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Investigating Reducing Building Energy Use at Urban Scale in Taipei

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ABSTRACT

Sustainable development related design and research has shown a focus shift from new building projects to existing ones; from the building scale to the regional and the urban scale; from construct and assessing the energy performance of buildings to participating at an earlier design stage. Taipei has been selected as the subject of this research due to its extremely high urbanization and huge pressure from the existing built environment. In order to achieve the national goal for reducing CO2 emissions, appropriate localized guidelines for buildings are urgently needed. Therefore, this research aims to understand, analyze and predict the energy performance of the architectures in Taipei, and offers a series of design strategies to help reduce the energy demand at building and urban scales. This will be achieved through the application of modelling, integrating SketchUp (@Last Software 2000), HTB2 v2.10 (WSA 2008; Alexander 2008), and Virvil Plugins (WSA 2012; Jones et al. 2011).

The whole research process is a two-phase study. The first phase is to create models at different scales based on observation of the practical building environment, analysis of architecture related data and practical situations in Taipei, and then simulate them in a bottom-up method to understand the fundamental energy performance of different buildings, groups, blocks and districts. In the second phase, the model is extended to examine important variables and related strategies at both building and urban scales.

This research finds that lighting, equipment efficiency, temperature settings of AC systems, orientation, glazing ratio, shading devices, and wall-to-volume ratio are important variables for architectures at building scale. Furthermore, development intensity, block usage type, wall-to-volume ratio, volume rate, building coverage ratio, average building height, surrounding road width, over-shading, insulation and outdoor environment are comparatively critical at urban scale. Additional interesting findings showed that the impacts brought by orientation, shading device, and insulation are not consistent at different scales. Lastly, some guidelines are presented to be used as a reference for new and existing buildings.

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Chapter 1

INTRODUCTION

A BRIEF INTRODUCTION TO THE BACKGROUND, SUBJECT, QUESTIONS, AIMS, OBJECTIVES, METHODOLOGY, STRUCTURE AND POTENTIAL CONTRIBUTIONS OF THIS RESEARCH

INTRODUCTION

1.1 Background

This section briefly introduces the history, definitions of sustainable development, and critical theories, projects and related strategies of architectures at both urban and building scales. It will indicate that how the history of sustainable development aptly explains the cause and the importance of it, and how each definition of it demonstrates a different perspective. Moreover, important strategies for buildings will be presented by reviewing master theories and practical projects. Finally, related research will help to point out future trends and challenges, and clarify the niche of this research.

1.1.1 Changes to our environment

The growth in popularity of the general public's consciousness of sustainability can be traced back to two main impacts upon human life. The first is energy and resource distribution, which has forced people to rethink and redevelop a new type of lifestyle. The second impact has accumulated through various negative environmental changes which have been proved to be directly or indirectly caused by human activities.

Firstly, limited natural resources remind people that we cannot increase consumptions in an uncontrolled way. The most obvious example is petroleum, which has a strong relationship with the economy, food, transportation, pollution, the bio-system, national security and even international relationships. The oil crisis which happened in 1973, and the energy crises in 1979 and 2000s, seriously impacted upon the global economy and all of them created disordered social problems. Moreover, in developed countries, economic growth has become regarded as being inextricably connected with increased well-being (Daly and Cobb 1989; Maz-Neef 1995; Layard 2005; Sassi 2006). In order to form stable economies and maintain high qualities of life and living environment, people desperately need to decrease their dependence on oil and must begin exploring the development of other energy replacements.

Secondly, the last three decades have seen a growing importance being placed on research into environmental changes. Greenhouse gases have abnormally accumulated in the atmosphere and have lead to global warming (IPCC 2007), which could be linked to other problems, including rainfall patterns, rising sea levels and expansion of deserts. Also, scientists have observed that the emissions of chlorofluorocarbons (CFCs) can cause Ozone depletion. In addition, urbanization, construction, mining and other human activities have been shown to be responsible for resource shrinkage, deforestation, soil degradation and extinction of flora and fauna (Sassi 2006). According to reports by reputable scientific institutions, tsunami, storms, rising sea levels, increasingly powerful typhoons, EI Nino, and some other natural threats are seen as evidence of climate change. Moreover, many scholars believe the situation will become more serious and unpredictable in the future (IPCC 2007).

On the other hand, considerable concern about the changes to the built environment in urban areas has arisen recently because architecture is responsible for approximately one third of the overall CO2 emissions in the world and could be seen as the main contributor to global warming (IPCC 2007). In the U.K., construction of buildings is responsible for almost 50% of primary energy (Howard 2000; Jones et al. 2009) and the majority of them existed in cities. Naturally, cities have become the subjects of studies in many different fields. Several studies have mentioned numerous disadvantages brought about by cities, including higher energy and material consumptions, worsened quality of life, and the urban heat island effect (UHI) (Landsberg 1981; Oke 1973, 1978, 1988, 1999; Santamouris et al. 2001; Streutker 2003; Tran 2006; Gartland 2008). Moreover, these situations would only increase through heightened urbanization and expanding urban sprawl. By

2003, the proportion of the population in urban areas had risen to 48%, and it is predicted to be 60% by 2030 (UN 2005).

In short, all the changes to our economy, environmental situation and our built environment are too obvious to be ignored. Human beings have the right and obligation to protect our planet. Therefore, the importance of sustainability cannot be questioned anymore. The real question is how and what we have to do to help transform our living environment into a sustainable situation.

1.1.2 Definitions of sustainable development

At the beginning of the 1970s, the "word" sustainability was mostly employed to refer to resource recycling in forests, which was one component of long-term, durable, systematic and sound practices (Filho 2000). In the succeeding years, many new definitions have appeared and have been used for different reasons and by different organizations. In 1980, IUCN - World Conservation Strategy said that the overall aim of achieving sustainable development is the conservation of living resources. Jacobs, Gardner and Munro (1987) believed that sustainable development seeks to respond to five broad requirements: integration of conservation and development; satisfaction of basic human needs; achievement of equity and social justice; provision of social self-determination and cultural diversity; and maintenance of ecological integrity. International Council for Local Environmental Initiatives (1996) asserted that sustainable development is a program to change the process of economic development so that it ensures a basic quality of life for all people, and protects the ecosystems and community systems that make life possible and worthwhile. Among these definitions, there is a broadly acknowledged one, which is part of the Brundtland Report and defined by the World Commission on Environment and Development (WCED) in 1987. "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*", this definition is not only referring to environmental conservation, but is also paying attention to economic, social and political considerations (Lin 2009a). Now, this definition has become the principal of the majority of design and researches involved in urban planning and building design.

1.1.3 Sustainable theories and practical projects

“Modern” urban planning emerged in the latter part of the 20th century and was believed to be a state function to deal with rapid growing cities and the industrial revolution. UN-Habitat (2009) explained that urban planning is a kind of technical activity employed in the physical planning and design of human settlements and other affairs, for the design of the master plan and land-use zoning scheme. In the 21st century, urban planning not only satisfies the need of human's living requirements, but also considers the balance between human settlements and the nature. As we know, the concept of sustainability has already been an indispensible part of urban design.

Firstly, at the beginning of 20th century, scholars had already discussed some sort of sustainable concepts in urban areas, such as the Village of New Harmony (Owen), Satellite City (Unwin 1922), and Broadacre City (Wright 1945). However, due to the pursuit of economical prosperity, these ideas were not seriously paid attention to by people. In the 1960s and 1970s, due to environment dangers and the energy crisis, sustainable thinking regained people's attention. Gill and Bonnett (1973) mentioned that a city is an urban ecosystem, which should function as biotic system. In 1981, the term "eco-polis", focusing on the interaction of organisms in urban areas and their interaction with communities, was introduced by a Russian scientist, O.Yanitsky. Richard Register (1987) took Berkeley as an experimental subject and used “mapping” skills to illustrate the application of sustainable thinking in urban areas, which is presented in Ecocity Berkeley: building cities for a healthy future. McHarg (1969) emphasized the importance to design with nature. Richard Rogers (2000) asserted that a city should be just, beautiful, creative, ecological, approachable, and diverse, and believed that a compact and polycentric city style would be more suitable for future development. In 2009, Paul F. Downton summarized the ideas from previous theories and issued a hundred year plan for Melbourne to describe a possible transformation path for a modern city.

Secondly, leading countries in the sustainable development field, particularly in Europe, have carried out many sustainable projects and promoted the concept to the rest of the world. These projects could be categorized into two different scales, individual buildings or small communities, and regional and the urban scale plans. For the former, BedZED (2002) in South London is a mixed-use scheme project, which is famous for its careful calculation for financial flow and successful monitoring after construction. Solar City in Linz (1990) is a sample for a new community development. Mixed use of land, an accessible transportation system for all residents, and linkages to nearby cities are concepts based on future-orientated urban planning. Vastra Hamnen in Sweden and the Ecocity Project for seven places in Europe are some of the popular community examples. In terms of regional scale projects, Eco-vikki in Finland (1999), Sino-Singapore Tianjin Eco-City in China (2007), DongTan Ecocity in Shanghai (2005), and MASDAR in the United Arab Emirates (2006) have showed more comprehensive plans, including advanced transportation systems, renewable energy applications, innovative passive design strategies and advanced public infrastructure systems.

Whether they are imaginary projects applied in master theories or real experience gained from practical projects, the author observed that they all restated the importance of sustainable development and mostly successfully achieved their aims. Moreover, these concepts and ideas have been interpreted and installed into the construction industries and its processes, and have changed the way cities and architectures are designed in the MASDAR project.

1.1.4 Design strategies at urban and building scales

The past century has witnessed growing interest in sustainable development. During this time, scholars and architects have implanted the concept into many theories and projects. Additionally, more and more researches related to sustainable strategies have become available.

On the one hand, at urban scale, Lock (2000) suggested that sustainable cities should contain seven characteristics, compact living style, mixed land uses, public transport-oriented designs, pedestrian-friendly streets, well-defined public spaces, the integration of nature in developments, and developments based on walking and cycling distances. High density development was seen as a basic prerequisite for urban planning (Jenks et al. 2005). Sassi (2006) agreed with this point and believed the concept of a compact city could offer many opportunities to help shape a sustainable urban environment. A high density development city has many potential advantages to achieve sustainability, which are efficient use of land, better protection of the natural landscape, easier access to culture, leisure, commercial and transport facilities, more employment opportunities, owning potential for district heating, and efficient recycling. Density may be the most important issue for urban environment, but scholars also discussed other issues, such as orientation (Ratti et al. 2003), building form and urban geometry (Adolphe 2001; Cheng et al. 2006; Stromann-Andersen et al. 2011). They applied advanced methods and technical tools to figure out the best urban design strategies through their case studies.

On the other hand, there has been more, and deeper, research involved in strategies for saving energy of blocks and buildings. Edwards (2010) believed that the best configuration is high-density / mixed-use / medium-rise urbanism. Lazzarin et al. (2005) had proved that green roof design can save energy significantly due to its function against incident solar radiation. Sassi (2006) reviewed related researches and concluded that shading is one of the more easily controllable design strategies and could be used in conjunction with natural ventilation, evaporative cooling or high thermal mass. Similar examples are abundant. Szokolay (2004) asserted that shape, fabric, fenestration and ventilation are the four greatest impact design variables for buildings. Lin (2009a), focussing on the weather style in Taiwan, generally concurred with these strategies and thought that building site and orientation, glazing ratio, shading device, and insulation are the most important issues for making buildings energy efficient.

1.1.5 Conclusions of literature review

Although minor debates related to definition, concept, and design strategies exist, through a review of the history of sustainability, its definition, theories, projects and researches, several critical future trends and challenges can be summarized.

Firstly, there has been a shift in attention from a focus on the energy performance of a single building to an emphasis on determining the sustainable design strategies for blocks at urban scale. In other words, a comprehensive plan for sustainable development should take care of both the urban environment and individual buildings. Secondly, the focus has shifted from creating new city plans toward the reuse of existing environments. Transforming the places people have inhabited into sustainable environments is much more important than creating whole new sustainable cities. Thirdly, the focus has turned away from reviewing the energy performance of buildings and instead seeks to join in at an earlier design stage. The earlier participation not only provides a correct development direction, but also helps to save more energy. Fourthly, there is no all encompassing answer for the sustainable development of cities or architectures. Depending on the different backgrounds of individual places, related strategies should be localized.

1.2 Research subject

Taking into account the different social and geometrical characteristics of each location, sustainable strategies vary accordingly. In other words, it is necessary to identify the local situation first and then select and localize the strategies. Due to its extremely high urbanization and huge pressure from the natural, economic and built environment, Taiwan has been selected as the subject in this study. Moreover, the capital of Taiwan, Taipei, is depicted as the main experimental subject.

First of all, Taiwan is located 180 kilometres off the south eastern coast of Mainland China and is a 34,507 km^2 island with a marine weather style. The "Sweet potato" shape island has a row of mountains in the middle and a population of 23 million people (Figure 1.1). In the Taipei metropolis, the population is close to seven million in 2012. In recent years, unstable climate changes and several natural disasters, such as earthquakes, typhoons and flooding, have happened more frequently than in the past. The Central Weather Bureau of Taiwan (2010) reported the latest statistical record on the history of the island's temperature changes. In the past 100 years, Taiwan has experienced a serious warming of the climate with average temperatures rising 1.3 °C, which is much higher than the world average of 0.6 °C.

Moreover, other natural changes such as rising sea level, species extinction and increased precipitation were observed.

Figure 1.1 Map of Taiwan and its capital, Taipei. (Source: CIA 2010)

Secondly, Taiwan is a typical energy-imported country. Over 98% of its energy is imported from other countries. Yet the relatively high cost of energy has not stopped Taiwan ranking 22nd for its CO2 emissions out of all the countries of the world (International Energy Agency, IEA 2009), which equals 1% of the overall world emissions. Furthermore, Taiwan is suffering from serious urban environment problems because over 80% of Taiwanese live in the cities and the figure is climbing. Additionally, the urban heat island effect (UHI) was measured as 3 to 4 °C higher than in suburban areas for every big city in Taiwan (Lin 2009a).

Being aware of the serious changes to the natural and built environment, the local government have reacted eagerly. In 1999, Taiwan published a series of mandatory regulations for new buildings, Ecology, Energy saving, Waste reduction, and Health (EEWH), and became the fourth country to implement a national certificate system for green buildings (Lin 2009a). In the same year, the government announced another series of political strategies in order to encourage sustainable development and set a goal to decrease CO2 emissions to year 2000 levels by 2025 and ultimately reduce to 50% by 2050. In 2010, scholars in Taiwan extended the scope of concern for the green building evaluation system to the urban scale. An evaluation system for both new and existing communities, EEWH-EC (Eco-Community), was transformed from the Japanese green building management system, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and was officially published in 2012. Although the intention of legislation was positive, related research lacked empirical measurement, investigation and practical test accounting of the local environment.

In short, Taiwan is experiencing huge pressure from urbanization, dwindling energy resources, and threats from the natural environment. Additionally, long-term ignorance of research accounting on the practical environment and weather style has culminated in misleading design strategies. Fortunately, the increase in the popular consciousness of sustainability and the ambitious goals of the national government give Taiwan a good opportunity to reverse the situation.

1.3 Questions, aim, scope and objectives

The review of the history, theories, projects and strategies of sustainable development not only indicates the importance of it, but also points out future trends and challenges. Based on these, several critical research questions are summarized as follows.

1. Facing the big challenges of natural and economic dangers, how and what should a city do to handle these problems? For example, extend urban areas or transform the existing places? Create more high or low density development? To be more specific, what kinds of strategies can urban designers and architects follow to help build sustainable cities and buildings?
2. Taiwan represents one of the archetypal places in Asia which owns a high level of urbanization whilst ignoring the balance between the natural and artificial environment. The permeation of thinking from leading countries and increasing pressure from the natural and economic environments have awakened peoples' consciousness of sustainability in Taiwan. The question is how can

these advanced strategies be localized and accounted for in a practical situation?

3. With the development of technology and digital tools, what kind of methods could be applied and what updated technical tools can be adopted and developed to understand the energy performance of buildings in a city?

4. The lack of fundamental research related to the energy performance of architectures, and the ignorance of urban design in the planning system of Taiwan, make the development of cities uncontrollable. Are there any advanced research tools or methods which can help correct this shortfall? Moreover, is it possible to make some suggestions for the political system related to building and urban design?

5. Although urbanization and urban sprawl are on the increase globally, the existing architectures still have to be more responsible for energy consumption. The strategies and methods to help refine our present situation are the new focus of research. How and what can we do to implant or transform the strategies which have been applied to the new building projects to make them relevant to the existing ones? Furthermore, what are the most useful and effective strategies?

6. The review of research related to sustainable development shows that the focus of sustainable research has shifted from the building scale to the regional scale. What are the differences for those design strategies when they are applied to a single building or groups? Should we pay attention to different issues when facing different scale projects?

This research is going to focus on the exploration of important variables and related design strategies of buildings at both building and urban scales. The aim of this thesis is to **understand, analyze and predict the energy performance of the architectures in Taipei, and offer a series of design strategies to help the buildings reduce energy use at building and urban scales through the application of modelling.**

For the research scope, due to the limited resources and time, it is impossible to consider all kinds of buildings in Taipei. Therefore, this research merely focuses on the majority of buildings in Taipei, which would cover 80% of normal buildings (Figure 1.2) (The National Geographic Information System, NGIS 2013). However, the restricted scope would not affect the simulation results because the buildings in Taipei are generally unified with several similar building styles and applied with similar construct methods and materials. Moreover, the short development construct history of Taiwan implies the unobvious technology improvements of buildings in Taipei. More details will be discussed in the Chapter Three. On the other hand, the impacts of the incomprehensive research scope would affect the deduction of guidelines. Based on the research for the majority of buildings in Taipei, the guidelines of building and urban design for shaping sustainable building environment can only consider the general issues. Some specific detailed problems related to special building types or situations should be compensated by further research works, such as the design strategies for high-rise buildings.

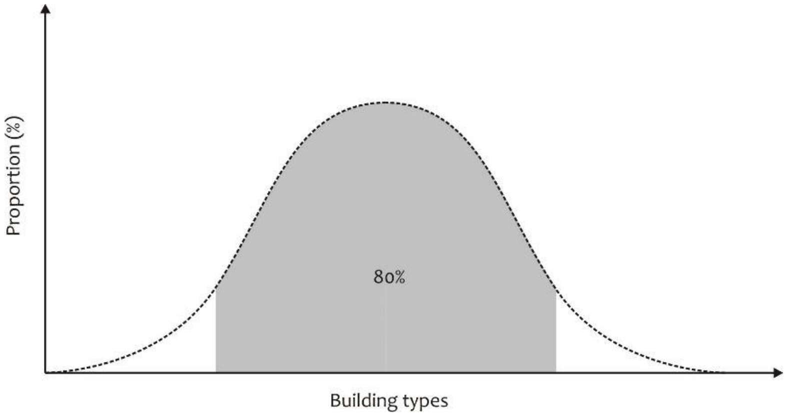


Figure 1.2 Scope of research modelling. (Source: The National Geographic Information System, NGIS 2013; Analyzed and drawn by Lin 2013)

And the objectives are as follows:

1. To realize the history, future trend and important variables concerning sustainable design strategies of the built environment and architectures through a review of global sustainable development history, its definition, critical theories and related projects.

2. To review the background of Taiwan, and researches related to sustainable development and official regulations, to understand the advantages and disadvantages of architectures and urban environment in order to help localize design strategies for buildings in the future.

3. To explore methodologies and updated technical tool development to select and define the most appropriate method for simulation of the energy performance of buildings at both building and urban scales.

4. To define several building prototypes, communities, blocks and districts through the observation of Taipei, and the analysis of its historical data and related architectural information, and then simulate them to understand the general energy performance of buildings in different situations and recognize potential variables.

5. To simulate and analyze critical variables at both building and urban scales, with different strategies for recognizing the degrees of their impact of energy demand and supply.

6. To summarize, guidelines including urban and building design strategies for Taipei reporting on national goals and practical situations through the simulation of different compositions of strategies.

1.4 Methodology

In order to answer the research questions and achieve the aims and objectives, it is necessary to define and select appropriate methods. For understanding the energy consumption of buildings in a city, there are two distinct approaches identified as either a 'top-down' or 'bottom-up' approach (Swan and Ugursal 2009). The top-down approach regards building units as energy sinks and mostly relies on statistical data and economic theory. On the contrary, the bottom-up method extrapolates the energy performance of architectures by calculating figures for a representative set of individual buildings to regional and national levels, by employing two methodologies, the statistical method and the engineering method (ibid.). Due to the coarse analysis of the top-down approach and the comprehensive ability of the bottom-up method to understand and predict energy performance, this research applies the bottom-up method through the enhanced application of technical tools.

On the other hand, although lots of advanced technical tools for calculating the energy performance of an individual building or a small group of buildings exist, such as Energy Plus (USDE), Ecotech (Autodesk 2009), there is very limited simulation software available for use at urban scale. Therefore, the proposed methodology of this research is linked by two unique technical tools, which are Sketch Up (@Last Software 2000) and HTB2 v2.10 (WSA 2008; Alexander 2008). The former is the most popular 3D modelling software known for its usable interface by architects (JeDin Information Inc. 2013). The latter is one of powerful and reliable energy calculation engines (Alexander 2003). Moreover, this research helps to develop Virvil Plugins (WSA 2012; Jones et al. 2011) which connects both of the above.

For the whole simulation process, a two-phase study has been designed to explore the outcome of the sustainable transformation mechanism for Taipei (Figure 1.2). The first phrase is to set up several prototypes through the observation of architectures and the analysis of historical data and related information, and then simulate them to evaluate and figure out the different types of energy performance of different buildings in Taipei. In the second phase, the model is extended to the urban scale and examines important variables at both building and urban scales. Moreover, several potential strategies are selected and composed as optimized packages and applied to practical building environment in Taipei. Lastly, through the analysis and comparison of simulation results, better strategy packages to save energy for architectures are summarized.

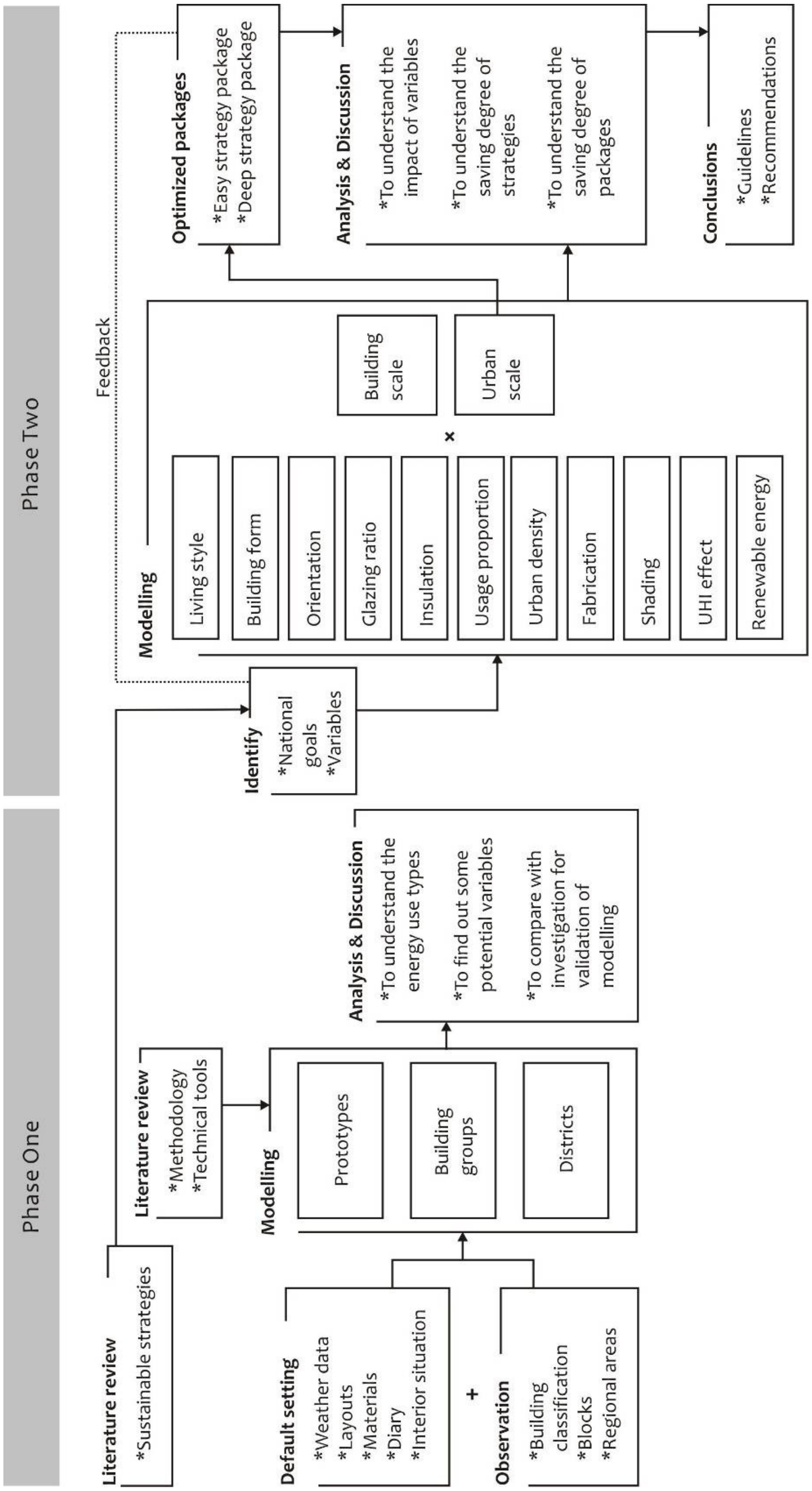


Figure 1.3 Framework of this research.

1.5 Structure of thesis

For its objectives to be achieved, this dissertation is divided into several chapters and structured as follows. Additionally, a flow chart (see Figure 1.3) presents the process and framework of this research.

Chapter One introduces the history of sustainable development, including the changes to the natural and built environment, definitions of sustainability, critical related theories and design strategies. Additionally, it briefly illustrates the background of the research subject, Taiwan. Moreover, methods, research questions, and the aim and objectives of this study are also presented. Furthermore, an introduction to the succeeding chapters and the potential contribution is included.

Chapter Two focuses on a review of the causes and impacts of the changes to the natural and built environment. Moreover, it extends the review of important sustainable theories and design strategies for the built environment and architectures. Furthermore, a review of practical projects in Asia and Europe are presented to point out future trends and summarize potential design strategies.

Chapter Three introduces fundamental information about the research subject, Taiwan and its capital, Taipei, including weather data, natural geographical attributes, and its social and economic development. Additionally, this chapter presents public actions, regulations, and researches related to sustainable development in Taiwan.

Chapter Four summaries the research methodologies related to understanding, analyzing and predicting energy performance of buildings and cities. Moreover, it explains the relationship of the constructed method in this research and the research questions. Additionally, it presents the composition of selected technical tools, which were developed for and applied to this research.

Chapter Five presents the process for understanding the energy performance of architectures in Taipei. Firstly, the classification and default setting of different types of buildings are explained. Secondly, the simulation process, result and analysis of buildings, groups, blocks and districts are presented in order to figure out the potential variables of the architectures in Taipei.

Chapter Six continues with the simulation and analysis. It shows the simulation process of several variables at urban and building scales. These variables are living style, building from, orientation, glazing ratio, insulation, usage proportion, urban density, fabrication, shading, UHI effect, and renewable energy. Moreover, some of them are selected and composed as optimized packages. Through the comprehensive simulation of these important variables and strategy packages, practical suggestions and useful design strategies will be concluded.

Chapter Seven contains the conclusion of all the previous chapters. Furthermore, a clear guideline of strategies to reduce the energy use of architectures in Taipei is presented. Finally, the recommendations for future research works are shown.

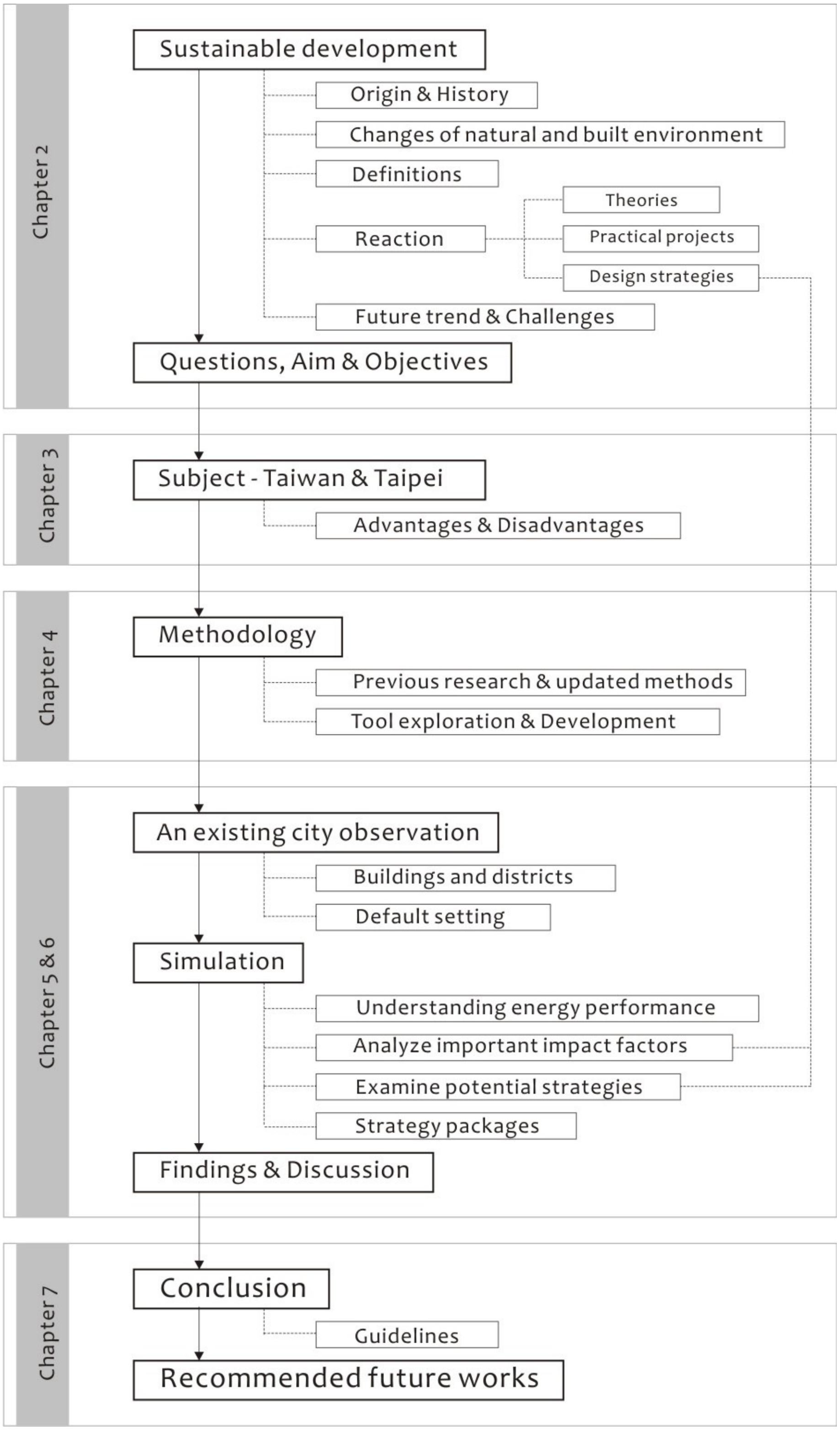


Figure 1.4 Flow chart of this research.

1.6 Contribution

The potential contributions are given as follows.

1. The simulation result provides references to the energy performance of different types of buildings, communities, blocks, and districts in Taipei, which will help future researchers undertaking energy consumption related studies.

2. The examination of strategies practically discussed and simulated in Taipei indicates the impact degree of different variables. In addition, this data identifies a better path to refine cities in Taiwan, which can be classified according to different scales. As shown in Figure 1.4, the saving degree of CO2 emissions would be different according to the scales at which the related strategies are applied. A composition of the strategies at all urban, building, and interior scales could maximize CO2 reduction (see Curve A in Figure 1.4).

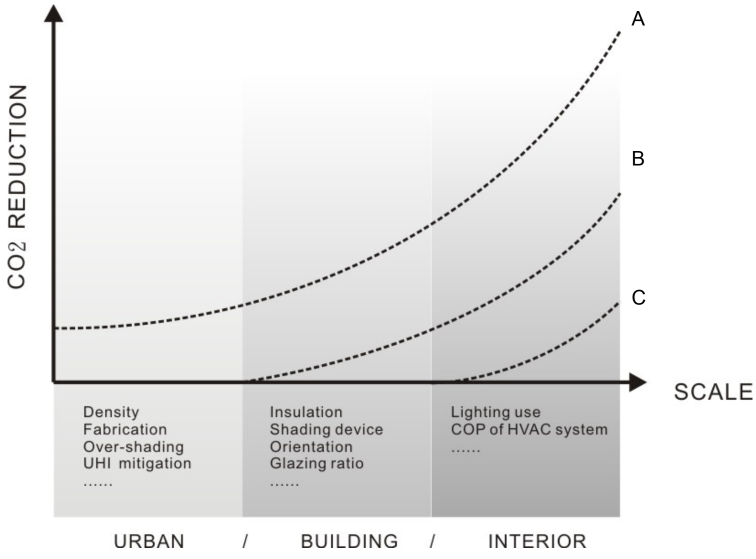


Figure 1.5 The hypothesized relationship of CO2 reduction and the design strategies application at different scales.

3. This bottom-up engineering method connects several powerful technical tools, which provide succeeding researchers with another option to understand, to analyze and to predict architectures at regional scale.

Chapter 2

SUSTAINABLE DEVELOPMENT AND DESIGN STRATEGIES

A REVIEW OF THE CAUSES, IMPACTS, AND DEFINITIONS OF SUSTAINABLE DEVELOPMENT, PROJECTS IN ASIA AND EUROPE, AND IMPORTANT THEORIES AND DESIGN STRATEGIES FOR THE SUSTAINABLE BUILT ENVIRONMENT AND ARCHITECTURES

SUSTAINABLE DEVELOPMENT AND DESIGN STRATEGIES

2.1 Introduction

Through the review the global sustainable development history, its definition, critical theories and related projects in Europe and Asia, this chapter aims to figure out the strategies which can help build sustainable cities and buildings and realize the history, the future trend and important variables concerning the sustainable design strategies of the built environment and architectures. Firstly, by exploring the history of sustainable development, people can understand the importance of it and get a glimpse of potential opportunities to refine our future. The research will mention critical events and solid scientific evidence involved in the origin of the concept of sustainability. Secondly, this chapter will discuss various definitions of sustainable development and subsequent research. Thirdly, theories from multiple perspectives will be explored, from Richard Register's Image of Ecocity to Richard Roger's Cities for a Small Planet. Fourthly, this chapter will also show future trends and useful strategies to reduce energy use by reviewing practical and imaginary projects and researches related to design strategies. Lastly, this chapter will summarize the strategies for sustainable buildings and cities for easier review and referencing for further model simulation.

2.2 The history of sustainable development

The appearance of the concept of sustainability in a broad sense could be traced back to two main impacts on human life. The first impact came through the arrival of energy and resource distribution, which forced people to rethink and develop new lifestyles. The second came through various types of negative changes to the natural and built environment, which have been proved to be directly or indirectly affected by human activities. In this section, the causes of sustainable development and the changes to the economic, social and natural environment are mentioned first and followed by definitions and related concepts.

2.2.1 Causes of sustainable development

After the Industrial Revolution which happened in the 18th and 19th century, the application of technology, and the economy related to it, generally became the most important activities in our society. Because of the aggressive pursuit of the prosperity (Maddison 2009), the application of industry has grown extremely fast and continues to ask for massive energy and natural resources.

Looking carefully at the present world energy consumption pattern (Figure 2.1), it can be seen that oil is the major resource, which occupies 33.7% of the all consumption (Farinelli 1994). Coal occupies 23.4% and natural gas 19.9% (ibid.). For modern life, fossil fuel has an irreplaceable status. Tracing back through the history of energy usage, there have been three oil crises which happened in 1973, 1979 and 2003. All of them directly created economical inflation and social disorder for several succeeding years. Moreover, global oil supplies will become exhaust in 40 years; coal will still be available for another 250 years; natural gas will be consumed in less than 60 years. With the rising fear of energy scarcity, there must be a greater desire to discover new resources (Afgan et al. 1998).

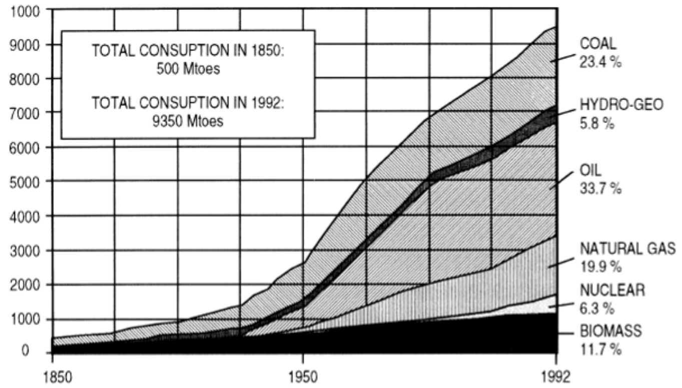


Figure 2.1 The consumption proportion of main resources around the world from 1850 to 1992. (Source : Farinelli 1994)

Additionally, a stable economy cannot depend solely on exploring new energy resources. The energy consumption style without any controls is not be allowed because of the limited resources. Reducing the energy on the demand side (Blok 2005; Lund 1999), energy efficiency improvements (Lior 1997; Lior 2002), renewable energy replacement (Afgan and Carvalho 2002) and large-scale renewable energy implementation plans (Li 2005; Muneer et al. 2005; Ghanadan and Koomey 2005; Hvelplund 2006) are believed to be the four major efficient methods to allow people to live in a world without depending on fossil fuels. An attitude to change the way people use energy has helped people to come up with solutions to keep the economic environment stable and shape the idea of what sustainability is.

In short, there is no doubt to say that people enjoy the convenience and international interaction brought by the industrial revolution. However, the past two hundred years of development has not only given people an era of unprecedented cultural flourishing, but has also left human beings with unpredictable usage of resources and environmental dangers (Lin 2008).

2.2.2 Changes to the natural and built environment

It is not hard to observe the comparatively slower rate of changes to the natural environment before the emergence of humanity (IPCC 2008). The nature of human activities threatens the environment and produces numerous problems. In the book, The Future of Life (Wilson 2002), the author warns people about the environmental state of the earth and describes the pressure imposed on it by human activities, including human-induced global warming, pollution, deforestation, habitat destruction and resource depletion. In addition, Sassi (2006) added Ozone depletion, water shortage, soil degradation and the extinction of flora and fauna.

Furthermore, considerable concerns for changes in urban areas and the built environment have arisen recently and are mainly to do with population growth and global urbanization. As the UN Centre for Human Settlements (1996) stated, it is not to be denied that cities are the main problems within the current concern for sustainable development. Moreover, some other critical changes are noticeable, such as pollution, waste, transportation and the urban heat island effect (UHI).

Firstly, the world population was just over six billion people at the end of the 20th century and had reached 6.5 billion by 2005. It is expected to increase to 9.1 billion during the next 45 years (medium variant) (UN 2005). It is well known that the global population will increase and that the areas where people live will also be different. In 1950, 0.73 billion people, namely 29.1% of the world population lived in urban areas; in 2005, the number had jumped to 3.17 billion, or 49.2%; by 2030, 4.94 billion people will live in urban areas accounting for a 60.8% proportion (UN 2005). Nevertheless, for developed countries, the UN predicts that 82% of the national population will live in cities.

Secondly, except the world population and urban rate, it may be worth mentioning that the density of a country could be another indicator of urbanization. According to the data, the cities with the highest density in the world are mostly located in Asia (Table 2.1). The reasons for this are the culture, lifestyle and economic situation, coupled with a lack of sustainable planning. Steemers (2003) believed that lower density development would result in greater physical separation and diffused dispersal of activities. Although the concentration of activities and people in cities is the main cause of environmental problems, it helps reduce the energy consumption per capita by intense use of land and shared public infrastructure, such as energy and water supply, drainage, roads, buildings and transport (ibid.). Moreover, Jabareen (2006) identified density as one of the seven design concepts for sustainable urban form, along with compactness, sustainable transport, mixed land uses, diversity, passive solar design, and greening.

Rank	City / Urban area	Country	Population	Land area (in sqKm)	Density (people per sqKm)
1	Mumbai	India	14,350,000	484	29,650
5	Shenzhen	China	8,000,000	466	17,150
6	Seoul/Incheon	South Korea	17,500,000	1,049	16,700
7	**Taipei**	**Taiwan**	**5,700,000**	**376**	**15,200**
10	Shanghai	China	10,000,000	746	13,400
12	Beijing	China	8,614,000	748	11,500
13	Delhi	India	14,300,000	1,295	11,050
20	Ho Chi Minh City	Vietnam	4,900,000	518	9,450
21	Cairo	Egypt	12,200,000	1,295	9,400
22	Baghdad	Iraq	5,500,000	596	9,250
25	Sao Paulo	Brazil	17,700,000	1,968	9,000
26	St Petersburg	Russia	5,300,000	622	8,550
27	Mexico City	Mexico	17,400,000	2,072	8,400
29	Singapore	Singapore	4,000,000	479	8,350

37	Bangkok	Thailand	6,500,000	1,010	6,450
38	Osaka/Kobe/Kyoto	Japan	16,425,000	2,564	6,400
42	Madrid	Spain	4,900,000	945	5,200
43	London	UK	8,278,000	1,623	5,100
50	Tokyo/Yokohama	Japan	33,200,000	6,993	4,750

Table 2.1 Selected largest cities in the world ranked by population density within 50 rankings. (Source : City and Mayors 2007)

Thirdly, cities are often associated with high levels of air pollution, mainly from transportation. Newman (1999) took fuel consumption and urban density as a comparison principle for his graph marking big cities around the world (Figure 2.2). Most "big" cities in the US have a comparatively lower density, but consume much higher energy per capita than others in Australia, Europe and Asia. Therefore, the US modern living style is definitely not suitable for sustainable development.

