damage is more likely with internal insulation and can only be avoided with extra ventilation or heating. External insulation keeps the building structure warm and lowers the risk of condensation. CIBSE (2004: 4.2.3) adds that external ventilation helps to stabilize the internal environment due to this de-coupling of structure's mass and the influence of the external environment. Roofs are a special case, and discussed in Note 5.

[4] Fixed elements are intended for non-solar facades as solar gain is not possible and heat loss is inevitable. Likewise, if solar facades do not adopt thermal mass or glazed thermal walls, then fixed insulation is accepted as an effective primary strategy. Removable elements are to be applied seasonally for solar facades utilizing thermal mass or glazed thermal walls; that is, insulation is to be applied during cooling periods only. Removable insulation elements are also to be applied usually internally and at night on glazed elements of all orientations. They are particularly recommended during heating periods and are to take account any ventilation requirements. Brown and DeKay (2001: 258-259) recommend their use at night, pointing out that heat loss occurs 10 times faster through a double-glazed window than an insulated wall and that in cool winter climates uninsulated solar elements can lose as much heat as they gain. They then present the two options of rigid panels, which require most storage, and flexible covers, which can be motorized. Lechner (2009: 289) also supports night insulation but states that it may be used as extra insulation during summer days when view and daylight are not required. In locations where louvers are already planned, he suggests that insulated louvers may be an option (2009: 489). It should be noted that removable systems are highly dependent on occupant use, and, as Balcomb (1992: 8-10) observed in low-rise buildings, if not designed properly and of ease of use, energy savings may not be a result.

[5] Floors and internal walls, unless designed for as thermal mass, would also benefit from increased insulation, particularly if rooms are heated independently. The thermal properties of floors and internal walls are discussed in more detail in Evans (1980: 101-102). If underfloor heating is desired, some insulation will still be essential (Evans, 1980: 103).

Step 23: REFERENCES

Unless acting as atria, roofs require insulation. However, unlike low-rise buildings, thermally the roof plays a smaller overall role in the tall building, and therefore its design is only relevant to the performance of top floors (Yeang, 2006: 222). Roof insulation can consist not only of the usual insulation materials but mechanical equipment as well (Yeang, 2006: 222). External insulation is more beneficial than an internal one as it absorbs much of the heat before it reaches internal materials (Givoni,1976: 152) and as heat is not essential for comfort at that location. Givoni (1976: 153) offers a discussion on roof construction and performance, concluding that insulation should be located above a concrete slab but that ventilation and some form of water vapor removal should be available between the insulation and the upper waterproofing layer. Fixed roof insulation is standard, essential when roof gardens or photovoltaics are applied, but it can also be movable, although this may be impractical and inefficient in tall buildings. In this case, the insulation would be coupled with a thermal mass layer below it, but again, in their illustration of the system, Santamouris and Asimakopoulos (1996: 433) state: 'it is of minor interest for multi-storey buildings, since only the spaces directly under the roof benefit from it.' A more common system among tall buildings is the inclusion of mechanical equipment, which may not eliminate insulation but can contribute to its effectiveness. As mechanical installations are required every twenty five floors or so (Daniels, cited in Eisele and Kloft, 2002: 180), they may need to be decentralized and their impact included in both floor and roof thermal calculations. A light-colored, reflective roof is recommended (Yeang, 2006: 222; Lechner, 2009: 252), unless a green roof is specified.

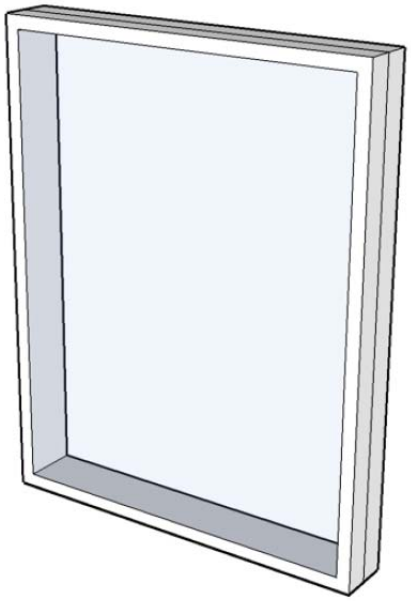
Although heat bridges are not covered in the schematic design strategies of this framework, it should be noted that balconies are best not designed as concrete cantilevers but as hung metal elements as they would otherwise act as 'cooling fins' in winter and 'heating fins' in summer (Lechner, 2009: 483). Heat bridges in general are becoming more critical as insulation standards are raised, accounting for between 5% and 20% of energy losses and serving as locations for mold and condensation (Hausladen et al., 2005: 44, 133), and so should be considered more fully in later construction specifications.

[6] Marcondes (cited in Gonçalves, 2010: 156-157) points out this limitation and the possible solution, adding that some thermal inertia could also be beneficial. However, this issue is much less of a concern in residential tall buildings than commercial ones, although some precautions should be taken if activities generating high internal heat gains are expected or undesirable heat gains, for example through western facades, are likely to occur during cooling periods.

Fabric: Visible Radiation (Increase)

Step 24

High Transmittance Glazing



Orientation:	*Season:*
North	**Autumn**
East	**Winter**
South	**Spring**
West	**Summer**

SPECIFY A CLEAR GLAZING TYPE

Clear glazing's high transmittance value provides the best conditions for daylighting [1].

Notes:

- Tinted glass reduces the amount of daylight transmitted into the building and so is best avoided [2].
- As reflective glass reflects light as much as thermal radiation, it should be reserved for situations where solar heat gain cannot be minimized with shading devices; therefore it may be most suitable for east and west facades [3].
- Heat-absorbing glass also affects the color of the glass, and hence the quality of daylight [4].
- As glare is a significant comfort concern, it can be avoided through prevention of excessively lit spaces and the provision of 15-20% glazing area percentages [5].

Limitations:

The effectiveness of glazing will also depend on the layers of glass included, but as thermal radiation takes precedence over visible radiation, a general suggestion for clear glazing is sufficient here [6].

Links:

7; 8; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 21; 22; 25; 26, O1; 26, O2

_ YES, GO TO STEP 25
_ NO, GO TO STEP 25

Step 24: REFERENCES

[1] This recommendation is based on Yeang (2006: 207) and is supported by most sources (Milne in Givoni, 1976: 183; Baker, 1993: sec. 5.26; Brown and DeKay, 2001: 273; Lechner, 2009: 393).

Low-e coating is included as a clear glazing type (McMullan, 2007: 18), but its benefits are discussed in Step 21.

[2] CIBSE (2004: 4.2.4.1) warns against tinted glass, and this advice is common elsewhere. There are benefits to avoiding tinted glazing, such as its negative psychological impact on users and the possibility of unwanted solar heat gain during cooling periods (Lechner, 2009: 249, 393), but its daylighting benefit is considered the most relevant here.

[3] This fact is noted in Lechner (2009: 247, 249, 393) and Yeang (2006).

[4] This fact is noted in Lechner (2009: 393), as is this type's disadvantage of reradiating absorbed heat inside and making the glass hot.

[5] This recommendation is based on Yeang (2006: 210). He also suggest a daylight factor of around 1.5-2% at the back of the room and a height-to-depth ratio of 1:2, which is somewhat different than the 1:2.5 ratio discussed in Step 8. It is assumed that this difference can be addressed through additional measures, such as louvers, as some form of shading devices are recommended on most facades. Evans adopts this logic, stating that 'it may be necessary to provide shading devices or shutters to exclude direct sunlight, even though temperatures are below the limit at which shading is required to prevent overheating' (1980: 117). He also warns against the use of low-transmission glazing. Brown and DeKay point out that 'The larger the windows, the more critical the glare' (2001: 273-274) and also suggests that windows be placed out of the direct line of sight of users or reducing the luminance of the reflective surface (2001: 246). Kwok and Grondzik (2007: 82-83) further point out that interior finishes, furniture layout and partition design can reduce glare, while specular finishes, on light shelves for example, may become potential sources of glare.

Serra (cited in Gallo et al., 1998: 127) distinguishes between two types of glare: 'veil glare' 'produced by a bright stop on a very dark background' and 'adaptation glare' existing 'where there is a great variation in luminance values'. He considers the latter more important for architectural design, and so most suggestions here refer to it.

[6] Halliday (2008: 223) lists the diffuse transmittance of clear single glazing as approximately 0.8 T and that of clear double glazing as 0.7. Therefore, it is not surprising that sources such as Baker et al. (1993: sec. 5.46) suggest that single glazing is 'often most appropriate'. Nonetheless, for this climate type, thermal performance is prioritized over daylighting, and so a minimum of double glazing is recommended.

Fabric: Visible Radiation (Increase)

Step 25

Material Reflectivity

Orientation:	*Season:*
North	**Autumn**
East	**Winter**
South	**Spring**
West	**Summer**

SPECIFY LIGHT-COLORED INTERIOR MATERIALS THAT REFLECT RADIATION

Materials with high reflectance values and of light colors enhance interior daylighting, and can also reduce solar gain in summer by reflecting solar radiation [1].

Notes:

- All interior surfaces that are the first to reflect daylight are especially encouraged to be reflective and light-colored [2].
- ‘Interior’ walls here include those of atria surfaces, which depend on reflected light for daylighting [3].
- Light-colored and reflective materials also help to reduce solar gain, so are also a possible strategy for reducing solar gain in external non-thermal walls and roofs [4].

Links:

2, O2; 6; 7; 8; 15; 17, O1; 17, O3; 23; 24; 26, O1; 26, O2

Limitations:

Surface reflectivity is most influential in light-weight, weakly-insulated buildings [5]. Daylighting is dependent on a suitable context, so dark urban canyons may decrease the effectiveness of this strategy [6]. It is also highly reliant on an appropriate building planning [7].

_ YES, GO TO STEP 26, O1
_ NO, GO TO STEP 26, O1

Step 25: REFERENCES

[1] Enhancing daylighting through reflective and light-colored surfaces is encouraged by a range of sources in a variety of contexts (Givoni, 1976; Santamouris and Asimakopoulos, 1996; Watson and Labs, 1983; Brown and DeKay, 2001; Yeang, 2006; Kwok and Grondzik, 2007; Lechner, 2009). Some example emissivity and absorbtivity coefficients of common materials are found in McMulan (2007: 18), although the basic adviece here is sufficient for schematic design.

[2] CIBSE (2004: 9.1.3) recommends light internal surfaces, especially for walls and ceilings, with a high reflectance, as dark surfaces absorb daylight. Watson and Labs (1983: 123) specify 'materials that absorb solar heat as it arrives and... reradiate back to the interior after the sun has passed' on all surfaces exposed to direct solar radiation, as they argue that spaces with large south windows can overheat in winter and as there is also a short period of solar radiation during that period. Lechner (2009: 397) lists the 'descending order of importance for reflecting surfaces' as 'ceiling, back wall, side walls, floor, and small pieces of furniture', specifying that ceilings 'should have the highest reflectance factor possible.' Kwok and Grondzik (2007: 88) agree with the primacy of the ceiling and advise a reflectance value of 90% or more. Brown and DeKay (2001: 219), however, claim that the first surface to reflect daylight is the most important in this respect, whether or not it is a ceiling: 'This surface may be the floor when light is coming directly from the sky, or the ceiling if the light is being reflected from exterior ground surfaces.' Brown and DeKay's reasoning is adopted here, particularly as it appears more suitable for tall buildings where ground reflectance is not as significant.

[3] Baker et al. (1993: sec. 5.39, 5.40) argue for high reflectances of atrium surfaces, adding that studies show that white atrium surfaces increase the quality of light in adjacent spaces more than light-directing elements. Goulding et al. (1994: 138, 149) and CIBSE (2004: 4.2.1.2) support this recommendation. Floor surfaces are also important, as Baker et al. (1993: sec. 5.39) point out that dark-colored materials and plants can reduce the reflectance of the atrium floor to very low levels.

[4] Most recommendations relating to the use of light colors and reflective materials elsewhere are also concerned with hindering solar gain. Yeang's advice (2006: 223-224) is not an exception, as many of his suggestions originated in hotter climate types. In the temperate climate, in cases other than the non-vegetated roof and non-shaded east and west walls, thermal radiation can be reflected with this strategy and reduce unwanted solar gains. This strategy only works with insulation though, not thermal mass, where dark surfaces with high absorbance values produce better results (Brown and DeKay, 2001: 220). In fact, Brown and DeKay (2001: 218) recommends that the two approaches can work together as 'surfaces of lightweight, nonmassive materials should be light in color, at least 50% reflectance, so that they will reflect solar radiation to the massive surfaces.' In terms of the overall effect of color on solar gain, Johnson (1991: 106) offers a short review: 'White paint is not a perfect reflector, it absorbs 10% of the solar radiation that strikes it. A solar ray entering such a room will undergo many multiple reflections and absorptions before it reaches the window again. An off-white room will absorb more than 90% of the entering solar energy if the window wall is less than 50% glazed.'

Step 25: REFERENCES

Reflective surfaces are commonly recommended specifically for roofs. Although clouds inhibit its effectiveness, radiant cooling is cited as an option (Lechner, 2009: 285; Santamouris and Asimakopoulos, 1996: 431), as are radiative heat barriers (Yeang, 2006: 235). Light-colored roofs, likewise, are also common suggestions, although Santamouris and Asimakopoulos (1996: 432-433) point out that 'This is a simple technique of rather poor performance and therefore applicable mainly in very hot countries.' Again, due to the additional advantages previously listed, green roofs and/or insulation are prioritized over these techniques.

[5] Watson and Labs (1983: 161) notes this limitation, in that 'Maximization of surface reflectance will therefore apply most advantageously to the southern regions where high R values for walls are not demanded.'

[6] Lechner (2009: 251) recommends the use of white external walls to increase daylighting levels in the lower floors.

[7] See the Context section for initial requirements.

REFLECTOR SYSTEMS

Hierarchy:

1. Option 1: Light Pipes

2. Option 2: Reflector Systems

Step 26

Reflector Systems

Option 1

Light Pipes

Orientation:	*Season:*
East	**Autumn**
South	**Winter**
West	**Spring**
	Summer

ADD LIGHT PIPES TO SOLAR FACADES

Light pipes extend daylight illuminance levels at 5 m to 9 m or more and improve the uniformity of daylight within a room [1].

Notes:

- The light pipes referred to here made of prismatic film that transmits light by internal reflection, as opposed to tubular skylights that rely on surface reflection [2].
- They work only with sunlight, so are best placed on south facades [3].
- Light pipes have a more efficient performance than light shelves throughout the year [4].

Links:

1; 2, O1; 2, O2; 5; 7; 8; 14; 17, O2; 24; 25; 26, O2

Limitations:

There are limitations regarding space requirements [5]. Alternatives include other types of prismatic systems [6].

_ YES, GO TO STEP 27
_ NO, GO TO STEP 26, O2

Step 26, Option 1: REFERENCES

[1] This recommendation is based on Yeang (2006: 208-209). Unlike the depth limitations outlined in Step 8, Yeang argues that traditional daylight design can only provide ‘adequate daylighting within about 4.6 metres’. He suggests that daylight illuminance levels at 4-5 m can be extended to 9 m and even at times to 12 m with experimental systems. Littlefair’s criteria for the use of light-deflecting elements is paraphrased in Baker et al. (1993: secs 5.63-5.64) as encompassing spaces that: demand visual comfort, are located by large external obstructions, have a high availability of sunshine and require uniformity of illumination that can not be achieved through windows alone. Their advantages, including the reduction of glare, are also pointed out by Baker et al. (1993: sec. 5.59).

[2] This distinction is made by Lechner (2009: 421). ASHRAE (2003: 32) limits the distance that light can be ‘piped’ into a building at about 27 m; due to a lack of specificity, it is assumed here that this distance refers to such vertical tubes rather than horizontal ones. The advantages, and disadvantages, of these ‘light conveyor’ systems are further discussed in ASHRAE (2003: 32). As the use of traditional skylights is limited to the upper levels of a tower, they are not discussed specifically in the framework; more information can be found in Johnson (1991: 134). Furthermore, as they create problems with shading, they are not advisable, and instead clerestory windows, or high windows, are recommended (Santamouris and Asimakopoulos, 1996: 331; Lechner, 2009: 217).

[3] This recommendation is adapted from Lechner’s statement that ‘Since diffused skylight cannot be focused, these light guides only work with sunlight’ when referring to fiber optics and light pipes (2009: 420).

[4] This statement is extracted from Yeang (2006), although supporting data is lacking.

[5] Disadvantages of light pipes, including space requirements, are discussed in Baker et al. (1993: sec. 5.59).

[6] Hausladen (2005: 147) categorizes prismatic systems as elements made of translucent panels that ‘can be attached in front of the façade, in the façade cavity of double-skin facades, in the glazing cavity or inside the room’. Baker et al. (1993: sec. 5.57) refers to the work of Bartenbarch, which alternatively organizes them as ‘Sunlight Directing Prisms’ and ‘Sunlight Extruding Prisms’. In any case, in addition to light pipes, they include ‘Fresnel-type lenses made of glass or acrylic’ (Baker et al., 1993: sec. 4.15) and fiber optic fixtures (Baker et al., 1993: sec. 4.17; Lechner, 2009: 420-421) Holographic systems can also be included in this group of alternatives, and are further discussed in various sources (Baker et al., 1993: secs. 4.15, 5.60, 5.61, 5.63; Hausladen et al., 2005: 147; Sadineni et al., 2011: 3622) With sufficient additional information, it is envisioned that these two devices could eventually form separate options for this step.

It should be noted, according to Baker et al. (1993: sec. 4.15), that ‘Prismatic devices can be made inexpensively but their poor transparency restricts their use to industrial buildings or some very specific locations, such as the upper parts of façade windows’. Although this is a dated assumption, the preference for clear windows within the framework suggests that such placement is still recommended.

Orientation:	*Season:*
North	**Autumn**
East	**Winter**
South	**Spring**
West	**Summer**

ADD LIGHT SHELVES

Light shelves extend daylight illuminance levels at 5 m to 9 m or more and improve the uniformity of daylight within a room [1].

Notes:

- External light shelves even out daylight levels and provide the advantage of blocking out direct sun and redistributing additional solar radiation. Interior types provide a more even light distribution, but decrease daylight levels at the window. A combined type may offer both benefits [2].
- The glazing above a light shelf should be clear and double-paneled, with the option of a horizontal shading between the panes [3]. Glazing above the shelf should be white or mirrored [4].
- Tilted light shelves may perform better than horizontal ones [5].

Limitations:

Additional shading is usually still required. Light shelves cannot correct deep spaces or low ceiling heights [6]. There are also concerns with glare, requiring placement above head height and a semi-specular finish [7]. They may interfere with airflow [8]. Alternatives include special blinds or mirrors [9].

Links:

2, 02; 5; 7; 8; 10; 11; 14; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 22; 24; 25; 26, O1; 27; 28; 29

_ YES, GO TO STEP 27
_ NO, GO TO STEP 27

Step 26, Option 2: REFERENCES

[1] This recommendation is based on Yeang (2006: 208-209). Unlike his depth limitations outlined in Step 8, Yeang argues that traditional daylight design can only provide ‘adequate daylighting within about 4.6 metres’. He suggests that daylight illuminance levels at 4 m to 5 m can be extended to 9 m and even at times to 12 m with experimental systems. The advantages of light shelves over more typical window arrangements are also discussed in Brown and DeKay (2001: 255), Johnson (1991: 132), Baker et al. (1993: secs. 5.22, 5.50) and, notably for multistory buildings, in Gonçalves (2010: 205), Lechner (2009: 401) and Hausladen et al. (2005: 147). However, some studies suggest that they may be less beneficial than supposed, as they can ‘have a greater negative effect on the amount of daylight than their positive contribution’ (Baker et al., 1993: sec. 5.54), so should be adopted carefully and as a supplementary, not primary, solution.

[2] Kwok and Grondzik (2007: 81-3) mention the various ways a light shelf may be positioned, pointing out that the ‘defining element’ of the system is glazing above the shelf. They note that the redistribution of solar radiation by light shelves can contribute to an additional heating load in summer through the captured solar radiation, despite their shading properties. Brown and DeKay (2001: 256) provide some solutions, for example shading the southern orientation during cooling seasons or recessing the upper glazing to the back of the shelf. This last suggestion is in opposition to Johnson’s (1991: 143) advice of placing the clerestory window as far as possible outside so that it remains ‘free of dirt’. Generally, they highlight that light shelves should extend beyond the building sufficiently enough if they are to reduce solar gain and should extend inside the building enough if the are to reduce glare. Based on parametric testing, Baker et al. (1993: sec. 5.52) also offers a number of conclusions regarding light shelf types, one of them being that the ‘internal part of any lightshelf acts mainly as an obstruction inside the space’; this contrasts with the benefits outlined by Kwok and Grondzik (2007: 81-83) and Baker et al. (1993: sec. 5.53).

Baker et al. (1993: sec. 5.64) refers to Littlefair in his assertion that solar tracking systems may be most effective, but if a fixed system is chosen, then ‘the sun position of March 21 at noon is appropriate to represent the whole year.’ Given the complexity of building technologies and context, a more individual approach, perhaps based on modelling, is instead recommended.

Brown and DeKay (2001: 257) state that light shelves can be used on any orientation if the skies are mostly overcast, but that glare is a particular concern on east and west facades. Place and Howard (1990, cited in Brown and DeKay, 2001: 256) recommend a length of 1.24-1.5 times the height of the clerestory glass if oriented 20° either side of south, and 1.5-2.0 times beyond that. Lechner (2009: 402) agrees that east and west light shelves should be much longer. However, he stands out among other sources by claiming that light shelves are ‘not needed at all on north windows’.

Goulding et al. (1994: 123) contradict with Brown and DeKay’s (2001: 257) assertion that light shelves can be used in any orientation if the skies are overcast, arguing that, as they reduce the light admitting area in the northern European context, they ‘are not therefore in general suitable for regions where the skies are mainly overcast.’ They instead advise roof apertures, but as the framework is based on multistory buildings with generally larger glazing, light shelves are nonetheless considered a suitable option. Johnson (1991: 132) also add a further advantage to Brown and DeKay’s stance, citing 1986 experiments by W.M.C. Lam, that demonstrate that light shelves improve lighting uniformity on cloudy days.

Step 26, Option 2: REFERENCES

[3] This recommendation is based on Kwok and Grondzik (2007: 82) and Lechner (2009: 401).

[4] If heat gain is not an issue, a mirrored light shelf with a white ceiling performs better than a white light shelf with a mirrored ceiling (Baker et al., 1993, p 5.52; Brown and DeKay, 2001: 257). Additional light shelf materials, such as aluminum and highly polished metals as discussed in Baker et al. (1993: sec 5.22), can be included under the mirrored category. The bottom of the light shelf should be painted in response to conditions for glare, and so lighter to reduce contrast glare and darker to reduce excessive ground-reflected light (Johnson, 1991: 144). In all cases, the ceiling should be highly reflective (Johnson, 1991: 143-144; Baker et al., 1993: sec. 5.53). Interior wall reflectance is discussed in Step 25.

[5] Kwok and Grondzik (2007: 82) state this finding, and Brown and DeKay (2001: 257) cite guidance by Moore (1991: 88-89): For south facades, the shelf should be tilted at 40° - (0.5 x latitude °); for east, west, and north orientations, the shelf should be tilted 15°. Additionally, he finds that the optimum shelf tilt decreases with the depth of the room and that further length or thickness may be required for shading if the shelf is tilted. If applied, Baker et al. (1993: sec. 5.52) offers guidance for a light shelf with a one meter window above it, claiming that a depth of 1:1 to 1:1.5 of that window height provides the ‘highest contribution of daylight for a slope of 30°’. Also of note are curved light shelves, as mentioned by Baker et al. (1993: secs. 5.50, 5.54). He states that convex lights shelves have the benefit of rejecting most light from high sun angles but admitting light from low angles.

[6] Kwok and Grondzik (2007: 81-2) state that bilateral apertures are more appropriate for deep spaces and other methods, including light pipes, are more suitable for spaces with low ceiling heights.

[7] This recommendation if found in Kwok and Grondzik (2007: 82-83) and Lechner (2009: 401). Brown and DeKay (2001: 228) quantify the required height of the top surface of the light shelf as at least 0.6 meters from the ceiling, with a room ceiling height of at least 3 meters. Keeping that advice in mind, light shelves should be located as low to the floor as possible to reflect the most light into the ceiling (Johnson, 1991: 143).

Lechner (2009) also suggests the use of an additional interior light shelf, which can be of more delicate material and be better in collecting sunlight than louvers in the upper glazing. In terms of combined systems, Baker et al. (1993: sec. 5.52) points out that ‘for a lightshelf situated within a window area, the combination of external and internal parts of the shelf results in a good glare performance. For narrow horizontal windows near the ceiling, only the exterior part of the lightshelf improves the glare situation.’

[8] This statement originates in Kwok and Grondzik (2007: 83), but further modelling is required to determine the best option.

Step 26, Option 2: REFERENCES

[9] Light-deflecting blinds and heliostats are discussed in Hausladen et al. (2005: 147). Light-deflecting blinds are two-part blinds, where the upper part deflects light into the room while the lower lamellae act as shading. Heliostats are mirrors guided on axes to deflect sunlight over long distances. A further discussion of the blind devices is found in Johnson (1991: 142), where thy are referred to as coming ‘close to the ideal because they do not produce light at the window and they do not interfere with the view when set nearly horizontally.’ Lechner (2009: 418) mentions the benefits of heliostats as mainly being the control of sunlight regardless of its angle. All options, as outlined by Hausladen et al. (2005: 46), can be either static or tracking systems. With sufficient additional information and testing, it is envisioned that these two devices could eventually form separate options for this step.

Fabric: Airflow (Increase)

Step 27

Cross-Ventilation

Season:
Autumn
Winter
Spring
Summer

DESIGN FOR CROSS-VENTILATION

Apartments with adjustable openings on differing facades provide comfort ventilation and night cooling [1].

Notes:

- Place inlets in higher pressure areas, i.e. windward, and outlets in lower pressure ones, i.e. leeward [2].
- Inlets should be placed perpendicularly or obliquely to the wind; all openings should avoid direct flow [3].
- For increased wind velocity, inlets should be located at a low level and outlets at a high one [4]. For comfort cooling, inlets can be placed 70-120 cm from the floor in living rooms and 50-80 cm in bedrooms [5].
- The opening area should be 20% of the floor area, spread equally between the inlet and outlet [6].
- Apartment partitions, when unavoidable, should be minimized and include openings for air flow [7].
- Cross-ventilation is usually applied as comfort ventilation but can also be used as night ventilation [8].

Limitations:

Adjacent apartments, like rooms, are problematic [9]. Outside temperature and humidity require attention, e.g. cooling requires at least 1.7°C indoor-outdoor difference. [10]. Shading devices affect performance [11]. Certain conditions may prohibit the use of natural ventilation, so a mixed-mode strategy may required [12].

Links:

2, O1; 2, O2; 3; 5; 6; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 23; 26, O2; 28; 29

_ YES, GO TO STEP 28
_ NO, GO TO STEP 28

Step 27: REFERENCES

[1] Cross-ventilation is defined by CIBSE (2004: 4.2.5.2) as occurring ‘when inflow and outflow openings in external walls have a clear internal flow path between them’ and occurs through both wind and buoyancy pressures (Awbi, cited in Gallo et al., 1998: 175). Cross-ventilation here refers to ventilation with multiple windows on walls with differing orientations, as opposed to what Givoni (1976: 296-297) refers to in single-sided windows where ‘Air enters through the first window and leaves through the second, in effect creating a cross-ventilation.’ However, even he is quick to point out that ‘... sometimes the expression is loosely used whenever the space has more than one access to the outside, regardless of their position in relation to the wind. This may well be misleading, for when all the openings of a space are facing zones at similar air pressures there will be very little internal air flow.’ (Givoni, 1976: 294).

As with other steps concerned with airflow, modelling, through computational fluid dynamics or wind tunnel testing, is usually required for tall buildings.

[2] This suggestion is stated in most sources, among them Watson and Labs (1983: 191), Awbi (cited in Gallo et al., 1998: 175), Brown and DeKay (2001: 167) and Yeang (2006: 214, 217). Givoni (1976: 229) indeed claims that ‘The principal requirement for satisfactory ventilation is the provision of openings on both the windward and the leeward sides of a building, a necessity confirmed by laboratory and field studies.’ Evans (1980: 129), in one respect contrary to Givoni, claims that the ‘position of the outlet has little effect on the pattern’, as does Lechner (2009: 275) and Olgyay (1963: 108), although both agree on the importance of the windward inlet. However, a windward inlet is not always possible, particularly in large tall buildings, so if the building configuration or other concerns do not allow for the placement of inlets on the windward side, but to a side parallel to the wind, then wing walls, otherwise reserved for single-sided ventilation, can be used to channel the wind into the building (Goulding et al., 1994: 163).

[3] Brown and DeKay (2001: 90, 182) claim that a maximum rate of ventilation is achieved when the wind is ‘relatively perpendicular’, that is, within 40° from the perpendicular, to the opening. Watson and Labs (1983: 193) argue that for ventilation to affect a larger volume of space and create higher overall circulation velocities, inlet and outlets should be placed ‘askew from the axis of prevailing winds.’ Givoni (1976: 289-290) and Olgyay (1963: 106) support this view.

[4] Numerous sources give this advice, without referring to specific heights, among them Goulding et al. (1994: 163) and Olgyay (1963: 112). Brown and DeKay (2001: 243) provide an explanation as to why entirely low-level or entirely high-level openings will not lead to maximum wind velocity in the occupied zone, arguing that mid-height or varied height openings work best. It should be noted that this advice especially applies to multiple-level apartments, where stack effect may be more prevalent and help to drive airflow.

Step 27: REFERENCES

[5] This recommendation is based on Givoni (1976: 280). Lechner (2009: 274) gives a lower range, at 30-60 cm, for all rooms requiring sitting or reclining, whereas Yeang (2006: 217) offers a more basic suggestion of within 2 m when day cooling is required, and above 2 m for night cooling and winter ventilation. This advice is opposed to the office requirements at 120-150 cm above the floor, due to a possible disturbance at desk level (Givoni, 1976: 280); that guidance can be applied to areas where desk work takes place, such as studies.

CIBSE (2004: 4.2.5.2) recommends that trickle ventilators typically be placed 1.75 m above floor level.

[6] Unlike the location of the outlet, which is considered negligible by many, its size is usually deemed crucial for both average and maximum velocities. There are a range of estimates available for inlet and outlet size, some more general than others. Brown and DeKay (2001: 167) recommend a 'large' area for both inlets and outlets, at about 2/3 of the wall width (2001: 90, 182), whereas Lechner (2009: 282) refers to an estimate of 20% of the floor area, which used here. Yeang (2006: 215) argues for full wall openings on both sides in the summer, but as the climate is not specified, this advice is not encouraged here and assumed as more suitable for hotter climates. Less specifically, Awbi (cited in Gallo et al., 1998: 175), states that openings can be small, such as trickle vents and grills, or large, such as windows and doors. Evans (1980: 130) gives a maximum opening size at about 40% of the wall area, claiming that anything beyond this does not significantly increase internal wind speeds. He also examines varied sizes of openings, stating that the combination of a small inlet and a large outlet leads to a poor distribution and low wind speeds in large areas, while a large inlet and a small outlet improves distribution but results in a lower maximum speed, so is more beneficial. Lechner (2009: 275) disagrees, arguing that 'if one opening is smaller, it should be the inlet, because that maximizes the velocity of the indoor airstream, and it is the velocity that has the greatest effect on comfort', although he generally recommends an equivalent size for both. Olgyay (1963: 108) similarly states that 'A relatively large ratio of outlet to inlet size secures the speediest, and hence most cooling, air flow within a building.' Givoni (1976: 293-294) discusses this issue as well, but concludes that the preference for a type of distribution, and by extension the inlet size, depends on the room's function. Due to the pressure differences within and around the building, the final design of the openings will nevertheless depend on some form of modelling.

Additionally, Sandberg (2004, cited in CIBSE 2006: 4.5.1.1.) argues for a maximum 50% opening area for trickle ventilators.

[7] Partitions clearly interfere with air flow, so it is of no surprise that for Kwok and Grondzik (2007: 140) 'The ideal footprint is an elongated rectangle with no internal divisions.' Additionally, outlets, rather than inlets, should be placed in kitchen and bathroom areas to minimize the distribution of smell and water vapor (Goulding et al., 1994: 163). Likewise, heat sources should be placed near outlets (Kwok and Grondzik, 2007: 141), although this advice may be overlooked for radiators, which may advantageously pre-heat the building in cooler periods (Hausladen et al., 2005: 72).

Step 27: REFERENCES

[8] Night ventilation, also referred to as comfort cooling, is a summer cooling strategy that has been shown to reduce maximum daytime temperatures by 2-3°C (CIBSE, 2004: 4.2.5.2; Halliday, 2008: 270). As it is less dependant on air speed, the placement of inlets and outlets is less crucial than for comfort cooling. As Kwok and Grondzik (2007: 139) summarize: 'Air speed is critical to direct comfort cooling; airflow rate is critical to structural cooling' and should therefore be located to maximize contact with thermally massive surfaces. Additional conditions are set out by Hausladen et al. (2005: 159): at a 15°C drop of outdoor temperatures at night, ceilings must be of concrete and not suspended, ventialton openings should be large, etc. Night ventilation is discussed in more detail in ASHRAE (2003: 1), CIBSE (2004: 4.2.5.2), Hausladen (2005: 159), Yeang (2006: 226) and Kwok and Grondzik (2007: 157-158). Advantages and disadvantages are also discussed in ASHRAE (2003). It also requires the use of materials with a thermal lag exposed to the airflow, as it dissipates the heat stored in the materials during the day (Santamouris and Asimakopoulos, 1996: 266; Kwok and Grondzik, 2007: 158), and as discussed in Step 15 and Step 16. The simplest form is ventilation through a window, but more complex, mixed-mode systems have been developed, and may need be applied when outside conditions prevent natural ventilation (Santamouris and Asimakopoulos, 1996: 266; CIBSE, 2004: 4.2.5.2; Lechner, 2009: 283; Gonçalves, 2010: 192). If windows are used, an openable window area of 10-15% of the floor area has been suggested by Lechner (2009: 283). Special attention needs to be made on spatial arrangement to ensure sufficient airflow (Kwok and Grondzik, 2007: 157). Although cross-ventilation is beneficial, stack ventilation is encouraged as wind speeds at night are at times low during the summer (Kwok and Grondzik, 2007: 157). Clearly, the comfort cooling recommendation in Note 5 should be avoided at night as nighttime temperatures are often outside the comfort range.

[9] Adjacent apartments, or rooms without permeable partitions, would usually require a pressurized bypass route between two windward routes, but its inclusion would fall outside of an entirely passive approach. As a leeward apartment is affected by the availability and quality of a windward apartment, the leeward apartment would perhaps benefit more from single-sided ventilation if the angle of wind is oblique on an adjacent wall. An alternative is to use an atrium, if existent, as a source of airflow, but again there are difficulties with this approach. Atria are discussed in Step 28.

[10] The 1.7°C temperature difference minimum is discussed in Kwok and Grondzik (2007: 139). Directing airflow 'across the occupants,' so that they experience high air speeds, is recommended when outdoor temperatures are high (Kwok and Grondzik, 2007: 140). Perhaps the greatest challenge of cross-ventilation is high humidity, which compromises comfort (Kwok and Grondzik, 2007: 141).

[11] As Kwok and Grondzik (2007: 139) state, 'Buildings are typically best naturally ventilated when they are very open to the breezes yet shaded from direct solar radiation.' However, this assumes that shading devices do not interfere much, if any amount, with airflow. There may be some turbulence in high wind conditions.

[12] Watson and Labs (1983: 193) point out that louvers' influence on air flow patterns can be used to control the air-stream path; for example, a row of louvers can be placed under a band of windows, across the length of the interior walls, to ensure uniform ventilation. Evans (1980: 129) also proposes similar solutions.

Fabric: Airflow (Increase)

Step 28

Stack Ventilation

Season:
Autumn
Winter
Spring
Summer

DESIGN FOR STACK VENTILATION

Stack ventilation can provide ventilation in apartments and common areas [1].

Notes:

- Stack ventilation is independent of orientation, and relies on temperature differences and stack heights. Nonetheless, wind pressure must be not be considered in isolation, and can enhance the effect [2].
- Both inlets, at lower levels, and outlets, at higher ones, should be large and roughly equal in size [3].
- Partitions, when unavoidable, should be minimized and include openings for air flow [4].
- Double facades use stack effect, but require depths greater than 250 mm and require further testing [5].
- Atria benefit from stack ventilation, but dimensioning and partitioning needs to be tested thoroughly [6].
- Stack ventilation is often applied to ventilate or remove heat, but it can also serve as a night strategy [7].

Limitations:

Stack ventilation is not a form of comfort ventilation [8]. Partitioning may be detrimental [9]. Average indoor temperature must be 1.7°C higher than that outside. [10]. Shading devices affect performance [11]. Certain conditions may prohibit the use of natural ventilation, so a mixed-mode strategy may required [12].

Links:

2, O2; 3; 6; 9; 10; 11; 12; 13; 15; 16; 17, O1; 17, O2; 17, O3; 18; 19, O1; 19, O2; 20; 23; 26, O2; 27; 29

_ YES, END
_ NO, GO TO STEP 29

Step 28: REFERENCES

[1] Yeang (2006: 216) defines stack ventilation as ‘a system of natural (non-mechanical) ventilation that employs vertical ‘stack’ ducts that allow internal air to be expelled from the built system by the motive forces that create pressure differentials’. CIBSE (2004: 4.2.5.2) lists ducks, shafts, solar chimneys and atria, which also act as heat buffers, as elements that can be used to ‘create a column of air at higher temperature thus generating pressure differences that give rise to the stack effect’. It usually occurs in places such as elevators, shafts and stairwells (Santamouris and Asimakopoulos, 1996: 226-7), but as these are likely to need mechanical pressurizing due to fire safety concerns, this step focuses on inhabited spaces instead.

It should be noted that cross-ventilation airflow also includes stack effect alongside wind pressure, but as those openings are designed primarily around maximizing wind pressure, are not further discussed here. Instead, the two most likely buoyancy-driven skyscraper elements, atria and double facades, are examined. It would be expected, upon further input, that these two would form separate, non-exclusive options, so at the moment this is a very broad introduction. It is envisioned that this step, furthermore, will become separated into two options, exposed and integrated stack ventilation, the former to include sunspaces and double facades and the latter to include atria. This separation, as highlighted by Kwok and Grondzik (2007: 146), is mainly based on the availability of solar access.

Like other forms of ventilation, the position and size of the inlets and outlets, as well as the overall geometry, needs to be tested through wind tunnel testing of CFD analysis (Awbi in Gallo et al., 1998: 175-176). Needless to add, the effects of pollution and noise also need to be assessed quantitatively.

[2] The average temperature difference between the indoors and outdoors is discussed in Lechner (2009: 271). Solar gain can increase the temperature difference, so rooms such as sunspaces may be of most benefit. Although wind pressure is secondary for this strategy, it needs to be assessed. As Abwi (cited Gallo et al., 1998: 175-6) points out, poor positioning of the inlet and outlet could reduce or reverse the stack effect, as is the case when air is forces through the outlet. CFD analysis and wind tunnel tests are advised to prevent this being the case. Furthermore, as Evans (1980: 126) discusses, to enhance cooling, inlets should be placed on the windward sides of the building. In any case, it is not advisable to place outlets in a windward direction (Kwok and Grondzik, 2007: 145). Stack heights would need to be modelled, bearing in mind that greater air movement is provided at lower levels of a stack (Kwok and Grondzik, 2007: 146). Specific requirements for atria and double facades are discussed in Notes 5 and 6.

[3] The general guideline of designing openings as large as possible and placing them apart vertically is mentioned in Lechner (2009: 271).

[4] It should be noted that due to the vertical nature of airflow encouraged by the stack effect, special attention needs to be paid to obstructions in this dimension (Lechner, 2009: 271). Partitions are also discussed in Watson and Labs (1983: 143).

Step 28: REFERENCES

[5] The inclusion of a double facade as a passive strategy, first and foremost, needs to be clarified. There is no consistency between sources as to whether a double skin is passive, with Yeang (2006) classifying it ‘mixed mode’, but it should be borne in mind that Yeang disqualifies the use of any fans as part of a passive strategy, whereas other sources do not. Nonetheless, most sources classify the double skin as a form of ‘natural ventilation’, implying that it can be entirely passive, although mixed-mode options exist. The framework here will focus on more passive options, with the admission of this lack of clarity in definition and with the recognition that mixed-mode solutions may be most suitable for particular conditions or floors above 300 m, as discussed in Step 12, Note 1.

It should also be noted that this step does not attempt to provide a thorough discussion on double facades, due to a combination of extensive modelling requirements, varieties of systems and the variation of their application at different heights. Some of these combinations and their resulting complications are discussed in a paper by Shameri et al. (2011: 1471) as part of a thorough literature review, as well as more in-depth texts. What this note instead provides is some basic guidelines to double facade use, adapting the general guidance of this step, which can be expanded upon by other sources and professionals. There is a great deal of research available on double facade systems, and increasingly tall building double facades, but it overwhelmingly relates to office buildings. Even so, there is much debate over the environmental performance of double facades, with many of the arguments relating to the inherent problems of high levels of glazing they imply. Boake (no date) discusses the arguments on both sides, adding that reliable, independent statistics ‘upon which to base *any* comparisons’ are difficult to find. Gonçalves (2010: 179) adds a further complication, as ‘the façade is expected to perform differently under various climatic conditions, from building to building, and even at different orientations of the same building.’ The suggestions offered here therefore should be adopted with much caution.

In general terms, worth noting are the advantages and disadvantages of double facades, prior to their adoption. Among the advantages listed are: extended conditions for natural ventilation, reduction of high-wind pressures and removal of access heat or its capture for space heating (Brown and DeKay, 2001: 271; Hausladen et al., 2005: 53; Yeang, 2006: 231; Gonçalves, 2010: 179; Shameri et al., 2011: 1469; Boake, no date). Disadvantages include: negation of air buffer benefits if cold external air introduced, a need for monitoring of wind speeds, strong oscillations of blinds during wind speeds of 30 m/s, a possibility of greenhouse effect on calm days in winter and a possibility of heat trap on calm days in summer (Yeang, 2006: 231; Shameri et al., 2011: 1469, Boake, no date). A key limitation is the required depth of the system. The depth of the airspace between the glass layers should be more than 250-300 mm, according to Yeang (2006: 231), or between 200-1400 mm, according to Hausladen et al. (2005: 53), although Lechner (2009: 284) reduces this measurement to 150 mm and Kwok and Grondzik (2007: 45) refer vaguely to ‘millimeters’ if opereable access exists into each facade unit. If large enough, the double facade can serve as an ‘external’ atrium, as defined in Note 6. Double facades do not need to make up an entire facade, and can alternate with other systems.

Step 28: REFERENCES

A large variety of double skin systems exists, making it difficult to propose not only any ‘rules of thumb’ but also a definitive classification system. Boake (no date) reviews a number of them, beginning with that of Battle McCarthy. This consists of five categorizations, namely of: sealed inner skins, openable inner and outer skins, opeanable inner skins with a mechanically ventilated cavity, sealed cavities and acoustic barriers. These are subdivided further. In contrast, Warner Lang and Thomas Herzog propose three types of general systems: buffer system, extract air system and twin face system. Boake (no date) also refers to a 2001 discussion on the Society of Building Science Educators listserve that suggests the latter system is the preferred one, although an additional, ‘hybrid system’, category would be beneficial. The existing types are further subdivided. Worth noting, however, is that these categories include systems that preclude natural ventilation, which would make them outside the scope of this framework. Kwok and Grondzik (2007: 44-46) offer their own three-part categorization, which focuses on the placement of the external skin in relation to the building structure; they also discuss the differences between typical European and North American approaches. Hausladen et al. (2005: 54-57) list specific types of double facades, namely box window facades, corridor facades, unsegmented double-skin facades and controllable double-skin facades. Eventually, the framework could be expanded to allow for passive categories, but the difficulties of categorizing them are apparent.

Inlets and outlets, as with all stack effect systems, need to be designed and tested individually for each building. They can be designed either as vents/grilles or as windows, openable internally, externally or both (Gonçalves, 2010: 179). Windows at higher levels may be openable only internally. Vents and grilles are discussed more in Boake (no date). A size of at least 150 mm can be expected for an external vent (Yeang, 2006: 231). As with other passive systems, outlets are placed above inlets. In any case, their quantities and their relationship to the indoor space is determined by the system category (Kwok and Grondzik, 2007: 45). Wind pressure also demands particular attention (Shameri et al., 2011: 1473), more so than in other stack effect systems.

The vertical partitioning of double skin facades ranges from single-story, applied to avoid cross-contamination and overheating, to those three to five stories height, which are found to increase efficiency (Gonçalves, 2010: 184). Some sources limit the range to 2 or 3 floors (Brown and DeKay, 2001: 271). Any higher than this increase the risks of overheating (Gonçalves, 2010: 184). Kwok and and Grondzik (2007: 45) separate the two types respectively into ‘corridor facades’ and ‘multistory facades’. Boake (no date) examines partitioning further, dividing his discussion into the undivided air space, divided by floor and divided vertically into bays. Gonçalves (2010: 179) further mentions isolation ‘by room’.

As overheating in hot periods is a major concern, louvers within the cavity are a key feature of many double facades and discussed in Step 17. Option 1. Louvers can also be placed externally, which would make them more efficient, or internally, making them less so. Gonçalves (2010: 184) also mentions a solution where the outer double skin is designed as a set of openable louvers. The effect of wind pressure and the stack effect on all types of louvres needs to be considered and modelled.

Step 28: REFERENCES

Systems related to the double facade include active and interactive walls, and these are thought to be more advantageous due to their compact depths (Yeang 2006: 232). A heat recovery system on the top floors is also beneficial and found in more recent towers (Gonçalves, 2010: 179). However, they require additional heating and/or fans, which bring them outside the scope of passive devices. Similarly, there exists some research into the integration of PV panels, summarized in Shameri et al. (2011: 1472), which are noted in Appendix X. Double facades can be used for night ventilation, which is discussed in Note 7.

[6] Abwi (cited in Gallo et al., 1998: 176) points out that stack ventilation is most convenient in the atrium as the existing solar gain, and hence a raised temperature, enhances the stack flow; furthermore, the atrium acts as a buffer zone that reduces heat losses in winter. The benefits of stack ventilation in atria are discussed further in Yeang (2006: 212-214).

As a complex topic that requires additional examination and testing prior to inclusion, this note will merely outline the basic issues. Worth noting is the fact that although many studies relating to atria exist, very few focus on residential or tall buildings; this problem has noted and discussed well in a paper by Kotani et al. (2003: 284). Many of the general notes for stack ventilation are here adapted. The definition of atrium adopted here is that of Baker et al. (1993: sec. 5.11): ‘An atrium is a space enclosed laterally by the walls of a building and covered with transparent or translucent material.’ This arrangement clearly assumes that the atrium is internal, or integrated; an ‘external’ atrium, where the atrium is placed in the perimeter of a building, is for the purposes of the framework classified as either a sunspace, or a deep double skin, and discussed in Notes 2 and 5.

Still dependent on temperature differences, exhaust air now travels through the atrium before leaving the building (Hausladen et al., 2005: 64). The result of the opening locations discussed here is a pre-heating of a common space, beneficial in colder periods but with risks of overheating at other times (Goulding et al., 1994: 138-139, 142; CIBSE, 2004: 4.2.1.2; Hausladen et al., 2005: 101). Shading or overshadowing is therefore necessary, as are high levels of ventilation in summer (CIBSE, 2004: 4.2.1.2); these are discussed further in Step 17. Additionally, with sufficiently sized ventilation flaps and perhaps underfloor heating, atria can be designed to provide cooling in the summer (Hausladen et al., 2005: 103), although this approach appears to be less common. In summer, however, the stack effect may not be effective, as it depends on a warmer indoor temperature than that of outdoors, which could already be too high (Goulding et al., 1994: 142).

A tall stack height is still required, but atria need to be separated vertically in tall buildings, due to wind pressures in inlets and outlets (Gonçalves, 2010: 208). Although these separations normally occupy the full height of the building (Baker et al., 1993: sec. 5.11), their dimensioning is varied and is most likely determined by lighting restrictions, as outlined in Step 7.

The low-level inlets and high-level outlets are to placed within the facade and outer part/ top of the atrium, respectively (Hausladen et al., 2005: 64). Halliday (2008: 260) gives a ‘rule of thumb’ for the exhaust atrium’s location as 3 m above the heads of standing people, but as most atria in tall buildings are multi-story in height, this advice requires further testing. Their sizing, as well any effects of partitioning, requires modelling.

Step 28: REFERENCES

[7] Night ventilation, also referred to as comfort cooling, is a summer cooling strategy that has been shown to reduce maximum daytime temperatures by 2-3°C (CIBSE, 2004: 4.2.5.2; Halliday, 2008: 270). As it is less dependant on air speed, the placement of inlets and outlets is less crucial than for comfort cooling. Kwok and Grondzik (2007: 139) summarize: 'Air speed is critical to direct comfort cooling; airflow rate is critical to structural cooling' and should therefore be located to maximize contact with thermally massive surfaces. Additional conditions are set out by Hausladen et al. et al. (2005: 159): a 15 °C drop of outside temperatures at night, ceilings must be of concrete and not suspended, ventialton openings should be large, etc. Night ventilation is discussed in more detail in ASHRAE (2003: 1), CIBSE (2004: 4.2.5.2), Hausladen (2005: 159) Yeang (2006: 226) and Kwok and Grondzik (2007: 157-158). Advantages and disadvantages are also discussed in ASHRAE (2003). It also requires the use of materials with a thermal lag exposed to the airflow, as it dissipates the heat stored in the materials during the day (Santamouris and Asimakopoulos, 1996: 266; Kwok and Grondzik, 2007: 158), and as discussed in Step 16. The simplest form is ventilation through a window, but more complex, mixed-mode systems have been developed, and may need be applied when outside conditions prevent natural ventilation (Santamouris and Asimakopoulos, 1996: 266; CIBSE, 2004: 4.2.5.2; Lechner, 2009: 283; Gonçalves, 2010: 192). If windows are used, an openable window area of 10-15% of the floor area has been suggested by Lechner (2009: 283). Special attention needs to be made on building space arrangement to ensure sufficient airflow (Kwok and Grondzik, 2007: 157). Although cross-ventilation is beneficial, stack ventilation is encouraged as wind speeds at night are at times low during summer nights (Kwok and Grondzik, 2007: 157).

Double facades can be used for night ventilation, and Lechner (2009: 284) indeed argues that they allow fore more control than windows as 'they prevent the entry of rain, control noise, and prevent excessively high airspeeds even on the fiftieth floor on a windy day.'

[8] Abwi (cited in Gallo et al., 1998: 175) argues for the superiority of stack ventilation in increasing air rates: 'Buildings which require ventilation rates greater than those achievable using either single-sided or cross ventilation may be ventilated using stacks.' However, it acts poorly as a form of comfort ventilation, so can be combined with either cross-ventilation or single-sided ventilation. [8] However, it can be combined with cross-ventilation if comfort cooling is required.

[9] As with other types of ventilation, room partitioning needs to ensure that airflow is not blocked. Additionally, stack ventilation is affected by vertical partitioning of spaces, as discussed in Note 4.

[10] The specific minimum temperature difference is based on Kwok and Grondzik (2007: 145)

[11] There may be some turbulence in high wind conditions that requires further modelling.

[12] The application of stack ventilation usually requires some form of mechanical pressurization of corridor space, alongside horizontal air barriers to dampen excessive stack effect (Yeang, 2006: 217). Extract fans can also enhance the stack effect (Halliday, 2008: 258). In atria, when natural ventilation is not feasible, a number of mixed-mode and full-mode options exist, and are discussed in Hausladen et al. (2005: 64-65).

Season:
Autumn
Winter
Spring
Summer

DESIGN FOR SINGLE-SIDED VENTILATION

Apartments with adjustable openings on a single facade provide comfort ventilation [1].

Notes:

- Openings should be placed obliquely or perpendicularly to the wind, on the windward facades [2].
- For best results, a pair of openings, rather than a single one, should be placed far apart [3].
- Partitions, where unavoidable, are to be placed near the outlet and upwind rooms to are be larger [4].
- The opening size is to be at least 1/20 of the floor area and a horizontal type is more efficient [5].
- For cooling, openings should be 70-120 cm from the floor in living rooms and 50-80 cm in bedrooms [6].
- Wing walls on one side of the openings and overhangs can enhance airflow [7].
- Single-sided ventilation is applied as comfort ventilation and is not effective as night ventilation [8].

Links:

2, O2; 3; 5; 6; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17, O1; 17, O2; 17, O3; 18; 23; 26, O2; 27; 28

Limitations:

Single-sided ventilation should only be used when ventilation is limited to one facade [9]. Draughts should be minimized [10]. Outside temperature needs to be considered [11]. Shading devices affect performance [12]. Certain conditions may prohibit the use of natural ventilation, so a mixed-mode strategy may required [13].

_ YES, END
_ NO, END

Step 29: REFERENCES

[1] Single-sided ventilation is recommended as a form of comfort ventilation after other types are exhausted. As CIBSE (2004: 4.2.5.2) summarizes, in single-sided ventilation ‘Exchange of air takes place by wind turbulence, by outward openings interacting with the local external air streams and by stack effects driven by temperature difference.’

Yeang (2006: 215) recommends adjustable or closing devices as they ‘assist in channeling the airflow in the required direction to match changes in wind direction’. Hausladen et al. (2005: 48) adds that ‘conventional tilt-and-turn fittings’ are not sufficient for ventilation throughout the year, so devices such as box windows can be used in conjunction. Therefore, although adjustable openings are recommended in any case, particularly due to the seasonal variations in the temperate climate and the effects of wind on the tall building’s height, further testing and resulting design guidance is required for determining the specific opening type.

Manual or automatic controls can be specified, noting that the advantage of the former is improved occupant satisfaction, while better energy performance in mixed-mode buildings results from the latter (Gonçalves, 2010: 191).

It should be noted that there are a number of advocates for a more mechanical approach to ventilation; they include Hausladen et al. (2005: 48, 134), who argues window ventilation prohibits heat recovery and is detrimental where high outside temperatures exist, and so should only be used if a low rate of air change is required. Nonetheless, it is assumed that natural ventilation is achievable for up to 300 meters (Gonçalves, 2010: 193).

[2] Givoni (1976: 289) emphasizes that indoor pressure rises to equal the external pressure if placed on windward sides and that it falls on leeward sides. He also explains that despite the general belief that inlet windows are most beneficial when facing the wind, in some cases an oblique angle is better, ‘particularly when good ventilation conditions are required in the whole area of a room’. ‘On the other hand,’ he adds, ‘if the two windows are located in adjacent walls, better ventilation is obtained with the wind perpendicular to the inlet window than when it is oblique, following the inlet-outlet direction’ (Givoni, 1976: 289-290).The wind direction is determined much by the orientation and configuration for airflow, discussed in Step 3 and Step 9 respectively, so this advice relates to individual openings. There is a general acceptance for this rule for both single and paired openings, with or without projections (Givoni, 1976: 297). Givoni (1976: 298) notes that projections and the inclusion of two windows had ‘almost no effect’ when placed in a leeward position. Projections are further discussed in Note 7.

[3] Givoni (1976: 295-298) emphasizes that single-sided ventilation usually provides poor airflow. He compares the indoor air velocity of a single central window, at about 4% of the outdoor free wind speed for a smaller type and 10% for a larger type, and that of a pair of windows: the latter has more than double the wind velocity. Santamouris and Asimakopoulos (1996: 223) agree with this assessment. To increase wind pressure, single openings can also be placed off-center (Lechner, 2009: 272).

Step 29: REFERENCES

[4] This advice is applicable only if the rooms have an open interconnection; the airstream will undoubtedly be affected, often negatively. ‘On the other hand,’ as Givoni (1976: 301) points out, ‘a greater total area of the apartment may be ventilated by the main stream, making the distribution of air velocities more uniform.’ He is also the source for the recommendation on partition placement and room size.

[5] Awbi (cited in Gallo et al., 1998: 174) and CIBSE (2004: 4.2.4.1), referring to Building Regulations Approved Document F, give the opening ratio, but this should be carefully reviewed as it is based on non-residential buildings. Furthermore, Givoni (1976: 291) adds that window size is greatly dependent on the type of ventilation, so that in rooms with windows on one wall ‘the size of the window will have little effect on the internal air velocity.’ Brown and DeKay (2001: 242) also cite Givoni (1976) and Melagarno (1982) in providing guidelines for air velocity averages, which may require further adjustment for building height. Trickle ventilators require much less area, at 500 mm2 per m2 of floor area with a minimum provision of 4000 mm2 per room (CIBSE 2004: 4.2.5.2). A further special case is communal areas, in which case Yeang (2006: 215) recommends 4 m2 openings for lift lobbies and 2 m2 ones for staircases, both at 6 air changes per hour. Particular to buildings at over 300 m, where window openings may not be possible, recessed windows with other ways of adjusting airflow and controlling wind-swept rain may be required (Yeang, 2006: 215).

Chand (cited in Goulding et al., 1994: 100) argues that ‘horizontal formats are more efficient in stimulating internal air velocities’ in buildings with single-sided ventilation. There is much discussion on generic window types in various sources (Givoni, 1976: 300; Watson and Labs, 1983: 193), but as tall building facades are often unconventional, they are not discussed here.

[6] This recommendation is based on Givoni (1976: 280). Lechner (2009: 274) gives a lower range, at 30-60 cm, for all rooms requiring sitting or reclining, whereas Yeang (2006: 217) offers a more basic suggestion of within 2 m when day cooling is required, and above 2 m for night cooling and winter ventilation. This is opposed to the office requirements at 120-150 cm above the floor, due to a possible disturbance at desk level (Givoni, 1976: 280); this guidance can be applied to areas where desk work takes place, such as studies. CIBSE (2004: 4.2.5.2) recommends that trickle ventilators typically be placed 1.75 m above floor level.