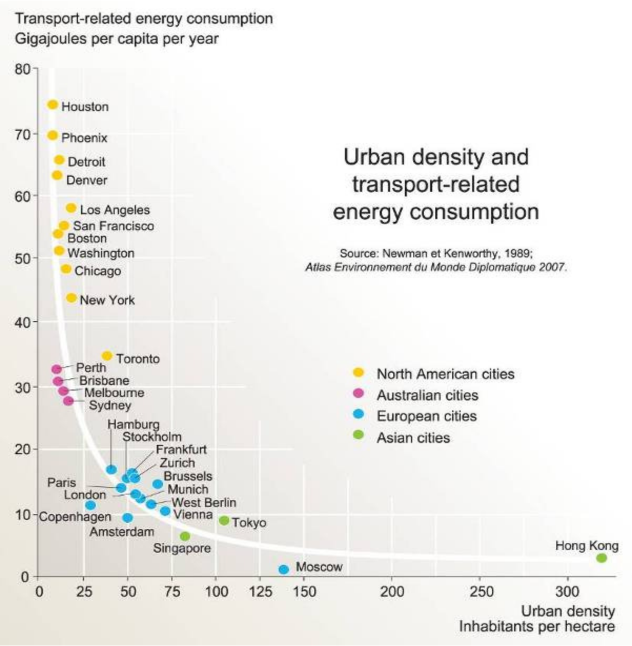


Figure 2.2 Population density against gasoline consumption per capital. (Source : Newman et Kenworthy 1989)

Fourthly, climate change is likely to lead to more frequent and intense heat waves (Lin 2009a). The phenomenon in urban areas, which have long been observed to have higher air and surface temperatures than their surroundings, is called the urban heat island effect (UHI) (Landsberg 1981; Oke 1973, 1978, 1988, 1999; Santamouris et al. 2001; Streutker 2003; Tran 2006; Gartland 2008) (Figure 2.3).

Gartland (2008) concluded that these causes could generally be summarized into five main groups effecting energy balance (Table 2.2), and each of them could be linked to a leading characteristic contributing to the UHI effect.

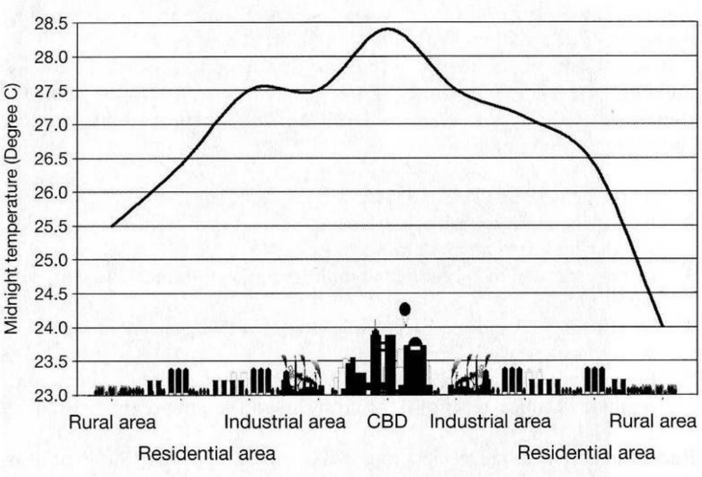


Figure 2.3 Sketch of an urban heat island profile of Singapore. (Source: Chen 2009)

Characteristic contributing to UHI	Effect on the energy balance
Lack of vegetation	Reduces evaporation
Widespread use of impermeable surfaces	
Increased thermal diffusivity of urban materials	Increases heat storage
Low solar reflectance of urban materials	Increases net radiation
Urban geometries that trap heat	
Increased levels of air pollution	
Urban geometries that slow wind speeds	Reduces convection
Increased energy use	Increases anthropogenic heat

Table 2.2 Urban and suburban characteristics important to UHI and their effect on the energy balance of the Earth's surface. (Source: Gartland 2008)

In cities, UHI exacerbates lower evaporative cooling and increases heat storage in roads and buildings, which creates a 5 to 11 °C rise in temperatures on average. The phenomenon not only brings about heat, but also has dramatic impacts on human health (Campbell and Corvalán 2007) and economic effects like decreasing productivity. Moreover, UHI would increase the cost of climate-control within buildings. Three major strategies are commonly employed to mitigate UHI, including increasing vegetative cover, using "cool" materials, and ventilation strategies (Chen and Wong 2009).

2.2.3 Definitions of sustainable development

Before the word “sustainability” was applied to the built environment, some architects and experts had already discussed concepts that were similar to sustainability, such as the Garden City (Howard 1898), the Village of New Harmony (Owen), Satellite City (Unwin 1922) and Broadacre City (Wright 1945). For their work during the decade from the 1920s to 1930s, the Chicago School of Sociology could be called the first group to do research in this field. Later, from the 1960s to 1970s, after massive shifts in the focus of technical and economic development, dangers from environmental catastrophes and several successive energy crises successfully attracted the public’s attention. Since the 1980s, more serious environmental changes and more solid scientific investigation involved in climate change have forced researchers to expand their focus to both natural and urban environmental issues. In 1987, the rough concept of an "eco-polis" was issued by the Russian scientist, O.Yanitsky, based on the notion of "urban ecology", which is a branch of ecology involved in dealing with the interaction of organisms in urban areas and their interaction with communities. This could be regarded as the formal starting point for the era of the sustainable urban environment.

At the beginning of the 1970s, the "word" sustainability was mostly employed to refer to resources recycling in forestry which involved long-term, durable, systematic and sound practices (Filho 2000). Extending the focus to nature due to the causes mentioned earlier, scholars had tried to consider issues for both the natural and artificial environments. A famous model was announced to explain the relationship between humans and the environment, the Egg of Sustainability, which illustrated that the human condition and the ecosystem should coexist in harmony to achieve sustainable social development (ibid.). After decades of discussion, a general and well-known concept emerged, which contains three dimensions, social needs, economic needs, and environmental capacity (Barton 1999) (Figure 2.4). These two critical concepts, the balance between the ecosystem and human society, and the comprehensive scope of society, the economy and the environment, could depict the core values of most definitions of sustainable development.

Figure 2.4 The diagram of sustainable development. (Source: Barton 1999)

After some long-term exploration which began in 1980, a significant step forward was generated and became broadly acknowledged as the Brundtland Report defined by the World Commission on Environment and Development (WCED) in 1987. The definition in the Brundtland Report is that sustainable development is development which "*meets the needs of the present without compromising the ability of future generations to meet their own needs*". Following the direction made by the Brundtland Commission, sustainable development has become a widely accepted principle informing a wide range of specific aims, such as achieving carbon neutrality, minimising the ecological footprint of products through their lifecycles, promoting renewable energy and maintaining biodiversity. In addition, there are some widely known definitions and related thinking done by other reputable researchers (Table 2.3).

Year	Definer - Source	Definition and related thinking
1789	Thomas Jefferson	... the Earth belongs to each generation during its course, fully and in its right no generation can contract debts greater than may be paid during the course of its existence.
1980	IUCN - World Conservation Strategy	The overall aim of achieving sustainable development through the conservation of living resources.
1987	Jacobs, Gardner and Munro	Sustainable development seeks ... to respond to 5 broad requirements: integration of conservation and development; satisfaction of basic human needs; achievement of equity and social justice; provision of social self-determination and cultural diversity; and maintenance of ecological integrity.
1987	WCED - Brundtland Report	... development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

1992	Agenda 21	The development requires taking long-term perspectives, integrating local and regional effects of global change into the development process, and using the best scientific and traditional knowledge available.
1995	FCES - the Earth Chapter	The protection of the environment is essential for human well-being and the enjoyment of fundamental rights, and as such requires the exercise of corresponding fundamental duties.
1995	Declaration of the CAETS	It means the balancing of economic, social environmental and technological considerations, as well as the incorporation of a set of ethical values.
1996	ICLEI et al.	Sustainable development is a program to change the process of economic development so that it ensures a basic quality of life for all people, and protects the ecosystems and community systems that make life possible and worthwhile.
2002	DEFRA - Achieving a Better Quality of Life	Sustainable development is about ensuring a better quality of life for everyone, now and for generations to come. Four key objectives: social progress which recognises the needs of everyone; effective protection of the environment; prudent use of natural resources; and maintenance of high and stable levels of economic growth and employment.

Table 2.3 List of definitions and related concept of sustainable development. (Source: Shown in the table)

On the other hand, the concept of sustainable development for the built environment has transformed through different terms, such as eco-polis (Yanitsky 1987), eco-city (Register 1975), sustainable city and green city. These terms not only extend the ideas of sustainability, but also offer some useful strategies.

The term "Eco-city" is thought to have originated from a non-profit organization, founded by Richard Register in 1975, which brought some green concepts into practice, such as stopping construction of a local freeway, holding conferences, building solar greenhouses and promoting bicycle and pedestrian pathways in Berkley. In the book, Eco-cities: rebuilding cities in balance with nature, Richard Register (1987) defined an eco-city as "an ecologically healthy city", but claimed there is no such city in existence. Gill and Bonnett (1973) stated that *"a city is an ecosystem - an intricate web of interacting organisms involving energy transfer and materials cycling"*, Douglas (1983) thought *"the urban eco-system is the most elaborate geographical control-system or integrated resource-management system in human experience"*. Additionally, a sustainable city is a complex system that coexists in a dynamic relationship with the world's ecosystems (Girardet 1999). Girardet also described a "sustainable city" in very careful way, as one that enhances well-being without degrading the natural world. Lastly, Downton (2009) clarified these ideas and recognized the differences among them. According to his opinion, there are four different related types of city and sustainability, which are named as a conventional modern city, a sustainable city, an eco-city or green city, and an eco-polis. The important characteristics of these four types are summarized in Table 2.4.

Characteristics	Conventional Modern City	Sustainable City	Eco-city or Green City	Eco-polis
Relationship to the Biosphere	In conflict. Incidental. Usually exploitative, extractive and polluting.	Mostly harmless	In balance with nature	Consciously integrated into biosphere processes to optimise their functioning for human purposes.
Ecosystem Connectivity: creating habitat	None, except in negative terms, e.g. polluting water courses.	Some connectivity with natural networks..	Functional connectivity with essential elements of the nature.	Conscious connectivity with all elements of the environment.
Response to Place	Weak	Fairly strong	Very strong	Very strong
Urban Form: Nodes / centres, patterns of connectivity that define structure and organisation	Poorly defined centres that exist subject to economic convenience, connectivity reliant on high energy use.	Compact core: some medium-density suburbs, urban villages, defines centres with some response to place.	Compact: urban village, distinct centres that are determined by topography and place.	Compact: urban villages, distinct centres that are determined by topography and place.
Architecture	Fashionable Inefficient	Moving towards sustainability. Stylistic issues may dominate other concerns.	Responsive. Bones of the architectural structure tuned to the local environment.	Organic. Highly responsive to climate, place and human needs. Use of biomimicry.
Community	Poorly defined, transitory. Tends to form reactively and be reactionary.	Unevenly represented. Not quite central to planning process.	Community characteristics associated with living processes.	Well established, integral to living systems and planning processes.
Economy	Exploitative	Market-driven. Central government	Market-driven. Ethical finance structures.	Market-driven, strong bioregional

		intervention on equity issues.	Some local economy. Equality concerns integral.	economy. Ethical finance structures. Equality concerns integral.
Climate Response	Denial	Some responsiveness. Tempered by economic limitations and social convention.	Responsive. E.g. solar greenhouses in cool climates shaded and breeze structures in hot climates.	Responsive. Biomimicry employed as primary design principle.
Principles	Pragmatic, primarily commercial. Social justice and equity issues subsumed by other concerns.	Pragmatic with principles subjugated to perceived political realities. Social justice and equity issues affected by other concerns.	Principled, seeking accommodation with politics and commerce without compromise. Social justice and equity issues seen as important.	Principled, with social, political and commercial issues all conditioned by ecological reality. Social justice and equity issues given prominence.

Table 2.4 A summary of the "geometry" of urban fractals. (Source: Downton 2009)

2.3 Sustainable theories and strategies

From the Renaissance period, scholars have been discussing issues involved with cities. But “modern” urban planning and design has had to wait until the latter part of the 19th century to become an individual subject, at which time it was believed to be a state function to deal with rapid growth in cities and the industrial revolution. This modern concept is the planning involved in creating a master plan and land-use zoning scheme, which is a kind of technical activity in the physical planning and design of human settlements and other affairs (UN-Habitat 2009). To put it more simply, the thinking of modern urban planning shapes the form and pattern of the majority of cities around the world. Due to the importance of modern urban planning, for a better future, sustainability has been considered and become an indispensible part. MASDAR is one of the world most famous examples. In this section, the critical context of urban theories and their latest developments are firstly mentioned, followed by a discussion of their impact upon the notion of sustainability. Then, the extended scope for design strategies at urban and building scales, and for places in subtropical zones, will be presented respectively.

2.3.1 Urban planning and design theories

Before the changes brought about by sustainability, the history of modern urban planning and design can be divided into three periods; classical urban design, the earlier part of 20th century, and the later part of it (Liang and Xiao 2006). Classical urban design insists Physical Determinism, which focuses on the order, axis and scale defined by classical aesthetics. Paris is one of the most famous cities based on the theory. The next stage of urban planning generally follows the radical economic and technical principals (ibid.). For example, Bauhaus treated cities as massive and high-running machines. In addition, in order to satisfy the need of modern life, several principals for building cities are set up by function in The Radiant City; cities should be divided according to their various usages, and the downtown areas should be occupied by comparative higher buildings to improve efficiency (Le Corbusier 1933). The concept behind these principals is still important until now. In the later stage of urban planning, Team 10 School (1959) believed people should rethink their physical environment and asserted the importance of the unity and integrity of human and urban environments. In 1978, Kevin Lynch's Image of the City concluded that it is five elements; paths, edges, districts, nodes, and landmarks, that offer citizens perspective toward a city. Like Colin Rowe's Collage City (1984), these theories added the concept of continuity to urban planning and basically have dominated urban planning and design until now (Liang and Hsiao 2006). However, the challenges that have arisen from rapid development and serious environmental damage were beyond their imagination and it is therefore necessary to adjust the planning attitude. Therefore, after the 1970s, the balance between cities and the ecological environment had begun to be mentioned. People understood that the impact of the urban environment could cause a series of damages to many aspects and possibly let human beings suffer the consequence. In the 21st century, the consideration of nature has gone further and now becomes the priority for modern urban planning.

At the beginning of the 19th century, several scholars had already discussed the concept of sustainability in urban areas, such as the Village of New Harmony (Owen), Satellite City (Unwin 1922), and Broadacre City (Wright 1945). However, due to the pursuit of economic prosperity the issue was ignored for a while. In the 1960s and 1970s, due to impending environmental dangers and the energy crisis, sustainable thinking regained people's attention. In 1973, Gill and Bonnett asserted that a city is an ecosystem. Since the Russian scientist O.Yanitsky conceived the term "eco-polis" in 1981, over the last few decades there has been a dramatic increase in the number of sustainable urban theories being published. The following are some of the important ones.

First of all, the notion of the Garden City lead the way for the concept of sustainable development in the field of urban planning, even though the definition of sustainability was not clearly defined at the time. Garden city was a term to describe self-contained communities, which contain residential, industrial and agricultural areas, and surrounded green districts (Howard 1898) (Figure 2.5). Once a city reaches full population, another garden city, which is called a satellite city, would be built nearby it and connected by rail and road (ibid.). The fundamental idea is basically to create multiple centres for a metropolis.

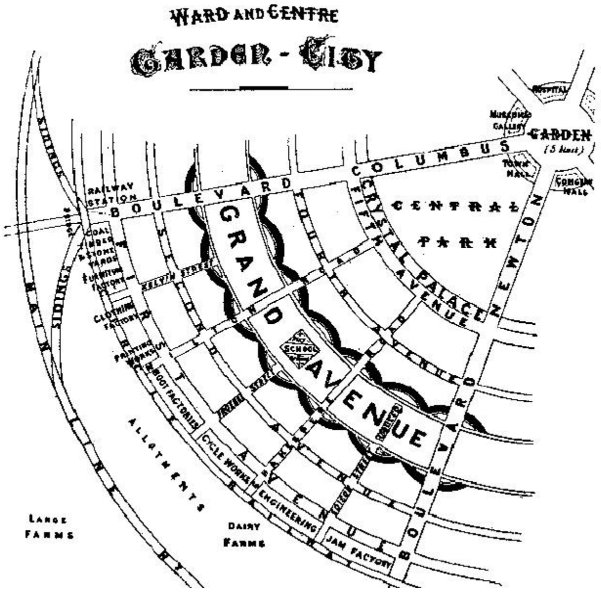


Figure 2.5 Diagrams of the essentials of the Garden City. (Source: Howard 1946)

Although there are no cities built completely by following this structure, in 1948, Copenhagen produced its famous master city plan, the Finger Plan (Figure 2.6). Instead of the idea of concentric circles, Copenhagen adopted the "finger" idea to encourage people to settle down next to selected suburban railway lines. Between these axes or branches of planning, open-space wedges would be preserved due to their poor accessibility (Hall 1998). The method offered a good solution to accommodate the growth of people and maintain the high quality of life by preserving the healthy balance between human settlement and nature.

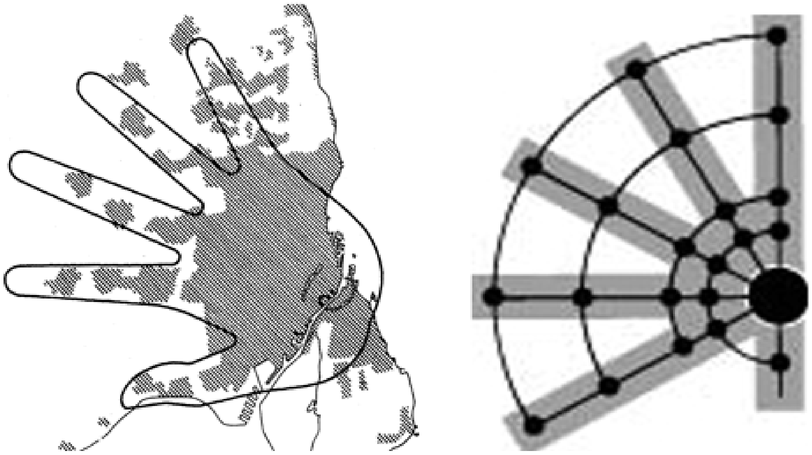


Figure 2.6 Copenhagen: Finger Plan. (Source: The municipality of Copenhagen)

The second important theory is Richard Register's (2006) exploration of the principals for an Eco-city, for which he believed the most important points are to build a city as a living system, fit the patterns of revolution, reverse the transportation hierarchy, enhance biodiversity, and incorporate "landusetructure". It also can be said the "landusetructure" is a kind of ecological mapping tool in order to remodel the existing city. The purpose of it is to transform the existing environment into a sustainable one. The resulting transformation would result in a multi-centred situation, which echoes the ideal of the Garden City.

In 1987, Richard Register took Berkeley as a case study and used his "mapping" tools to illustrate the application of sustainable thinking in a real urban area. He started with an up-to-date map of the real city and found out where the centres of greatest occupancy were. Then, he defined the potential hotspots according to living circles and features of nature. Next, the author overlapped the maps and set plans to control the future development areas (Figure 2.7). Although the whole transformation process should go through many generations, this outstanding theory at least gives the potential solution to reverse the poor living environment of an existing city.

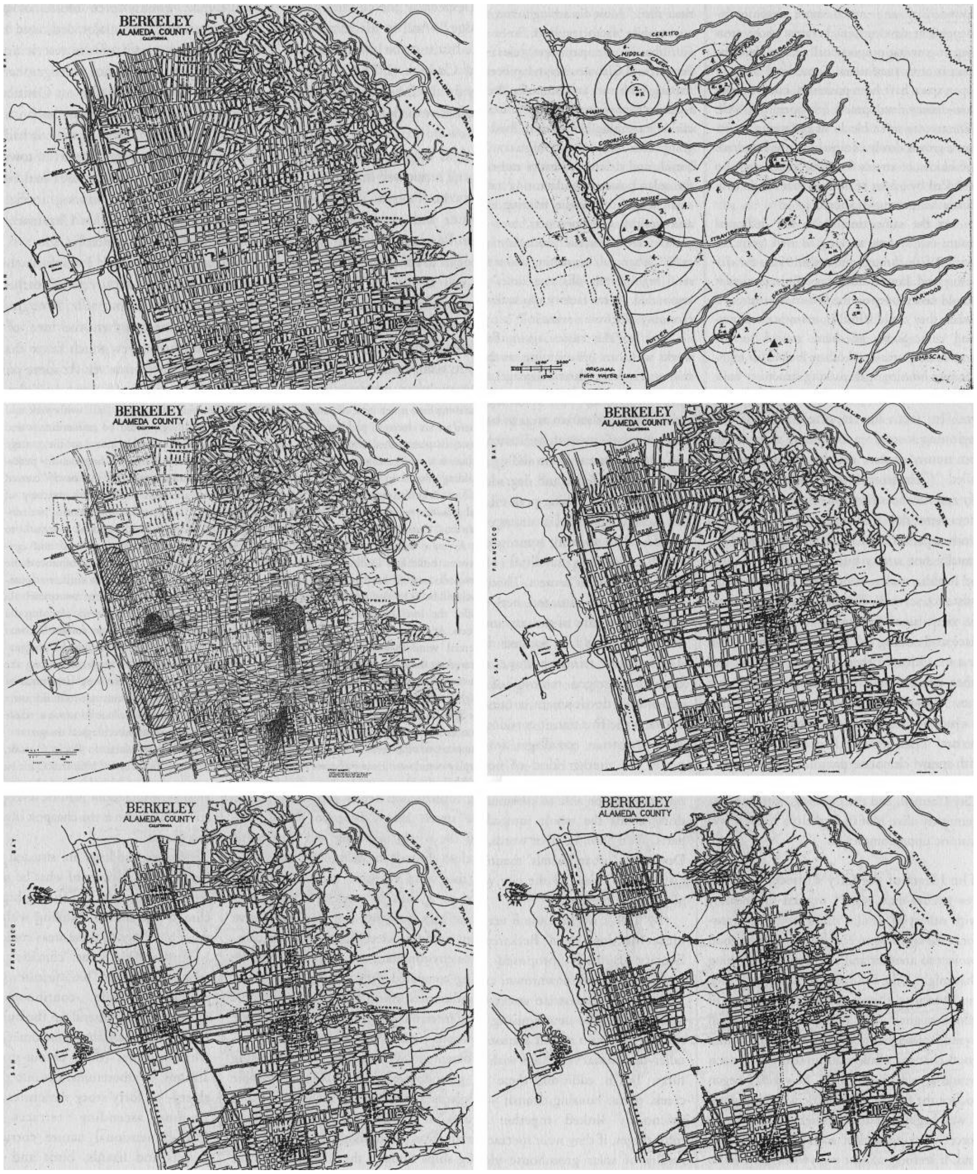


Figure 2.7 A series of plans showing the transformation of Berkley for sustainable development; the existing urban fabrication (top left), major and minor centres (top right), overlay map (middle left), 30-40 year development (middle right), 60-100 year reshaping (bottom left), and well-balanced achievement (bottom right). (Source: Register 2006)

Thirdly, the introduction of nature to the city is deeply emphasised in Ian McHarg's book, Design with Nature (1967), which emphasizes the importance of nature and explains how to deal with it. Unlike most other urban theories, features of nature are always given the priority, even higher than the foundational needs of humans. Both for new and existing areas, the author highlights the importance of the land value. The "value" of land has to be defined by nature first and then integrated into the benefits of human settling. Land value would be variable depending on the selected target area, and the recommended land use in a metropolis might contain surface water and riparian areas, marshes, 50-year floodplains, aquifers, prime agricultural lands, steep lands, and forests and woodlands. Considering these things together with overlapped mapping, the potential areas for transport routes or development could be marked. Although the value of nature is comparatively critical, Ian McHarg did not forget to show the maps related to social and economical activities in the composite plan which he presented for the hinterland of New York City (Figure 2.8). In general, the dedicated analysis and observation of land use gave rise to the concepts of research and design which apply GIS systems.

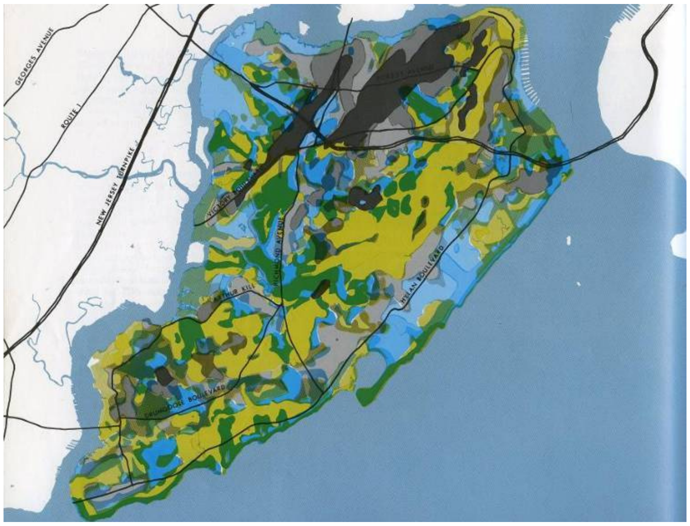


Figure 2.8 Composite: conservation (green), recreation (blue), and urbanization (grey) areas for the hinterland of New York City. (Source: McHarg 1967)

Fourthly, in Richard Roger's Cities for a small planet (2000), he reminded people to focus on how cities could be designed with a capacity for the massive increases in urban growth while remaining sustainable. He drew a diagram of the circular metabolism of a city, to explain the concept of minimizing resources input while maximizing recycling (Figure 2.9). This organic system not only reduces the demand for various kinds of resources, but also decreases pollution and slows down the expansion of erosion of fertile lands. Furthermore, he particularly mentions the creation of the modern Compact City, which rejects single-function development and the dominance of vehicles. Social and commercial activities are located at the nodes of public transportation. The network of neighbourhoods, parks and public spaces can meet the needs of general living, leisure and work simultaneously (Figure 2.10). This concept is similar to Howard's multi-centre approach, but at a smaller scale, and aims to both decrease the city's carbon footprint and reemphasizes the importance of dense, mixed-use urban development. Moreover, Roger (2000) asserted that a sustainable city should be just, beautiful, creative, ecological, diverse, allow easy contact, and be compact and polycentric.

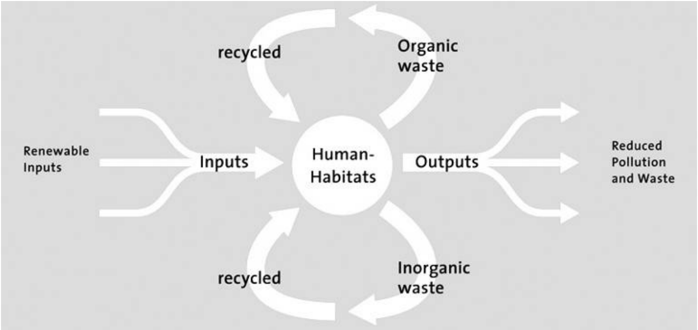


Figure 2.9 The recycling concept of resources. (Source: Rogers and Power 2000)

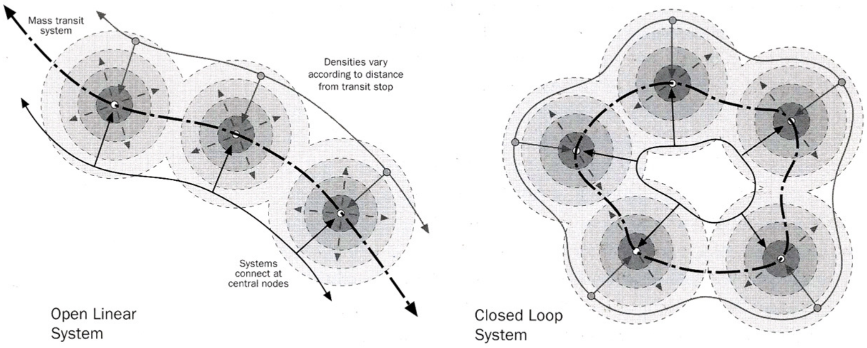


Figure 2.10 The network of a Compact City. (Source: Rogers and Power 2000)

Fifthly, Downton (2009) summarized preceding important theories and published his conclusions in his book, Ecopolis: Architecture and Cities for a Changing Climate. The author extended the scope of the term eco-city to, ecopolis, and asserted it to be the vital link between social and environmental issues. *"An Ecopolis seeks to minimise ecological footprints (biophysical) and maximise human potential (human ecology) to repair, replenish and support processes that maintain life."* (Downton 2009). For the biophysical aspect, the five main objectives are land use, bioregions, development balance, a compact city, and energy efficiency. For the human ecology aspect, economy, community, and history and culture are included, but with more emphasis on social justice and equity, and health and security. The theory reminds people to think in a bottom-up way based on community planning strategies and the respect of democracy. In additional, Downton (ibid.) presented a set of actions with seven steps toward a clear understanding, which was named SHED (Sustainable Human Ecological Development). The context and sequence are shown as Figure 2.11. Biological processes dominate the first four steps and the remaining three highlight community processes.

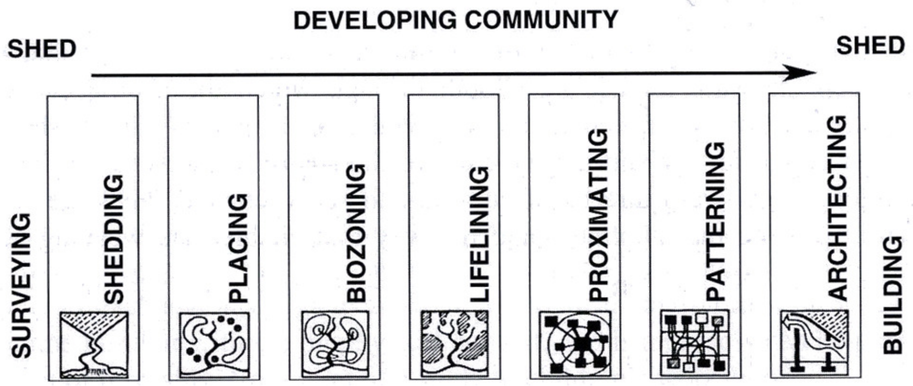


Figure 2.11 The context and sequence of SHED (Sustainable Human Ecological Development). (Source: Downton 2009)

Furthermore, a hundred year plan for Adelaide was presented to describe the possible transformation path for a modern city. In Adelaide's case, the transformation process was planned in a bottom-up way, but the hypothetical result of urban patterns remains in agreement with McHarg and Register's top-down master plan (Figure 2.12).

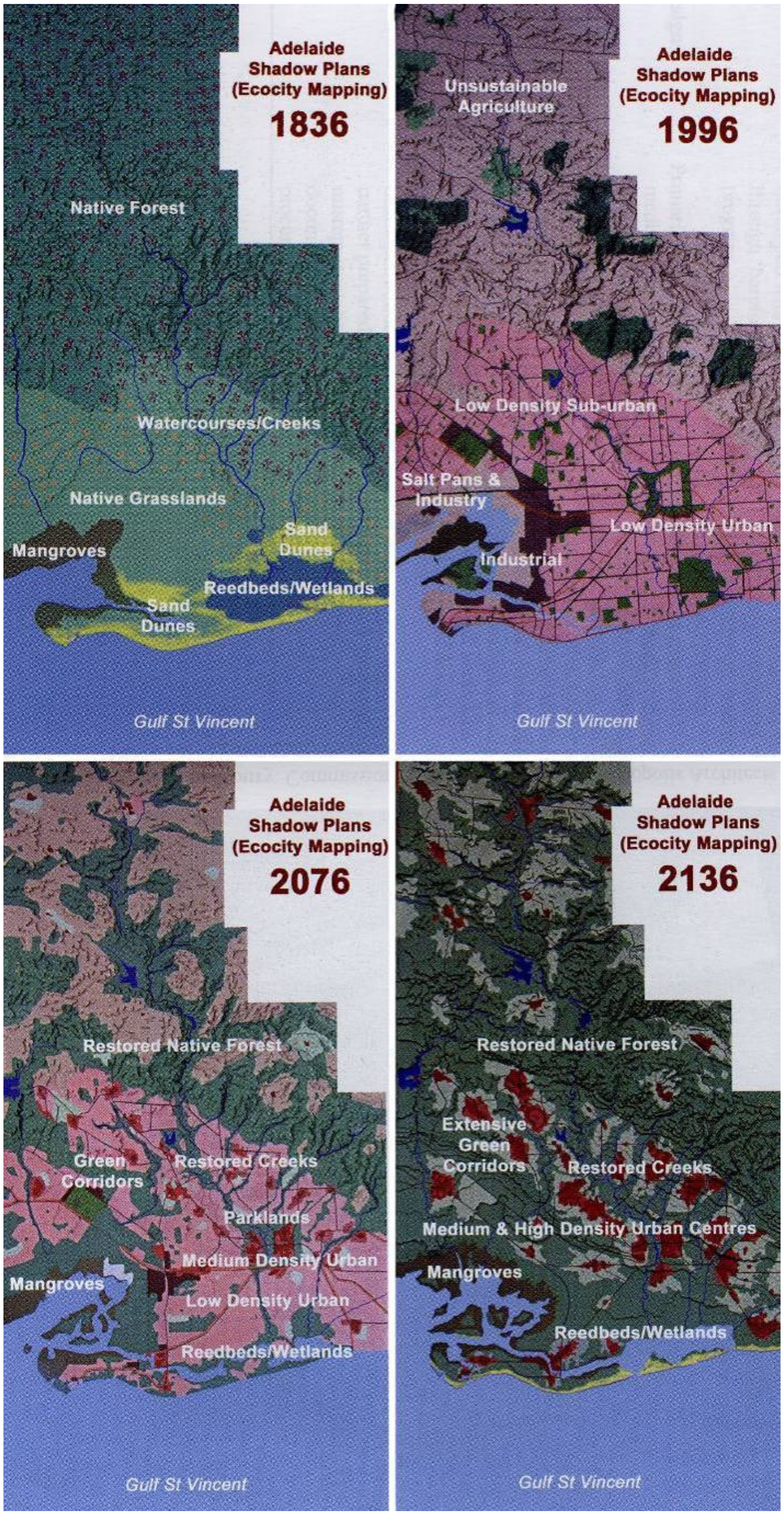


Figure 2.12 The developing images for a hundred year plan for Adelaide. (Source: Downton 2009)

In short, these critical theories offer foresighted perspectives for urban planning and design, which mostly focus on the balance of nature and human settlement. They not only give useful suggestions for sustainable urban planning and design strategies, but also present their ideas through introducing some imaginary projects. Furthermore, some of them have been applied in practical projects, which have also proved beneficial for our future.

2.3.2 Sustainable strategies at urban and building scales

In order to bring a sustainable urban environment into existence, sustainable strategies are just as important as theories. In order to fulfil sustainable concepts and ideas, deeper understanding variables and how to make appropriate strategies should be explored. In general, these variables or strategies can be divided into three different levels, urban-macro, urban-micro and building levels. Those at the urban-macro level concern green and blue belts, transportation, public infrastructure and others. Those at the urban-micro level refer to communities or a group of buildings. Land use in blocks, relationships among buildings, and distance for pedestrians, are some issues in this category. And these two levels are usually seen as belonging to the urban scale in the architectural field. Additionally, the building level is for a single building, including interior and exterior variables. This section discusses important variables and related strategies for all three levels.

First of all, urban density is one of the most popular issues remaining a matter for debate. Most scholars believe that a high density city has more advantages than a lower density development as a sustainable environment. Probably opinions would vary greatly depending on certain factors, such as local culture and lifestyle. For the Chinese and Japanese, a crowded urban life is much more easily accepted. For western countries, people prefer living with open spaces. Take a look at an extreme case which might intrigue our thinking. For the imaginary project, Hanoi 2110 – Sustainable Megacity, a high density development was recommended as a good solution for rapid growing Asian cities (Jones et al. 2010). The horizontal space arrangement at urban scale is similar to the concept of the Garden City and helps to save 90% of the land in Hanoi, whilst coexisting with its agricultural surroundings (Figure 2.13). But in the vertical section, a new concept, Metabolic

Super Cluster, was presented, which particularly focused on time and its relationship with land use layers, building envelopes and orientations (Figure 2.14). Designers believed that the model has many of the benefits that a high density city can bring, such as short access, better social interaction, land saving, higher productivity, offering efficient energy and low cost public infrastructure. Although the project has not become a reality, the ideas can still be used as a reference for a metropolis.

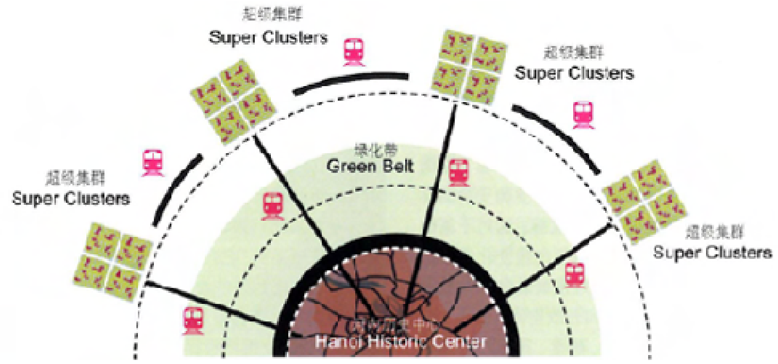


Figure 2.13 Regional connection model. (Source: Jones et al. 2010)

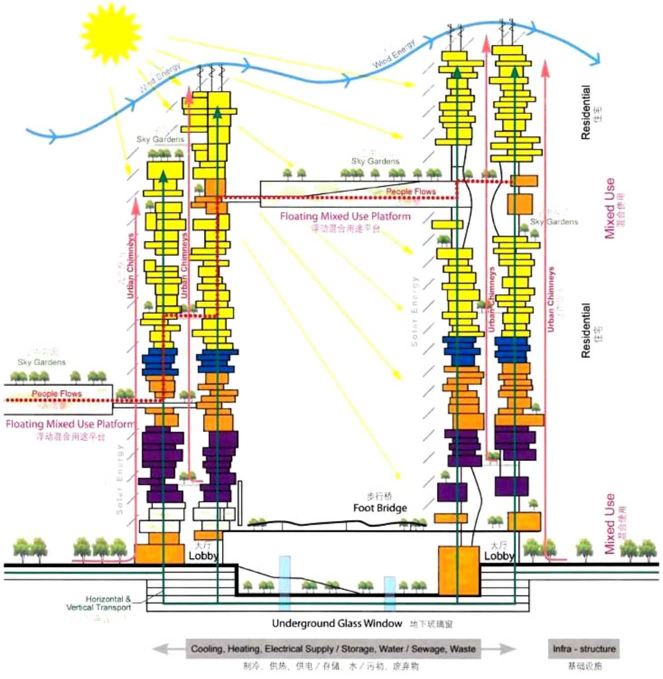


Figure 2.14 An illustration of a vertical city – environmental impact, infrastructure and traffic flow. (Source: Jones et al. 2010)

However, there is no perfect solution which solves the rapid urban growth whilst not damaging the quality of life at the same time. The highly condensed city might have potential problems, including loss of privacy, higher levels of noise, crime and deprivation (Sassi 2006).

Secondly, past research has mostly studied and simulated the energy performance of buildings and their behaviour, but neglected urban geometry. Nevertheless, some research has pointed out how the form of a city may have huge impacts. Ratti et al. (2005) built a 3D database and used a digital elevation model (DEM) to examine some important parameters, including surface-to-volume ratio, ratio of passive and non-passive zones, and orientation of façade (Figure 2.15). They found that urban geometry could largely affect the energy consumption of a city and concluded that urban design theoretically can influence building design, the efficiency of building systems and occupancy behaviour.

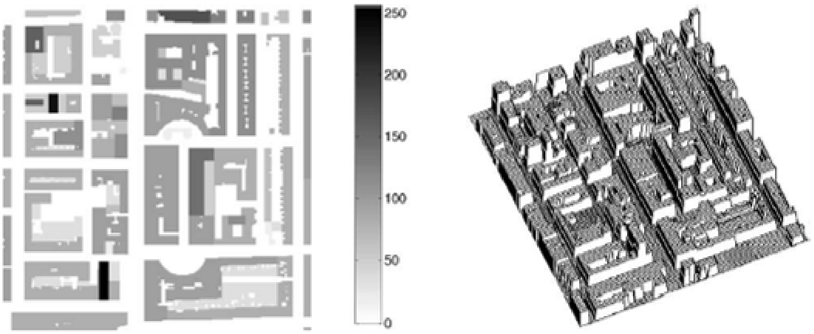


Figure 2.15 Digital elevation model (DEM) for a site in central London (left) and its axonometric view (right). (Source: Ratti et al. 2005)

Additionally, concerning urban amenities, urban fabrication is one of the most important things which affects the outdoor climate, the energy balance of buildings, and the diffusion of pollutions (Adolphe 2001). In order to understand the complexity of the frame geography of a city, Adolphe (2001) tested a city with several figures at a community scale by using a GIS system, which were density, rugosity, porosity, sinuosity, occlusivity, compacity, contiguity, solar admittance and mineralization. In his research, although there was no clear conclusion to mention the most critical variables for the urban environment, the author offered a systematic way to think about the frame of a city.

Thirdly, both at macro and micro levels, it is land-use patterns that have a huge impact on CO2 emissions. A dispersed angle land use city definitely generates a great deal more CO2 emissions than a mix-use neighbourhood or typical modern suburban area (Edwards 2010). From the 1960s, experts have addressed a popular question "what kind of building forms make the best use of land?" As we known, the efficiency of land use is not only related to the area, but also connected with the energy performance. Once the building can get more daylight, it might save lighting and heating costs for those in cold weather zones. Therefore, in order to answer the question, Carlo Ratti et al. (2003) compared various different types of buildings accounting for surface-to-volume ratio, daylight availability, shadow density and sky view factor. They discovered that the courtyard configuration has a better response than the pavilion type of dwelling in most of the testing of these environmental variables. For hot arid climates, they concluded that the courtyard form would be the best one without sacrificing floor space for a given plot, as it creates a microclimate in the form of an intermediate environment. Moreover, the courtyard type offers a more quiet, clean, and private environment and better social interaction than general street arrangements (Ratti et al. 2003).

Additionally, Gauzin-Muller (2002) presented that the impact of a building to its surroundings depends upon its position, shape, structure, materials and energy needs. He believed that a simple and compact volume can have environmental and economic advantages. Multi-storey housing blocks not only occupy less land, but lower the cost of construction and energy consumption. To meet the goal of increasing urban density and solving the rising urban population problem, offering low-rise but high-density housing can be a useful solution (Gauzin-Muller 2002). Many city planners agreed that the best configuration is high-density, mixed-use, medium-rise urbanism and argued further that the development of buildings would be better if they are from 6 to 10 storeys high (Edwards 2010).

Fourthly, layout integrated with nature plays a very important role to mitigate the negative environmental problems in urban areas. Planting and vegetation are the most widely applied mitigation measures, which are believed to be able to reduce the temperatures in cities from 1.3 to 3.0 °C (Rosenfield et al. 1998; Tong et al. 2005;

Ca et al. 1998; Ashie et al. 1999; Alexandri and Jones 2008; Shahidan et al. 2012) (Figure 2.16). Such temperature reduction can bring significant benefits, including decreasing the cooling demand, saving electricity, and creating a comforting thermal environment (Memon et al. 2008).

As previously described, there is no doubt that the urban geometry would have a serious impact upon the thermal environment, particularly for densely populated cities in hot weather zones. The spaces exposed to the sun most of the day, with some covered by strong reflective materials, and some with a lack of vegetation, will combine to result in an increase of temperatures (Bourbia and Boucheriba 2010). Within street canyons, the effect can be reduced by controlling the sky view factor and by the inclusion of vegetation. Plants reduce heat gain by both directly shading buildings and by evapotranspiration. The most popular and effective strategies include adding vegetation to the environment, abundant planting, and incorporating vegetation on the buildings' roofs or walls (ibid).

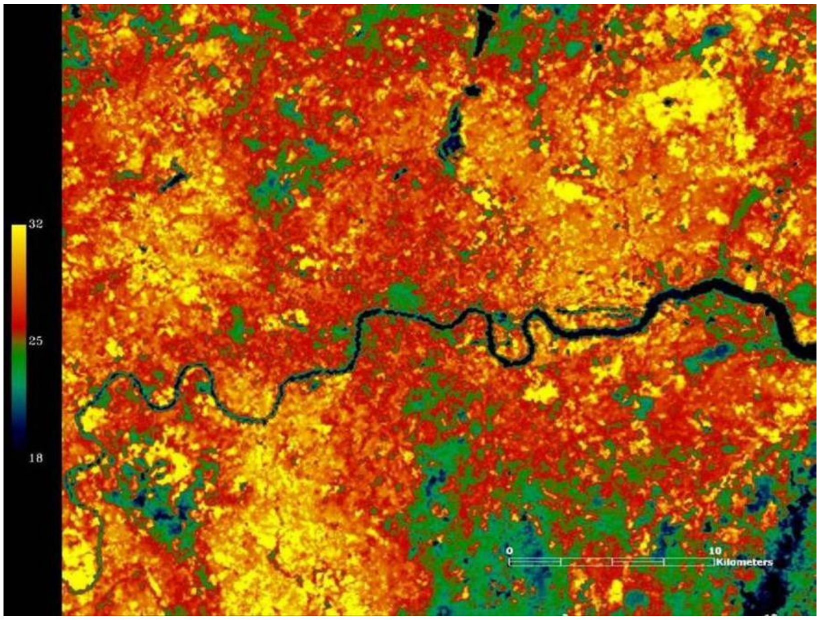


Figure 2.16 The comparison of ground temperature for the coverage of vegetation and planting in London, UK. (Source: Center for Environmental Science Applications, CESA 2003)

Fifthly, some researchers have compared the effects of different building morphology, including site and orientation, and concluded that natural ventilation has a direct impact of urban temperature. In other words, the site and orientation of buildings not only shapes the pattern of a city, but also has a strong relationship with the direction and the speed of the wind. Yuan and Ng (2011) presented a study of a highly compact city which observes the effects of different urban patterns on the pedestrian-level natural ventilation environment by applying CFD simulation (Figure 2.17). Through a comparison of the results, it is clear to understand the sensitivity of wind speed. A sustainable environment should not ignore the importance of wind field. Following the natural rules of ventilation, the urban environment can reduce the ground temperatures and mitigate the urban heat island (UHI).

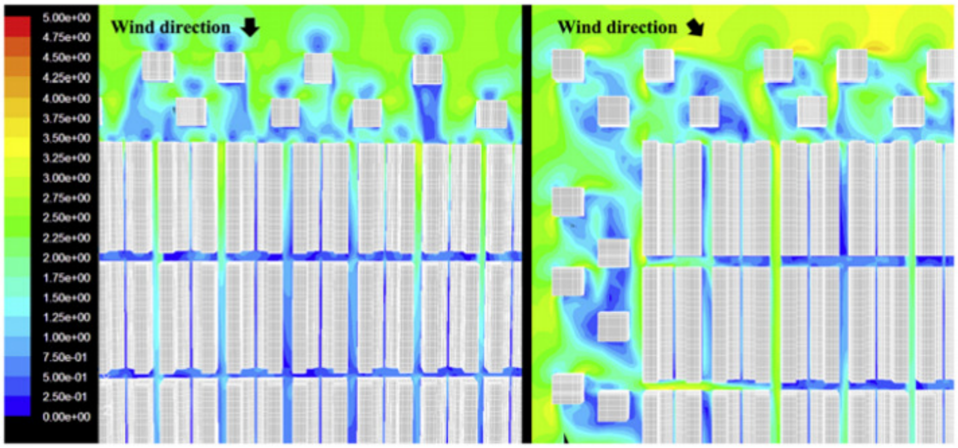


Figure 2.17 Variation of wind speeds in a city based on different urban planning against the natural ventilation direction. (Source: Yuan and Ng 2011)

Sixthly, green roofs and green walls play important roles in the mitigation of urban ground temperature. At a conceptual level, these strategies can be seen to replace the original plating at ground level. At a practical level, they provide various environmental benefits, including additional insulation against the cold and the heat, more rainfall absorption, reduction of smog and dust particles, and reduction of ambient temperatures (Sassi 2006). Moreover, some scholars have proven that green roofs can save energy significantly due to their function as incident solar radiation barriers (Lazzarin et al. 2005) (Figure 2.18). If this strategy can be widely applied in a city, the benefits will be obvious.

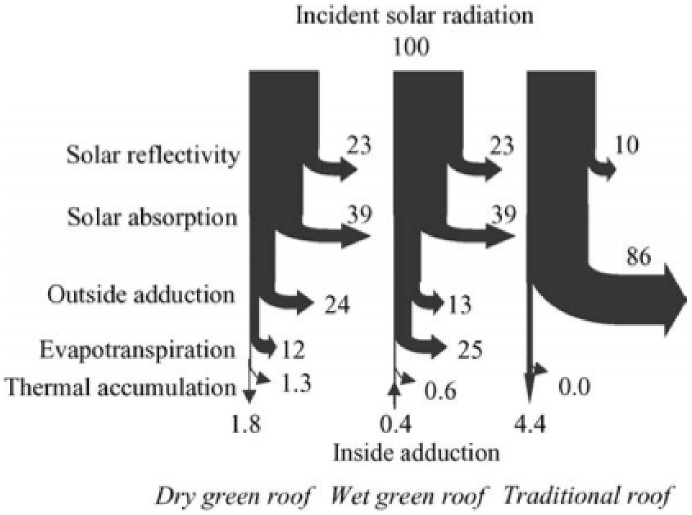


Figure 2.18 The comparison of different types of roofs in summer by taking incident solar radiation as 100 units. (Source: Lazzarlin et al. 2005)

Seventhly, sheltering layouts and glazing ratio control the passive solar gain and lighting acceptance. Shading can be the most important factor for buildings and urban microclimates. There are two types of shading, shading device or self-sheltering offered by the buildings themselves or over shading from planting or nearby obstacles. Particular for those cities in tropical and subtropical zones, shading can decrease the ground temperature and create a more comfortable thermal environment, whilst also reducing the solar gain of buildings. Furthermore, it is one of the more easily controllable design strategies and could be used in conjunction with natural ventilation, evaporative cooling or high thermal mass, for maximising the effect (Sassi 2006).

Eighthly, façade materials are responsible for the radiation management inside street canyons. The emitted infrared radiation from many kinds of buildings and street pavements would be entrapped inside the canyon, and this phenomenon has a strong relationship with the surface materials. The total amount of absorbed solar radiations is increased due to the multiple reflections between buildings (Santamouris and Assimakopoulos 1997). In order to ascertain the most suitable materials for outdoor paving, Doulos et al. (2004) tested 93 commonly used pavement materials outdoors and concluded that the most important physical characteristics of materials are the colour, the surface texture and the construction materials. They consequently divided the materials into two groups, cold and warm categories. The cold ones generally have a light colour and a smooth flat surface, and are made of marble, mosaic or stone. In short, applying the cold materials to streets or buildings was proven to reduce the absorbed solar radiation and give a positive thermal balance in the urban environment. Moreover, they agreed that a better solution is the combination of light colour surfaces and the planting of trees.

2.3.3 Strategies for buildings in hot and humid weather zones

It is widely known that the best design strategies for buildings should be based upon the local environment, particularly concerning those physical factors of meteorology. In this section, design strategies for buildings in hot and humid weather will be particularly discussed.

First of all, Lin (2009a) investigated offices in seven different weather zones, ranging from arid and cold to humid and hot (Table 2.5). For these commercial buildings, orientation shows an average influence from 3.6% to 10%. Although glazing ratio presents similarly, the variable is much more important than the impact of orientation. Lin (2009a) also asserted that, for either cold or hot climates, the higher fenestration ratio comes with higher energy consumptions. Next, for those buildings in subtropical and tropical areas, including Taipei, Hong Kong and Singapore, shading should be responsible for 42.7% to 47% of the electricity consumptions of HVAC systems. In contrary, for offices in cold areas, the U-Value of the building envelop is the key issue.

Weather Zone (Location)	Impact degree (%)				
	Orientation	Glazing ratio	Shading device	Insulation	Others
Humid continental (Harbin)	5.0	17.9	0.0	72.3	4.7
Humid continental (Beijing)	7.7	36.3	15.8	29.0	11.2
Humid subtropical (Shanghai)	3.6	37.1	8.7	44.8	5.9
Humid subtropical (Tokyo)	4.7	43.2	20.1	20.3	11.7
Humid subtropical (Taipei)	**5.5**	**49.0**	**42.7**	**0.0**	**6.5**
Humid subtropical (Hong Kong)	4.8	44.2	45.7	0.0	6.3
Tropical wet (Singapore)	10.0	40.4	47.0	0.0	6.3
Simulation subjective: 10-story office building with 25*50 m floor plan HVAC conditions: AHU + CAV system with COP = 5.5					

Table 2.5 The comparison of different variables for HVAC system in different weather zones. (Source: Lin 2009a)

Secondly, in hot and humid regions, research indicated that few citizens visit big open public spaces when the thermal index is high. Lin et al. (2010) stated that the largest number of people visit squares when the thermal condition is close to the thermal comfort range. They also concluded that the outdoor thermal environment is involved in microclimate, e.g. ground surface covering (Lin et al. 2007), evaporation and evapotraspiration of plants (Robitu et al. 2006), anthropogenic heat (Ichinose et al. 1999), and shading by plants and man-made objects. In Taiwan, 93% of people who go out in summer prefer staying under trees or in building shade. Shading is definitely not only one of the important issues related to square use, but also affects the energy consumption of surrounding buildings. Abundant shading can create lower outdoor temperatures and reduce the cooling load of buildings by blocking incident solar radiation.

In short, the focuses of design strategies for buildings should be different in hot and humid zones. Reducing solar gain is the most important issue related to lowering energy needs. Thus, urban planners should consider over-shading and architects have to consider self-shading and shading devices. Moreover, vegetation, appropriate glazing ratio, and wall-to-volume ratio should be specifically designed. Lin (2009a) concluded further that the three most important requirements for buildings in subtropical zones are appropriate fenestration ratio, abundant shading and natural ventilation. Additionally, these three strategies were successfully applied in EDITT Tower project in Singapore (Yeang 1998) (Figure 2.19).

Figure 2.19 A demonstration of green building design in hot and humid zone - EDITT Tower in Singapore. (Source: Yeang 1998)

2.4 Projects exploration

In Europe, there are many leading countries in the sustainable development field, which have already carried out some practical projects and promoted their ideas to other developing countries. These projects around the world generally can be categorized into two groups, a single or small group of buildings, or a city. For the former, BedZED (2002) in South London is a mixed-use scheme project, which is famous for its careful calculation of money flow and successful post-build monitoring. Solar City in Linz (1990) is another example of a new community development. Its mixed use of land, accessible transportation system for all residents, and linkage with nearby cities, are all concepts based on future-orientated urban planning. Vastra Hamnen in Sweden and the Ecocity Project for seven places in Europe are some other popular examples. For city scale projects, Eco-vikki in Finland (1999), Sino-Singapore Tianjin Eco-City in China (2007), DongTan Ecocity in Shanghai (2005), and MASDAR in the United Arab Emirates (2006), show more comprehensive plans and develop new transportation and public facilities systems. Whether these schemes realise smaller scope projects or the bigger ones, they all offer valuable opportunities to comprehend better strategies to refine our living environments and indicate the future trends of sustainable design.

2.4.1 Europe

Abundant ideas and practical cases based on different purposes could be found in Europe. This section presents for strategy application discussion of some leading projects related to sustainable development spanning from Britain to Sweden.

The first case is a demonstration of cooperation among cities, which is called ECOCITY. The concept of the ECOCITY project was to plan seven model settlements in Austria, Spain, Hungary, Finland, Slovakia, Germany and Italy (Figure 2.20). In this scheme, creating a framework for sustainable transportation patterns was the first priority. The second priority was to find sustainable solutions in the sectors of energy, material flows and socio-economy. Notably, not only experts and architects were involved with the design work, but also inhabitants were encouraged to join in through community participation.

Figure 2.20 The overall ECOCITY Project. (Source: ECOCITY Book 2 - How to make it happened 2008)

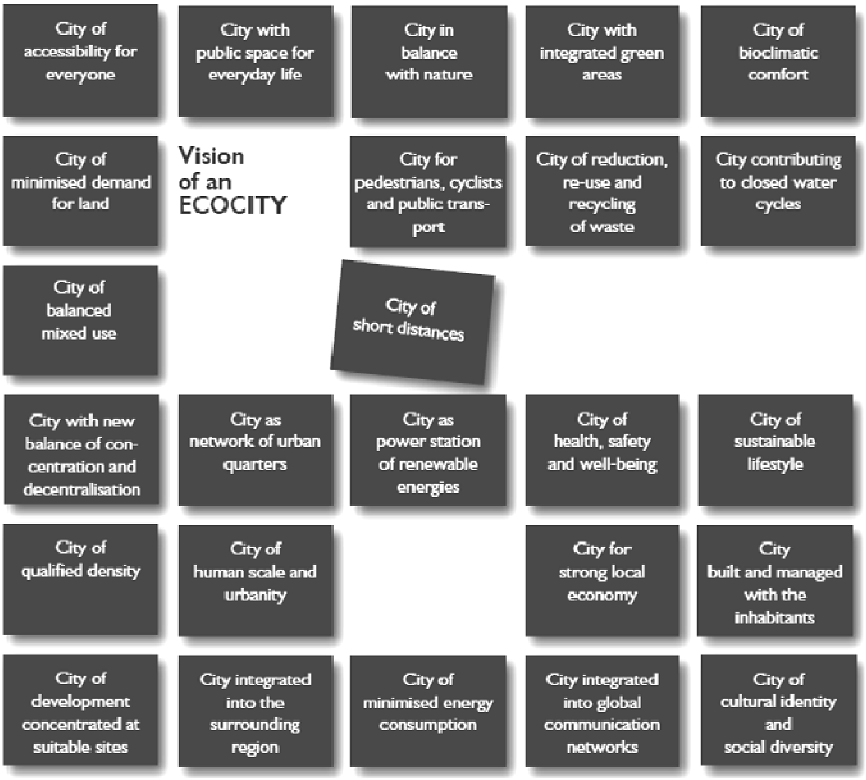


Figure 2.21 The vision of ECOCITY. (Source: ECOCITY Book 2 - How to make it happened 2008)

ECOCITY has a clear vision, which contains many features (Figure 2.21). As the figure shows, transportation is the key issue that would affect the patterns of land use, living circles, city forms and energy supply systems. A city built to have short distance living circles and appropriate densities is the goal of the project (Gaffron et al. 2008). Short distances could reduce energy costs in many aspects, including transport infrastructure, information, water, and sewage and energy supply systems. Furthermore, it can help achieve a balanced mix of land uses, such as residential, educational and leisure uses, distribution and supply, green and grey spaces, whilst retaining the flexibility of the economic infrastructure (ibid.). Efficient energy supply and operation systems were considered at an early stage of the design, and soils, water, waste and other resources were all designed for recycling. Moreover, the existing landscape was considered so that it remains in harmony with new green spaces, and ecological systems were taken into account when considering social needs.

The international nature and vast scale of a project such as ECOCITY is rare. Solar City in Linz, Austria, was one of the medium scale cases (Figure 2.22). Solar City was a perfect example of future-oriented urban planning. Every construction stage was undertaken according to the set ecological criteria and used economical low-energy methods. Furthermore, considering local social demands, the government tried to connect the SolarCity to an existing downtown area of "Alt-Pichling" instead of creating an isolated satellite city, which allowed Pichling's residents to profit from the expansion (Treberspurg 2008).

Figure 2.22 A bird's eye view of Solar City in Linz Pichling. (Source: Treberspurg 2008)

The project was divided into two parts and buildings were planned to be built in a step by step progression. Like typical sustainable concepts, it focused on issues related to transportation, building volumes, structure, building envelopes, passive and active measures, solar collection and power storage. Moreover, the framework of the "house of the future" as a net-based assessment tool was set up from the outset. Under the directions of the criterion system, SolarCity proved that if a standard could be set or an assessment could be carried on at the beginning of construction, it would be easier to achieve goals and help occupancies to maintain the intended function and remind people to live in a sustainable way (Jurgen and Jurgen).

In Malmo, Sweden, Vastra Hamnen is another, albeit smaller, new city district development project (Figure 2.23). The singular and ambitious goal for the project was to become a 100% renewable energy settlement (e-on). With the requirement set for a maximum energy consumption of 105 kWh per square meter annually, the government installed many public facilities to support this condition, including wind power station and solar panel courts. Moreover, dense development, high-quality and friendly transportation systems, recreational facilities, and a comprehensive plan for ecological issues were included.

Figure 2.23 The overall of Vastra Hamnen. (Source: Google Earth)

The fourth case is a sustainable community project (Figure 2.24) called the Beddington Zero Energy Development (BedZED) which is a mixed-use scheme in South London initiated by the BioRegional Development Group and Zedfactory. The goal of the scheme was to offer a place for people to live more sustainably without sacrificing a modern, urban and mobile lifestyle. It has been made famous by its approaches to housing, including design, construct and financial plan, which challenge existing conventions.

Figure 2.24 The overall view of BedZED. (Source: Bill Dunsters)

To begin with, the design of facilities and services was conceived to cause occupants to naturally reduce waste, recycle water and minimize car use. Next, a financial strategy was carefully planned and calculated at the beginning, i.e. the cost of larger green areas, recycling equipment and technical facility investments would be made up for by a 20% increase in house sale prices. In addition, during the construction phase, strictly local resources and materials were used and had to be transported from within a 60 km radius. Moreover, heat, electricity, energy and water demands were successfully decreased by careful design and monitoring systems (Table 2.6).

	Monitored reduction	Target reduction
Space heating	88% (73%)	90%
Hot water	57% (44%)	33%
Electricity	25%	33%
Mains water	50%	33%
Fossil fuel mileage	65%	50%

Table 2.6 Comparisons between BedZED and the UK national average and new homes built according to the 2000 Building Regulations (in brackets). (Source: Lazarus 2003)

2.4.2 Asia

In addition to Asian countries' strong economic performance at the beginning of 21st century and the huge need for housing in Asia, there was a desire to create sustainable development. In this section, three cases are introduced; two in China and one in the United Arab Emirates.

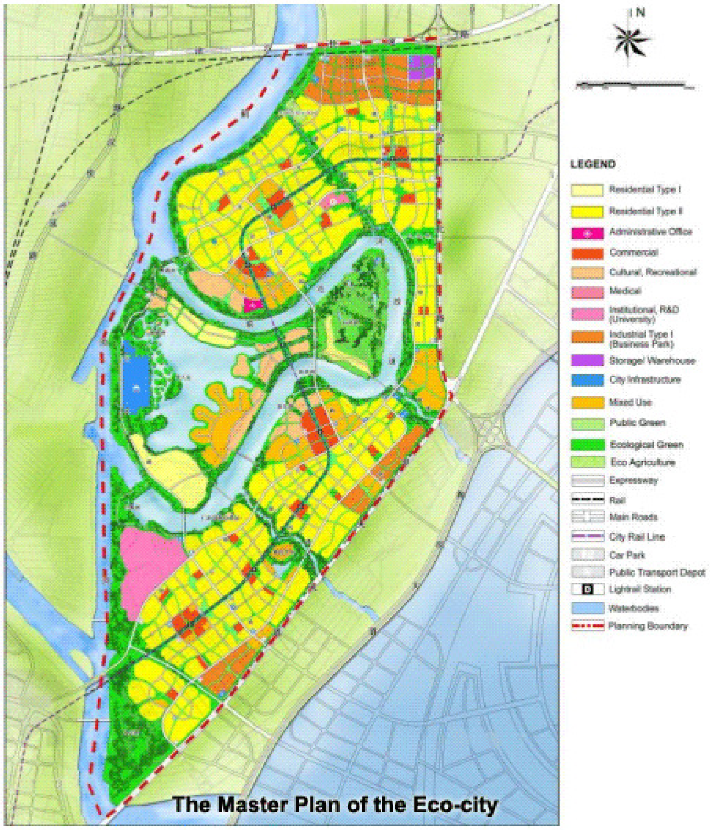


Figure 2.25 The master plan of land use in TianJin Eco-City. (Source: TianJin Eco-City)

In Tianjin, China, Sino-Singapore Tianjin Eco-City is a city plan for 350,000 new inhabitants (Figure 2.25). The goal of the project was to build a liveable, efficient and compact city, which would be developed in an ecologically sound and environmentally sustainable manner. The core of the development was to conserve ecological wetlands and be surrounded by several multi-usage areas, including commercial, cultural and recreational districts. They would be integrated completely and offer a healthy live-work-play living environment, close to the natural core. Moreover, abundant open space along the waterfront would be easy to access for every inhabitant.

Following the master land plan, a comprehensive green transportation system would be set in the eco-city. Moreover, in terms of the economic issues, the government tried to put hotels, businesses and industry in the sub-centre areas in order to shorten commuting distances. This kind of basic eco-cell concept is a typical example of mixed land use (Boon). Like the previous sustainable plans, this project hoped to use renewable energy, recycle its water and waste, build green architecture and green transportation system and be environment friendly. Moreover, social harmony, the conservation of heritage, and economy area planning were as important as environmental issues.

In Chongming, southern China, DongTan Eco-City was another gigantic scale development undertaken by ARUP (Figure 2.26). DongTan Eco-City was conceived as a composition of three villages which had individual characteristics. In order to connect all of them and nearby cities, DongTan was planned as a collection of towns connected by cycle routes and public transport corridors. Furthermore, Chongming's existing local businesses, including farming and fishing, would have significant new opportunities in newly developed places. Additionally, this project had a huge natural environmental area composed of massive wetlands and a reserve for migrating birds (Yan and Girardet 2006).

Figure 2.26 A virtualisation of DongTan Eco-City. (Source: ARUP)

Like China, the United Arab Emirates also has ambitions to invest in a build huge projects. MASDAR was one of these projects which became a reality (Figure 2.27). The ultimate goal of MASDAR was to achieve zero CO2 emissions. Another main goal for MASDAR was to be the first city where all waste can be converted into energy resources. Due to the harsh environment of its dessert location, many advanced technologies and design strategies were applied. The transportation system was one of the priority issues. All vehicles would be prohibited within the city, thus, good connections between nearby cities, approachable transportation systems within the city and unique personal carries were planned for construction. Moreover, narrow streets and shaded walkways were designed to reduce the solar gain and help to decrease the cooling demand of buildings. Secondly, advanced technology played an important role in this project, including transportation, building construction and monitoring. Thirdly, it has been designed so that electricity comes from a solar power station and the majority of building's roofs are covered by solar collectors. Additionally, water comes from storage tanks set into the surrounding areas. In MASDAR, approximately 80% of the water is recycled and reused as many times as possible. Also, MASDAR considered the carbon footprint of the construction process, and the amount of emissions created was offset after completion by the mass planting of trees.

Figure 2.27 A bird's eye view of MASDAR. (Source: Foster + Partners Associate)

2.5 Conclusion

Through a review of the history of sustainable development, its theories, projects and related design strategies, the important points can be concluded as follows.

Sustainability will be the focus of built environment and architectures for succeeding generations.

In the 19th century, sustainability was just a scattered concept employed in some subjects related to ecology and city planning, such as resources recycling in forests (Filho 2000) and the Garden City (Howard 1898). Through the pursuit of economic prosperity and the focus of the technical revolution, comparatively fewer scholars thought about issues concerned with the limitation of our global resources and the potential dangers brought by the mode of development. By the middle of the 20th century, scholars had started to become aware of the pressure from the rapid growth rate of the global population and had observed the changes occurring to the natural and built environment. These changes were not only the easily understandable problems, such as pollutions, but also long-term ones, including Ozone depletion (NASA 2000), rising global temperatures (Macilwain 2000; IPCC 2007; Hassan 2009), rising sea level (IPCC 2008; SLRG 2011), urbanization (UN2004; UN2005; LSE 2008), urban sprawl (Giddings et al. 2005), and the UHI effect (Landsberg 1981; Oke 1973, 1978, 1988, 1999; Santamouris et al. 2001; Streutker 2003; Tran 2006; Gartland 2008). Radhi (2009) agreed that there is a strong relationship between human activities and these changes. In addition to the unstable economic situation, particularly concerning the energy and oil crises of 1973, 1979 and 2005, considerable concerns about the protection of the environment (Sassi 2006; IPCC 2008; Lin 2008) and the replacement of energy had arisen (Daly and Cobb 1989; Max-Neef 1995; Afgan et al. 1998; Afgan and Carvalho 2002; Layard 2005).

On the other hand, through a review of the origins of sustainable development, it is easy to understand the importance and necessity of bringing sustainable strategies into action. Initially, scholars tried to define the concept of "sustainable development" from 1980s (IUCN 1980; Jacobs et al. 1987; WCED 1987; Agenda 21

1992; FCES 1995; ICLEI 1996; DEFRA 2002). The successful definition in the Brundtland Report in 1987 could be seen as a significant step forward for sustainable development. Meanwhile, the concept of sustainability has emerged in theories involved in building and the urban environment. O.Yanitsky (1987) proposed the concept of the "eco-polis" to illustrate the right way to develop urban areas in accordance with the idea of sustainable development. Since then, a series of terms related to sustainable development in urban areas have been coined, including sustainable city, eco-city, and green city (Downton 2009).

In short, through the developmental history of thinking concerning sustainability, it is clear to understand why people need it and how important it will be for future generations.

The scope of research involved in sustainable design is being continually extended and its focus is moving toward larger scale projects and the existing environment.

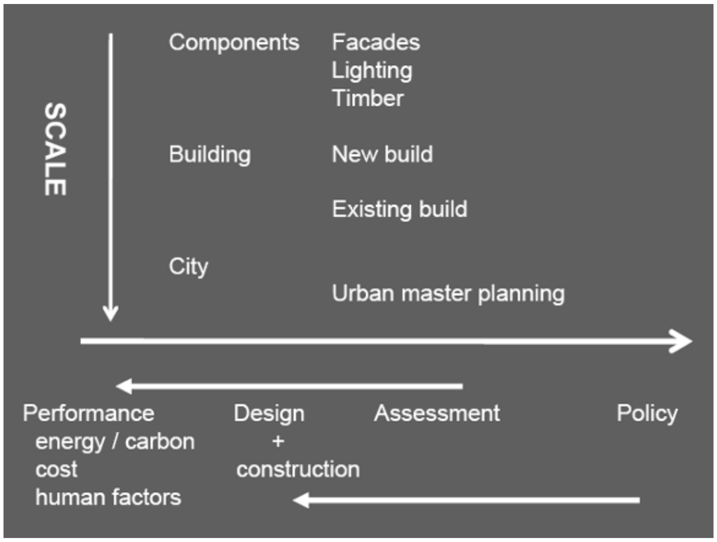


Figure 2.28 The frame work of built environment research. (Source: Jones 2009)

By reviewing the history of sustainable development, we are able to understand that an updated comprehensive plan for sustainable development should consider many perspectives, from components of buildings to a whole city, and from energy performance assessment to policy (Jones 2009) (Figure 2.28). Additionally, because the majority of CO2 emissions are created by the existing environment, more researchers are moving their focus from new building projects to how to adapt existing ones. Also, they are trying to increase their influence over the entire process, from construct to the earlier design stage.

Different strategies should be applied depending on different scales and the local background.

Due to the limited pages, this chapter can not present all design strategies. Therefore, based on the framework EEWH-UD (Lin et al. 2008), some essential strategies are summarized by the author through the review of the practical projects, assessment systems and critical theories mentions before (Table 2.7).

First of all, at the urban-macro level, density, urban fabrication, the walkability of a city, better mixed land use, smart transportation systems, and practical and efficient energy system are some of important issues. Aside from these issues, multi-centre urban planning can be seen in many master theories.

Secondly, for the urban-micro level, types and forms of blocks and buildings are usually discussed. The position, orientation, structure, street pavement and the relationship among buildings all will affect the energy needs of buildings. Moreover, layouts with abundant inclusion of nature, including green walls and green roofs, are believed to be highly effective strategies.

Thirdly, at building scale, façade materials, glazing ratio, and shading device not only affect the energy needs of buildings themselves, but also impact upon the microclimate. It may be worth mentioning, in passing, that good design of the architectures has the effect of changing and encouraging a better lifestyle (Edward and Turrent 2000).

Lastly, although the summary of design and planning strategies indicates a potential way forward for building sustainable environments, it is still necessary to respect different local characteristics. The Asian cities would receive positive effects through applying some of the same strategies as European cities, but the influence degree will be different. In other words, depending on different local weather patterns and geometric backgrounds, the strategies should be modified.

Scale	Issues	Strategies
Urban - Macro	Respect of ecological environment	1. Preserve wetland, forest, rivers, etc. 2. Maintain biodiversity and local features of nature 3. Build green and blue belts
	The balance between nature and human settlement	1. Appropriate master urban planning, such as concentric circle master plan of Garden City or Finger Plan of Copenhagen 2. Consider the land usage for long-term floodplains, agriculture, industry, etc. 3. Use brown areas first
	Polycentric development plan	1. Multi-centre plan for metropolis 2. Multi-centre plan within a city 3. Mixed land use in urban areas
	Compact master plan	1. Increasing density of urban areas 2. Offer low-rise, high-density housing
	Mitigation for UHI	1. Consider wind field / Increase outdoor ventilation 2. Abundant vegetation and planting 3. Decrease dust density in urban areas 4. Increase evaporation and decrease surface radiation by building lakes, lawns or open spaces 5. Increasing over-shading
	Transportation	1. Connect with nearby cities 2. Accessible public transportation system 3. Reverse traditional transportation hierarchy
	Efficient and better public infrastructure	1. Efficient systems for electricity, gas and water 2. Renewable energy development 3. Potable water infrastructure
	Decrease pollution	Avoid air, noise, water, soil and related pollutions
Urban - Micro	Networks between neighbourhoods	1. Compose spaces for work, living and leisure within walkable distances 2. Socially mixed areas 3. Mixed building use in blocks
	Microclimate responsive design	1. Leave space and shape paths for wind 2. Over shading from manmade obstacles or planting 3. “Cool” street pavement 4. Introduce parks, gardens, and small green areas between buildings
	Eco-community design	1. Community semi-treated waste water system 2. Biodiversity 3. District electricity and heating and cooling supply
	Neighbourhood pattern and design	1. Appropriate building forms and arrangement for energy saving 2. Diversity of building types
Building	Site design	1. Appropriate site selection, such as using brownfield areas 2. Design for the best use of passive solar gain 3. Appropriate orientation for natural ventilation

	Material and construction	1. Building reuse 2. Reduce CO2 footprint of materials 3. Building life cycle management 4. Appropriate U-Value design for walls and roofs, particularly for buildings in cold weather zones
	Lighting and shading	1. Appropriate glazing ratio 2. Green roofs, green walls and other planting strategies 3. Lighting accessibility 4. Abundant shading, particular for buildings in hot weather zones
	Water efficiency	1. Recycling system 2. Reduce water usage
	Waste control	1. Construction waste management 2. Reuse waste and materials
	Optimize energy performance	1. Renewable energy application 2. Highly efficient system, particular for HVAC system
	Interior design	1. Avoid over-design for lighting 2. Avoid over-decoration 3. Design for healthy environment, including materials, chemical and pollutant free, thermal comfort, daylight and acoustic environment.

Table 2.7 List of most well-known design strategies for sustainable built environment and architectures. (Source: Lin et al. 2008; Re-organized by the author)

Chapter 3

SUSTAINABLE DEVELOPMENT IN TAIWAN

AN INTRODUCTION TO THE BACKGROUND OF THE SUBJECT OF THIS RESEARCH, TAIWAN AND ITS CAPITAL, TAIPEI, AND A PRESENTATION OF PREVIOUS RESEARCH AND ACTIONS INVOLVED IN SUSTAINABLE DEVELOPMENT IN TAIWAN

SUSTAINABLE DEVELOPMENT IN TAIWAN

3.1 Introduction

This chapter aims to understand the advantages and disadvantages of architectures and urban environment in Taiwan through the review of the background of Taiwan and researches related to sustainable development and official regulations, which is divided into several parts and is composed of an introduction, the background of Taiwan, the latest research involved in sustainable development in Taiwan, sustainable actions by the local government, and a conclusion. In the background section, Taiwan's geographical natural attributes, and social and economic development, are presented separately. After that, the built environment of Taiwan is discussed. In the next section, summaries of previous research related to sustainable development in Taiwan are demonstrated. Lastly, the context illustrating the ambitions of the local government and related public systems are explored.

3.2 Background of Taiwan

Sustainable development has been a trend for the majority of countries around the world. Most developed countries located in the temperate zone have produced abundant planning and design strategies, such as the U.K., Germany and the U.S. However, Taiwan is one of the developed countries that has made comparatively slow steps towards sustainability. Furthermore, due to its production orientated economy, Taiwan has an extremely high CO2 emissions density. Wang et al. (2012) concluded that an area 42 times the size of Taiwan is needed to satisfy its enormous consumption in 2007, while the ecological deficit equals 20 times that of the overall land area. Thus, a comprehensive and appropriate package of sustainable strategies is eagerly needed for Taiwan.

3.2.1 Geographic characteristics

Taiwan, located 180 kilometres off the south eastern coast of Mainland China, is a 36,008 km^2 island that is 395 km long and 144 km wide (Government Information Office, GIO 2011). The Tropic of Cancer crosses the middle of the land mass, which means the island is integrated with two kinds of hot and wet weather styles, tropical and sub-tropical (Figure 3.1). Furthermore, because Taiwan is between the Yangtze Plate and Okinawa Plate, it naturally has complicated geological characteristics (ibid.). Due to the orogeny between these plates, the "Sweet potato" shape island has a row of mountains in the middle from the north to the south and its highest mountain, Yushan or Jade Mountain, ranks the 4th highest island peak in the world (Figure 3.2) (ibid.). A massive belt of mountains and hills occupy two-thirds of the total land area. In other words, plateaus, plains and basins only occupy one third of the land and are scattered across the island (ibid.). Fortunately, these places are mostly located in the western part of the island, which lends them the protection of the mountains against the fierce Pacific Ocean typhoons from the east. However, in recent decades, unstable changes to the climate and several unpredictable natural disasters, such as earthquakes, typhoons and flooding, have begun to happen more frequently (CWB 2010).

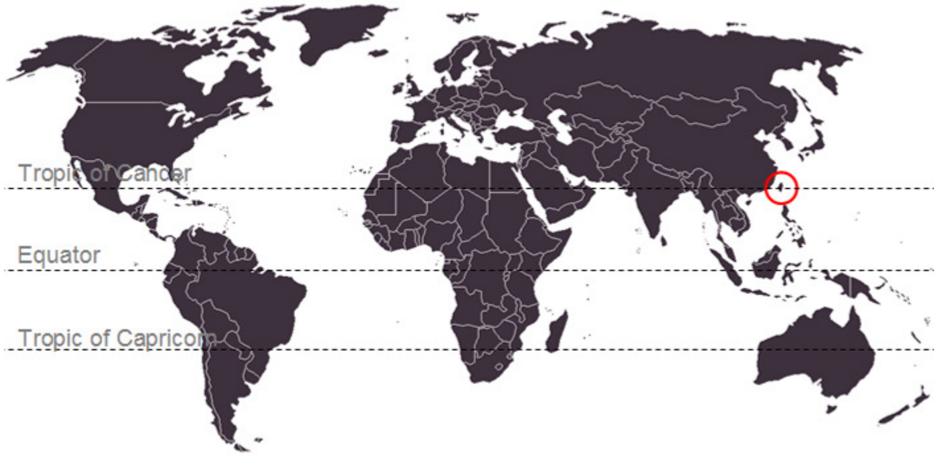


Figure 3.1 Taiwan's location on the world map.

Figure 3.2 Map of Taiwan. (Source: RB-DESKKART and Medienservice 2011)

The complex tectonic situation not only limits the land area available for living, but also affects the accessibility of natural resources. Water shortage is one of the most serious problems. The relatively short length of rivers and steep slopes of the riverbeds in Taiwan mean that work to keep and collect water is extremely difficult. Moreover, the huge volumes of rainfall rushing into the river makes the water level rise fast and flood frequently. In short, the abundant precipitation does not bring a comfortable life for Taiwanese (Figure 3.3). Instead, life is disturbed by the shortage of water and serious flooding problems. Considering the climate changes, the director of The Climate Change Research Centre in Taiwan, Liu (2009), predicted a rise by one degree Celsius would increase precipitation in Taiwan by 1.4 times. The researcher also mentioned that it is highly likely that we will observe a rise in rainfall of 2.8 to 5.6 times by the end of the 21st century, if the ecological environment does not change. Moreover, Taiwan has been listed as one of the most endangered islands by the UN (2009) in terms of threats from rising sea levels.

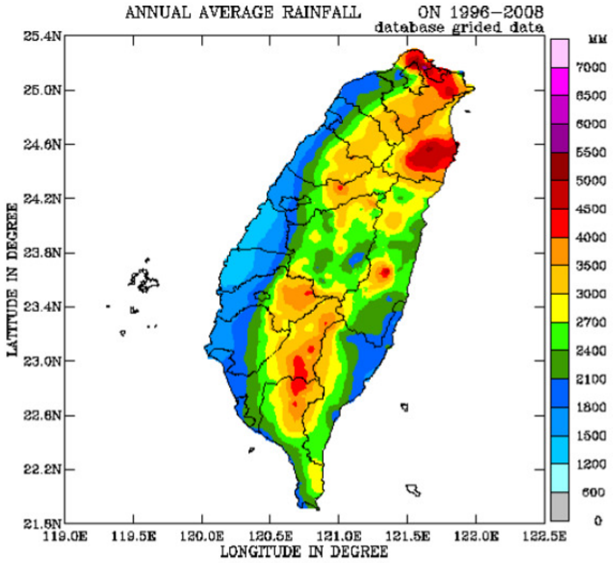


Figure 3.3 Map showing the distribution of annual average rainfall in Taiwan during 1996 to 2008. (Source: Hung 2009)

According to Köppen's climate classification, Taiwan's major climate types are humid subtropical weather (Cfa) and tropical monsoon climate (Am). Hot and wet are significant characteristics for both weather styles in Taiwan. Based on data from the Central Weather Bureau (2010), the mean annual temperature range for the last decade in Taiwan was between 20 and 30 degrees Celsius (Figure 3.4). From May to September, the daily temperature can reach 27 °C to 35 °C. On the contrary, the winter time is much shorter than nearby countries because the cold air from mainland China would be mitigated by the surrounding sea. Lin (2009a) argued that the climatic situation in Taiwan does not fall into the normal comfort zone for citizens because the most comfortable temperature for humans wearing thin shirts and pants is between 23 to 28 degrees Celsius with a humidity of between 36% and 54%. The temperature in Taiwan usually lies in this range, however the humidity in Taiwan never falls below 70% throughout the year. In short, both of these climate characteristics present challenges for sustainable design and planning in Taiwan. Additionally, Taiwan's low latitude exposes the land to strong sunlight for long hours. According to the national statistics, the average radiation in Taiwan is approximately 3.0 kW/(m^2.day); and 2.4 kW/(m^2.day) for Taipei City (Lin 2009a).

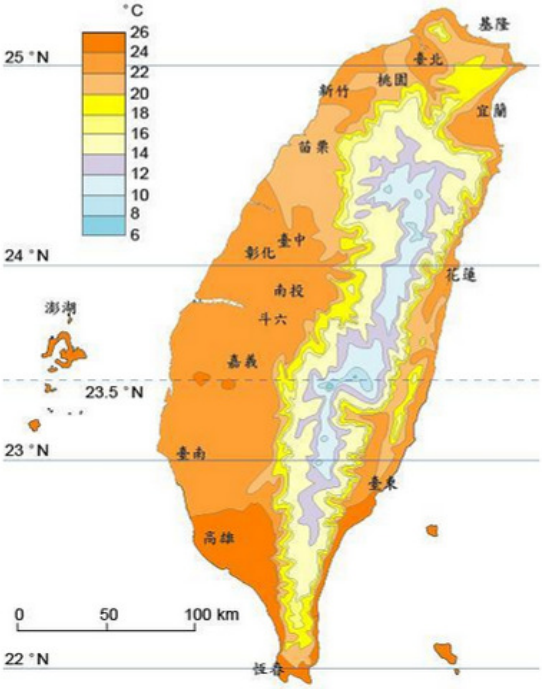


Figure 3.4 Distribution of annual average temperature in Taiwan. (Source: Central Weather Bureau 2010)

On the other hand, the Central Weather Bureau (2010) announced a statistical report related to the history of temperature and precipitation changes during the past century (Figure 3.5). Due to the economy-orientated development policy of the last century which added vast amounts to global CO2 levels, Taiwan has experienced serious climate warming problems. The average temperatures has risen 1.3 degrees Celsius which is much higher than the world average of 0.6°C. Moreover, this rising trend is also higher than nearby countries, such as Japan, Philippine and China. This unfamiliar change has not only been observed in urban areas, but also can be seen in mountain territories or in poor underdeveloped areas. It proves that the change is not a regional problem or a problem related to the heat island effect in urban areas, but one that affects the whole ecological system around the island. In terms of precipitation, no obvious increase has been noted, but more comparatively unstable changes have occurred. Most significantly, there were four major dips in the quantity of precipitation which occurred approximately once per decade from the 1960s. In short, since the 1950s, the climate in Taiwan has become more and more unpredictable.