[7] Overhangs are beneficial for comfort cooling only if placed at ceiling height, rather than directly above the window opening, as the latter pushes the air flow above the living zone (Olgyay, 1963: 110). Lechner (2009: 273) supports this statement, and also add that a louvered overhang or gap of 15 cm or more in the overhang can affect the airflow, at times more beneficially. The effect of the overhang, if not in a beneficial location, can be negated by placing a sufficiently-sized gap between the structure and projection (Watson and Labs, 1983: 195). Balconies would technically fall under the category of projections, but Olgyay (1963: 110) found that they were less effective than other projections.

Step 29: REFERENCES

Givoni (1976: 296-299) Santamouris and Asimakopoulos (1996: 223) and (Brown and DeKay, 2001: 183-184) recommend wing walls for further improving ventilation, although Yeang (2006: 216) does so most in the context of tall buildings. Givoni (1976: 298) points out that two windows with vertical projections can have an indoor velocity much like that of cross-ventilation, especially with oblique wind. The recommended depth of the wing wall is to be at least 0.5 to 1 times the opening width, and the spacing between wing walls is to be at least 2 times the opening width (Brown and DeKay, 2001: 184). Santamouris and Asimakopoulos (1996: 224) agree with these opening widths, stating that the latter is 'optimum'. Givoni (1976: 230) states that 'it is possible to induce cross-ventilation in rooms with only a single exterior wall, to which the wind is oblique at an angle of up to 60°, by providing each of the windows in that wall with a vertical projection', but in the context of this framework, 'cross-ventilation' here is replaced by 'single-sided double opening ventilation'; in any case, wing walls are suitable for both types of single-sided openings. The angle referred to by Givoni is not universally accepted, as a wider range, from 20° to 160° is stated as effective by Santamouris and Asimakopoulos (1996: 223) and Evans (1980: 63) recommends at least 30°. Projections on both sides of a window destroy the effect, so only should be placed on one side. Furthermore, care has to be taken that they do not interfere with the ventilation of adjacent rooms, requiring, as Givoni (1976: 299) states, 'no more than one-half the distance between the projection of the outlet window of the first room and the beginning of the inlet of the second room'. They will also not work on leeward sides of a building, but may provide some airflow through increased pressure when placed on an opening that is parallel to the wind flow and on its downward side. (Brown and DeKay, 2001: 183-184, 195).

[8] As night ventilation, it may require additional mechanical equipment and significantly larger openings.

[9] This restriction is highlighted by CIBSE (2004: 4.2.5.2), who recommends it when building form or location are limiting factors.

[10] This limitation is pointed out by CIBSE (2004: 4.2.5.2). Additionally, as Awbi (cited in Gallo et al., 1998: 174) points out, in single large windows, cooler air enters the lower part and warm air leaves the top, affecting uniformity; this can also be interpreted as a further complication for comfort.

[11] A 5°C to 24°C outside air temperature is suitable for comfort ventilation; anything above or below this requires some form of adjustment, often by mechanical means (Hausladen et al., 2005: 48). In more general terms, the cooler the outdoor air temperature, the more effective the comfort ventilation (Lechner, 2009: 282). Hausladen et al. (2005: 48) lists possibilities for adjustment, including, in winter, the mixing of supply air with existing room air, the placement of radiators near the facade and air preheating; in summer, the situation is more complicated, and ventilation should be limited. This increase in outdoor temperature in summer can also increase the air temperature in the boundary layer of the facade 5-10°C above the outdoor levels (Hausladen et al., 2005: 50), but it is interpreted that this result stipulates a closed facade. CIBSE (2004: 4.2.5.2) also discusses the application of trickle ventilation during winter as a way to provide minimum fresh air intake without leading to energy loss. In case of higher humidity, however, the air rate should be increased (Goulding et al., 1994: 102).

Step 29: REFERENCES

[12] Watson and Labs (1983: 193) point out that louvers' influence on air flow patterns can be used to control the air-stream path, for example, by placing a row of louvers under a band of windows across the length of the interior walls to ensure uniform ventilation. Evans (1980: 129) also proposes similar solutions.

[13] Gonçalves (2010: 192) provides a guideline, albeit for justifying mixed-mode over full-mode: 'As a reference, in the European context, practice indicates a figure of 30 per cent of yearly occupational hours of natural ventilation in order to economically justify the introduction of the mixed-mode strategy.' Mixed-mode, or full-mode for that matter, should not be adapted too eagerly in tall buildings, as is usually the case, for as Gonçalves (2010: 193) also points out, 'On calm days, even in buildings that are 300m high or more, windows can still be opened.' Hausladen et al (2005: 62) provides further information on mixed-mode ventilation. A type of mixed-mode system often mentioned by Yeang (2006), fans are also recommended by Lechner (2009: 281) when sufficient wind is present. Further information on 'supply air ventilation windows', related to multi-layer facades, can be found in Brown and DeKay (2001: 254).

APPPENDICES

Appendix A: Stage 1

Birmingham test tower notes

Yeang and Birmingham tower aesthetics

S	Input		Des. Element			Link	Notes
1	O	IN	Thermal Radiation	I	Build orientation	O: Air (I)	How does placing a glass walkway interfere with solar gain?
b	O	IN	Thermal Radiation	I	Primary Mass Location		Solar gain most beneficial early morning- how does this translate architecturally? No mention of floor depth, floor height, placement of rooms Section deals only with plans, unless building Image missing for shadow step
2	O	IN	Airflow	I	Build orientation	F: Air (I)	Solar gain higher priority than ventilation If wind wanted, wide, if not? If no solar gain, best choice to start
3	C	IN	Visible Radiation	I	Floorplate depth	C: Air (I)	
b	C	IN	Visible Radiation	I	Floorplate depth	C: Air (I)	How does this translate into residential room sizes and placement? Suggestions for apartment types Floorplate layout to determine floor height?
4	C	IN	Thermal Radiation	I	Built form ratio		What happens if ratio bigger? What happens if ratio smaller? Heating and cooling over ventilation
5	C	IN	Airflow	I	Vent- floor depth	F: Vis Rad (I)	When to consider use of atrium
b	C	IN	Airflow	I	Vent- zones		At what levels zone change (at what height)?
c	C	IN	Airflow	I	Vent- ground floors		At what wind speeds should ground floor be closed from outside?
6	C	IN	Airflow	D	Primary mass	C: Air (I)	Add information on why not completely solid cores? No sunlight blocking No blocking airflow in summer
						pg. 12 Air (I)	First N place, if not (ex.blocks out daylight) then E-W
7	F	IN	Visible Radiation	I	Glass-clear	F: Th Rad (I)	Tinted glass chart
b	F	IN	Visible Radiation	I	Glass- glare		Chart with glare relationship What is the limit on non-residential building in terms of room depth More information on reducing glare

							Not a biocliamtic, but occupant and comfort safety- perhaps doesn't belong in the framework (ex. fire safety)
c	F	IN	Visible Radiation	I	P. daylight		Light pipe- better distribution
						F: Th Rad (D)	Light shelf- better distibution?
							Definition of low sun path
							More info on passive daylight devices
8	F	IN	Thermal Radiation	I	Glass - location	F: Vis Rad (I)	Missing daylight chart- window size/daylight depth
						F: Air (I)	Consider passive solar devices
b	F	IN	Thermal Radiation	I	Glass- clear	F: Vis Rad (I)	
						F: Th Rad (D)	
c	F	IN	Thermal Radiation	I	Glass- glazing		
d	F	IN	Thermal Radiation	I	Glass - façade systems		More related to ventilation than solar gain- move category?
e	F	IN	Thermal Radiation	I	Wall - heat sinks		Chart of heat sink materials
							What are the properties of heat sink materials (definition)?
f	F	IN	Thermal Radiation	I	Wall - insulation		Chart for materials with high insulation levels
g	F	IN	Thermal Radiation	I	Wall - gl.		Glazed thermal wall systems image
							Definition of cloudy climate
							Is climate in UK too cloudy for glazed thermal walls?
							Can glazed thermal walls be used in skyscrapers? Any precedent?
9	F	IN	Thermal Radiation	D	Glass - clear	F: Th Rad (I)	Chart with glass types
						F: Th Rad (I)	Order of preference in chart
b	F	IN	Thermal Radiation	D	S. control device		Order of application (ex. zones, entrance)
							Full- height glazed thermal wall (provided it meets other criteria) possible for office, what about
							Types of intelligent angle control?
							Indoor and outdoor space glazing
					Fixed overhangs	F: Vis Rad (I)	Is this most effective for south façade or most effective overall?
							Is this the same as balcony?

							Can this be used for E & W façade?
							Missing chart with values and images
							Assumption: daylight won't change if open?
					Louvres	mid-pane,	Internal louvres = blinds?
						link with	Chart with values missing
						double façade	Mid-pane option possible only after consideration of natural ventilation
						color	Check options with daylight
						daylight	Chart with details
					Movement	F: Air (I)	When can fixed louvres be vertical?
						F: Air (D)	When organizing, make a + and - list regarding
							Chart missing with distance between blinds and dimensions, angles
							Can choice be broken down into zones, with each section with own choice of shading
						vegetation	Where does vegetation fit in?
							If no option- vegetation? (as vegetation is not as reliable?)
							At this point, designer can add additional balconies on non-solar facades
c	F	IN	Thermal Radiation	D	Opaque - color		Chart with colors and properties
							Comparison of color with vegetation
							High mass incorporation - more information & diagram
					Opaque - absorp.	material (eco)	When making charts, have preference gradients, highlights or ranks
d	F	IN	Thermal Radiation	D	Vegetation	veg (eco)	Organize - by location (façade, roof, ground), plant
							Missing better images / diagrams
							Restructure juxtaposition / intermixing / integrating
							Breathing wall- not passive?
							Images of and info about wall types- spiral, green, breathing
							Can vegetation override shading devices?
							Note on shading not interfering with plant growth

							All fabric deals with integration of vegetation in building façade (2D)- only S, W, E - N no effect from thermal radiation?
							Eco materials deal with horizontal integration?
							Fabric can be improved by vegetation, whereas interior vegetation more optional as it does not affect solar gain especially
e	F	IN	Thermal Radiation	D	Roof - insulation	vegetation	Mechanical equipment- not a p. solar choice? Also dissipates heat
							Is vegetation a valid category here as well?
					Roof - shade		
					Roof - colour		Missing chart with values
					Roof - absorption		Missing info
					Roof - vegetation	material (eco)	More info on permaculture
							Different types of vegetation- ex. trees, shrubs, etc.
							What is primary (preferred) - vegetation or colour?
10	F	IN	Airflow	I	Vent - ss-airpath	F: Air (D) cool	Already determined in elevation (configuration) zones?
							Diagram/ chart missing
					Vent - ss-geom	F: Air (D) cool	Relies on cross-ventilation?
							Windows/openings- diagram/chart of adjustable/closing devices to match changes in wind
						C: Air (D)	Needs a link with zoning in configuration (in relation to building height)
							Winter vs. summer
							Use 15-20% ratio of wall area to decide on window opening size
							Special case- recessed windows- link with zones
					Vent - cv -		
					Vent - cv -		Missing info on location of inlets and outlets
					Vent - sv - skycourt		What is a louvered roof - options?
							Information about movement of air at different levels- atrium vs. 3-stories, etc.

							Differences between external and internal temperatures needed for stack effect Where (at what wind speeds) are sliding screens needed as windbreaks
						C: Air (I) nat vent	Pg. 78 in Skyscraper Bioclimatically Reconsidered: skycourts are not "multi-storey recessed transitional space" switches position in Ecodesign?
						F: Th Rad (D)	Missing info on height, depth of skycourts Can skycourts be as balconies - do they need to be surrounded completely? Skcourts located in upper parts - at what level
					Vent - sv-cavity wall		More info needed - see pg. 216 diagram
					Vent - sv-double façade	F: Th Rad (D)	Missing diagram of system Pg. 231 for solar heat collectors diagram
					Vent - sv-triple façade	F: Th Rad (D)	Double vs. triple façade stats General information and diagrams missing
					Vent - sv-active wall		Missing image and diagram
					Vent - sv-interactive		Missing info and image
b	F	IN	Airflow	I	Cool - comfort vent		Best way to organize this section? What temperatures are required?
					Cool - wing walls		See pg. 212 Ecodesign Are wing walls fabric or configuration? What are the best wind conditions for their use? Fin size/ height/ depth -chart Placed perpendicular to wind?
					Cool - nocturnal vent cooling		During what seasons and what times can it be used? Diagram/ chart missing

					Cool - radiant cooling		Diagram/ chart missing
					Cool - direct evap cooling		During what seasons and what times can it be used? Diagram/ chart missing
					Cool - indirect evap cooling		During what seasons and what times can it be used? Diagram/ chart missing
					Cool - cooling outdoor space	vegetation (eco)	What techniques are available?
							Overall- need a decision for every façade Fit in information on window shape Areas within building can be broken down into sections· ex. apartment, hallway
11	F	IN	Airflow	D	Vent -wind speed		More info on recessed windows (diagram/chart) Sliding screens needed for openable windows as well? When? More info on materials for sliding screens Adjustable/closing devices for wind direction change- at what angle? Are not all these determined in airflow (I)? Is air (I) = warm, openings, air (D) = cold, Are adjustable/ opening devices able to be combined, or is it better to separate in case of one choice?
12	F	EX	Water		Rainwater - veg		More info Can rainwater be filtered? Where in process?
					Rainwater - landscape		Info missing: rainwater filtration systems, rainwater collector systems for (high-rise) buildings Add chart regarding porous surfaces
					Greywater - veg		More info on different systems (diagrams/charts) More info on systems using only plants (diagrams/charts)
					Groundwater - fixtures		Does the framework need to focus on these- are they more related to interiors? What are examples of low-flow plumbing fixtures (chart?)

					What is the difference between plumbing and appliances? Should plumbing fixtures and water-efficient appliances be combined? More info on M & E equipment Are not all these systems part of "system" category? - same for rainwater/ graywater Need to plan vegetation before most things? extra info- all systems? Is conservation = configuration or elements & system = recycling, the way they function?
13	F	EX	Materials	In - renew/recy	Note: potential for reuse and recycling given a greater priority at the level of 'embodied energy' value; not priority for low embodied energy values? Chart/diagrams
				In - potential	Is this the same as design for dematerialization? Chart/diagrams
				In - low e energy	See pg. 391 for explanation Chart/diagrams
				In - eco impact	What is the difference between low e energy? Reducing pollution includes both manufacture and disposal Place background info into charts/graphs
				In - biodegrade	Is this not the same as potential for reuse/recycling? Charts/graphs, diagrams
				In - local product	Diagrams Information or links to databases for materials (organic and renewable) in cool temperate climate
				In - low toxicity	Chart missing
				In - method install	Is this not the same as reuse/recycling & embodied energy? Incorporate material examples- reorganize into charts and diagrams

b	F	EX	Materials		An - general	F: water F: mat (in)	Ideally, what percentage of total area? 20%
					An - element		Surroundings/ context = land?
					Types		General strategy: indigenous and/or low-water use Maintenance issues? Missing info on plants found in temperate climate or links to sources/ sites/ organizations providing that information
14	F	EX	Land		Eco linkages		What is the definition of land? Can land be designed? How is this category separate from vegetation? More subcategories than eco linkages? Is vegetation on building = material; vegetation around building = land? Where is the boundary?
15	S	IN	Thermal Radiation	I	Active solar collectors		Where is the line between passive systems and systems if pumps, etc are used? Are all these really more passive systems as they rely on climate (sun & wind) most of all? Missing images for all
					Open loop	Water?	Is this more passive mode as well? Or do we group all passive systems as system? Is there a better name for this category ("system")?
16	S	IN	Thermal Radiation	D	Radiant Heat		Is this in passive mode as well?
17	S	IN	Airflow	I	Propeller fans Evaporative coolers Dehumidifiers		Are all these more passive systems?
					Displacement ventilation		Part of notes missing Missing notes / charts
18	S	EX	Water		Water evap		Part appears to belong to land section
19	S	EX	Materials		Desiccant cooling		Any impact of extraction/disposal of desiccant on environment? Can it be used in temperate climates?

						Pg. 235 for chart Unsure of what category this falls under - is this not more cooling? Or thermal radiation (D) (I?)- uses solar rays or cooling because air moved General notes become more specific in framework? Where do fuel cells go? Are they sustainable? Do they belong in the "materials" category? Missing diagram/ chart Where does full-mode, composite mode, etc. fit in Should framework deal only with elimination of the use of energy and not in energy efficiency? Where do building automated systems fit in?
20	R	IN	Visible Radiation	Photovoltaics	F: Vis Rad	Missing diagrams/charts
21	R	IN	Airflow	Wind generators	F: Air (I?)	Missing charts/diagrams
						Can be considered in orientation, but would need to look at all steps afterwards
22	R	EX	Water	Hydroelectric		Related to land?
						Missing charts/diagrams, more info
23	R	EX	Materials	Biomass		Missing charts, graphs
24	R	EX	Land	Geothermal		More info

Aesthetics overview

In *Ecodesign*, Yeang sets aside a section 'Other Considerations' a chapter entitled 'What is the green aesthetic?' The fact that the chapter is an 'other consideration' negates the idea that aesthetics is central to his design process, but its inclusion nonetheless recognizes its significance. This section will examine his relationship with aesthetics in order to compare it to the results obtained in the Birmingham test tower.

As mentioned in the literature review, Yeang considers the climate as the source of architectural expression. In the *Skyscraper, Bioclimatically Considered*, he states:

> As the location's most endemic factor, *climate* provides the designer with a legitimate starting point for architectural expression in the endeavour to design in relation to place, because climate is one of the dominant determinants of the local inhabitant's lifestyle and the landscape ecology (1996).

This statement furthermore applies to the architectural aesthetic as his tall buildings defiantly avoid the use of traditional form and materials. They instead focus on merging modernism with the local and regional climate requirements, most notably through the use of vegetation. The terms bioclimatic and ecological themselves present a visual description of Yeang's aesthetic, as both are much more specific in referring to an architecture related to nature and climate than the more generic terms sustainable and green.

In his consideration of the more general 'green aesthetic,' Yeang is quick to point out that it plays a secondary role to the building's environmental standards. In *Ecodesign* he writes: 'It is the benign environmental systemic integration between our built systems and the natural systems in nature that is ecologically the more important aspect of design, over its aesthetic aspirations' (2006: 415). This lesser significance of aesthetics nonetheless does not render it unimportant, as he recognizes that 'the work of ecodesigners might be valued as much for its aesthetic as for its environmental performance' (2006: 414). He does not promote aesthetics for its own sake, but instead due the effect it has on ecodesign's opportunity for acceptance as a mainstream method of design. There is a certain fear that drives his interest in aesthetics, the fear of past green designs' failures repeating themselves. He refers specifically to the 1970s efforts to harness solar energy, which he states 'failed because the built forms then were not beautiful and ultimately such endeavours did not function well and often many were not even cost-effective' (1996: 415). 'If we

ever needed great designers,' he continues, 'it is now as an environmentally based architecture needs to be widely aesthetically acceptable' (2006: 415). Therefore, while acknowledging that the green aesthetic does not determine the success of a design, he recognizes that a poor aesthetic ultimately leads to failure.

Yeang also acknowledges 'the aesthetics of ecodesign must also permit a multiplicity of interpretations and visions by individual designers' (2006: 414). He does not label any style or approach to green design as 'correct' or 'preferred,' but does show a dislike towards certain forms of architectural expression. Although influenced by the Metabolist architects and Archigram, he does not share the enthusiasm about technology that those groups, and especially the 'high-tech' architects of today, display. 'At present,' he writes in *Ecodesign*, 'there is a tendency to over-emphasize technological components, and current resultant purported green design appears remote from the image of nature' (2006: 414).

Perhaps the most well known architect in that group is Norman Foster, as his prominent 'high-tech' aesthetic is applied to his green skyscrapers – Commerzbank, Swiss Re, Hearst Tower. Antony Wood, in a paper entitled 'Sustainability: a new high-rise vernacular' compares the two approaches, stating that 'whereas Yeang has created a new aesthetic for the skyscraper, based on a material palette which encompasses verdant vegetation, Foster's aesthetic does not depart radically from the commonly accepted Western palette of steel and glass.' He uses the work of these two architects as symbols of debate of 'a possible future new high rise vernacular' and asks the question if the aesthetics of sustainable high-rises should be 'green' or 'grey' (2007: 405). Wood concedes that some high-tech towers, such as the Bahrain World Trade Centre, are worthy of acclaim, but then states:

> it seems that many of the environmental technologies in tall buildings exist at the 'applied' level—solar panels, water recycling, ground source heat pumps—which are applied to the standard, glass, air- conditioned box model with very few other 'concessions' to environmental considerations in the design. Worse, these technologies often only serve to overcome inadequacies in the design through the lack of holistic thinking in sustainability at the design concept stage—fundamental errors in building orientation, form, etc. (2007: 406).

This particular type of misuse of environmental technology is indeed what Yeang fears, as it is reminiscent of the failed attempts of 1970s environmental design. It can be argued that his search for a green aesthetic is an attempt to promote more holistic sustainable design, one that is beautiful, functional and cost-effective, rather than deride any particular style. In reality, Yeang does share much in common with the

high-tech group, particularly as both building types communicate their functions through architectural expression. What sets them apart visually then is their emphasis: vegetation for Yeang replaces technology.

Before considering what Yeang describes as his current aesthetic, one should also consider another group of architects he distinguishes himself from, the more formal architects, corresponding to Höweler's 'visual' category. These architects, like the high-tech group, also have a visual preference that is not based on ecology. However, because their focus is on the building's configuration and fabric, their design approach is more passive and closer to Ken Yeang's earlier bioclimatic skyscrapers. Despite Yeang's own promotion of such principles, he is quick to point out that such designs fall short of achieving ecological integration because of a visual bias. First describing his own process of design, Yeang states:

> The presence of organic matter on its [the building's] external areas, most likely on those aspects of the built form that will receive the most sun, will give the design a fuzzy or 'hairy' or densely vegetated organic aesthetic. Some ecologists contend that ecological quality tends to look aesthetically 'messy.' What is good for the landscape may not look good and what looks good may not be good. The distinction between function and appearance may distress idealists who regard presentation as dissembling, but it is intrinsic to the concept of design, in which each design is recognized as one of any number of possible designs for a particular place. (2006: 414).

While the visual architects Yeang writes of here are less concerned with the environment than with design aesthetic, Wood also identifies a group of architects that can be placed in a more benign formal category. He describes these as those who 'recognize the need for greater opacity in the skin of a tall building' and highlights as one the greatest advocates of this approach Ken Shuttleworth of Make Architects (2007: 408). His 2005 proposal for the Spiracle Tower is one such example, and this building's rounded form, visual lack of a glass facade and bands of opacity surprisingly recalls the work of one of Yeang's early high-rises, the Menara Mesiniaga. In fact, one can clearly see both the technological and formal influence on Yeang's building, but once again it is the inclusion of vegetation, rather than the bioclimatic strategies that sets it apart from Shuttleworth's.

Yeang's green aesthetic, therefore, separates itself from both technologically- and formally- driven architecture through its use of vegetation. He sees his design as the logical evolution of green design. 'While it appears that low-energy and ecological design strategies and solutions are applicable regardless of an individual designer's architectural style,' he writes, 'as ecodesign advances there may be strong ecological

determinants that influence building configuration, the range of materials used and the inevitable curbing of decorative excess' (2006: 415-6). This is also echoed in a later statement: 'The complete change in the value-systems inherent in an ecologically responsive and sustainable approach to design imposed by implementing ecodesign and planning principles will probably eventually generate a new ecological aesthetic by virtue of its own merits' (2006: 415-6). Noteworthy here as well is what Yeang does not state: he never claims that *his* aesthetic is *the* green aesthetic. Yeang throughout his written work referrers to his own search for a green aesthetic, but it is the most prominent visual feature of his towers – the vegetation – that he sees as critical in the future.

This is not to say that vegetation is his greatest environmental concern – building configuration, orientation and non-vegetated fabric comprise the most important factors in how his buildings function. His original skyscrapers were described as bioclimatic, and, although he has since then shifted to ecology, the design process still places significance on these bioclimatic principles. Nevertheless, Yeang highlights vegetation in aesthetics, a decision that has defined his design aesthetic. There are many factors that one can assume had an influence on his choice. For one, this fact helps Yeang to distinguish himself from the environmental architects of the 1970s with a radically different verdant imagery. The nature of the skyscraper, particularly on small urban sites, leaves less room for architectural expression in form, and to a lesser extent, fabric than is available for low- or medium-rise projects. It is the expression of the building as a part of nature that leads to his aesthetic preference. The vegetation inhabiting the inside and outside of the building, both the vertical and horizontal surfaces, in ecocells or ungrouped, reflects Yeang's pursuit of an architecture visually relating to site and climate. The building is expected to merge with the landscape, the designer 'regarding the landscape as an intrinsic part of the built form of infrastructure.' "Building as landscape, and landscape as building" he writes, restating that "the design's aesthetics should capture a true sense of connectedness and biointegration in nature' (2006: 415).

Hence, Yeang does not justify his use of vegetation as an aesthetic choice solely because of its ecological role. He recognizes the environmental benefits of the plants throughout his work, but he is aware that other options, such as louvers for preventing solar gain, may contribute to a building that is just as environmentally responsive as a one shaded by vegetation. To strengthen his case, Yeang also presents social and psychological arguments, such as 'the genetic tendency by

humans to respond positively to nature,' biophilia (2006: 149). Yet he is most concerned with the articulation of an ecological architecture in terms of the green aesthetic and sees vegetation as a logical choice in visually expressing his buildings' aims.

Other than vegetation, his towers share a modernist white skeleton and have a dislike of decorative detail. He sees this simplicity as the 'inevitable curbing of decorative excess' (2006: 416). However, it is in this simplicity that he is often criticized for, as it is sometimes difficult to distinguish visually between his European and Asian buildings. One would assume that towers in the temperate climate, for example, would be more enclosed than those in the tropics, but considering the catalogue of his work this is not as apparent as one would expect. The fact that they share a minimal white structure also does not help to give an impression of being rooted to one site, climate and culture. This impact is not ameliorated by the publicized images of his work, which do not relate to any specific orientation and visually fail to link any configuration choice, such as the inclusion of a wing wall, with local climatic conditions.

Furthermore, although he claims that 'decorative excess' is necessarily eliminated, the recurring characteristic of his towers, the vegetation, can be considered as such. His architecture, unlike that of classical modernist buildings, celebrates the use of greenery, and 'fuzziness' results to a point where it becomes more visually important than any other element in the façade. Combined with his statement that environmental towers can have a more mechanical appearance, his use of greenery demonstrates that its use is a preference, not a prerequisite, and thus can be considered a form of decoration. Seen in this light, Yeang's architecture is capable of having a significant contribution in the current revival of interest in ornamentation in architecture, particularly in defining a new form of functional and ecological alternatives to stylistic ornamental preferences.

Yeang's choice of vegetation can be scrutinized as well. Throughout his work, and particularly in his chapter on aesthetics in *Ecodesign*, Yeang alludes to the image of the rainforest as a model for ecodesign. He describes the 'mosaics within mosaics' of leaves and tress placed in an efficient manner, plants organized so there is minimum overlap (2006: 416). This image relates especially well to the vegetation of the tropical climate, and his buildings there in fact do convey that image well. However, the character of local vegetation in the temperate climate is not communicated as

effectively. This ties in and compounds Yeang's earlier problem with using white as the main color of his structures. One does not have any sense of a deciduous forest inhabiting his temperate skyscrapers but instead that the rainforest has been misplaced in them. More so, one could assume that a Yeang building in the hot, dry climate would also display such an aesthetic, despite a low distribution of vegetation, which takes away from Yeang's aim of creating a climate-specific architecture. Although difficult in the large scale of the skyscraper, the vegetations' origins need to be more convincing, through a more drastic choice of local plantings, particularly trees. The more extensive use of color, in both plant choice and building façade, could also place Yeang's towers in a more specific context. This would not only make the buildings more varied and climate-specific, but, with the use of local materials and colors, also less culturally indifferent.

Before considering the aesthetics of the Birmingham test tower, two other aesthetic approaches to green design should be considered as they relate to Ken Yeang's work. The first, biomorphic architecture, calls for buildings to resemble natural organisms. Yeang's environmental agenda does often state the importance of a building's function imitating a natural organism. He especially describes this in a chapter on ecomimicry, defining it as 'designing architectural ecosystems to emulate the properties, structure, functions and processes of ecosystems in nature' (2006: 45). One of his justifications for utilizing ecomimicry is that 'nature's 'designs' and 'technologies' are far superior to any of our human designs and technologies' (2006: 45). This sounds much like the reason Hugh Aldersey-Williams, in *Zoomorphic,* describes for the application of biomorphic architecture: 'as Aristotle observed, if there is a better answer to a problem, then nature has probably already found it' (2003: 31). Biomorphic architecture, like Yeang's, attempts to signal its commitment to the environment, but this time is more overt in resembling a natural organism, generally with a softer and organic form. Aldersey-Williams moreover writes about Yeang's towers, stating that they 'look novel in skyscraper terms but they are not especially biomorphic,' hence are not included in that category (2004: 21) .

The aesthetic of Yeang's buildings, then, falls between the biomorphic and a more practical approach that Wood describes as 'hybrid.' Such an approach 'use environmental technologies aesthetically in a more subtle way' or that is 'less preoccupied with developing irregular form than articulating the possibilities of skin.' He describes this approach as a combination of Yeang's and Foster's aesthetic and points to Oppenheim Architect's COR Tower for Miami. The building is described as

balancing opaqueness and transparency in the skin, incorporating environmental technologies in the form of wind turbines more subtly and, most notably, ‘departing not too radically from the standard orthogonal form and construction of the skyscraper’ (2007: 409). He sees this as an acceptable option for current tower design, particularly when considering the interests of those responsible for funding and constructing the building.

Birmingham test tower aesthetics

The Birmingham tower is also aesthetically like the ‘hybrid’ tower Wood describes. It is assumed to be an orthogonal building from the very beginning and is subtle in displaying its environmental technologies. However, this was a conscious choice, as the test tower was designed from a fairly neutral standpoint in terms of design and therefore meant to test what visual impact the framework with Yeang’s principles would have with minimal design input. Unlike Yeang’s towers, it does not introduce vegetation as a form of green aesthetic, but on those facades and places where it has an environmental function. Although the framework is of a hierarchical nature, with bioclimatic principles featuring more prominently than those of ecology or renewable power, the designer is free to place emphasis on others. There is a possibility that a building focusing on renewables might be of a high-tech style while an emphasis on vegetation would likely produce a tower similar to Yeang’s. However, as this research did not concentrate on green aesthetics, the resulting standard tower is not meant to be radically different from the more practical green towers and is therefore closest to resemblance to the ‘hybrid’ form.

This is not to say that this tower’s designer had no decisions to make in terms of design aesthetic. There are numerous options where there is more than one ‘correct’ sustainable solution, but the choice taken was usually the one most conventional. Furthermore, if there were two occurrences with the same options, for example the same options for two different facades, often a different choice was selected in order to utilize as many options as possible in the design of this tower. Nonetheless, there were experimental, rather than aesthetic decisions, so it is likely that the building could have had a different aesthetic if other options were chosen. There were also places in the design process where there was no available sustainable preference, for example in apartment floorplans, and once again a standard solution was applied.

Other than this research’s focus on the environmental aspect of sustainability, there

is also a more practical reason that aesthetics is left to the designer. As was not the case in the 1970s, there is today a more widespread acceptance of the need for a sustainable approach to design. Climate change is presumed a fact by governments and the public alike, and therefore the pressure from both groups is certain to make sustainable design a prerequisite to design in general. It is therefore believed that there is little risk of failure in green design today, although some interpretations of green architecture, as any stylistic decisions sometimes do, may fall out of favor.

Secondly, a point brought up by Aldersey-Williams relative to biomorphic architecture can be applied to the more general green aesthetic as well. 'It seems likely," he claims "that that this is a transitional stage, and when at last every new building does more to minimize its environmental impact, this signalling will become unnecessary' (2003: 21). Yeang himself proposes a similar statement in *Ecodesign*, when he states that:

> The complete change in the value-systems inherent in an ecologically responsive and sustainable approach to design imposed by implementing ecodesign and planning principles will probably eventually generate a new ecological aesthetic by virtue of its own merits (2006: 416).

He does however, propose an aesthetic based on the image of the rainforest, although he acknowledges there is more than one green aesthetic. To limit green design to one aesthetic would be unreasonable, and so the framework presented is created to be as aesthetically neutral as possible.

The Birmingham building does nonetheless have one factor that determines its aesthetic outcome. Like the work of the Metabolists, who claim to be the creators of the 'world's first Eco-Architecture' (Kurokawa, 2002: 11) and state that architecture should not be static but continuously capable of undergoing change, the framework is designed so that it is capable of adaptation as information and products evolve. As the Metabolists derive their sustainability criteria mainly from this recycling ability, Yeang relates well to that group, but his aesthetic is much less technologically driven. That group of architects, like Yeang, were also keen to compartmentalize the buildings into systems of parts, such as cores and frames. This framework is designed with such compartmentalization in mind, one dimension of the chart consisting of building elements that are further segmented into principles such as louvers and passive daylight devices. The framework, then, acts as a structure for organizing individual design options, and this translates into the aesthetics of the Birmingham building.

The test tower is organized into compartments, which become more detailed as the design process comes to an end. Thus, the building's form is first segmented into four segments, or orientations, which are furthermore segmented into zones for wind, down through window sizes and location of photovoltaic panels for individual apartments. However, this does not limit the aesthetics of the final building as there are various options at each level and many of the principles are linked with each other, affecting the choices available. The tower could have had a number of outcomes, but considering the organization of the framework, it is most likely to have a somewhat logical appearance. This is expected, as the source of the framework is linked with Yeang's seach for biomimicry. Organisms in nature, particularly plants, are visually specific because their orientation, materiality, etc, is linked with the local climate and they often have a repetitive, mathematical organization, such as the standardized placement of leaves on a stem. Yeang's principles are based on the same climatic concern, so it is logical that the framework rooted in those principles generates a tower with a structure with a more logical appearance than a more random, stylistic approach would produce. A less rational aesthetic is possible if that is the designer's imperative, but having an environmentally sustainable building does not necessarily result in a more organic, or for that matter biomorphic, design.

It is worth noting that Yeang's more recent buildings, such the Elephant and Castle Eco-towers, have a social agenda that also shapes their appearance. They are less orthogonal than others and have an aversion to what Yeang terms as the 'concrete tray in the air' approach to skysraper design (1996: 23). Therefore, his more recent structures are less symmetrical and more varied than his earlier works. The framework does not encompass social sustainability and so the Birmingham tower is more proportional and reminiscent of Yeang's earlier work. The relegated status of vegetation also makes the building's focus on envelope more reminiscent of Shuttleworth's building than Yeang's. The latter's abundance of greenery makes windows appear obsolete, whereas in the Birmingham tower, particularly on the north and east facades, their framing defines much of the façade's character.

Also meriting examination is the way that the test tower departs from a more typical approach to tower design. As the Birmingham site at the time of this writing is currently being developed, a very relevant comparison exists. Like the test tower, the V Building, designed by Eric Kuhne**,** consists of 50 floors, totaling to 150 m in height. It is also a residential building, comprising of 600 apartments and also claims to have 'gone through an intensive environmental sustainability audit, where the glass and

materials have been specially selected for their green credentials.' Kuhne continues, 'The V Building will be on of the most sustainable buildings of its kind' (*Sustainable Building* website, 2007). However, that is as much information as is provided about its sustainability, so it is safe to assume that in reality, it is not much different from the current standard approach to green design, which is more interested in energy efficiency and technological innovation than in bioclimatic and ecological considerations. This building may have a lower energy consumption, but, like One Bryant Park and the Conde Nast building, it does not depart radically from the standard, non-sustainable skyscraper in its aesthetic. The V Building is more concerned about its landmark status and the appearance of luxury. In fact, as it 'shines in the daylight and glows at night,' the V building's imagery is instead one focused on consumption, as its predominantly presented night-time façade outshines all buildings in its surroundings with its extensive use of artificial lighting (VBuilding Vision Brochure, n.d.: 3).

The V Building and the Birmingham prototype tower do share a similar narrow, south-oriented floorplan, as well as standard, uniform floor heights. However, the aesthetic comparison ends there. Whereas the V Building has a very glassy appearance, the Birmingham prototype is mostly opaque. Whereas the V Building has a uniform, rather smooth façade, the Birmingham prototype is more segmented and varied. Most significantly however, whereas the four facades of the V Building are all of the same smooth, glassy appearance, other than decorative design elements such as the V shape, each of the Birmingham prototype's facades is distinct, responding to the variance of wind and sun available for each orientation.

To summarize, the Birmingham test tower's aesthetic derives from Yeang's bioclimatic principles. Yeang's buildings themselves include most of this aesthetic but he places more significance on ecology with his extensive use of greenery. The environmentally sustainable framework, on the other hand, does not attempt to suggest a green aesthetic, and therefore the tower it produces is more like the 'hybrid' category of buildings that mediate between standard skyscraper designs and the more drastic green proposals by architects such as Yeang. The framework attempts to be as design-neutral as possible, although the elements suggested focus on passive measures that have an inevitable influence on the design. This nonetheless leads to a departure from standard uniform tower design and a skyscraper with variety, certainly, between differently oriented facades and, most likely, within each façade itself.

Appendix B: Stage 2

London test tower step notes

New York test tower step notes

London test tower SAP worksheet

1	O	Ther Rad	I	E-W long axis	N/A	Building as square, no axis
2	O	Ther Rad	I	Primary mass location	Y	Option 2: North
3	O	Airflow	I	Summer wind direction	N	Same as winter direction, square
4	C	Vis Rad	I	Narrow floorplate	Y	15 m, interferes with core if left as is
5	C	Vis Rad	I	7.5 daylight maximum	Y	Determines placement of apartments
6	C	Ther Rad	I	Built form ratio	N/A	No change
7	C	Airflow	I	14m max for nat vent	N	core on north side
8	C	Airflow	I	Zoning for wind	Y	3 zones of 50m
9	C	Airflow	I	Ground floor open	Y	6m height interior determines columns
10	C	Airflow	D	Cores as wind buffers	N	Wind same all seasons, INTERIORS
11	F	Vis Rad	I	Glass: clear	?	But can't decide until ther rad- move?
12	F	Vis Rad	I	Reduction of glare	?	A bioclimatic strategy??
13	F	Vis Rad	I	Light pipe	N	Necessary due to extensive shading
14	F	Vis Rad	I	Light shelf	N	Not necessary
15	F	Ther Rad	I	Min. north-face glass	Y	Info daylight- chart; note only resi
16	F	Ther Rad	I	Glass: clear	N/A	No change
17	F	Ther Rad	I	Glass: glazing	Y	Double glazing
18	F	Ther Rad	I	Secondary glass skin	N	Split into skin & buffer space?
19	F	Ther Rad	I	Wall: heat sink	N	More specifically?
20	F	Ther Rad	I	Wall: high insulation	Y	Wall location missing- add to 15?
21	F	Ther Rad	I	Wall: trombe wall	N	More info on suitability in tall building
22	F	Ther Rad	I	Wall: water-container	N	More info on suitability in tall building
23	F	Ther Rad	I	Wall: TAP	N	More info on suitability in tall building
24	F	Ther Rad	I	Wall: TIM	N	More info…FAÇADE OUTLINE
25	F	Ther Rad	D	Glass: other than clear	N/A	Clear glass already chosen
26	F	Ther Rad	D	Shading: location	Y	S, E, W shading
27	F	Ther Rad	D	Shading: type	Y	Fixed- living room; louvres - others
28	F	Ther Rad	D	Shading: if louvres	Y	Mid-pane
29	F	Ther Rad	D	Shading: if louvres	Y	Most fixed (except E/W liv.r), SHADING
30	F	Ther Rad	D	Wall: color	Y	White
31	F	Ther Rad	D	Wall: absorption	Y	Concrete- link with Material
32	F	Ther Rad	D	Wall: vegetation	Y	E/W vegetation- interaction with wall?
33	F	Ther Rad	D	Roof: options	Y	3- vegetation
34	F	Ther Rad	D	Roof: veg options	Y	1- roof garden
35	F	Airflow	I	Single: path location	Y	Living room- 2 levels, others 1
36	F	Airflow	I	Single: geometry	N	More information, orientation
37	F	Airflow	I	Single: location	N	More information, orientation
38	F	Airflow	I	Single: window open	Y	Many windows openable to wind
39	F	Airflow	I	Single: recessed	N	At what height?
40	F	Airflow	I	Cross: path location	N	Not possible
41	F	Airflow	I	Cross: geometry	N	Not possible
42	F	Airflow	I	Cross: location	N	Not possible
43	F	Airflow	I	Cross: window open	N	Not possible
44	F	Airflow	I	Cross: recessed	N	Not possible
45	F	Airflow	I	Stack: skycourts	Y	More info, what direction preferred?
46	F	Airflow	I	Stack: ventilated wall	N	When is this needed?
47	F	Airflow	I	Stack: atrium	N	Not deep enough, dimensions, early
48	F	Airflow	I	Stack: double façade	Y	Certain facades w/ shading
49	F	Airflow	I	Stack: triple façade	N	Benefits?
50	F	Airflow	I	Stack: active wall	N	When in high-rise?
51	F	Airflow	I	Stack: interactive wall	N	When in high-rise?
52	F	Airflow	I	Cooling: wing walls	N	Summer and winter same
53	F	Airflow	I	Cooling: nocturnal	N	When is this needed in temperate?

54	F	Airflow	I	Cooling: radiant	N	Not needed, high ceilings
55	F	Airflow	I	Cooling: direct	N	When is this needed in temperate?
56	F	Airflow	I	Cooling: outdoors	Y	Vegetation
57	F	Water	/	Rainwater: vegetation	Y	More information
58	F	Water	/	Rainwater: landscape	N/A	More information
59	F	Water	/	Greywater: vegetation	Y	More information
60	F	Water	/	Greywater: landscape	Y	More information
61	F	Water	/	Groundwater: fixtures	Y	Specify low-flow, need numbers
62	F	Water	/	Groundwater: applian	Y	Specifics needed
63	F	Water	/	Groundwater: M&E	Y	Specifics needed
64	F	Materials	/	Animate: Strategy	Y	Integration
65	F	Materials	/	Animate: Elements	Y	E & W facades
66	F	Materials	/	Animate: Skycourts	Y	More information
67	F	Materials	/	Animate: Balconies	Y	Plants
68	F	Materials	/	Animate: Roof	Y	Use wild grass
69	F	Materials	/	Animate: Skygardens	Y	Vegetated
70	F	Materials	/	Animate: Surrounding	N/A	No site design
71	F	Materials	/	Animate: Trees	Y	Various
72	F	Materials	/	Animate: Plants	Y	Various
73	F	Materials	/	Animate: Grass	Y	Various
74	F	Materials	/	Inanimate: Sources	Y	Specify recycled materials
75	F	Materials	/	Inanimate: Reuse	Y	Specify reuse of materials
76	F	Materials	/	Inanimate: Embodied	Y	Specify use of low embodied energy
77	F	Materials	/	Inanimate: Biodegrad	Y	Specify biodegradable, more info
78	F	Materials	/	Inanimate: Local	Y	Local sourcing, more info
79	F	Materials	/	Inanimate: Toxicity	Y	Specify low toxicity
80	F	Materials	/	Inanimate: Life cycle	Y	Design for reuse, recovery, more info
81	S	Vis Rad	I	Lighting	Y	Specify low energy bulbs, more info
82	S	Ther Rad	I	Solar hot water collect	N	Right category?
83	S	Ther Rad	D	Radiant heat barrier	N	Vegetation as barrier
84	S	Airflow	I	Propeller fan	N	no interior design
85	S	Airflow	I	Evaporative coolers	N	When is this needed in temperate?
86	S	Airflow	I	Dehumidifiers	N	When is this needed in temperate?
87	S	Airflow	I	Displacament vent	N	Needs testing
88	S	Materials	/	Fuel cells	N	Not necessary?
89	R	Vis Rad	/	Photovoltaics	Y	South balcony fence
90	R	Airflow	/	Wind turbines	Y	Top of building
91	R	Water	/	Hydroelectic	N	More info needed
92	R	Material	/	Biofules	N	More info needed
93	R	Land	/	Geothermal	N	More info needed

1	O	Ther Rad	I	E-W long axis	N/A	Building as square, no axis
2	O	Ther Rad	I	Primary mass location	Y	Option 1: North
3	O	Airflow	I	Summer wind direction	Y	Orient building, allow for wind on sides
4	C	Vis Rad	I	Narrow floorplate	Y	15m
5	C	Vis Rad	I	7.5 daylight maximum	Y	7.5, 2.5m corridor needed
6	C	Ther Rad	I	Built form ratio	N	Dimensions to change- south orient.
7	C	Airflow	I	14m max for nat vent	Y	Corridor needed
8	C	Airflow	I	Zoning for wind	Y	3 zones of 50m
9	C	Airflow	I	Ground floor open	Y	6m height, interior determine column
10	C	Airflow	D	Cores as wind buffers	Y	Winter wind north, INTERIOR
11	F	Vis Rad	I	Glass: clear	?	Can't decide until thermal rad?
12	F	Vis Rad	I	Reduction of glare	?	Not a bioclimatic strategy?
13	F	Vis Rad	I	Light pipe	N	Not necessary
14	F	Vis Rad	I	Light shelf	N	Not necessary
15	F	Ther Rad	I	Min. north-face glass	Y	Info on daylight
16	F	Ther Rad	I	Glass: clear	N/A	No change
17	F	Ther Rad	I	Glass: glazing	Y	Double glazing
18	F	Ther Rad	I	Secondary glass skin	N	Not enough room?
19	F	Ther Rad	I	Wall: heat sink	N	More information?
20	F	Ther Rad	I	Wall: high insulation	Y	Is building assumed to be wall?
21	F	Ther Rad	I	Wall: trombe wall	N	More info on suitaibility in tall building
22	F	Ther Rad	I	Wall: water-container	N	More info on suitaibility in tall building
23	F	Ther Rad	I	Wall: TAP	N	More info on suitaibility in tall building
24	F	Ther Rad	I	Wall: TIM	N	More info… FAÇADE OUTLINE
25	F	Ther Rad	D	Glass: other than clear	N/A	Clear glass already chosen
26	F	Ther Rad	D	Shading: location	Y	S,E,W shading
27	F	Ther Rad	D	Shading: type	Y	Fixed, louvres, blinds
28	F	Ther Rad	D	Shading: if louvres	Y	Mid-pane, blinds
29	F	Ther Rad	D	Shading: if louvres	Y	Fixed, movable
30	F	Ther Rad	D	Wall: color	Y	White
31	F	Ther Rad	D	Wall: absorption	Y	Concrete- link with material
32	F	Ther Rad	D	Wall: vegetation	Y	E/W vegetation- wall option interaction
33	F	Ther Rad	D	Roof: options	Y	3- vegetation
34	F	Ther Rad	D	Roof: veg options	Y	1- roof gardens
35	F	Airflow	I	Single: path location	Y	Bedrooms, bathrooms
36	F	Airflow	I	Single: geometry	N	More information, orientation
37	F	Airflow	I	Single: location	N	More information, orientation
38	F	Airflow	I	Single: window open	Y	Some openable windows
39	F	Airflow	I	Single: recessed	N	At what height?
40	F	Airflow	I	Cross: path location	Y	Living room, summer
41	F	Airflow	I	Cross: geometry	N	More information, orientation
42	F	Airflow	I	Cross: location	N	More information, orientation
43	F	Airflow	I	Cross: window open	Y	Some openable windows
44	F	Airflow	I	Cross: recessed	N	At what height?
45	F	Airflow	I	Stack: skycourts	N	Wind direction?
46	F	Airflow	I	Stack: ventilated wall	N	When is this needed?
47	F	Airflow	I	Stack: atrium	N	Not deep enough, dimensions
48	F	Airflow	I	Stack: double façade	Y	Certain facades w/shading
49	F	Airflow	I	Stack: triple façade	N	Benefits?
50	F	Airflow	I	Stack: active wall	N	When in high-rise?
51	F	Airflow	I	Stack: interactive wall	N	When in high-rise?
52	F	Airflow	I	Cooling: wing walls	N	When in high-rise?
53	F	Airflow	I	Cooling: nocturnal	Y	Hallways cross-ventilation

54	F	Airflow	I	Cooling: radiant	N	More info needed
55	F	Airflow	I	Cooling: direct	N	When is this needed in temperate
56	F	Airflow	I	Cooling: outdoors	Y	Vegetation
57	F	Water	/	Rainwater: vegetation	Y	More info needed
58	F	Water	/	Rainwater: landscape	N/A	More info needed
59	F	Water	/	Greywater: vegetation	Y	More info needed
60	F	Water	/	Greywater: landscape	Y	More info needed
61	F	Water	/	Groundwater: fixtures	Y	Low-flow
62	F	Water	/	Groundwater: applian	Y	More info needed
63	F	Water	/	Groundwater: M&E	Y	More info needed
64	F	Materials	/	Animate: Strategy	Y	Integration
65	F	Materials	/	Animate: Elements	Y	E & W facades
66	F	Materials	/	Animate: Skycourts	N	More info needed
67	F	Materials	/	Animate: Balconies	Y	Plants
68	F	Materials	/	Animate: Roof	Y	Use wild grass
69	F	Materials	/	Animate: Skygardens	Y	Vegetated
70	F	Materials	/	Animate: Surrounding	N/A	No site design
71	F	Materials	/	Animate: Trees	Y	Various
72	F	Materials	/	Animate: Plants	Y	Various
73	F	Materials	/	Animate: Grass	Y	Various
74	F	Materials	/	Inanimate: Sources	Y	Specify
75	F	Materials	/	Inanimate: Reuse	Y	Specify
76	F	Materials	/	Inanimate: Embodied	Y	Specify
77	F	Materials	/	Inanimate: Biodegrad	Y	Specify
78	F	Materials	/	Inanimate: Local	Y	Specify
79	F	Materials	/	Inanimate: Toxicity	Y	Specify
80	F	Materials	/	Inanimate: Life cycle	Y	Specify
81	S	Vis Rad	I	Lighting	Y	Specify
82	S	Ther Rad	I	Solar hot water collect	N	Right category?
83	S	Ther Rad	D	Radiant heat barrier	N	Vegetation as barrier
84	S	Airflow	I	Propeller fan	N	No interior design
85	S	Airflow	I	Evaporative coolers	N	When is this needed in temperate
86	S	Airflow	I	Dehumidifiers	N	When is this needed in temperate
87	S	Airflow	I	Displacament vent	N	Needs testing
88	S	Materials	/	Fuel cells	N	Not necessary?
89	R	Vis Rad	/	Photovoltaics	Y	South balcony fence
90	R	Airflow	/	Wind turbines	Y	Top of building
91	R	Water	/	Hydroelectic	N	More info
92	R	Material	/	Biofules	N	More info
93	R	Land	/	Geothermal	N	More info

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	32.078	(1a) ×	2.5	=	80.20
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	32.078	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	80.20

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.25

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.55
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.55
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			2
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.85
Adjusted infiltration rate			(19) x (21) = 0.47

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.64
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.97
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.72
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.61
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	6.5	×	0.7	1/[(1/U-value) +0.04] =	4.43
Windows (type 2)*	9.125	×	0.7	1/[(1/U-value) +0.04] =	6.21
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	13.375	×	0.15	=	2.01
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	29.00 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 12.65

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.32

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 14.97

Ventilation heat loss (25) × 0.33 × (6) = 13.23

Heat loss coefficient, W/K (35) + (36) = 28.20

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.88

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1177.22

Distribution loss (Table 1, column (c) 207.75 207.75

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 353.74

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 1744.97

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 748.50

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		241.14
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		14.17
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	85.45
Total internal gains	(53) + (53b) + (54) - (53a) =	312.42

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a		G Table 6b		FF Table 6c		Gains (W)
North	1	×	6.5	×	29	× 0.9 ×	0.63	×	0.7	=	74.82
North east	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
East	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
South east	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
South	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
South west	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
West	0.54	×	9.125	×	48	× 0.9 ×	0.63	×	0.7	=	93.87
North west	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00

Total solar gains [(56) + …. + (64)] = 168.69

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W	(55) + (65) =	481.1
Gains/loss ratio (GLR)	(66) ÷ (37) =	17.06
Utilisation factor (Table 7, using GLR box (67))		0.65
Useful gains, W	(66) × (68) =	313.6

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type	1	18.88
Temperature adjustment from Table 4e, where appropriate			0.00
Adjustment for gains	{[(69) ÷ (37)] - 4.0}× 0.2 × R =		1.42
R is obtained from the 'responsiveness' column of Table 4a or Table 4d	R =		1.00
Adjusted living room temperature	(70) + (71) + (72) =		20.30
Temperature difference between zones (table 9)	control type	1	0.40
	Living room area =		27.28
Living area fraction (0 to 1.0)	Living room area ÷ (5) =		0.85
Rest of house fraction	1 - (75) =		0.15
Mean internal temperature	(73) - [(74) × (76)] =		20.24

8. Degree days

Temperature rise from gains	(69) ÷ (37) =	11.12
Base temperature	(77) - (78) =	9.12
Degree days (use box (79) and table 10)		796

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37)	=	538.68

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	718.24
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2326.62

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	14.29
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	46.30
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.17	×	7.12	× 0.01 =	1.01
Additional standing charges (Table 12)					34.00
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				95.60

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.74
SAP rating (Table 14)		89.7

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	718.24	×	0.194	=	139.34
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2326.62	×	0.194	=	451.36
Space and water heating				(101) + 102) + (103) =	590.70
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.17	×	0.422	=	5.98
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1957.26
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-61.02

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	32.078	(1a) ×	2.5	=	80.20
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	32.078	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	80.20

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.25

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.55
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.55
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			2
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.85
Adjusted infiltration rate			(19) x (21) = 0.47

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.64
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.97
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.72
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.61
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	6.5	×	0.7	1/[(1/U-value) +0.04] =	4.43
Windows (type 2)*	9.125	×	0.7	1/[(1/U-value) +0.04] =	6.21
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	13.375	×	0.15	=	2.01
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	29.00 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 12.65

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.32

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 14.97

Ventilation heat loss (25) × 0.33 × (6) = 13.23

Heat loss coefficient, W/K (35) + (36) = 28.20

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.88

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1177.22

Distribution loss (Table 1, column (c) 207.75 207.75

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 0.00

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 1744.97

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 748.50

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		241.14
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		14.17
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	85.45
Total internal gains	(53) + (53b) + (54) - (53a) =	312.42

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a		G Table 6b		FF Table 6c		Gains (W)
North	1	×	6.5	×	29	× 0.9 ×	0.63	×	0.7	=	74.82
North east	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
East	0.54	×	9.125	×	48	× 0.9 ×	0.63	×	0.7	=	93.87
South east	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
South	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
South west	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
West	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
North west	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×	0	×	0	=	0.00
Total solar gains									[(56) + …. + (64)] =		168.69

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W	(55) + (65) =	481.1
Gains/loss ratio (GLR)	(66) ÷ (37) =	17.06
Utilisation factor (Table 7, using GLR box (67))		0.65
Useful gains, W	(66) × (68) =	313.6

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type	1	18.88
Temperature adjustment from Table 4e, where appropriate			0.00
Adjustment for gains	{[(69) ÷ (37)] - 4.0}× 0.2 × R =		1.42
R is obtained from the 'responsiveness' column of Table 4a or Table 4d	R =		1.00
Adjusted living room temperature	(70) + (71) + (72) =		20.30
Temperature difference between zones (table 9)	control type	1	0.40
	Living room area =		27.28
Living area fraction (0 to 1.0)	Living room area ÷ (5) =		0.85
Rest of house fraction	1 - (75) =		0.15
Mean internal temperature	(73) - [(74) × (76)] =		20.24

8. Degree days

Temperature rise from gains	(69) ÷ (37) =	11.12
Base temperature	(77) - (78) =	9.12
Degree days (use box (79) and table 10)		796

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37) =	538.68

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	718.24
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2326.62

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	14.29
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	46.30
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.17	×	7.12	× 0.01 =	1.01
Additional standing charges (Table 12)					34.00
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				95.60

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.74
SAP rating (Table 14)		89.7

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	718.24	×	0.194	=	139.34
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2326.62	×	0.194	=	451.36
Space and water heating				(101) + 102) + (103) =	590.70
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.17	×	0.422	=	5.98
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1957.26
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-61.02

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	45.045	(1a) ×	2.5	=	112.61
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	45.045	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	112.61

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.18

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.48
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.48
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			2
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.85
Adjusted infiltration rate			(19) x (21) = 0.41

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.58
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.91
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.66
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.58
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	9.5	×	0.7	1/[(1/U-value) +0.04] =	6.47
Windows (type 2)*	6.25	×	0.7	1/[(1/U-value) +0.04] =	4.26
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	20.375	×	0.15	=	3.06
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	36.13 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 13.78

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.68

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 16.46

Ventilation heat loss (25) × 0.33 × (6) = 18.58

Heat loss coefficient, W/K (35) + (36) = 35.04

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.78

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1366.10

Distribution loss (Table 1, column (c) 241.08 241.08

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 353.74

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 1967.18

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 822.39

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		307.03
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		19.90
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	93.88
Total internal gains	(53) + (53b) + (54) - (53a) =	381.01

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a			G Table 6b		FF Table 6c		Gains (W)
North	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
East	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South	0.77	×	9.5	×	72	× 0.9 ×		0.63	×	0.7	=	209.04
South west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
West	0.54	×	6.25	×	48	× 0.9 ×		0.63	×	0.7	=	64.30
North west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00