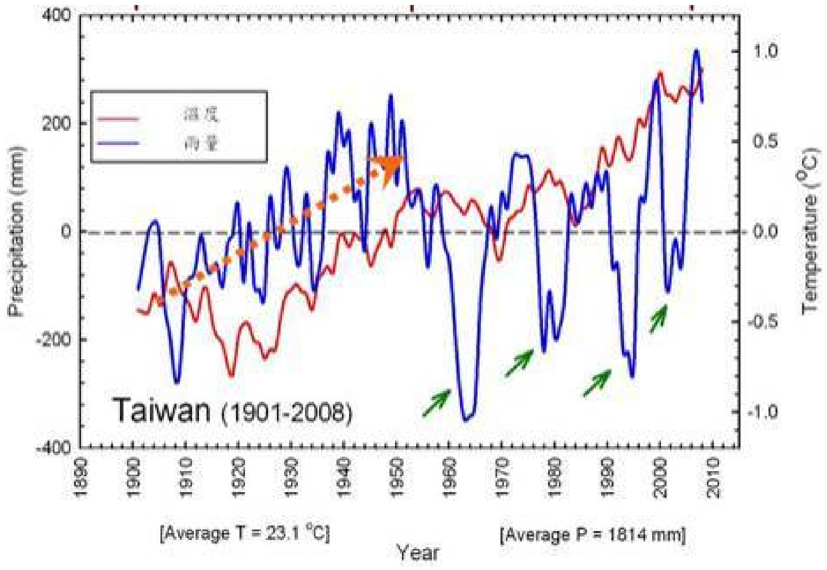


Figure 3.5 Changes in temperatures and precipitation in Taiwan during the past 100 years (Red Line: Temperatures; Blue Line: Precipitation). (Source: Central Weather Bureau 2010)

3.2.2 Social and economical development

Sustainable development covers three dimensions, social, economic and ecological. Thus, it is necessary to examine all three aspects of our subject, Taiwan, instead of only focusing on ecology. Taiwan is a highly developed place, which was officially listed in 2009 as one of the most developed countries. In 2010, its human development index (HDI) ranked No. 13 in the world, which was close to Canada (8), Germany (10), Japan (11) and France (15) (Directorate General of Budget, Accounting and Statistics, DGBAS 2010). In this section, Taiwan's background and economical development are introduced to indicate the importance of its cultural value and strong economic power.

First of all, Taiwan has been through extremely hard times in its quest to become an independent country, yet it is still not recognised as such by the United Nations even now. From the 12th century, China had set up public organizations to dominate the island for several valuable agricultural products, but the relationship was not strong and was frequently interrupted by pirates. During the colonial period of the Western World, Portugal was the first country to reach Taiwan for rice and opium exchange. In 1624, China made an agreement to transfer the control of Taiwan to the Netherlands. Since that moment, the consciousness of a national identity started to grow in the heart of the people living on the island. Due to the high economic value of Taiwan's agriculture products, the Dutch increased the force of their colonial domination and fought with the Spanish. After expelling the Spaniards, the Dutch built the first official public system of government in Taiwan and regarded Taiwan as their base of business operations in Far East Asia. However, the period of European settlement lasted no longer than half a century and was terminated by the notorious pirate, Zheng Chenggong, from the Taiwan Strait. Later, China's Qing Dynasty overthrew Zheng and began its own 200-year-domination of Taiwan. Since the late 17th century, Chinese culture has deeply permeated Taiwan as immigrants from China have become the majority of Taiwan's population. However, the ruling power in Taiwan was overthrown once again, this time by the Japanese, after the signing of the Treaty of Shimonoseki. The 50-year-era under the rule of the Japanese Empire became the most influential period for the modernization of Taiwan, influencing education, public facilities, construction, city planning and political affairs. After W.W.II, the Japanese government gave Taiwan back to the Republic of China (R.O.C). Due to changes in the political situation in mainland China, the R.O.C political group was driven out by the People's Republic of China (P.R.C), so the R.O.C retreated to Taiwan and several islands nearby it. In 1971, the United Nations forced Taiwan to give up its membership and gave the place to China. Fortunately, the harsh political situation did not hinder the development of Taiwan. On the contrary, Taiwan is now not only an example for democracy in Asia, but also a representative of economical development around the world.

Secondly, because most of the Taiwanese population have emigrated from mainland China, Mandarin was officially recognized as the national language by the R.O.C.. Additionally, due to the background of the island's different ancestral groups, more than 70% of the population can speak Taiwanese; 15% can speak Hakka; whilst a small percentage can speak native aboriginal languages. Furthermore, Japanese is one of the popular languages for elder generations in Taiwan, but its popularity has declined with younger generations. In short, Taiwan integrates various different cultures from both the East and West, and this composite character is reflected in other areas, including its urban planning and the architectures.

Thirdly, although political conflicts between mainland China and Taiwan exist, they did not affect the economical development of this tiny island. During the Japanese colonial period, Taiwan went through a rapid industrialization process, which has been called the "Taiwan Economic Miracle". In 1961, the GDP per capita of Taiwan was 153 US Dollars; in 2011, it had grown to over 20,000 USD. Ranking No.16 in the global economy in 2011, Taiwan could be seen as an example of a successful transformation from an agriculture orientated economy to an industrial, high-tech and service orientated economy. Now, Taiwan is famous for its electrical products around the world, such as laptops and products related to integrated circuits (IC). However, due to its economic development, Taiwan should be held responsible for a small part of global CO2 emissions (Table 3.1). Compared with other countries of a similar scale, Taiwan obviously produces much more CO2. This is illustrated by its No.2 rank in Asia, excluding the Middle East, for CO2 emissions per capita in 2005.

Country	CO2 emissions (million ton) / World ranking	World percentage (%)	CO2 emissions per capita (ton) / World ranking
China	7,219.2 (1)	19.12%	5.5（72）
US	6,963.8 (2)	18.44%	23.5（7）
EU	5,047.7 (3)	13.37%	10.3（39）
Russian	1,960.0 (4)	5.19%	13.7（18）
India	1,852.9 (5)	4.91%	1.7（120）
Japan	1,342.7 (6)	3.56%	10.5（37）
Brazil	1,014.1 (7)	2.69%	5.4（74）
Germany	977.4 (8)	2.59%	11.9（25）
Canada	731.6 (9)	1.94%	22.6（8）
UK	639.8 (10)	1.69%	10.6（36）
Mexico	629.9 (11)	1.67%	6.1（65）
Iran	566.3 (13)	1.50%	8.2（54）
Italy	565.7 (14)	1.50%	9.7（45）
France	550.3 (15)	1.46%	9.0（47）
South Korea	548.7 (16)	1.45%	11.4（31）
Spain	438.7 (19)	1.16%	10.1（41）
Saudi Arab	374.3 (23)	0.99%	16.2（13）
Thailand	351.3 (24)	0.93%	5.6（71）
Taiwan	**271.2 (27)**	**0.72%**	**11.8（26）**

Table 3.1 2005 national CO2 emissions, their percentages in the world, and CO2 emissions per capita for important countries. (Data source: World Resources Institute, WRI 2007)

3.2.3 Built environment development

People's consciousness of sustainable development does not only come from their concerns about ecological and environment dangers, but also from economic pressures. Like the majority of developed countries around the world, the energy and oil crises have been seriously detrimental to the foundations of Taiwan's economy due to the island's typical need for imported energy. Almost 99% of energy was imported from other countries in 2008, including coal, oil, natural gas and uranium (Hwang and Chang 2011). According to 2008 national statistics, they have different usage proportions; 32.4% for coal; 49.5% for oil; 9.42% for natural gas; 8.3% for nuclear power and 0.29% for hydropower (Figure 3.6). Obviously, oil plays a very important role and the renewable energy, hydropower, solar and wind power in total, occupy less than 1%.

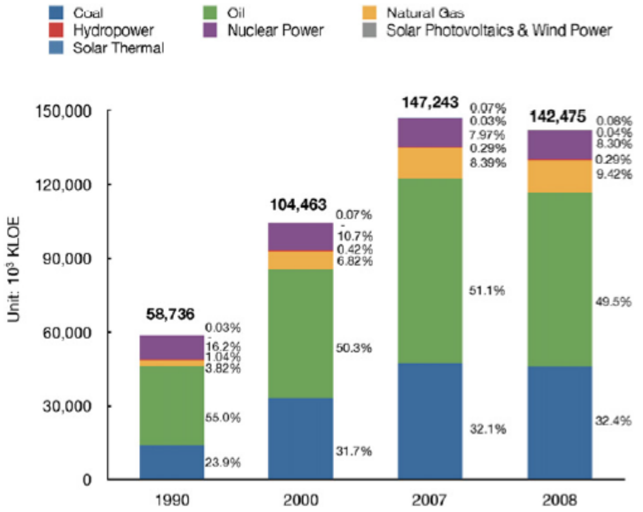


Figure 3.6 The proportion of different energy usage in Taiwan between 1990 and 2008. (Source: Hwang and Chang 2011)

On the other hand, economic activities have created serious problems in urban areas, such as air, noise, waste and water pollution. Furthermore, Taiwan's economic prosperity since the 1920s has generated rapid population growth. The population in 2001 is seven times that of 1905. Now, there are 23 million people living on the 36,008 km^2 island (Figure 3.7). The density of the country equals 668 people per sq km and ranks No. 11 in the world. However, the majority of Taiwan's land mass is mountainous. Thus, the real density of cities is much higher than the number depicts. For instance, the density of one county in New Taipei City, Yonghe, has 41,262 people per km² (DGBAS 2011).

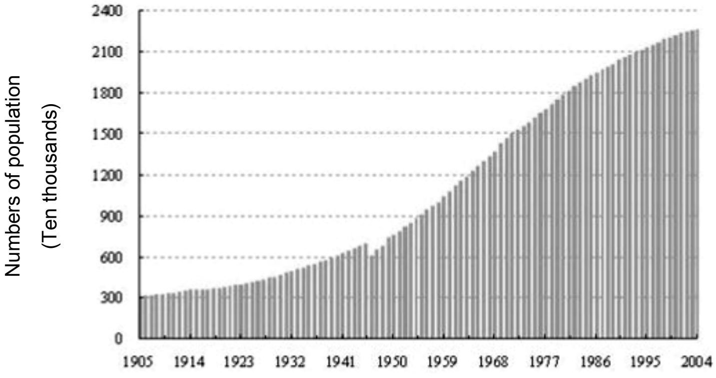


Figure 3.7 The population of Taiwan during the past century. (Source: Urban and Housing Development Department UHDD 2008)

High density development is not the only phenomenon can be observed in the Taiwan cities. Highly urbanization is another. In 2011, more than 80% of Taiwanese lived in cities and the number is growing (Figure 3.8). Although the total population is predicted to decline after 2015 due to the lowest newborn babies rate around the world, social statistics indicate that more and more Taiwanese intend to move to the city for the convenient and comfortable lives (Urban and Housing Development Department, UHDD 2008).

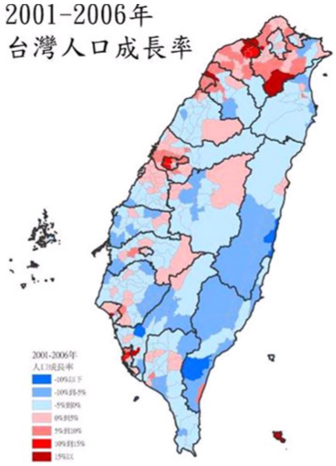


Figure 3.8 Population changes in different areas of Taiwan between 2001 and 2006 (Red means positive rate; Blue means negative rate). (Source: UHDDC 2008)

The pressures of high density cities and urbanization bring lots of problems for the built environment in urban areas. Akin to other big cities in the world, massive CO2 emissions, the urban heat island effect (UHI), heavy traffic and costly loans for transportation, and unsustainable architecture, are some of the problems easily found in Taiwanese cites. In the following paragraphs, some important issues are discussed respectively, including CO2 emissions from architecture, UHI effect, transportation, and land usage proportions.

First of all, CO2 emissions produced by businesses related to architecture dominate 28.8% of the national total emissions (Lin 2009a). The biggest portion in the construction industry is related to residential buildings, which dominates 11.88%. Next are materials, business usage and transportation, which dominate 9.31%, 5.94% and 1.49% respectively (Lin 2011). Although Taiwan does not belong to any important international official institutions, the local government has sensed the importance of CO2 emissions and aims to follow the Kyoto Protocol and set up several strategies and measures to achieve it.

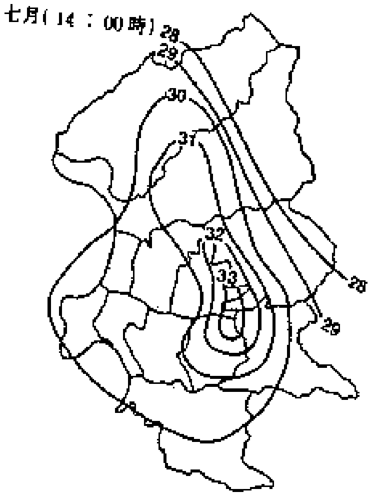


Figure 3.9 The distribution of temperature (℃) in Taipei at 2pm in July. (Source: Lin 2009a)

Secondly, research has been underway into the UHI effect for cities in Taiwan since the 1980s, although this was begun much later than in most developed countries. According to research by Lin (2009a), urban areas in Taiwan had an obvious UHI effect with temperatures measuring 2.7 to 4.5 degrees Celsius higher than suburban areas (Figure 3.9). In Taipei, if the temperature rises by one degree, the cooling systems will consume an extra 6% of electricity. Lin (2009a) therefore concluded that, due to the seriousness of the UHI effect, the cooling load of buildings in central Taipei City during the summer time is increased by one quarter over those in surrounding areas.

Thirdly, transportation is one of the main elements with a strong relationship to the increase of CO2 emissions (Lu 2007). From 1998 to 2007, the number of automobiles in Taiwan increased by approximately 24% from 5.37 million to 6.68 million (Urban and Housing Development Department 2008). In addition to vehicles, for most Taiwanese motorcycles are another important mode of transport due to the limited space and high population density. The number of motorcycles per 1,000 people in 2007 was 618.8, which is two times as many as automobiles. Although the percentage increase in numbers of motorcycles is not as much as automobiles, an almost 20% rise from 10.5 million to 14.1 million (an increase of 3.6 million), that is still more than three times the increase in numbers of automobiles for the same period (ibid.). In short, in addition to passenger vehicles, motorcycles for personal usage have also played a significant role in negative environmental effects. What is more, Taiwan's government has tried to reduce traffic pressure in cities along the west coast of the island and has proposed several gigantic transportation plans, namely a Metropolitan Rapid Transit System, a Light Rail Rapid Transit System and a new route bus system. However, owing to the global economic recession, most parts of these plans have been postponed and replaced by a policy to encourage and educate citizens in how to use the existing public transportation systems (The Executive Yuan 2010).

Fourthly, land usage is another issue involved in controlling the size of a city and the strength of the urbanization. In Taiwan, all land can be categorized into two different groups, non-urban planned districts (Figure 3.10) and urban planned districts (Figure 3.11). There are eight land categories for urban planned districts, and nine for the non-urban. The former has many limitations for development, which have been set for managing the development in urban areas specifically. Due to the capital city of Taipei's high controllability, it is possible to list all types of land in its urban planned districts (Figure 3.12).

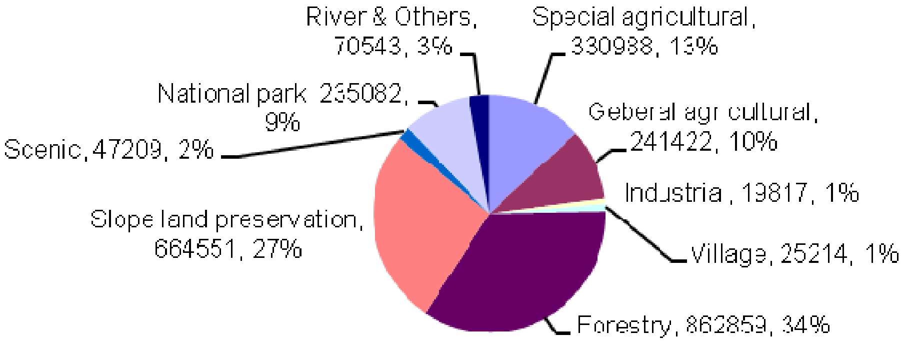


Figure 3.10 Land use zoning in non-urban planned districts of Taiwan (Ha). (Data source: UHDD 2008)

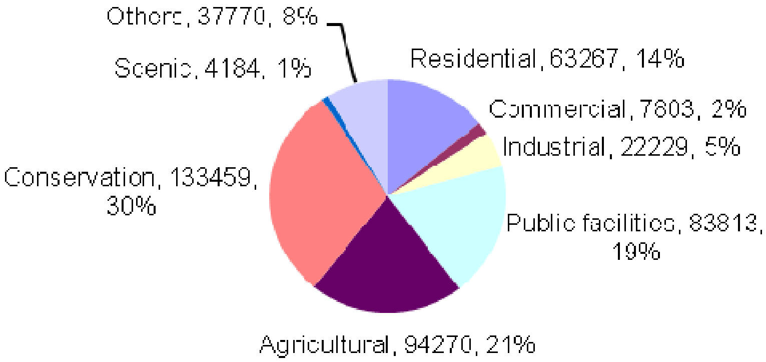


Figure 3.11 Land use zoning in urban planned districts of Taiwan (Ha). (Data source: UHDD 2008)

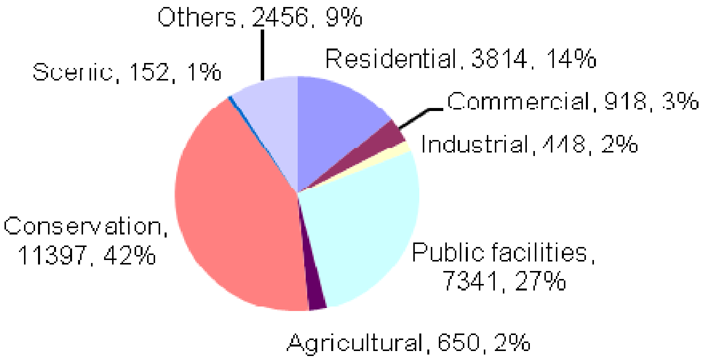


Figure 3.12 Land use zoning in urban planned districts of Taipei (Ha). (Data source: UHDD 2008)

3.3 Previous research of Taiwan's involvement in sustainability

As mentioned above, Taiwan has a hot and humid weather style, and this is the most difficult type of weather to deal with (Lin 2003; Lin et al. 2010). The problem is that it is not only hot, but also is a composition of moisture and heat. Due to this phenomenon, some scholars in Taiwan have undertaken related research to understand the energy performance of buildings. However, while considerable attention has been paid in the past to research issues related to sustainable development, the creation of literature on issues of practical sustainable strategies for design and planning has only been attempted by a small group of researchers. Even so, this section still explores some updated researches in the following three areas; research involved in sustainable strategies, research involved in assessment systems, and research involved in the practical measurement of energy use.

3.3.1 Research involved in sustainable strategies

Before discussing the research related to sustainable strategies in Taiwan, it is necessary to understand the overall picture. Research in Taiwan frequently focuses on the renewable energy technology and the assessment systems for buildings. Researches into new technologies are abundant, such as solar panels, LED lights, and efficiency for machines, which are usually supported by green industries. On the other hand, research into sustainable building assessment and indicators help the government set up public regulations for green buildings and eco-communities. However, limited research is undertaken in order to understand the energy performance of a single building or a city and the related strategies. Additionally, due to the ignorance about sustainable development at urban scale, research involved in urban design and planning strategies can only be found scattered across different topics.

First of all, for building type selection, Wang et al. (2012) asserted both for urban and rural areas in Taiwan, “collective housing” or “cohousing” was a good choice to reduce land and energy use. A dense development not only solves the limited land accessibility problem, but also meets the living style of Taiwanese. Secondly, Lin (2003) took a prototype to compare the different solar gain figures for its four main façades. If we take the general solar radiation of the south façade during May to October in Taiwan as 1.00, the east, west, north, and horizontal flat (roof) facades would be 1.24, 1.24, 0.81, and 2,78 respectively (Lin 2003). In other words, it is necessary to approach the façade design carefully to avoid getting too much heat from the east, west and from the roof. Moreover, Lin (2003) concluded that once the glazing ratio increases by 1% in Kaohsiung, the cooling demand will also rise by 1%. Thirdly, although insulation may not be considered as important as by architects in cold weather zones, it cannot be ignorable. The present green building regulations in Taiwan state that the U-Value of roofs should be under 1.0 W/m^2.k for both residential houses and office buildings (Construction and Planning, Agency Ministry of the Interior, CPAMI 2012). Furthermore, for large volume buildings, e.g. assembly and commercial buildings, the U-Value of the façades cannot exceed 3.5 W/m^2.k. Fourthly, shading is another important issue for buildings in hot weather zones. Lin (2003) claimed that a normal building with appropriate shading devices can decrease energy demand by 6 to 18% in Taipei. Lastly, Lin (2009a) compared several important variables for buildings and concluded that glazing ratio, shading, and orientation are the most important ones for buildings in Taiwan.

3.3.2 Research involved in assessment systems

In 1999, Taiwan brought in advanced evaluation systems from leading countries as references for green building design (Lin 2009a). The concept and framework of the present green building certification system in Taiwan is known as EEWH (renamed EEWH-BC in 2010). It originated from LEED (Leadership in Energy and Environmental Design Green Building Rating System), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), and HQE (High Quality Environmental standard) (Lin et al. 2008). The term EEWH is an abbreviation of Ecology, Energy saving, Waste reduction and Health. EEWH contains nine indicators in four main categories, which are water soil content (infiltration and retention), energy savings (for the building envelope, lighting and HVAC), CO2 emissions reduction, construction waste reduction, water conservation, garbage and sewage improvements, biodiversity and indoor environmental quality.

In 2003, the national government made the decision to extend the scope of EEWH from buildings to urban scale in order to help transform existing and newly built projects in urban areas into sustainable ones. The Architecture and Building Research Institute considered the framework of EEWH and the existing eco-community evaluation systems carried out in Europe, America and Japan and then drafted EEWH-UD in 2008, followed by the first edition of EEWH-EC (EEWH Eco-Community) which was officially announced in 2011 (Chen et al. 2010). Moreover, the government plans to issue EEWH-GF (Green Factory), EEWH-IU (Intelligence Upgrade), EEWH-RN (Renovation), and EEWH-SH (Smart House) in the near future (Architecture and Building Research Institute , ABRI 2010).

Next, using questionnaire and AHP methods, Chang et al. (2007) reassessed the indicators of GBTool 2005, which was developed by the International Initiative for a Sustainable Built Environment (iiSBE) in 1996. The context of GBTool 2005 was divided into four levels; goals, issues, categories, and criteria. All indicators were put into the questionnaire and responded to by academic and professionals, government, and architects in Taiwan. The results presented four key issues which are more important than others: environmental loadings, energy and resource consumption, indoor environmental quality, and site selection / project planning and development. Also, the results clearly showed the disagreement and the gap between thinking and doing for the professionals in Taiwan.

Next, Lee and Huang (2007) took the “Database of Taipei Sustainability indicators in 2004” as their testing target and concluded that the development of Taipei is on the right course toward sustainability. But, unlike the quality control of GBTool 2005, the indicators for Taipei are designed for political convenience, based on quantity, and judge the performance of a city from an incomprehensive perspective.

Moreover, Huang et al. (2009) employed a semi-quantitative systematic modelling tool, sensitivity model (SM), to test the sustainable development indicators for Taiwan (SDI for Taiwan). They concluded that the natural environment in urban area is one of the most critical components and that urban economic production plays a highly active role in affecting sustainable development in Taiwan.

In short, the research related to the sustainable development assessment systems in Taiwan is abundant and successfully helps indicate the potential path for sustainable development.

3.3.3 Research involved in practical environment

In Taiwan, analyzing the national historic statistical data and undertaking practical measurement and investigation are the most popular methods to understand the energy performance of buildings. For both methods, electricity usage is the most widely acknowledged standard for calculating and judging the energy performance of a city in Taiwan.

Firstly, for residential houses, Ku (2003a) calculated the energy usage by taking measurements and distributing a questionnaire. Focusing on the composition of lighting, air conditioners, and main electronic machines, the author concluded that there were different usage types for apartments and individual houses. Furthermore, the author calculated that the average usage of electricity for residential buildings in Taiwan is 36.29 kWh/ m^2/yr.

Secondly, in order to offer useful design strategies, Ku (2003b) compared the impact of different building components by multiple objective programming, including window size, materials, orientation, shading, ventilation, and lighting. However, due to the small number of experimental cases, the result could not be objective principals or references.

Thirdly, for business districts, Chen (2006) selected two of Taiwan's cities, Taipei and Tainan, to compare the intensity of land use with annual electricity consumption. The comparison proved that the highest density of electricity usage would increase with the strongest business usage. Moreover, the model of calculation employed in the research was believed to be suitable for further prediction for both business and residential districts. The conclusions were tested again for Taichung City (Lai 2007) and resulted in a similar conclusion.

Fourthly, Chen (2006) measured residential buildings in 23 blocks, spread across seven different districts in Taipei. He found that the general annual electricity usage of residential houses in mixed land use blocks in Taipei, the capital of Taiwan, is 58.32 kWh/m^2/yr. Additionally, the usage of modern residential communities is slightly higher than that of traditional ones.

Fifthly, the overall average electricity usage of commercial buildings in Taipei is 215.6 kWh/m^2/yr (Kan2009). However, their electricity usage varies depending on their commercial use type, block attribute, and building height. Furthermore, the author proposed that the general height of blocks and the shape and orientation of buildings are much less important than the road width, which has strong relationship with solar gain.

Lastly, according to the methodology classification by Swan and Ugursal (2009), previous research in Taiwan mostly used the top-down method and the bottom-up statistical method (SM). In other words, research using the bottom-up engineering method (EM) is rarely seen.

3.4 Sustainable actions in Taiwan

Political action plays a very important role in sustainable development because it can ensure that principals are followed thoroughly. For example, the local government in Taiwan has tried to replicate and follow the developed countries by setting up green building regulations and undertake related control actions. This section discusses the national goals in Taiwan and the advantages and disadvantages of the political system involved in urban land and building management.

3.4.1 National goals

The second highest political organization in Taiwan, Executive Yuan (行政院), set up Taiwan's "National Council of Sustainable Development" in 1997 to process national affairs related to sustainable development. In 1999, this group directed the National Science Council to create "The Vision of Sustainable Development in Taiwan". One year later, following the footsteps of international institutions, the "21st Century Agenda – National Principals and Strategies for Sustainable

Development of R.O.C." was published. In 2002, the president announced the Basic Environment Act and Sustainable Development Action Plan. Then, 2003 was named as the starting year for sustainable development action. Executive Yuan also produced The Declaration of Sustainable Development and Sustainable Development Indicators for Taiwan (SDI for Taiwan) in sequent years. In 2005, the national plan and its related actions were localized by promoting The Assessment System for Local Sustainable Development (Juan 2010). The history of sustainable development in public departments has a close connection with international policies, but most of them just present public slogans without any solid or practical strategies. Therefore, the assessment systems are taken as the most useful actions for understanding sustainable development in Taiwan.

In 2008, the Taiwanese government implemented the Frameworks for Sustainable Energy Policy – An Energy Saving and Carbon Reduction Action Plan. It proposed that CO2 emissions should return to 2008 levels by 2020, be reduced to 2000 levels by 2025, and consequently be 50% of 2000 levels by 2050 (Figure 3.13) (Hwang and Chang 2010).

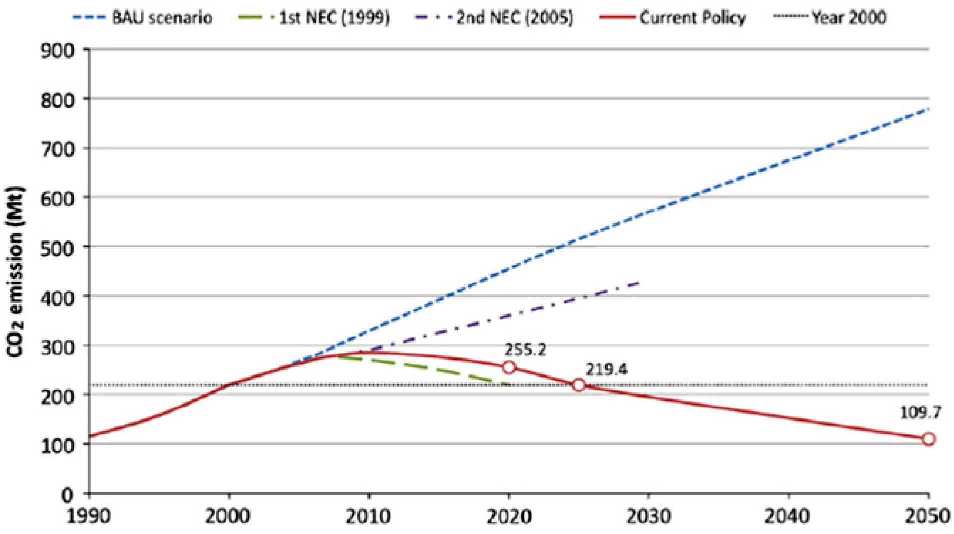


Figure 3.13 Variations of CO2 emissions reduction targets in Taiwan. (Source: Hwang and Chang 2010)

Additionally, in the updated edition, the government proposed a set of goals called Two High Two Low; the goals are high energy usage and production efficiency, high side effect value for energy use, low CO2 emissions and low energy reliance. Behind the goals, Executive Yuan framed six main actions to be undertaken in order to achieve the goals. First of all, the government will rearrange the structure of the energy supply and improve the efficiency of electrical power stations. The government also hopes to increase the proportion of renewable energy to 8% in the near future. In the second action, the government will encourage the development of green industries and plans to enforce companies to decrease at least 30% of their CO2 emissions by 2025. The third action aims to support and encourage citizens to use public transportation and improve the efficiency of new vehicles by 25 % before 2015. The ultimate goal of the fourth action is to shape the low carbon living environment by promoting the construction of green buildings, use recycled / recyclable materials, improve the efficiency of machine operations, and use energy efficient lighting systems. The next action focuses on educating people about footprint reduction, planting and waste recycling. The last action is to draw up fundamental laws and regulations including a CO2 emissions exchange market mechanism, eco-community principals, and a reinforcement of international cooperation and relationships (Council for Economic Planning and Development, CEPD 2008).

3.4.2 The political system in Taiwan related to sustainable development

According to the present public system in Taiwan, the development purpose and intensity of land use are the most important things for controlling urban development. Concerning the urban built environment, these two things are controlled by two plans, namely the Master Plan and the Detailed Plan. Following their principals, urban planners, designers and architects can make specific plans for different areas. The plans for specific areas should contain urban design and building design, which would in turn be examined by the Council of Assessment. The content of the plans specifically involved with the urban environment should follow the Master Plan and the Detailed Plan, while the content specifically related to buildings should follow the Regulations for Architecture (Figure 3.14). Tzeng (2008) asserted that there are no problems in their co-relationship, but the control parameters in the Master Plan and Detailed Plan are insufficient and have no scope for sustainable development.

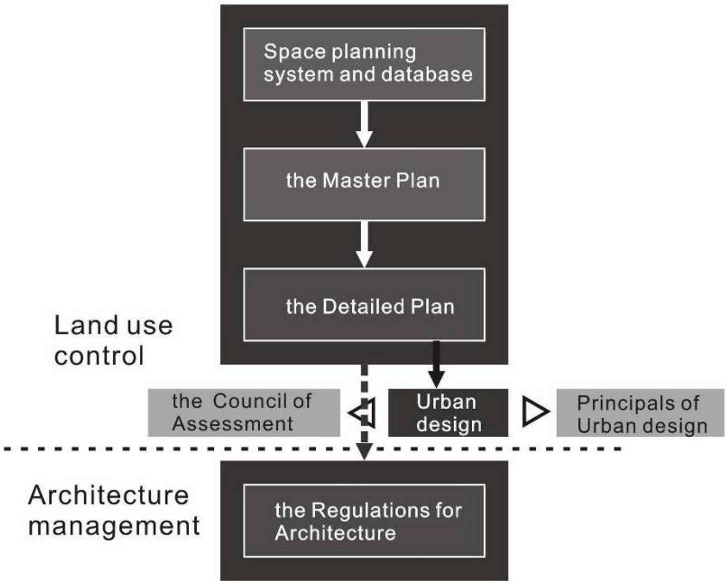


Figure 3.14 Diagram showing land use control and architecture management systems in Taiwan. (Source: Tzeng 2010)

The Master Plan and Detailed Plan control the urban development by utilising the concept of "zones", which examine urban plans by a series of quantitative evaluations, such as the proportion of parking space, building height, open space area, and numbers of vehicular entrances. Without considering the quality of the environment, the sustainable development and comprehensive perspective, these two plans are taken as calculation tools which conflicts with the original purpose of creating them (Tzeng2008). Furthermore, the urban design plan is effective only for specific site bases and can not affect the Master Plan for further use (Figure 3.15). In other words, better ideas or necessary changes for the future are difficult to incorporate into the Master Plan, unless the political system changes. Additionally, Su (2008) believed that the five main reasons which make people ignore urban design in Taiwan could be listed as follows: the laws involved in enforcing urban design are too minor to make people follow them; the Master Plan for cities lacks context involving urban design; the resources and databases for urban design are incomplete; people mistake the assessment system for principals or control tools for urban design; the principals should be responsible for both quantity and quality.

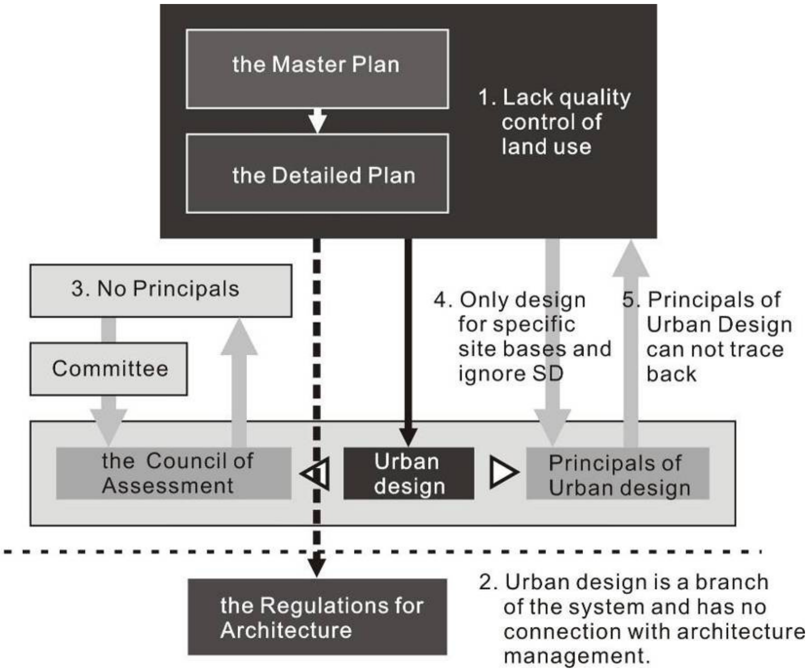


Figure 3.15 The problems of urban design of the public system in Taiwan.
(Source: Tzeng 2010)

3.5 Conclusion

Through the review of sustainable development in Taiwan, some perspectives can be concluded as follows.

Taiwan is an appropriate subject due to its background and emergent dangers.

Taiwan is a small island in south eastern Asia with a special natural environment and a strong economy. The annual average temperature of Taiwan is between 20 °C to 30°C with a 70% average annual humidity. The wet and hot weather style has become the typical impression of Taiwan and remains a challenge as attempts are made to keep the urban environment in the comfort zone. Furthermore, limited natural resources force Taiwan into heavy reliance upon imported energy. Almost

99% of energy in Taiwan is imported from nearby countries, mainly coal and oil. As a result, the situation has stimulated the growth of consciousness about sustainable development. Moreover, the mountainous terrain of the island enforces 80% of its people to group together and live in cities. Therefore, urbanization and urban sprawls are common phenomena for Taiwan. However, the pressure on the urban environment is growing with the convenience brought by urbanization. In short, in order to solve these problems and maintain the living quality in Taiwan, sustainability is definitely the most important issue.

Taiwan lacks the comprehensive fundamental statistical data for different kinds of buildings to allow further researches related to the energy performance of buildings.

Through the review of researches undertaken in Taiwan, it is not difficult to see how the lack of fundamental statistical data for the buildings in cities is hindering researches related to the energy performance of buildings. Data for the proportion of newly built architectures, the construction history of buildings, and the numbers of different kinds of buildings in cities are mostly unavailable. The loss of relates data might have been caused by the complicated political situation. In Taiwan's short history, there have been many different dominating authorities and their intensions to stay on the island were due to economic benefits or their political situation. In other words, the changeable social situation has made the records related to buildings fragmented. Now, in order to catch up with sustainable building development, most researches and political regulations have been directly implanted from the standards of advanced developed countries, including the U.S., the U.K., Japan, Germany and Canada. Therefore, massive investigation and measurement of buildings in cities has to be undertaken to change the situation.

Taiwan needs more building and urban design research related to practical situations and applying advanced methods and technical tools.

The loss of fundamental research related to urban and building design and practical situations is a serious issue in Taiwan. The majority of researches discussed new technology purely for economical benefits, such as solar PV panels, LED technology, and improved efficiency for AC systems. Other major research topics covered assessment systems exploration and energy usage measurement. A small portion of them explored sustainable design strategies for individual buildings. In other words, comprehensive studies covering urban and building issues or related studies based on practical situations are rare. Furthermore, advanced technical tools and methods are hardly seen in this field. In order to give guidelines for urban and building design systems, the losses must be compensated.

Chapter 4

RESEARCH METHODOLOGY

A PRESENTATION OF THE DEVELOPMENT AND CONSTRUCTION OF METHODS AND SIMULATION SYSTEMS FOR THIS RESEARCH TO ACHIEVE ITS GOAL AND OBJECTIVES

RESEARCH METHODOLOGY

4.1 Introduction

The purpose of this chapter is to figure out the most appropriate methods and simulation system to employ in this research in order to understand, analyze and predict the energy performance of architectures in Taipei, and offer a series of design strategies to help buildings reduce energy use at building and urban scales. In order to achieve this goal, the review of literature and methodologies should be presented first and followed by defining methods (Figure 4.1).

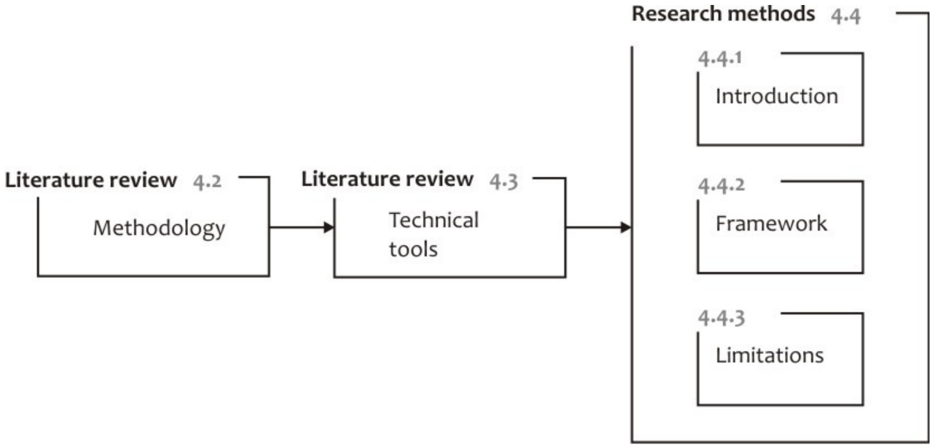


Figure 4.1 Framework of this research methodology.

In Chapter Two, a review of sustainable development has been presented, which successfully helps to point out design strategies and related variables. In this chapter, an overall background of the available methods to understand the energy performance of buildings is reviewed first. Then, a comparison of up-to-date research which employs these methods is presented. The next section introduces the development of technical tools applied in the methods. Lastly, a full diagram of the simulation has been drawn to show the whole flow and connection of the tools.

4.2 Methods exploration

In order to understand the energy consumption of buildings, in general, there are two distinct approaches known as the top-down and bottom-up methods (Swan and Ugursal 2009). The top-down approach regards building units as energy sinks and mostly relies on statistical data and economic theory. On the contrary, the bottom-up method extrapolates the energy performance of buildings by calculating data from a representative set of individual buildings and multiplying figures to regional and national levels. The bottom-up method also consists of two methodologies, the statistical method (SM) and the engineering method (EM) (ibid.).

4.2.1 Methods to find the energy performance of architectures

Because the energy consumption of either an entire city or a single building is complicated and inter-related, many different types of models have been created to assess the impacts of design or planning strategies. Swan and Ugursal (2009) said that these methods should be comprehensive and accurate enough to evaluate effects. According to their research in 2009 involved in residential sectors, they categorized these methods of energy simulation into two groups, the top-down approach and the bottom-up approach. Moreover, due to the adoption of information and basic data from different levels, and the degree of details, the two models probably produced various results (ibid). In other words, these two kinds of methods have different advantages, weakness, capability, and applicability.

Before the individual discussion of these two methods, it is necessary to mention some basic and practical information collection methods. The most popular and commonly employed method is to undertake a survey. The preliminary estimate of energy consumption is usually done by national institutions and governments. Research units in Canada (Office of Energy Efficiency, OEE 2006), the US (Energy Information Administration, EIA 2006), the UK (Department for Business Enterprise & Regulatory Reform, DBERR 2007), and Taiwan (Wang 2005) all have provided indicators and statistics, such as billing records from energy suppliers, to estimate the energy consumption in residential or commercial blocks. However, without a sufficient correlation of information about houses and dwellings' behaviour, the combined results could be too generalised for particular subjects. Therefore, the Tyndall Centre (Macmillan and Kohler 2004) improved the survey by adding a review of the investigation procedure to define the house geometry, thermal envelope, appliances and other characteristics. Due to this comparatively specific information, the improved survey method is superior to the previous general survey. However, the massive task and difficulties involved with collecting all the basic information from individual subjects takes far too much time and makes the method impractical for large scale studies.

On the other hand, for individual buildings or small groups of houses, the sub-metering method is one of the most practical methods, because it places energy metering devices in regular appliances which record usage profiles for each hour, and if necessary even for each minute. This method is much more detailed and specific than any other methods and is very helpful for building renovation or retrofit projects. However, for large scale studies the huge cost of supplying data recording devices is the biggest obstacle to prohibit the application of this method.

Top-down models focus on ongoing long-term changes and consider pertinent variables to estimate the effect on energy consumption. The variables which are commonly used by top-down methods are gross domestic product (GDP), employment rates, price indices, climatic conditions, housing construction and demolition rates, appliance ownership, and units (Swan and Ugursal 2009). These variables are widely available and simple to understand, which is the biggest advantage of this method. According to the inertia of historic records, the future changes to these variables are likely to be easily deduced. However, Swan and Ugursal (2009) also mentioned that the reliance on historic data is a disadvantage of the top-down method. For example, the application of new technology for new houses possibly reduces energy consumption, but that would not be shown in the historic data and therefore will be ignored by the top-down method. Moreover, the lack of consideration about details related to the individual end-uses means that the top-down approach could not avoid having a comparatively rough presentation style.

In contrast, the bottom-up method encompasses many different types of models that use and input data from an individual level to a regional level. In other words, this approach can calculate the energy consumption of an individual representative house, or groups of houses, and extrapolate the result to regional or even national levels. Depending on different research purposes, researchers can adopt the data which is thought to be more useful for their modelling and combine some of the sub-methods to make it more comprehensive. Generally, the bottom-up method covers two ways of working, via statistical methods (SM) and via engineering methods (EM). By observing to the input data for both of methods, it is clear to see that the bottom-up approach considers much more details than the top-down method, such as geometry, envelop fabric, equipment and appliances, indoor temperatures, occupancy schedule, and equipment use (Swan and Ugursal 2009). Statistical methods mainly use historical data and build up a connection between end-uses and energy consumption. By the relationship between several representative models, statistical methods can predict and estimate the energy use of blocks. On the other hand, engineering methods account for the energy consumption of end-uses in a reliable and logical way without depending on past records. In short, a notable advantage of the bottom-up method is its capability, which not only can consider many details, but also can be adjusted immediately for new design strategies or technical application. However, the massive data input requirement can make this model seem a little complicated.

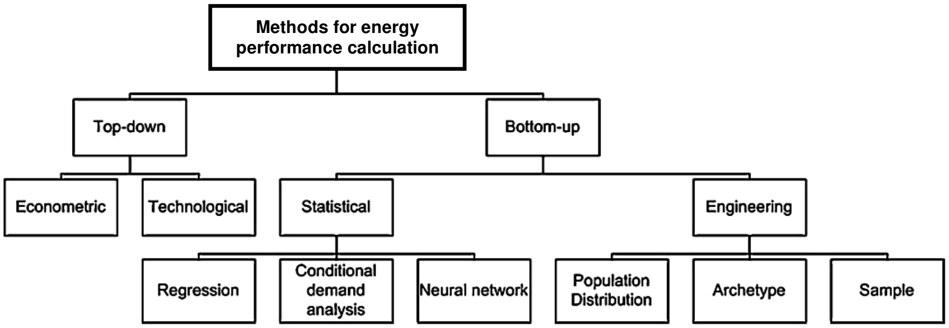


Figure 4.2 Framework of top-down and the bottom-up modelling techniques for estimating building energy performance. (Source: Swan and Ugursal 2009; Modified by Lin 2012)

Swan and Ugursal (2009) have summarized and structured the framework of these modelling methods, as above, which could be used as a reference for the majority of research involved in energy consumption modelling. Figure 4.2 clarifies the relationship between the top-down and bottom-up methods and presents their supporting sub-models.

4.2.2 Top-down method

A rapid growth of the top-down approach occurred due to the energy crisis which happened in 1970s. The development process of the top-down method built a strong link between econometric theory and itself. Swan and Ugursal (2009) asserted that the majority of top-down methods used similar statistical data and econometric theory, which usually employ broad economic models without considering small details. The approach treats the building sector as an energy sink and determines the trend of energy consumption by considering the major econometric figures, and then processes the calculation.

In 1977, Hirst et al. simply built a model of the US residential houses to predict the changes in number of houses annually and the overall energy consumption. In that model, census data, housing attrition and new construction are some of the econometric variables. Considering the housing and technology components, they successfully determined the possible trend of US housing and then calculated the total energy consumption based on historic values. After two decades, the model was improved by adding “irreversible improvements in technical efficiency” (Haas and Schipper 1998). Haas and Schipper (1998) thought the model should not just consider the econometric indicators. Thus, they considered the consumers’ response to rising prices and their attitude about upgrading their dwellings. Although they did models for many countries and during different time periods, the results did not perfectly match their hypothesis. After that, Bentzen and Engsted (2001) set some models to examine the energy consumption of residential houses in Denmark. They found that in order to maintain the energy consumption level, the energy price plays a very important role in defining consumers’ behaviour. If the energy price stays constant while income grows, people will consume more energy than their original level of consumption. After that, the sort of models employing the top-down method have improved by integrating with many different variables, such as GDP, population, house production, appliance sales (Ozturk et al. 2004), the forecast of housing stock and technology, and policy analysis. However, the top-down approach had mainly stayed in the econometric level until 2005. A solid model for 68,200 buildings was built up and its result were presented using geographical information systems (GIS) (Tornberg and Thuvander 2005). Although the spatial model was at an early stage, it still offered useful information to identify the high consumption areas. Furthermore, Balaras et al. (2007) constructed a model of the Hellenic housing stock, which clearly indicated that adding insulation to the old housing stock could reduce energy consumption by 49% for space heating systems. Since that, the top-down model not only considers econometrical variables, the prediction of technology and consumers' behaviour, but also extends its scope to examine strategies to respond to possible negative effects which might occur in the near future.

4.2.3 Bottom-up method

The bottom-up approach extrapolates the energy consumption of groups of buildings at regional and national levels which are based on solid and representative sets of individual buildings (Swan and Ugursal 2009). There is a growing interest in anticipating the energy consumption of communities by applying this kind of method. Some research applied the statistical method (SM); some used the engineering method (EM); others combined different parts of each and became multi-methods. The determination of which method should be used depends on availability and the purpose of the research. The SM method not only gets the information from a sample house, but also calculates the energy consumption according to it, which utilizes the regional and national indicators, such as macroeconomic, energy price and income (ibid.). Therefore, the SM method gains the advantage of the top-down method and considers some of the details about end-uses. On the other hand, the EM method focuses on the identical characteristics of a single building or some small groups of buildings and aggregates the result logically to depict the total energy consumption at regional or national levels. The method is able to singularly examine new technology or design strategies (ibid.). The flexibility of the method is its biggest advantage and that is why it will be chosen for this research.

First, it is the vast quantity of data related to consumers' behaviour that becomes the solid foundation for the SM method. However, it is impossible to analyze and consider every detail of the end-uses because there is lots of information which is useless for energy modelling. Thus, there are three well-documented techniques to help handle the problem and compose the SM method; regression, conditional demand analysis (CDA), and the neural network (NN) (Swan and Ugursal 2009). The regression technique analyzes the importance of end-uses variables and determines the input parameters. The negligible information for energy changes would be removed in this model. Therefore, the coefficient link between the energy consumption and the variables can be regarded as its key point. The source of the data for the CDA technique is different from the regression technique, because it is based on the survey of end-use appliances. Swan and Ugursal (2009) believed that the main strength of this technique is how easy it makes obtaining the required data from a simple appliance survey of occupant and energy billing data from the supplier. Similar to the regression technique, the NN technique tries to minimize the errors and unnecessary information by setting up a simplified mathematical model, which is based on an interconnected parallel tree structure (ibid.). Like the biological neutral networks, the parameters in each level can affect the others, which make it become a dynamic model.

Secondly, the EM approach is the only method which can account for the energy consumption at both building and urban scales. Swan and Ugursal (2009) asserted that the EM approach has the highest degree of flexibility and capability. It can give rough results by just considering the general climate data, such as heating degree days (HDD) or it can be very specific by setting dynamic models to calculate instant heat transference. Although the approach could be employed in various forms, the information about occupants' behaviour is indispensable. There are three techniques composing the EM method, distributions, archetypes and sample, which have different functions to support them.

To start with distribution, this technique estimates the overall energy consumption at regional or national levels by aggregating the end-use of appliances. It would be better to say that this technique depends on the rating system for appliances, including the ownership, the use, the efficiency, and the characteristics of the appliance. However, this technique would not consider the interactions among different appliances. Once the number, types of buildings, and distribution of their appliances are known, the total energy consumption could be estimated. For example, Jaccard and Baille (1996) created a model by using the INSTRUM-R simulation tool to calculate the performance of Canadian residential houses. They adopted various data to become their input parameters, such as historic energy consumption, price, distribution levels of technologies, and cost and availability of appliances. The INSTRUM-R simulation tool potentially helped them to predict the changes of appliance use in residential houses for the near future and successfully estimate the total energy consumption according to that. Similar to the previous research, in 2007, Kadian et al. combined micro-level data with the concept of distribution to develop a model for Delhi. They considered many types of end-use appliances at the micro-level, including lighting, heating, air conditioning, refrigeration, cooking, and washing. In addition, they predicted the changes caused by population trends, income, and number of houses. Then, the authors incorporated both sets of information and summed up the figures.

Next, a small number of buildings can be applied to represent a bigger group of buildings, and this is called the archetype technique. Depending on the goals and requirement of the research, the archetype technique can have a varied level of detail. Furthermore, this model often functions at three different levels by calculating minimum, average, and maximum values to give an appropriate and reasonable range. Due to the approach being typically involved in sets of highly detailed information about houses, Swan and Ugursal (2009) proposed that the processing speed of the computer used and the capability of its software are critical. However, researchers can limit the number of buildings and only select relevant useful information about energy consumption to simulate results.

MacGregor et al. (1993) set 27 archetypes in the Nova Scotia residential model, which used typical values of details, such as occupancy, appliances and lights. They calculated the values by using an hourly analysis program and extrapolated the results to a bigger scale. Consequently, they found the results for the provincial level are in agreement with the top-down method. Even though the variables and number of archetypes they used were not sufficient, their results were still good enough to prove the accuracy and reliability of the method which could estimate energy consumption without depending on historic data. Moreover, Kohler et al. (1997) built a more complicated model for the German building sector. They recognized the difficulties involved with collecting data from each building, thus they decomposed the results of the survey for buildings. In other words, in order to solve the problem of the lack of specific information, the units of buildings, such as windows, were seen as individual components and would be recomposed for some "reference" buildings. Although the "reference" buildings did not practically exist, their characteristics were based on solid investigation. Like the result of MacGregor's research, they proved again the agreement between the top-down method and the archetypes technique.

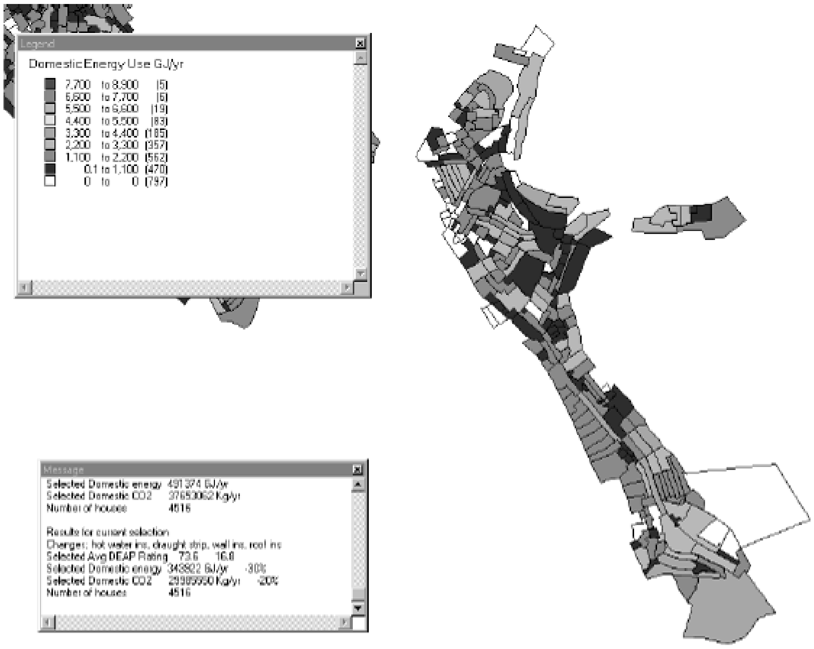
Then, Jones et al. (2001) developed a unique archetype model for energy prediction, which is called the Energy and Environmental Prediction (EEP) model. In that model, by integrating the advantages of GIS systems, Jones et al. successfully increased the number of archetypes. First, they classified the housing into different groups based on five features; location, building dimensions, age, built form, and assumptions for future distribution and technology, which are some of the characteristics having the strongest relationship with domestic energy performance. Secondly, they developed a selection menu for design strategies, as shown in Figure 4.3. In that model, they not only estimated the energy consumption of housing, but also pointed out the potential areas where more energy would be consumed, and which strategies could reduce CO2 emissions more effectively (Figure 4.4).

Improve the building stock by

- ☐ Hot water tank insulation
- ☑ Fully draught proofed
- ☑ Wall U Value as current regs
- ☑ Roof U Value as current regs
- ☐ Partial double glazed
- ☑ Fully double glazed
- ☐ New condensing boiler

Percentage take up rate: 100

Figure 4.3 The list of energy conservation measures. (Source: Jones et al. 2001)



Domestic Energy Use GJ/yr

7,700	to	8,900	(5)
6,600	to	7,700	(6)
5,500	to	6,600	(19)
4,400	to	5,500	(83)
3,300	to	4,400	(185)
2,200	to	3,300	(357)
1,100	to	2,200	(562)
0.1	to	1,100	(470)
0	to	0	(797)

```
Selected Domestic energy  491374 GJ/yr
Selected Domestic CO2     37653062 Kg/yr
Number of houses          4516

Results for current selection
Changes: hot water ins, draught strip, wall ins, roof ins
Selected Avg DEAP Rating    73.6     16.0
Selected Domestic energy  343922 GJ/yr      -30%
Selected Domestic CO2     29985950 Kg/yr      -20%
Number of houses          4516
```

Figure 4.4 The results, presented by GIS system, of applying conservation measures for housing in Neath Port Talbot. (Source: Jones et al. 2001)

The archetype technique is not just used for residential houses. Carlo et al. (2003) created a model to help develop the number of archetypes used for commercial buildings. The author discovered three primary characteristics which would influence energy consumption the most, including roof area ratio, facade area ratio, and internal load density. The author combined them in different groups to develop twelve archetypes, and then added other variables to represent the energy consumption of 695 buildings. The research successfully gave feedback about proposed changes to the building code. In short, so far, how the archetype technique works and its high capability and flexibility have been presented. These advantages of the techniques have made it become more and more popular as an energy prediction tool for the majority of scholars.

Thirdly, the sample technique is similar to the representative concept of archetypes, but estimates the energy performance using limited prototypes. Farahbakhsh et al. (1998) developed a model for Canadian housing, which only had 16 archetypes to calculate the national consumption. Due to the use of real information from houses, the sample technique can be in agreement with other methods and offer some practical suggestions for the building code or new technological applications.

4.2.4 Summary of methods

Swan and Ugursal (2009) believed that the top-down method is easier to use than the bottom-up method because the required database is more limited and at a bigger scale. The information which is needed by the top-down approach mainly involves economic indicators, such as GDP, population, house production, appliance sales, income, and climate. Due to the reliance on long-term historical data, the top-down method is good at predicting trends of general use and can offer solid information for supply analysis and energy demand. However, it loses flexibility when accounting for changes brought by newly designed strategies or appliances. Swan and Ugursal (2009) also asserted this method cannot help the development of policy or as an incentive to encourage them because the top-down approach can not offer an indication of the potential impacts of new technologies.

The bottom-up approach considers much more detail than the top-down method, such as occupancy behaviour and diary, geometry, envelop fabric, equipment and appliances, indoor temperatures, and equipment use (Swan and Ugursal 2009). The consideration of detailed information related to the end-uses is the most important advantage of it. Additionally, its flexibility and capability to be applied to different types of buildings and changes of technology allow the bottom-up method to offer useful suggestions for the future. The bottom-up approach has various supporting techniques, which are generally classified into two groups, the statistical technique (SM) and engineering technique (EM).

On the one hand, the SM technique employs useful regional and national information and detailed end-uses data to estimate the energy consumption. Therefore, this approach could be seen as the bridge between the econometric information and micro-scale models. For the SM technique, there are three sub-models to support it, regression, conditional demand analysis (CDA), and neural network (NN). The regression technique adjusts the way to sieve out the regional and national information. It focuses on data related to energy performance and reduces the loan of input parameters. Unlike the regression technique, the CDA technique chooses information based on the survey of end-use appliances. The NN prefers employing mathematic formulas to make the model function more dynamically.

On the other hand, the EM technique heavily depends on detailed information without the input of any historical records. This kind of technique is used to calculate the energy performance of end-uses according to the specific description and information about a package of representative buildings. It not only offers as accurate results as the other methods, but also can calculate the effects of various changes in the future (Swan and Ugursal 2009). Its biggest advantage is examining the potential impacts of policy or design strategies and offering useful feedback. Furthermore, the strong computational ability of the technical tools allows them to calculate extremely detailed information and run dynamically. Kavgic et al. (2010) said that "*the new generation of the bottom-up simulation tools should include multidisciplinary and dynamic approaches*", so that they can solve instant changes in policy development and various design strategies. However, the huge quantity of data to input costs too much time and becomes the biggest shortcoming for the EM technique.

	Top-down	Bottom-up statistical (SM)	Bottom-up engineering (EM)
Positive attributes	1. Long-term forecasting in the absence of any discontinuity 2. Inclusion of macroeconomic and socioeconomic effects 3. Simple input information 4. Encompasses trends	1. Encompasses occupant behaviour 2. Determination of typical end-use energy contribution 3. Inclusion of macroeconomic and socioeconomic effects 4. Uses billing data and simple survey information	1. Model new technologies 2. "Ground-up" energy estimation 3. Determination of each end-use energy consumption by type, rating, etc. 4. Determination of end-use qualities based on simulation
Negative attributes	1. Reliance on historical consumption information 2. No explicit representation of end-uses 3. Coarse analysis	1. Multicolinearity 2. Reliance on historical consumption information 3. Large survey sample to exploit variety	1. Assumption of occupant behaviour and unspecified end-uses 2. Detailed input information 3. Computationally intensive 4. No economic factors

Table 4.1 Positive and negative attributes of the top-down method, bottom-up SM method and EM method. (Source: Swan and Ugursal 2009)

In short, based on different subjects and research goals, scholars should choose the most suitable method or use multiple methods. Swan and Ugursal (2009) listed the general positive and negative attributes of these methods in Table 4.1. Due to the coarse analysis of the top-down approach (ibid.), this research prefers the archetype technique under the bottom-up EM method and is enhanced by the application of technical tools, which will be discussed more specifically in the next sections.

4.3 Introduction and comparison of technical tools

A recent surge of technical tools for energy analysis and sustainable design strategies has given new opportunities, particularly for the bottom-up archetype technique. Lots of advanced technical tools for calculating the energy performance of an individual building or small groups of buildings now exist, such as TRNSYS, DesignBuilder, Energy Plus, HTB2 and Ecotech. However, there is comparatively limited software available for simulation at urban scale. Therefore, the gaps between tools for the building scale and urban scale should be bridged. The proposed methodology of this research is based on the concept of an archetype technique and links several technical tools, including Sketch Up (@Last Software and Google), HTB2 v2.10 (Welsh School of Architecture, WSA, Cardiff University 2008), and Virvil Plugins (WSA, Cardiff University 2012). The advantages, disadvantages and limitations of these tools are specifically and individually discussed in this section.

4.3.1 Comparison of advanced technical tools

Due to the accuracy and efficiency of the representative model, it is critical to employ the best tools for the bottom-up method. Moreover, after the 1980s, computer simulation has become more and more important, as it potentially guides building and urban design. Therefore, Alexander (2003) concluded four different approaches to compare and validate thermal simulation models, including open inspection, analytical, empirical and internal (or inter-model). The result of the test could help to indicate the most appropriate technical tools for this research.

First of all, open inspection is concerned about the errors existing in the programming, which is inevitable as errors are made during the typing process, even by senior programmers. Therefore, a series of strict methods to check coding is necessary before and after testing. It is to be believed that the majority of technical tools, both for commercial and academic use, have a few mistakes in their programming (Alexander 2003).

Secondly, analytical validation is a way to compare the results of models to know the general acceptable solution (Alexander 2003). However, the general acceptable solution ignoring trivial details may not meet the practical situation. Although the approximate result does not disobey the goal of the model, it is still not an appropriate reference for this research, particularly concerning the decision of which tools to use for the bottom-up method.

Thirdly, in order to overcome the shortcoming of analytical validation, empirical validation measures the real subjects and compares the practical investigation with the results of different simulation models (Alexander 2003). Take an experience of a double glazed room for instance(Lomas et al. 1997). As the results show in Figure 4.5, the measured energy load for the subject house is the deep pink vertical bar, which allows a 5% range of differences shown by the light pink area. There are several results from simulation models which are in agreement with the measured one, such as TSB1 v2.0, CHEETAH v1.2, 3TC v1.0, APACHE, HTB2 v 1.10, HTB2 v1.2, CLIM2000 v1.1, BLAST v3.0, and SERI-RES v1.2. In this test, HTB2 v1.2 performed much better than the others being closest to the measured figures. However, in Alexander (2003), Lomas (1996), and Lomas et al.'s (1997) simulation models, the simulation results run by HTB2 were not always located in the measured areas, but it still performed consistently.

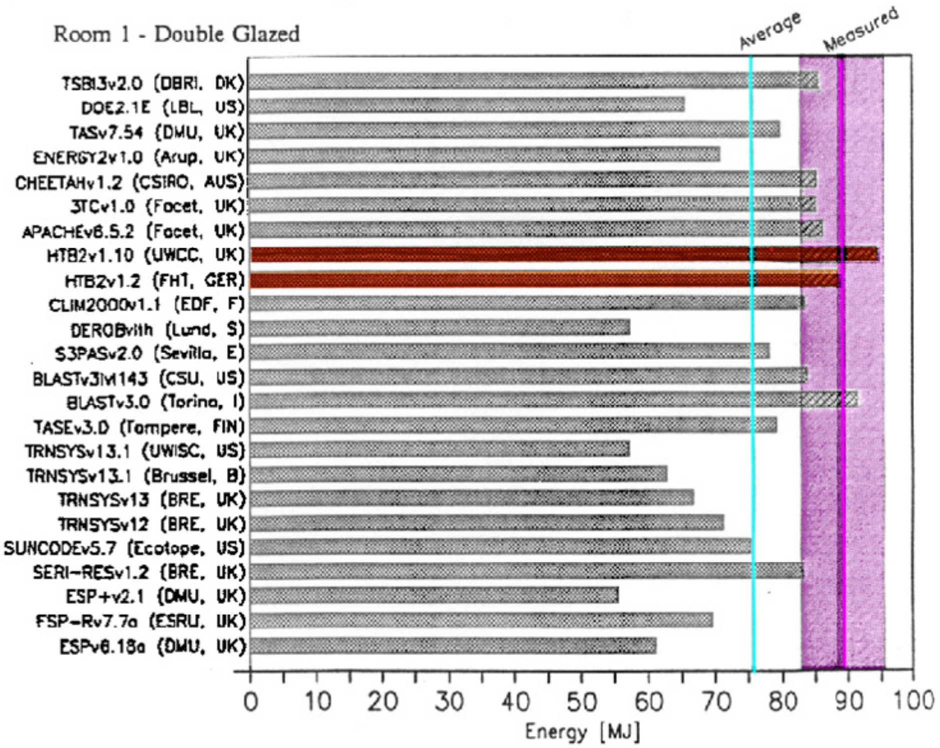


Figure 4.5 The measured and average energy consumption results of different simulation tools for a double glazed room for 7-days in October, 1987. (Source: Alexander 2003)

Fourthly, internal validation, also known as inter-model comparison, offers a sounder theoretical basis for simulation and has gained more attention recently. This method integrates the detailed consideration of empirical validation and the powerful mathematical calculation of analytical validation. Although there is no need for real models to be references, the input data is based on diverse models which are specifically examined and selected by developed formula. Alexander (2003) took a standard model, BESTEST/ASHRAE-140 suite, to be the subject and compared the results from nine simulation tools. The simulation results of them are shown in Figure 4.6. In the comparison, HTB2 was the only model that came close to the acceptable areas for predicting both heating and cooling load.

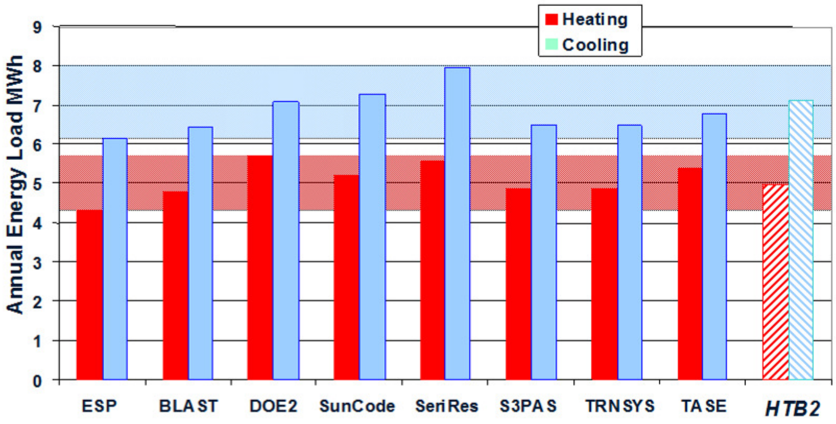


Figure 4.6 The overall simulation results of different tools used to estimate one case of the BESTEST/ASHRAE-140 suite. (Source: Alexander 2003)

According to the comparison results of these four different validation tests, Alexander (2003) concluded that HTB2 has been proved powerful enough for energy use calculation and internal temperature prediction. Therefore, for the bottom-up method, HTB2 could be seen as one of the most useful calculation engines to accurately estimate the energy consumption of archetypes.

4.3.2 Introduction of selected tools - Sketch Up

Due to the aim of this research, the relationship among buildings at urban scale is one of the most important objectives, including urban geometry, pattern of blocks, and characteristics of buildings. Thus, it is critical to find the balance between detailed building and urban models. It is the three-dimension model that not only contains the geometrical characteristics of the space, but also includes the basic information of a city, such as densities, distances among buildings, directions of block and building facade, and over-shading. By combining the geometrical information, a 3D model can be explicitly located and calculated using natural and meteorological information. In main stream research and practical fields, SketchUp (@Last Software 2000) is the most popular technical tool for three dimensions drawing. In recent years, the development of SketchUp has grown extremely quickly and has been employed widely because of its human-orientated operation interface and strong capability to implant various plug-ins (JeDin Information Inc. 2013). Therefore, SketchUp is adopted by this research to be the main tool to build up 3D models of the existing built environment. Furthermore, the usable operation system of SketchUp allows future researchers do similar research in the same method easily.

SketchUp was developed by @Last Software in 2000 and bought by Google in 2006, and then by Trimble in 2012. The purpose of the software, *3D for everyone*, has made its development process considerably faster than any other similar technical tool. Unlike other professional tools, Sketch Up is reputed to have an intuitive drafting process for beginners. "Push and Pull" are two of the best examples. Although SketchUp is composed of numerous easily approachable tools, it can also draw very complicated 3D models as 3D Max does. Except for the function of animation, there is no difference between SketchUp and other advanced tools. Additionally, from version SketchUp 4.0, SketchUp was initially designed to be written in an advanced coding language, Ruby (Yukihiro Matsumoto), which has been developed for object-oriented programming (Lu 2007). Based on the Ruby programming language and free public usage of SketchUp, engineers can code and add some additional functions to SketchUp by themselves. By 2011, there had been more than one thousand plugins designed for SketchUp and more than 50 technical tools which can be connected with it (JeDin Information Inc. 2013). In this research, to save time during 3D model building, a package of plugins called SketchUp Architectural Plugin Pack (SUAPP 1.0) (SUAPP 2008), will be employed. The Plug-ins in the pack can help build 3D models, but they cannot bridge the gap between HTB2 and SketchUp. Therefore, in order to connect with the main calculation engine, HTB2, there is another package called Virvil Plugins, developed by the WSA in Cardiff University in 2011, which will be used to examine the simulations in this research.

4.3.3 Introduction of selected tools - HTB2

HTB2 v2.10 was the latest version (2012) of HTB2, and was originally released in 2008 by the Welsh School of Architecture at Cardiff University. HTB2 was initially programmed for simulation of the interior thermal conditions of a single building, including internal temperature prediction, solar gain, humanity and ventilation (Alexander 2008). After a series of improvements, HTB2 is now able to simulate a group of buildings. However, due to being an investigative research tool, HTB2 is not a simple model and makes beginners feel it is hard to learn. Even though the PC version based on a Windows environment was released, it is still too complicated for architects and urban designers. Additionally, users have to set up all parameters in each required file step by step, which makes it easy to make mistakes. The complicated setting process possibly affects the accuracy of its simulation result. Furthermore, without a virtual windows environment and instinctive operation interface, it is hard to define the parameters specifically. Take the relationship between two buildings for example (Figure 4.7). A regular standard model can easily to be described by digital figures, but it will need much more data to describe an irregular model or building composition. For an existing built environment, there will be many cases of irregularity. Without the support of 3D models, it is impossible to describe the building neighbourhood environment clearly and that is the reason why it is necessary to connect SketchUp with HTB2.

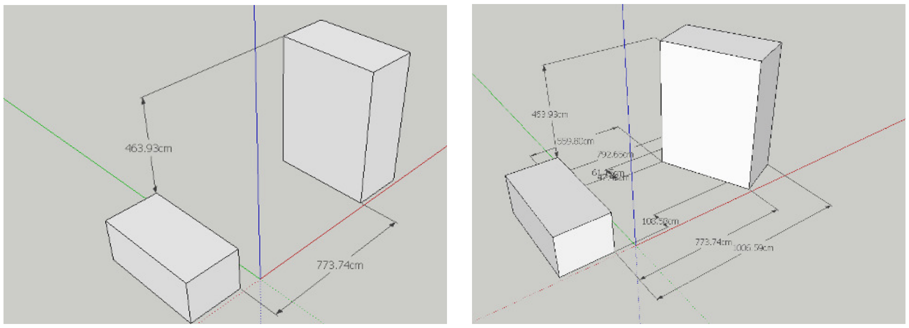


Figure 4.7 The examples of relationship comparison between two buildings in regular standard situation (left) and irregular situation (right).

Although there are many disadvantages with HTB2 involved in describing complicated models, there are many important reasons to use it. As described in the previous section 4.3.1, HTB2 has the best performance involved in energy prediction for buildings because it is a good example of a Dynamic Thermal Model (DTM) and its dynamic calculation engine was written with Fortran-77 code (Alexander 2003). Moreover, this research is planning to discuss energy performance of buildings at building and urban scales using a bottom-up method, therefore the accuracy of simulation tools should satisfy both scales to make sure the model is consistent. Besides, Alexander (2008) asserted that HTB2 has other advantages, such as a design for easy alteration and extension, investigation of both long and short time-scale phenomena, customized meteorological data settings, dynamic calculation for convective and radiant gains, provision for shading and zoning, flexible glass transmission specification, flexible operation schedule settings, and flexible output intervals and details. The flexibility of HTB2 can be useful to examine various advanced sustainable design strategies.

HTB2 regards buildings as a series of spaces, which are linked to each other and connected to the outdoor environment by walls, roofs, windows and ventilation paths (Alexander 2008) (Figure 4.8). The calculation mechanism of HTB2 mainly considers heat exchanges from the external climate, heating systems, and a network of incidental heat sources (ibid.) (Figure 4.9).

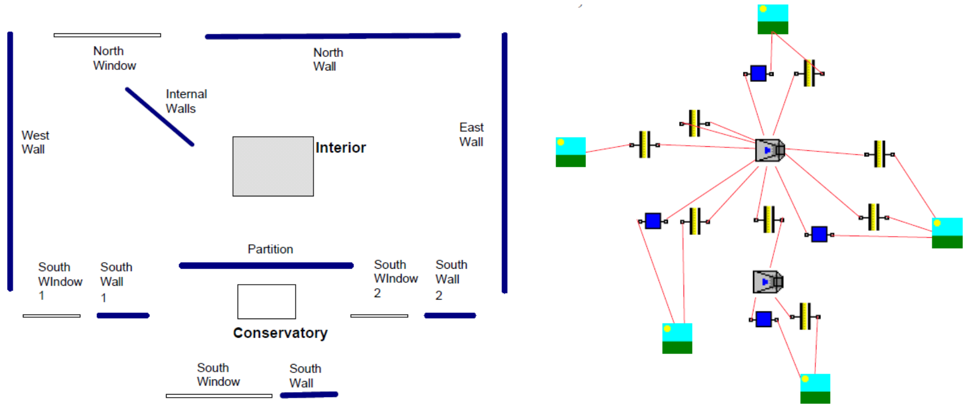


Figure 4.8 The units of a space are decomposed by HTB2 (left) and rearranged in HTB2 Schematic tools (right). (Source: Alexander 2008)

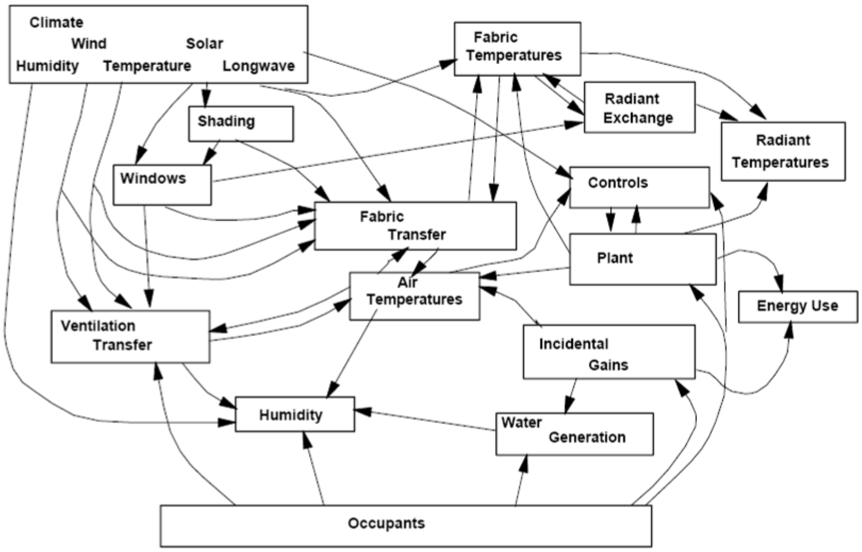


Figure 4.9 The diagram of heat exchange and interaction among units of HTB2. (Source: Alexander 2008)

All the parameters from these units should be calculated together based on their time, which can be set between a single minute to a whole year. In short, model builders should decompose a building or spaces first and reorganize them according to HTB2's hieratical levels (Figure 4.10). For each level and topic, there are corresponding files to manage the data. Then, HTB2 will calculate these data together and produce a final report.

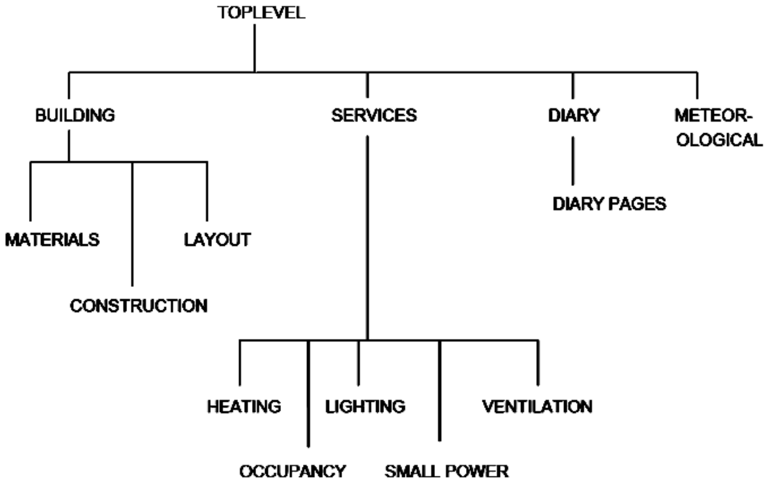


Figure 4.10 The hierarchical structure of HTB2 files. (Source: Alexander 2008)

4.3.4 Introduction of selected tools - Virvil Plugins

Virvil Plugins is a tool originally developed for energy simulation at urban scale (Jones et al. 2011), which strongly considers the relationship between buildings.

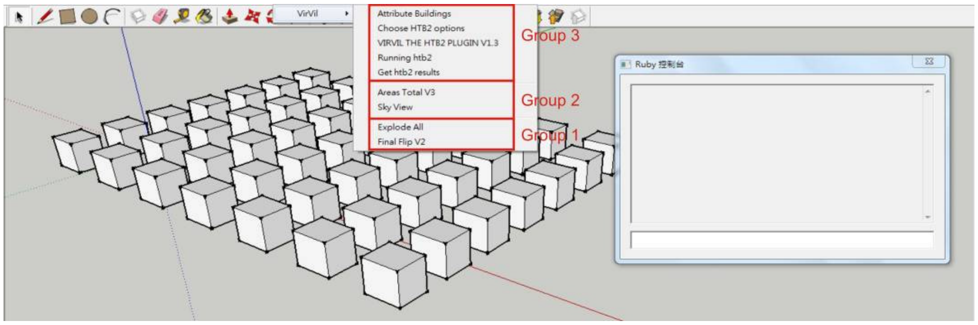


Figure 4.11 The operation interface of Virvil Plugins v1.3 in SketchUp software.

There are nine different tools in the version, Virvil Plugins v1.4, which are divided into three groups (Figure 4.11). The first was designed to help simplify the process of 3D model building. The second was developed to build the relationship between the model and location and surrounding areas. Areas Total v3 is one of the tools in this group to help identify the orientation of façades of buildings in the 3D models, which can recognize façades by different colours from eight angles (as illustrated in Figure 5.12 in the next chapter). The other tool is Sky Cover v3 which is used for figuring out the relationship between buildings (Figure 4.12). This tool is used to set up the attributes of the facade, buildings or blocks and control HTB2 to calculate the model.

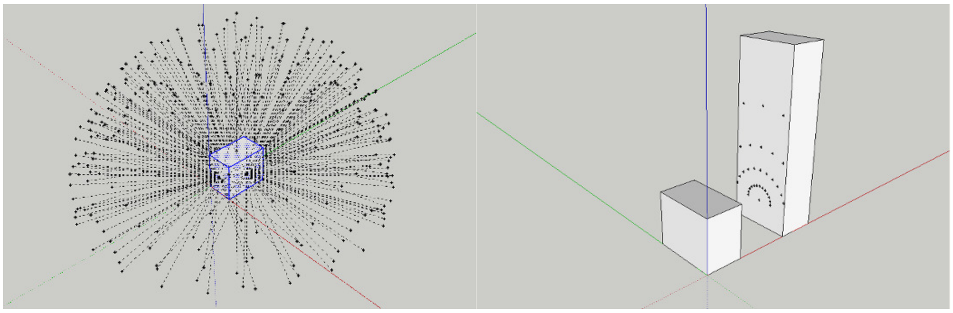


Figure 4.12 Sky Cover v3 - the rays from each facade in particular angle division system (left); the dots from the rays hindered by nearby building's facades help to make the shading mask (right).

4.4 Methods in this research

In this section, the relationship between research objectives, goals and the research methods would be explained first. Then, the requirement of simulation setting and the process of using the methods and tools would be presented.

4.4.1 Introduction of research methods

On the one hand, to address the specific research questions and achieve the aim and objectives set out in the first chapter, this study needs to establish research methods by applying technical tools with consideration of the practical environment in Taipei. There are a few main reasons to adopt these technical methods and tools.

1. In order to compensate for the lack of fundamental researches involved in the general energy performance of different kinds of buildings in Taiwan, the methods should be able to understand and analyze the energy usage situation of buildings. Practical investigation, measurement and simulation all qualify as means to achieve the requirements. However, due to this study's limited research time and resources, simulation would be the best method to utilize. Moreover, the same concept of bottom-up method is adopted. Several prototypes would depict the buildings in a whole city or specific regions to be examined.

2. In order to recognize better strategies and give guidelines for how to reduce the energy use of buildings in Taipei, the method should be able to examine and predict the impacts brought by different design strategies for various kinds of buildings. The flexibility and powerful predictability of technical methods make them become the only choice.

3. In order to satisfy the research requirements for understanding the energy performance of buildings at both building and urban scales, a new simulation system integrated by advanced technical tools should be developed.

In short, through the review of methods and the comparison of different technical tools, the technical application of the bottom-up engineering method is the most appropriate to satisfy the all needs of this research. Moreover, the usability of these selected technical tools that were mentioned in previous sections will allow succeeding researchers to easily undertake related researches by applying the same methods.

4.4.2 Framework of research methods

As mentioned before, computer simulation plays the most important role of the methods in this research to figure out the best design strategies for buildings in Taipei. With focusing on the simulation, a two-phase study is designed to explore the solutions of sustainable transformation mechanisms for architectures (Figure 4.13).

The goal of the first phase research method is to understand the general energy performance of different types of buildings, building groups, blocks and districts in Taipei and check the validation of the EM method. Additionally, through a series of modelling procedures, some potential opportunities would be indicated. First of all, by observing Taipei City and analyzing historical data, building prototypes would be defined and attributed with different default settings, including diary, layouts, materials, interior situation setting and related information. This stage helps to understand the different energy performance types of different buildings. Moreover, it highlights potential opportunities to reduce the energy use. In the next stage, according to the observation of Taipei, some prototypes depicting different types of building groups are applied to be examined. The models are also simulated by the same tools. The output would present the differences of energy performance of buildings between a single building model and regional model. Thirdly, several large scale models would be built to depict typical blocks and districts in Taipei. Again, all of the archetypes would be simulated by SketchUp, HTB2 and VirVil Plugins. The simulation results would be compared with previous models and with practical measurements to figure out the potential variables and prove the accuracy and validation of the method. In short, through the simulation of different buildings at different scales, the first phase of research method would offer solid information about the energy use of buildings in Taipei and compensate for the lack of fundamental research.

On the other hand, based on the technical method, there are some requirements, mainly concerning the "input". The background information of different kinds of building subjects are needed. First of all, whether at building or urban scale, it is necessary to select and define appropriate cases through observation or calculation to depict the general situation. Secondly, the data related to buildings should be defined by collecting and analyzing national statistics or practical investigation or measurement, which should include the diary of inhabitants, the diary and heat output of facilities and lighting, the layouts and materials of general buildings and equipment efficiency. In this research, due to the lack of benchmarks in Taiwan, standards defined by developed countries would be adopted, such as CIBSE. Thirdly, the 3D models of the practical situation should be complete enough, that is to say they should at least contain information about the weather background, terrains, geometric information of buildings, and important public infrastructure.

Next, the goal of the second phrase is to recognize the degrees of impact of different variables and strategies on energy demand and supply through modelling at both building and urban scales. First, eleven variables would be summarized according to the past research, which would be simulated at both building and urban scales. The eleven variables are defined and selected based on the literature review, which are living style, building form, orientation, glazing ratio, insulation, usage proportion, density, fabrication, shading, UHI effect, and renewable energy application. Then, through the analysis and discussion of differences between modelling at different scales and the comparison of the original and adjusted models, better strategies would be concluded. Additionally, some strategies would be composed as optimized packages to examine the effects. Lastly, according to the simulation results and national goals, clear and practical development guidelines and recommendations will be concluded.