Total solar gains [(56) + …. + (64)] = 273.34

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W	(55) + (65) =	654.3
Gains/loss ratio (GLR)	(66) ÷ (37) =	18.67
Utilisation factor (Table 7, using GLR box (67))		0.62
Useful gains, W	(66) × (68) =	404.8

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type	1	18.88
Temperature adjustment from Table 4e, where appropriate			0.00
Adjustment for gains	{[(69) ÷ (37)] - 4.0}× 0.2 × R =		1.51
R is obtained from the 'responsiveness' column of Table 4a or Table 4d	R =		1.00
Adjusted living room temperature	(70) + (71) + (72) =		20.39
Temperature difference between zones (table 9)	control type	1	0.40
	Living room area =		29.00
Living area fraction (0 to 1.0)	Living room area ÷ (5) =		0.64
Rest of house fraction	1 - (75) =		0.36
Mean internal temperature	(73) - [(74) × (76)] =		20.25

8. Degree days

Temperature rise from gains	(69) ÷ (37) =	11.55
Base temperature	(77) - (78) =	8.70
Degree days (use box (79) and table 10)		726

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37)	=	610.91

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	814.54
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2622.90

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	16.21
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	52.20
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.71	×	7.12	× 0.01 =	1.05
Additional standing charges (Table 12)					34.00
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				103.45

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.71
SAP rating (Table 14)		90.1

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	814.54	×	0.194	=	158.02
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2622.90	×	0.194	=	508.84
Space and water heating				(101) + 102) + (103) =	666.86
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.71	×	0.422	=	6.21
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1880.87
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-41.76

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	53.288	(1a) ×	2.5	=	133.22
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	53.288	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	133.22

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.15

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.45
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.45
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			3
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.775
Adjusted infiltration rate			(19) x (21) = 0.35

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.52
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.85
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.60
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.56
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	2	×	0.7	1/[(1/U-value) +0.04] =	1.36
Windows (type 2)*	9	×	0.7	1/[(1/U-value) +0.04] =	6.13
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	7.375	×	0.15	=	1.11
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	18.38 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 8.60

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.68

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 11.28

Ventilation heat loss (25) × 0.33 × (6) = 21.98

Heat loss coefficient, W/K (35) + (36) = 33.26

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.62

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1483.15

Distribution loss (Table 1, column (c) 261.73 261.73

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 353.74

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 2104.88

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 868.17

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		348.41
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		23.54
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	99.11
Total internal gains	(53) + (53b) + (54) - (53a) =	423.98

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a			G Table 6b		FF Table 6c		Gains (W)
North	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
East	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South	0.77	×	11	×	72	× 0.9 ×		0.63	×	0.7	=	242.05
South west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
West	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Total solar gains										[(56) + …. + (64)] =		242.05

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W		(55) + (65) =	666.0
Gains/loss ratio (GLR)		(66) ÷ (37) =	20.03
Utilisation factor (Table 7, using GLR box (67))			0.59
Useful gains, W		(66) × (68) =	394.9

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type 1		18.88
Temperature adjustment from Table 4e, where appropriate			
Adjustment for gains		{[(69) ÷ (37)] - 4.0}× 0.2 × R =	0.00
R is obtained from the 'responsiveness' column of Table 4a or Table 4d		R =	
Adjusted living room temperature		(70) + (71) + (72) =	18.88
Temperature difference between zones (table 9)	control type 1		0.40
		Living room area =	32.97
Living area fraction (0 to 1.0)		Living room area ÷ (5) =	0.62
Rest of house fraction		1 - (75) =	0.38
Mean internal temperature		(73) - [(74) × (76)] =	18.73

8. Degree days

Temperature rise from gains	(69) ÷ (37) =	11.87
Base temperature	(77) - (78) =	6.85
Degree days (use box (79) and table 10)		462

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37)	=	369.04

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	492.06
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2806.51

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	9.79
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	55.85
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.17	×	7.12	× 0.01 =	1.01
Additional standing charges (Table 12)					
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				66.65

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.31
SAP rating (Table 14)		95.6

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	492.06	×	0.194	=	95.46
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2806.51	×	0.194	=	544.46
Space and water heating				(101) + 102) + (103) =	639.92
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.17	×	0.422	=	5.98
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1908.04
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-35.81

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	53.288	(1a) ×	2.5	=	133.22
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	53.288	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	133.22

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.15

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.45
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.45
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			3
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.775
Adjusted infiltration rate			(19) x (21) = 0.35

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.52
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.85
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.60
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.56
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	2	×	0.7	1/[(1/U-value) +0.04] =	1.36
Windows (type 2)*	9	×	0.7	1/[(1/U-value) +0.04] =	6.13
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	7.35	×	0.15	=	1.10
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	18.35 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 8.59

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.68

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 11.27

Ventilation heat loss (25) × 0.33 × (6) = 21.98

Heat loss coefficient, W/K (35) + (36) = 33.25

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.62

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1483.15

Distribution loss (Table 1, column (c) 261.73 261.73

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 0.00

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 2104.88

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 868.17

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		348.41
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		23.54
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	99.11
Total internal gains	(53) + (53b) + (54) - (53a) =	423.98

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a			G Table 6b		FF Table 6c		Gains (W)
North	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
East	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South	0.77	×	11	×	72	× 0.9 ×		0.63	×	0.7	=	242.05
South west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
West	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Total solar gains										[(56) + …. + (64)] =		242.05

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W	(55) + (65) =	666.0
Gains/loss ratio (GLR)	(66) ÷ (37) =	20.03
Utilisation factor (Table 7, using GLR box (67))		0.59
Useful gains, W	(66) × (68) =	394.9

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type	1	18.88
Temperature adjustment from Table 4e, where appropriate			
Adjustment for gains	{[(69) ÷ (37)] - 4.0}× 0.2 × R =		0.00
R is obtained from the 'responsiveness' column of Table 4a or Table 4d	R =		
Adjusted living room temperature	(70) + (71) + (72) =		18.88
Temperature difference between zones (table 9)	control type	1	0.40
	Living room area =		32.97
Living area fraction (0 to 1.0)	Living room area ÷ (5) =		0.62
Rest of house fraction	1 - (75) =		0.38
Mean internal temperature	(73) - [(74) × (76)] =		18.73

8. Degree days

Temperature rise from gains	(69) ÷ (37) = 11.88
Base temperature	(77) - (78) = 6.85
Degree days (use box (79) and table 10)	462

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37)	= 368.95

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	491.94
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2806.51

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	9.79
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	55.85
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.17	×	7.12	× 0.01 =	1.01
Additional standing charges (Table 12)					
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				66.65

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.31
SAP rating (Table 14)		95.6

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	491.94	×	0.194	=	95.44
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2806.51	×	0.194	=	544.46
Space and water heating				(101) + 102) + (103) =	639.90
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.17	×	0.422	=	5.98
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1908.07
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-35.81

SAP WORKSHEET (version 9.80) - Dwelling Emission Rate

1. Overall dwelling dimensions	**Area (m²)**		**Average room height (m)**		**Volume (m³)**
Ground floor	45.045	(1a) ×	2.5	=	112.61
First floor	0	(2a) ×	0	=	0.00
Second floor	0	(3a) ×	0	=	0.00
Third and other floors	0	(4a) ×	0	=	0.00
Total floor area (1a) + (2a) + (3a) + (4a) =	45.045	(5)			
Dwelling volume				(1) + (2) + (3) + (4) =	112.61

2. Ventilation rate

				m³ per hour	
Number of chimneys	0	× 40	=	0	(7)
Number of open flues	0	× 20	=	0	(8)
Number of fans and passive vents	2	× 10	=	20	(9)
Number of flueless gas fires	0	× 40	=	0	(9a)

			Air changes per h
Infiltration due to chimneys, fans and flues	= (7) + (8) + (9) + (9a) =	20 ÷ box (6) =	0.18

If a pressurisation test has been carried out proceed to box (19)

Number of storeys in the dwelling		1 (11)	
Additional infiltration			[(11) - 1] × 0.1 = 0.00
Structural infiltration: *0.25 for steel or timber frame or 0.35 for masonry construction*			0.25
If suspended floor, *enter 0.2 (unsealed) or 0.1 (sealed)* else enter 0			0.00
If no draught lobby, enter 0.05, else enter 0			0.00
Percentage of windows and doors draught stripped		100 (16)	
Enter 100 in box (16) for new dwellings which are to comply with Building Regulations			
Window infiltration			0.25 - [0.2 × (16) ÷ 100] = 0.05
Infiltration rate			(10) + (12) + (13) + (14) + (15) + (17) = 0.48
If based on air permeability value, then [q50÷20] + (10) in (19), otherwise (19) = (18)			q50 0.48
Air permeability value applies if a pressurisation test has been done, or a design air permeability is being used			
Number of sides on which sheltered			2
(Enter 2 in box (20) for new dwellings where location is not shown)			
Shelter factor			1 - [0.075 × (20)] = 0.85
Adjusted infiltration rate			(19) x (21) = 0.41

Calculate effective air change rate for the applicable case

a) If balanced whole house mechanical ventilation with heat recovery	(22) + 0.17 = 0.58
b) If balanced whole house mechanical ventilation without heat recovery	(22) + 0.5 = 0.91
c) If whole house extract ventilation or positive input ventilation from outside *if (22) <0.25, then (23b) = 0.5; otherwise (23b) = 0.25 + (22)*	0.66
d) If natural ventilation or whole house positive input ventilation from loft *if (22)≥1, then (24) = (22); otherwise (24) = 0.5 + [(22)² x 0.5]*	0.58
Effective air change rate - enter (23) or (23b) or (23a) or (24) in box (25)	0.50

3. Heat losses and heat loss parameters

ELEMENT	Area (m²)		U-Value (W/m²K)		A × U
Doors		×		=	0.00
Windows (type 1)*	9.5	×	0.7	1/[(1/U-value) +0.04] =	6.47
Windows (type 2)*	6.25	×	0.7	1/[(1/U-value) +0.04] =	4.26
Rooflights*		×		1/[(1/U-value) +0.04] =	0.00
Ground floor		×		=	0.00
Walls (type 1) *excluding windows and doors*	20.375	×	0.15	=	3.06
Walls (type 2) *excluding windows and doors*		×		=	0.00
Roof (type 1) *excluding rooflights*		×		=	0.00
Roof (type 2) *excluding rooflights*		×		=	0.00
Other		×		=	0.00
	36.13 (32)				

** For windows and rooflights, use effective U-value calculated as given in paragraph 3.2*

Fabric heat loss W/K (26) + (27) + (27a) + (28) + (29) + (29a) + (30) + (30a) + (31) = 13.78

Thermal bridges - Σ (l x Ψ) calculated using Appendix K 2.68

If details of thermal bridging are not known calculate y x (32) [see Appendix K] and enter in box (34)

Total fabric heat loss 16.46

Ventilation heat loss (25) × 0.33 × (6) = 18.58

Heat loss coefficient, W/K (35) + (36) = 35.04

Heat loss parameter (HLP) W/m²K (37) ÷ (5) = 0.78

4. Water-heating energy requirements **kWh/year**

Energy Content of hot water used from (Table 1, column (b) 1366.10

Distribution loss (Table 1, column (c) 241.08 241.08

If instantaneous water heating at point of use, enter '0' in boxes (40) to (45)

For community heating use Table 1(c) whether or not hot water tank present

Water storage loss:

a) If manufacture's declared loss factor is known (kWh/day) : (41)

Temperature factor Table 2b (41a)

Energy lost from water storage, kWh/year (41) x (41a) x 365 = 0 (42)

b) If manufacture's declared loss factor is not known :

Cylinder volume (litres) including any solar storage within same cylinder 100 (43)

If community heating and no tank in dwelling, enter 110 litres in box (43)

Otherwise if no stored water (this includes instantaneous combi boilers) enter '0' in box (43)

Hot water storage loss factor from Table 2 (kWh/litre/day) 0.0152 (44)

If heated by community heating and no tank, enter 110 litres in box (43)

Volume factor from Table 2a 1.063 (44a)

Temperature factor from Table 2b 0.6 (44b)

If community heating and no tank in dwelling, use cylinder loss from Table 2 for 50mm factory insulation in box (44)

Energy lost from hot water storage, kWh/yr (43)×(44)×(44a)×(44b)×365 = 353.74 (45)

Enter (42) or (45) in box (46) 353.74

If cylinder contains dedicated solar storage, box (47)= (46)×[(43)-(H11]/(43), else (47)=(46) 0.00

Primary circuit loss (Table 3) 360.00

Combi loss from Table 3a (enter '0' if not combi boiler) 0.00

Solar DHW input calculated using Appendix H (enter '0' if no solar collector) 0.00

Output from water heater, kWh/year (39) + (40) + (47) + (48) + (49) - (50) = 1967.18

Heat gains from water heating, kWh/year 0.25 ×[(39) + (49)] + 0.8 [(40) + (47) + (48)] = 822.39

Include (47) in calculation of (52) only if cylinder is in the dwelling or hot water is from community heating

5. Internal gains

		Watts
Lights, appliances, cooking and metabolic (Table 5)		307.03
Reduction of internal gains due to low energy lighting (calculated in Appendix L)		19.90
Additional gains from Table 5a		0.00
Water Heating	(52) ÷ 8.76 =	93.88
Total internal gains	(53) + (53b) + (54) - (53a) =	381.01

6. Solar gains

	Access Factor Table 6d		Area m²		Flux Table 6a			G Table 6b		FF Table 6c		Gains (W)
North	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
East	0.54	×	6.25	×	48	× 0.9 ×		0.63	×	0.7	=	64.30
South east	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
South	0.77	×	9.5	×	72	× 0.9 ×		0.63	×	0.7	=	209.04
South west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
West	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
North west	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00
Rooflights	0	×	0	×	0	× 0.9 ×		0	×	0	=	0.00

Total solar gains [(56) + …. + (64)] = 273.34

Note: for new dwellings where overshading is not known, solar access factor is '1'

Total gains, W	(55) + (65) =	654.3
Gains/loss ratio (GLR)	(66) ÷ (37) =	18.67
Utilisation factor (Table 7, using GLR box (67))		0.62
Useful gains, W	(66) × (68) =	404.8

7. Mean internal temperature

			°C
Mean internal temperature of the living area (Table 8)	heating type	1	18.88
Temperature adjustment from Table 4e, where appropriate			0.00
Adjustment for gains	{[(69) ÷ (37)] - 4.0}× 0.2 × R =		1.51
R is obtained from the 'responsiveness' column of Table 4a or Table 4d	R =		1.00
Adjusted living room temperature	(70) + (71) + (72) =		20.39
Temperature difference between zones (table 9)	control type	1	0.40
	Living room area =		29.00
Living area fraction (0 to 1.0)	Living room area ÷ (5) =		0.64
Rest of house fraction	1 - (75) =		0.36
Mean internal temperature	(73) - [(74) × (76)] =		20.25

8. Degree days

Temperature rise from gains	(69) ÷ (37) =	11.55
Base temperature	(77) - (78) =	8.70
Degree days (use box (79) and table 10)		726

9. Space-heating requirements

Space heating requirement (useful), kWh/year	0.024 × (80) × (37)	=	610.91

9a. Energy requirements - individual heating systems, including micro-CHP

Note: when space and water heating is provided by community heating use the alternative worksheet 9b

Space heating

Fraction of heat from secondary system (Use value from Table 11 or Appendix F or Appendix N)		0.00
Efficiency of main heating system %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Efficiency of secondary/supplementary heating system, % *(use value obtained from Table 4a or Appendix E)*		0.00
Space heating fuel (main) requirement, kWh/year	[1 - (82)] × (81) × 100 ÷ (83) =	814.54
Space heating fuel (secondary), kWh/year	(82) × (81) × 100 ÷ (84) =	0.00

Water heating

Efficiency of water heater, %		75.00
SEDBUK or from Table 4a or 4b, adjusted where appropriate by the amount shown in the 'efficiency adjustment' column of Table 4c)		
Energy required for water heating, kWh/year	(51) × 100 ÷ (86) =	2622.90

Electricity for pumps and fans

each central heating pump (Table 4f)	0.00
each boiler with fan-assisted flue (Table 4f)	0.00
warm-air heating system fans, (Table 4f)	0.00
mechanical ventilation -balanced, extract or positive input from outside (Table 4f)	0.00
maintaining keep-hot facility for gas combi boiler (Table 4f)	0.00
pump for solar water heating (Table 4f)	0.00
(87a) + (87b) + (87c) + (87d) + (87e) + (87f) =	0.00

10a. Fuel costs - individual heating systems

	Fuel required kWh/year		**Fuel price** (Table 12)		**Fuel costs** £/year
Space heating - main system	(85)	×	1.99	× 0.01 =	16.21
Space heating - secondary system	(85a)	×		× 0.01 =	0.00

Water heating

Water heating cost (electric, off-peak tariff)					
On-peak percentage (Table 13 or *Appendix F for electric CPSUs*)					
Off-peak percentage				1 - (90) =	1
			Fuel price		
On-peak cost	(86a) × (90) ×			× 0.01 =	0.00
Off-peak cost	(86a) × (90a) ×			× 0.01 =	0.00
Otherwise, water-heating costs	(86a) ×		1.99	× 0.01 =	52.20
Pump and fan energy cost	(87) ×		7.12	× 0.01 =	0.00
Energy for lighting (calculated in Appendix L)	14.71	×	7.12	× 0.01 =	1.05
Additional standing charges (Table 12)					34.00
Renewable and energy -saving technologies (Appendix M, N and Q)					
Energy produced or saved, kWh/year	6052.00	(95)			
Cost of energy produced or saved, £/year	(95)	×		× 0.01 =	0.00
Energy consumed by the technology, kWh/year		(96)			
Cost of energy consumed , £/year	(96)	×		× 0.01 =	0.00
Total energy cost	(88) + (89) + (91) + (91a) + (91b) + (92) + (93) + (94) - (95a) + (96a) =				103.45

11a. SAP rating - individual heating systems

Energy cost deflator (SAP 2005)		0.91
Energy cost factor (ECF)	{[(97) × (98)] - 30} ÷ { (5) + 45.0} =	0.71
SAP rating (Table 14)		90.1

12a Dwelling CO_2 Emissions Rate (DER) for individual (including micro-CHP)

	Energy, kWh/year		Emission factor kg CO_2/kWh		Annual emis (kg CO_2/yea
Space heating, main - from box (85)	814.54	×	0.194	=	158.02
Space heating, secondary - from box (85a)	0.00	×		=	0.00
Energy for water heating from box (86a)	2622.90	×	0.194	=	508.84
Space and water heating				(101) + 102) + (103) =	666.86
Electricity for pumps and fans- box (87)	0.00	×		=	0.00
Energy for lighting Form Appendix L	14.71	×	0.422	=	6.21
Energy produced or saved in dwelling box (95)	6052.00	×	0.422	=	2553.94
Energy consumed by the above technology box (96)	0.00	×		=	0.00
Total CO_2, kg/year				(107) + 108) + (109) - (110) + (111) =	-1880.87
Dwelling CO_2 Emission Rate				(112) ÷ (5) =	-41.76

Appendix C: Stage 3

Student questionnaire

Framework student notes

CF final presentation

CP final presentation

CN final presentation

Ian Simpson Architects interview protocol

Ian Simpson Architects interview questions

Post Design Questionnaire

University/School:

Group:

The objective of this questionnaire is to clarify and elaborate on your experience using the recommended design framework. 'Framework' here refers to the entire design tool, rather than the table at times previously referred to as the framework. Here 'framework' includes the table, the recommended paths and advice in each step. As some of you have provided extensive written feedback already, you are welcome to refer to previous feedback where relevant.

Design foundations

1. How would you describe your group members' knowledge of environmental design prior to using the framework?

2. Did you already have a particular method of work towards environmental design in mind before starting?

3. What were the main drivers behind your design? (Thermal performance, building function, etc.). Highlight any one or two that were particularly important.

4. Did you already have specific aims for environmental performance in mind before starting?

Framework application

5. How much of the framework did you consult in the development of your design? Please approximate roughly in terms of percent.

6. Which parts of the framework did you apply to your design?

7. Did you consult any other resources for additional information or alternative design processes during this project? Please state which sources, how they were used and what additional information they provided.

Effect of framework on design assumptions

8. In what ways did you find the framework supported your assumptions about environmental design?

9. In what ways did you find the framework added to your assumptions about environmental design?

10. In what ways did you find the framework conflicted with your assumptions about environmental design?

Framework utility

11. How helpful was this particular design framework for you as an educational tool for the environmental design of tall buildings?

12. Which parts of the framework did you find most useful?

13. Which parts of the framework did you find least useful?

14. Based on your experience of using the framework to guide your decision-making in the design of a specific building, how do you think its use influenced the following aspects of your design:

a) Overall building form:
strongly/slightly/not at all beneficially/adversely

b) Structure of the building:
strongly/slightly/not at all beneficially/adversely

c) Outer building envelope:
strongly/slightly/not at all beneficially/adversely

d) Thermal design:
strongly/slightly/not at all beneficially/adversely

e) Lighting design:
strongly/slightly/not at all beneficially/adversely

f) Ventilation design:
strongly/slightly/not at all beneficially/adversely

g) Internal planning:
strongly/slightly/not at all beneficially/adversely

h) Water use:
strongly/slightly/not at all beneficially/adversely

i) Material selection:
strongly/slightly/not at all beneficially/adversely

j) Renewable technologies:
strongly/slightly/not at all beneficially/adversely

Areas for improvement

15. In what ways can the framework be improved with respect to:

a) Its structure?

b) Its clarity?

c) The guidance it gives?

d) The path it suggests for the design process?

e) Its relationship to non-environmental aspects of design?

16. Did you find the recommendations in the framework or its structure restrictive? If so, please list the restrictive elements.

17. Please list the strengths of the framework that you have not already mentioned.

18. Please list the weaknesses of the framework that you have not already mentioned.

19. Please list any errors you may have found in the framework document.

Design evaluations

20. How did you evaluate the building resulting from the design process, especially in regards to its environmental responses?

21. What were the results of these evaluations? If available, please also attach the results of these evaluations separately.

Design challenges

22. What environmental aspects of the design of tall buildings did you find most challenging?

23. What non-environmental aspects of the design of tall buildings did you find most challenging?

24. What non-environmental aspects of the design of tall buildings would the framework benefit from including?

Addendum: design guidance

25. In general, what advantages could a framework for environmentally sustainable tall buildings provide you as a:

a) Student?

b) Practitioner? (please state your profession)

Please state any further comments here.

Please respond to this questionnaire as soon as possible, preferably by October 1st. Email all responses to sabina1130@yahoo.com. Please also feel free to include any additional information that may help to evaluate the framework (e.g. scanned images, course journals, modeling results).

Framework Student Notes

Student Comment	Action
Cardiff: Using Framework: Notes	
'This step doesn't exist in framework' between step 19-20- 'glass, other than clear.'	Remove, address with reorganization.
Step (25? and) 26: 'This must be a conjunction of two relevant existing steps'- Wall Material absorption properties.	Referring to step 26- incorporate in restructuring of wall material steps.
Delete Step 29, options * and **	See additional student notes.
Steps 32-38: 'Conflict between arrangement in the flowchart and the framework.'	Address with reorganization, update flowchart.
Configuration: Thermal Radiation (Decrease) 'There are no steps relative to these parameters, they are overseen.'	Black out interaction as not of primary importance.
Fabric: Airflow (Decrease) 'There are no steps relative to these parameters, they are overseen.'	Some steps from Fabric: Airflow (Increase) fit into this category- e.g. special case- recessed windows)- move.
System: Visible Radiation (Decrease) 'There are no steps relative to these parameters, they are overseen.'	Black out interaction.
System: Airflow (Decrease) 'There are no steps relative to these parameters, they are overseen.'	Black out interaction.
System: Water 'There are no steps relative to these parameters, they are overseen.'	Research systems related to water.
'The framework **matrix**, which is a tool to present factors to be considered during the procedure, should have been explained better.'	Improve upon the Introduction.
'Also, considering the **matrix**, the factors to been taken into account, are highlighted but they haven't been given an importance factor. Is this because the editor considers that it is subjective or varies for different sites or it was just neglected? Someone will need some guideline about this, for the framework to work as a tool, since some contradicting choices depend upon this.'	Highlight preferred choices in steps page layout and discussed in new information sheets for each interaction.
'There are some **parameters** mentioned in the matrix that are omitted in the framework.'	Address with restructuring and blacking out interactions.
'The **flowchart** is a good idea, to help the designer, but this is cannot be the final one. Discrepancies have been noticed, the resolution is poor and we consider that a less linear approach would be more appropriate.'	Highlight that all steps are optional in instructions. Improve resolution, print in larger format. Add links table and notes in steps.

'There is no mentioning of the **surrounding** area and how this affects the building design. This is a major omission; some general principals should be mentioned. This would affect the position on the building in the site, which is also not mentioned.'	Include in new 'Pre-Design' section.
'Several steps lack supporting **information** and comments. None of them has specific sources, although some were sent to us afterwards.'	Incorporate literature review and additional sources into framework steps. (Framework given only based on Yeang, without additional information).
'Defects have been located in some of the steps which are mentioned in the analytic table on the side.'	See additional student notes.
'When options or suggestions are given that relate of affect some previous choices, a **footnote** should be made to make sure the designer will go notice and consider both before deciding.'	Make links to past steps as well as current ones on steps page layout.
'A lot of pages are **blank** with only a title. This makes the framework look unfinished. This is predominant phenomenon towards the end, especially in the system and renewables section.'	Add additional information and sources into framework steps. (Framework given only based on Yeang, without additional information).
'There seems to be a feeling of confusion during some steps, deriving not so much from the sequence of the steps, as from their **internal relationships**.'	Highlight links between steps and add and discuss in new information sheets for each section.
'Some steps are more "**office oriented**" than "residences oriented" e.g. residential buildings require smaller ventilation rates -> lower internal gains per m2. Also, a lot of the references are for office buildings that have to cope with higher internal gains.'	Verify information through literature review. Research into internal loads in residential tall buildings. Discuss differences between commercial and residential tall buildings in the Introduction. Add information on ventilation in steps.
'There is a great focus on **Yeang's**work. When he has not elaborated on a specific subject, there seems to be an inconsistency in the framework. This is not Yeang's framework and should be enriched with general principles and strategies for these cases.'	Framework is based on Yeang's work, updated framework not distributed to test Yeang's information validity. Current framework to include additional sources and steps found through literature review.
'There is no consideration of social parameters like privacy, common areas, social interaction of the residents etc.'	Framework focuses on environmental aspects only. Note this in the Introduction, but provide references for other aspects for student information.
'**Spelling** mistakes are appearing in several steps.'	Edit text.
'There is a great focus on **vegetation**.'	Correct, partly as a result of focus on Yeang. See section in thesis relating to this, and address in framework in the Introduction.
'There should be some indication on	Highlight particularly important steps in

important steps that they should better not be rejected.'	steps pages and in new information sheets.
'Sub-categorizing of choices seems to be incoherent sometimes. Also some steps could be options of one step.'	Address with restructuring of framework. Some tiers for steps required.
'For the framework to be followed strictly, some features have to be assumed.' 'A rectangular plain.'	Discuss assumptions in the Introduction. Highlight that rectangular plan in framework images for illustrative purposes only. Add additional options in Configuration: Visible Radiation (Increase), Configuration: Thermal Radiation (Increase) and Airflow (Increase).
'For the framework to be followed strictly, some features have to be assumed.' 'A south orientation of the largest façade.'	Correct assumption, as it is the preferred option. However, discuss alternative orientations in 'Pre-Design' section.
'For the framework to be followed strictly, some features have to be assumed.' 'An orientation of the building aligned to the 4 points of the horizon. Always mentioning E, W, N, S façade.'	Correct, for the purpose of simplification. Include information on designing for alternative orientations in the Introduction.
'Worth including' 'The Urban Heat Island phenomenon, resulting in vertical variation, is not that much included in the steps.'	Discussion of Urban Heat Island effect to be included in thesis, with mention and links in the Introduction.
'Worth including' 'Up-going winds endangering shading devices.'	This is mentioned in Step 8 and in ventilation, but to be further discussed and referenced in steps pages. Research into effect of wind on tall building ventilation, discussing window types appropriate for various heights, required.
'Worth including' 'Option for top lighting'.	An option to be included in roof design. Despite the number of roof-related steps, the new section information sheet needs to point out the relative lack of significance of the roof design on tall buildings as opposed to their facades.
'**CONCLUSION** Designing following strictly the framework results in assumptions and limitations in the designing process. This is not only a problem referring to this specific piece of work, but we consider that such attempts should reach a level of high detail and accuracy to be considered design guides and still will not be able to cover all the	Discuss framework limitations and assumptions in the Introduction and the thesis text. Framework intended as a guide, rather than a checklist. Could possibly be used as a 'checklist' for interactions, but this is not its intended purpose. Difference between checklists, guides,

possible choices. It is apparent that it is still a work in progress and needs refinement, additions, corrections, context and summarizing. We consider this to be overall a good effort. It would be much more helpful as a guide or a checklist when it is finished.	etc. to be discussed in the thesis text.
Step 1: 'South orientation is dominant in the framework, deviation would complicate the procedure.'	Correct. Include information on designing for alternative orientations in the Introduction.
Step 2: 'Different meaning of the primary mass for the two options. More options several steps ahead.'	Address with restatement of text in Step 2.
Step 3: 'Deviation from south would complicate the procedure.'	Correct. Include information on designing for alternative orientations in the Introduction.
Step 5: 'Orientation of the façade not specified; the one facing the winds? Single-sided only.'	Mislabeling of the step- replace Orientation: Airflow (Increase) with Configuration: Visible Radiation (Increase)
Step 6: 'Corrupted picture. Confusing.'	Picture used in different format. Remake in SketchUp.
Step 7: 'There is no guidance for an atrium further ahead.'	Guidance on atrium to be included in Step 4 (Configuration: Visible Radiation (Increase) as an option for daylighting and included again in Step 7. Research into daylighting and airflow via atriums in tall buildings. Specify maximum height.
Step 8: 'A bit early for ventilation devices-configuration section.'	Provide general information on height and natural ventilation. Link to devices in later sections.
Step 10: 'Mentioned again in step 2. Factor weighing.'	Link to Step 2 and highlight priority of core placement according to thermal radiation over airflow. (This step relates to peripheral placement, rather than orientation, highlight this).
Step 11: 'A summary table for glass would be useful. Mentioned for different parameters and steps.'	Link step with new appendix glass types. Restructure section on glass (and rename windows/openings)
Step 12: 'Visible radiation- Decrease maybe?'	Glare to be omitted from framework and discussed in non-environmental aspects in the Introduction. However, do mention in glass types advantages and disadvantages.
Step 13: 'Pictures, operation, advantages, disadvantages, comparison, references would be helpful.'	Include image. Include advantages, disadvantages, comparisons, references in new steps layout format. (both options in this step).
Step 14: 'Thermal radiation decrease	Glass placement needs to be linked with

maybe? Only north façade mentioned.'	orientation and configuration. If moved to (decrease), would cause inconsistencies in hierarchy. Other option- restate as glass placement: south primarily, as this increases thermal radiation (north/east/west have little effect).
Step 16: 'Variation between facades not mentioned.'	Create hierarchy for glazing options and link to new appendix glass types.
Step 18: 'Confusing; heat sink material to increase thermal radiation and insulate?'	Link and discuss relationship with glass. Mention two options- solar gain through insulation, solar gain through glass. Research effectiveness of two options, placing a hierarchy in framework.
Step 19: 'No comment on position in matrix. Intersecting in the thermal radiation increase part.'	Add title to page (Fabric: Thermal Radiation (Increase)).
Step 20: 'More information needed for options 2,3.'	Add more information and references for water-container wall. Add more information and references for thermosiphon air panel (TAP).
Step 21: 'More information needed for option 3.'	Add more information on 'intelligent' glazing systems. Separate 'intelligent' glazing systems into different options.
Step 22: 'Vertical louvres proposed but horizontal shown in picture. Contradiction.'	Update page with discussion on horizontal vs. vertical louvres. Link with vertical louvres option. Perhaps placement of louvres should be discussed somewhat in Orientation, as this step is inconsistent in layout. Address in framework restructuring.
Step 24: 'Ideal presentation. Materials for louvres not mentioned.'	Maintain format and use in other steps. Link to new appendix on building materials. Link to Fabric: Materials.
Step 25: 'No relevant step for thermal radiation increase. This mainly applies to hot climates.'	Link to new appendix on material properties/colors. Step required on increasing thermal radiation through color, or removal of this step and incorporation of both in other steps.
Step 26: 'No relevant step for thermal radiation increase. This mainly applies to hot climates.'	Link to new appendix on material properties/absorption. Perhaps add hierarchy of wall material

	properties as a step, and link to appendix for choice.
Step 27: ‘Same as step 39. References and suggestions could be helpful.’	Integrating, intermixing and juxtapositioning more to do with material properties than decreasing thermal radiation. Only have these options in Step 39. Step 27 could be integrated into movable solar control devices (Step 2, Option 2Bii)? In this case, function as building elements, fully integrated into design
Step 28: ‘Option 1: A bit early to know about mechanical equipment.’	Mechanical equipment not included in framework (unless relating to particular bioclimatic steps). Here mechanical equipment acts as a form of insulation. Rearrange options in Step 28 to reflect hierarchy.
Step 29: ‘2 options to be removed according to additional notes.’	Restructure section on Fabric: Airflow (Increase).
Step 31: ‘Option 3: There is only one roof. For every ceiling maybe?’	This step only applies to roof. However, noted that there needs to be some guidance on insulation, etc. between floors.
Step 32: ‘Rainwater also for flushing and showering if free of pollutants. Why overseen?’	Add option for rainwater use for flushing. Add option for rainwater use for showering. Note pollution levels.
Step 33: ‘Rainwater also for flushing and showering if free from pollutants. Why overseen?’	Add option for rainwater use for flushing. Add option for rainwater use for showering. Note pollution levels.
Step 36: ‘More information is required to make a decision.’	Add additional information and references.
Step 37: ‘More information is required to make a decision.’	Add additional information and references.
Step 38: ‘More information is required to make a decision.’	Add additional information and references.
Step 39: ‘Repeating step 27.’	Integration, intermixing and juxtapositioning only to be included in this step.
Step 40: ‘The additional notes sent to us must be incorporated.’	Incorporate additional information sent to students.

Step 41: 'The additional notes sent to us must be incorporated.'	Incorporate additional information sent to students.
Step 50: 'Should have been System-Water?'	Water step deals with conservation/quality of water. Solar hot water related to heating, using radiation.
Step 51: 'More information is required to make a decision.'	Add additional information and references.
Step 52: 'More information is required to make a decision.'	Add additional information and references.
Step 53: 'More information is required to make a decision.'	Add additional information and references.
Step 54: 'More information is required to make a decision.'	Add additional information and references.
Step 55: 'More information is required to make a decision.'	Add additional information and references.
Step 56: 'More information is required to make a decision.'	Add additional information and references.
Step 57: 'More information is required to make a decision.'	Add additional information and references.
Step 58: 'More information is required to make a decision.'	Add additional information and references.
Step 59: 'More information is required to make a decision.'	Add additional information and references.
Step 60: 'More information is required to make a decision.'	Add additional information and references.
Step 61: 'More information is required to make a decision.'	Add additional information and references.
References: Efficient services-supplementary materials' notes, Don Alexander	Reference document in Systems
References: http://www.cibse.org/pdfs/Datasheet04.pdf	Reference document in Fuel Cells (Step 56)
References: http://www.zae-bayern.de/english/division-2/north-facade.html	Reference in section introduction to wall material types (transparent insulation)
References: http://www.green-energy-efficient-homes.com/transparent-insulating-blinds.html	Reference in section introduction to Fabric: Thermal Radiation (Decrease) (insulated blinds) and to wall material types (transparent insulation)
References: http://www.consumerenergycenter.org/home/windows/windows_future.html#Photochromic	Reference in 'intelligent' glazing systems (Step 21, Option 3)
Cardiff Using Framework: Questionnaire 1	
Framework: 'Valuable when complete and when treated as a guidelines tool instead of a step-by-step process to be followed.'	Emphasize in the Introduction that framework is a guideline document, not meant to limit options.
Least useful: 'The last part about services'.	Add additional information and references on services. Framework not to focus on services.
Framework adversely affects building form.	Emphasize in the Introduction that framework is a guideline document, not meant to limit options.

	Add additional information and options in Step 1 and relevant steps.
Framework adversely affects water use and not at all.	Add additional information and options in Steps 32-38.
'The section of the window shading devices was the best structured part.'	Model sections on window shading, where each interaction relates to a building element.
'Some steps are comfusing and other even controversial. Set priorities.'	Improve upon information available in steps. Add alternative views in step information. Highlight particularly important steps in steps pages and in new information sheets.
'It needs to be complete and corrected at some points. The last part gives very limited guidance. Some steps were blank.'	Address with restructuring of framework and additional information.
'It has very limited reference to non-environmental aspects. Structure, aesthetics and other aspects could be added.'	Framework focuses on environmental aspects only. Note this in the Introduction, but provide references for other aspects for student information. Note where building form and fabric impacts on structure.
Did you find the recommendations in the framework or its structure restrictive? 'At some points yes; e.g. the first references to the orientation of the building restricted the building shape we could create to be able to follow the next steps.'	Emphasize in the Introduction that framework is a guideline document, not meant to limit options. Add additional information and options in Step 1 and relevant steps.
Please list the weaknesses of the framework that you have not already mentioned. 'Connection of framework to matrix not obvious, several errors and gaps, sometimes un-clear instructions.'	Discuss connection between framework and matrix more fully in the Introduction. Edit. Provide further information and links.
What non-environmental aspects of the design of tall buildings would the framework benefit from including? 'The interaction with the surrounding buildings. (eg consider right to light)'	Include information on context in 'Pre-Design' section.
'All the beneficial effects and the vast potential of this frameworks exist solely in the case of a concise, complete and correct final version of it.'	Address with restructuring of framework, editing and additional information.
Cardiff Using Framework: Questionnaire 2	
'Sometimes we just had to search through the internet for the specific meaning of some terms new to us, or for the exact operation of some	Provide a new Glossary. Add additional information and references.

techniques/technologies that were not stated in the framework.'	
'Some parts were a bit difficult to understand and to follow, as they were conflicting with each other. It was not easy to follow a one-way route towards the last step. Most times we had to go back and review previous assumptions.'	Improve clarity and edit. Add links table and notes in steps. Add alternative views in step information.
Which parts of the framework did you find most useful? 'The first parts that had the most details.'	Add additional information and references.
Which parts of the framework did you find least useful? 'Some parts in the end, which had no clues about the title stated on those pages. They were completely empty!'	Incorporate literature review and additional sources into framework steps. (Framework given only based on Yeang, without additional information). Provide a new Glossary.
Framework adversely affects building form.	Emphasize in the Introduction that framework is a guideline document, not meant to limit options. Add additional information and options in Step 1 and relevant steps.
Framework adversely affects structure of the building.	Note where building form and fabric impacts on structure. Include additional information on atriums in Orientation and Configuration and additional building use (e.g. office space at base).
Framework adversely affects outer building envelope.	This may be referring to glass options, as group had positive feedback on shading devices. Address with restructuring of framework and additional information.
Framework does not affect internal planning.	Incorporate internal planning into steps, particularly in Configuration.
Framework does not affect water use.	Add additional information and options in Steps 32-38.
'I think the process with the steps was helpful enough so as to decide if you are going right to the next step or you have to jump some steps according to your assumptions.'	Maintain steps format in framework reformatting.
'More details can be provided in the parts that contain terms and techniques/technologies difficult to understand. The blank pages (including title only) should be definitely filled with relevant information.'	Provide a new Glossary. Add additional information and references.
'There could be more details in some steps. It should be noted that the first steps are more than adequately	Add additional information and references.

explained.'	
'I am quite certain that Sabina has done a lot of research to come up with that path. However, from my point of view (and as long as I was involved in this project), I believe that it is very difficult to follow a one-way route towards the end. There are so many considerations relating to every single step and so many interactions and relationships among the distinct parts (e.g. thermal performance, lighting design, ventilation etc.) that you will always have to do turn-overs and go back and forth again.'	Add links table and notes in steps, particularly those that have already been completed.
Did you find the recommendations in the framework or its structure restrictive? 'Yes. For example, the plan of each floor of the building cannot be other than rectangular. This was a major constraint. You don't have many choices and you cannot be really creative within this context.'	Emphasize in the Introduction that framework is a guideline document, not meant to limit options. Add additional information and options in Step 1 and relevant steps.
Please list any errors you may have found in the framework document. 'These were stated in the presentation of the Environmental Design Application project. Some steps were kind of misplaced.'	Address with restructuring of framework and additional information.
Cardiff Partly Using Framework: Notes	
'The option to locate the core on the East-West side is not suggested until step 10 where it might be too late in order to relocate it'.	Address with restatement of text in Step 2. Add additional options in Step 2.
'Optimizing daylighting and natural ventilation are not considered at the same time and therefore different maximum values are suggested (Step 4-7). Furthermore, the steps are more applicable to open plan spaces. For apartments, the rule of the 6m meters will be more appropriate. The placement of the core in the east-west sides is a strategy suggested by Ken Yeang but it is suitable for hot tropical climates where parametric studies showed that it can reduce the cooling load significantly.'	Add links table and notes in steps, particularly those that have already been completed. Add information on internal planning. East-west core, as noted, not preferred for temperate climate. Address with restatement of text in Step 2. Add additional options in Step 2.
'The location of a building into the site is not mentioned anywhere in the framework. Some simple should be suggested (eg prefere north side of the side)'	Include information on context in 'Pre-Design' section.
'Further guidance should be provided in	Glare to be omitted from framework and

relation to how to reduce glare. For istance, make sure that the contrast between the two halves of the room is less than 1/3.'	discussed in non-environmental aspects in the Introduction. However, do mention in glass types advantages and disadvantages.
'Step 20: glazed thermal walls. There is not radiation in London for such strategy. It will be a good idea to provide the designer with strategies according to the climate which they design for. Step 24: solar control devices. Only horizontal devices have been taken into account. There is no guideline for vertical devices.'	Add additional information and references, highlighting sub-climates where particular steps unsuitable. Update Step 22 with discussion on horizontal vs. vertical louvres. Link with vertical louvres option.
'The guidelines are the same for both side and cross ventilation. It would be useful if some guidelines about the size of the inlets and outlets was provided. No specific instructions are given on how to reduce wind speeds.'	Restructure section on Fabric: Airflow (Increase). Add additional information on outlet/inlet sizes. Add further information and references on reducing wind speeds.
'It is quite useful in general because it makes sure that the designer does not forget to consider all the necessary steps for a successful sustainable design. However, it seems that it most oriented to the design of open plan spaces rather than residences. This was reflected in our design process since the initial plans followed this approach. For a successful sustainable design, a more holistic approach is needed; daylight, ventilation and thermal behaviour are needed to be taken into account at the same time ,since there is interaction between them. More some aspects some specialised guides are needed and some steps need to be clarified in more detail (flue wall for instance). Finally, little information is provided for services and there is no guideline about the size and location of the plant room.'	Add information on internal planning. Add links table and notes in steps, particularly those that have already been completed. Add additional information and references.
Cardiff Partly Using Framework: Questionnaire- Joint Response	
'We consulted eurocode 1 for the calculation of the wind profile. We made use of Daysim in order to calculate	Assess and include information in appropriate steps.

daylight autonomy. Also we consulted Double-skin Facades Oesterle, Lieb, Luz, Heusler, 2001 for the design of the box windows'.	
'The framework needs to address the main environmental aspects (lighting, thermal analysis, ventilation) in a more holistic way. In addition the framwwork suggests 15-20% glazing /wall ratio for good light penetration something that didn't work for our design'.	Add links table and notes in steps, particularly those that have already been completed. Add suggestions and cautions for steps that are not preferred.
Which parts of the framework did you find most useful? 'Steps 1 -29'.	Steps 1-29 were the most complete. Add additional information and references, especially to following steps.
Framework adversely affects structure of the building and not at all.	Note where building form and fabric impacts on structure. Include additional information on atriums in Orientation and Configuration and additional building use (e.g. office space at base).
Framework adversely affects internal planning and not at all.	Incorporate internal planning into steps, particularly in Configuration.
Improvement in structure: 'Back and forth between different aspects'.	Add links table and notes in steps, particularly those that have already been completed.
'It would be useful if references were provided or additional information to explain some aspects to a greater depth (eg step 29)'.	Restructure section on Fabric: Airflow (Increase). Add additional information and references.
Did you find the recommendations in the framework or its structure restrictive? 'It was restrictive in the process to choose a building form (only a rectangular form was considered in the framework)'.	Emphasize in the Introduction that framework is a guideline document, not meant to limit options. Add additional information and options in Step 1 and relevant steps.
'In step 2 the location of the core is examined. The possibility of locating the core in the west or east side of the building is examined in step 10 where it can be very late. The location of the building within the site it is not examined at all. No specific guidance is provided in order to reduce glare. We suggest that the contrast between the two halves of the room does not exceed the value of 1/3. Only horizontal shading devices are considered.'	Address with restatement of text in Step 2. Add additional options in Step 2. Rename Step 2 'Core Placement.' Include information on context in 'Pre-Design' section. Glare to be omitted from framework and discussed in non-environmental aspects in the Introduction. However, do mention in glass types advantages and disadvantages. Update Step 22 with discussion on horizontal vs. vertical louvres. Link with vertical louvres option.

	Perhaps placement of louvres should be discussed somewhat in Orientation, as this step is inconsistent in layout. Address in framework restructuring.
'Steps 4 and 7 suggest different maximum values for the maximum allowable floor depth. The framework provides exactly the same guidelines for both side and cross ventilation.'	Step 4 relates to Visible Radiation and Step 7 to Airflow. If both to be considered, hierarchy correct as is. Restructure section on Fabric: Airflow (Increase).
'It would be usefull if the framework suggests strategies for appropriate climates. For example the framework suggests the use of glazed thermal walls (step 20) a stetegy not appropriate for the climate of London where our building was located'.	Add additional information and references, highlighting sub-climates where particular steps unsuitable.
Cardiff Not Using Framework: Questionnaire- Joint Response	
'Architect Engineers. An architect can benefit from the framework as a basis for a tall building design However, there are plenty of other issues to be considered and thus it is essential that there is a cooperation among other professions (such as civil and mechanical engineers) in order to realize the project.'	Add information in the Introduction and in new information sheets for each interaction on involvement of other professionals.
Nottingham: Using Framework: Notes	
Step 2: 'due to the building being triangular in form and north of site were the river views'.	Correct understanding of framework in that it shouldn't prohibit other forms. Nonetheless, due to notes from Nottingham group, emphasize in the Introduction that framework is a guideline document, not meant to limit options.
Step 4: 'essential knowledge to allow for to maximum growing space'.	Comments suggest students want information relating to measurements, so use of elements as interactions and sizing of elements to be used throughout.
Step 5: 'height was double storey'.	Include options for double height spaces, especially as they relate to Configuration: Airflow (Increase).
Step 8: 'lower one of the building had louvres and canopy to stop the wind from blowing at groundlevel'.	Zonining of the building to be specified according to height. Link zoning to particular Airflow (Decrease) strategies in Configuration and Fabric. Include information on context in 'Pre-Design' section.
Step 14: 'had north facing glass due to	Correct understanding of framework in

river views'.	that it shouldn't prohibit other orientations. Nonetheless, it should discuss impact of alternative orientations.
Step 16: 'used double glazing glass. as single glaze would loses too much heat that was required for containing heat levels for plant growth.'	Single glazing to be avoided as it would lose much heat. Provide hierarchy in step. Research and discuss glazing further.
Step 20, Option 4: 'wanted as much heat energy to be absorbed by plants'.	Research and discuss levels of lighting needed for plant growth in Fabric: Visible Radiation (Increase).
Step 21, Option 2: 'due to plant growth maximum solar heat gain was always required'.	This group's objective was specific and beyond the framework's focus. Nonetheless provide list of plants and requirements in new appendix on vegetation.
Step 22: 'horizontal shading devices were used on east and west facade only in the office section of the building not higher up in the residential or growing spaces'.	Correct understanding of framework in that it shouldn't prohibit other orientations. Nonetheless, it should discuss impact of lack of east/west shading.
Step 28, Option 1: 'the vertical tower required a constant mechanical floor after every section/village'.	The location of mechanical floors is beyond the aim of the framework. Framework to reduce number of mechanical floors. However, perhaps include information related to mechanical floors in sections on zoning (e.g. Step 8).
Step 28, Option 3: 'orientated to collect solar panel as well as acting as a water collection surface'.	Link step with photovoltaics. Discuss relationship between tilt of photovoltaics and energy output. Link roof (and façade) to Fabric: Water.
Step 29, Option 1B: 'mix of option 1a and 1b'.	Options function for different purposes so cannot be used at same time. Discuss compatibility, provide links and address with restructuring of framework.
Step 29, Option *: 'got confused with all the * and **'.	Label all steps and sub-steps with numbers and letters. Address with restructuring of framework.
Step 29, Option **: 'did not really understand what leeward was'.	Provide a new Glossary. Clarify leeward in step with image.
Step 30, Option 1: 'had growing platforms which i assume is similar to skycourts?'	Add image of skycourts, and skycourt types. Link skycourts to Fabric: Materials (e.g. Step 39 and Step 40). Link skycourts to external fixed shading devices. (Step 24, Option 1).
Step 30, Option 2: 'not sure'.	Research stack effect, particularly as a

	strategy in tall buildings.
Step 30, Option 3: 'had atrium like space in each growing/residential village but glass atrium not as roof but as the south facing wall'.	Discuss atrium types and provide options. Include information on atriums in Configuration: Visible Radiation (Increase) (Step 5).
Step 33: 'rainwater collection was used to water the plants in a way it was landscaping?'	Landscaping here refers to context, rather than the building. Remove this step, but refer to 'Pre-Design' section.
Step 34: 'water recycling played a major role in our design. check out the our booklet and it will have more details in it.'	Add additional information. Include relevant information provided in student booklet.
Step 36: 'not sure we went into that much detail'.	Framework not to discuss plumbing in detail. Quantify 'low-flow' and link to rainwater steps (Steps 32-33).
Step 37: 'not sure we went into that much detail'.	Framework not to discuss appliances in detail. Quantify appliance types.
Step 38: '?'.	Research and include further information. Framework not to discuss M & E in detail.
Step 40, Option 5: 'not sure what the difference between skygarden and skycourt'.	Add image of skygardens, and skygarden types. Link skygardens to Fabric: Materials (e.g. Step 39 and Step 40).
Step 41, Option 1: 'positioning of trees are shown in a plan in the booklet. the types of trees and species was dependent on the residence who grew them and thus not part of the design process'.	Add relevant information from student booklet.
Step 42: 'didnt go into detail of designing from renewable sources.'	To avoid overwhelming section on materials, provide basic guidelines in steps and link to new appendix on building materials.
Step 50: 'was part of design consideration refer to booklet'.	Add relevant information from student booklet.
Step 57: 'used PV on roof as well as facade design on the NW and NE facade refer to booklet'.	Add additional information. Add relevant information from student booklet. Discuss relationship between tilt and orientation of photovoltaics and energy output. Link photovoltaics with Configuration: Visible Radiation (Increase).
Step 60: 'did use biofuel. explained in booklet'.	Add additional information. Add relevant information from student booklet.
Nottingham Using Framework: Questionnaire	
In what ways did you find the framework	Comments suggest students want

added to your assumptions about environmental design? 'gave measurements that were useful such as step4,5,7'.	information relating to measurements, so use of elements as interactions and sizing of elements to be used throughout.
Which parts of the framework did you find most useful? 'floorplate depths and floorplate configurations'.	Comments suggest students want information relating to measurements, so use of elements as interactions and sizing of elements to be used throughout. Include plans in images and explanations.
Which parts of the framework did you find least useful? 'parts without the pictures. and parts that was repeated was a little confusing. the parts with * and ** with multiple options was confusing'.	Add additional information and references. Add additional images. Address with restructuring of framework.
Framework does not affect building form at all.	Correct understanding of framework in that it shouldn't prohibit other options. Nonetheless, it should discuss impact of alternative forms, particularly in new information sheets for each interaction. This is particularly important in the early steps.
Framework does not affect lighting design at all.	Framework not to discuss lighting design in detail. Nonetheless, it should provide some useful basic guidelines.
Framework does not affect water use at all.	Framework not to discuss lighting design in detail. Nonetheless, it should provide some useful basic guidelines.
Framework does not affect material selection at all.	Framework not to discuss lighting design in detail. Nonetheless, it should provide some useful basic guidelines.
Framework does not affect use of renewable technologies at all.	Framework not to discuss lighting design in detail. Nonetheless, it should provide some useful basic guidelines.
Improvement in structure: 'sometimes when the yes and no next step was the same it was confusing to understand what difference it made'.	Clarify that steps join at each interaction in matrix in the Introduction. List and quantify number of design variations possible while using framework.
Improvement in clarity: 'maybe colour images would be helpful'.	Include color images where appropriate.
Improvement in guidance: 'more information or consistant amount of information per page'.	Add additional information and references. Aim to have all information for an option on a single page.
Did you find the recommendations in the framework or its structure restrictive? 'it was unadaptable for a building not in the form of a rectangle but that was	Emphasize in the Introduction that framework is a guideline document, not meant to limit options.

mainly in regards to core placement'.	Add additional information and options in Step 1 and relevant steps.
What non-environmental aspects of the design of tall buildings would the framework benefit from including? 'circulation'.	Discuss circulation in Configuration: Visible Radiation (Increase) (Step 4 and Step 5) and link to Step 2. Perhaps a new step required for overall building plan.

Welsh School of Architecture
MSc Environmental Design of buildings

Environmental Design Application
Tall buildings group
Anna Afiontzi & Aikaterini Chatzivasileiadi

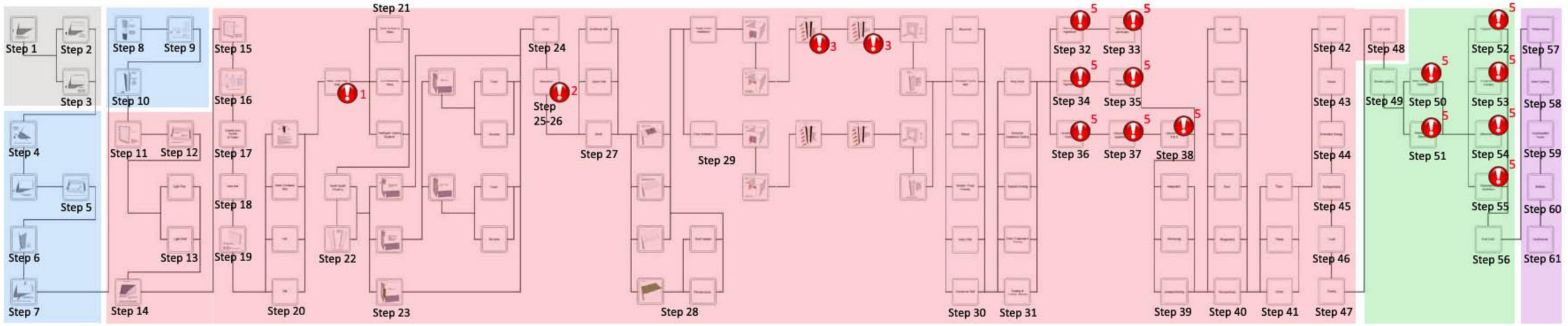


Figure 1: Framework flowchart

Table :1 Matrix indicating the relationship between resources and sections of the framework and discrepancies detected

			Orientation	Configuration	Fabric	System	Renewables
Inexhaustible resources	Visible	Increase					
	Radiation	Decrease				6	
	Thermal	Increase					
	Radiation	Decrease		6			
	Airflow	Increase					
		Decrease			6	6	
Exhaustible resources	Water					6	
	Materials						
	Land						

Table :2 Colour coding for the framework flowchart

Colour coding	
Colour	Chapter
	Orientation
	Configuration
	Fabric
	System
	Renewables

Design paths: *Following the framework faithfully*

• All the options offered in the framework will be considered and the members of the team will respond to them as directed.

• If the members of the team find something difficult to understand, they will respond as best as they can rather than consult the author.

• If an aspect of design is not mentioned, this allows the members of the team the freedom to do whatever they think best with respect to that.

Objectives

• Study how a tall building for a fairly central site in London can be designed to maximize sustainability

• Assessment of framework

Table 3: Discrepancies of the framework and meaning

	Discrepancies
1	This step doesn' t exist in the framework.
2	This must be a conjunction of two relevant existing steps.
3	These will be deleted (additional notes).
5	Conflict between arrangement in the flowchart and the framework.
6	There are no steps relative to these parameters, they are overseen.