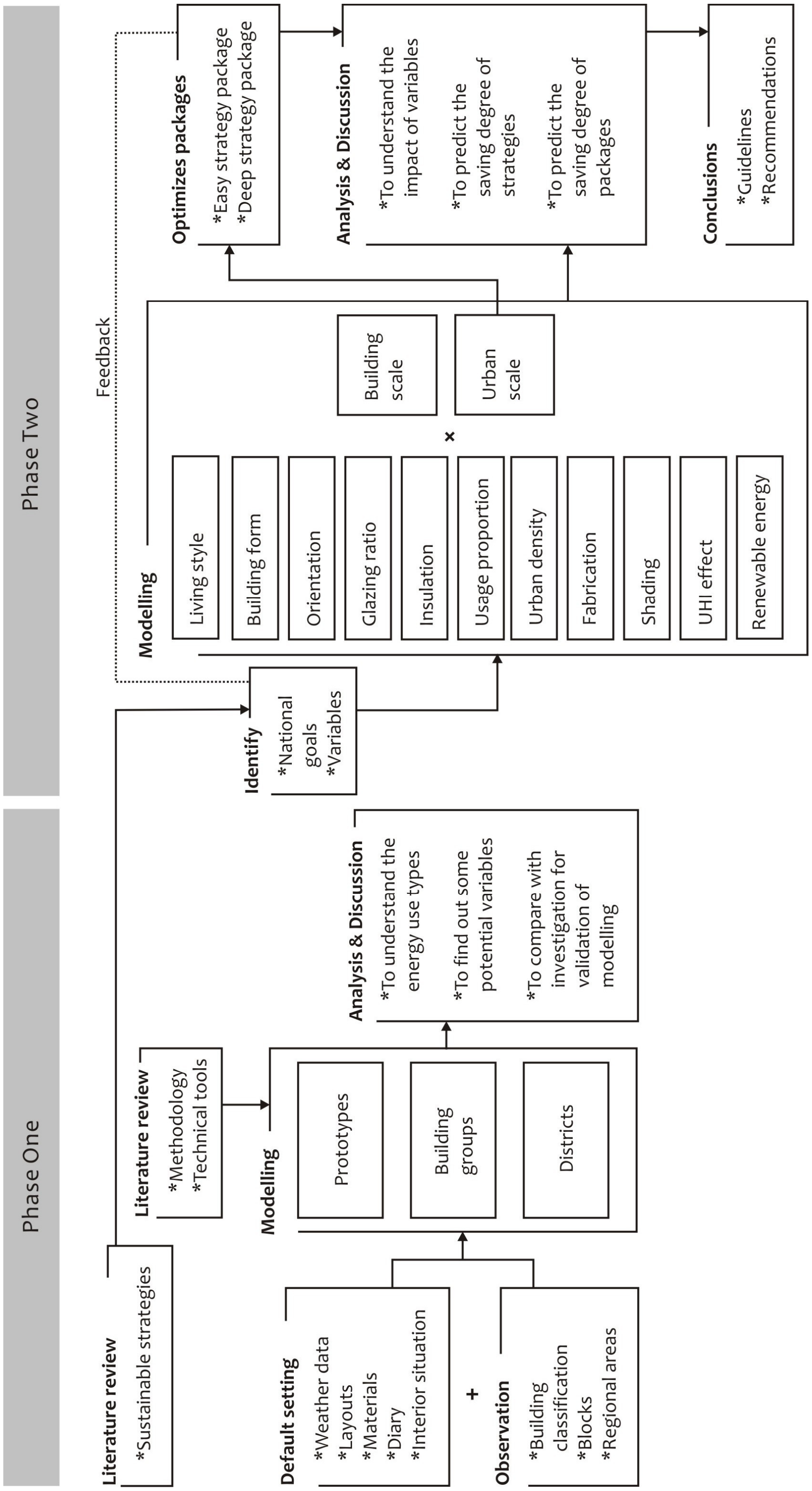


Figure 4.13 Framework of research methods.

4.4.3 Limitations of the method

In this research, archetype technique is the main method to be employed. Although the advantages of this approach have made it become more popular than the others for the majority of scholars, its limitations and disadvantages also probably constrict the range of this research.

First of all, without complete detailed historical records and fundamental research in Taiwan, some parts of the default settings are based on general national statistics, such as the end-uses of occupant behaviour both for domestic and non-domestic buildings. Fortunately, the differences between the assumption situation and practical measurement might affect the result of one single building simulation, but the deviation they bring at a bigger scale would be acceptable.

Secondly, the usage of technical tools itself brings both limitations and opportunities. The processing ability of up-to-date computers affects how much detailed information for energy consumption can be calculated. Theoretically, the model can be calculated by second, minute, hour, day, or even year. However, it is necessary to choose the one which can produce results within a reasonable range instead of the most precise one. Moreover, the development of VirVil Plugins is still at an early stage. Some functions have not yet been fully developed, such as outdoor ventilation and microclimate consideration. In short, there remains space for the improvement of computer calculation speeds and the coding development of VirVil Plugins.

Thirdly, according to the definition of sustainability, there are three aspects; the social, ecological and economic fields. But, for the technical method, the focus would be on the ecological aspect only and the results would be judged by numbers. In other words, the issues involved in economic and social aspects will not be considered. Many important issues are excluded, such as transportation and new electricity supply systems. If they can be considered together, the result would be more complete and comprehensive.

Fourthly, within the scope of this research related to the selection of subjects, the sensitivity analysis on models would be less important. The first reason is the discussion of the model in this research covers almost 80% building types in Taipei according to the analysis of GIS data offered by The National Geographic Information System (NGIS 2013). The majority of types of buildings are classified into nine different buildings prototypes and discussed in three different scales. Furthermore, the rest buildings also share the similar building styles by adopting close construct method and materials, which has been introduced the causes and history of Taiwan in Chapter Three. In other words, the primary and the most important part of buildings would be discussed in this research. The second reason for the absence of sensitivity analysis is that it is used to be applied for testing the verification and accuracy of a mathematical model or system for only one variable. The related researches are abundant which have been introduced in Chapter Two, including the examination for HTB2 (Alexander 2003). Moreover, Jones et al. had applied the similar research method in Chongqing Banan project (Jones et al. 2011). Thus, there is no question to repeat the test again. Furthermore, in this research, the modelling scale covers both urban and building scales and the discussion for variables are extended to eleven variables and their interaction impacts in individual and composition situation. Due to the complicated issues, this research confirms its validation and accuracy by comparing the results of simulation models with practical investigation instead of adopting sensitivity analysis.

4.5 Conclusion

Through the review of the methodology involved in energy performance of buildings, some important points can be concluded as follows.

The bottom-up engineering method can not only predict the energy performance of buildings, but also helps to understand it at urban scale.

The top-down and bottom-up methods are two of the most important categories to calculate and predict the energy consumption of buildings or a city. For the former, there are two methods to support it; economic and technological. Both of them should be calculated according to the historical data, such as gross domestic product (GDP), employment rates, price indices, climatic conditions, housing construction and demolition rates, appliance ownership, and units (Swan and Ugursal 2009). The reliance on historic data is one of the benefits of the method, which gives the most possible direction for the future. However, the changes brought by technology or strategies can not be calculated in the method. Furthermore, the ignorance of end-use details is another disadvantage of the method.

For the bottom-up approach, there are two main groups of techniques; the statistical methods (SM) and the engineering method (EM). SM takes care of historical data and detailed information, but requires an extremely large survey and measurements. EM is a way to calculate the figure by setting up “sample” or “archetype” models instead of considering the whole historical data. Additionally, by supporting technology, it can run in a complicated dynamic system and consider a variety of occupancy behaviour. Its high flexibility and applicability have made it become the most popular method in this research field.

Due to the goal of this research, the EM method is accepted to help calculate and predict the energy consumption of the buildings in Taipei. It may be worth mentioning, in passing, that the research using the bottom-up method is very rare in Taiwan, thus, it is a huge niche to introduce this method.

A technical two-phase research method is built to explore the solution of a sustainable transformation mechanism for Taiwan’s cities.

In order to compensate for the loss of fundamental researches involved in the general energy performance of different kinds of buildings in Taiwan and help to recognize better strategies and give guidelines for how to reduce the energy use of buildings, the methods should be able to understand, analyze and predict the energy usage of buildings in different situations and at different scales. The flexibility and predictability of technical methods make them become the best choice.

Therefore, a two-phase study is designed to address the questions in this research. The first phrase evaluates energy performance of different building types, building groups, blocks and districts using the bottom-up EM method. Through the simulation, general energy consumption types would be presented. Moreover, the model would help to indicate potential variables of the buildings. In the second phase, numerous models are created and examined for various variables both at building and urban scales. Furthermore, the differences between the performance of original and experimental models would be compared and discussed. After analyzing the differences, suggestions with comprehensive strategies for the architectures of Taipei would be concluded.

Advanced multi-tools formed by VirVil Pluging, SketchUp and HTB2 satisfy the requirements of modelling in this research.

Technical tools for analysis and prediction of energy performance of buildings and sustainable design are abundant. Based on the comparison results of Alexander's research (2003), HTB2 is one of the most precise calculation engines. Moreover, SketchUp would be used to build 3D models due to its wide acceptability and usability. In addition, Virvil Plugins was developed to connect these two tools. In other word, Virvil Plugins extends the capability of HTB2 to run at a bigger scale. On the other hand, the scope of this research is not only for buildings, but also for blocks and districts. The application of multi-tools avoids the data loss caused by information transformation among technical tools.

Chapter 5

FUNDAMENTAL RESEARCH INTO ENERGY PERFORMANCE

TO UNDERSTAND AND ANALYZE THE ENERGY PERFORMANCE
OF DIFFERENT BUILDINGS AT DIFFERENT SCALES IN AN EXISTING
ENVIRONMENT - THE EXAMPLE OF TAIPEI

FUNDAMENTAL RESEARCH INTO ENERGY PERFORMANCE

5.1 Introduction

This chapter focuses on answering the research question: “The lack of fundamental research related to the energy performance of architectures, and the ignorance of urban design in the planning system of Taiwan, make the development of cities uncontrollable. Are there any advanced research tools or methods which can help correct this shortfall?”

Sustainable development has only recently come to the public’s attention in Taiwan. The related research and actions are still at an early stage, including practical measurement of energy performance of buildings and regional investigation related to architectures. Although some evaluation systems and green building regulations have been officially legalized by adopting and transforming them from developed countries, such as the UK, US, Japan and Canada, a lack of fundamental research involved in Taiwan’s practical situation still exists. In particular, the shortage of the energy use distribution of different building types seriously hinders researches involved in sustainable development.

Therefore, this chapter aims to apply technical tools to simulate several prototypes and models by integrating HTB2, Virvil Plugins and SketchUp to compensate the lack of research involved in energy use of buildings. The simulation process presents logical to set up prototypes and building models to understand and analyze the energy performance of general buildings in Taipei (Figure 5.1). Additionally, the simulation results explain the fundamental energy consumption of different building types and the differences among various building groups or blocks.

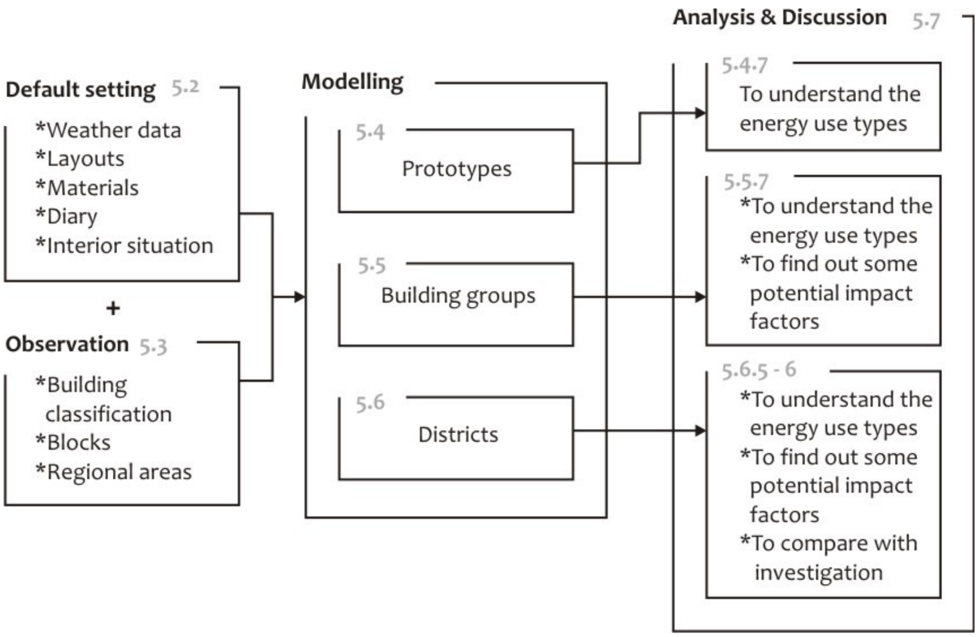


Figure 5.1 Framework of modelling in phase one.

5.2 Default setting for Simulation

Computer simulation has been extensively applied as the most important tool to understand and analyze the energy performance of buildings and cities. However, most of the research related to Taipei's built environment still uses traditional methods, such as formula calculation and hand-drawn analysis. These studies are limited by technical problems and cannot make dynamic and complicated calculations. Due to the huge lack of basic research involved in building performance in Taipei, it is necessary to obtain a basic understanding of buildings in Taipei City through the application of technical tools. The process of simulation starts with the background and default settings of prototypes and then extends to larger scales.

As mentioned in the previous chapter, HTB2 is the main engine to calculate the energy use of buildings in this research. In order to satisfy the requirements of the technical tool (Figure 4.10), this section will introduce them in three aspects. The first is the weather background, which includes the outdoor temperature, humidity, wind speed and related meteorological information. The second part concerns the materials, layout and construction of buildings. Third, the interior condition includes the setting of services and diary.

5.2.1 Background of weather

The first stage of the default setting process should consider the geographic location, topographic features, and climatic characteristics of Taipei. Those required data can be collected from several official institutions, including Google Earth, the U.S. Department of Energy, and the Central Weather Bureau of Taiwan. The U.S. Department of Energy (2011) asserted that their weather data around the world has been recorded on a real-time basis and made hourly since 1994.

Some critical characteristics of the subject are drawn by Ecotech (Autodesk 2010); the low latitude makes buildings in Taiwan can accept solar radiation from all directions (Figure 5.2); the wind mainly comes from the East (Figure 5.3); the extreme high temperatures (Figure 5.4) and high relative humanity (Figure 5.6) are two main characteristics of the weather style. Additionally, the high cloud cover depicts highly active convection of the air in Taipei (Figure 5.5).

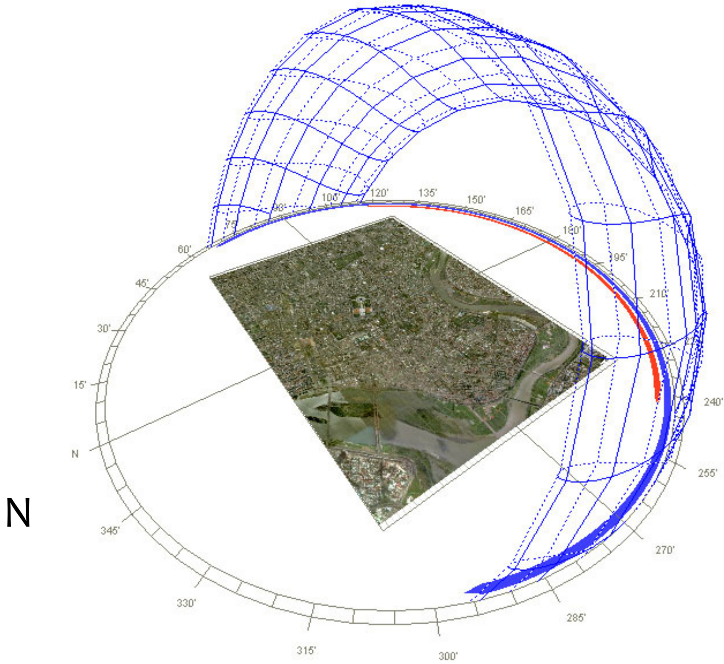


Figure 5.2 The sun path diagram of Taipei. (Source: Ecotech 2010)

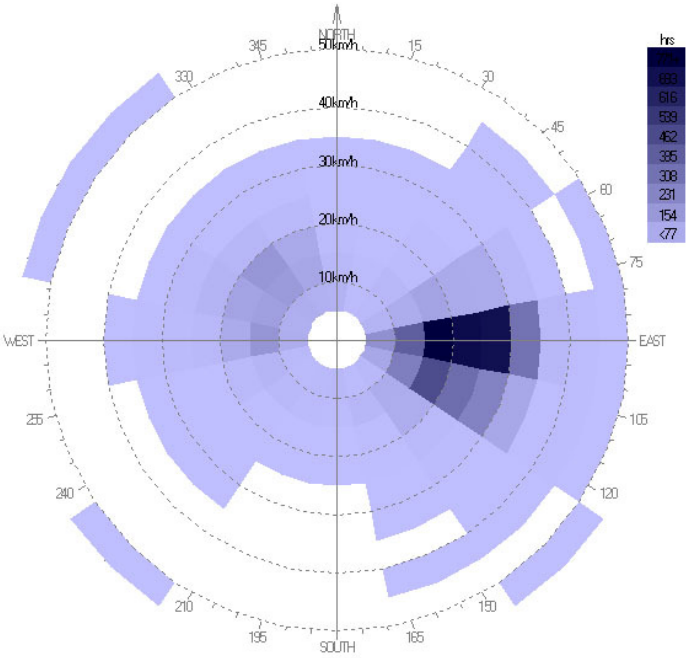


Figure 5.3 Prevailing winds in Taipei. (Source: Ecotech 2010)

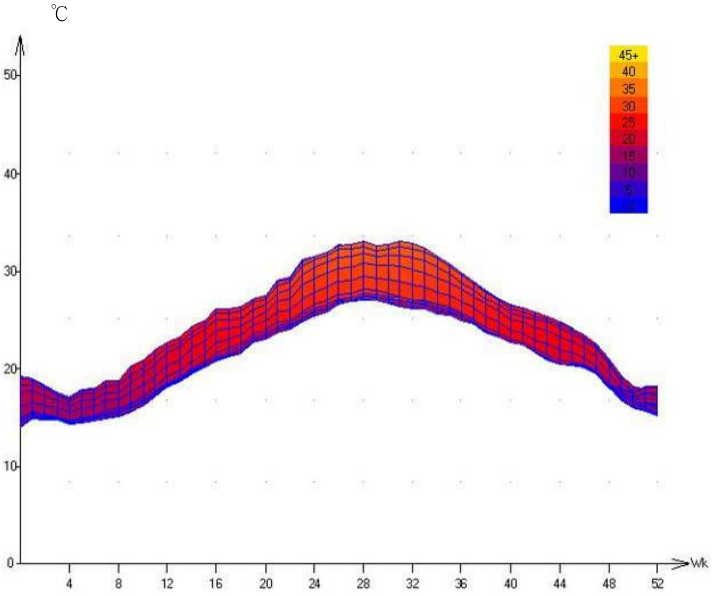


Figure 5.4 Annual temperature change (℃) of Taipei. (Source: Ecotech 2010)

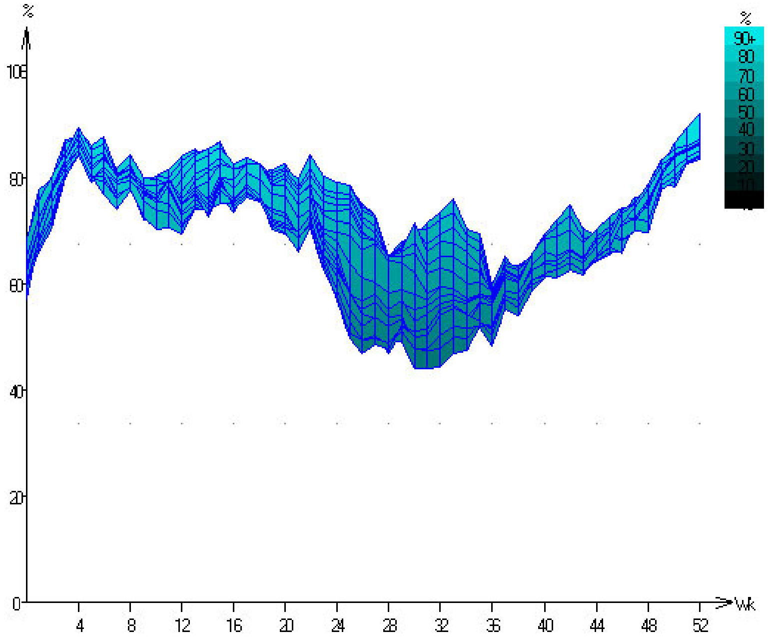


Figure 5.5 Cloud cover of Taipei. (Source: Ecotech 2010)

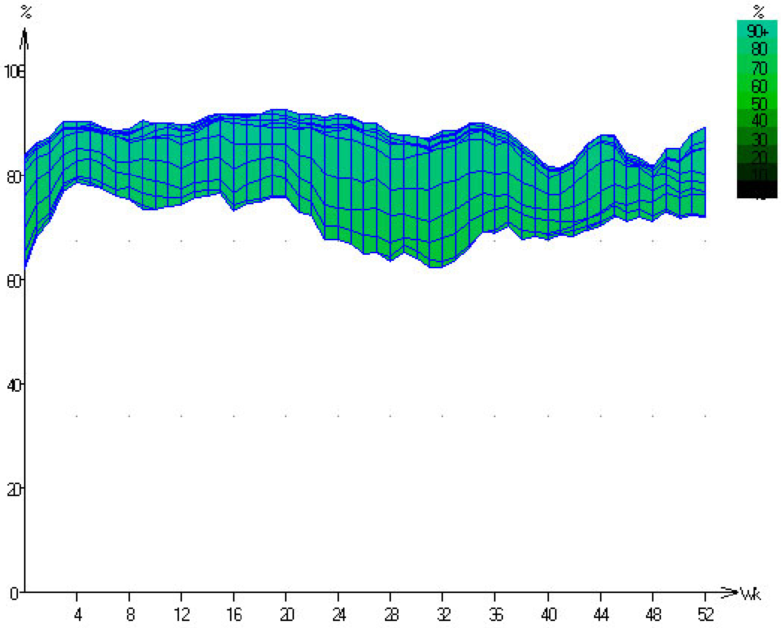


Figure 5.6 Relative humidity (%) of Taipei. (Source: Ecotech 2010)

5.2.2 Layouts, construction and materials of buildings

The materials, construction and layouts of buildings are determined according to the national statistics of Building Construction in Taiwan (DGBAS 2002 and 2011), including the numbers of issued permits for occupancy, building, and demolition. These data indicate the construction development history and general usage in Taiwan. In addition, the data would be adopted from the year 1999 onwards, from which point the new building classification system was applied in Taiwan. Moreover, the Technical Handbook for Green Building Design in Taiwan (Architecture and Building Research Institute, ABRI 2005) summarized general fundamental information, including façade materials, glazing ratio, and lighting tools usage. All of these basic data would be transformed as the default settings of models (Table 5.1 & 5.2). The representativeness of construction details

Building type	Construction	U-Value (W/m^2.℃)	Material	Thickness (mm)
Commercial & Industrial	External Wall (from external to internal)	1.15	Cement mortar	8
			Foamed concrete 730	120
			Cement mortar	15
	Internal wall	2.09	Cement mortar	10
			Standard sintering shale hollow brick	150
			Cement mortar	10
	Window (from external to internal)	2.80	High-transparent Low-E Glass	6
			Cavity	12
			Glass	6
	Standard floor slab (from up to down)	3.59	Fine aggregate concrete 2300	30
			Reinforced concrete	100
			Cement mortar	20
	Roof (from up to down)	1.01	Fine aggregate concrete 2300	40
			Cement mortar	10
			XPS plate	20
			High polymer waterproof sheet	3
			Cement mortar	10
			Reinforced concrete	120
			Cement mortar	10
	Ground (from up to down)	0.77	Fine aggregate concrete 2300	30

			Reinforced concrete	100
			Earth	1200
Assembly, Commercial, Institutional, Residential & Others	External Wall (from external to internal)	3.34	Glazed brick	10
			Cement mortar	15
			Reinforced concrete	150
			Cement mortar	10
	Internal wall	3.70	Cement mortar	10
			Reinforced concrete	120
			Cement mortar	10
	Window	5.41	6mm window glass	5
	Standard floor (from up to down)	3.54	Glazed brick	10
			Cement mortar	15
			Reinforced concrete	120
			Cement mortar	10
	Roof (from up to down)	1.16	Fine aggregate concrete 2300	40
			Cement mortar	10
			XPS plate	16
			High polymer waterproof sheet	3
			Cement mortar	10
			Reinforced concrete	120
			Cement mortar	10
	Ground (from up to down)	1.13	Glazed brick	10
			Cement mortar	15
			Reinforced concrete	200
			SBS modified asphalt rolling material	3
			Fine aggregate concrete 2300	60
			Earth	600

Table 5.1 Detailed construction information for different buildings (ABRI 2005).

Building type	Glazing ratio
Assembly Commercial Industrial Institutional	60 %
Residential Others	30 %

Table 5.2 Default setting of glazing ratio for different buildings (Lin 2009a).

5.2.3 Diary and interior condition

First of all, the internal condition setting is related to lighting, small power, occupancy, cooling and heating. Except setting the operation period of lighting and small power facilities, it is necessary to calculate their heat output because the heat output of lighting, small power and occupancy should be calculated together with outdoor impacts, including solar gain, ventilation, and fabric gain to decide the overall cooling and heating demand. The data related to the interior environment would be defined based on the Design and Technique Directions for Energy Saving of Buildings (CPAMI 2011), Urban and Regional Development Statistics (UHDD 2008), practical investigation (Chen 2006 & Kao 2005), and the CIBSE Guide A (2006). There are two reasons to adopt CIBSE standards; the first is there is no official benchmarks in Taiwan at the moment, and the second is the default setting of models in the majority of previous researches were defined according the ones of developed countries.

Take commercial buildings for example. According to the national statistics (DGBAS 2011), the average density of commercial buildings in Taipei is 0.1 person per m^2, namely 10 m^2 per person. And because of the lack of benchmarks about occupancy and small power in Taiwan, CIBSE is taken as a reference. Corresponding heat outputs of occupancy and facilities can be checked in the CIBSE Guide A (2006) (Table 5.3). Furthermore, based on the statistics, the average lighting usage of commercial buildings is 66.18 kWh/m^2/yr, and the heat output is equally 15.15 W/m^2 (see the following formula). Therefore, the total incidental gain for commercial building is 47.25 W/m^2 (Figure 5.7). In the same way, the incidental gain of industrial, residential and other types of buildings could be defined (Table 5.4).

Factor		Heat gains (W/m^2)					
Density (m^2/ person)		4	8	**10**	12	16	20
Sensible heat gain	People	20	10	**8.35**	6.7	5	4
	Equipment	25	20	**17.5**	15	12	10
	Lighting	12	12	12	12	12	12
Latent heat gain		15	7.5	**6.25**	5	4	3
Total heat output for occupancy = (Sensible heat gain - People) + (Latent heat gain), Ex. 8.35 + 6.25 = 14.6							

Table 5.3 Internal heat gains for a typical office (UK). (Source: CIBSE 2006)

(Lux: Lm/m^2) x (Operation time through a year: hr/yr) / (luminous efficacy: Lm/W x luminaire efficiency) = (Electricity requirement: kWh/m^2/yr) = (Heat output: W/m^2) (Lin 2009b)

Commercial: 800 x 84 x 52 / (66 x 80%) Whr/m^2/yr = 66.18 kWh/m^2/yr (= 15.15 W/m^2)
Residential: 150 x 60 x 52 / (47 x 60%) Whr/m^2/yr = 16.60 kWh/m^2/yr (= 5.32 W/m^2)

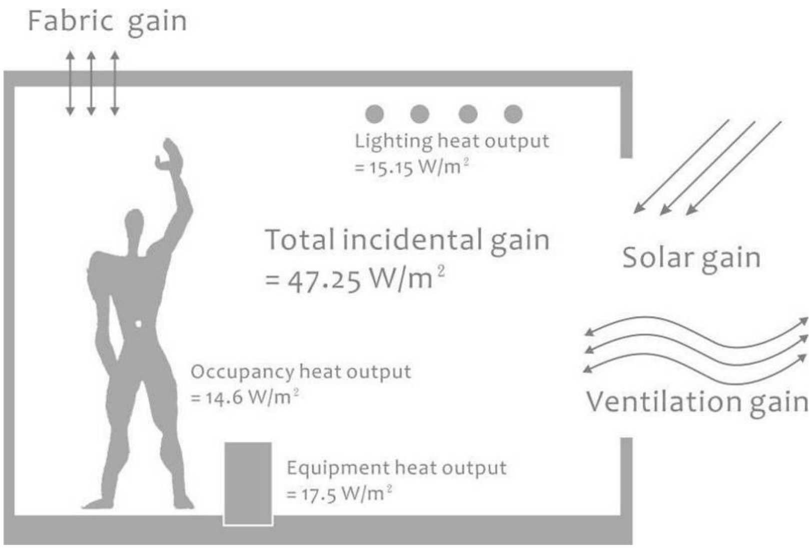


Figure 5.7 The interaction of outdoor and internal heat gains of commercial buildings in Taiwan.

Secondly, the "diary", referring to the time setting of heating and cooling systems, lighting, small power, ventilation, and occupants' activities during the examination period of simulation, was partially defined through practical investigation done by previous researchers (Ku 2003a; Ku 2003b; Kuo 2005; Lai 2007; Lin 2003). The working hours in Taiwan are normally much longer than western countries. Moreover, the operation hours of facilities in commercial and industrial buildings would not pause at weekends. The detailed information for all kinds of buildings can be checked in Table 5.4.

	Heating / cooling	Incidental gains (from lighting, small power and occupancy)		Ventilation	
	Design temperature & operation schedule	Output power	Operation schedule	Weekday	Weekend
Assembly	18-23℃ Monday to Sunday: 08:00-20:00	47.25 W/m^2	Monday to Sunday: 08:00-20:00	0.5, 2.0, 2.0, 26℃ On during 08:00-20:00	On during 08:00-20:00
Commercial					
Industrial		35.00 W/m^2			
Institutional					

Residential	18-26℃ Monday to Friday: 00:00-08:00 & 18:00-24:00; Saturday to Sunday 00:00-24:00	13.32 W/m^2	Monday to Friday: 00:00-08:00 & 18:00-24:00; Saturday to Sunday 00:00-24:00	0.5, 1.0, 1.0, 26℃ On during 00:00-08:00 & 18:00-24:00	On during 00:00-24:00
Others					

Table 5.4 The default settings of interior condition and diary of different building groups (Ku 2003a; Ku 2003b; Kuo 2005; Lai 2007; Lin 2003).

5.3 Observation of the architecture environment in Taipei

The architecture environment covers numerous aspects, including building forms, building usage, block attributes, urban fabrication, and related building information. This section focuses on the issue with an observation of buildings at building and regional scales.

5.3.1 Observation of buildings

Wang et al. (2012) clearly indicated that the biggest problem for doing research involved in the architectures and built environment in Taiwan is the lack of fundamental data. For calculating ecological footprints for individual building or communities or offering practical sustainable strategies for a whole city, this lack of data presents one of the most enormous disadvantages. In order to solve the problem, the next step is to begin with the classification and definition of building categories.

For building classification, the widely accepted procedure is to undertake a study of building usage type and occupancy, which can be seen in the building code of the E.U., International Building Code of the U.S. (ICC 2006), and most regulations in Asian countries. In Taiwan, the same concept is shared in most official documents and research. Naturally, there are also other different classifications for specific purposes, such as fire safety and cooling load. Lin and Wang (2005) regrouped buildings depending on their prediction of cooling usage and building space volume

(Table 5.5). However, the disadvantage of such cataloguing is that the materials and other building characteristics of one group are various, which creates difficulties when attempting to set up a model for simulation.

Building type		Example
Buildings with heavy cooling load	Office	Office, bank, government
	Department	Department, shopping mall, stores
	Hotel	Hotel, Motel
	Hospital	Hospital
Residential buildings		Community, apartment, dormitory
Schools		Cram school, kindergarten, classroom
Buildings with big volume		Assembly – stadium, concert hall Transportation – terminal, station Amusement – KTV, pub Culture – Museum, library Religion – Temple Others – Restaurant, gyms
Others		Factory, warehouse

Table 5.5 Building classification according to their different energy using types. (Source : Lin and Wang 2005)

According to the latest version of the Building Technique Regulation (CPAMI2012), there are nine different groups of building, including Assembly, Commercial, Industrial and Storage, Leisure and Educational, Religion, Health and Welfare, Office, Residential, and High Hazard. However, these building classifications are not suitable for this research because the original purpose of the regulation was to control building design, not for energy analysis. Thus, there are too many scattered and dedicated pieces of information existing in each group. On the other hand, residential buildings are the most common building units in Taiwan and it is unreasonable to regard them as one type. The same problem occurred with commercial buildings. Through the process of re-gathering and re-classification, the results are shown in Table 5.6. In the following research, the analysis of related data and the default setting of buildings in the modelling of this research will be according to the new classification.

Source	International Building Code (U.S.) (ICC 2012)	Code for design of civil buildings (China) (MOHURD 2005)	Building Technique Regulation (Taiwan) (CPAMI 2012)	Prototypes (This research)
Building groups	Assembly	Stadium Transportation Cultural (e.g. theatre, museum, library)	Assembly	Assembly
	Business	Commercial	Commercial	Commercial-Large (e.g. department, office building)
		Public (e.g. office building)	Office	
		Science		
		Legislation		
	Mercantile (e.g. department, grocery, gas station)	Composition	Commercial (cont.)	Commercial-Small (e.g. convenient store)
	Factory	-	Industrial and Storage	Industrial
	Storage (e.g. warehouse, parking space)	-		
	Educational	-	Leisure and Educational	Institutional
	Institutional (e.g. hospital, prisons)	-	Religion Health and Welfare	
		Hospital		
	Residential	Residential	Residential	Residential-Large
		Dormitory		Residential-Medium
				Residential-Small
	High-Hazard	-	High Hazard	Others
	Utility and Miscellaneous (e.g. water storage)	-	-	
	-	Memorial	-	
	-	Garden	-	

Table 5.6 The comparison of building classifications. (Source: Shown in the table)

5.3.2 Observation of the districts

Taipei is the capital city of Taiwan, which has been economical and political centre since the era of the Japanese Empire. There are more than 2.6 million people living in the city and the density currently reaches 9,635 per km^2. Combined with New Taipei City, the population of the metropolis was close to seven million people in 2012 (Figure 5.8).

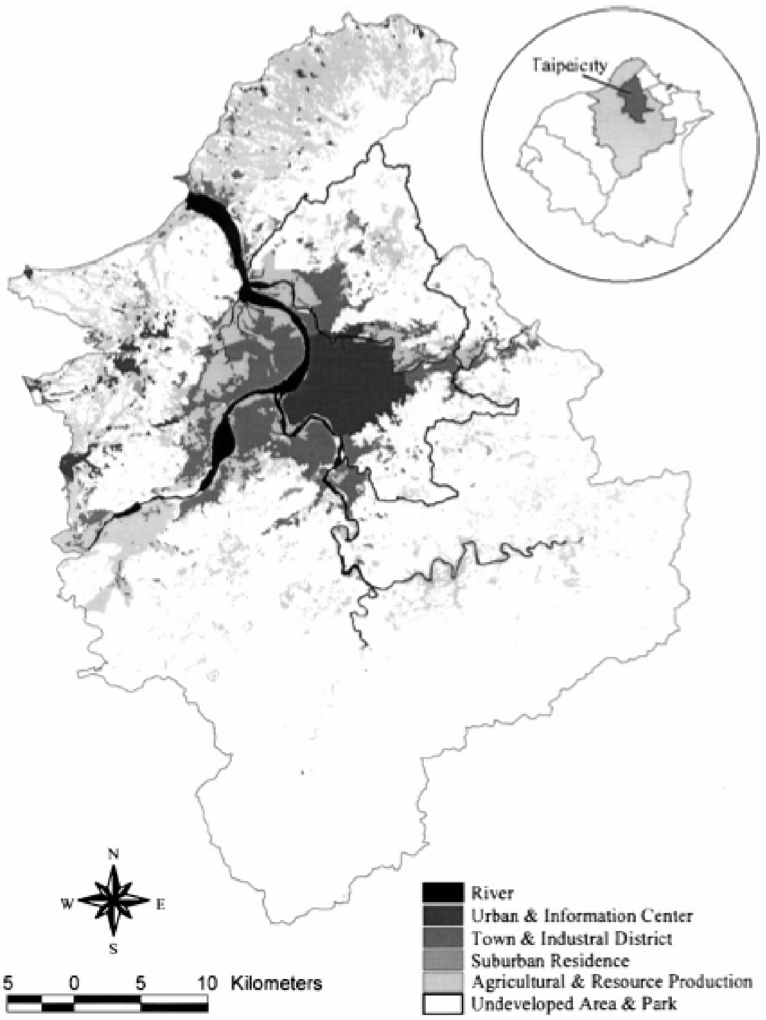


Figure 5.8 Regional context and land use of Taipei Metropolitan Region. (Source: Huanga et al. 1998)

Taipei is a city which gives a unified impression because of the oriental culture and living habits. The most important characteristic of the oriental living environment is that people get used to living in a complete integrated environment. Houses, Shops, a school, restaurants and other facilities needed for life would be mixed within a circle of walking distance, which will naturally obscure the boundaries of new and old land and building usage. The co-existence of modern and traditional buildings or residential and commercial buildings is commonly seen through the city.

Although the unified impression of the city exists, along with the urban sprawl and historic development, Taipei is politically divided into twelve districts (Figure 5.9) and there are recognizable differences of the urban fabrication and building characteristics in them.

District			Population	Area
Hanyu Pinyin	漢字	Wade-Giles	as of 2009	km²
🟩 Běitóu	北投區	Pei-t'ou	249,319	56.8216
🟧 Shìlín	士林區	Shih-lin	285,459	62.3682
🟦 Dàtóng	大同區	Ta-t'ung	124,466	5.6815
🟥 Zhōngshān	中山區	Chung-shan	218,551	13.6821
🟧 Sōngshān	松山區	Sung-shan	209,903	9.2878
🟦 Nèihú	內湖區	Nei-hu	267,120	31.5787
🟩 Wànhuá	萬華區	Wan-hua	190,050	8.8522
🟥 Zhōngzhèng	中正區	Chung-cheng	159,464	7.6071
🟨 Dà'ān	大安區	Ta-an	313,371	11.3614
🟩 Xìnyì	信義區	Hsin-yi	227,232	11.2077
🟥 Nángǎng	南港區	Nan-kang	113,462	21.8424
🟪 Wénshān	文山區	Wen-shan	261,523	31.5090

Figure 5.9 The district division of Taipei City and related basic information. (Source: Taipei City Government 2010)

Wan-hua district is located in the South-west region of Taipei, which runs alongside the Tam-sui River (Taipei City Government 2010). As the earliest development area, Wan-hua owns various traditional heritages and attractions, such as the Hsi Men Ting neighbourhood and Lung-shan Temple. Thus, the urban pattern and building forms are in the typical style of older areas, making it a good selection for one of the experimental models in this research. Chung-cheng and Ta-an districts are political centres, which were planned according to a mechanical master plan with roughly vertical and horizontal broadways (ibid.). These two districts can be seen as extensions of Wan-hua district. Therefore, the mixture of modern and traditional development is obvious in their blocks. On the right (east) side of them, the Hsin-yi district is a new economic region for business, which is famous for its prevailing high buildings and towers, including the previous highest building in the world, Taipei 101 (ibid.). This development model had been copied by Nei-hu district and other counties in Taiwan. Chung-shan and Sung-shan districts were planned in a relatively stricter way with vertical and horizontal broadways (ibid.). The modern residential community is one of the area's characteristics. On the other hand, the rest of the districts are partially mixed with natural resources. Nan-kang district is located on the east side of Taipei with a long history as a port. However, the region’s economic advantage has been lost. Due to the limited living areas, Nan-kang has much fewer opportunities to transform into a modern place. Unlike Nan-kang district, Nei-hu is a developing district for high-tech business (ibid.). Massive buildings containing companies’ head offices have sprung up rapidly. The majority of them are the design interpretation of the Taiwanese preferred curtain tower. Lastly, the rest of the three districts, Pei-t'ou, Shih-lin, and Wen-shan, are areas mostly covered by natural environments.

Judging from the above, different areas present different local characteristics of buildings. According to them, this research selects one block in Hsin-yi, Ta-an, Shih-lin, Wan-hua and Nan-kang districts individually as experimental subjects for simulation at block scale. Moreover, this research select some blocks in Chung-Shan, Ta-an, Sung-Shan districts and one big area of Ta-an District as experimental subjects for the regional scale modelling. Due to the requirement of the bottom-up research method, the main reason to choose these subjects is that they are the most typical areas which can depict the general situation for their types in Taipei.

5.4 Simulation for building prototypes

Following the building classifications defined in the previous section (Table 5.6), there are nine prototypes; Assembly, Commercial-Large, Commercial-Small, Industrial, Institutional, Residential-Large, Residential-Medium, Residential-Small, and Others (Figure 5.10). The default settings of building layouts are based on general volume, most popular construction type, regular diary, and average heating and cooling usage. More specific information for each building would be introduced in the following sections.

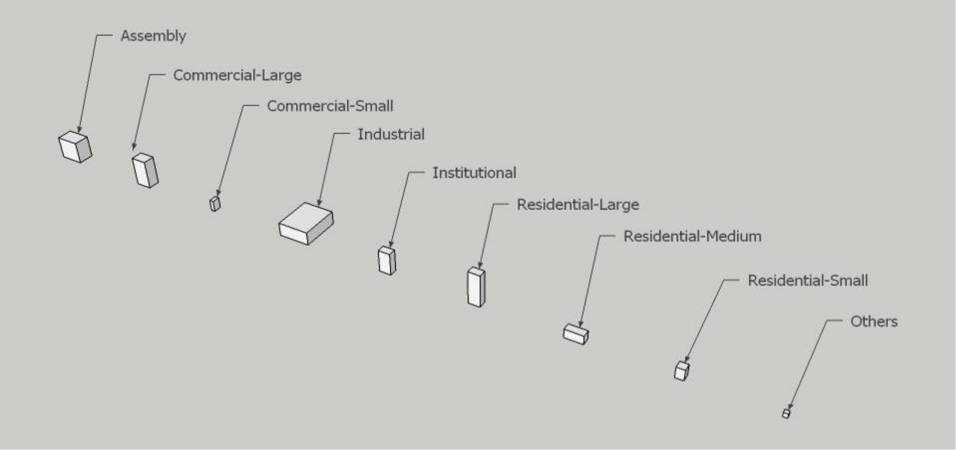


Figure 5.10 The 3D models of nine prototypes: Assembly, Commercial-Large, Commercial-Small, Industrial, Residential-Large, Residential-Medium, Residential-Small, and Others (from left to right).

For each part in the following sections, an introduction of the default settings involved in volume and floor plan of the building prototypes, and an image of the real buildings in that group, heads the presentation. Then, a drawing of the prototypes from two main directions by SketchUp 8 (Google 2010) would be shown, whose facades are marked by VirVil plugins v1.3 (WSA 2012) to show different orientation; east in deep green, south in bright red, west in bright green, north in dark red, south-eastern in orange, south-western in bright yellow, north-eastern in grass green, and north-western in light green (Figure 5.12). Afterward, the results of the simulation are presented at the end. From the results, the average figures of prototype's solar gain, heater gain, ventilation and related data can be clearly seen. Lastly, after completing the description of these nine prototypes, the overall analysis and discussion would be presented at the end.

5.4.1 Assembly

The assembly group represents theatres, museums, bus stations, train stations, market places and other spaces where people would gather frequently or rarely (Figure 5.11). Although assembly buildings are diverse, one general building prototype is still needed. According to the national statistics of Building Construction in Taiwan (Directorate General of Budget, Accounting and Statistics, DGBAS 2002 and 2011), the average area of an assembly building constructed between 2006 and 2010 was 103,058 m^2. By considering the average number of projects, the average volume of the projects can be calculated as 5,906 m^3. And the majority of these buildings are approximately 10-storeys high. Thus, a simple cuboid, 30 meters long, 20 meters wide and 10 storeys high is created as a prototype (Figure 5.12). The detailed layout materials of the construction and indoor conditional settings are based on the analysis and calculation of related data and local social culture and living habits (Table 5.1 to 5.4).

Figure 5.11 A practical case of an Assembly building: The Taipei New Theatre. (Source: TPE Film Commission 2013)

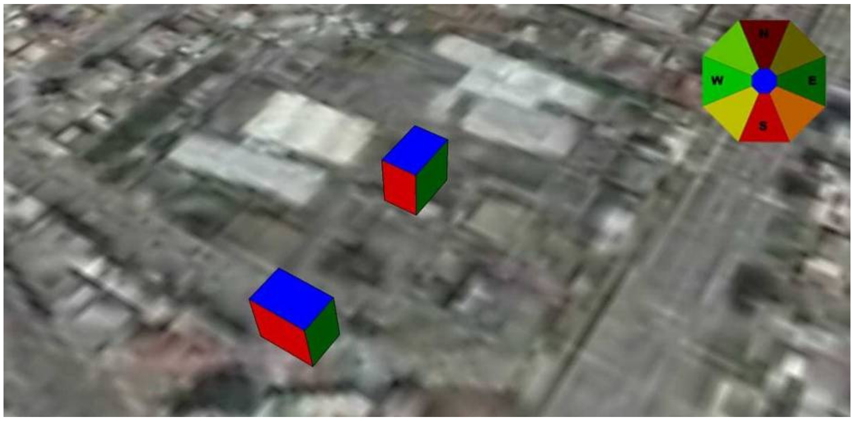


Figure 5.12 Assembly prototypes in two main directions.(Orientation of each façade is marked by VirVil Plugin; deep green for east, bright red for south, bright green for west, dark red for north, orange for south-east, bright yellow for south-west, grass green for north-east, light green for north-west.) (Below is Bld_1; above is Bld_2.)

The modelling results present the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.13 & 5.14). First of all, incidental gain, referring to the summation of interior space heat gains from lighting, small power, and occupancy, dominates the heat sources throughout the whole year. Second, solar gain is the second major factor to heat buildings, which is roughly one fourth of incidental gain monthly. Third, fabric gain, referring to the conduction of heat across the fabric surfaces of the testing spaces and ventilation gain, referring the total energy movement involved in ventilation and infiltration, fluctuate through a year. From November to April, they assist buildings to release heat gathered from solar and incidental sources. From May to October, the heat coming from buildings reverses direction and makes the buildings warmer, which would be mostly balanced by cooling. Fourth, the figures show that there is a big requirement for cooling in every month, particularly during the summer time. Last, for all kinds of buildings, there is no obvious requirement of heating. In short, as these diagrams indicate, for Assembly buildings, reducing the amount of incidental and cooling gains might be the biggest opportunities to save energy.

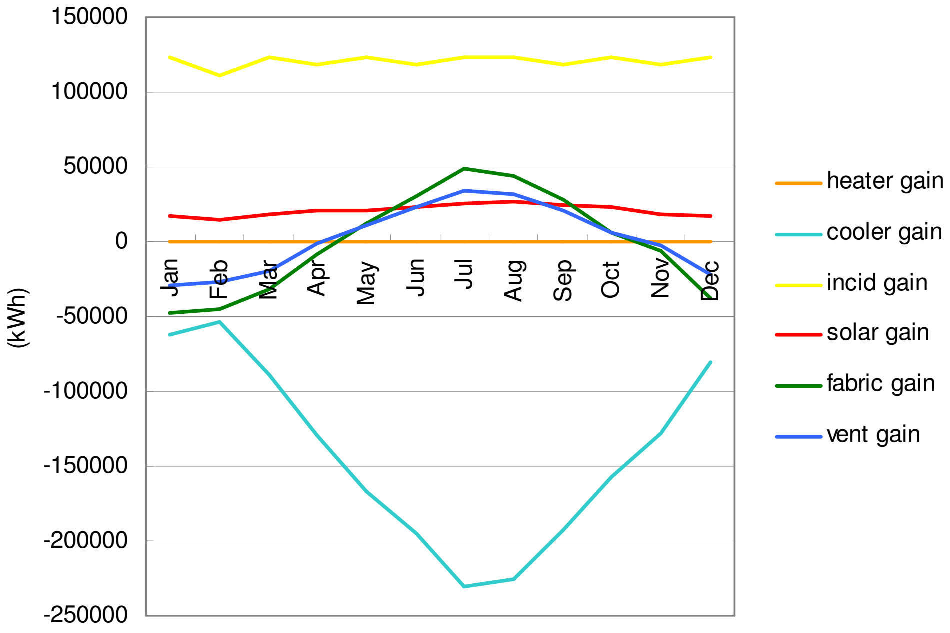


Figure 5.13 The average values of gain by sections from heater to vent for the Assembly prototype.

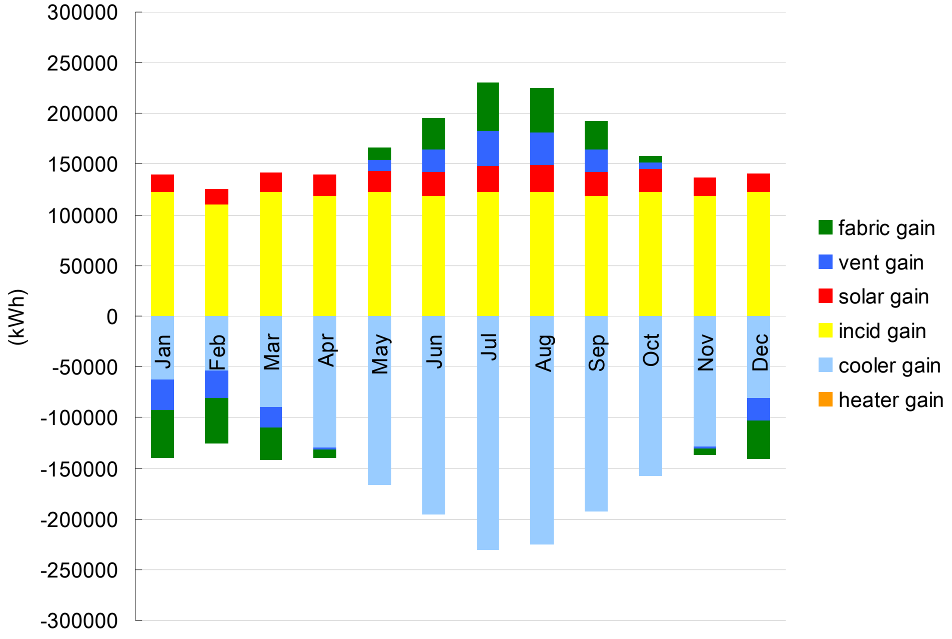


Figure 5.14 The average monthly proportion of gain by sections from heater to fabric for the Assembly prototype.

5.4.2 Commercial

After residential buildings in Taipei, commercial buildings are the second most popular building type (Figure 3.12), which contain departments, office buildings, convenient stores, banks, restaurants and any buildings involved in business and commercial activities.

5.4.2.1 Commercial-Large

According to the national statistics of Building Construction in Taiwan, the average area of commercial and office buildings from 1991 to 2010 was 9,352,500 m^2. By considering the average number of projects, the average volume of each project could be calculated as 6,263 m^3. Due to the complexity and various different sizes of commercial and office buildings, two simple cuboids are built to depict large and small volume spaces separately; one 20 meters long, 15 meters wide and 13 storeys high, and the other 5 meters long, 10 meters wide and 5 storeys high. The former group is called Commercial-Large (Commercial-L) (Figure 5.15 & 5.16).

Figure 5.15 Practical cases of Commercial-L buildings: Three bank branch offices along a main city axis of Taipei, Sung-Chiang Rd.. (Source: Google Map 2012)

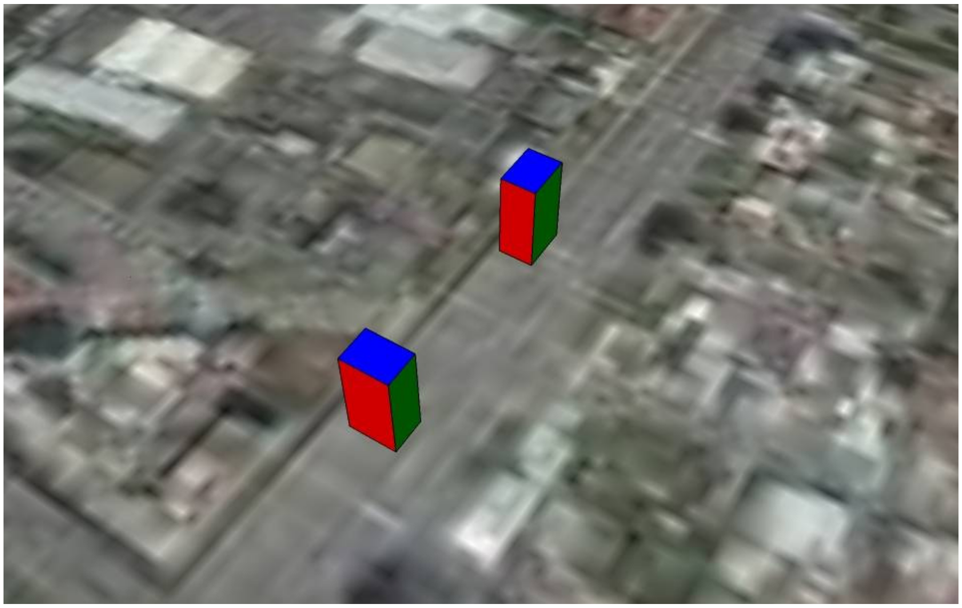


Figure 5.16 Commercial-L prototypes in two main directions. (The lower is Bld_1; the upper is Bld_2)

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.17 & 5.18). First of all, incidental gain dominates the heat sources throughout the whole year. Second, the solar gain is the second major factor to heat buildings, which is comparatively lower during the winter time. Third, the fabric and ventilation gains fluctuate throughout a year. From November to April, they help buildings to release the heat accumulated from solar and incidental sources. From May to October, they increase the total heat, which would be mostly balanced by cooling. Fourth, the figures show that there is a big requirement for cooling in every month, particularly during the summer time. Last, for all kinds of buildings, there is no obvious requirement for heating. In short, as these diagrams indicate, for Commercial-L buildings, reducing the amount of incidental, solar and cooling gains might be the biggest opportunities to save energy.

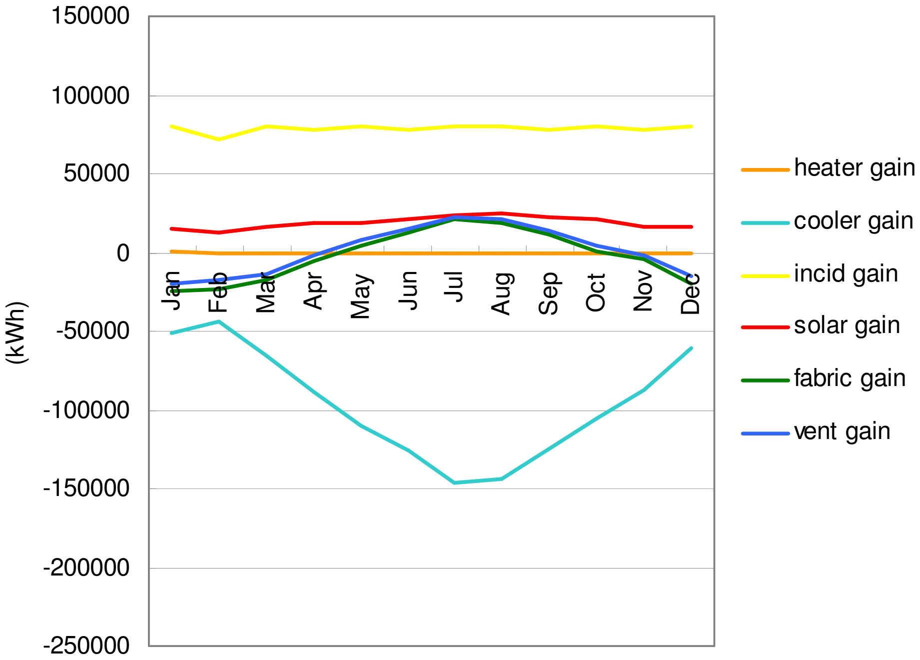


Figure 5.17 The average values of gain by sections from heater to vent for the Commercial-L prototype.

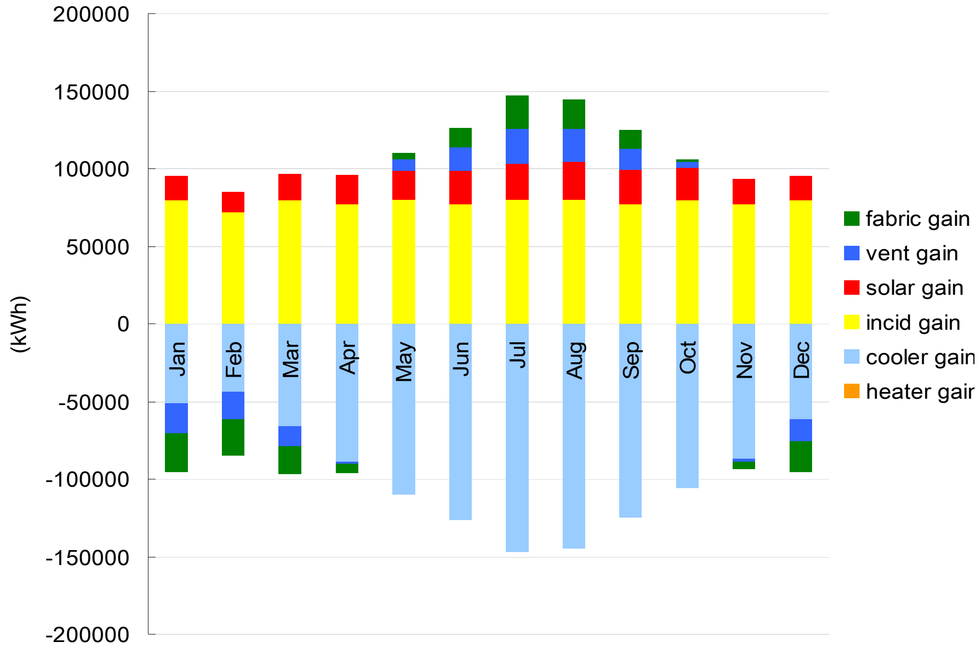


Figure 5.18 The average monthly proportion of gain by sections from heater to fabric for the Commercial-L prototypes.

5.4.2.2 Commercial-Small

Following on from the previous section, the other commercial group with smaller volume is called Commercial-Small (Commercial-S), which is attributed to be 5 meters long, 10 meters wide and 5 storeys high. These kinds of buildings are easily seen in the streets and form the basic economic units in Taipei (Figure 5.19 & 5.20).

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.21 & 5.22). First of all, incidental gain is the major heat source throughout the whole year. Second, the solar gain is the second major factor to heat buildings, which is slightly lower than incidental gain during the summer time. Third, the fabric gain is markedly different in every month. From October to April, it helps buildings to release the heat; from May to September, it increases the total heat. In contrary, the ventilation gain presents much more stable. Fourth, the figures show that there is a big requirement for cooling from April to November. Last, for all types of buildings, there is no obvious requirement of heating. In general, as these figures indicate, for Commercial-S buildings, reducing the loans of incidental, solar, fabric and cooling gains might be the biggest opportunities to save energy.

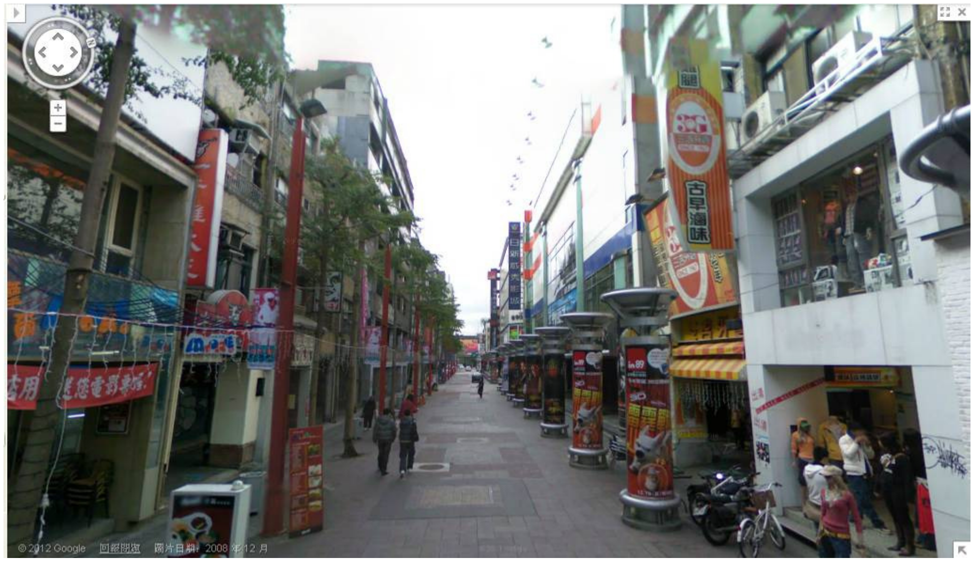


Figure 5.19 Practical cases of Commercial-S prototypes: Several stores in a popular shopping area of Taipei, Hsi Men Ting. (Source: Google Map 2012)

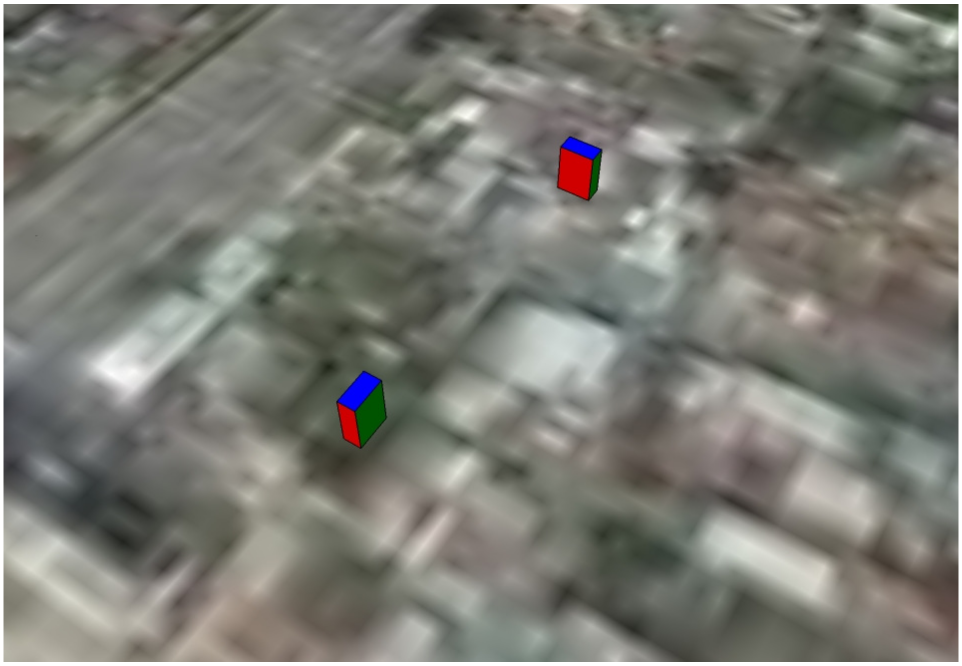


Figure 5.20 Commercial-S prototypes sited in two main directions. (The lower is Bld_1; the upper is Bld_2)

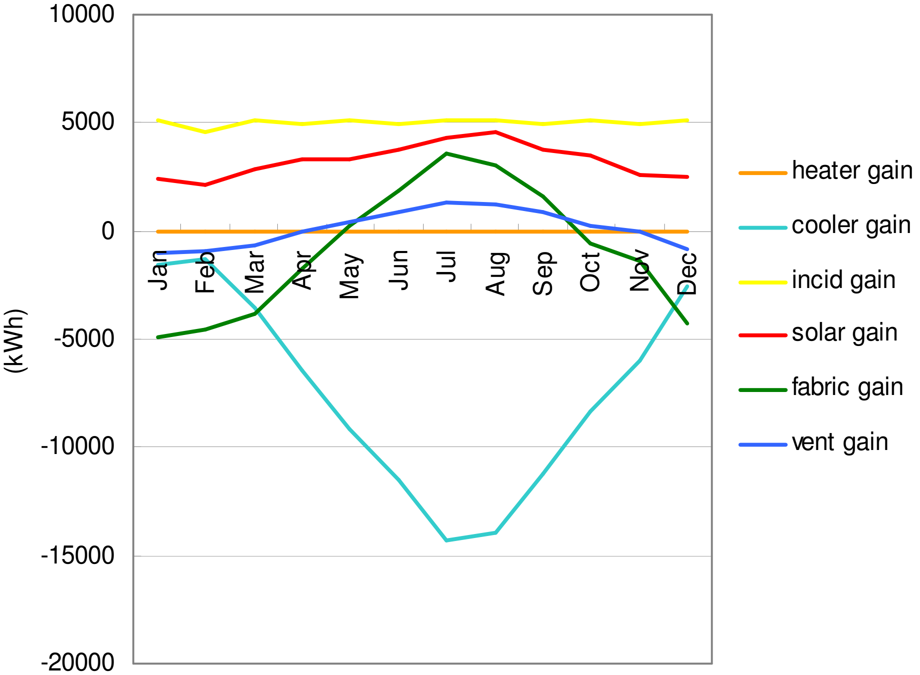


Figure 5.21 The average values of gain by sections from heater to vent for the Commercial-S prototype.

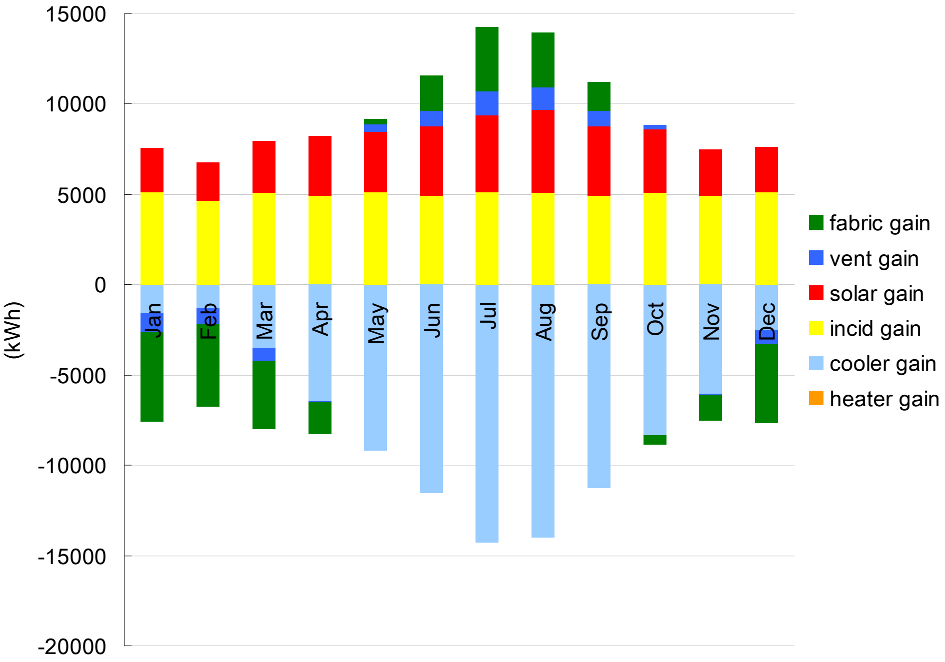


Figure 5.22 The average monthly proportion of gain by sections from heater to fabric for the Commercial-S prototype.

5.4.3 Industrial

The industrial group are the third most common type of buildings in Taipei. Due to their large space requirements, the main portion of these buildings have been built in suburban areas and nearby cities. The majority of industrial buildings in Taipei's central urban environment were built for hi-tech manufacture (Figure 5.23). According to the national statistics of Building Construction in Taiwan, the average area of industrial and storage buildings constructed from 1991 to 2010 was 4,882,965 m^2. During that time, the average number of projects and constructed units fluctuated dramatically. Therefore, the industrial buildings in Nei-hu district are used as a reference to create a simple cuboid, 40 meters long, 50 meters wide and 6 storeys high as a prototype (Figure 5.24).

Figure 5.23 A practical case of an Industrial building: the TSMC head office and manufacturing facility in the Science-based Industrial Park. (Source: Google Map 2012)

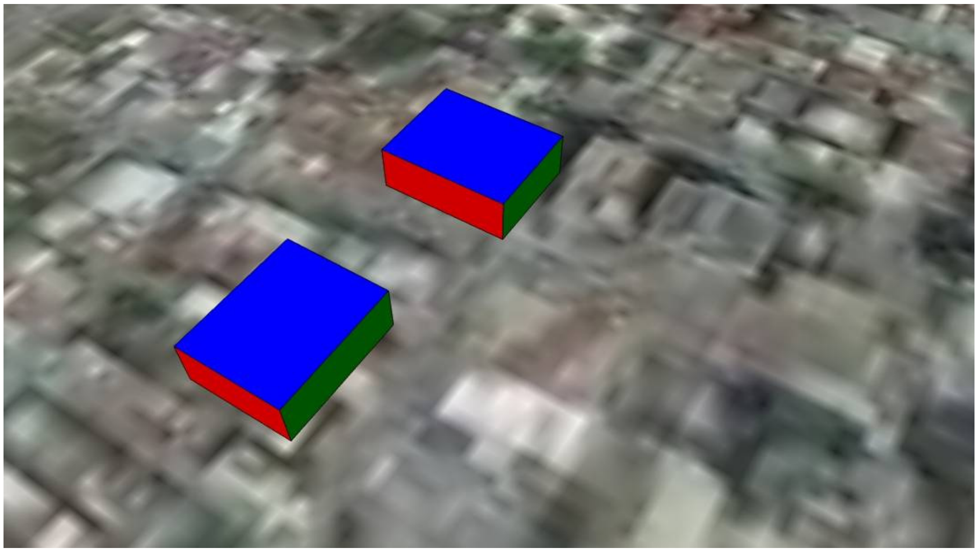


Figure 5.24 Industrial prototypes cited in two main directions. (The lower is Bld_1; the upper is Bld_2.)

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.25 & 5.26). First of all, incidental gain dominates the heat sources throughout the whole year. Second, the solar gain keeps stable, which is almost one sixth of the incidental gain. Third, the fabric and ventilation gains fluctuate throughout the year. From October to May, fabric helps to release the heat accumulated from solar and incidental sources, while from June to September it increases the total heat. Fourth, ventilation plays an important role in increasing heat during the summer time and decreasing it during the winter time. From May to September, the ventilation gain would be more than the solar gain and becomes the second major heat factor. Fifth, the figures show that there is a big requirement for cooling in every month, particularly from April to November. Last, for all types of buildings, there is no obvious requirement for heating. In short, as these diagrams indicate, for Industrial buildings in Taipei, reducing the amounts of incidental, solar, ventilation and cooling gains might be the biggest opportunities to save energy.

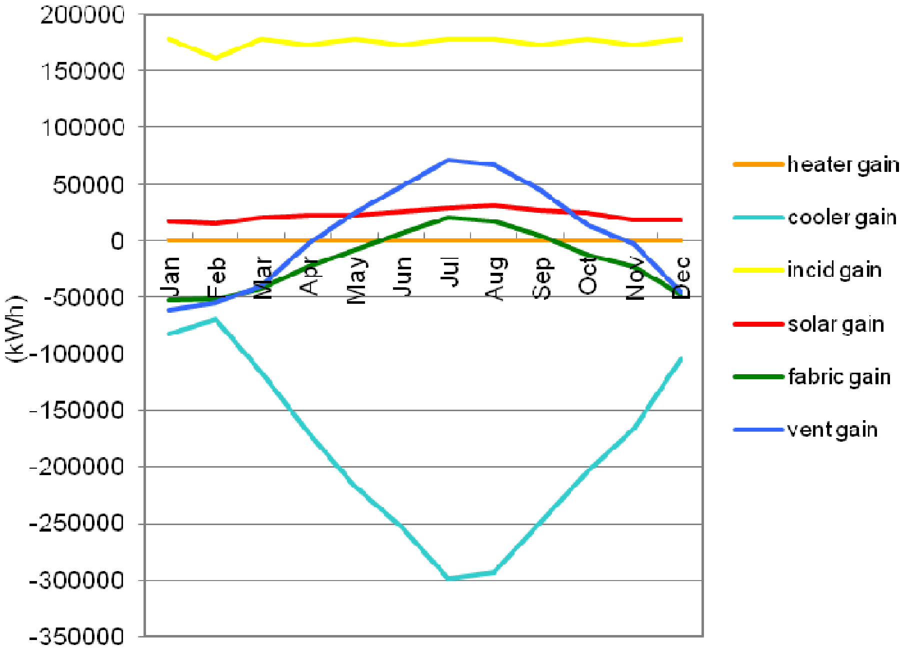


Figure 5.25 The average values of gain by sections from heater to vent for the Industrial prototype.

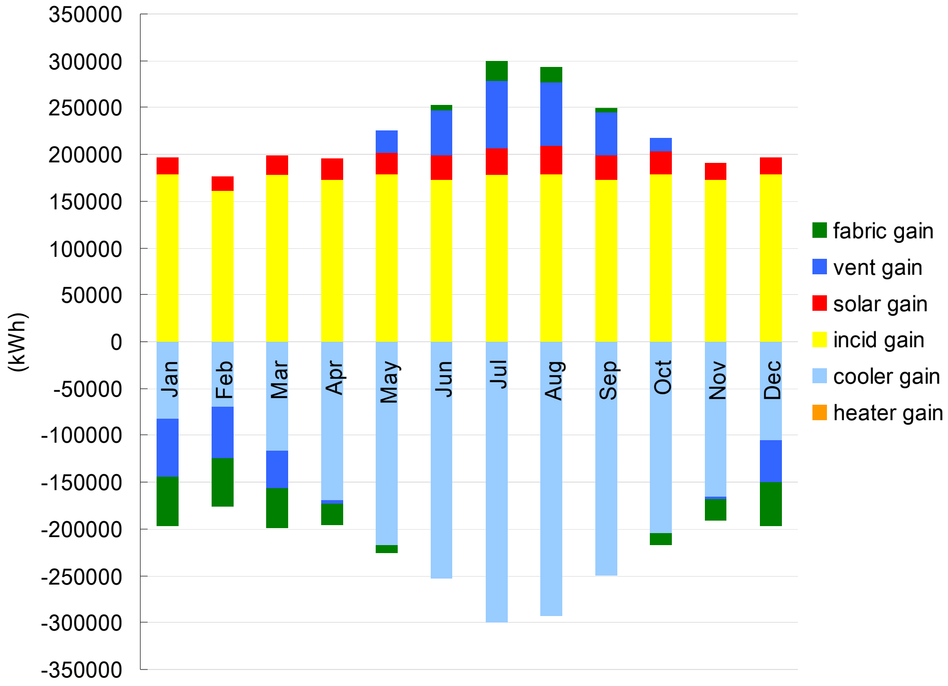


Figure 5.26 The average monthly proportion of gain by sections from heater to fabric for the Industrial prototype.

5.4.4 Institutional

Hospital and schools are examples of institutional buildings, which are set up purely for a single usage purpose and run according to a stable and regular schedule (Figure 5.27). According to the national statistics of Building Construction in Taiwan, the average area of institutional buildings constructed between 1991 and 2010 was 2,118,727 m^2. By considering the average number of projects, the average volume of the projects can be calculated as 1504 m^3. Also, the majority of these buildings are approximately 10-storeys high. Thus, a simple cuboid, 15 meters long, 10 meters wide and 10 storeys high is created as a prototype (Figure 5.28). The detailed materials and layouts of the construction would be set up exactly the same as for the assembly and residential building prototypes. However, the diary of usage is completely different (Table 5.4).

Figure 5.27 A practical case of an Institutional building: Zhong-zheng Second Police District, Taipei City Police Department. (Source: Google Map 2012)

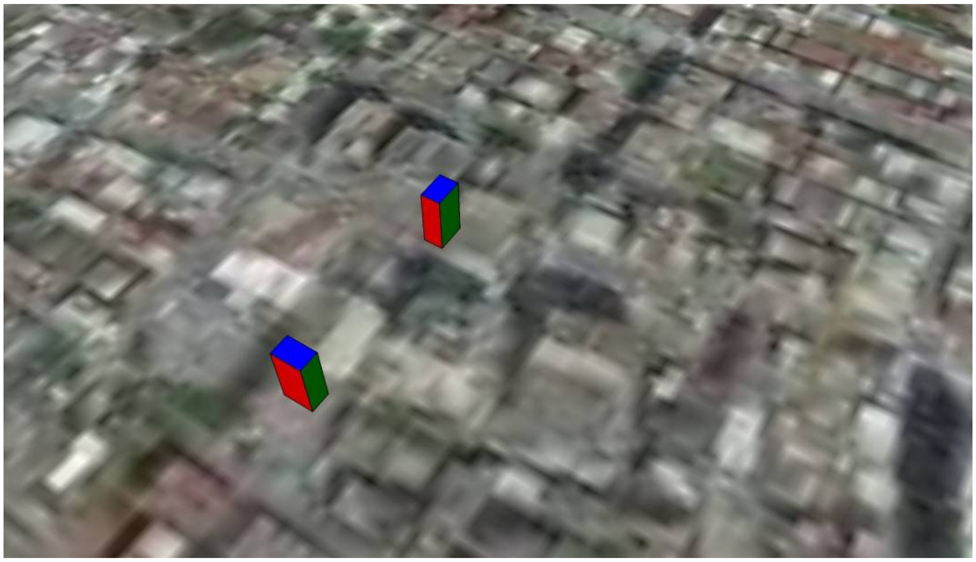


Figure 5.28 Institutional prototypes situated in two main directions. (The lower is Bld_1; the upper is Bld_2.)

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.29 & 5.30). First of all, incidental gain dominates the heat sources throughout the whole year. Second, the solar gain keeps stable, which is almost half of the incidental gain. Third, the fabric and ventilation gains fluctuate throughout the year. From November to April, fabric helps to release the heat accumulated from solar and incidental sources. From May to October, it increases the total heat. Fourth, ventilation shows comparative stability. It presents a similar effect for heat gain during the same periods of a year as fabric gain. Fifth, the figures show that there is a big requirement for cooling during the year except in the winter time. Last, for all types of buildings, there is no obvious requirement of heating. In short, as these diagrams indicate, for Institutional buildings in Taipei, reducing the amount of incidental, fabric, ventilation, solar, and cooling gains might be the biggest opportunities to save energy.

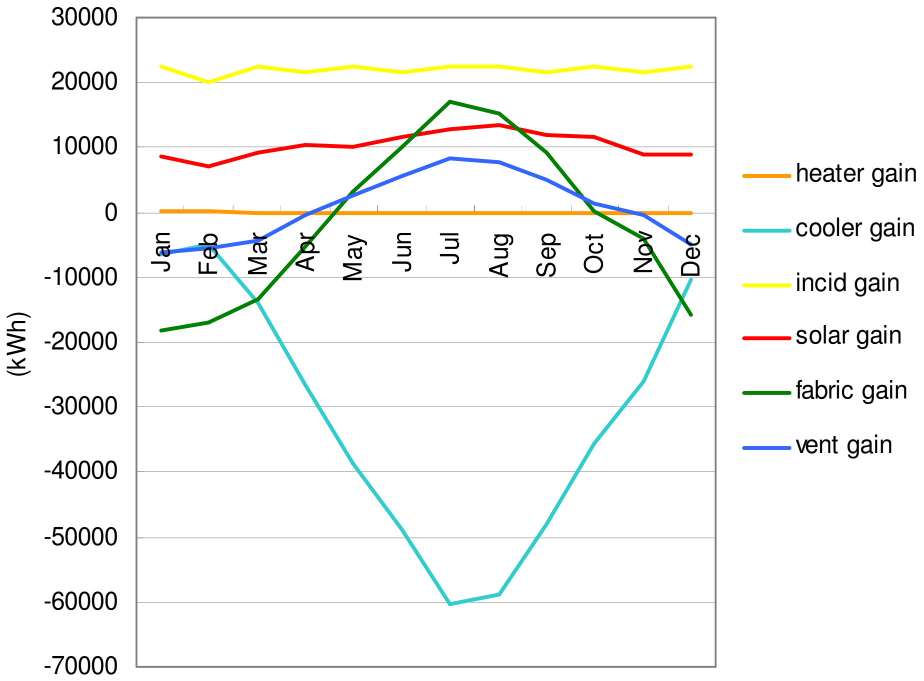


Figure 5.29 The average values of gain by sections from heater to vent for the Institutional prototype.

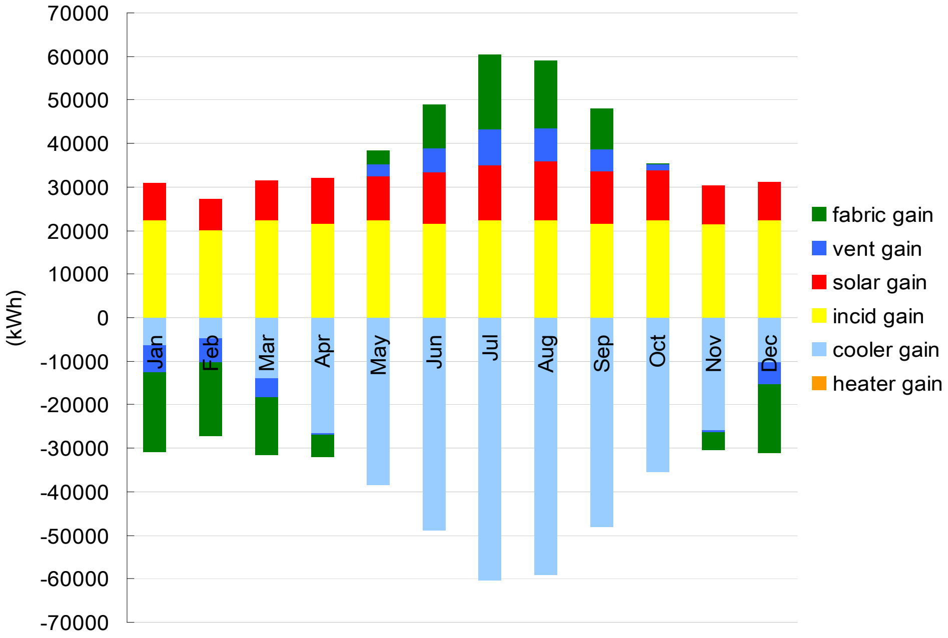


Figure 5.30 The average monthly proportion of gain by sections from heater to fabric for the Institutional prototype.

5.4.5 Residential

Throughout Taipei, the residential group occupies massive areas and is the most important element to affect the built environment (UHDD 2008). Social community, dormitory and any other kinds of buildings used for living are included in this group. According to the national statistics of Building Construction in Taiwan from 1999 to 2010, the average volume of residential projects was 823.47 m^3. However, the long history of development and various types of residential buildings make it impossible and unreasonable to create only one prototype to depict all of them. Therefore, we adopt the average space per household in 2008, 99.3 m^2 (ibid.). Based on the data and the most common types of residential buildings in Taipei, three different prototypes have been created; Residential-Large (Residential-L), Residential-Medium (Residential-M) and Residential-Small (Residential-S) .

5.4.5.1 Residential-Large

Residential-Large (Residential-L) prototype depicts the buildings with modern styling as 15 meters long, 10 meters wide and 15 storeys high (Figure 5.31 & 5.32). This kind of building could be seen along the several main roads in Taipei.

Figure 5.31 Practical cases of Residential-L buildings: Housing along Lo Szu Fu Rd.. (Source: Google Map 2012)

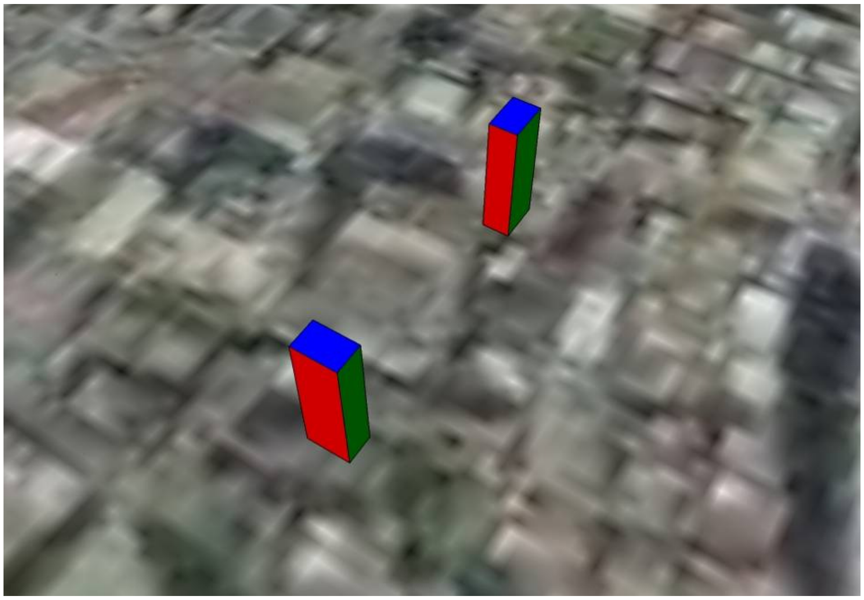


Figure 5.32 Residential-L prototypes situated in two main directions. (The lower is Bld_1; the upper is Bld_2.)