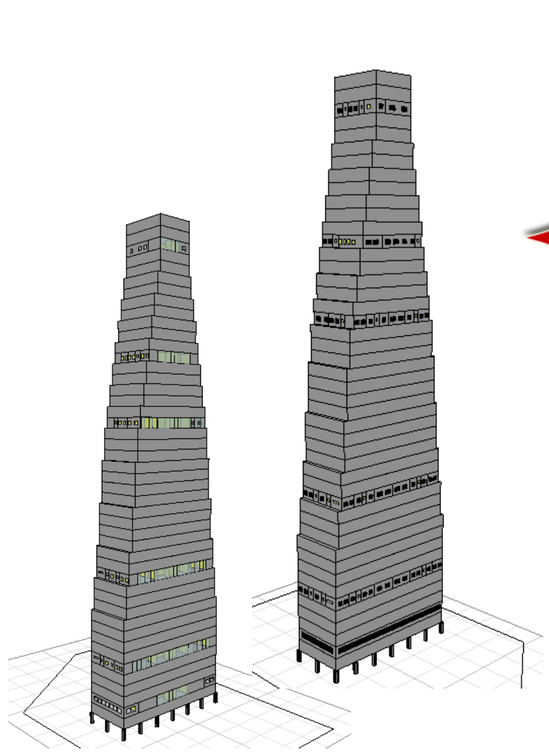
Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

Table 4: Framework steps and decisions

Steps	Matrix position	Title	Choice
1	Orientation/ Thermal radiation (Increase)	Building orientation	Yes
2	Orientation/ Thermal radiation (Increase)	Primary mass location	Yes. Option 2
3	Orientation/ Airflow (Increase)	Building orientation	No
4	Configuration/ Visible radiation (Increase)	Floor-plate configuration	Yes
5	Configuration/ Visible radiation (Increase)	Floor-plate configuration	Yes
6	Configuration/ Thermal radiation (Increase)	Built form ratio	No
7	Configuration/ Airflow (Increase)	Floor depth	Yes
8	Configuration/ Airflow (Increase)	Height zones.	Yes
9	Configuration/ Airflow (Increase)	Ground floor	Yes
10	Configuration/ Airflow (Decrease)	Building core	No
11	Fabric/ Visible radiation (Increase)	Glass	Yes
12	Fabric/ Visible radiation (Increase)	Glare	Yes
13	Fabric/ Visible radiation (Increase)	Passive daylight devices	No
14	Fabric/ Thermal radiation (Increase)	Glass	Yes
15	Fabric/ Thermal radiation (Increase)	Glass	Yes
16	Fabric/ Thermal radiation (Increase)	Glass: glazing	Yes. Option 1,2
17	Fabric/ Thermal radiation (Increase)	Double and triple façade	No
18	Fabric/ Thermal radiation (Increase)	Heat sink materials	No
19	Fabric/ Thermal radiation (Increase)	Wall Insulation	Yes
20	Fabric/ Thermal radiation (Increase)	Glazed thermal walls	Yes. Option 4
21	Fabric/ Thermal radiation (Decrease)	Glass	Yes. Option 3
22	Fabric/ Thermal radiation (Decrease)	Solar control devices	Yes
23	Fabric/ Thermal radiation (Decrease)	Solar control devices	Yes
24	Fabric/ Thermal radiation (Decrease)	Solar control devices	Yes. Option 2Aii
25	Fabric/ Thermal radiation (Decrease)	Wall material color	No
26	Fabric/ Thermal radiation (Decrease)	Wall material absorption properties	No
27	Fabric/ Thermal radiation (Decrease)	Vegetation	Yes. Option?
28	Fabric/ Thermal radiation (Decrease)	Roof	Yes. Option 4A
29	Fabric/ Airflow (Increase)	Ventilation	Yes. Option $1A^{3,4}$, $2A^{1,3,4}$
30	Fabric/ Airflow (Increase)	Stack ventilation	No
31	Fabric/ Airflow (Increase)	Comfort ventilation	Yes. Option 2
32	Fabric/ Water	Rainwater- Vegetation	Yes
33	Fabric/ Water	Rainwater- Landscape	Yes
34	Fabric/ Water	Greywater- Vegetation	Yes
35	Fabric/ Water	Greywater- Landscape	Yes
36	Fabric/ Water	Groundwater- Fixtures	Yes
37	Fabric/ Water	Groundwater- Appliances	Yes
38	Fabric/ Water	Groundwater- M & E	Yes
39	Fabric/ Materials	Vegetation	Yes. Option 2
40	Fabric/ Materials	Vegetation elements	Yes. Option 1,4,6
41	Fabric/ Materials	Vegetation types	Yes. Option 2,3
42	Fabric/ Materials	Inanimate materials- Sources	Yes
43	Fabric/ Materials	Inanimate materials- Reuse	Yes
44	Fabric/ Materials	Inanimate materials- Embodies energy	Yes
45	Fabric/ Materials	Inanimate materials- Biodegradable	Yes
46	Fabric/ Materials	Inanimate materials- Local	Yes
47	Fabric/ Materials	Inanimate materials- Toxicity	Yes
48	Fabric/ Materials	Inanimate materials- Life cycle	Yes
49	System/ Visible radiation (Increase)	Efficient lighting	Yes
50	System/ Thermal radiation (Increase)	Solar hot water	Yes
51	System/ Thermal radiation (Decrease)	Radiant heat barrier	No
52	System/ Airflow (Increase)	Propeller fans	Yes
53	System/ Airflow (Increase)	Evaporative coolers	No
54	System/ Airflow (Increase)	Dehumidifiers	Yes
55	System/ Airflow (Increase)	Displacement ventilation	No
56	System/ Materials	Fuel cells	Yes
57	Renewables/ Visible radiation	Photovoltaics	Yes
58	Renewables/ Airflow	Wind turbines	No
59	Renewables/ Water	Hydroelectric power	No
60	Renewables/ Materials	Biofuels	No
61	Renewables/ Land	Geothermal	Yes



Framework



Framework assessment

Steps	Comments
1	South orientation is dominant in the framework, deviation would complicate the procedure.
2	Different meaning of the primary mass for the two options. More options several steps ahead.
3	Deviation from south would complicate the procedure.
4	No comments.
5	Orientation for the façade not specified; the one facing the dominant winds? Single-sided only.
6	Corrupted picture. Confusing.
7	There is no guidance for an atrium further ahead.
8	A bit early for ventilation devices- configuration section.
9	No comments.
10	Mentioned again in step 2. Factor weighing.
11	A summary table for glass would be useful. Mentioned for different parameters and steps.
12	Visible radiation- Decrease maybe?
13	Pictures, operation, advantages, disadvantages, comparison, references would be helpful.
14	Thermal radiation decrease maybe? Only north façade mentioned.
15	No comments.
16	Variation between facades not mentioned.
17	No comments.
18	Confusing; heat sink material to increase thermal radiation and insulate?
19	No comment on position in matrix. Intersecting in the thermal radiation increase part.
20	More information needed for options 2,3.
21	More information needed for option 3.
22	Vertical louvers proposed but horizontal shown in the picture. Contradiction.
23	No comments.
24	Ideal presentation. Materials for louvers not mentioned.
25	No relevant step for thermal radiation increase. This mainly applies to hot climates.
26	No relevant step for thermal radiation increase. This mainly applies to hot climates.
27	Same step as 39. References and suggestions could be helpful.
28	Option 1: A bit early to know about mechanical equipment.
29	2 options to be removed according to additional notes.
30	No comments.
31	Option 3: There is only one roof. For every ceiling maybe?
32	Rainwater also for flushing and showering if free of pollutants. Why overseen?
33	Rainwater also for flushing and showering if free of pollutants. Why overseen?
34	No comments.
35	No comments.
36	More information is required to make a decision.
37	More information is required to make a decision.
38	More information is required to make a decision.
39	Repeating step 27.
40	The additional notes sent to us must be incorporated.
41	The additional notes sent to us must be incorporated.
42	No comments.
43	No comments.
44	No comments.
45	No comments.
46	No comments.
47	No comments.
48	No comments.
49	No comments.
50	Should have been System- Water?
51	More information is required to make a decision.
52	More information is required to make a decision.
53	More information is required to make a decision.
54	More information is required to make a decision.
55	More information is required to make a decision.
56	More information is required to make a decision.
57	More information is required to make a decision.
58	More information is required to make a decision.
59	More information is required to make a decision.
60	More information is required to make a decision.
61	More information is required to make a decision.

General comments

- The framework **matrix**, which is a tool to present factors to be considered during the procedure, should have been explained better.
- Also, considering the **matrix**, the factors to been taken into account, are highlighted but they haven't been given an importance factor. Is this because the editor considers that it is subjective or varies for different sites or it was just neglected? Someone will need some guideline about this, for the framework to work as a tool, since some contradicting choices depend upon this.
- There are some **parameters** mentioned in the matrix that are omitted in the framework.
- The **flowchart** is a good idea, to help the designer, but this is cannot be the final one. Discrepancies have been noticed, the resolution is poor and we consider that a less linear approach would be more appropriate.
- There is no mentioning of the **surrounding** area and how this affects the building design. This is a major omission; some general principals should be mentioned. This would affect the position on the building in the site, which is also not mentioned.
- Several steps lack supporting **information** and comments. None of them has specific sources, although some were sent to us afterwards.
- Defects have been located in some of the steps which are mentioned in the analytic table on the side.
- When options or suggestions are given that relate of affect some previous choices, a **footnote** should be made to make sure the designer will go notice and consider both before deciding.
- A lot of pages are **blank** with only a title. This makes the framework look unfinished. This is predominant phenomenon towards the end, especially in the system and renewables section.
- There seems to be a feeling of confusion during some steps, deriving not so much from the sequence of the steps, as from their **internal relationships**.
- Some steps are more "**office oriented**" than "residences oriented" e.g. residential buildings require smaller ventilation rates -> lower internal gains per m^2. Also, a lot of the references are for office buildings that have to cope with higher internal gains.
- There is a great focus on **Yeang's** work. When he has not elaborated on a specific subject, there seems to be an inconsistency in the framework. This is not Yeang's framework and should be enriched with general principles and strategies for these cases.
- There is no consideration of social parameters like privacy, common areas, social interaction of the residents etc.
- **Spelling** mistakes are appearing in several steps.
- There is a great focus on **vegetation**.
- There should be some indication on important steps that they should better not be rejected.
- Sub-categorizing of choices seems to be incoherent sometimes. Also some steps could be options of one step.

Making assumptions…

- For the framework to be followed strictly, some features have to be assumed.
- A rectangular plain.
- A south orientation of the largest façade.
- An orientation of the building aligned to the 4 points of the horizon. Always mentioning E, W, N, S façade.

Worth including

The Urban Heat Island phenomenon, resulting in vertical variation, is not that much included in the steps.
Up-going winds endangering shading devices.
Option for top lighting

CONCLUSION

Designing following strictly the framework results in assumptions and limitations in the designing process. This is not only a problem referring to this specific piece of work, but we consider that such attempts should reach a level of high detail and accuracy to be considered design guides and still will not be able to cover all the possible choices.
It is apparent that it is still a work in progress and needs refinement, additions, corrections, context and summarizing.
We consider this to be overall a good effort. It would be much more helpful as a guide or a checklist when it is finished.

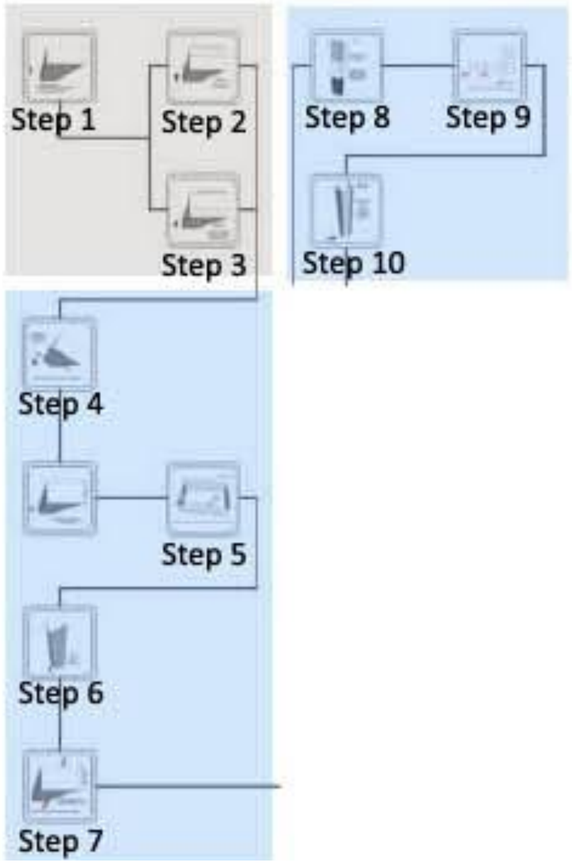
REFERENCES

Efficient services- supplementary materials' notes, Don Alexander
http://www.cibse.org/pdfs/Datasheet04.pdf
http://www.zae-bayern.de/english/division-2/north-facade.html
http://www.green-energy-efficient-homes.com/transparent-insulating-blinds.html
http://www.consumerenergycenter.org/home/windows/windows_future.html#Photochromic

Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

Design: Part_01

Figure : Framework_Part01



Orientation

•We choose a south orientation (step1) and a north location of the primary core mass- stairs and elevators (step2), to increase thermal radiation.

•To be able to keep our due south orientation we didn't rotate to increase airflow (step3).

Configuration

•Our plan is about 14m deep to increase visible radiation (step 4) and airflow (step5).
•We choose a reduced plan as the height increases to intensify the upwards going winds (we do not want wind going downwards, because it will affect the pedestrians and surrounding environment). The inspiration for this comes from step 8 that implies a need for variation with height.
•The bottom flow is chosen to be open to outside in summer to increase airflow and create a transitional space (step 9).

•In step 6 we chose following the guidelines for visible rather than thermal radiation; the depth would otherwise have to be about 23 m.
•We don't consider any ventilation devices (step 8).
•Considering step 10, we stick to the choice of northern centered mass location (core). Because of the prolonged shape of the building, the stairways and elevators should be in a central position to avoid creating a long path to the nearest exit (about 25 m maximum distance, from doors).

Figure 2: Orientation, depth, primary mass location.

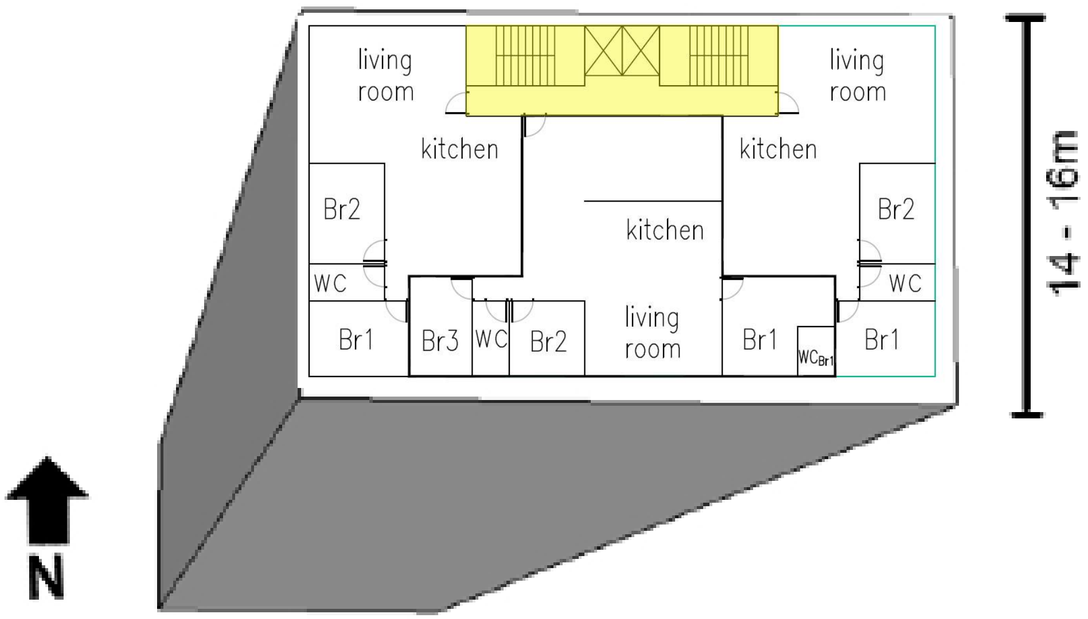
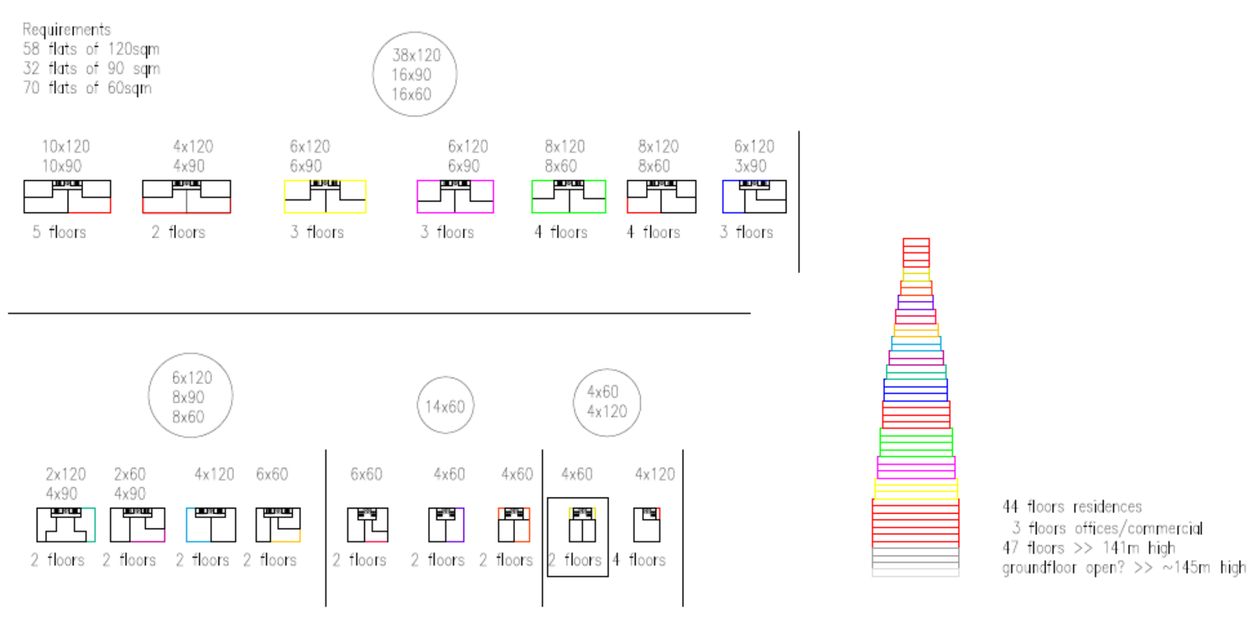


Figure 3: Primary building and plan forms and calculations



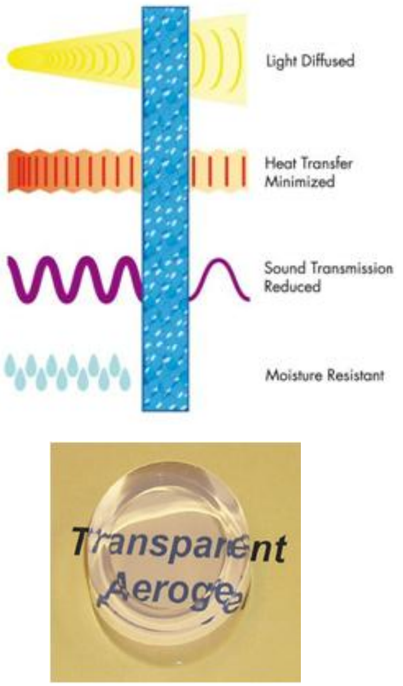
Design: Part_02

Fabric

•Clear glass chosen for openings (steps 11, 15) to increase visible and thermal radiation.
•To protect from glare (step 12: Visible radiation-Increase), we choose to follow the instructions for good light penetration, assuming a **15-20% glazing** for the **south** and **north** facades (since the building is designed to be lit mainly through them). For the **west** façade, due to dominant W-SW winds for the 11 months of the year, we chose a smaller ratio or will apply some way to protect it (15%). For the **east** façade we keep a ratio of 20%. **Office** and **commercial** floors have larger glazing areas since they are overshadowed by the surrounding buildings most of the time of the day.
•We choose to minimize north facing glass as suggested in step 14; 15% of glazing rather than 20%.
•We choose to use double glazing for all the facades and single glazing for a part of the south one to increase thermal radiation (step 16). **Vertical variation**. Considering the overshadowing by neighboring buildings and the airflow we choose to use single glazing for the 6 lower floors of the **south** facade (1 commercial, 2 offices and 3 residential - 25m). Single glazing will allow more daylight into the building and more solar radiation during the heating period. It is limited to the lower floors though to avoid heat loss from winter winds and to be in the "protected" by the urban heat island warm area.
•The walls will be insulated as suggested in step 19.
•We choose to incorporate Transparent Insulation Materials (TIM) in our design (step 20). It will be used in the **north** façade, which requires daylight without being ideal for large ratios of glazing. Instead of 15% (the lowest ratio) of glazing we can have about 10% of glazing with another 10% of TIM (or more since it has lower transparency and thermal conduciveness) behind glass. Thus, we insure solar radiation and daylight without the danger of heat loss. The material we will use is aerogel.

•Special daylight devices like light tubes and light selves can be used only if considered essential for day-lighting after modeling (step 13).
•We choose to not use this option of ventilated double or triple skins; we consider it more appropriate for hot and humid climates (step 17).
•Heat sink materials will not be used in the fabric (step 18).
•A Trombe wall reduces the area for windows in the south façade, that is why it was rejected in step 20.

Aerogel (step 20) is a gel in which the liquid component has been replaced with a gas. The result is an extremely low-density translucent solid, with a huge effectiveness as a thermal insulator, because the nanoporous filled of air.
Nanogel ® aerogel is reusable and ecological systems, and is created through a closed loop process with little to no impact on the environment.
The translucent granulate has a high porosity of over 90% with pore diameters of prox. 20 nanometer. This literally freezes the air-molecules and thus achieves an unsurpassed thermal insulation with an U-value of 0.64 [W/m2K] per 25 mm.
Moreover, aerogel provides good light transfer, sound reduction and are moisture resistance.



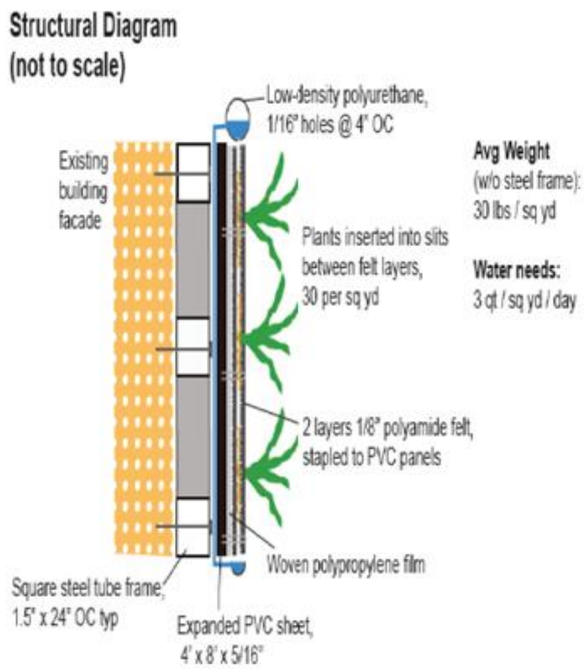


Figure: Vegetation

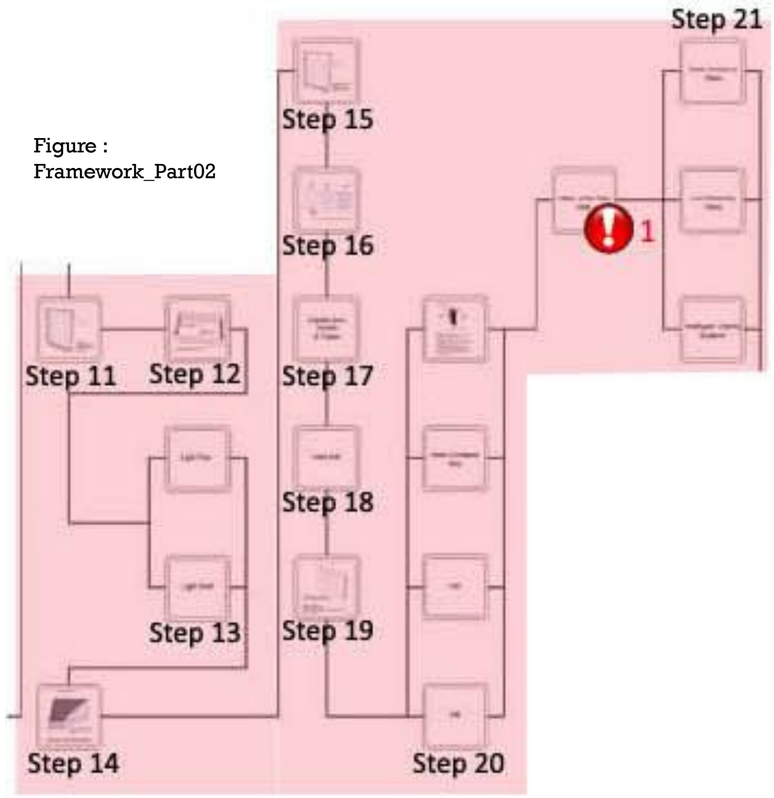


Figure : Framework_Part02

Design: Part_02

Fabric

•Other than clear glass (step 21) we are using electrocromic rather than photochromic glass (our first choice) on the southern parts of the East and West facades.
•For the **east** façade, the overshadowed area is 8 floors for the morning hours (shading snapshots for Mike).
•Vertical louvers will be placed on the **west** façade of the north facing apartments, above the 29th floor and on the **east** façade above the 8th floor (step 22- shading snapshots for Mike). Horizontal louvers will be also placed on the **south** facade (step 23).
•The external louvers choice is suggested to be the most efficient one (step 24), to control thermal radiation. We use **horizontal louvers (material tinted glass)** for the **south** façade which will be movable (being retracted to the top of the opening when no sun or during the night- Zurich building "Ta media"). For the **vertical** louvers on the **east and west** façades, we chose **movable transparent insulating** material (aerogel); they can be closed at night to reduce heat loss. For the **office** floors, we introduce internal operable blinds.
•We choose an inxtermixing option for **vegetation** (step 27), distributing green patches on the south, east and west facades of the building. These patches extend on the width of each façade and between the window areas. There is also vegetation on the roof and on the "steps" on the east and west facades.
Advantages: Cool, insulate, aesthetics, pollution, ambient temperature, ambient environment quality, reduce air speed and "protect" the louvers.
Disadvantages: Maintenance, Conservation, Structural.
•For the roof (step 28) we choose a combination of roof garden with pergola, to be used also as a common space for the residents.
•Step 29 refers to ventilation.
•**Single sided ventilation**: We choose this option for the residential flats that mainly do not have access on both the windward and leeward side of the building. We also choose Option 1A- Comfort air path location but with 1m windows, with distance 1m from the floor level. Also choose a ventilation control system- Option ***; the windows will be able to be opened and closed to the inside of the building or sliding manually. The windows will be recessed- Option****.
•**Cross ventilation**. We choose this option for the commercial and office floors that have an open plan. We also choose Option 1A- Comfort air path location but with 1m windows, with distance 1m from the floor level. Also choose a ventilation control system- Option ***; the windows will be able to be opened and closed to the inside of the building or sliding manually. The windows will be recessed- Option****.
•Our windows will be operated by a double **system** that allows them to be opened as an inclination of the top and of the side.
•**Nocturnal ventilative** cooling (comfort ventilation, step 31) to be combined with the cross and single sided ventilation for the cooling period. Take into consideration that we will have to use thermal mass for this method to have high efficiency- mostly for the floor area.

•We mainly have a heating issue, so we prefer darker colours with medium-high absorptance (steps 25, 26).
•We have chosen to ventilate through one sided and cross ventilation before, stack ventilation is not required (step 30).

Photochromic glass has yet to be done successfully on a large-scale, commercial level for window-sized pieces. An **electrochromic** window, on the other hand, can change from clear to fully darken or any level of tint and is operated manually. The action of an electric field signals the change in the window's optical and thermal properties. Once the field is reversed, the process is also reversed. The windows operate on a very low voltage -- one to three volts -- and only use energy to change their condition, not to maintain any particular state.



Façade variation-thermal and visible radiation: Chosen for the **west** façade of the south facing apartments, from the 29th floor (84m) and up (below that level there is shading effect from the high rise building on the west). The south facing façade will have to be shaded, so we choose a measure of shading for the apartments west side that will not limit daylight and view. This measure is restricted from the north facing apartments since they will be able to have view and daylight from the north (no shading is required), and so shading devices (eg vertical louvers) can be used here. (Snapshots with highlighted variation).

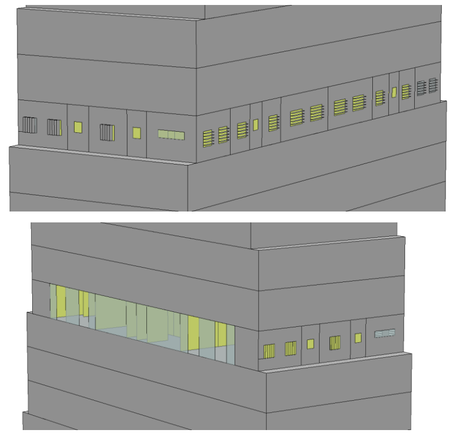


Figure : SW (above) and NW (below) views of the building

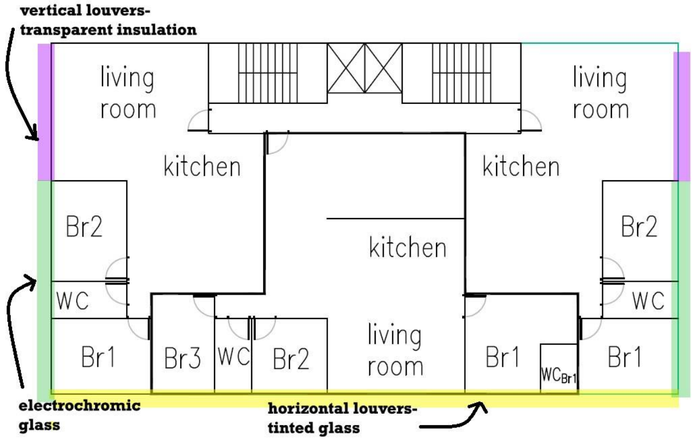


Figure : Façade variation for Visible radiation (Decrease)

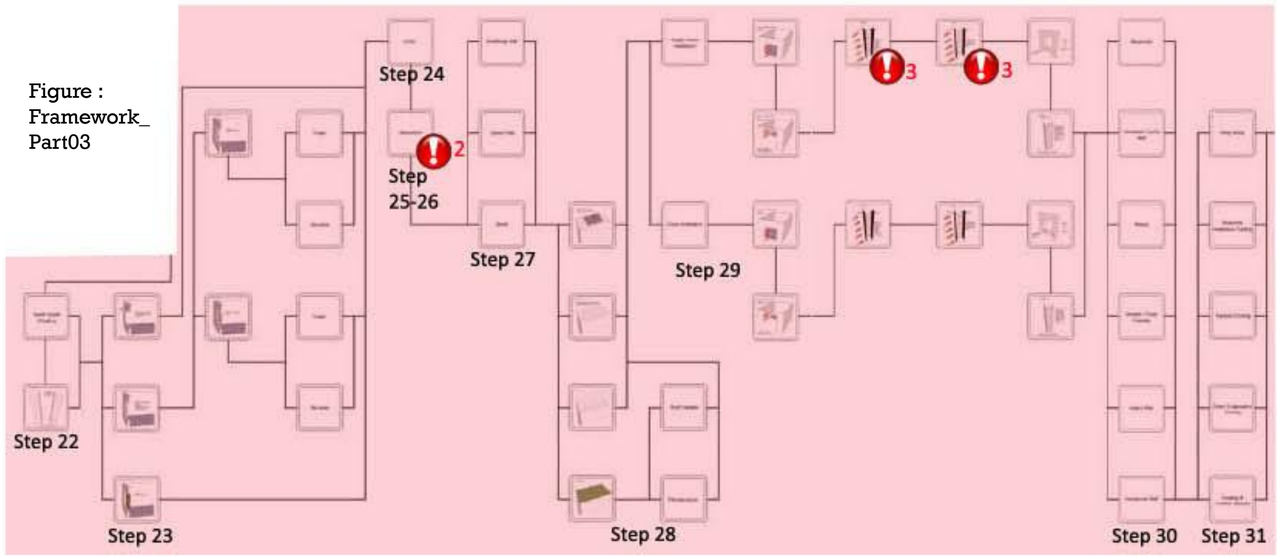


Figure : Framework_ Part03

Design: Part_03

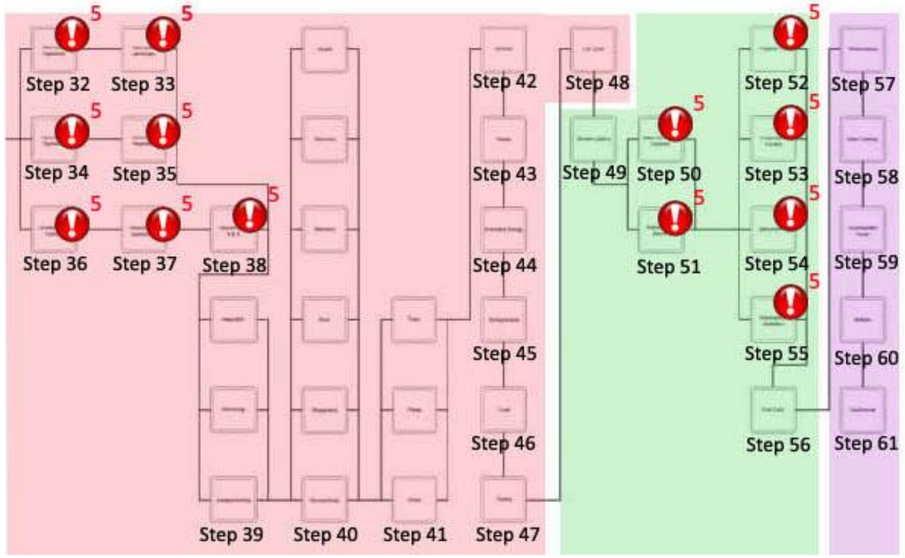


Figure : Framework_Part 04



Figure : Wall construction

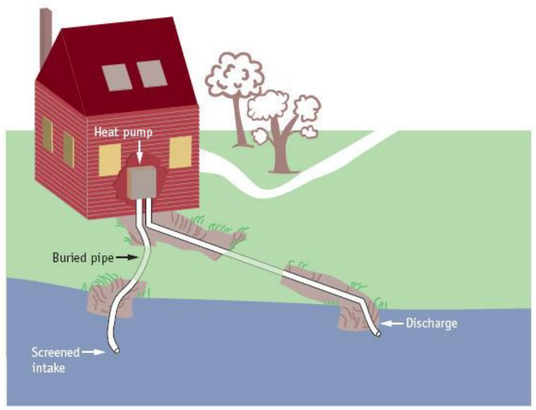


Figure : Open loop Water Source Heat Pump (WSHP)

Fabric

•We choose to collect rainwater for watering the green patches and landscape (steps 32, 33). Rainwater can be also used in the bathrooms for flushing and shower if clean from pollutants.
•We choose to use greywater for watering the green patches and landscape (steps 34, 35).
•The vegetation types (step 41) are trees and plants for the site, plants for the roof and grass for the facades and steps.
•The inanimate materials used will be complying, on some level with the requirements in steps 42-48; Local sources, reusable, recyclable, low embodied energy, biodegradable, non- toxic. Use **of steel structure frame** as proposed in step 44 (reinforced concrete frame construction almost the same embodied energy as steel but less recyclable; steel can be used the same way as functional units-beams (Reusable) while concrete ,mainly as aggregate. (recyclable and reusable step 42- lightweight step). Concrete prefabricated slabs for internal **floors** on steel infrastructure (thermal mass for night insulation). Walls- multilayer panels.

•We assume to adopt groundwater solutions (steps 36, 37, 38) if available and feasible.

Systems

•Efficient lighting techniques (modeling, artificial lighting design, low energy consumption lamps etc) will be incorporated as proposed by step 49.
•Solar hot water from photovoltaic panels (PV) and Water Source Heat Pumps (WSHP) for step 50.
•Propeller fans (step 52) and dehumidifiers (step 54), used in the auxiliary mechanical ventilation system proposed, including a heat exchanging unit.
•Fuel cells (step 56) will be used as auxiliary system of energy production, in addition to WSHP and PVs.

•No use of radiant heat barrier (step 51), nor evaporative coolers (step 53).
•Displacement ventilation (step 55), works better for large volumes of air (halls, auditoriums, stadiums).

Renewables

•PV panels (step 57) will be replacing the vegetation on the south façade and roof. Roofs have the best efficiency for PVs; we will put them inclined to be normal to the solar noon. The next best thing for efficiency is due south facing panels. They will be placed across the south façade's width in "stripes" between the windows.
•We are not going to use exactly geothermal energy (step 61) but the WSHP used instead of GSHP, usually fall under this category. They are more efficient (water is better than ground for thermal capacity and transfer) and there is the Thames river nearby to supply the required water volume.

•Wind turbines (step 58); we consider there is not enough wind-power to justify such a choice in comparison to capital costs.
•The same applies for hydro-electric power (step 59).
•Biofuels (step 60) are not considered essential.

An energy consumption analysis should be made, considering our results from the thermal and lighting analysis, to calculate the energy load and decide on the final combination of systems to be used

Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

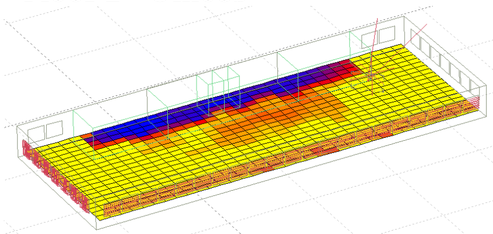
Daylight analysis

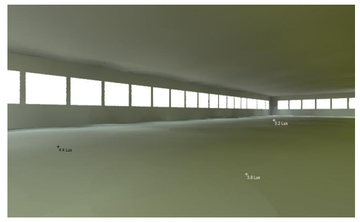
Winter solstice – 21 December, solar noon

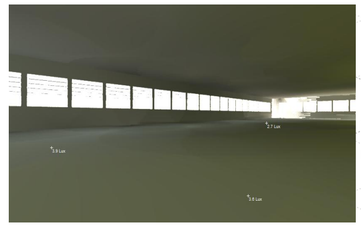
Summer solstice – 21 June, solar noon

Six floors with different interior arrangement of the flats are selected for daylight analysis. One of them , the lowest one, has office use, while the rest are residences. On the left hand side of the poster, the daylight factor in each floor for the winter solstice is presented. On the right hand side, respectively, the daylight factor for the summer solstice is presented. Some snapshots depicting interior views of the flats are also provided next to each floor. It should be noted that the exterior louvers have been orientated according to London's sunpath diagram, avoiding the summer sun and accepting the winter sun.

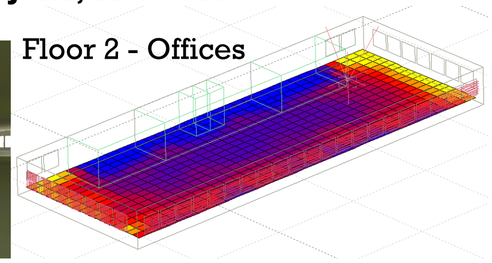
Floor 2 - Offices



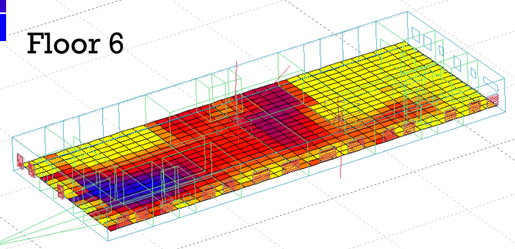


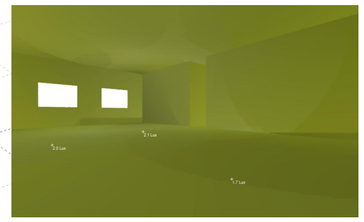


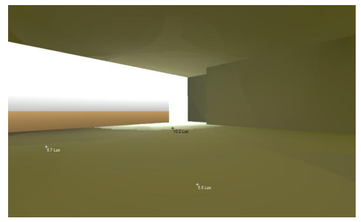
Floor 2 - Offices

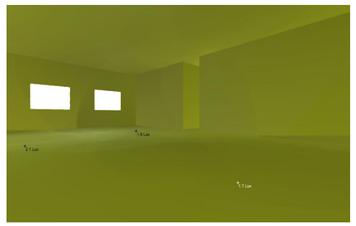


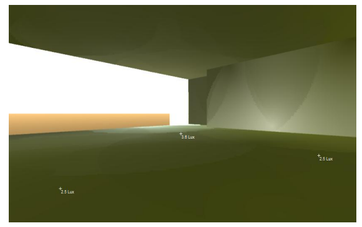
Floor 6



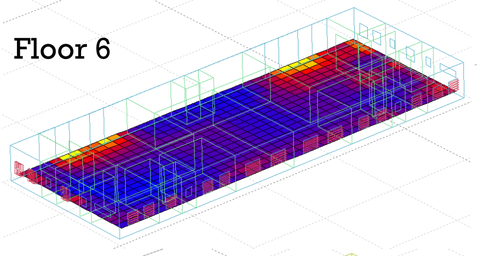




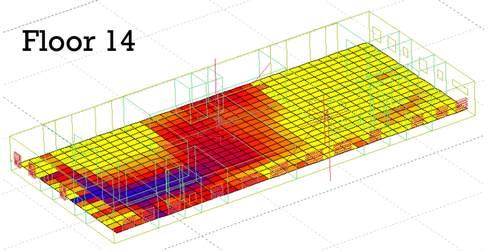


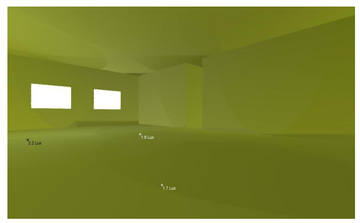


Floor 6



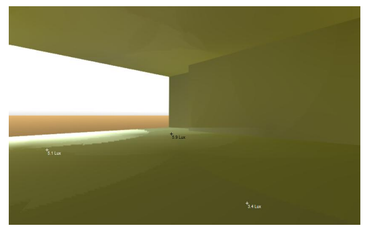
Floor 14



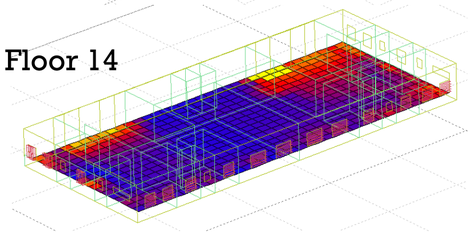




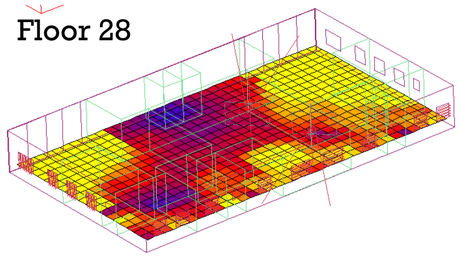


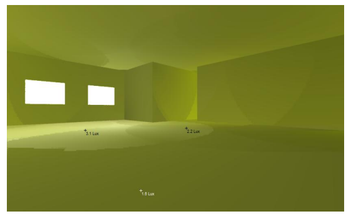


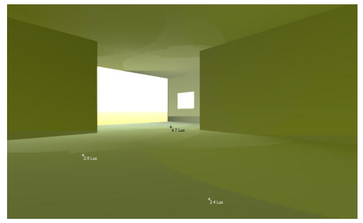
Floor 14



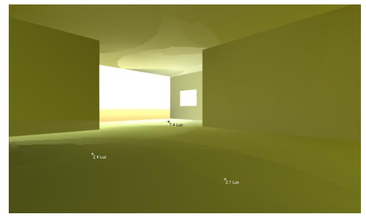
Floor 28



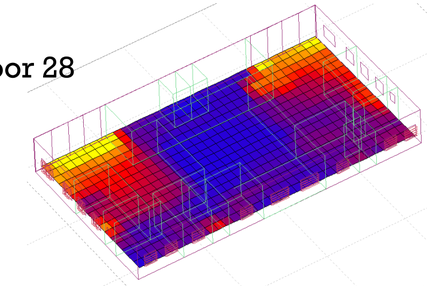




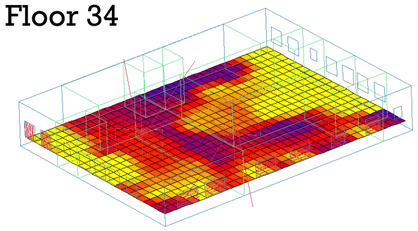


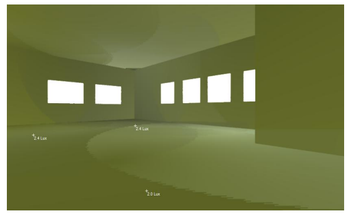


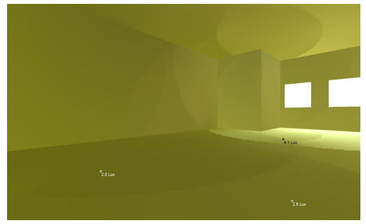
Floor 28



Floor 34



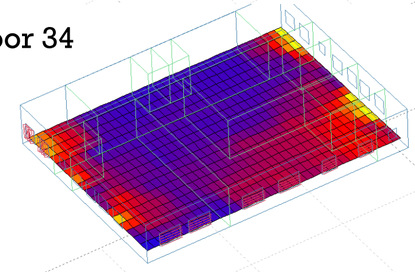




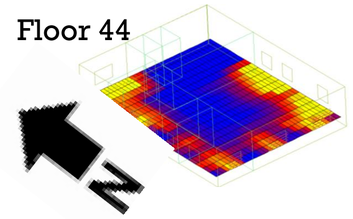


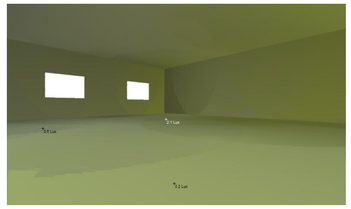


Floor 34



Floor 44

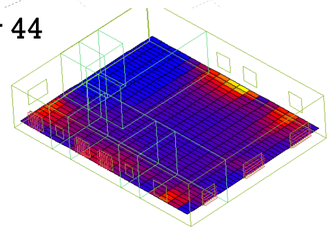




The daylight analysis showed that the daylight factor in the floors is quite satisfying and the rooms are almost adequately lit in the two extreme cases of the position of the sun in the sky for this latitude. In other words, the position and amount of openings, the type of glass and the position and type of louvers had a positive effect on the illumination of the interior. However, there are cases where artificial lighting is required to satisfy the demands of the occupants.



Floor 44



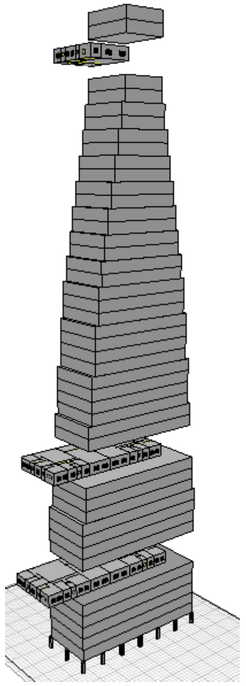
%DF

10.00+
9.10
8.20
7.30
6.40
5.50
4.60
3.70
2.80
1.90
1.00

Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

Thermal analysis

Three floors have been simulated in Ecotect to roughly evaluate the thermal performance of the building. These are the 6th, whose south facing wall is within the shaded part of the south façade of the building, the 14th and the 44th floors, whose southern façade is exposed to direct solar radiation all year round.
The input data for each one of these three zones are quite similar, that is comfort band 19°C-24°C, clothing value 0.4clo for the cooling period and 1clo for the heating period, humidity 60% and ventilation rate 0.29 ach which corresponds to 8l/person. The occupancy varies and is 14 people for the 6th and the 14th floor and 4 people for the 44th floor.
The U-value of the walls, which are a lightweight metal structure with multilayer insulative panels, is 0.11 W/m²K. Different types of glazing are suggested for the openings, such as double glazing (U-value = 1.4 W/m²K), transparent insulation material (aerogel, U-value = 0.15 W/m²K) or electrochromic glazing (U-value = 1.2 W/m²K). Concrete slab is forming the floors (U-value = 0.41 W/m²K) of the building, followed by a layer of timber boards or tiles. The thermal mass of the slab contributes to the night ventilation of the building. The roof is well insulated with sandwich insulative panels and plaster underneath and has a U-value of The system providing heating or cooling is full air-conditioning, operating daily in a 24h basis.



The average heating and cooling loads per m² for each of the selected floors are presented on Table 5. Through these values, an estimation for the loads on shaded and unshaded floors has been made. This lead us to the calculation of the total annual cooling and heating loads for the whole building, which are found to be 410,879 kWh. Table 6 shows their peak loads for each zone. It is apparent that the sixth floor whose south facing façade is blocked from direct solar gains for the most of the time has the maximum heating and cooling loads. Looking at the passive breakdown graphs at the bottom, it is obvious that the heating loads are highly related to ventilation losses and to fabric losses, as well.

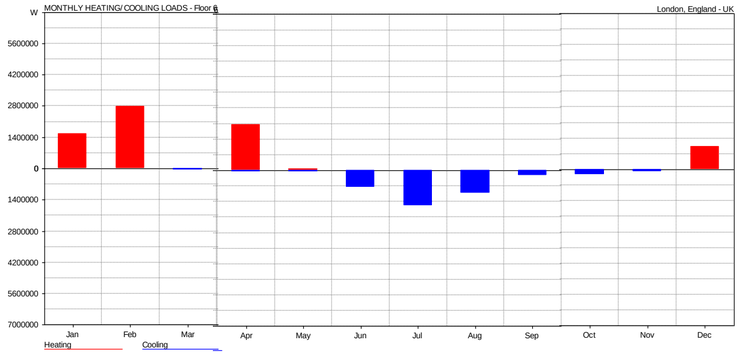
Table 5: Average cooling and heating loads per m² for each floor

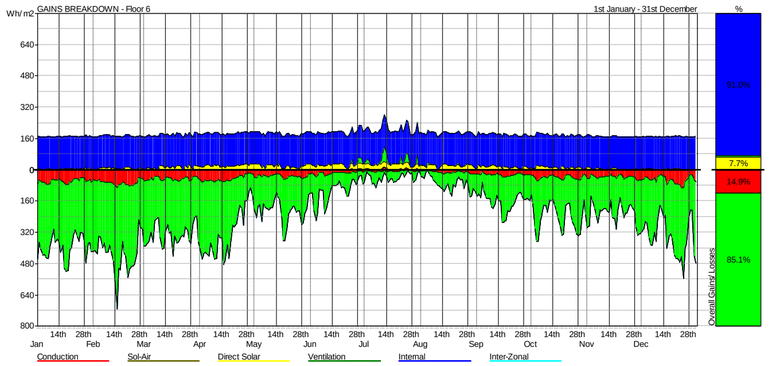
Average loads per m²	
Floor 6	19,705.5
Floor 14	24,951.375
Floor 44	27,602.792

Table 6: Peak cooling and heating loads for each floor

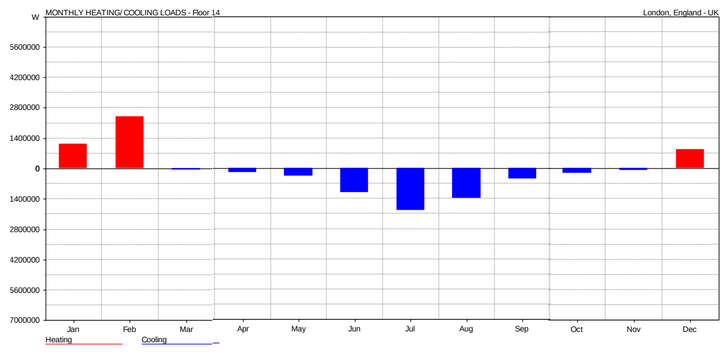
Peak loads		
	Max. heating (W)	Max. cooling (W)
Floor 6	13164	9358
Floor 14	11715	9433
Floor 44	4026	3221

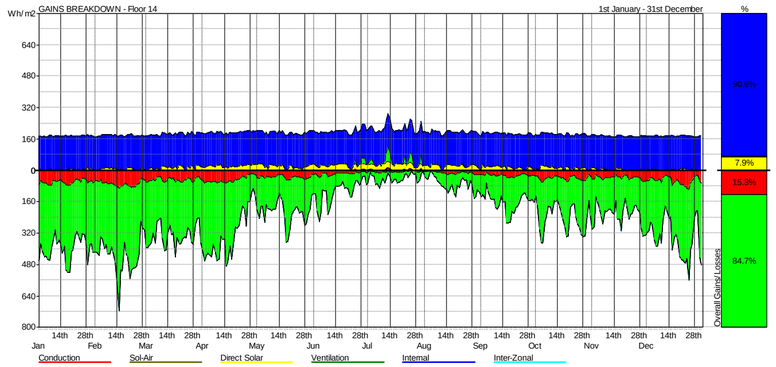
Floor 6



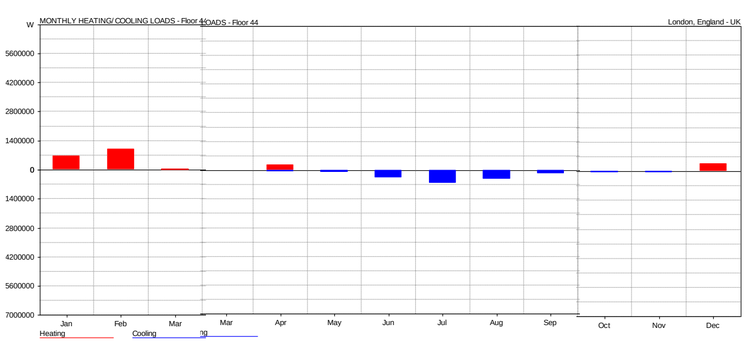


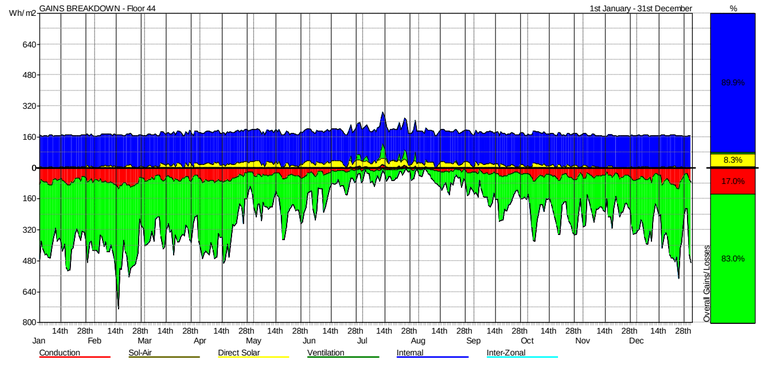
Floor 14





Floor 44



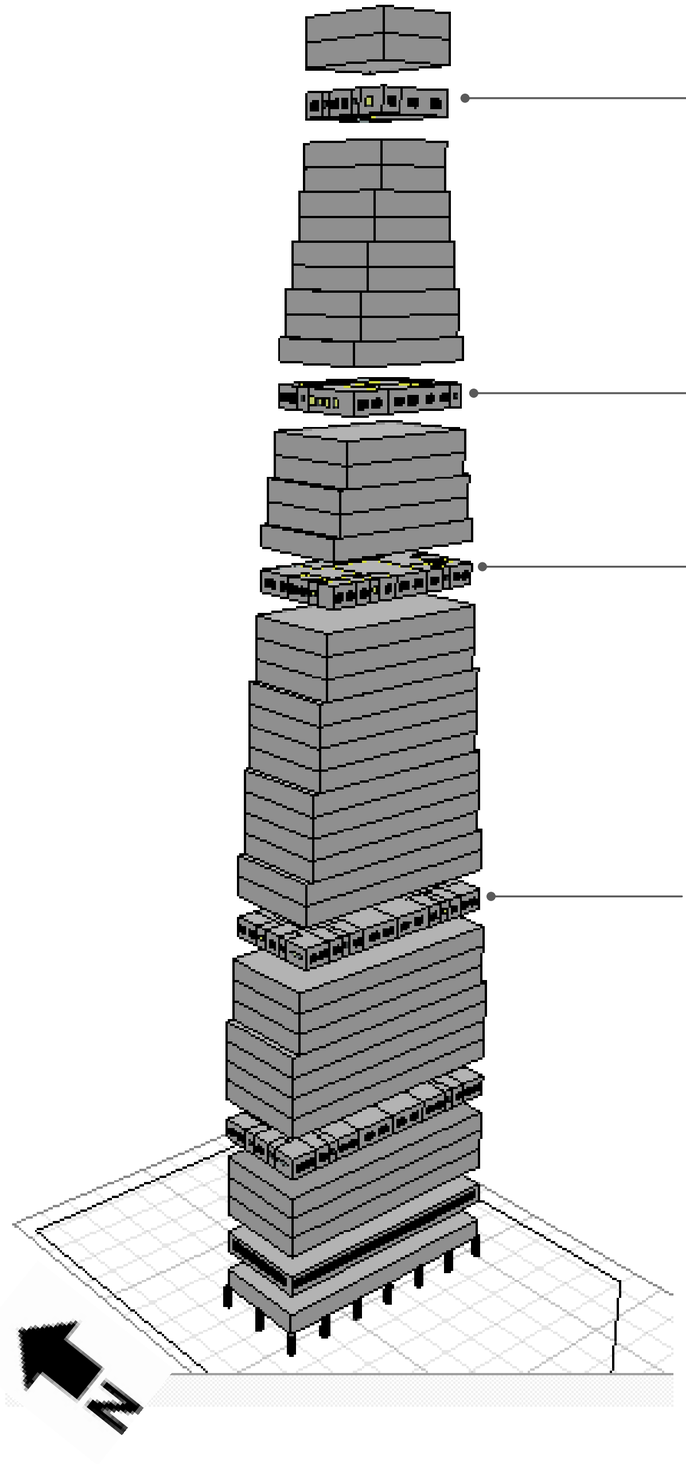


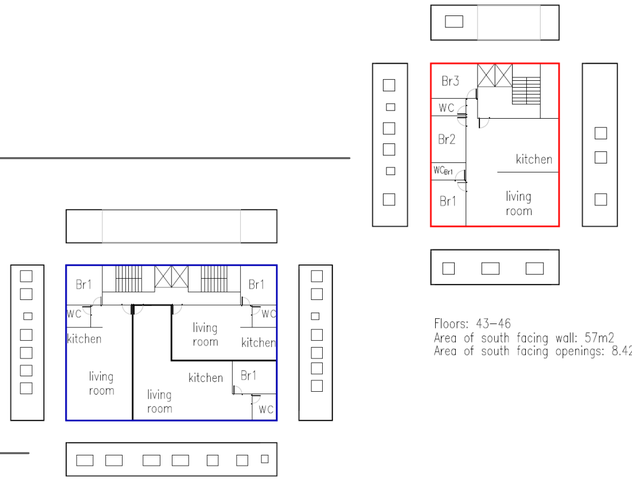
Monthly cooling and heating loads

Passive gains breakdown

Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

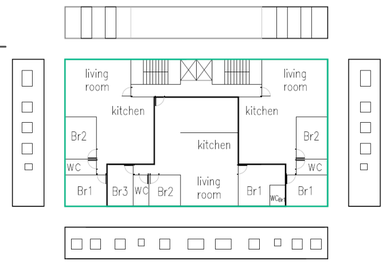
Design solution



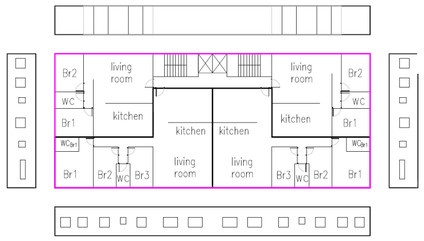


Floors: 43–46
Area of south facing wall: 57m2
Area of south facing openings: 8.42 m2 [8.55–11.4 m2 (15–20% of total surface area)]

Floors: 34–35
Area of south facing wall: 57m2
Area of south facing openings: 8.42 m2 [8.55–11.4 m2 (15–20% of total surface area)]



Floors: 28–29
Area of south facing wall: 75m2
Area of south facing openings: 10.84 m2 [11.25–15 m2 (15–20% of total surface area)]



Floors: 14–16
Area of south facing wall: 99m2
Area of south facing openings: 14.84 m2 [14.85–19.8 m2 (15–20% of total surface area)]

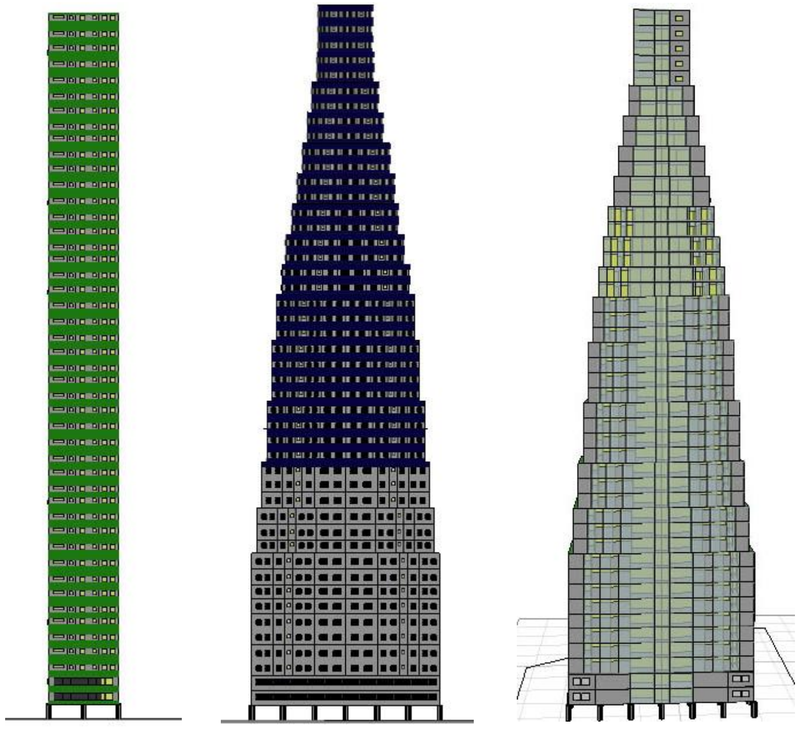


Figure : façade variation. From left to right: east/west, south and north facade

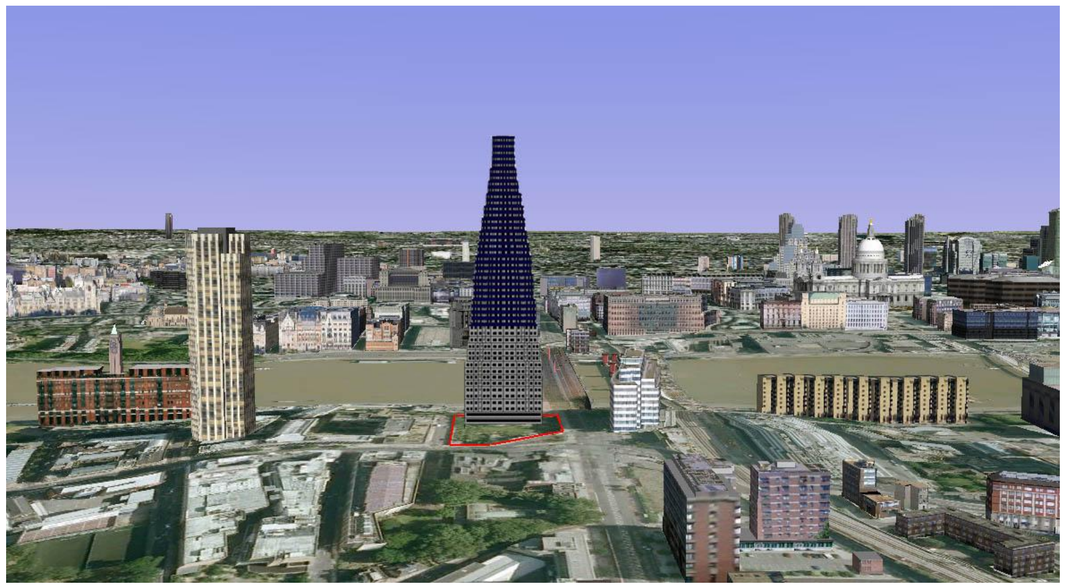
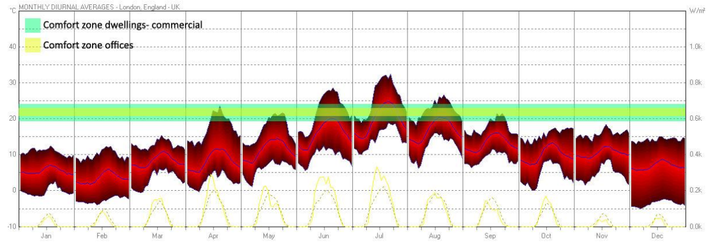
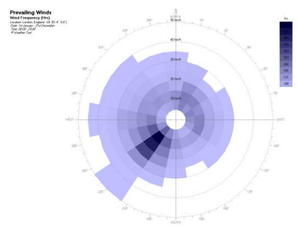


Figure : view of the tall building on site within its surroundings

Prerequisites

London's climate
- temperate marine climate
- extremely high or low temperatures are rare
- only 1468 hours of sunshine per annum
- warm summers (Ts>20 °C) on over 90% of days
- chilly winters (Tw<16 °C)
- Spring is a very mixed affair and is normally the driest time of year
- Autumn: Ta> 18 °C



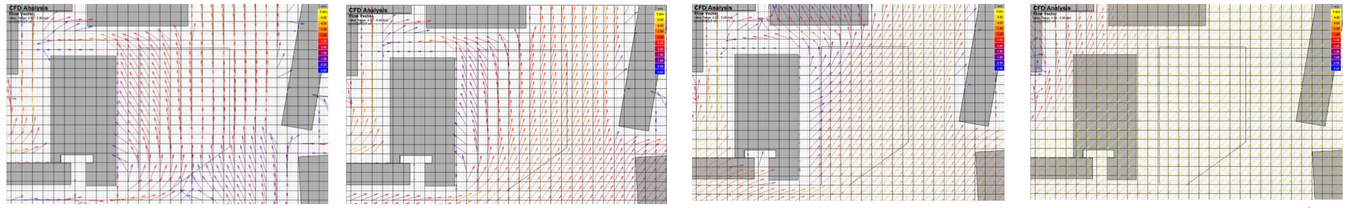


Wind
A wind analysis was performed for the site on several heights. We found that generally there are not very strong winds in the site and they would mostly meet the building from SW. Furthermore, the effect of the surrounding buildings ceases above 35m.

Site
Plot ratio: max. 5:1
Site coverage: <75%
Building height: max. 1000 ft (304 m)

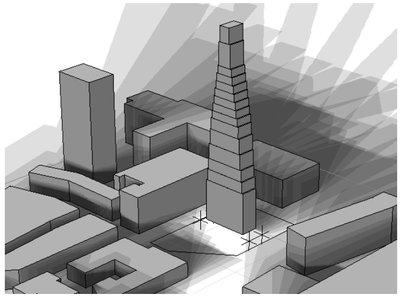
Parking space location: Underground and on the site.



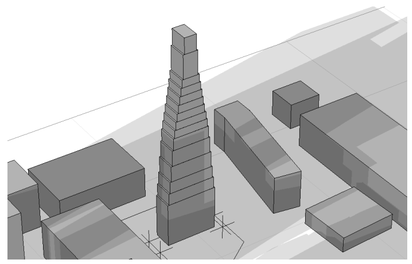


Air flow patterns in different heights with 5 m intervals. The air flow applies for predominant wind of SW direction (42°) and speed 10 knots.

Shade
We have performed a shading analysis. We found that there is some overshadowing of the building from the West up to the 29th floor, form the East up to the 8th floor and to the South up to the 16th floor.



Shadow range: 9.00-13.00
January



Shadow range: 17.00-20.00
October

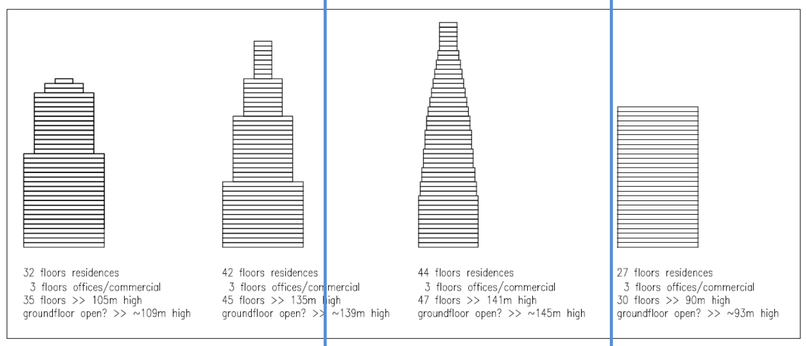
Building characteristics

No of floors: 47
Height: 145
Area: 20,700 m²

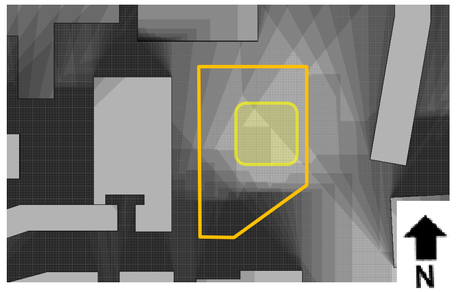
Use
Ground Floor use: Retail
1stand 2ndfloors: Offices
Rest floors: Residential

Flat arrangement
58 flats of 120 m²
32 flats of 90 m²
70 flats of 60 m²

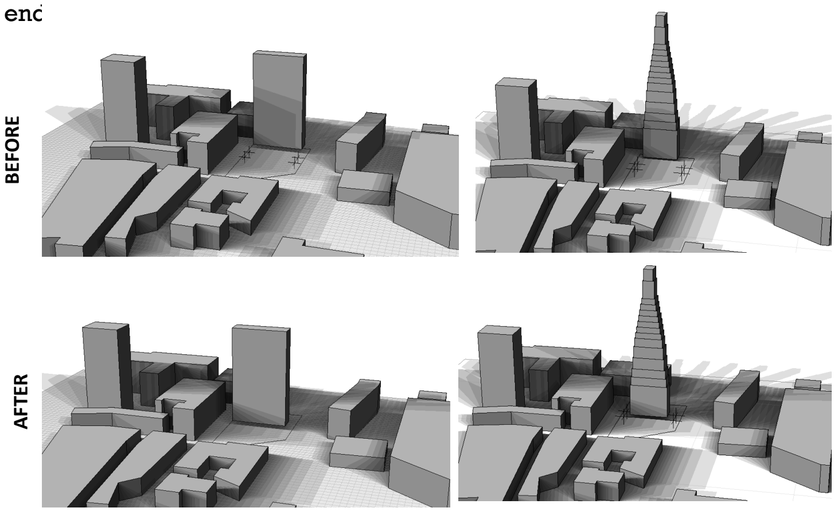
Form exploration
At first, we were considering 4 building forms.
The "*Dummy's Box*" choice: we considered that a "dummy" using the framework strictly would result in a choice like that for form. Since the framework promotes a rectangular plan and does not mention location, the simple choice would be a box in the centre of the site.
The final "*Bottle*" form was a result of a primary tendency to divert from such a simple and compact form. A decreasing plan (as moving upwards) was chosen, to promote the upwards move of the SW predominant wilds and provide comfortable environment for the pedestrians. Three forms of this type were chosen and the highest one with the smallest maximum plan area was chosen, to allow pathways around the building, in the site.



Position
Shadow range of the surrounding buildings, on the ground level, showed that the optimum position for the building in the site was on its north towards the centre.
After testing the "Dummy's box" choice in the centre of the site though, we realised that on a vertical level the shadows are better as we approach the south enc



Shadow range (9.00-17.00)



"Dummy's Box" and "Bottle tower" models: shadows are better as we approach the south end of the site

Anna Afiontzi & Aikaterini Chatzivasileiadi - working with framework

Environmental Design Application: Tall Buildings Brief

Maria - Angeliki Zanni
Konstantinos Mourkos



Latitude: 51.508 N Longtitude: 0.105 W

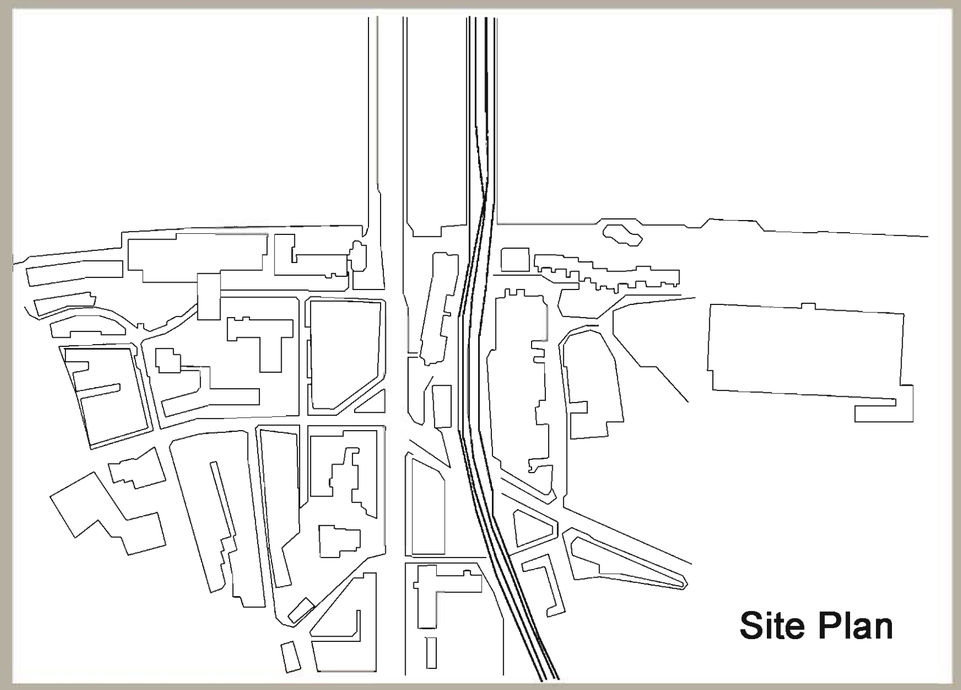
Site Details

Location: London, UK
Climatic Zone: Cfb (Koppen classification)
Climate: Marine West Coastal
(Data from EnergyPlus)
Area: 4.723 sq.m.
Plot ratio: 5:1
Coverage: 75%
Limit for Height: 1000 foot

Architectural Program Summary:

- ground floor commercial use
- 1st, 2nd floors office use
- residential use:

30% (70) of 60 sq.m. with 1 bedroom,
20% (32) of 90 sq.m. with 2 bedrooms,
50% (58) of 120 sq.m. with 3 bedrooms.



Site Plan

Blackfriars site





Introduction

Surveys show that the population of big cities throughout the world is increasing rapidly. By 2050 the urban world population will be 6 billion. Taking into account that the majority of the big cities are overcrowded and there is a shortage of open spaces the vertical expansion of the cities seems to be a realistic and sustainable solution that can address the above issues.

Aim

"The tall building over and above other built typologies uses a third more (and in some instances much more) energy and material resources to build, to operate and eventually to demolish. It is regarded here as a building type that if inevitable, needs to be made ecological as much as possible" (Ken Yeang, 1998).

Our aim is by following the framework produced by Sabina Fazlic to design a skyscraper mainly for accommodation use that it is as environmentally friendly as possible.

Objectives:

-Follow the frame work but not strictly, as we think best

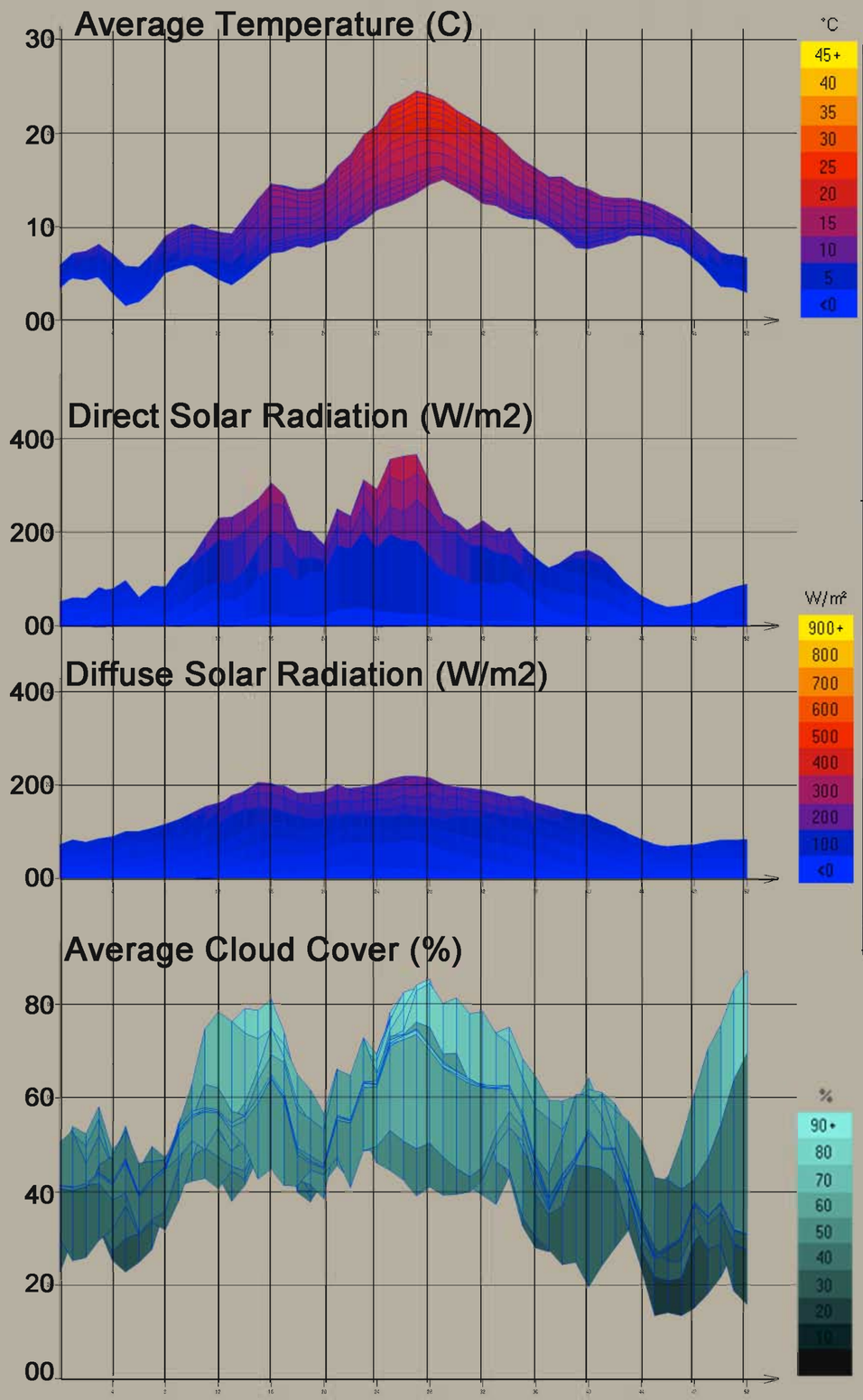
-Freedom to explore more complex resolutions of issues

-If we find something difficult to understand, we will respond as best we can rather than consult the author.

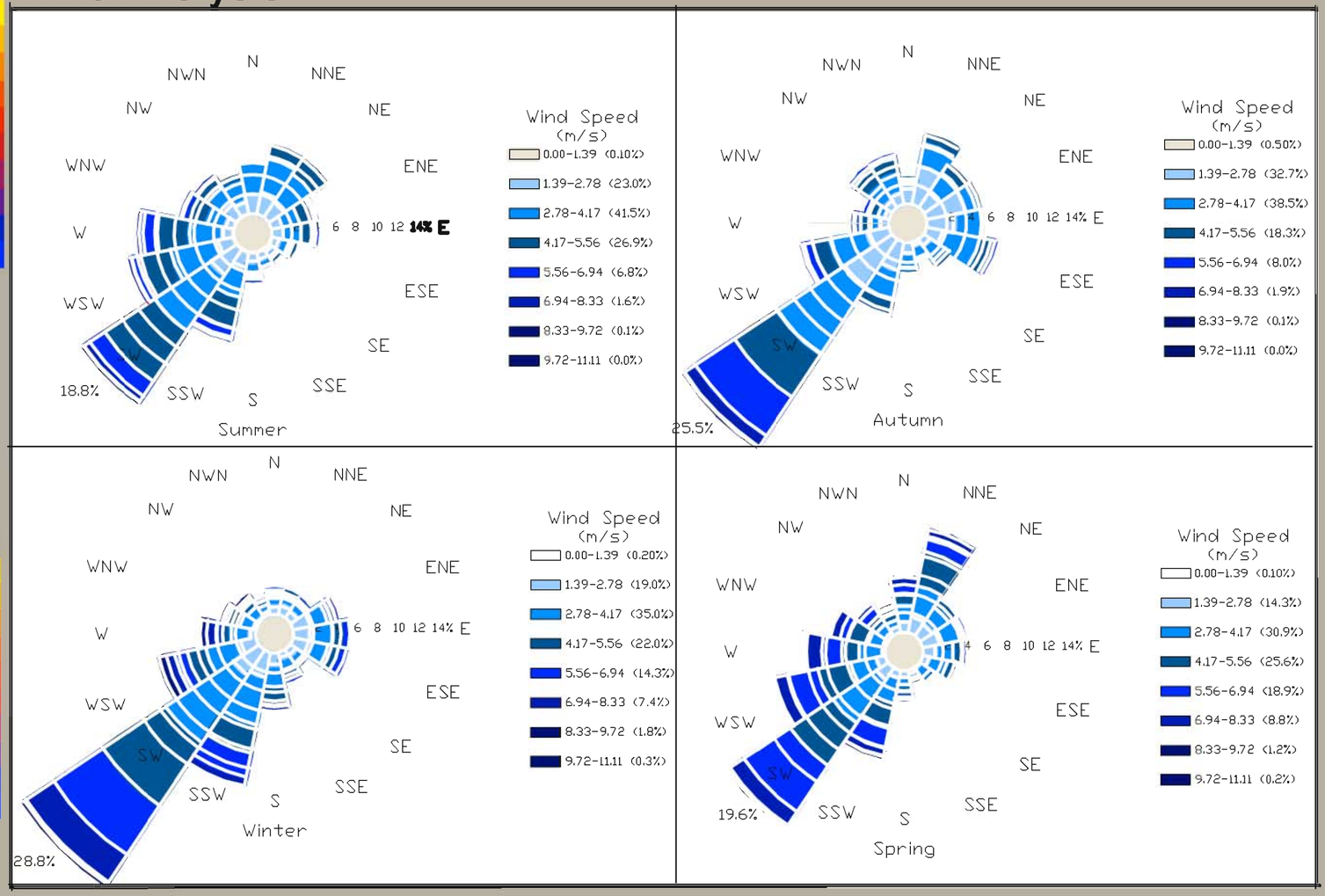
-Our main focus is the environmental performance of the building.

Climate Data

Maria - Angeliki Zanni
Konstantinos Mourkos



Wind Analysis



From the graphs we see average minimum temperature 3.4 C on February and average maximum temp 19.0 C on July. Minimum and maximum temperatures occur on July and December and they are equal to 30.3 C and -1.1 C respectively.

Direct solar radiation levels are quite low especially during the winter. An average seasonal value is equal to 200 W/m2. In addition, diffuse solar radiation is low with an average equal to 100 W/m2 and a maximum equal to 200 W/m2. The weather is most of the time cloudy, 80% average cloudness is excited many times throughout the year.

From the wind analysis it is apparent that the predominant direction is southwest (SW). Only during spring there is also a significant wind coming from north northeast direction.

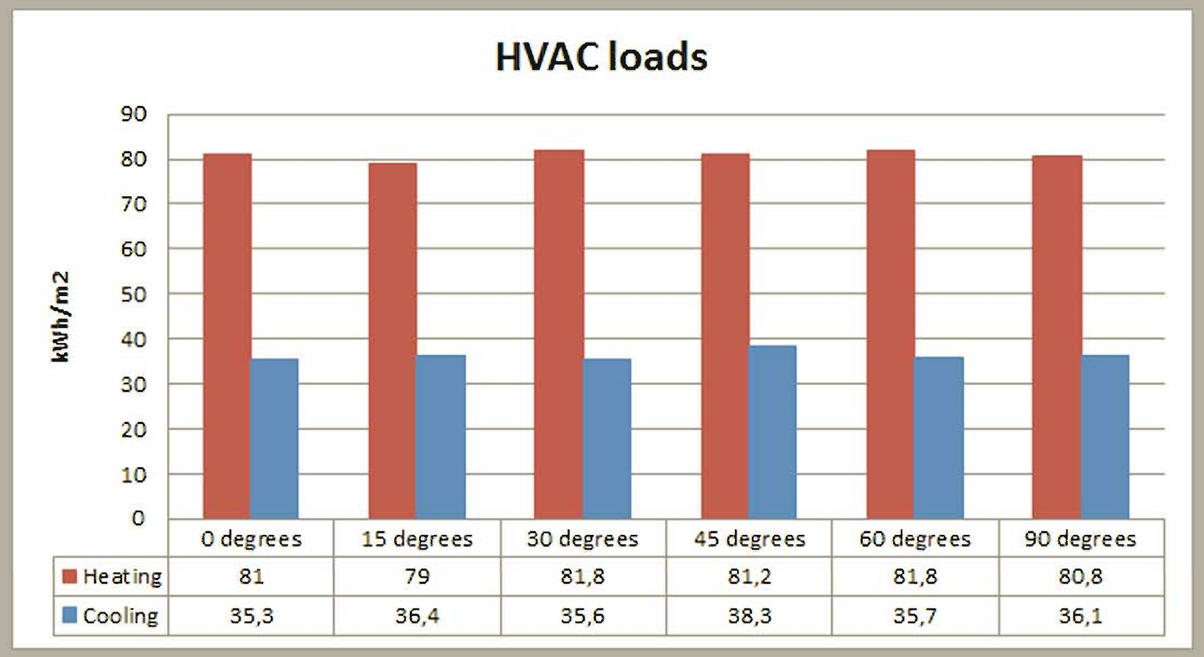
(Source Weather Tool)

Orientation: Thermal Radiation (Increase) - Airflow (Increase)

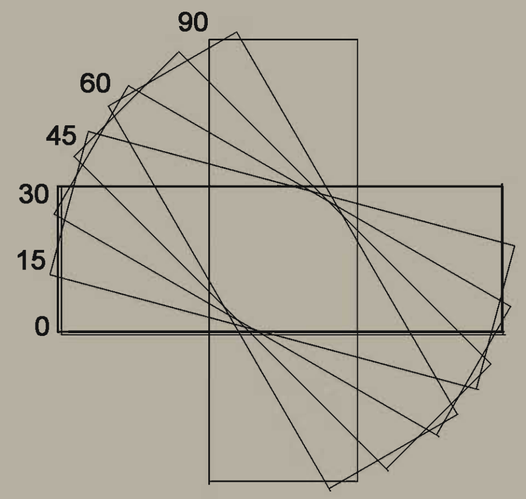
Maria - Angeliki Zanni
Konstantinos Mourkos

Step 1: Building Orientation

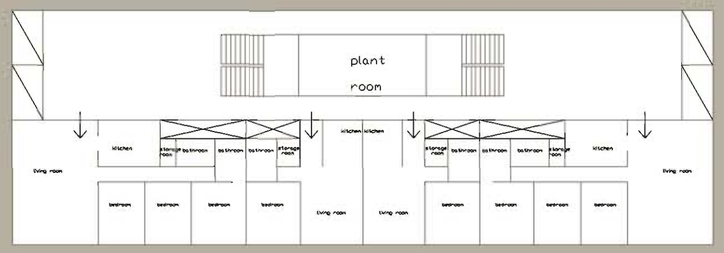
"Long axis oriented E-W
-maximize sun penetration into building
-air-conditioning load reduced."



	0 degrees	15 degrees	30 degrees	45 degrees	60 degrees	90 degrees
Heating	81	79	81,8	81,2	81,8	80,8
Cooling	35,3	36,4	35,6	38,3	35,7	36,1

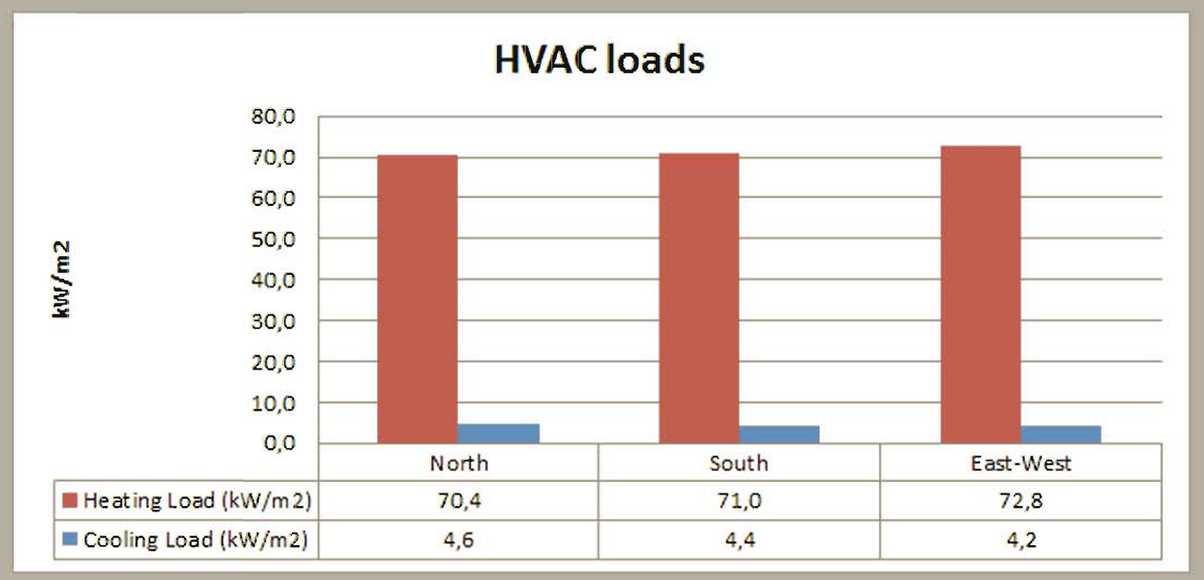


Initial floor plan



Step 2: Primary Mass Location (core)

"Option 1: North: solid core to reduce heat loss
Option 2: South: walkways or galleries to reduce excess heat loss"



	North	South	East-West
Heating Load (kW/m2)	70,4	71,0	72,8
Cooling Load (kW/m2)	4,6	4,4	4,2

Step 3: Building Orientation

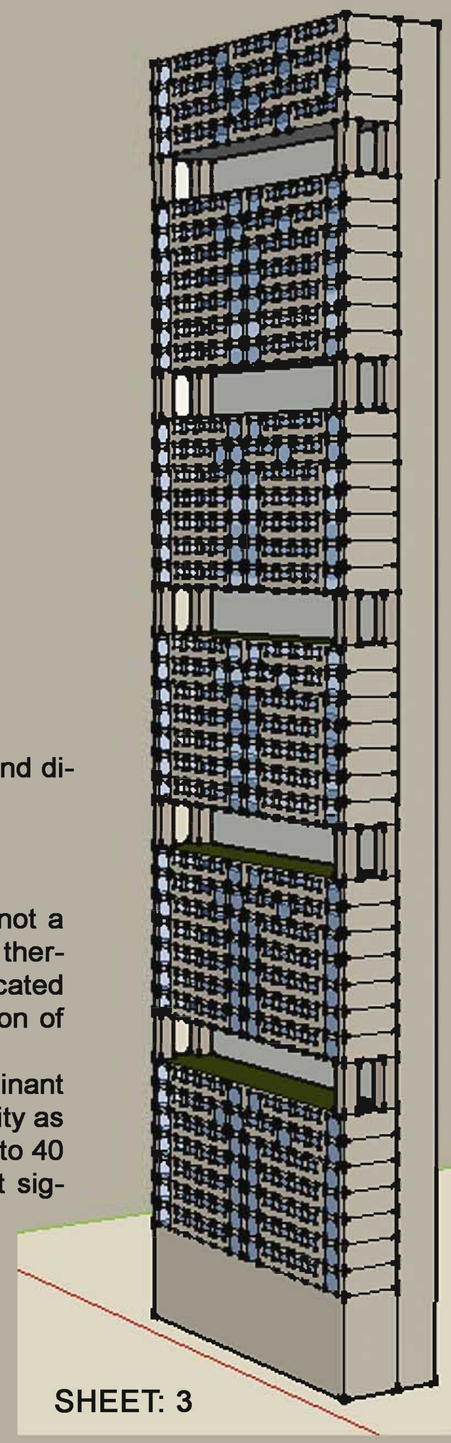
"Orientation to maximize exposure to required summer wind direction
Note:solar orientation priority over summer ventilation"

Conclusion:

Is seems from the thermal analysis that orientation has not a significant influence on the heating and cooling loads. The thermal performance of the building was tested with a core located in the north, south and east-west sides. The north position of the core is slightly beneficial.
The building was not orientated according to the predominant direction of the wind because solar orientation was a priority as suggested by the framework. "Variations in orientation up to 40 degrees from perpendicular to the prevailing wind do not significantly reduce ventilation" (Givoni, 1976 pg. 289)

Framework Assesment:

The option to locate the core on the East-West side is not suggested until step 10 where it might be too late in order to relocate it.



SHEET: 3

Configuration: Visible Radiation (Increase) - Airflow (Increase)

Maria - Angeliki Zanni
Konstantinos Mourkos

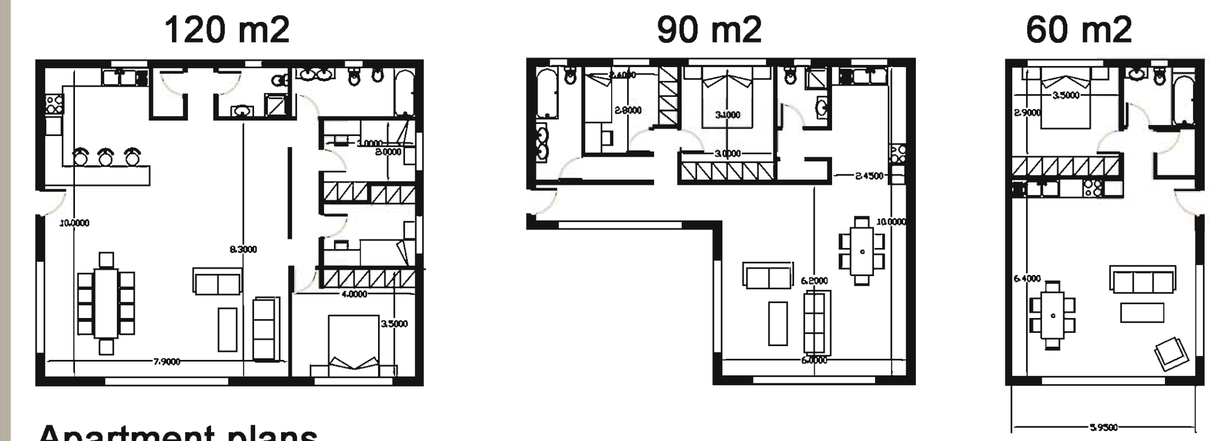
Step 4: Floorplate configuration
"Optimise daylight through narrower floorplate (14-16 m)."

Choice: YES
The width of the plan is 10 m, less than the maximum value suggested by the framework.

Step 5: Floorplate configuration
"Furthest desk 5-7.5 m from outside wall; depth of room no more than 2.5 times the room height."

Choice: YES

The furthest of each room is not more than 2.5 times the room height as suggested by the framework.



Apartment plans

Step 6: Built From Ratio
"Built form ratio 1:1.6 optimal for solar control in cool temperate climate."

Choice: NO
The plan of the building is elongated along the east-west axis in order to split the apartment units from each other to provide natural ventilation and increase daylight levels.

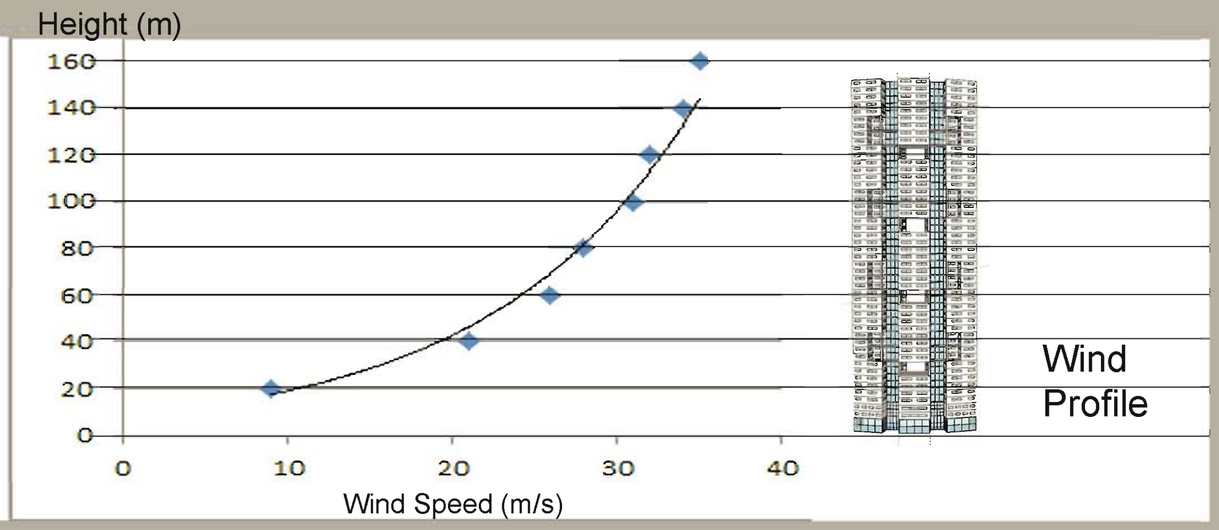
Framework Assesment:
Optimizing daylighthting and natural ventilation are not considered at the same time and therefore different maximum values are suggested (Step 4 - Step 7). Furthermore, this steps are more applicable to open plan spaces. For apartments, the rule of the 6m meters will be more appropriate.
The placement of the core in the east-west sides is a strategy suggested by Ken Yeang but it is suitable for hot tropical climates where parametric studies showed that it can reduce the cooling load significantly.

Step 7: Floor Depth
"Open plan (14 m max) needed for natural ventilation."

Choice: YES

Step 8: Height Zones
"Wind performance grows exponetially as it moves upwards."

Choice: NO
The vertical profile was calculated following the Leaves and Harris model. The displacement height is equal to 15 m (Euro code 1, January 2010). The mean wind velocity is calculated :Vm=32.2 m/s from the formula: Vm(z)=Cr(z)*Co(z)*Vb (4.3) where Cr(z) is roughness factor, Co(z) is orography factor taken as 1 and Vb=22m/s taken from figure NA.1 (UK National Annex to Eurocode 1).



Step 9: Ground Floor
"Open to outside in summer:
-naturally ventilated space in summer
-transitional space"

Choice: NO
Transitional spaces are provided at the intermediate level of the building. Furthermore, in order to minimise the discomfort experienced by the pedestrians at the ground level due to uncomfortable wind conditions (horseshoe vortex effect) vegetation and pergolas maybe provided.

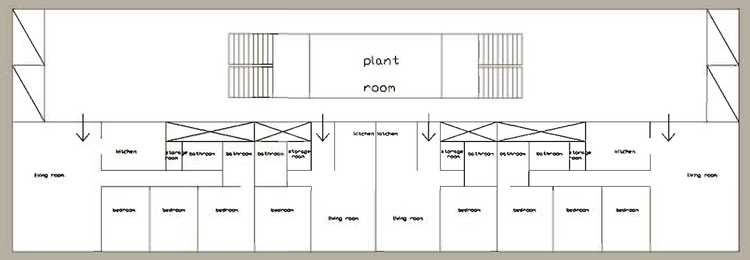
Step 10: Building Core
"Peripheral cores act as wind buffers."
"Reduction in air-conditioning as opposed to central core."

Choice: NO
The decision was to place the core in the north side of the building to minimize heat losses (reference step 2).

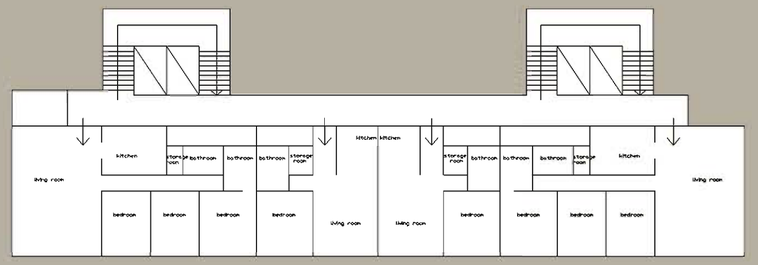
Design Process

Maria - Angeliki Zanni
Konstantinos Mourkos

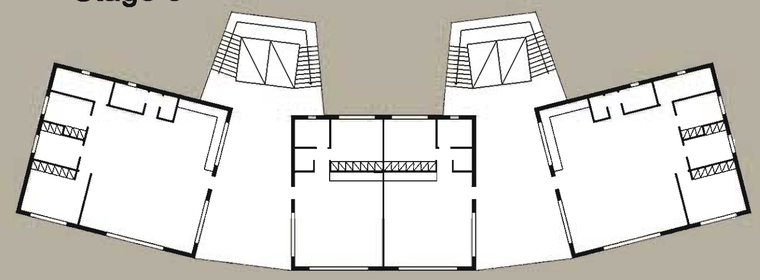
Stage 1



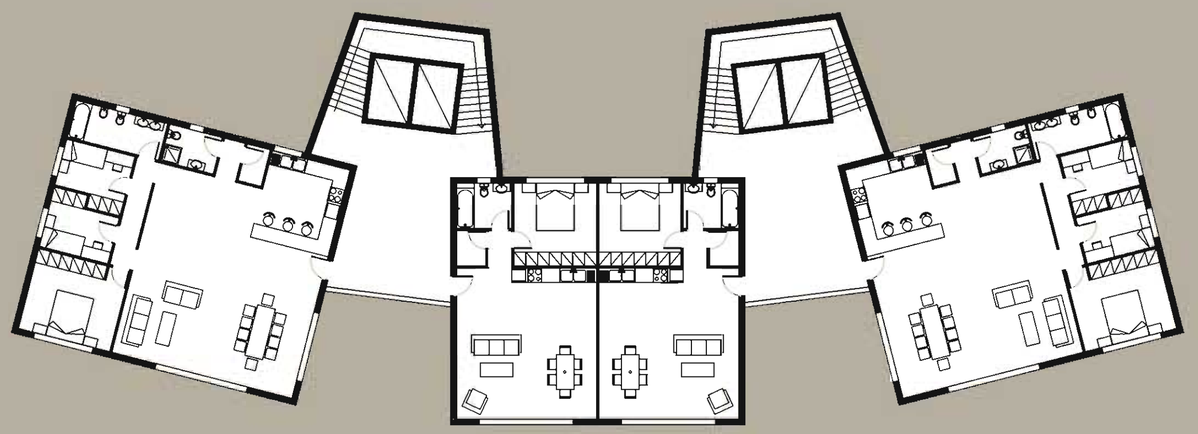
Stage 2



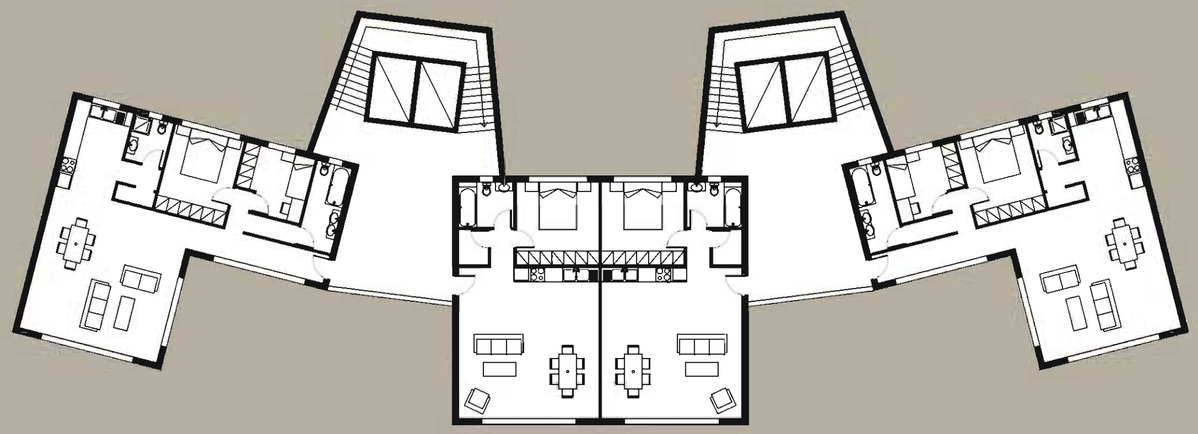
Stage 3



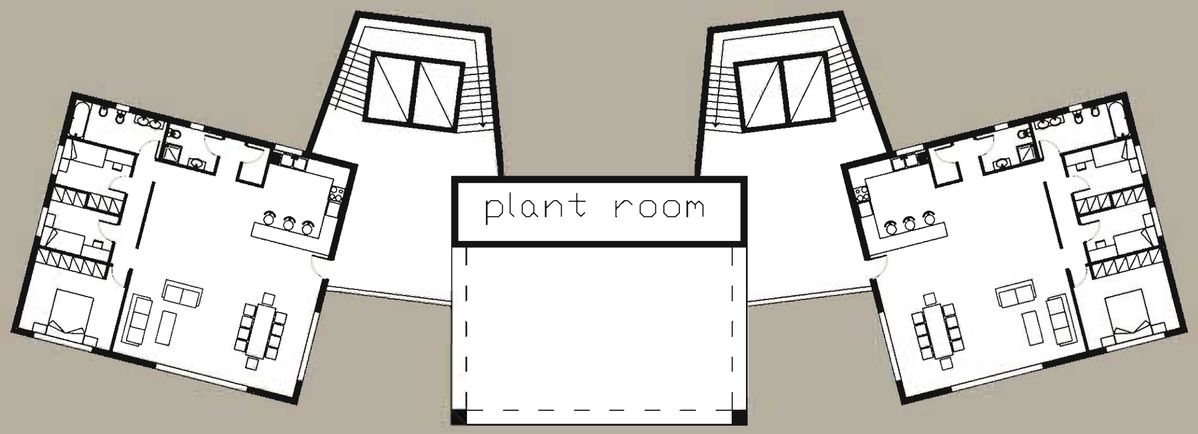
Stage 4: final plans



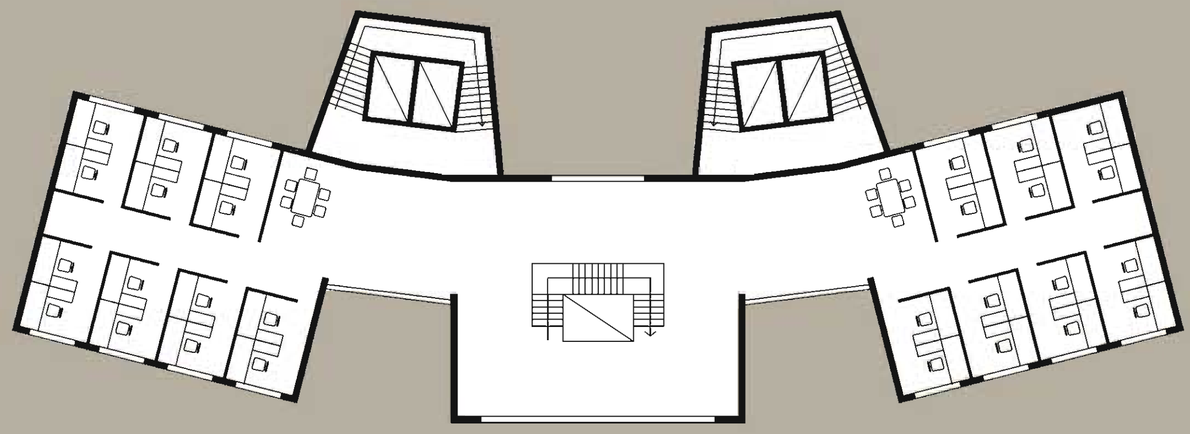
2 apartments of 120 m2 and 2 of 60 m2



2 apartments of 90 m2 and 2 of 60 m2



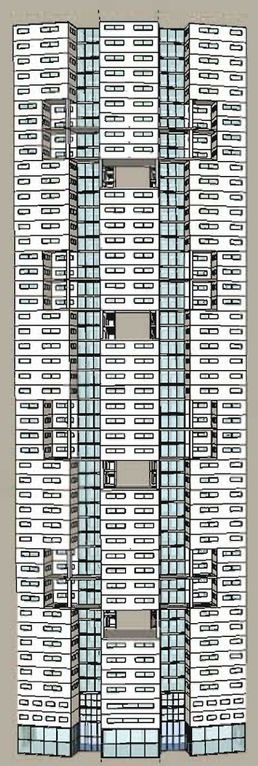
2 apartments of 120 m2 and communal space



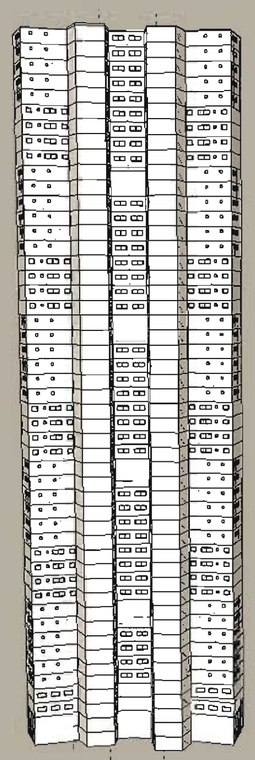
offices

Design Process

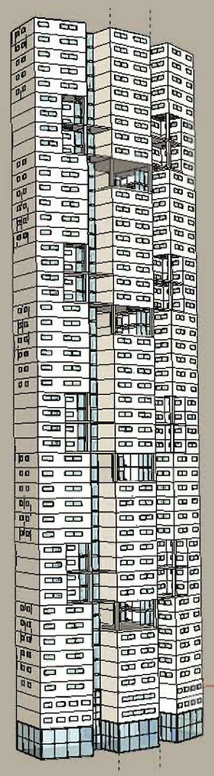
Maria - Angeliki Zanni
Konstantinos Mourkos



South elevation



North elevation

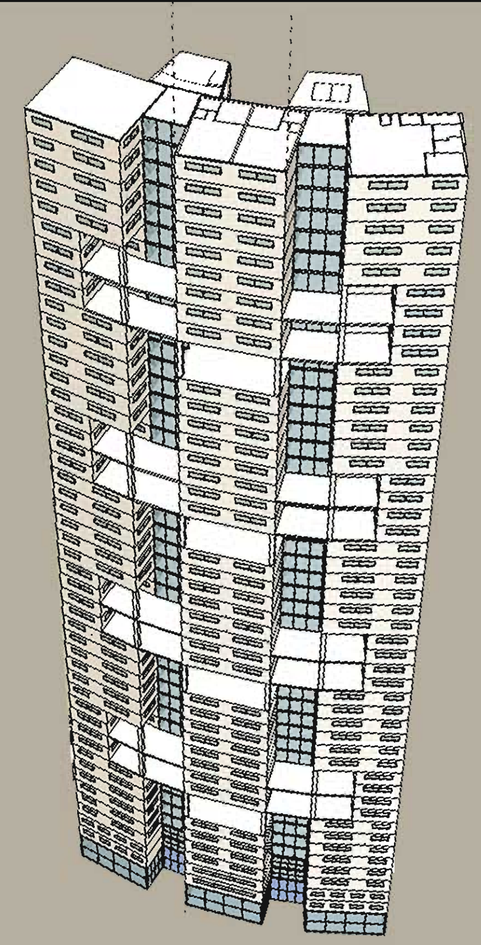


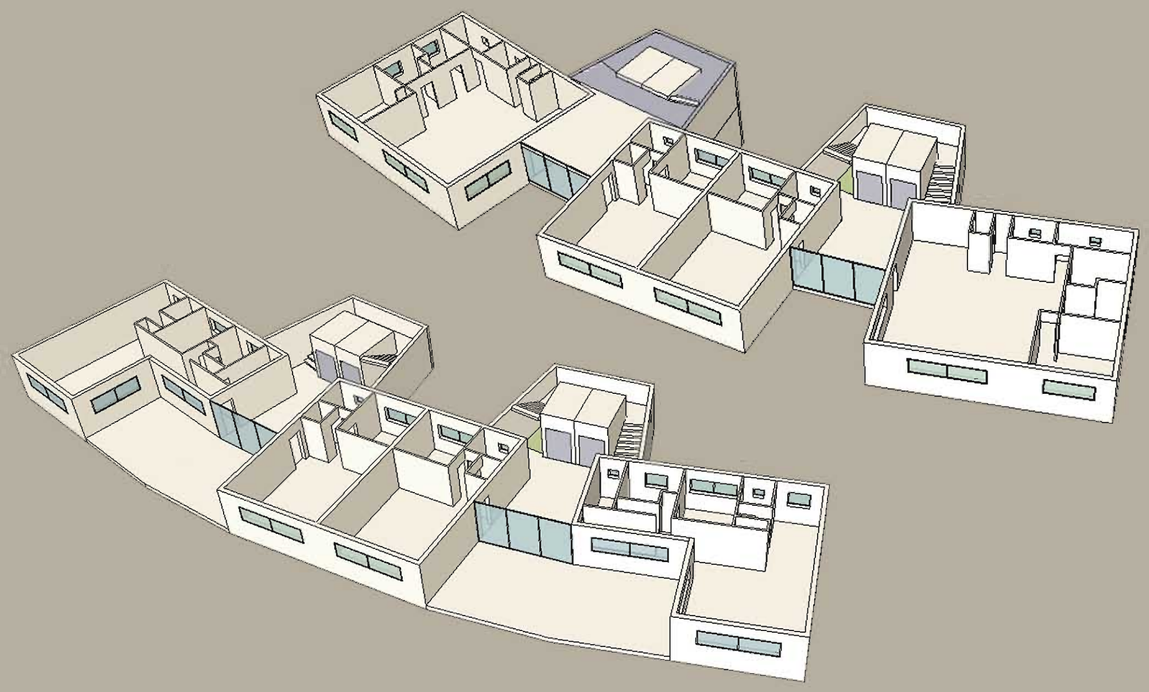
Perspective

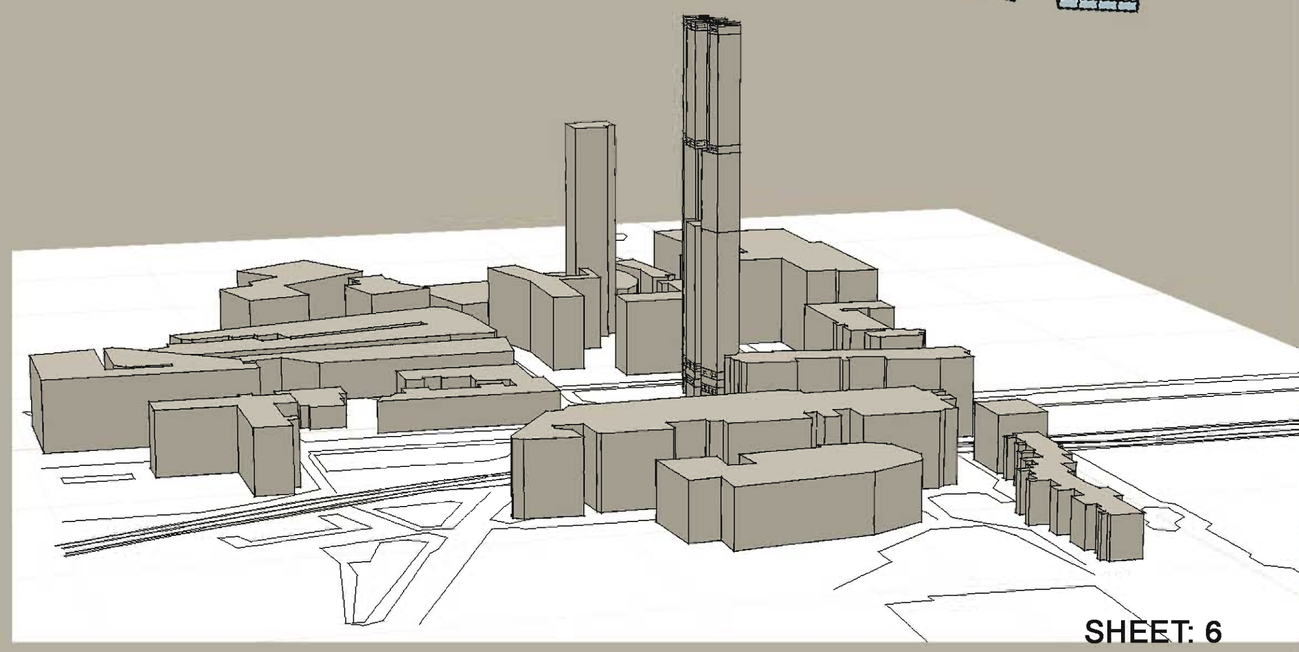
Key Ideas:

- *Vertical Expansion*, instead of expanded horizontally.
- *Transitional Spaces* are provided for all the occupants independently of the location of the apartment.
- *Subdivision of the Building* in five smaller units.
- *Sense of neighboring* is enhanced.
- *Open the plan to the south*, protection from north.

The first four levels are occupied by public spaces, the first two are stores and the second two are offices.
The residential use starts from the fifth (5th) floor until the forty-nineth (49th). As mentioned above, the building is subdivided in five smaller. Each one of them consists of:
-4 floors with 2 apartments of 120 m2 and 2 of 60 m2,
-2 floors of 2 apartments of 120 m2 and a two-storey communal space between them,
-2 floors of two apartments of 90m2 and 2 apartments of 60m2.
The remaining upper 5 floors consist of 2 apartments of 120m2 and 2 of 60m2 (3 levels) and 2 apartments of 120m2 and public spaces between them (gym, cafeteria etc.)



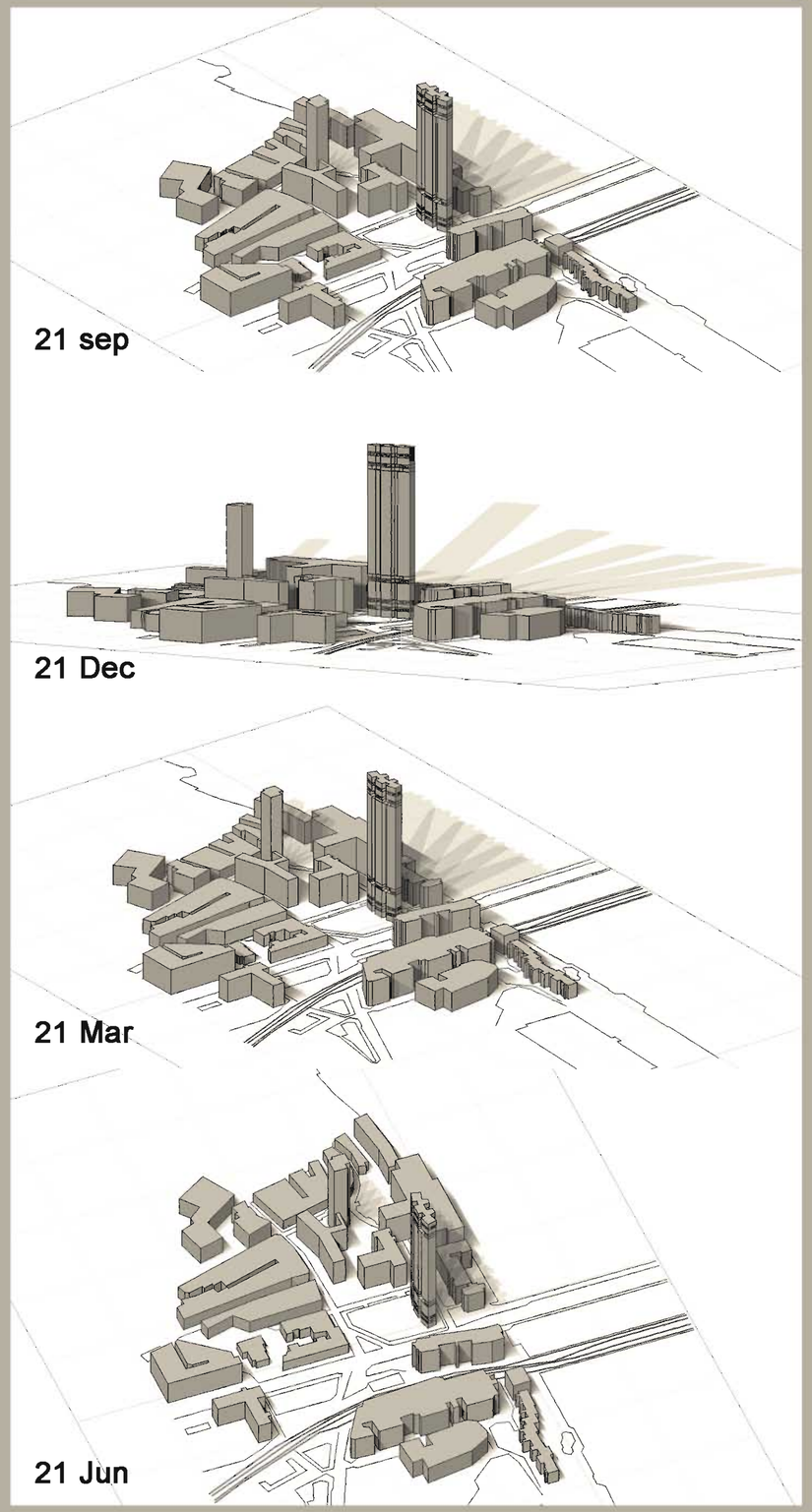




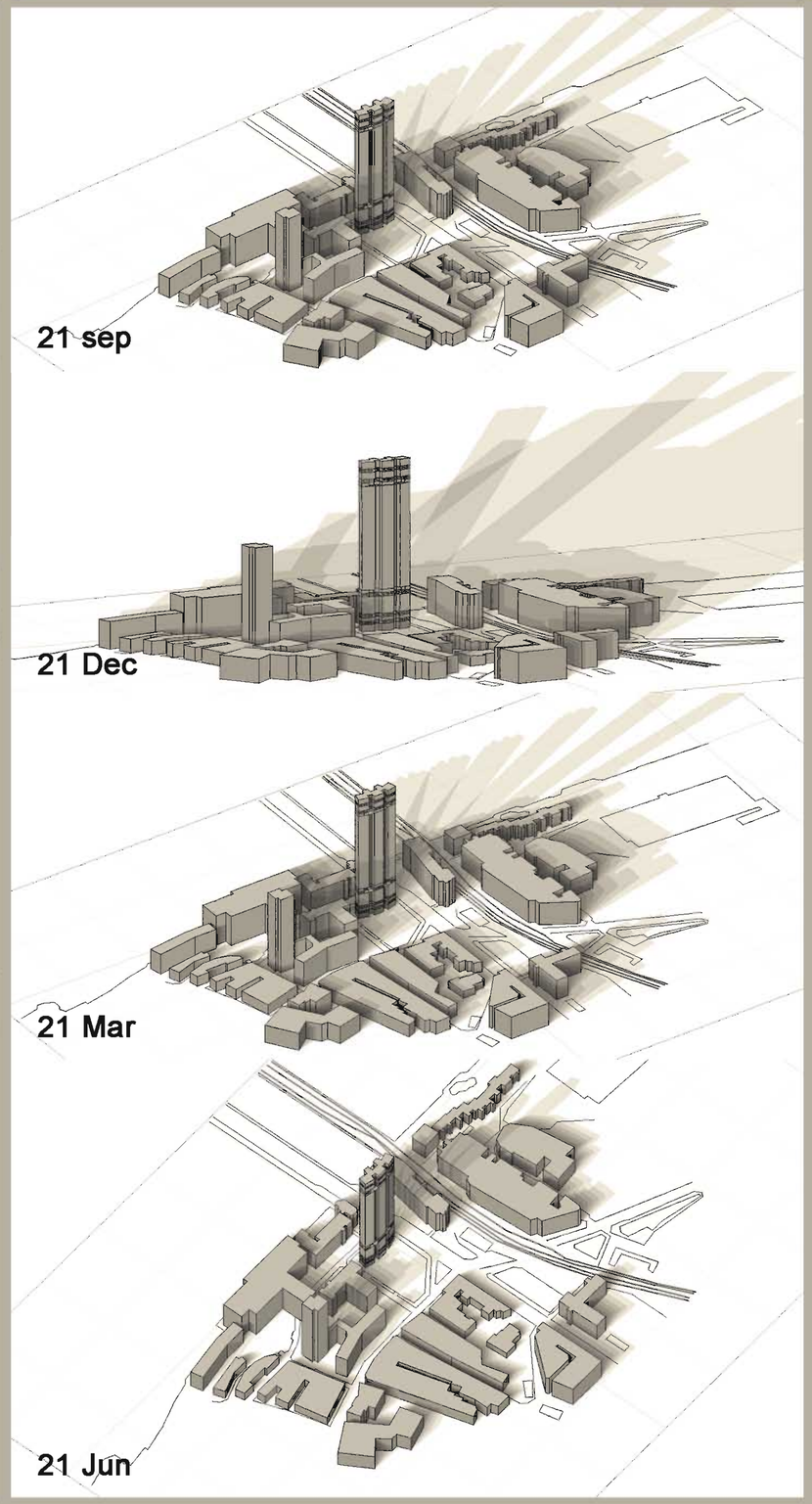
Overshadowing: North Position

Maria - Angeliki Zanni
Konstantinos Mourkos

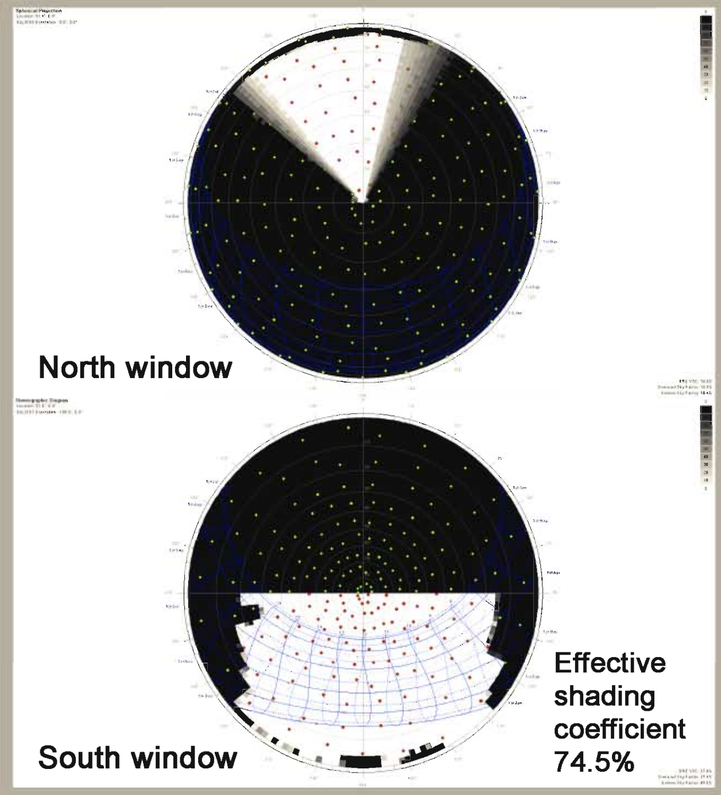
Shadow Range 09:00-12:00am
View from Sun position 09:00am



Shadow Range 14:00-17:00pm
View from Sun position at 14:00pm



Shading Masks with Dayligth Factors



Two postions were assessed (one in the north side of the site and another in the center). The images show the shadow range for four characteristic days (equinoxes and solstices) for three hour in the morning and three hours in the afternoon. The perspective is from the sun position showing which parts are in shadow and which are not at the specific time.

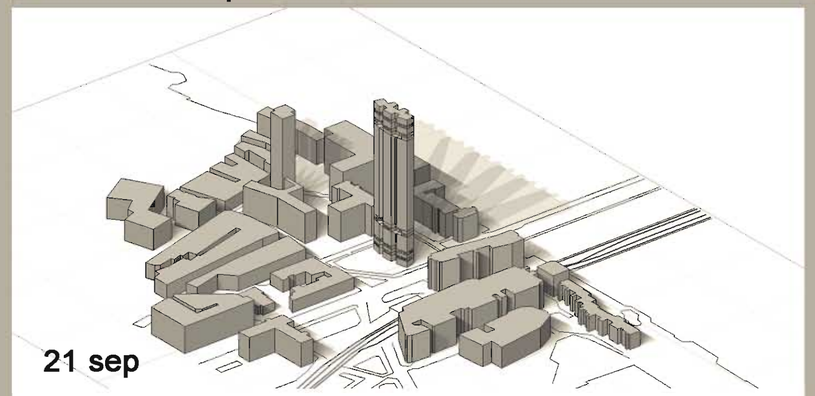
The north position is in general accepted as a good one because it ensures that the building's south face has some access to the south sun. Furthermore, a well lit front space is created. On the other hand, in this case, our building overshadows completely the buildings behind of it.

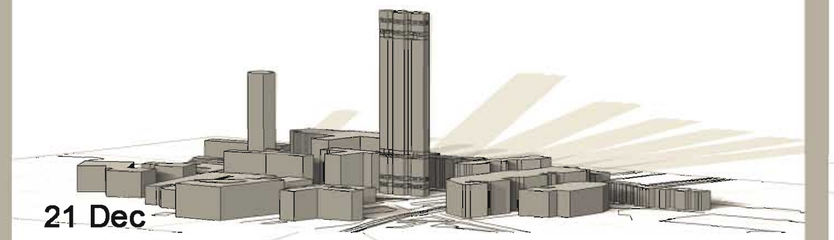
The above diagrammes are shading masks of one north and one south window of the fifth floor. The red spots show the visible parts of the sky, each one represents 0.5% of the daylight illuminance from a CIE overcast sky.

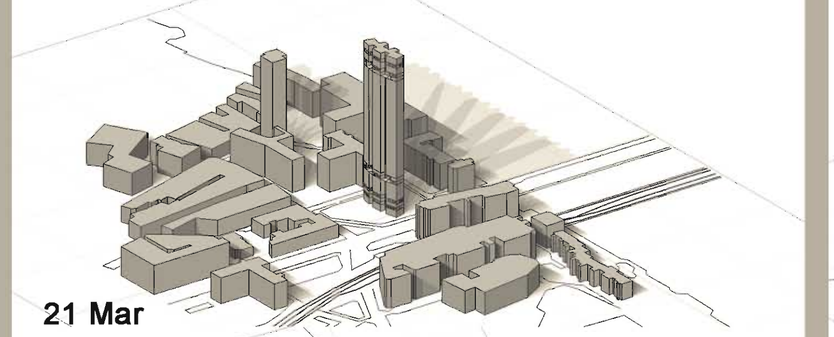
Overshadowing: Central Position

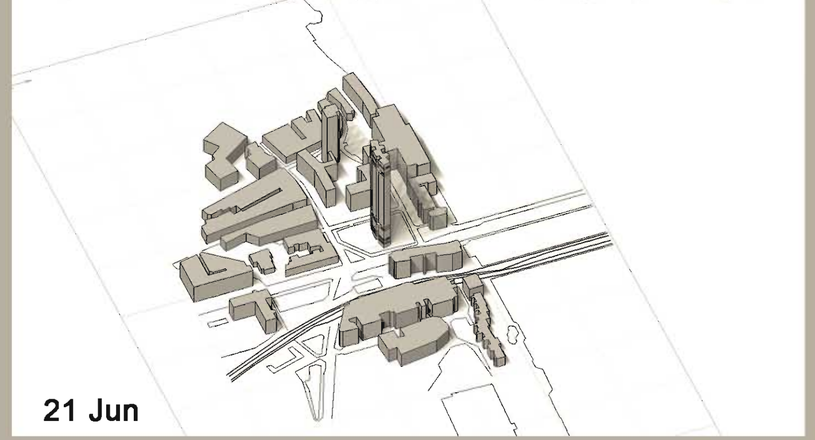
Maria - Angeliki Zanni
Konstantinos Mourkos

Shadow Range 09:00-12:00am
View from Sun position 09:00am

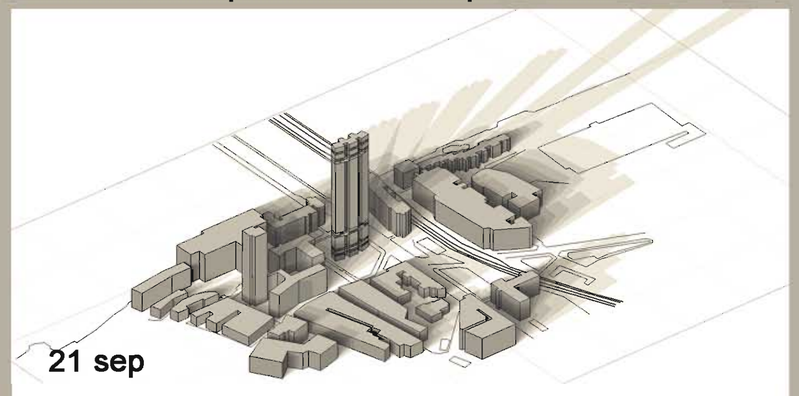


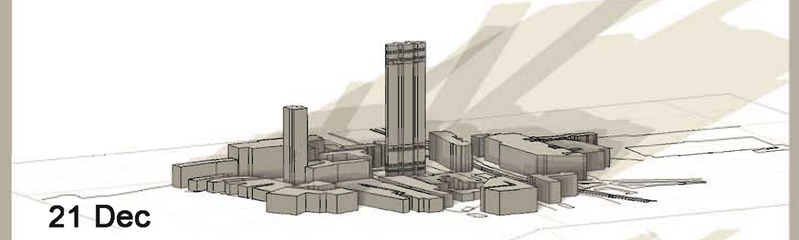


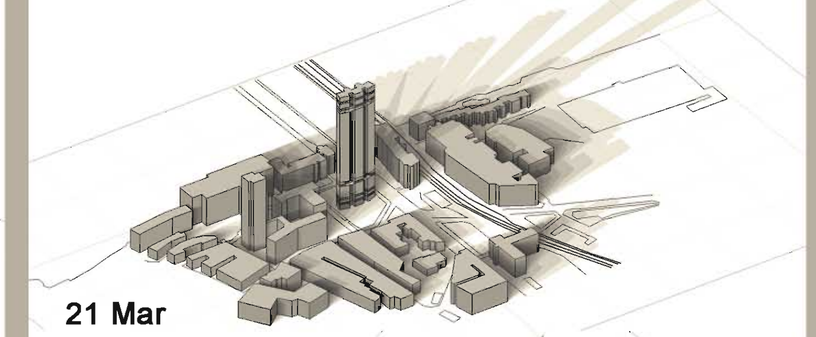


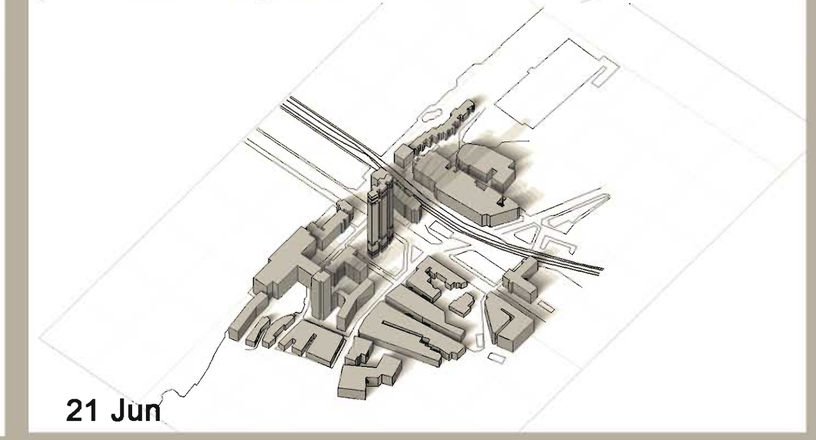


Shadow Range 14:00-17:00pm
View from Sun position at 14:00pm

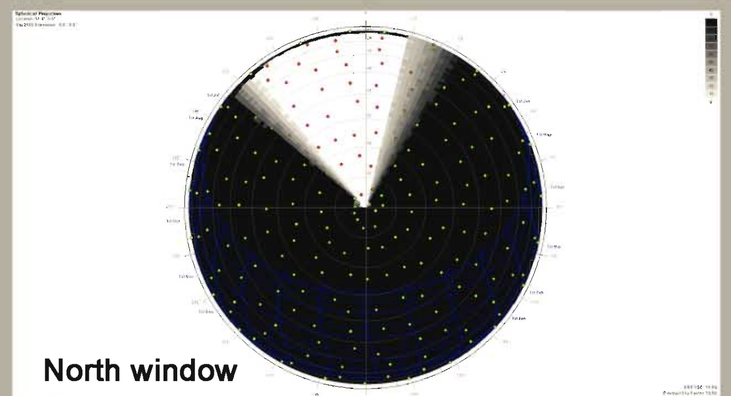


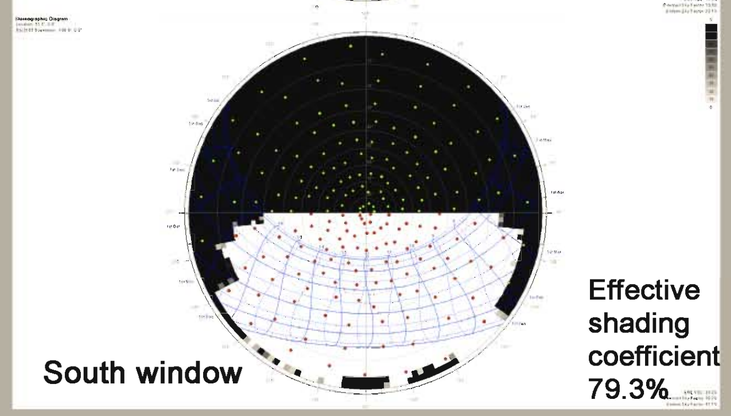






Shading Masks with Dayligth Factors





The area in the south side of the site is again not shadowed for most of the year although this time the area suitable for landscape features is smaller. The building overshadows again the buildings in the north site but at least allows them to have some access to the sky.

From the shading masks we determine that the south window is less shadowed than the previous one and both windows (north and south) have larger daylight factors than those in the north position.

Framework Assessment:

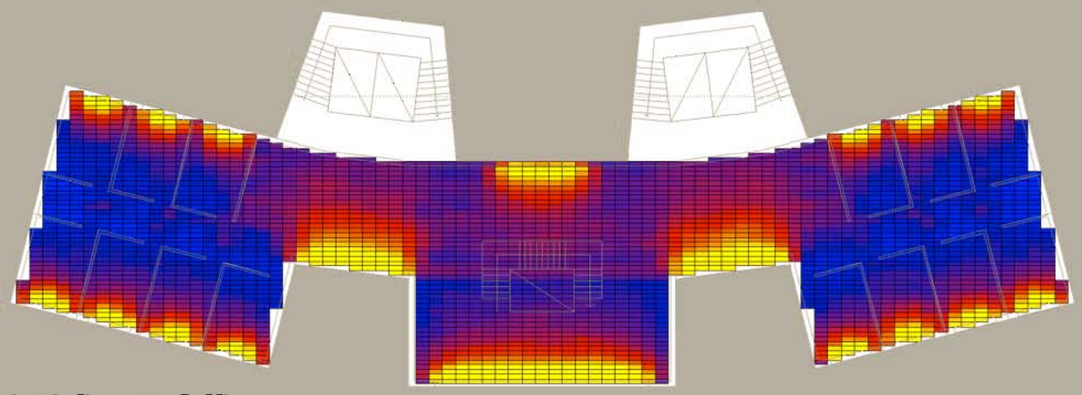
The location of a building into the site is not mentioned anywhere in the framework. Some simple should be suggested (eg. prefere north side of the side)

Fabric: Visible Radiation (Increase)

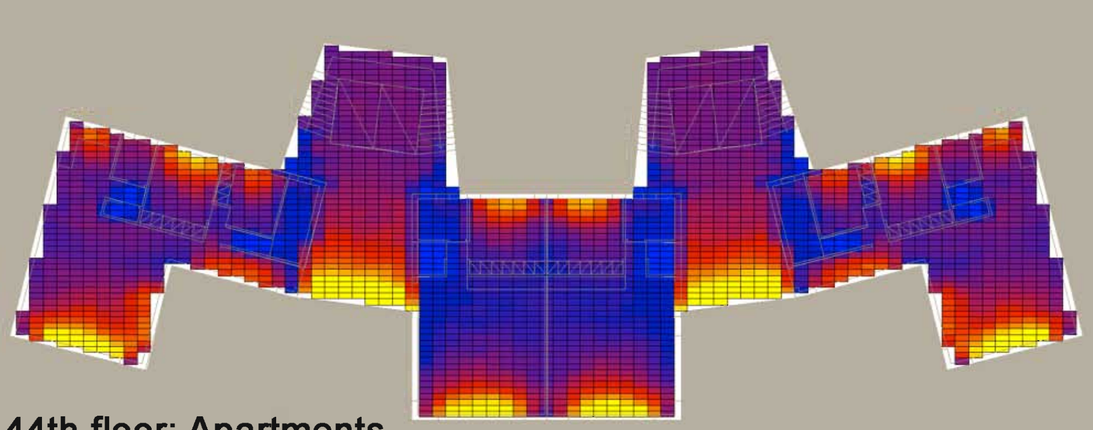
Maria - Angeliki Zanni
Konstantinos Mourkos

Initial Daylight Analysis

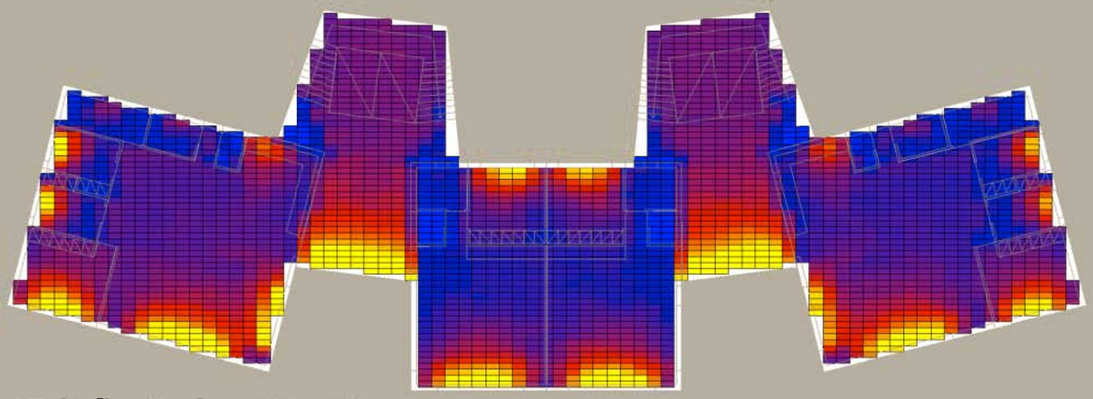
Windows
Area:15-20% of wall - Height:1.00 m - Sill Height:1.20 m
Reflectance
Walls:0.56 - Partitions:0.77 - Ceiling:0.70 - Floor:0.59



3rd floor: Offices



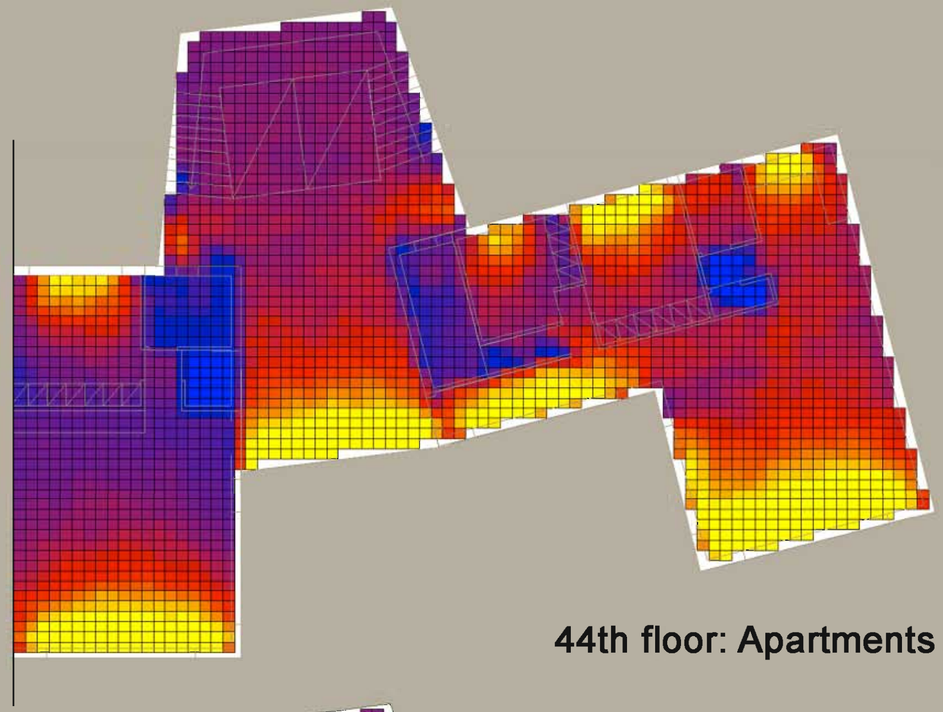
44th floor: Apartments



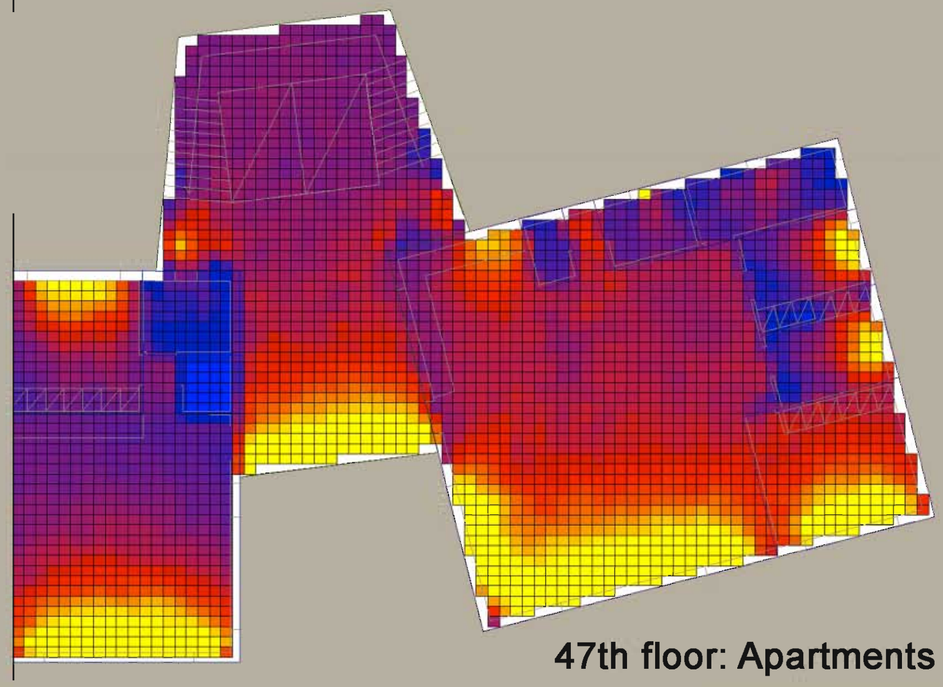
47th floor: Apartments

1st Change

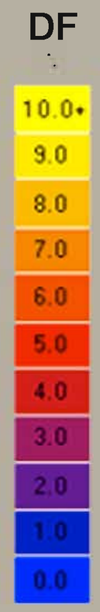
Windows
Area (south oriented):40% of wall - Height:1.50 m - Sill Height:1.20 m
Reflectance
Walls:0.56 - Partitions:0.77 - Ceiling:0.70 - Floor:0.59



44th floor: Apartments



47th floor: Apartments



Fabric: Visible Radiation (Increase)

Maria - Angeliki Zanni
Konstantinos Mourkos

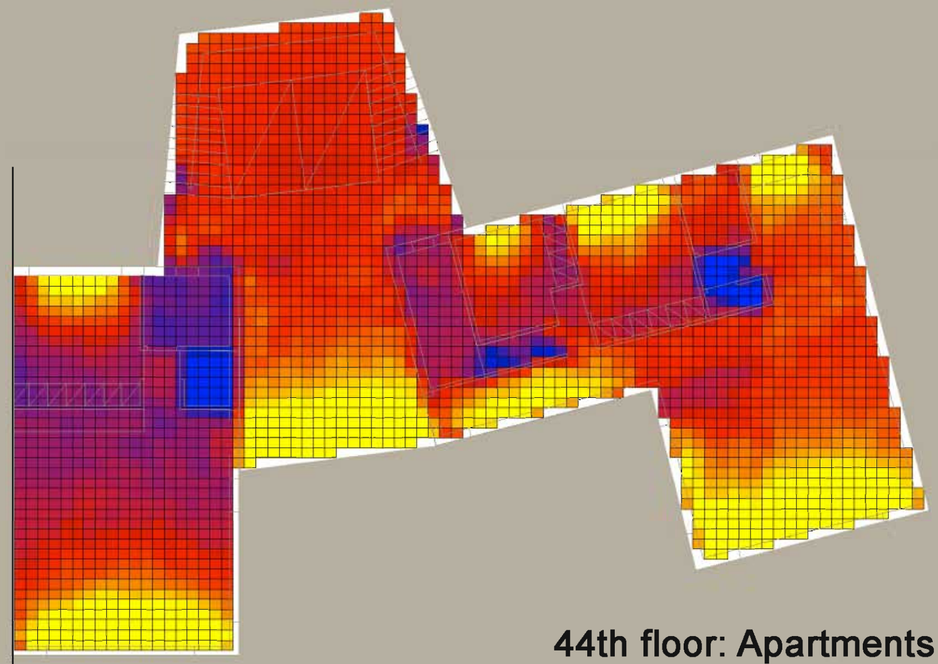
2nd Change

Windows

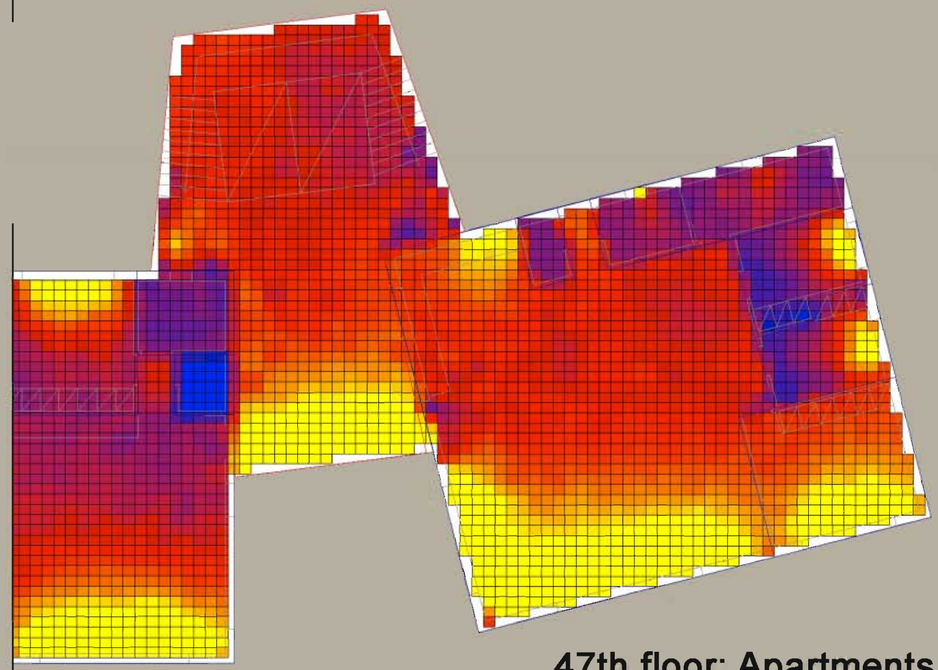
Area (south oriented):40% of wall - Height:1.50 m - Sill Height:1.20 m

Reflectance

Walls:0.84 - Partitions:0.84 - Ceiling:0.84 - Floor:0.59



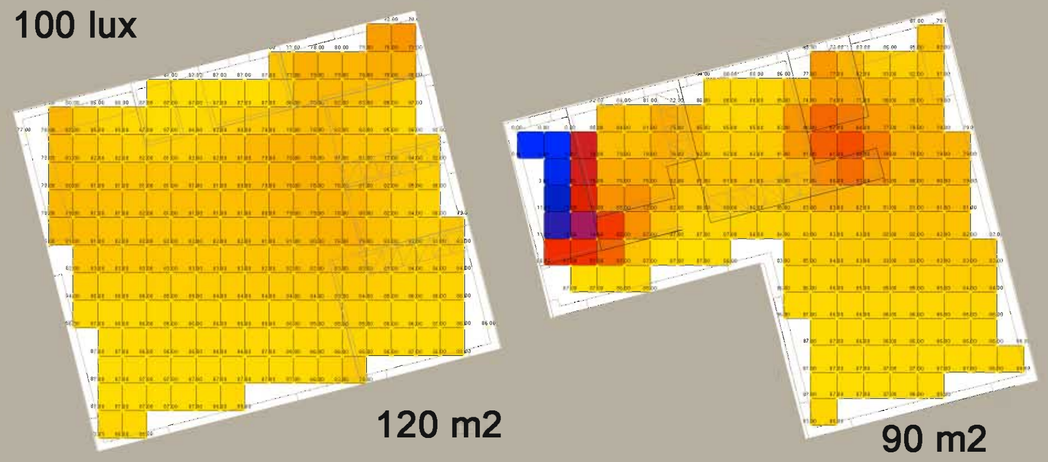
44th floor: Apartments



47th floor: Apartments

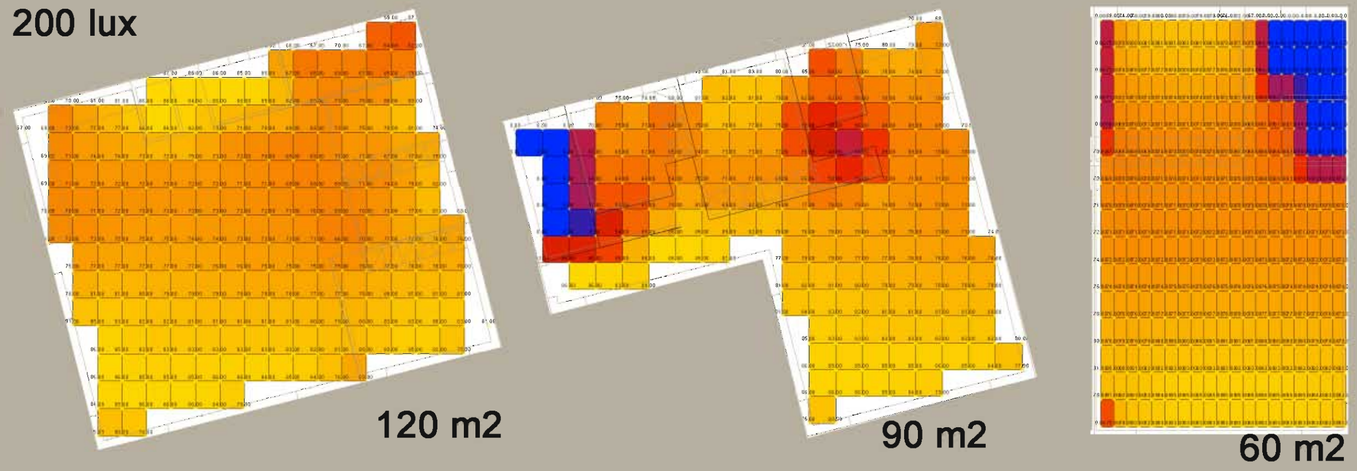
Daylight Autonomy Analysis

100 lux



120 m2 | 90 m2 | 60 m2

200 lux



120 m2 | 90 m2 | 60 m2

DF: 10.0+ | 9.0 | 8.0 | 7.0 | 6.0 | 5.0 | 4.0 | 3.0 | 2.0 | 1.0 | 0.0

DA: 100+ | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0

The first daylight analysis was conducted for a glazing to wall ratio of 15-20% according to the framework (Step 12). Daylight levels were relatively low (approximately 3% DF), the rear spaces appeared gloomy and high contrast between the front and back spaces existed. In the second analysis the glazing to wall ratio increased to 40% for the south windows and all windows increased from 1m height to 1.5m. Also openings over the entrances were provided and in the 120 m2 apartment the ceiling of the WC was lowered and and an opening was provided in order to lit the back of the room. The daylight levels were improved (5% DF). Finally, by increasing the reflectance of the internal walls and ceiling the daylight levels increased to approximately 6% DF.

The Daylight Autonomy Analysis was performed using Daysim software . The daylight autonomy shows the percentage of the time of the year when the illuminance is above the required minimum level. Daysim calculates daylight levels taking into account all possible sky conditions that may occur at a specific site in a year. The analysis was performed for two levels of illuminance 100 and 200 lux.

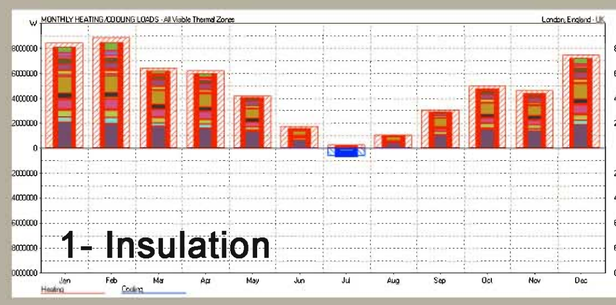
Framework Assessment:

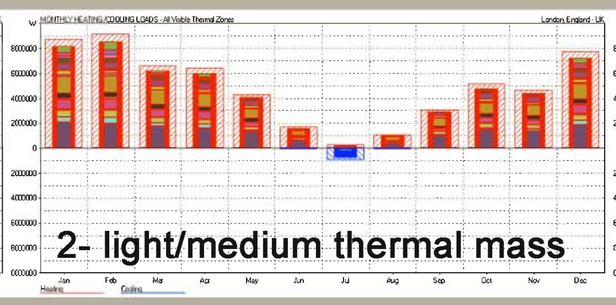
Further guidance should be provided in relation to how to reduce glare. For istance, make sure that the contrast between the two halves of the room is less than 1/3.

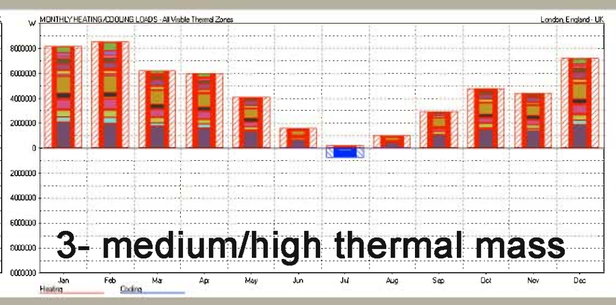
Fabric: Thermal Radiation (Increase)

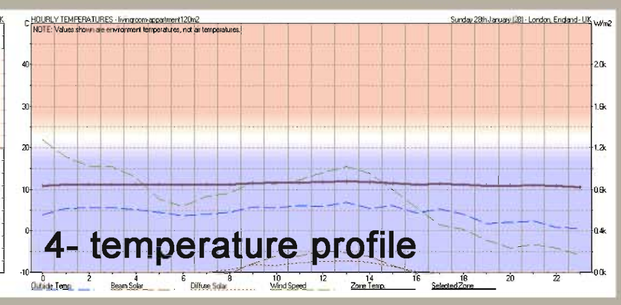
Maria - Angeliki Zanni
Konstantinos Mourkos

Thermal Analysis



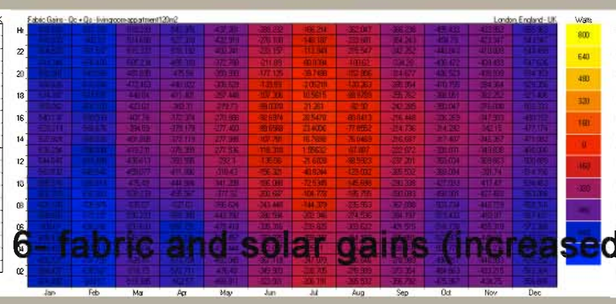


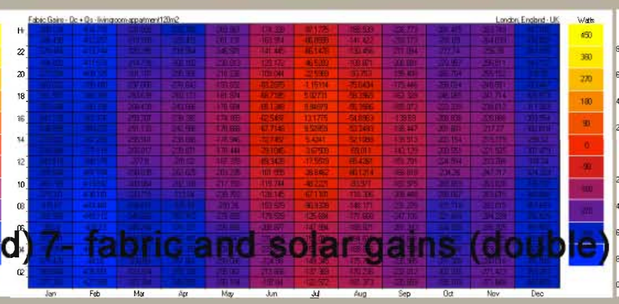


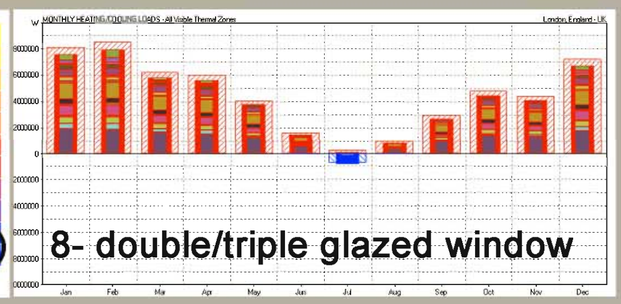


At first, two types of construction were considered one with U-Value equal to 0.67 W/m2K and another with a U-Value 0.31 W/m2 (figure 1). The lower U-Value reduces the heating load but increases slightly the cooling load in contradiction to the framework (Step 19). So, overall it is beneficial for the performance. Then three types of thermal mass were tested; light, medium and low mass (graphs 2,3) [light: 0.3h thermal lag, medium: 5h thermal lag, high: 9.2h thermal lag]. From the above graphs, it is obvious that the increase in the mass from the low level to the medium decreases both heating and cooling loads (figure 2). A further increase to the level of thermal mass integrated in the building has no effect on the mechanical loads. Graph 4 shows the internal variation of temperature for a winter day with some direct solar radiation for the living room area of the 120 m2 apartment. It is apparent that the temperature profile is constant but it is well below the comfort zone.

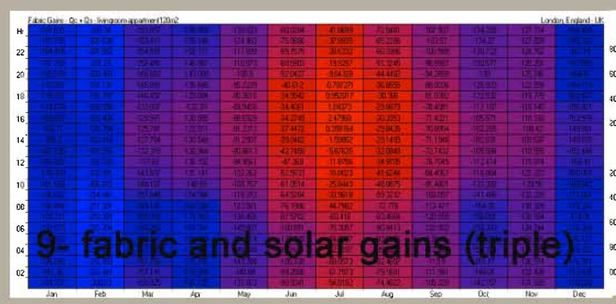


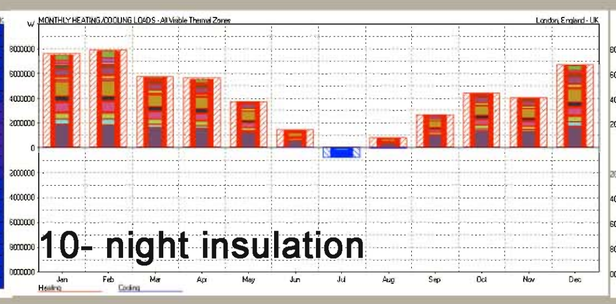


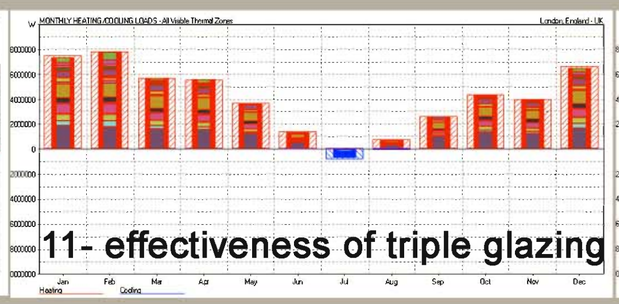


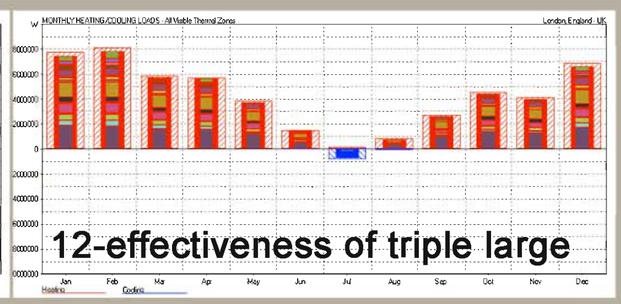


Attempting to increase solar gains, we increased the glazing area (almost double). From the monthly heating-cooling loads graph we determined that actually auxiliary loads increased (graph 5). In the next two graphs (6,7) we see that the solar gains are too low to offset the fabric losses even in mid-day hours. Due to the fact that the initial size of the windows provide a sufficient daylight level, is was decided not to decrease their size and at the same time to minimize any heat losses though them. For this reason, triple glazing was applied that such characteristics that they combine very low U-Value (0.7 W/m2K) with high solar gains (g-Value 79%). From graph 8 we see that mechanical loads are reduced for the whole season (Step 16).









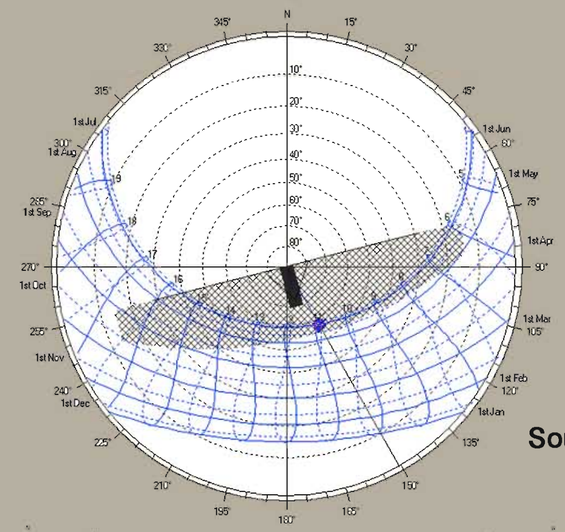
Graph 9 shows that for the triple glazing heat losses are further reduced. In order to minimize heat losses during the night, night insulation is provided in the form of blinds that is used between 7:00am-07:00pm. The gragh (10) shows a slight reduction in the heating and cooling loads, this is maybe due to the fact the U-Value of the window is already too low. Finally, tht two last graphs (11,12), show the thermal behaviour of the living room of the 120 m2 apartment with and without the window. We see that in both cases window is liability. For the larger glazing area this effetc is more aparent.

Fabric: Thermal Radiation (Decrease)

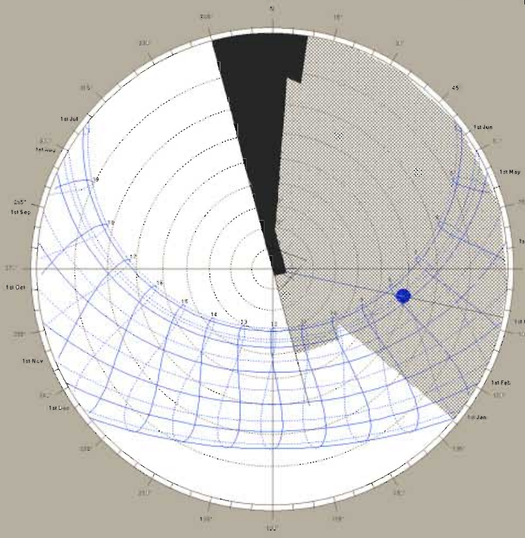
Maria - Angeliki Zanni
Konstantinos Mourkos

Solar Control Devices

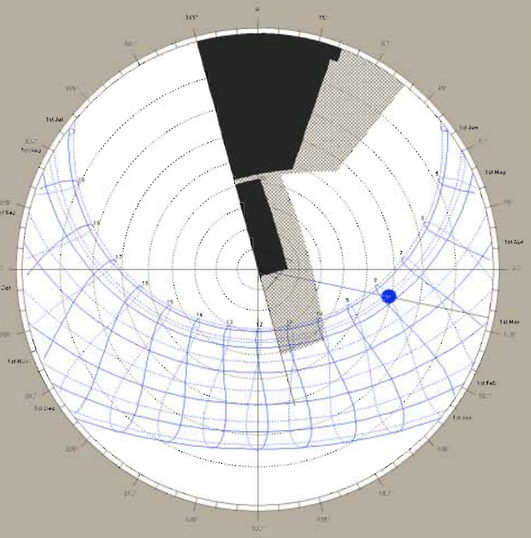
Sun path diagrammes



South Window



East Window: summer case

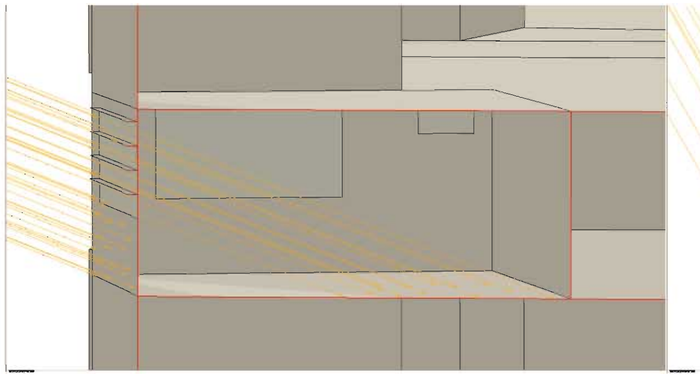


East Window: winter case

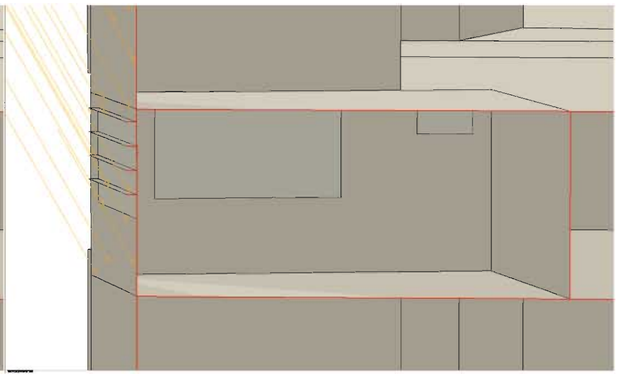
In order to shade the south window during the summer horizontal louvres were placed (150 mm long spaced every 375mm). From the corresponding sun-path diagram we see that from 6:00am to 3:30pm for June and July the sun is blocked and from 13:00pm during August (Step 23- Step 24, option 2b)

For the east window, a combination of horizontal and vertical louvres is used. A horizontal overhang is provided (400mm long) and vertical louvers (200mm long spaced every 256mm). During the summer the are tilted 66 degrees and during the winter they are perpendicular to the window. For the summer case the window is shaded from June to August (Step 22)

Livingroom 120 m2

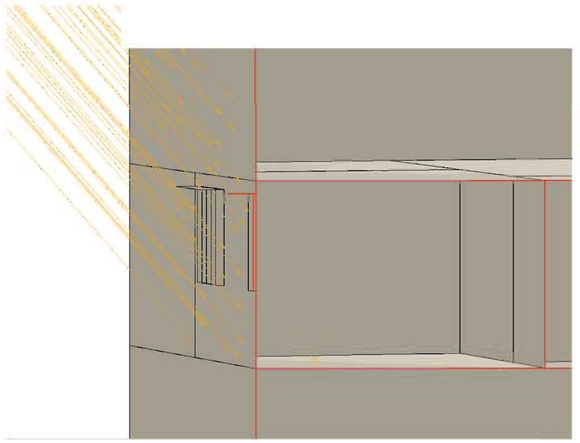


November 12th 12am



July 12th 12am

East bedroom 120 m2



July 12th 09am



April 12th 09am

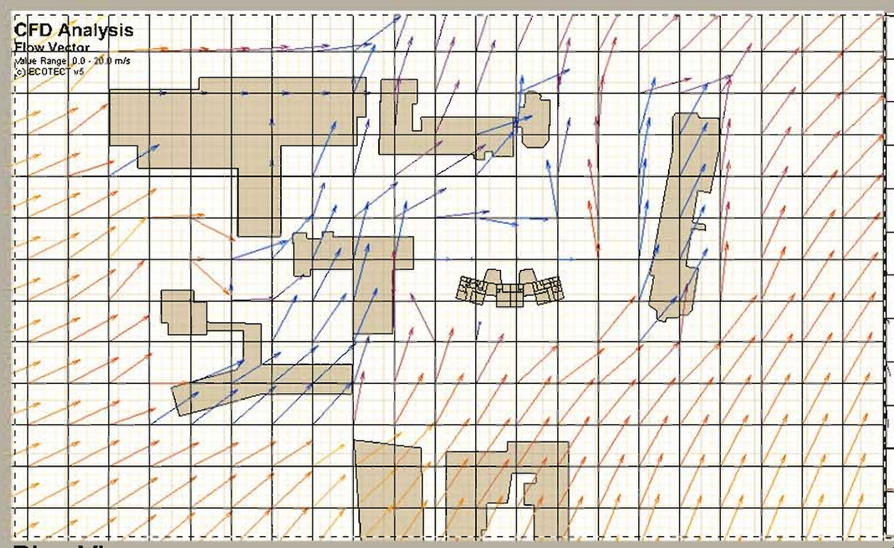
Framework Assessment:

Step 20: glazed thermal walls . There is not enough radiation in London for such strategy. It will be a good idea to provide the designer with strategies according to the climate which they design for.
Step 24: Solar control devices. Only horizontal devices have been taken into account. There is no guideline for vertical devices.

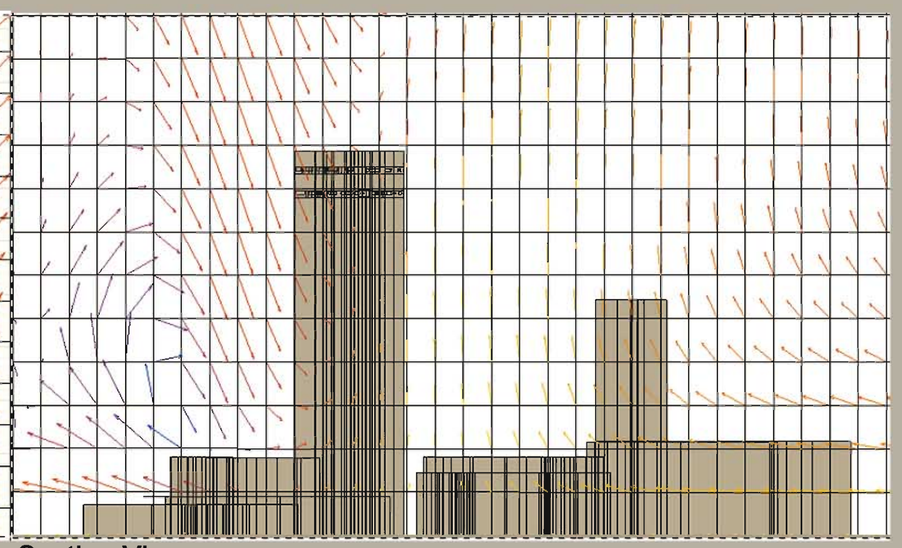
Fabric: Airflow

Maria - Angeliki Zanni
Konstantinos Mourkos

CFD Analysis

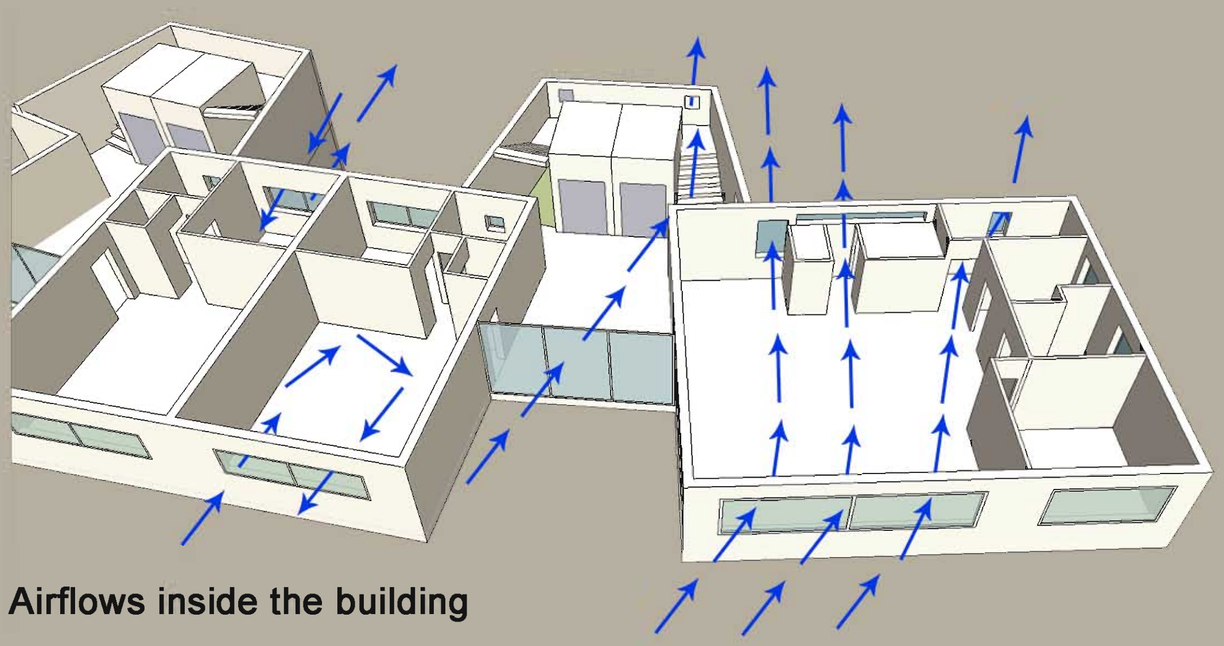


Plan View



Section View

The above images are from CFD Analysis undertaken using Winair 4. In the plan view we see the air flows around the building. In the section view image the vortex effect is apparent.
The image below shows the airflow inside the apartments for the major wind directions. Cross ventilation is employed in the 120m2 apartments and core. The north window above the auxiliary spaces serves two functions: optimises daylight levels in the back of the room and at the same time to make possible cross ventilation. The 60m2 apartments are mainly ventilated by side ventilation. The diagrams below show possible flow patterns.



Airflows inside the building

For a high rise building, a double facade is a viable solution as it is suggested by the framework. For aesthetic reasons we chose not to follow this strategy because it is mainly used for offices.

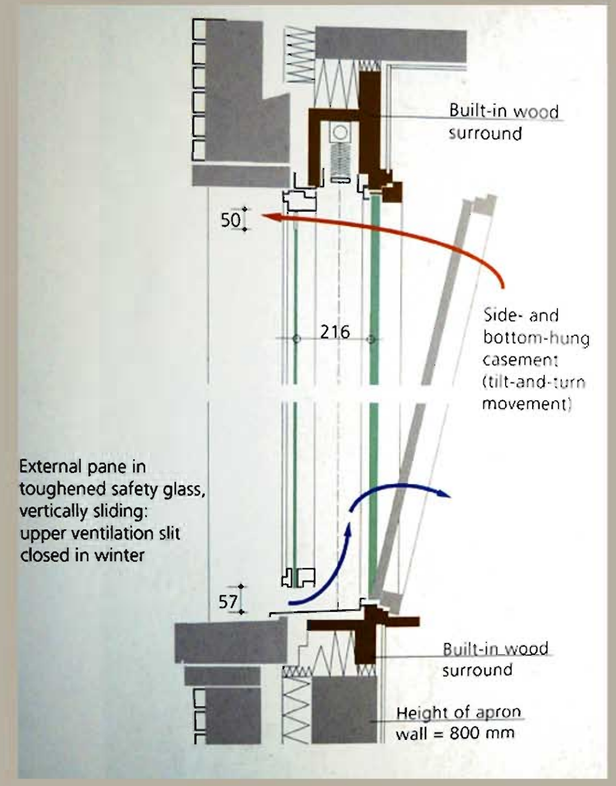
As a solution we decided to make use of the box window which is mainly a glass facade but restricted to the height of the window. This was done for two reasons; the main one is to control the speed of the air inside the building, because as we saw from the wind profile, large velocities develop at higher levels. Also, this type of windows eliminated the problem of noise.

Framework Assessment:

The guidelines are the same for both side and cross ventilation.

It would be useful if some guidelines about the size of the inlets and the outlets was provided.

No specific instructions are given on how to reduce wind speeds.

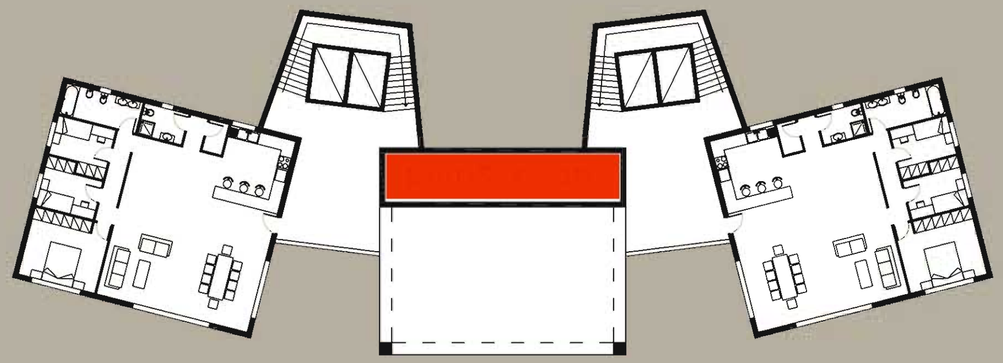


Detail of box window
(source: Oesterle et.al , 2001)

System: Visible Radiation - Thermal Radiation - Airflow

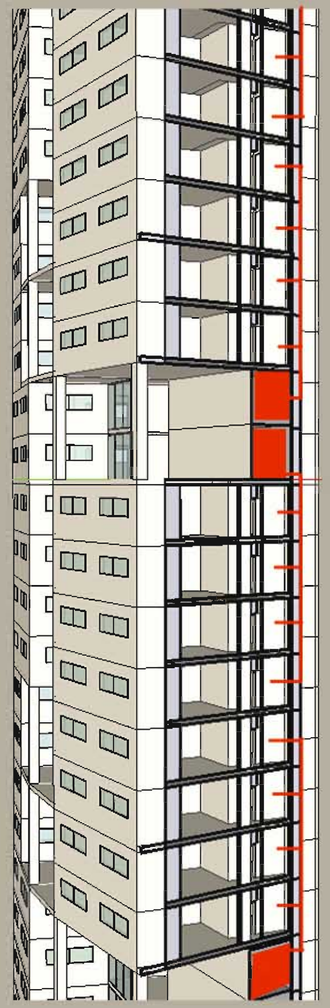
Maria - Angeliki Zanni
Konstantinos Mourkos

Location of the plant room

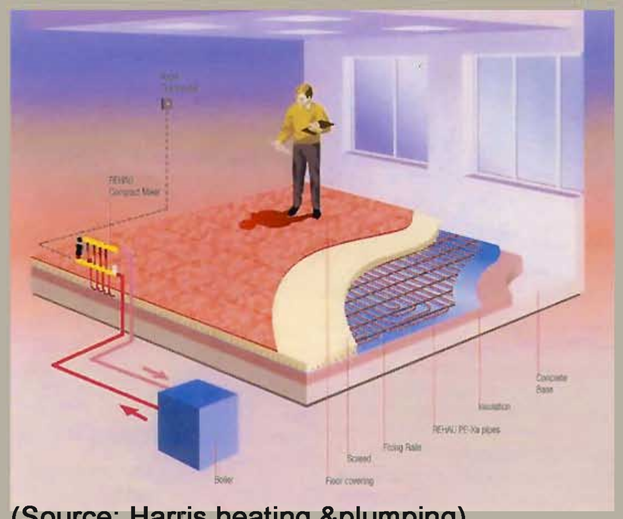


Plan

Section

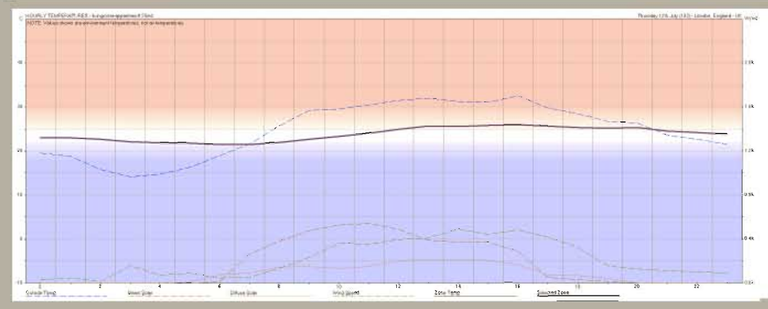


The plant room is located at the rear of the communal space and is two storey high. It is divided in two levels each serves five floors. In this way losses through the duct work are minimised, the system becomes more responsive due to the fact that the serviced plants and the pant rooms is reduced. Therefore, the overall performance is increased.
Also the plant rooms act as a buffer zone from the north to the communal space.
The selected system for heating is the under floor heating. It is the appropriate for residences because the system very slow responsive but high efficient. Thus, it is more better for continuous occupational schedule.

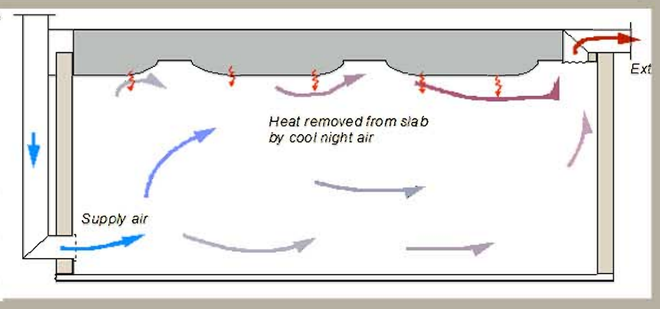


(Source: Harris heating &plumping)

Diurnal Temperature Profile for the hottest summer day.



Night ventilation



From the above diagram we see that there is some need for cooling during the day. Since the outside temperature during the night is lower than that needed for comfort, night ventilation can be employed. Natural night ventilation can be assisted by fans located at the ceiling.

The strategy needs high thermal mass and in the building concrete is used in the form of precast form panels. This were used for the high thermal mass they possess, the good sound insulation and the ease of construction. As insulation material cork is used for its high efficiency and because it is a sustainable material.

General assessment of the framework:

-It is quite useful in general because it makes sure that the designer does not forget to consider all the necessary steps for a successful sustainable design.
-However, it seems that is most orientated to the design of open plan spaces rather than residences. This was reflected in our design process since the initial plans followed this approach.
-For a successful sustainable design, a more a holistic approach is needed; daylight, ventilation and thermal behaviour are needed to be taken into account at the same time ,since there is interaction between them.
-More some aspects more specialised guides are needed and some steps need to be clarified in more detail (flue wall for instance).
-Finally, little information is provided for services and there is no guideline about the size and location of the plant room.

References:

- Brown, G. Z. & Dekay, 2001. Sun, Wind & Light, Architectural Design Strategies. Wiley-Interscience Publication, John Wiley & Sons, Inc. New York, Chichester, Brisbane, Singapore, Toronto. ISBN 978-0-471-34877-1
-Daysim software
-Deaves and Harris model, wind speed calculator
-Euro code 1, 2010
-Fazlic, S. Design Framework Guideline Booklet
- Givoni, B., 1994. Passive and Low Energy Cooling of Buildings, Van Nostrand Reinhold, An International Thomson Publishing Company. ISBN 0-442-01076-1
-Oesterle, Lieb, Luz, Heusler, 2001. Double-skin Facades
-UK National Annex to Euro code 1, 2010

DESIGN A SUSTAINABLE SKYSCRAPER

flowchart



- Accommodation Brief
- Region Analysis
- Activity Analysis
- Climate Analysis
- Comfort Analysis



1. SURROUNDINGS & BUILDING

- Social Aspects: Urban Life & Vertical Communities
- Local Microclimate
- Relationship with Surrounding Buildings

2. BUILDING AND CLIMATE

- Shape
- Orientation
- Plan & Core
- Atrium
- Configuration
- Services
- Fabric



1. CONFIGURATION OF FORM

- Numerical arrangement of flats per floor - detailed accommodation brief
- Assesment of different patterns for building layout
- Choice of final form
  - Finalize typical floor patterns
  - Finalize vertical distribution

2. Interior layout design according to **passive principles** (*provide, ensure and optimise thermal comfort, natural ventilation and daylight.)*

- Room Arrangement
  - South: continuously occupied rooms
  - North: Buffer zones: circulation areas, bathrooms, auxilliary spaces
- Depth of rooms
  - Airflow
  - Daylight

- Core(s)
  - main circulation core(s)
  - security staircase - fire escape
- Shading of Facades
  - South-North-West-East
- Materials for external elements
  - Insulation
  - Thermal Mass
  - Reflectivity
  - Absorptivity
  - Colour
- Glazing
  - Ventilation
  - Type
  - Special coatings
- Vegetation
  - Per floor
  - Roof
- Services
  - Heating/cooling systems
  - Mechanical plant floor
  - Active features
- Water Saving Features
  - Rainwater collection
  - Greywater collection



- Ventilation
- Thermal Performance
- Daylight Distribution
- Check design and make improvements
- Check performance again

Completed Design



Context

Type of building: **Sustainable Tall building**
Location: **London, UK, Blackfriars site**
Climate: **Temperate**
Function: **Residential + Commercial activities and offices**
Traget: **provide a *"sustainable and comfortable living experience"***

Features

The main focus of the project is to provide thermal and visual comfort to the residential part of the tower, through optimum plan and façade design and investigation, according to zoning configuration.
The sustainable tower will look up to the following issues:

- Provide adequate daylight, in order to reduce the need artificial lighting.
- Optimize the building fabric, in order to minimize heating and cooling loads
- Provide adequate ventilation (natural or mechanical) in all zones according to their requirements.
- Introduce renewable energy sources and technologies and efficient services.
- Prove all the above through literature and simulation programs.

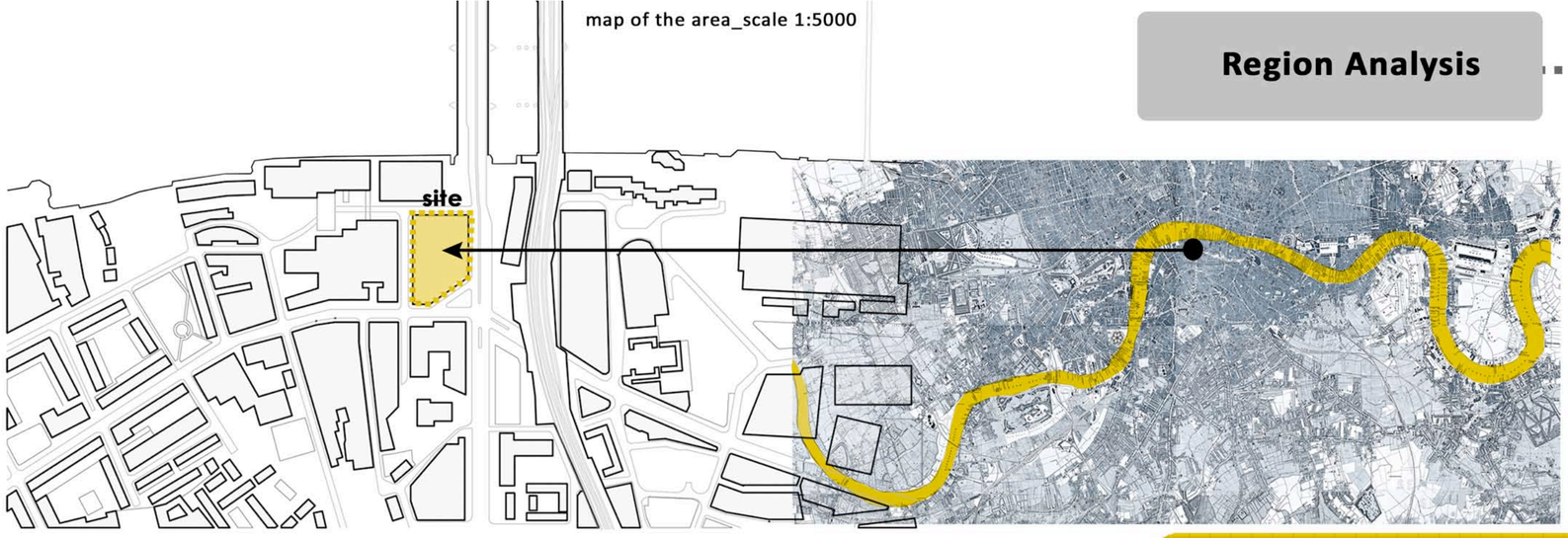
The final morphology, vertical arrangement, skin and services, will reflect the location, the climatic and cultural aspects of the place.

Objectives

1. Design a sustainable skyscraper
2. Draw up a "framework" for use in developing strategies for designing a sustainable tall building, without the "framework guideline booklet".

Additional options, both environmental and non-environmental, will be explored.

map of the area_scale 1:5000



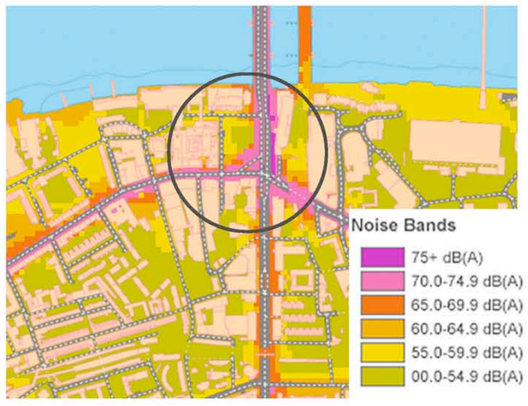
Region Analysis

INCEPTION

Accommodation Brief

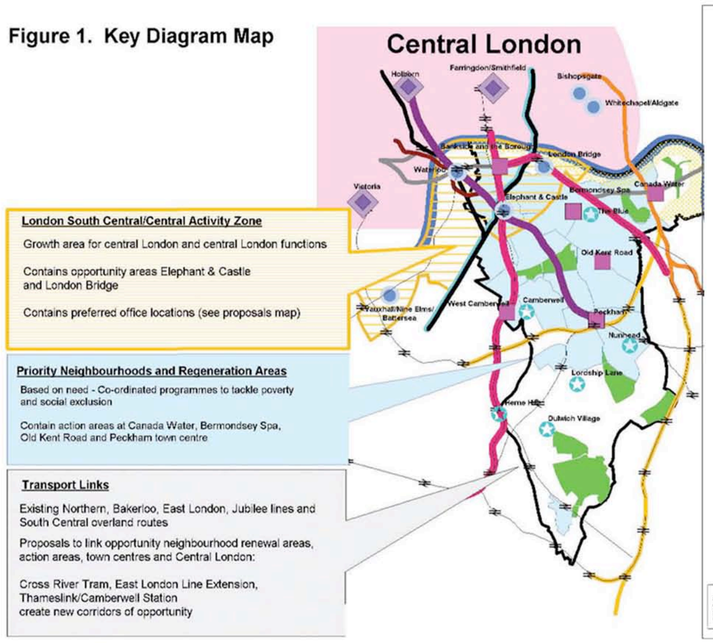


Air Pollution map (source: London Air Quality Network)

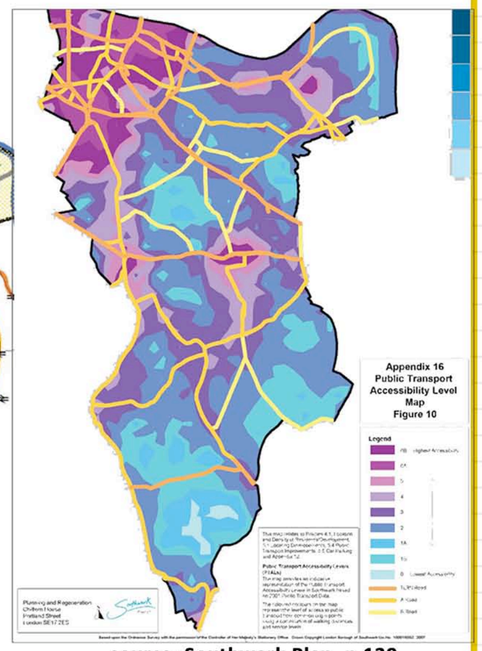


Noise pollution map (source: DEFRA, Noise Mapping England)

Figure 1. Key Diagram Map



source: Southwark Plan, p.15



source: Southwark Plan, p.139

Maximum allowed plot ratio for Central London sites can be up to 5:1 and site coverage <75% (Supplementary Planning Guidance)

- Total site area: 4,678 sqm
- **Total allowed maximum built area: 23,390 sqm**
- **Max coverage: 3,500 sqm**

The site is located in the **CENTRAL ACTIVITY ZONE** (Southwark Plan, p.15, fig.1: Key Diagram map), *for which* **650-1100 habitable rooms per hectare** *are permitted* (Southwark Plan, p.64).

- Total site area: 4,678 sqm or 0.4678 hectares

For 1000 habitable rooms/hectare, 468 habitable rooms are allowed for this site:
50%: 58 flats of 120sqm (4 h.r.)
20%: 32 flats of 90sqm (3 h.r.)
30%: 70 flats of 60sqm (2 h.r)
Sum (+30% auxiliary and circulation areas)= **18,252 sqm FOR RESIDENCES**

- **Max floor area: 500 sqm** (assuming 3*120+30%)
- **2,000 sqm are COMMERCIAL ACTIVITIES AND OFFICES** (4floors*500)

Regarding public transport, the site is located in a ***HIGH ACCESSIBILITY ZONE*** (Southwark Plan, p.139, Appendix 16), *for which the provision of residential car parking space is 0.4 per unit, for offices 1 per 1500sqm, and no provision for commercial and retail uses.*

- RESIDENCES: 160 flats * 0.4 = 64 car parking places
- OFFICES: + 2 car parking places
- Total parking floor area = (66 * 11.5) + 30% = **1000sqm FOR PARKING**

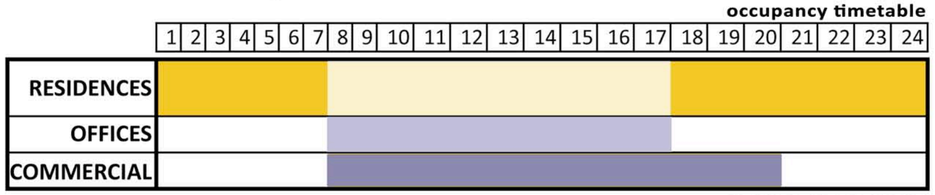
TOTAL BUILT AREA: 22,400 sqm

RESTRICTION: Height allowance <1000ft (304.8m)

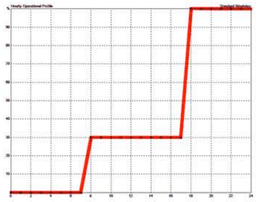
- 21,400 / 500 = 42 floors -> **145m height**

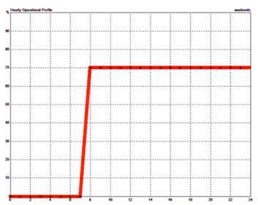
Activity Analysis

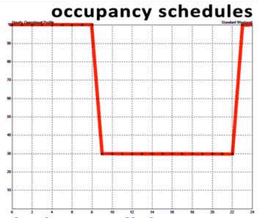
occupancy timetable



occupancy schedules


living room_weekdays


living room_weekends


bedroom_all days

Comfort Analysis

Adaptive Thermal Comfort

For the living rooms the following equation for adaptive thermal comfort in mechanically ventilated buildings was used:

$23.9 + 0.295(T_{ave}-22)\ exp([-(T_{ave}-22)/33.941]^2)$ (Humphreys and Nicol, 1998)

For the bedrooms, the following equations were used as indicated by Peeters and de Dear (2008), for when the occupantsare expected to be sleeping:

$T_{comf}=0.23T_{outdoor}+16$ (for $0°C<T_{outdoor}<12.6°C$)

$T_{comf}=0.77T_{outdoor}+9.18$ (for $12.6°C<T_{outdoor}<21.8°C$)

requirements and input data

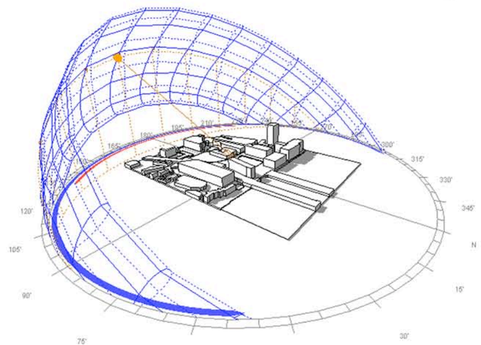
		BEDROOMS	LIVING ROOMS	KITCHEN	BATHROOMS	TOILETS	HALLS
	Activity Rate	0.9	1.1	1.6	1.2	1.4	1.8
Winter	T_{comf} (°C) (according to adaptive theory)[2,3]	17	17.5	-	-	-	-
Winter	operative temperature range (°C) (according to CIBSE,Guide A,2006,table 1.6)	**17-19**	22-23	**17-19**	**20-22**	**19-21**	**19-24**
Winter	combination of adaptive theory and CIBSE (°C)	-	**19-21**	-	-	-	-
Winter	clothing levels	2.5	1.0	1.0	0.25	1.0	0.75
Summer	T_{comf} (°C) (according to adaptive theory) [2,3]	22.6	22.5	-	-	-	-
Summer	operative temperature range (°C) (according to CIBSE,Guide A,2006,table 1.6)	23-25	23-25	**21-23**	**23-25**	**21-23**	**21-25**
Summer	combination of adaptive theory and CIBSE (°C)	**22.6-25**	**22.5-25**	-	-	-	-
Summer	clothing levels	1.2	0.65	0.65	0.25	0.65	0.65
	Illuminance (lux)	**100**	**50-300**	**150-300**	**150**	**100**	**100**
	Ventilation Rate	**0.4-1 ACH** (to control moisture)	**0.4-1 ACH** (to control moisture)	**60L/s/person**	**15L/s/person**	**>5ACH**	-
	Noise rating (NR)	25	30	40-45	-	-	-

References:

1. CIBSE, Guide A (2006), Table 1.6
2. Humphreys and Nicol, 1998
3. Peeters L. and de Dear R., 2008

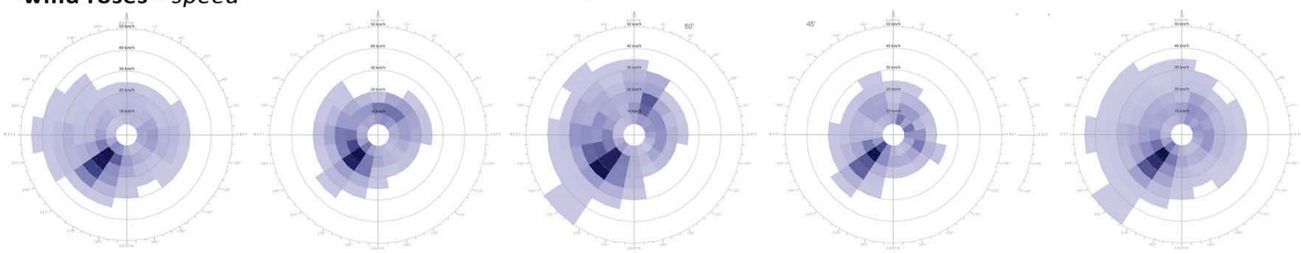
Climate Analysis

INCEPTION

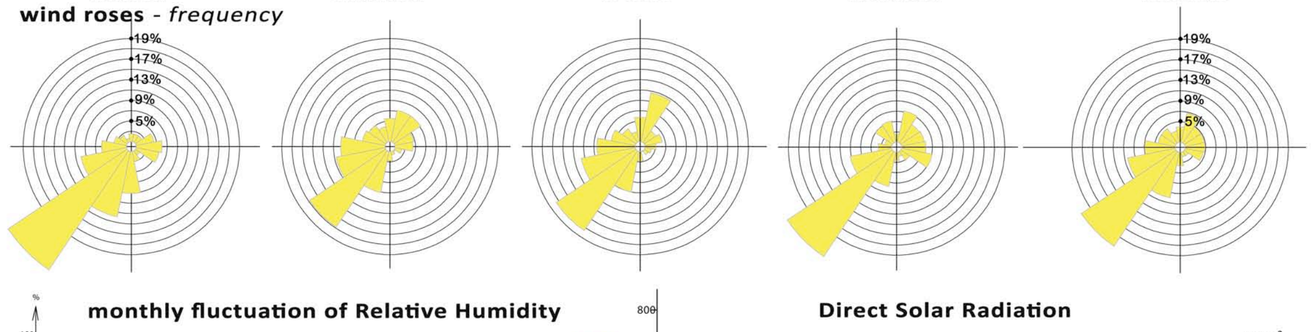


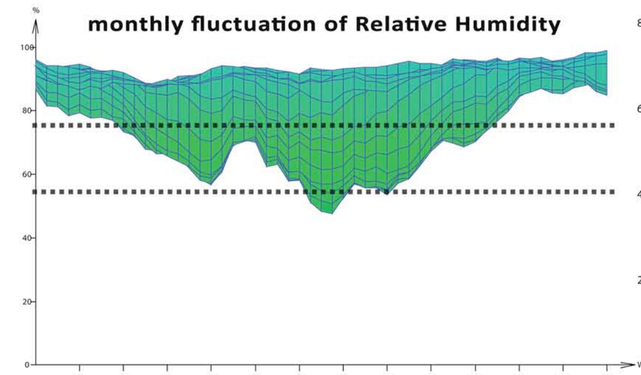
LONDON - UK
Climate: **Temperate**
(Köppen classification Cfb)
Latitude: 51.4°
Altitude: 12.8°

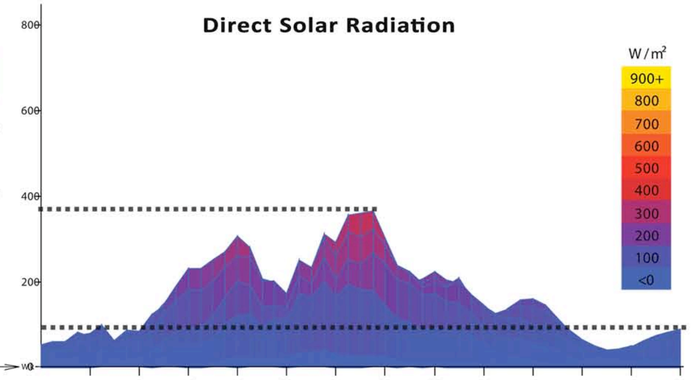
wind roses - *speed*

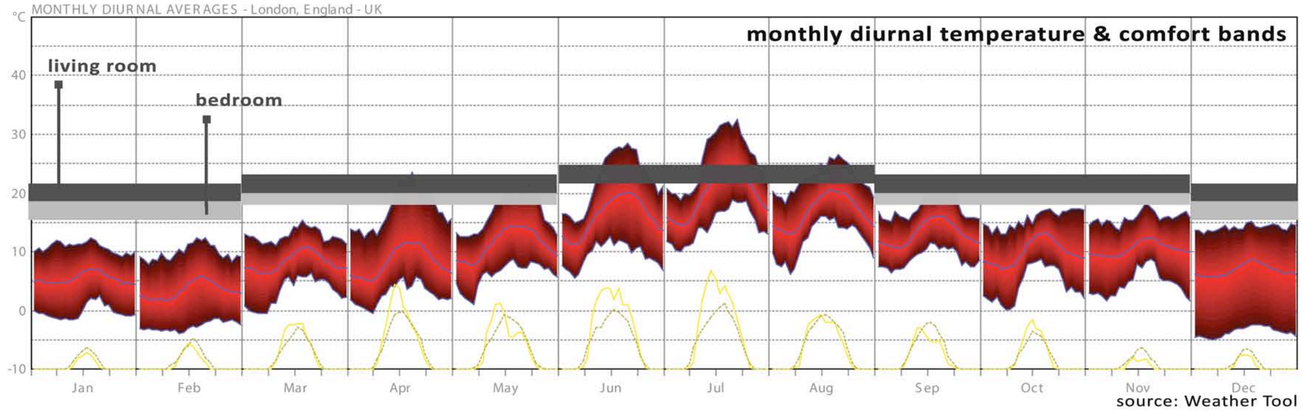


wind roses - *frequency*







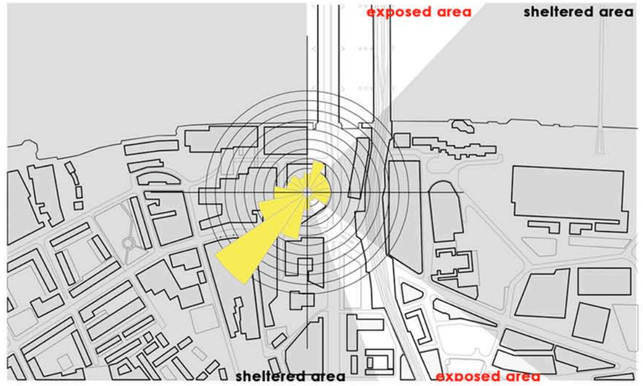


source: Weather Tool

Local Microclimate

1. SURROUNDINGS & BUILDING

DESIGN PARAMETERS



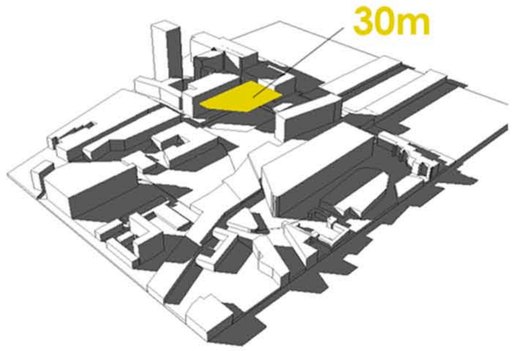
wind analysis: due to tall surrounding buildings, the site is quite well protected from the most frequent North-West winds (mostly on ground level). This effect, however, is subject to change vertically with height.

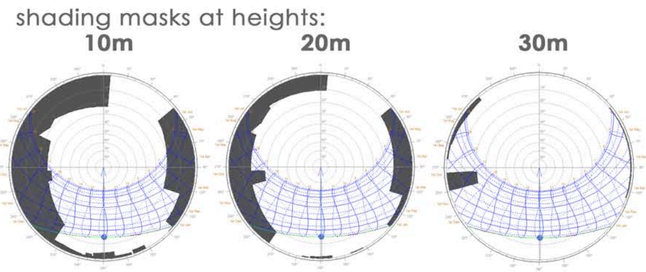


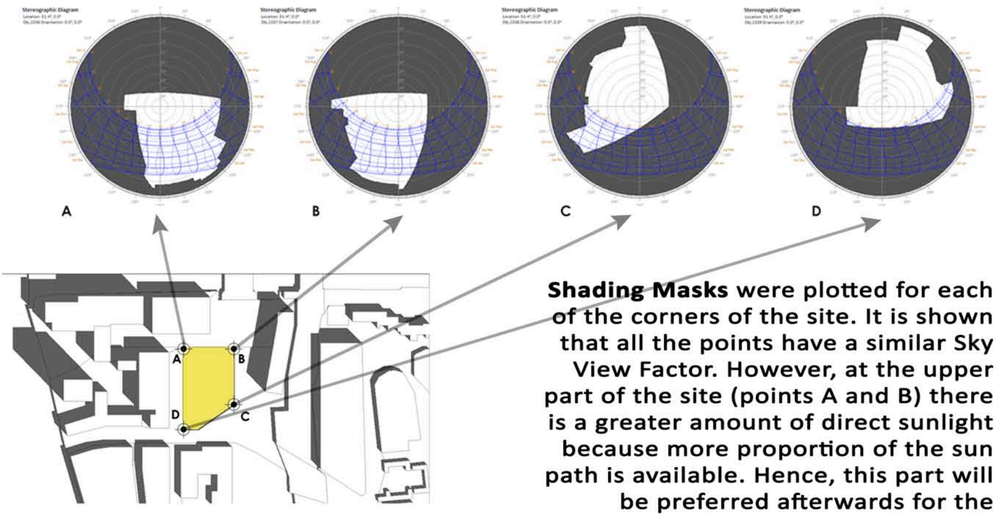
shadow ranges: representative months and hours

Relationship with Surrounding Buildings

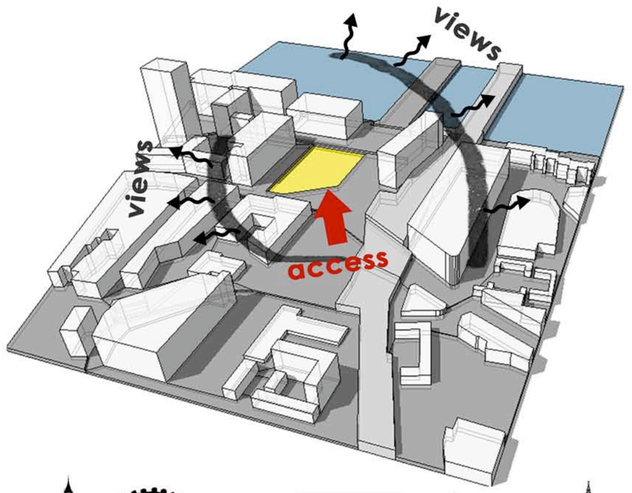
- From this level up the site is not affected by its surroundings.



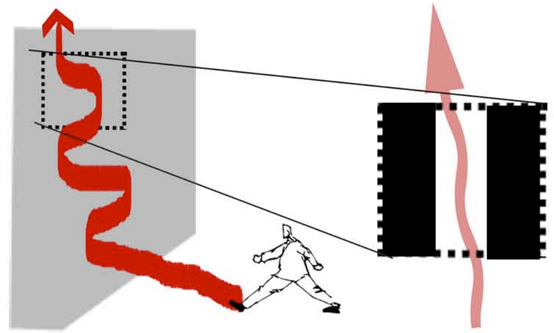




Shading Masks were plotted for each of the corners of the site. It is shown that all the points have a similar Sky View Factor. However, at the upper part of the site (points A and B) there is a greater amount of direct sunlight because more proportion of the sun path is available. Hence, this part will be preferred afterwards for the location the building.



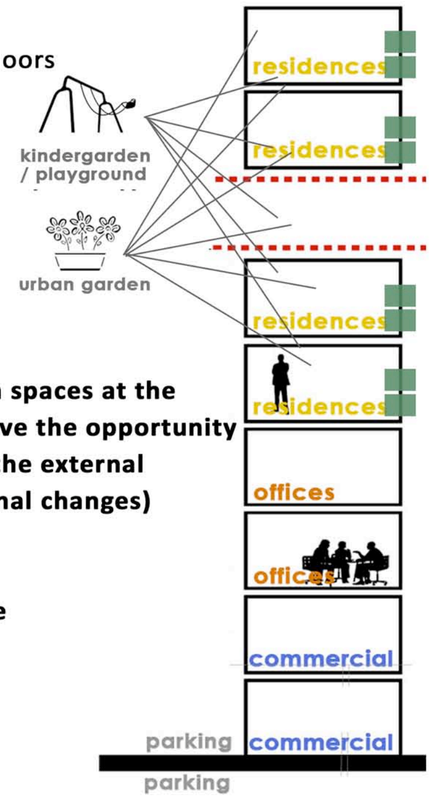
Social Aspects: Urban Life & Vertical Communities

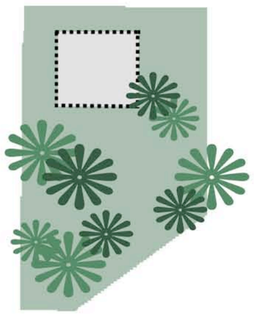


a. ground floor
✔ **OPEN to the city**
-> enhance street life

b. mixed use & vegetation

✔commercial activities at lower floors
✔communal spaces, with playgrounds and kindergardens
-> less use of trasportation
-> communication with the neighbours
✔vegetation and small gardens throughout the residential part
✔skycourts and balconies
-> provision of in-between open spaces at the upper part of the tall building give the opportunity to the occupants to experience the external environment (diurnal and seasonal changes)
(Yeang, 2004)
-> daylight penetration
-> close relationship with nature
-> aesthetic benefits





c. green public urban space accessible to everyone (provision of underground parking maximises the use of the urban public space and provides more free space for planting).

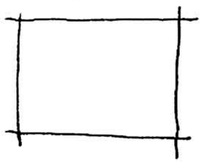
2. BUILDING AND CLIMATE

Developing a design strategy **responsive** to the external climate

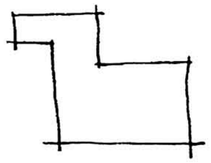
DESIGN PARAMETERS

Shape

compact



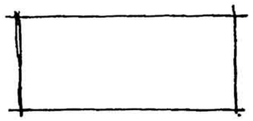
loose



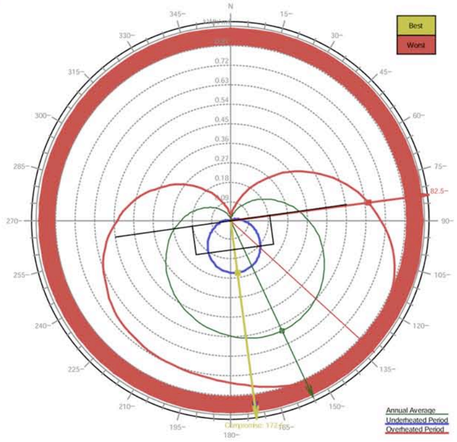
In a cold climate, a compact shape has less exposed surfaces and less heat losses through the envelope.

Orientation

E-W axis



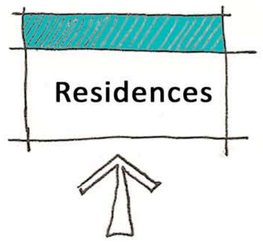
with long facades facing South



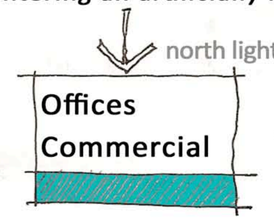
Optimum orientation for London from Weather Tool

Plan & Core

The core(s) provide **buffer zones***, insulating internal spaces. Besides that, it is important that they offer **views** to the exterior. As Yeang mentions, when the core(s) are located to the sides, *"the user of the building leaving an elevator at an upper floor can see out and be aware of the place, instead of entering an artificially lit lobby that could be anywhere in the world."*



✔core located at the North facade to provide protection from heat losses

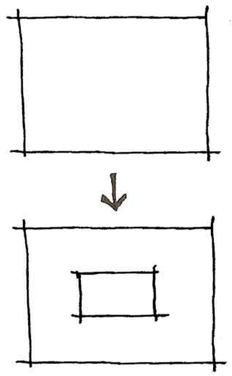


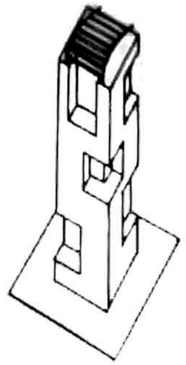
- high internal gains

✔a core located at the South will provide protection from overheating.

**auxilliary spaces, such as bathrooms and storage rooms, can also serve as buffer zones.*

Atrium / Skycourts



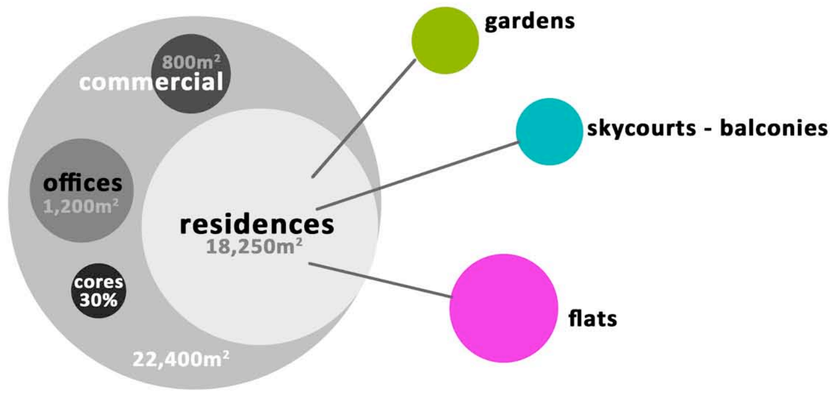


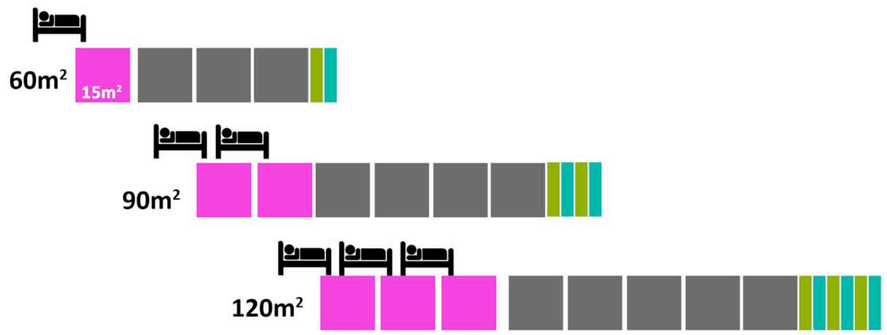
for **Daylight - Ventilation** penetration to the inner parts of the building (Yeang):

✔**atrium:** should be shielded by louvered roof to encourage wind flow through the inner areas of the building

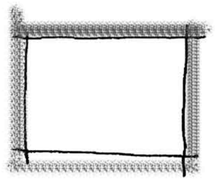
✔**skycourts:** they are zones located between the interior and the exterior, providing access to balcony spaces that can serve as evacuation spaces, or as large terraces for planting and landscaping, and as flexible zones for the addition of future facilities.

Configuration



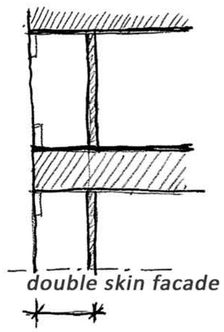


Fabric



external walls & glazing

✔materials
✔type
✔thermal mass
✔insulation
✔U-value



double skin facade

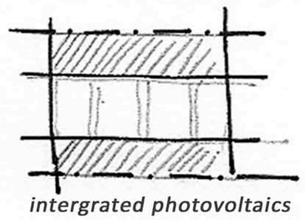
Services

✔**Mechanical plant**
centralised / de-centralised
location/size of plant room

✔**Heating - Cooling System**
boilers and chillers
distribution systems

✔**Renewables**
wind turbines
photovoltaics

✔**Water saving features**
rainwater
greywater



intergrated photovoltaics on Southern facade

1. CONFIGURATION OF FORM

Numerical arrangement of flats per floor - detailed accommodation brief

From the initial accommodation brief it was assumed that the maximum floor area would derive from 3 flats of 120m². This is typology A. The other typologies were calculated taking that as a starting point, in order to include flats of 90m² and 60m². The combination of flats made in each floor are shown in the following diagram.

120m² 90m² 60m²

Typology A: 3x120m²



Typology B: 2x90m² + 2x60m²



Typology C: 1x90m² + 1x120m² + 2x60m²

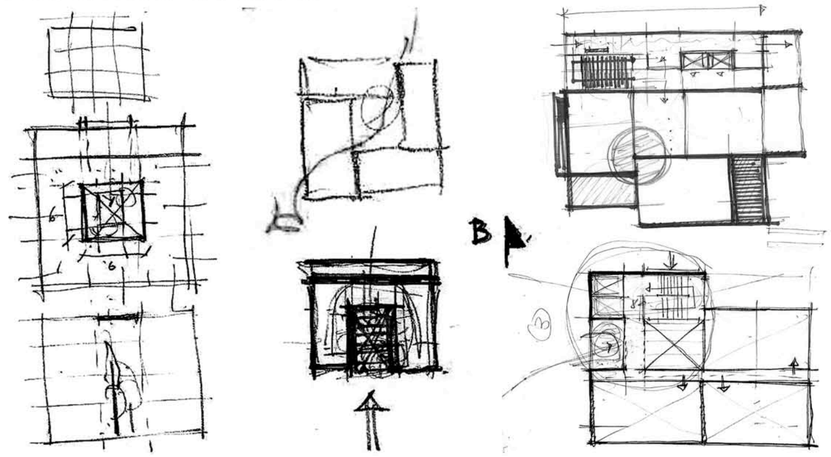


Typology D: 1x90m² + 4x60m²

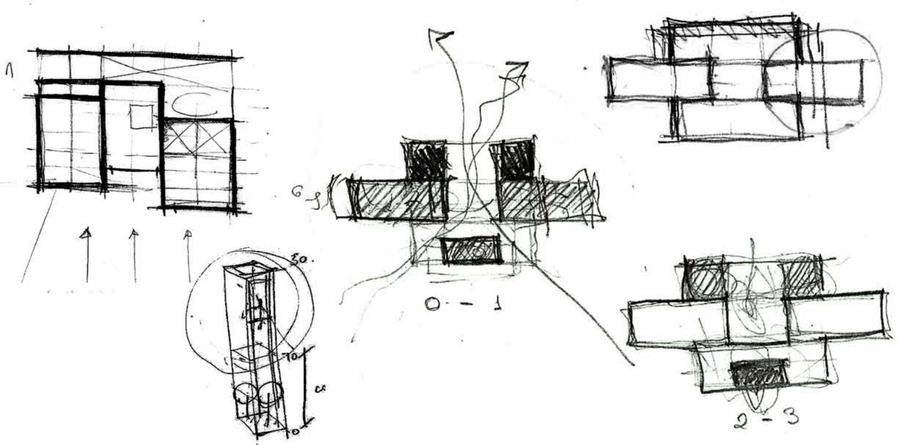


Assesment of different patterns for building layout

compact form and atrium



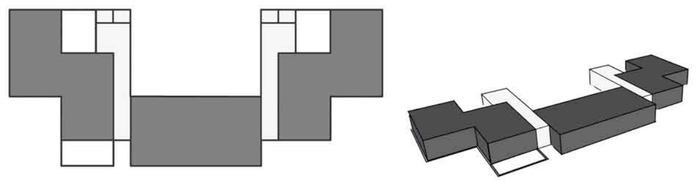
flexible form - shallower plan -> dailght & cross ventilation



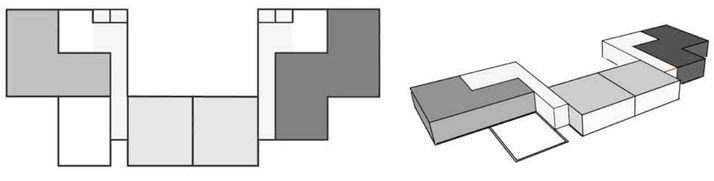
Choice of final form
- Finalize typical floor patterns
- Finalize vertical distribution

120 90 60

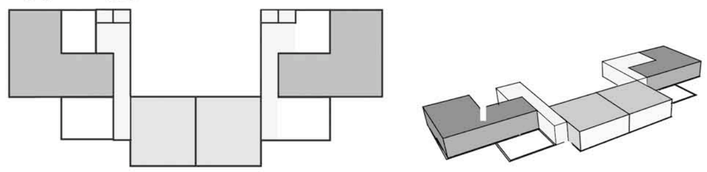
Typology A



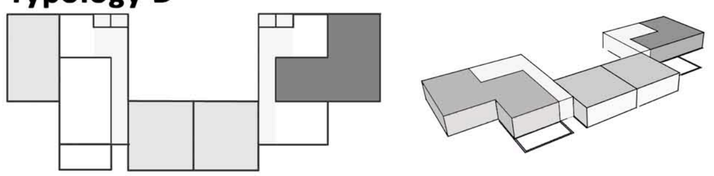
Typology C



Typology B

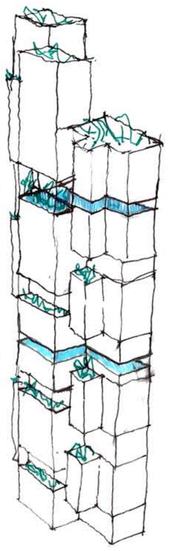


Typology D

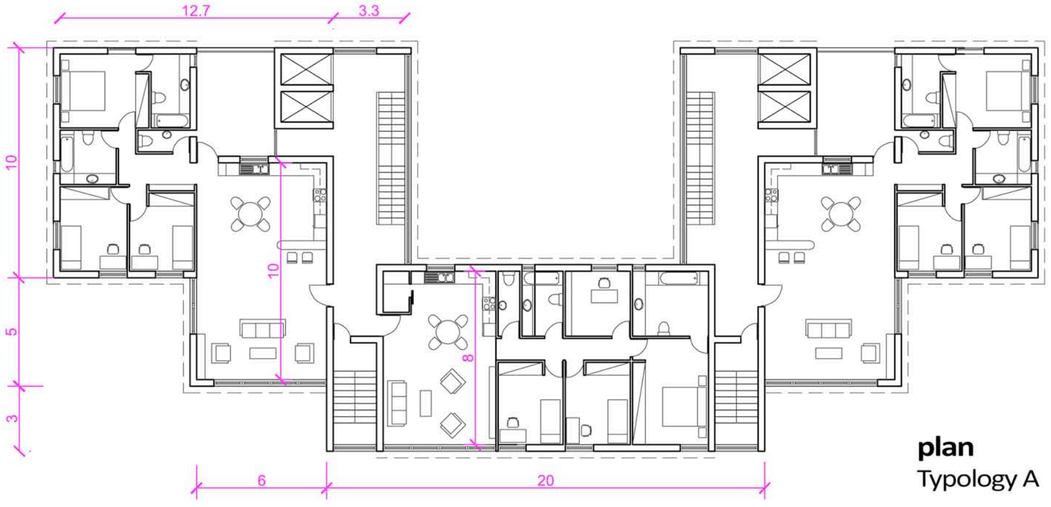


scale 1:500

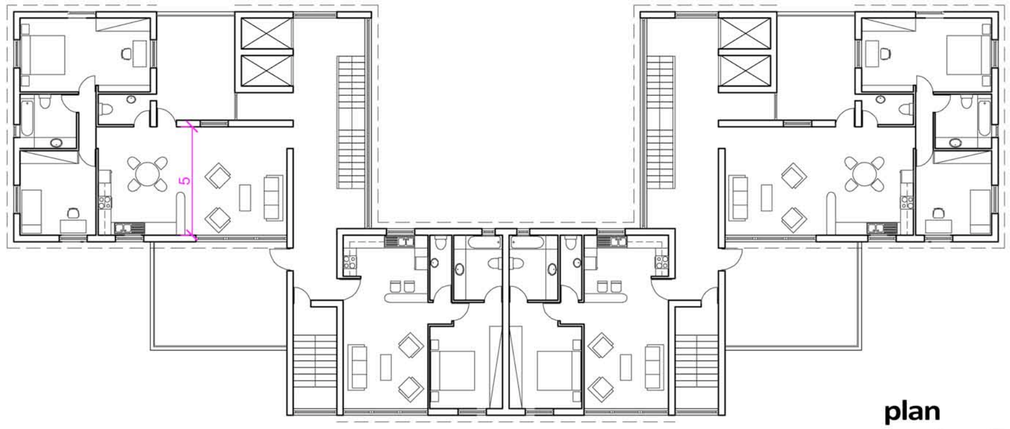
The four typologies are repeated vertically in groups of 4-7, so that **skycourts** are formed in between.



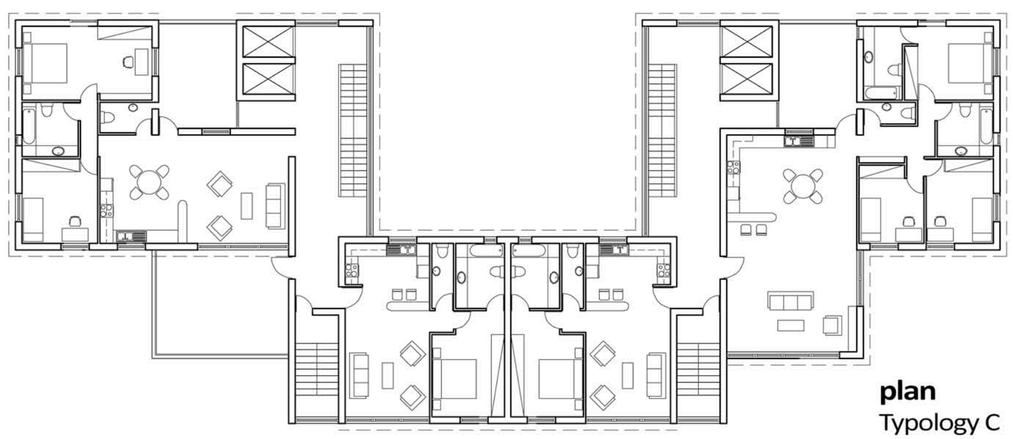
1. CONFIGURATION OF FORM



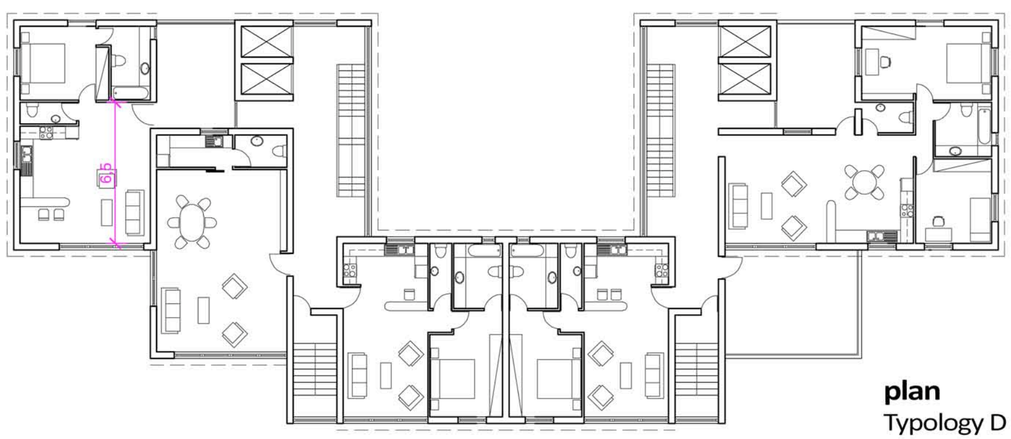
plan
Typology A



plan
Typology B



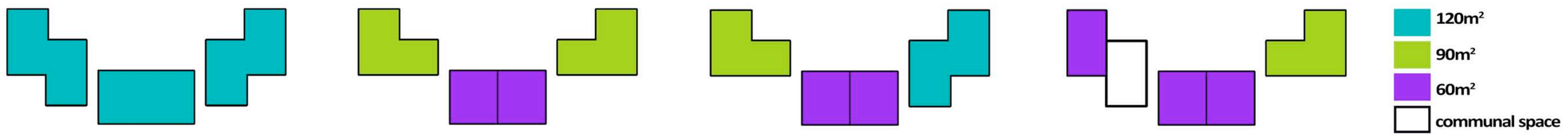
plan
Typology C



plan
Typology D

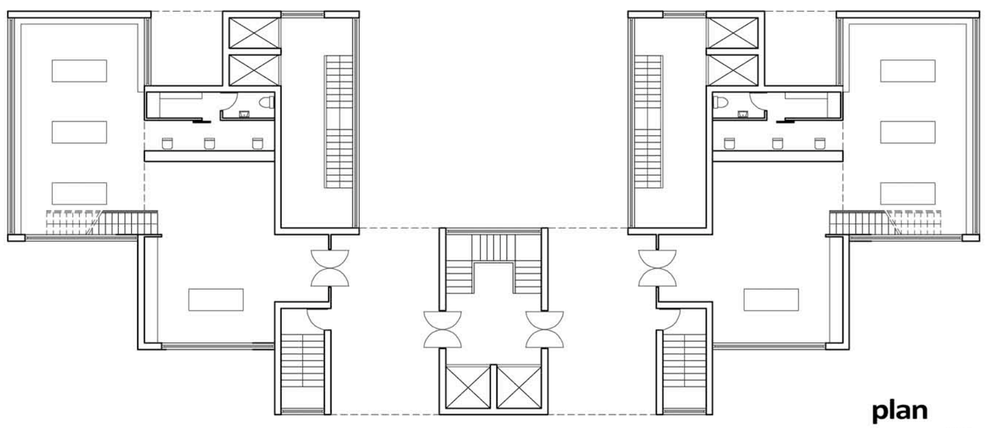
scale 1:200



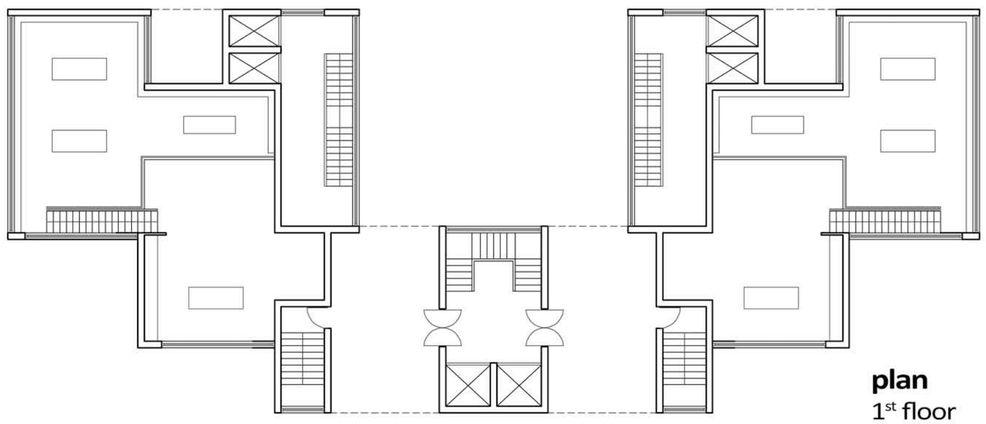


1. CONFIGURATION OF FORM

COMMERCIAL



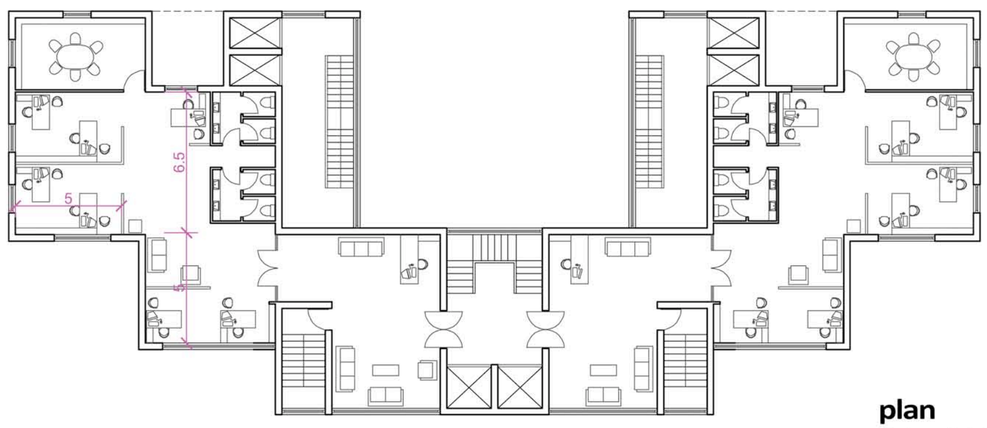
plan
ground floor



plan
1st floor



OFFICES



plan
2nd and 3rd floor

scale 1:200



plot of the area

scale 1:2000

Thermal Performance

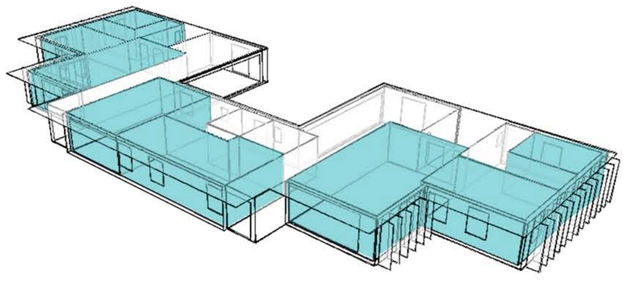
The baseline design of the ecological skyscraper involves materials and features that are commonly used in high rise constructions. Double skin facades with integrated controlled shading devices are used in order to reduce heat losses and enhance ventilation to the rooms placed behind. Vertical louvres were placed to the Western and Eastern facade to control solar gains. As regards the materials these include concrete masonry units (concrete blocks) with external insulation. The following tables describe the seasonal and annual patterns of energy demands for the baseline residential typologies. In terms of modelling since the flats are repetitive to some typologies, thermal simulations were run only for those that present different configuration and orientation.

baseline materials

walls: u - value 0.45
glazing double low- e coating glazing with aluminum frame u-value: 2.41
floors/roof u-value: 0.8

120m²
90m²
60m²

Typology A.

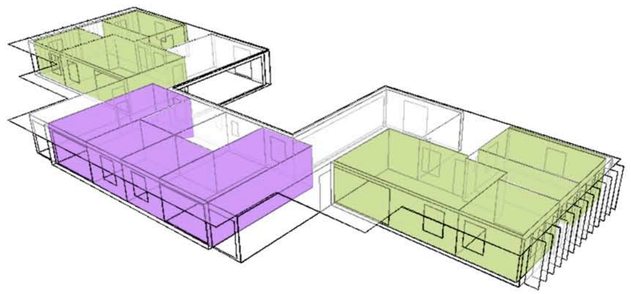


[W]	baseline heating loads (Kwh/m²)
winter	55
summer	18
spring	47
autumn	35
annual	154

[E]	baseline heating loads (Kwh/m²)
winter	54
summer	20
spring	47
autumn	35
annual	156

[S]	baseline heating loads (Kwh/m²)
winter	35
summer	13
spring	30
autumn	22
annual	101

Typology B.



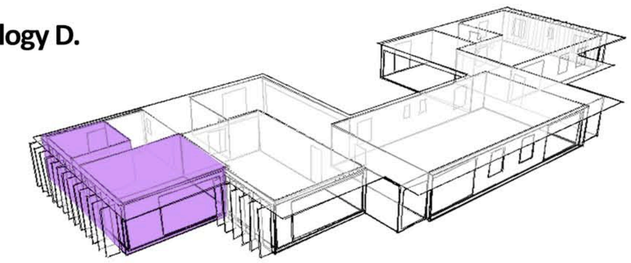
[W]	baseline heating loads (Kwh/m²)
winter	59
summer	21
spring	50
autumn	37
annual	167

[E]	baseline heating loads (Kwh/m²)
winter	63
summer	21
spring	50
autumn	37
annual	172

[SW]	baseline heating loads (Kwh/m²)
winter	100
summer	31
spring	38
autumn	28
annual	197

[SE]	baseline heating loads (Kwh/m²)
winter	96
summer	31
spring	38
autumn	28
annual	193

Typology D.



[E]	baseline heating loads (Kwh/m²)
winter	61
summer	19
spring	55
autumn	43
annual	178

	baseline cooling loads (Kwh/m²)
typology A	0
typology B	0
typology C	0
typology D	0

INTERNAL GAINS			
electrical appliances			
equipment	**rate of heat gain (W)/sensible heat** (CIBSE, Guide A, Table 6.17)	**usage factor** (CIBSE, Guide A, Table 6.16)	**final rate of heat gain (W)**
blender	310	0.5	155
coffee brewing (small)	420	0.5	210
dishwasher	50	0.5	25
freezer (large)	320	0.5	160
mcirowave oven	600	0.5	300
mixer (small)	15	0.5	7.5
refrigerator (small)	690	0.5	345
steam kettle	24	0.5	12
toaster	560	0.5	280
oven (full size, convenctior	850	0.42	357
SUM			**1851.5**

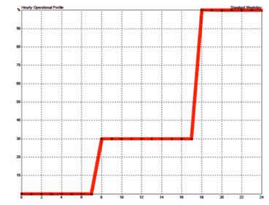
W/m²		
	flat 120m² (*living room area 60m²*)	**30.86**
	flat 90m² (*living room area 43m²*)	**43.06**
	flat 60m² (*living room area 32m²*)	**57.86**

artificial lighting	
Lamp Type (CIBSE, Guide A, Table 6.4)	**Average installed power density**
fluorescent triposphor	**7**

TOTAL W/m²		
	flat 120m² (*living room area 60m²*)	**37.86**
	flat 90m² (*living room area 43m²*)	**50.06**
	flat 60m² (*living room area 32m²*)	**64.86**

EVALUATION OF THE DESIGN

occupancy schedules







Methodology

In order to identify the heating and cooling demands for each flat, thermal simulations were run for the living rooms and the bedrooms for each residence for each season since they have different comfort bands. The results from the simulations were added together to establish the energy demands from the occupied spaces in each flat level. It was observed that the bedrooms facing East and West have similar thermal performances, while the Northern ones have more need for heating. The living rooms have more heating loads due to higher internal gains as a consequence of the fact that the kitchen is included in them. Finally, the heating loads are domimant in relation to the cooling ones that do not contribute at all to the energy demands throughout the year.

Conclusion

According to energy benchmarks for residences (CIBSE guide F, p. 20-2) all the typologies have efficient thermal performance. However, investigations will be made to the external fabric and type of glazing to reduce the heating demands.

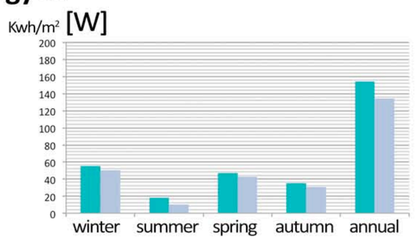
The Energy Benchmark for good practice in residential buildings is 247 Kwh/m².

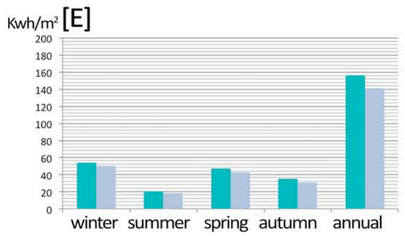
Thermal Performance

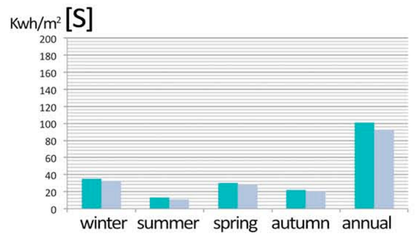
Modifications

According to UK Regulations there are typical U-values standards for external walls that of **0.27 W/m²K** [1]. Therefore modification has been made to the fabric of the baseline design in order to comply with the Regulation and to reduce the heating loads, while, in addition, modification has been made to the type of glazing by introducing **triple glazing** with u-value of 1.9. The graphs display the comparison of the seasonal and annual heating demands for the baseline design (dark colour) and the modification (light colour).

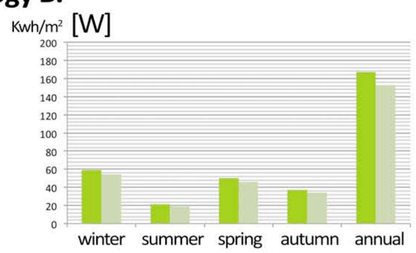
Typology A.

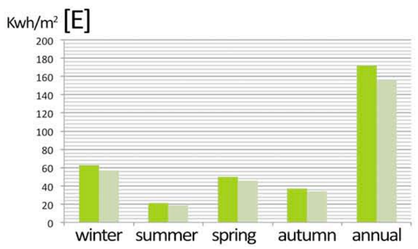


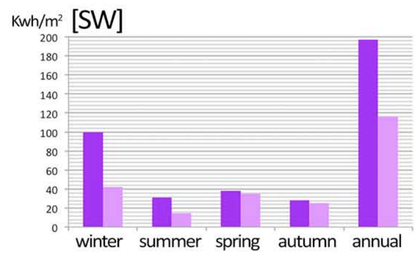


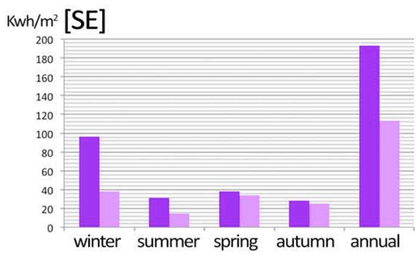


Typology B.

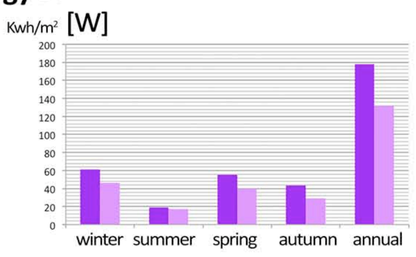








Typology D.



Seasonal and annual load reduction (Kwh/m²)

[W]	baseline	modification
winter	55	50
summer	18	10
spring	47	43
autumn	35	32
annual	154	134

[S]	baseline	modification
winter	35	32
summer	13	11
spring	30	28
autumn	22	20
annual	101	92

[E]	baseline	modification
winter	54	50
summer	20	18
spring	47	43
autumn	35	31
annual	156	141

[W]	baseline	modification
winter	59	54
summer	21	19
spring	50	46
autumn	37	34
annual	167	153

[SW]	baseline	modification
winter	100	42
summer	31	15
spring	38	35
autumn	28	25
annual	197	116

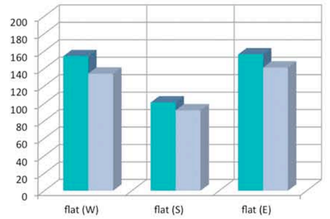
[SE]	baseline	modification
winter	96	38
summer	31	15
spring	38	34
autumn	28	25
annual	193	113

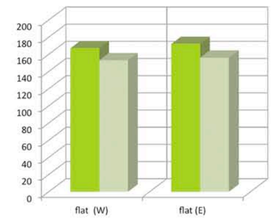
[E]	baseline	modification
winter	63	57
summer	21	19
spring	50	46
autumn	37	34
annual	172	156

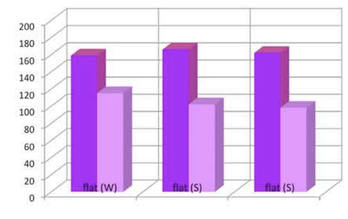
[W]	baseline	modification
winter	61	46
summer	19	17
spring	55	40
autumn	43	29
annual	178	132

Comparison of Flats

Comparisons have been made to the types of flats found in residences, in order to identify the ones with less energy consumption according to their orientation and interior configuration. The flat of 120m² facing South presents the least energy comsumption due to less internal gains and exposure to the North, followed by the flats of 60m² facing South. The flats of 90m² present the greatest energy consumption due to their orientation, interior configuration and internal gains similar to that of 120m² facing East and West.

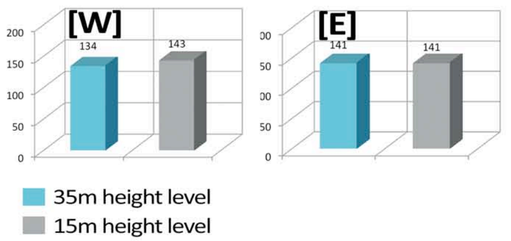


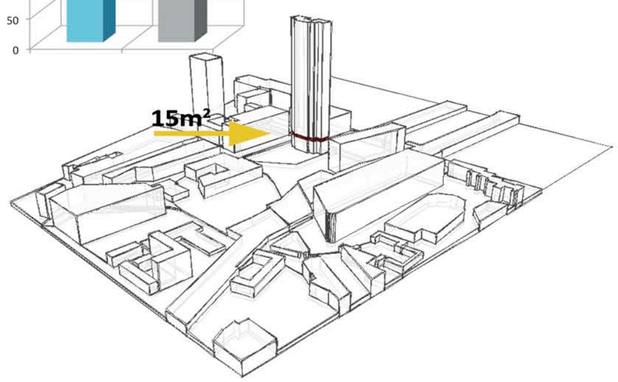




Conclusions

The modification of the initial desing proved beneficial for the total heating loads in all floor configurations, with a reduction of 10% in typology A and 25% in typology B in annual energy demands approximately. Finally, an investigation has been made in order to identify whether the level in the high rise building and therefore the relationship with the surroundings contribute to the thermal performance of the floors. In the first 30m height the envelope is partially affected by the shading that the surrounding buildings provide during the winter, autumn and spring. The thermal simulation has been made to the first typology which is placed below 30m compared to one that is fully exposed to the sun few meters above. The tables below displays the results in annual heating demands of both placements since the cooling demands remain unsgnifcant. There is an increase in heating loads in the flats facing West, however, the thermal performance in Eastern and Southern flats is similar, a fact that leads to the conclusion that the double skin facade with incorporated louvres, the external shading devices, and the thermal mass have significantly contributed on energy demands, creating a uniform performance un-influenced from the surrounding built environment.

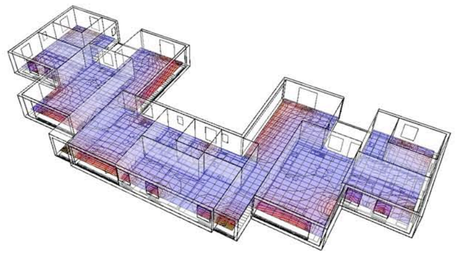




Daylight distribution

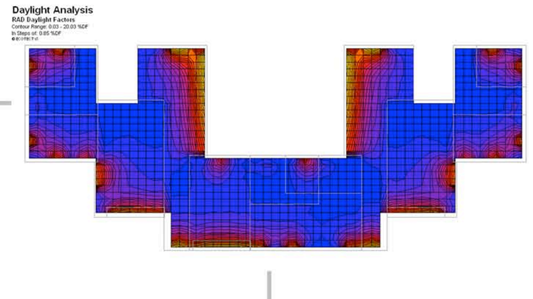
Typology A

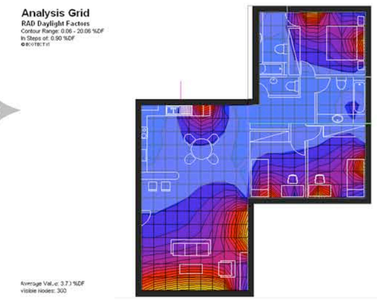
The daylight factor is calculated for typologies A, B, D by exporting from Ecotect to **Radiance** software. **Overcast sky** condition was chosen for all the calculations, in order to check the design under worst case conditions. The scale for the measurements is fixed in order to allow for comparisons between the designs and is set from 0.4% to 20.4% (contours 1.2).



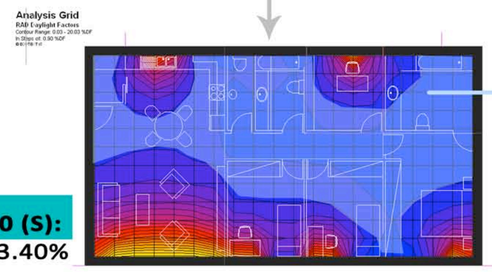


flat 120 (W):
average daylight factor 3.70%





flat 120 (E):
average daylight factor 3.78%

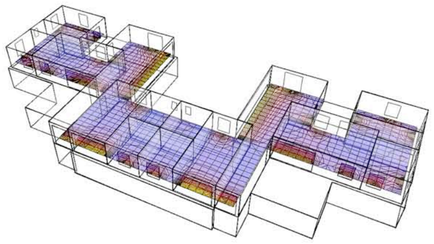


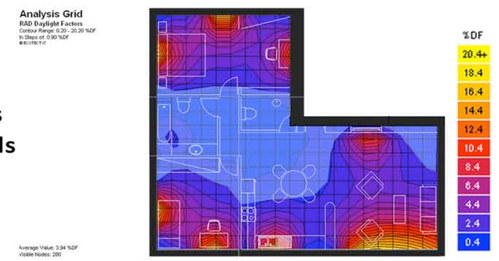
flat 120 (S):
average daylight factor 3.40%

The highlighted areas are zones with DF less than 2%, and might appear gloomy. This is caused because of the internal partitions between the rooms. However, this areas are not occupied very often, as they are mostly corridors, storage rooms, WCs, and the back part of the bedrooms, where closets can be placed.

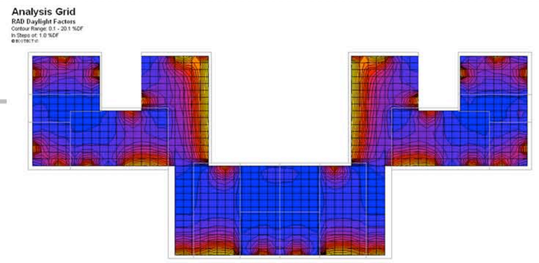
Typology B

According to Oesterle et al. (2002), double skin facades reduce the amount of daylight that enters a building compared to single skin types. This leads to reduced daylight factors overall. This effect, however, is compensated by the large amount of glazed areas.



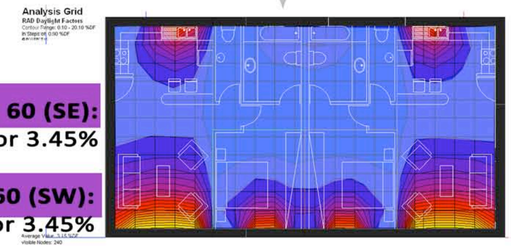


flat 90 (W):
average daylight factor 3.94%





flat 90 (E):
average daylight factor 3.94%

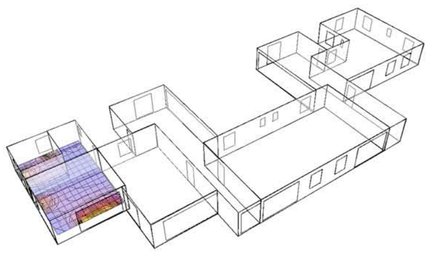


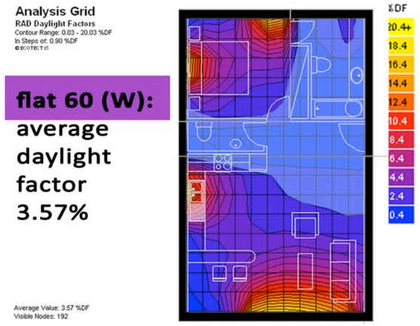
flat 60 (SE):
average daylight factor 3.45%

flat 60 (SW):
average daylight factor 3.45%

The west and east 90m² flats in this typology achieve a better and higher daylight distribution than the west and east 120m² flats in typology A, because they are less deep. In all typologies, the western and eastern flats, achieve a slightly higher Daylight Factor than the southern flats because they have more available external walls where windows are located.

Typology D

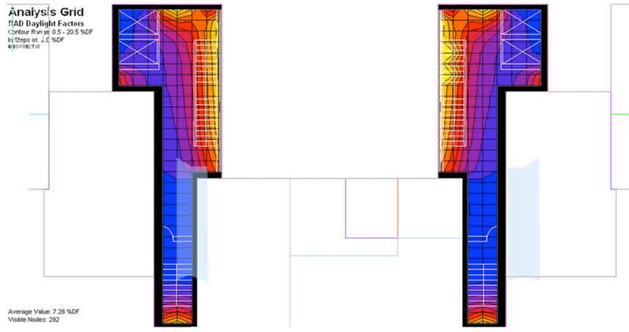




flat 60 (W):
average daylight factor 3.57%

Circulation Areas

average daylight factor 7.28%



The two circualtion areas achieve a relatively high Daylight Factor (7%), due to the large galzing area besides the staircase. This offers at the same time views to the exterior and makes the interior space to appear more cheerful and pleasant.

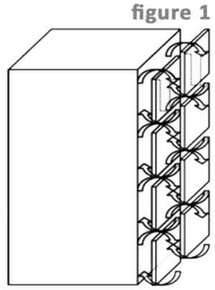
Double Skin Facade

Tall buildings are subject to **wind pressure that increases with height**. Double skin facade is a strategy that can allow natural ventilation even at the highest levels.

There are 4 different types of double skin facades:

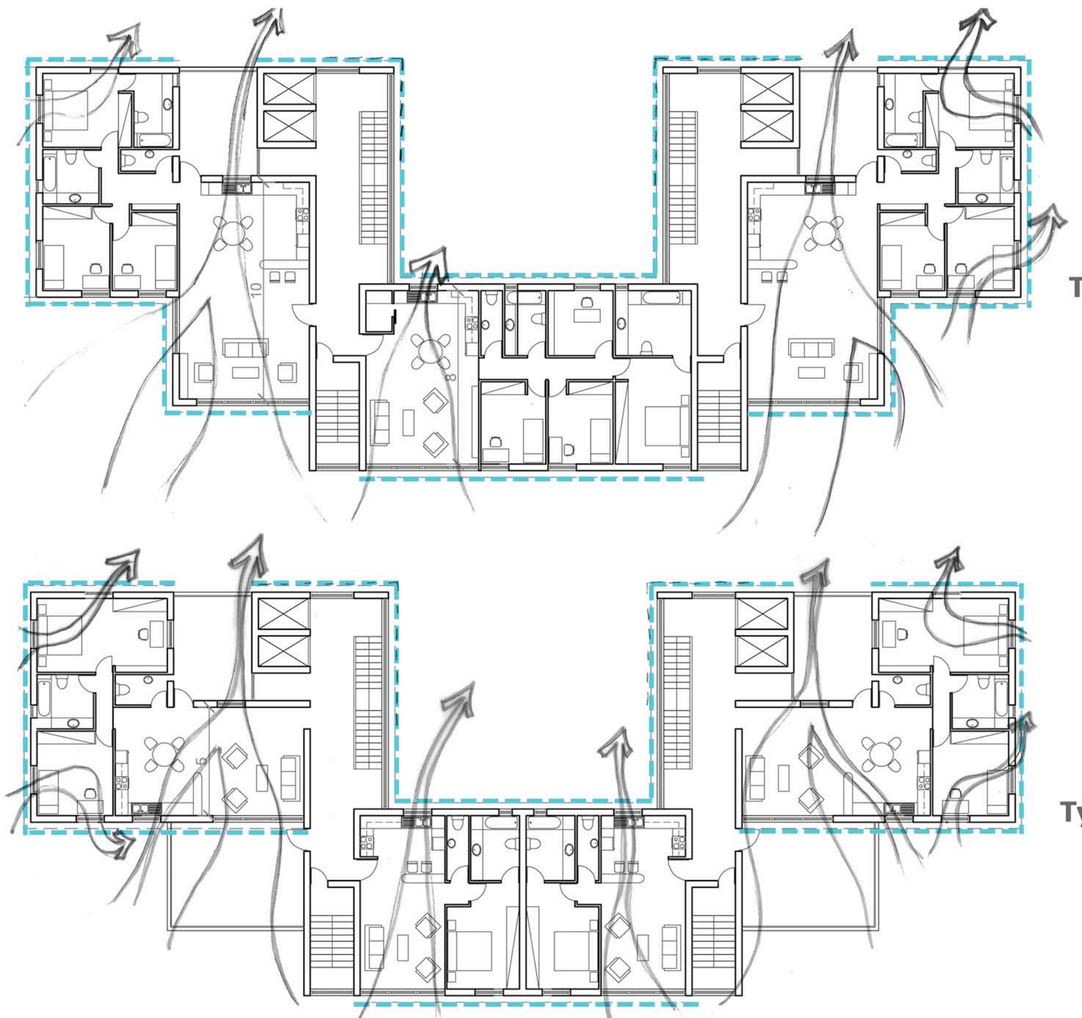
- "Shaft box type"
- "Corridor façade"
- "Multi-storey"
- "Box of window": vertical and horizontal division of the intermediate space.

figure 1



Box window type

The **"box of window"** type is chosen in order to have minimum sound, noise and odour transmissions from flat to flat, or from room to room (figure 1).



Typology A

Typology B

figure 2: cross ventilation patterns typology A and B

Constructional characteristics

- **External skin:** fully glazed usually with single glazing type.
- **Internal skin:** not fully glazed, with double or triple glazing, low emissivity coating, clear.
- **The intermediate space – cavity:** varies from 200mm to 2m. In this project a 300mm cavity is used with integrated controlled shading devices.

Seasonal function (see diagram 1 for more details)

WINTER: the cavity forms a thermal buffer zone, which reduces heat losses to the exterior and enables passive solar gains from solar radiation.

SUMMER: the integrated blinds block solar radiation from entering the space. However, the cavity has to be very well ventilated in order to avoid overheating risks. The air velocity and type of flow inside the cavity depends on the depth of the cavity, the type of interior openings and the type of exterior openings.

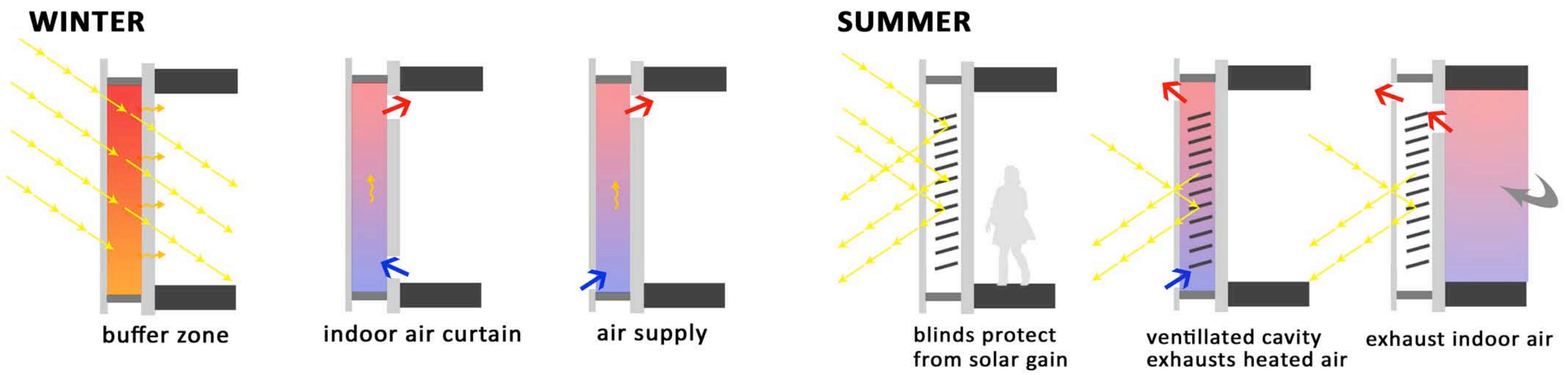
Advantages

1. Natural ventilation
2. Thermal insulation and Low energy losses
3. Wind protection *(it acts as a curtain wall)*
4. Acoustic insulation
5. Natural daylight

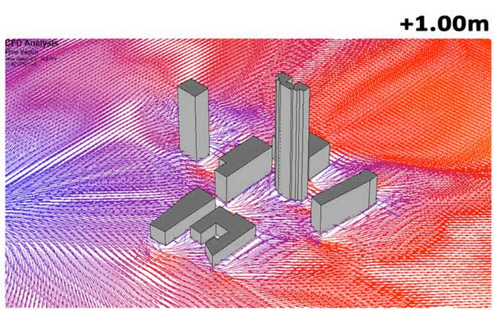
Disadvantages

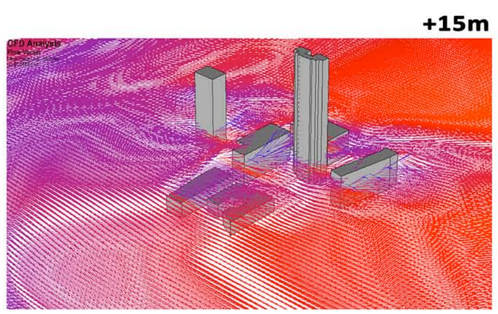
1. Overheating risks
2. Maintenance costs
3. Additional weight on structure
4. Reduced daylight due to external skin
5. Fire protection *(is still questionnable)*

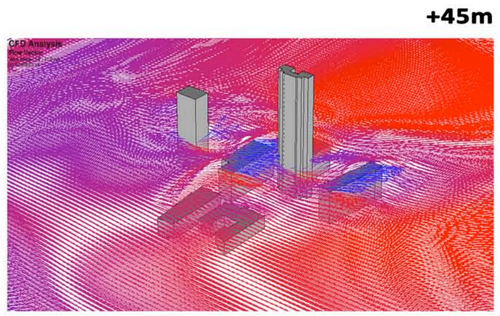
diagram 1: **DIFFERENT FUNCTIONS OF A DOUBLE SKIN FACADE**

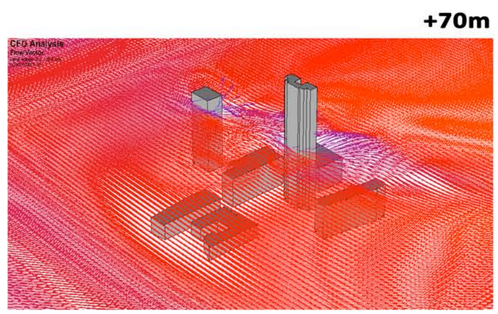


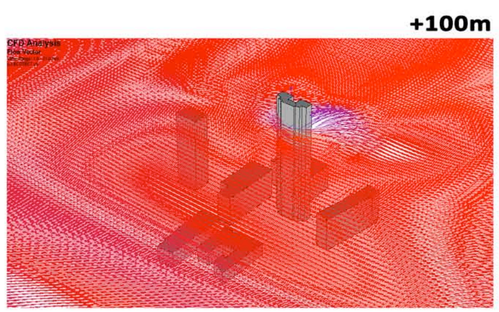
Wind Analysis

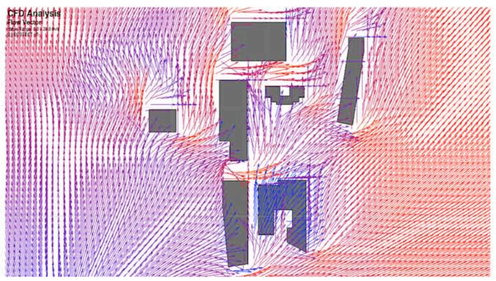


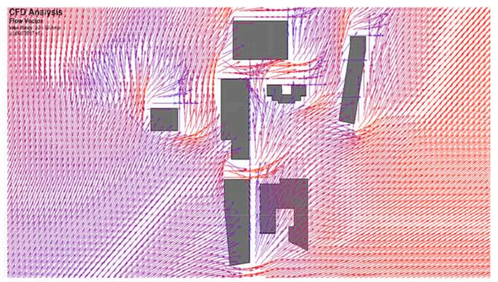


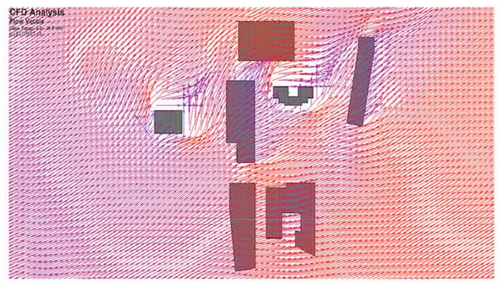


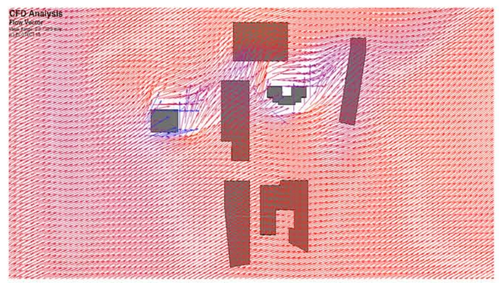


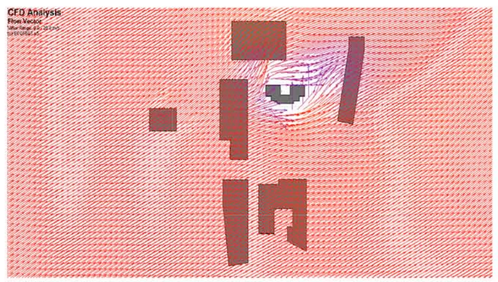








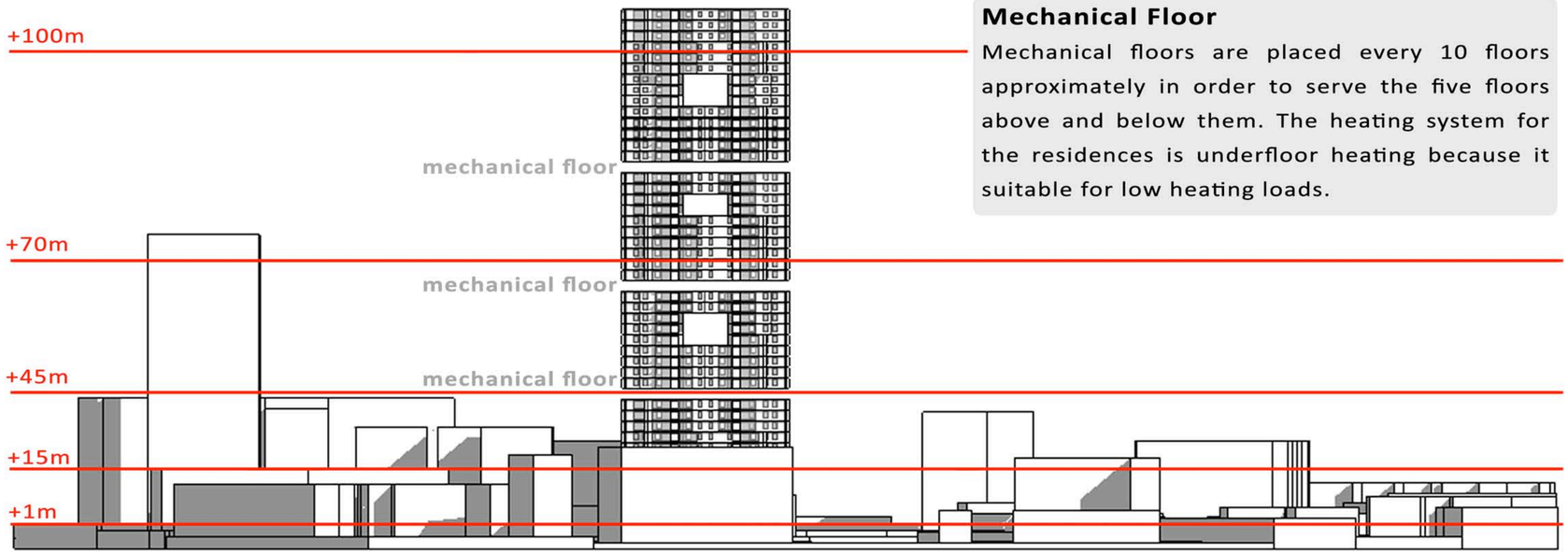




Air flow patterns

The figures above display the air flow patterns around the site and the influence of the surrounding built environment. Measurements were taken at five different levels with a North West wind direction that is the most frequent throughout the year. The simulations were perfomed by exporting data from Ecotect to Winair software.

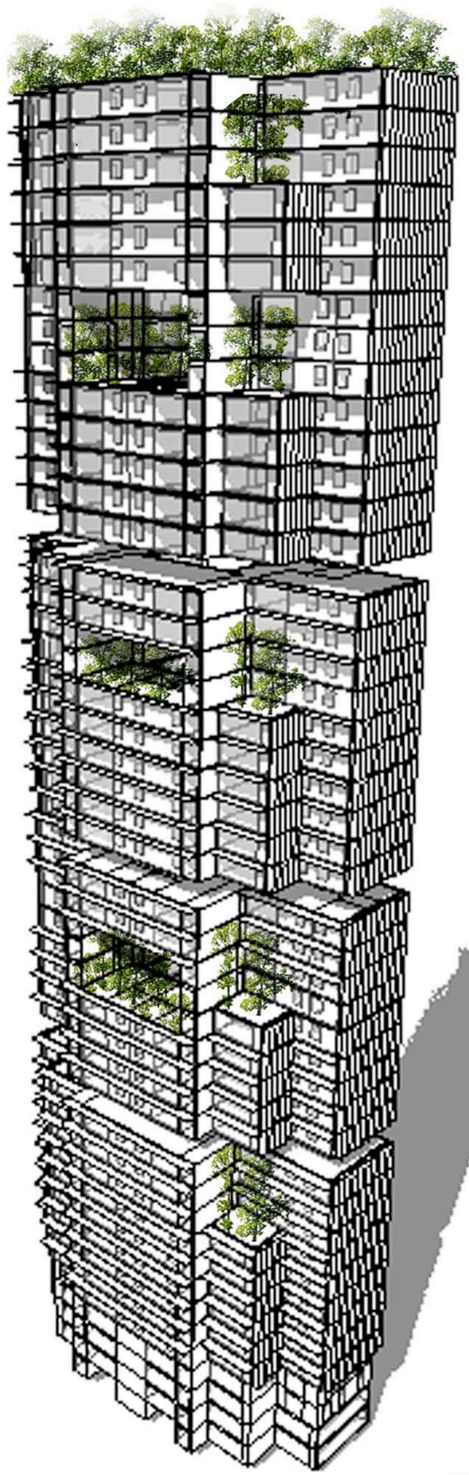
It can be seen that on the ground level the air flow presents more frequent changes in direction that are reducing as the height increases. Moreover the air velocity becomes faster in the upper levels were the building is almost fully exposed, undisturbed from the surroundings. The opening of a windon at such height should be avoided. Therefore double skin facade is essential to offer the opportunity for natural ventilation and protection from high wind speeds.

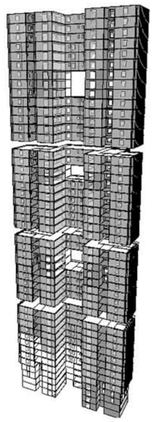


Mechanical Floor

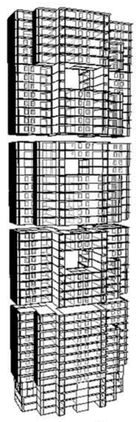
Mechanical floors are placed every 10 floors approximately in order to serve the five floors above and below them. The heating system for the residences is underfloor heating because it suitable for low heating loads.

COMPLETED DESIGN

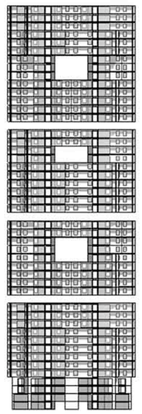




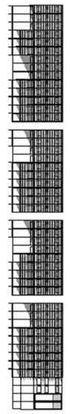
north view



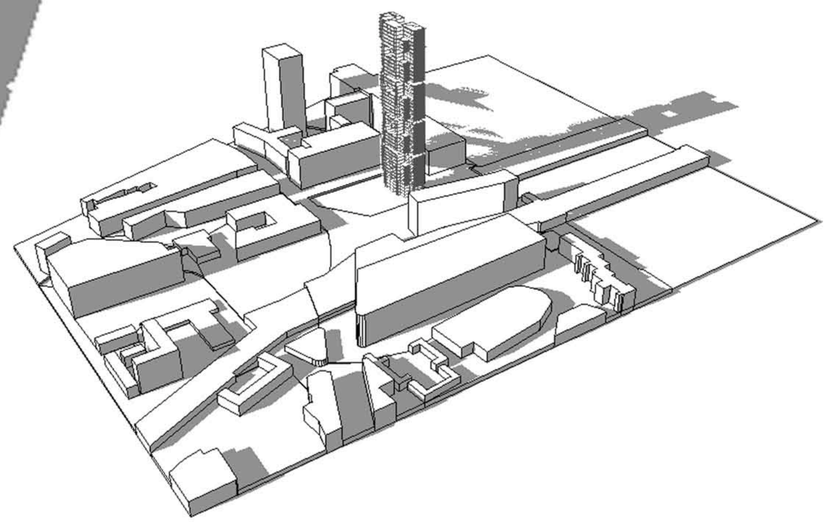
south view



front view



side view



Conclusions

The aim of this project is a tall building development in terms of sustainability. The proposed ecological skyscraper is placed in the temperate climate of London and involves 160 flats of 120m², 90m² and 60m², commercial sector and offices. The process followed is based on a flowchart of designing a sustainable skyscraper that has four main steps. The first one involves the inception of the building design. That is the accomodation requirements, climatic and regional context and setting the comfort parameters for the occupants. Secodly, there has been an identification of the relationship with the surrounding built and social environment and the local climatic conditions that would affect the building configuration. The design of the skyscraper starts in the third step, based on passive techniques used in the specific climatic conditions. After establishing the envelope of the skyscraper the next step is to locate the interior spaces and specify their form according to the occupancy schedules and comfort requirements. The final stage is to evaluate the performance of the building in terms of energy consumption, daylight availability and natural ventilation. Simulations were carried out in the occupied spaces of each flat concluding in an overall performance in floor level, that compared to the energy benchmarks for residencies the building meets the requirements efficiently.

References

Brown, G. Z. and DeKay, M., 2001. Sun, Wind and Light: architectural design strategies. 2nd edn. New York: John Wiley.

CIBSE Guide A, 2006. Environmental design. London: CIBSE

CIBSE Guide F, 2004. Energy efficiency in buildings. London: CIBSE

Losantos, A. and Canizares A.G., 2007. HIGHRISES – Social Living. Barcelona: LOFT Publications

Oesterle, E., Lieb, R-D., Lutz, M., & Heusler, W. (2001). Double Skin Facades –Integrated Planning. PrestelVerlag: Munich, Germany

Poirazis, H. 2006. Double Skin Facades –A literature Review. Division of Energy and Building DesignDepartment of Architecture and Built Environment Lund Institute of Technology (LTH). Available at: http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

Powell, R., 1999. Rethinking the skyscraper: the complete architecture of Ken Yeang. London: Thames & Hudson

Fazlic, S., 2008. Design Strategies for Environmentally Sustainable Residential Skyscrapers. In: Tall and Green: Typology for a Sustainable Urban Future. CTBUH 2008 World Conference, Dubai, United Arab Emirates, 3-5 March, 2008. pp. 808-818. Available at: http://www.ctbuh.org/AboutCTBUH/OrganizationPeople/PeopleAZ/SabinaFazlic/tabid/1415/language/en-US/Default.aspx

Szokolay, S., 2008. Introduction to architectural science: the basics of sustainable design. Oxford: Elsevier ltd

Yeang, K., 1999. The green skyscraper: the basis for designing sustainable intensive buildings. New York: Prestel

Yeang, K., 2002. Reinventing the skyscraper: a vertical theory of urban design. Chichester: Wiley-Academy

Yeang, K., 2007. Eco skyscrapers. Mulgrave Vic: Images Publishing

Yeang, K., 1994. Bioclimatic skyscrapers. London: Artemis London

Electronic sources - websites

<http://www.battlemccarthy.com/external%20site_double%20skin%20website/analysis/doubleskinanalysis.htm>

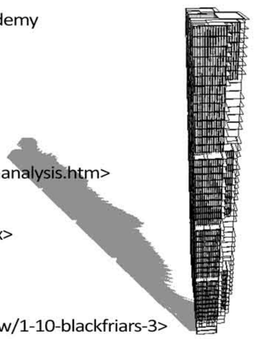
<http://www.bestfacade.com/textde/01_history_gesamt.htm>

<http://www.knaufinsulation.co.uk/selfbuildinsulationcom/self_build_solutions/external_walls.aspx>

<http://www.londonair.org.uk/london/asp/default.asp>

<http://www.evolo.us/architecture/ecological-skyscraper/>

<http://webarchive.nationalarchives.gov.uk/20110118095356/http:/www.cabe.org.uk/design-review/1-10-blackfriars-3>



Interview Protocol

Christian Male
Associate Director
Ian Simpson Architects

Description of the Research

Title:
Design Strategies for Environmentally Sustainable Residential Towers in the Cool Temperate Climates of Europe and North America.

Aims:
The project focuses on the development of a coherent method for the design of high-rise towers in particular climates.

Context:
The recent shift in the focus of tall buildings towards sustainability presents considerable challenges as architects often lack knowledge of sustainable principles and environmental methods of design suited for the type. Furthermore, there is relatively little research in this emerging field and only a small number of architects, notably Ken Yeang, have systematically applied sustainable approaches in practice. Based on a comprehensive review of literature, this research will therefore aim to introduce a design process, in the form of a framework, for environmentally sustainable towers, which is to be effective both in terms of improving building performance and as a method of guidance.

Objectives:
1) An evaluation of existing environmental design principles for residential skyscrapers in the specific climate, particularly those developed in the work of Ken Yeang.
2) The development of an accessible design process for the specific building type.
3) An analysis of design variations within the temperate climate.
4) Ensure that the method is applicable in practice.

Description of the Interview within the Research:

The interview (and supporting documents) correlates to the fourth objective of the research. Ian Simpson Architects' design for 1 Blackfriars Road is to act as a 'control group,' to be compared with 3-4 student 'test groups' from the Department of Architecture and Built Environment, University of Nottingham and the Welsh School of Architecture, Cardiff University. One of the groups from Cardiff University is to act as an additional control group. Whereas the purpose of the test groups is to apply the framework to the design of a tall building, the control groups are to act as reference points to alternative design processes. Both control groups are to provide information on the process leading to their designs and, where appropriate, models of/ information on the designs that can

be evaluated for environmental performance. In addition, it is hoped that information provided by Ian Simpson Architects will allow further insight into issues relating to environmental design encountered by architects in practice, which could indicate the suitability of the application of the framework in that context.

Aims of the Interview:

Interview
The interviews are to provide greater clarification into the design and offer insights into the design process behind the tower. They are to follow a semi-structured format, ranging from general questions relating to the practice's approach to sustainable design to specific ones concerning particular features of the building. One main interview is envisioned, lasting approximately an hour, with succeeding interviews clarifying certain aspects of the design to be arranged as necessary. Whereas the first interview is to take place in the architect's practice, succeeding ones could possibly take place by telephone or be replaced by email communication. The first one is estimated to occur in mid-April, with subsequent ones completing no later than the start of June.

It should be noted that, in addition to planned questions and those that result from discussion, the questions relating to the design process are to be structured with the framework in mind. Therefore, some of the questions refer to specific interactions with the framework, while others are to check whether specific design strategies have been applied. This approach is not meant to suggest any compliance with the framework, but to allow for the framework to be more fully comparable to the design process.

The interview is to be recorded digitally, as well as though additional notes.

Access to documents
Access to the documents allows for a greater comprehension of the design process and its result, and would be used, with permission, for a sustainability assessment through a building performance analysis tool, such as IES.

Suggested documents include:

- Sketches/drawings of the building, referring to design concept, environmental strategies, etc.
- Finalized drawings of the planned building, including relevant sections, plans and 3D renderings.
- Interim drawings, showing points at which there were significant alterations to previous designs.
- Sustainability reports.

The documents to be securely stored, with public ones, and those with permission of the author, to be published in the thesis.

Interview Questions

Introductory information:

- The purpose of the interview.
- The terms of confidentiality.
- The format and length of the interview.
- Clarification of interviewee concerns, if any.

General questions on Ian Simpson Architects

How would you define environmental sustainability?

How would you ensure that projects meet this definition?

Particularly, tall building projects?

In terms of sustainability, what are the main challenges posed by tall buildings?

Many of the practice's tall building projects are a combination of residential and hotel functions.

Why (historical) the practice has much focus on these?

Why the combination of residential with hotel?

What challenges to residential tall buildings specifically face (sustain)?

General questions on 1 Blackfriars Road

Current status of building: completion date/height/functions/adjacent build/etc.

What were the most important criteria behind the design?

How many architects and other professionals were involved?

How long did the design process take?

Please describe the design process.

Did you use any environmental design guidance to inform the design?

Were any environmental consultants involved?

Was there any testing of microclimate conditions prior to design? (shade/wind)

Have any of the environmental design features been modeled?

If yes, what were the results?

If no, why not?

Are there any design features that were considered, but rejected? (glass?) Why?

What types of energy or carbon savings are expected?

What design features contribute to this reduction most?

Are any post occupancy evaluations intended?

Questions on the design process of 1 Blackfriars Road (referencing framework)

Areas of interaction within the framework

- Orientation: Thermal Radiation (Increase)- p.10
- Orientation: Airflow (Increase)- p.11
- Configuration: Visible Radiation (Increase)- p. 13
- Configuration: Thermal Radiation (Increase)- p.14
- Configuration: Airflow (Increase)- p.17
- Configuration: Airflow (Decrease)- p. 8
- Fabric: Visible Radiation (Increase)- p.22
- Fabric: Thermal Radiation (Increase)- p.32
- Fabric: Thermal Radiation (Decrease)- p.58
- Fabric: Airflow (Increase)- p.83
- Fabric: Water- p.90
- Fabric: Materials- p.109
- System: Visible Radiation (Increase)- p.110
- System: Thermal Radiation (Increase)- p.111
- System: Thermal Radiation (Decrease)- p.112
- System: Airflow (Increase)- p.116
- System: Materials- p.117
- Renewables: Visible Radiation- p.118
- Renewables: Airflow- p.119
- Renewables: Water- p. 120
- Renewables: Materials- p.121
- Renewables: Land- p.122

Which strategies were applied?

Which additional strategies were applied?

Framework applicability

Generally speaking, would your office benefit from a framework/guide for the environmentally sustainable design of (residential) tall buildings?

If no, why not? (main concerns)

If yes, why do you feel this would be advantageous?

If yes, what would its main features expected to be?

If yes, what type of information would it contain?

If yes, what kind of format would be most beneficial?

If yes, how would it be incorporated into the design process?