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.33 & 5.34). First of all, incidental and solar gains are the two major heat sources throughout the whole year. Second, from October to May, the ventilation gain helps to release the heat; from June to September, it increases the total heat. Third, the fabric gain fluctuates dramatically through a year. During the summer time, it becomes the most important heat source. Moreover, during the winter time, it becomes the biggest heat loss factor. Fourth, heating is mildly needed from December to March. In other words, there is no need for cooling during this period of time at all. Fifth, from May to October, the figures show that there is a big requirement for cooling, particularly in July and August. In short, as these diagrams indicate, for Residential-L buildings in Taipei, reducing the amounts of incidental, solar, fabric and cooling gains would be the biggest opportunities to save energy.

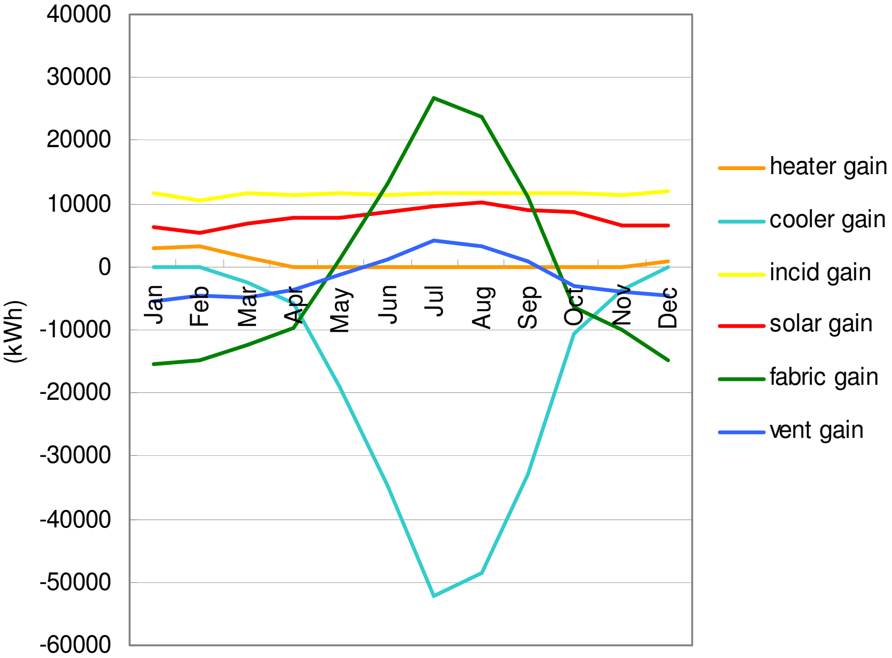


Figure 5.33 The average values of gain by sections from heater to vent for the Residential-L prototype.

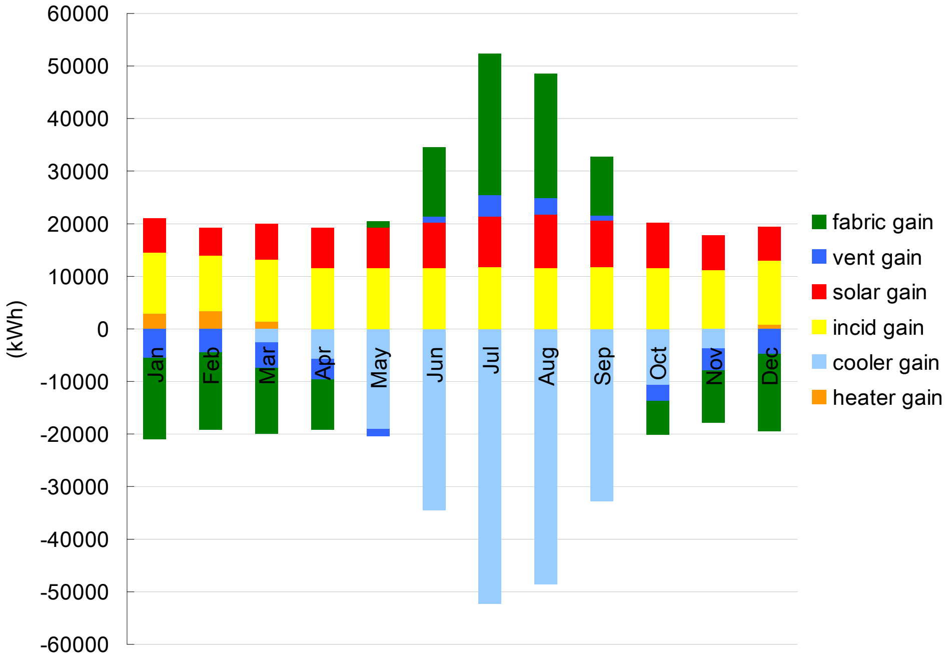


Figure 5.34 The average monthly proportion of gain by sections from heater to fabric for the Residential-L prototype.

5.4.5.2 Residential-Medium

The Residential-Medium (Residential-M) prototype depicts the majority of row housing as 23 meters long, 10 meters wide and 4 storeys high (Figure 5.35 & 5.36). This kind of building is one of the most popular house styles in Taipei, which can be seen in the most blocks and old areas.

Figure 5.35 A practical case of a Residential-M building: a typical detached apartment in Taipei.

Figure 5.36 Residential-M prototypes situated in two main directions. (The lower is Bld_1; the upper is Bld_2.)

The modelling results show the average values of the Bld_1 and Bld_2 models in different gains (Figure 5.37 & 5.38). The energy performance of Residential-M prototype is generally similar to Residential-L. First of all, incidental and solar gains are two major heat sources throughout the whole year. Second, from October to May, the ventilation gain helps to release the heat; from June to September, it increases the total heat. Third, the fabric gain changes dramatically. In July and August, it becomes the most important heat source. Additionally, from October to April, it becomes the largest heat loss factor. Fourth, heating is needed from December to March. Meanwhile, there is no need for cooling. Fifth, from May to September, the figures show that there is a big requirement for cooling. In short, as these diagrams indicate, for Residential-M buildings in Taipei, reducing the loans of incidental, solar, fabric and cooling gains might be the biggest opportunities to save energy.

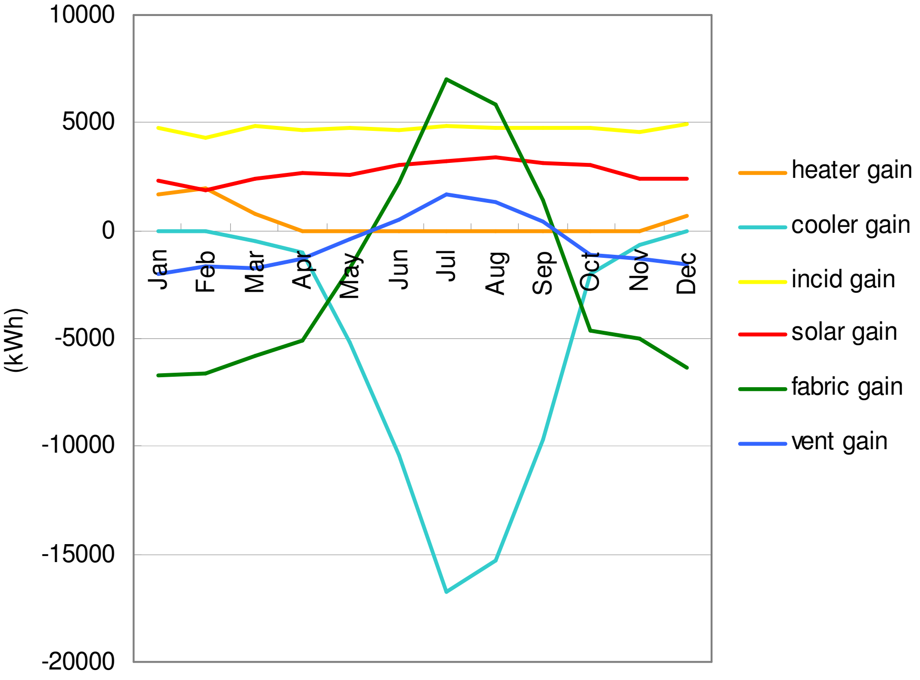


Figure 5.37 The average values of gain by sections from heater to vent for the Residential-M prototype.

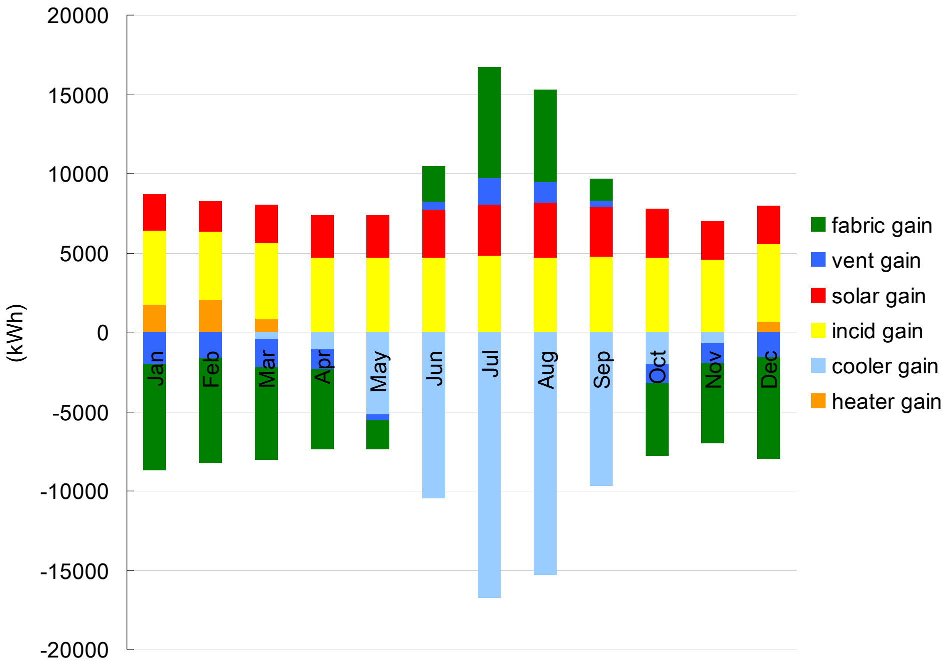


Figure 5.38 The average monthly proportion of gain by sections from heater to fabric for the Residential-M prototype.

5.4.5.3 Residential-Small

The Residential-Small (Residential-S) prototype depicts general apartments as 10 meters long, 10 meters wide and 5 storeys high (Figure 5.39). This kind of building is also one of the most popular housing in Taipei. Sometimes they would be built together as small communities, but sometime they could be constructed individually.

The modelling results show the values of Residential-S model in different gains (Figure 5.40 & 5.41). First of all, incidental and solar gains are two major heat sources throughout the whole year. In August, the solar gain would be more than the incidental gain. Second, from October to May, the ventilation gain helps to release the heat; from June to September, it increases the total heat. Third, the fabric gain fluctuates dramatically through a year. In July and August, it becomes the most important heat source. Moreover, during the winter time, it becomes the biggest heat loss factor. Fourth, heating is mildly needed from December to March. In March, heating and cooling are both needed. Fifth, from May to October, the figures show that there is a big requirement for cooling, particularly in July and August. In short, as these diagrams indicate, for Residential-S buildings in Taipei, reducing the amount of incidental, solar, fabric and cooling gains would be the best strategies to save energy.

Figure 5.39 Practical cases of Residential-S buildings: Housing along Lo Szu Fu Road.

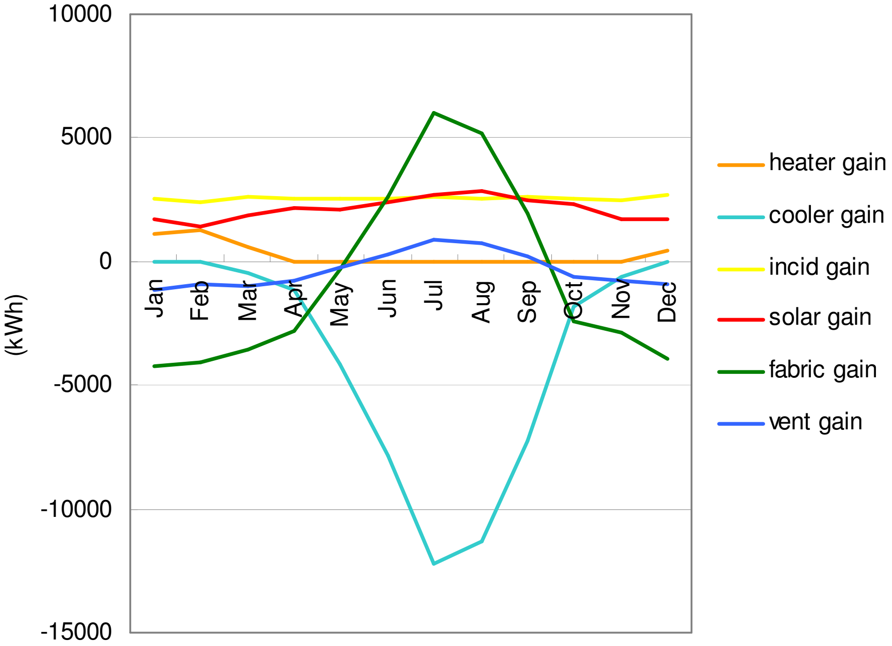


Figure 5.40 The values of gain by sections from heater to fabric for the Residential-S prototype.

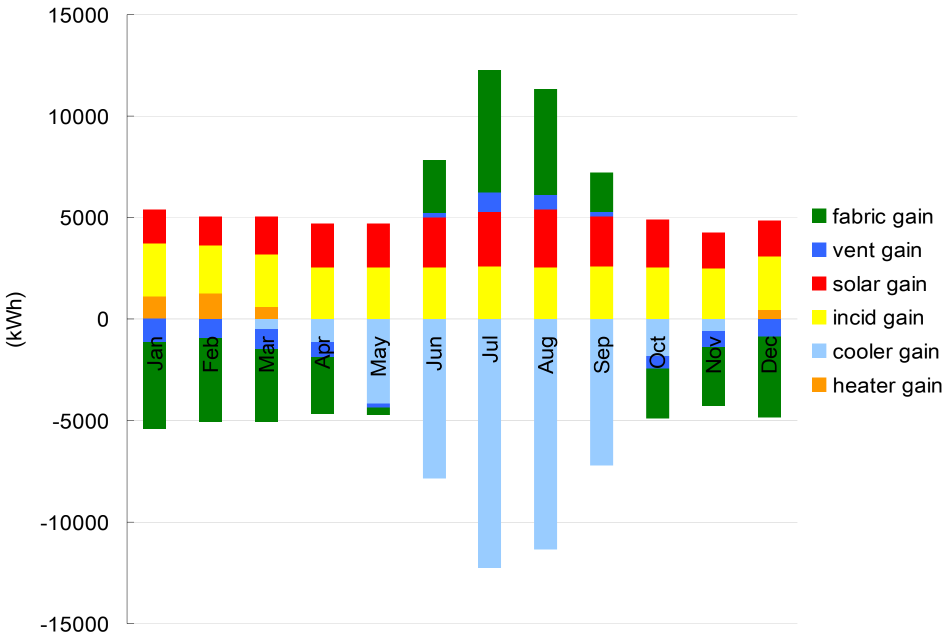


Figure 5.41 The monthly proportion of gain by sections from heater to fabric for the Residential-S prototype.

5.4.6 Others

The remainder of buildings that were not considered in the previous groups are collected together in this category. According to the national statistics of Building Construction in Taiwan, the average area of buildings in the Others category constructed between 1991 and 2010 was 2,840,787m^2. There is no information about the average number of this project. Thus, a simple cuboid, 5 meters long, 5 meters wide and 2 storeys high is hypothesized as a prototype. The prototype is supposed to be the basic form to compose larger buildings. The detailed materials and diary of usage follow the residential buildings prototypes.

The modelling results show the Others model in different gains (Figure 5.42). First of all, solar gain is the major heat source throughout the whole year. Second, the incidental gain presents next highest volume of the solar gain. Third, from October to May, the fabric gain helps to release the heat; from June to September, it increases the total heat. Fourth, the ventilation gain gradually climbs from January and steadily decreases towards the end of year. Fifth, heating is needed from December to April, particularly in January and February. Sixth, from May to October, the figures show that there is a big requirement for cooling. In short, as these diagrams indicate, for Others buildings in Taipei, reducing the amounts of incidental, solar, fabric and cooling gains would be more effective to save energy.

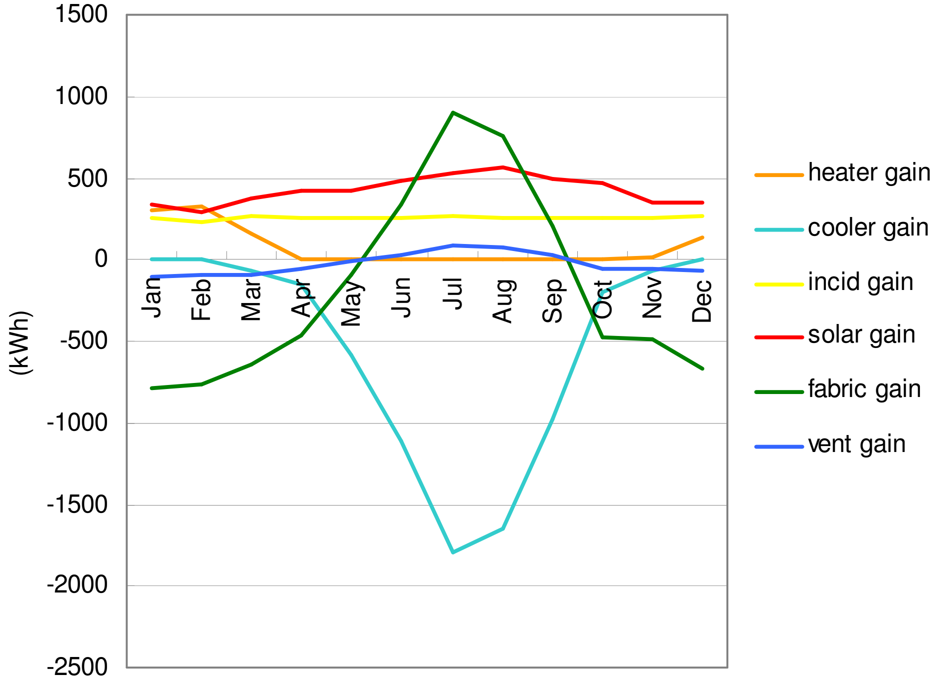


Figure 5.42 The values of gain by sections from heater to vent for the Others prototype.

5.4.7 Analysis and discussion

Through the process of building prototype modelling, it is clear to understand the energy consumptions of different types of buildings in Taipei. There are some important findings as follows.

First of all, according to the energy demand proportions throughout a year, the period from May to October can be seen as summer time due to these five months having the highest solar gain and cooling demand, while the remaining months would be seen as winter time (Table 5.7 & 5.8). However, for Assembly, Commercial, Industrial and Institutional building types, the average cooling load in April and November still remains high. Basically, during the summer time, the heat from fabric, ventilation, solar and incidence would be balanced by AC systems.

Month	Solar gain (kWh/m^2/yr) of building prototypes								
	Assembly	Commercial-L	Commercial-S	Industrial	Institutional	Residential-L	Residential-M	Residential-S	Others
Jan	2.78	3.91	10.06	1.49	5.59	2.79	2.41	3.36	6.72
Feb	2.35	3.31	8.53	1.25	4.74	2.36	2.04	2.85	5.70
Mar	3.08	4.34	11.18	1.65	6.21	3.10	2.68	3.74	7.47
Apr	3.51	4.95	12.76	1.87	7.09	3.53	3.06	4.27	8.53
May	3.49	4.92	12.68	1.86	7.05	3.51	3.04	4.24	8.48
Jun	4.00	5.63	14.51	2.13	8.06	4.02	3.48	4.85	9.71
Jul	4.41	6.21	16.00	2.36	8.89	4.43	3.83	5.35	10.70
Aug	4.69	6.60	17.01	2.51	9.45	4.71	4.07	5.69	11.37
Sep	4.06	5.71	14.71	2.17	8.17	4.08	3.52	4.92	9.83
Oct	3.83	5.39	13.90	2.05	7.72	3.85	3.33	4.64	9.29
Nov	2.89	4.07	10.49	1.55	5.83	2.91	2.51	3.51	7.01
Dec	2.86	4.02	10.37	1.53	5.76	2.87	2.48	3.47	6.93
Total	41.95	59.04	152.21	22.42	84.57	42.17	33.96	50.88	101.76

Table 5.7 A list of monthly solar gain for all prototypes.

Month	Cooling demand (kWh/m^2/yr) of building prototypes								
	Assembly	Commercial-L	Commercial-S	Industrial	Institutional	Residential-L	Residential-M	Residential-S	Others
Jan	-9.73	-12.96	-6.61	-6.90	-4.17	0.00	0.00	0.00	0.00
Feb	-8.27	-11.25	-5.14	-5.83	-3.27	0.00	0.00	0.00	0.00
Mar	-14.19	-17.00	-13.88	-9.68	-9.40	-1.15	-0.56	-0.99	-1.35
Apr	-20.96	-22.92	-25.33	-14.09	-17.82	-2.67	-1.26	-2.24	-3.13
May	-27.19	-28.31	-36.16	-18.07	-25.90	-8.67	-5.94	-8.31	-11.61
Jun	-31.94	-32.46	-45.62	-21.07	-32.89	-15.61	-11.75	-15.66	-22.19
Jul	-37.84	-37.84	-56.19	-24.88	-40.67	-23.61	-18.77	-24.50	-35.91
Aug	-37.05	-37.28	-54.95	-24.37	-39.66	-21.96	-17.21	-22.63	-33.01
Sep	-31.41	-32.05	-44.57	-20.73	-32.14	-14.74	-10.74	-14.42	-19.57
Oct	-25.58	-27.11	-33.15	-17.01	-23.71	-4.78	-2.27	-3.63	-3.90
Nov	-20.69	-22.34	-24.25	-13.84	-17.22	-1.69	-0.70	-1.21	-1.32
Dec	-12.70	-15.64	-10.22	-8.74	-6.80	-0.03	0.00	0.00	-0.02
Total	-277.54	-297.13	-356.07	-185.21	-253.63	-94.91	-69.20	-93.59	-132.02

Table 5.8 A list of monthly cooling load for all prototypes.

Secondly, from the simulation results, these nine different building types can be generally classified into two groups; non-domestic and domestic (Figure 5.43). Assembly, Institutional, Commercial, and Industrial buildings belong to the non-domestic buildings group; the rest belong to the domestic group. For the former, the cooling need exists throughout the whole year, particularly from April to November. For the latter, the need is shorter, from May to October, namely in the summer time. Additionally, the domestic building group requires heating from December to February, but there is very little need for the non-domestic group. On the other hand, based on the distribution of heat gain, incidental gain has a significant potential to reduce for non-domestic buildings. For domestic buildings, decreasing the solar gain and incidental gain are equally important. Moreover, for domestic buildings, the differences in cooling consumption between summer and winter periods are obvious, which in turn has a strong negative correlation with the fabric gain.

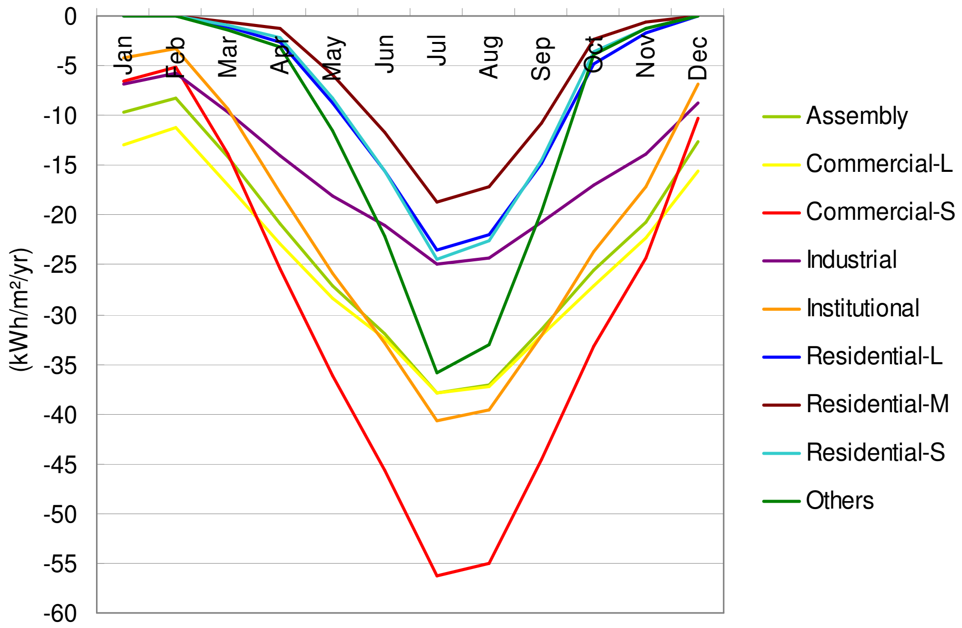


Figure 5.43 The monthly cooling load of all nine building prototypes.

Thirdly, for each different prototype, the main heat sources vary (Figure 5.44). The incidental gain overwhelms other heat sources for the majority of building types except those in the Others category. It occupies the annual total heat gain of Assembly, Commercial-L, -S, Industrial, Institutional, Residential-L, -M, and -S types totalling 84.08%, 79.46%, 59.76%, 82.76%, 66.29%, 57.52%, 61.97% and 52.75% respectively (Table 5.9). On the other hand, solar gain is the second main heat source, which affects these nine prototypes by 14.51%, 19.41%, 38.93%, 14.34%, 31.67%, 39.14%, 35.75%, 43.75%, and 58.30% respectively. The incidental gain is strongly connected with living style, mostly related to density of occupancy, lighting usage and small power facility usage. As we known, the efficiency of lighting and the usage of electrical equipments not only directly reduces the electricity consumption, but also produces less heat and lowers the cooling demand. Therefore, these two energy saving strategies would be the research focuses to reduce the energy demand of buildings in Taipei.

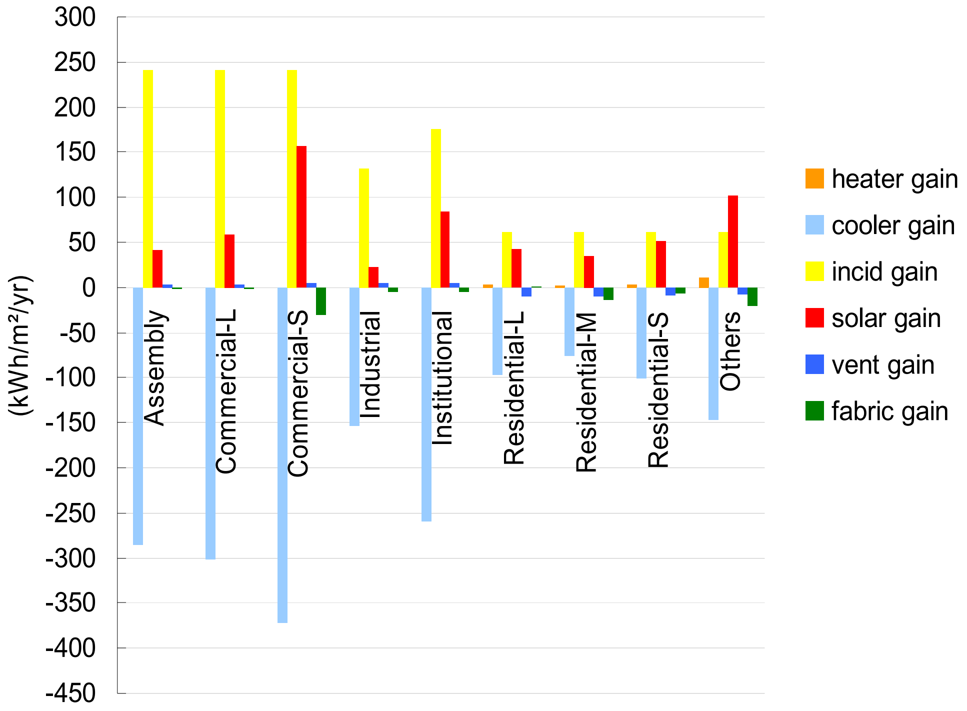


Figure 5.44 The annual distribution of heat gain for all nine buildings prototypes.

Prototype	heater gain (%)	cooler gain (%)	incidental gain (%)	solar gain (%)	vent gain (%)	fabric gain (%)
Assembly	0.00	-99.58	84.08	14.51	1.41	-0.42
Commercial-L	0.00	-99.66	79.46	19.41	1.13	-0.34
Commercial-S	0.02	-92.44	59.76	38.93	1.30	-7.56
Industrial	0.00	-97.00	82.76	14.34	2.90	-2.99
Institutional	0.01	-98.07	66.29	31.67	2.03	-1.93
Residential-L	2.72	-90.19	57.52	39.14	-9.81	0.62
Residential-M	2.27	-76.27	61.97	35.75	-9.95	-13.78
Residential-S	3.50	-86.27	52.75	43.75	-8.22	-5.51
Others	6.55	-84.00	35.15	58.30	-4.55	-11.45

Table 5.9 A list of annual heat gain proportions for the nine building prototypes.

Lastly, based on the distribution of heat gain for these building prototypes, the focuses of potential strategies to reduce the energy use are different. The strategies related to reducing the incidental and cooling gains are important to all kinds of buildings. Except the Assembly buildings, for which solar gain is another potential factor. Moreover, the strategies involved in the ventilation gain should be applied in Industrial and Institutional buildings. Additionally, for Commercial-S, Institutional, Residential-L, -M, -S, and Others buildings, the fabric gain is another critical issue.

5.5 Simulation for building groups

In this section, the simulation for building groups for single use purpose would be presented. The objective of this simulation stage is to understand the energy performance of different building group types and find out what changes occur if the buildings with the same usage purpose gather at a larger scale, and what alterations are caused by different building situations.

According to the observation of Taipei presented in section 5.3.2, six popular and typical groups are found; Commercial-Large-Scattered (Commercial-L-S), Commercial-Large-Dense (Commercial-L-D), Commercial-Small-Unregulated (Commercial-S-U), Commercial-Small-Regulated (Commercial-S-R), Residential-

Large-Community (Residential-L-C), and Residential-Medium-Terrace (Residential-M-T).

In each of the next sections, an image of an existing building group and a 3D model drawing head the presentation, followed by the results of the simulation, including a figure and a visualized image. From the results, it has been possible to clearly observe the changes to different gain sections throughout a year. After all the descriptions of the six building groups, an overall analysis and discussion is presented at the end.

5.5.1 Commercial-Large-Scattered

The Commercial-Large-Scattered (Commercial-L-S) (Figure 5.45 & 5.46) group are based on the Commercial-L prototype, which depict large commercial building types in new development areas in Taipei. Generally, the buildings in these areas are taller than 40 meters and the distances between them are larger than 30 meters.

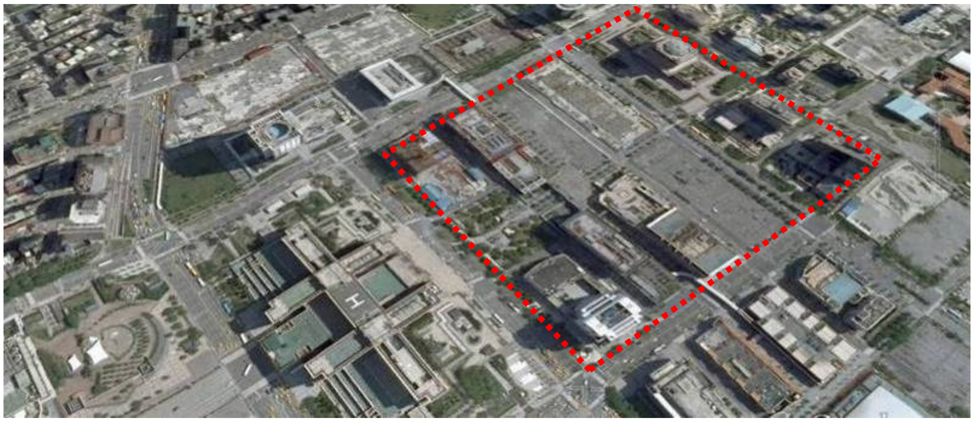


Figure 5.45 An existing Commercial-L-S group in Xinyi District. (Source: Geo Force Technologies 2012)

From the simulation result (Figure 5.47 & 5.48), the incidental gain is the main heat source, which is 13 times higher than the solar gain. Moreover, the ventilation and fabric gain could help to increase or decrease the heat depending on the seasons. However, the cooling demand is required throughout the whole year, which reaches a climax in July. Additionally, compared with the simulation result of

Commercial-L, there are two differences worth noting. The first is the proportion of the total heat for the incidental gain of Commercial-L-S building groups is much more than Commercial-L building type. The second is the change of the ventilation gain becomes more obvious.

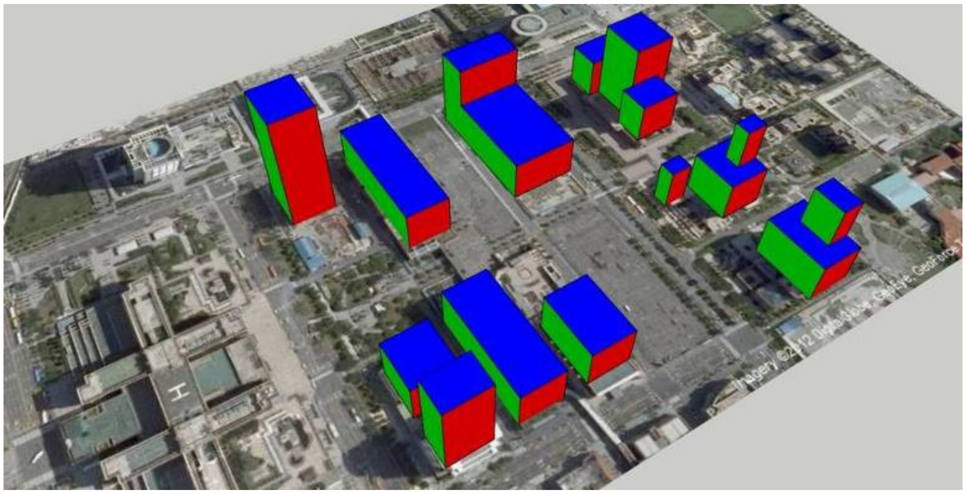


Figure 5.46 A 3D model of a Commercial-L-S group in Xinyi District.

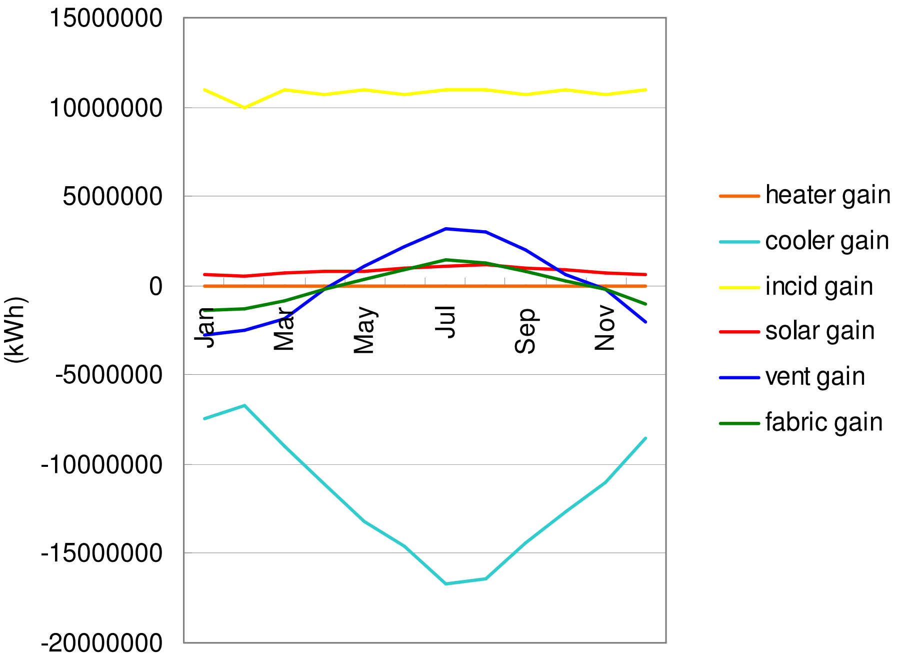


Figure 5.47 The annual heat gain by sections for the Commercial-L-S group.

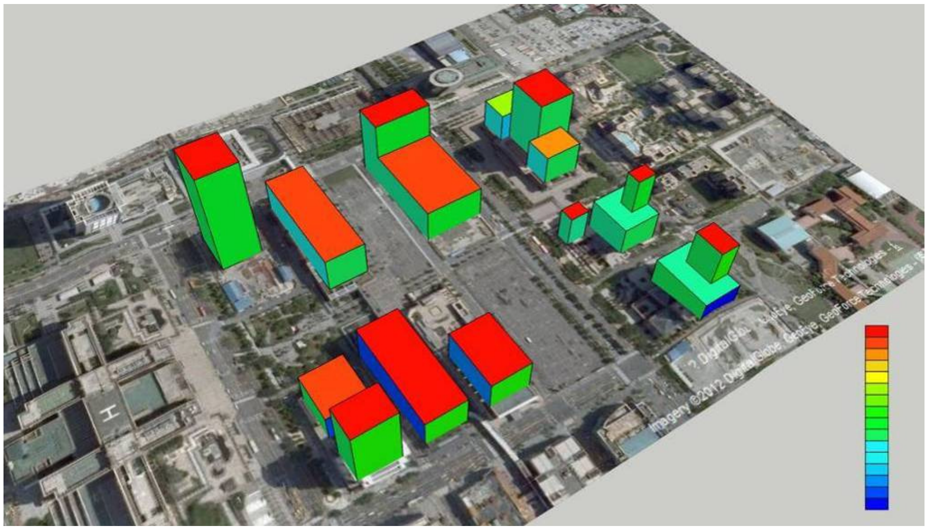


Figure 5.48 The visualized result for the Commercial-L-S group: Xinyi District. (The sequence of solar radiation from maximum to minimum is divided into 16 different colours shown in the colour legend as red to blue.)

5.5.2 Commercial-Large-Dense

The Commercial-Large-Dense (Commercial-L-D) building group depicts the majority of commercial building blocks in Taipei (Figure 5.49 & 5.50). Compared with Commercial-L-S, they have longer construction history, lower building height and are located in high density areas.

Figure 5.49 An existing Commercial-L-D group along Chung Hsiao East Rd.. (Source: Geo Force Technologies 2012)

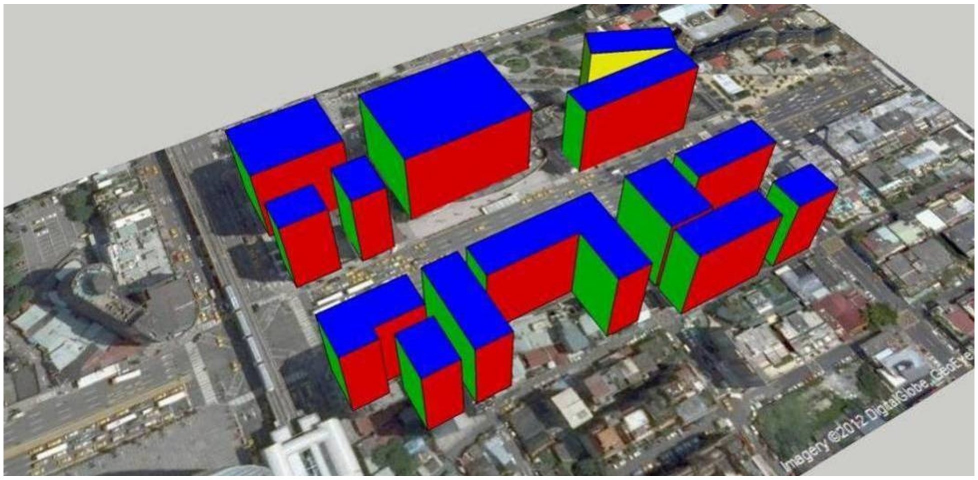


Figure 5.50 A 3D model of a Commercial-L-D group along Chung Hsiao East Road.

From the simulation result (Figure 5.51 & 5.52), the incidental gain is the main heat source, which is 9.7 times the solar gain. Moreover, the ventilation and fabric gain could increase or decrease the heat depending on the seasons. As the simulation results of Commercial-L-D show, the cooling demand is needed throughout the whole year, which also reaches a climax in July. Additionally, compared with the simulation results of Commercial-L and Commercial-L-S, there are three differences worth noting. The first is the proportion of the total heat for the incidental gain of Commercial-L-D building groups is between Commercial-L building type and Commercial-L-S building groups. The second is the fabric and ventilation gains from June to September are more than the solar gain. Lastly, the average cooling demand of Commercial-L-D is less than Commercial-L-S.

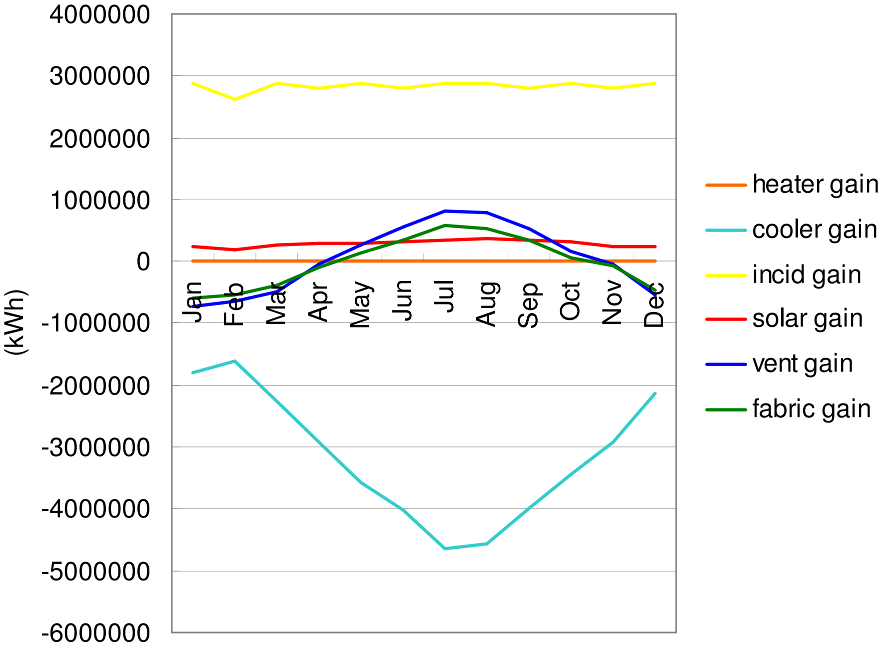


Figure 5.51 The annual heat gain by sections for the Commercial-L-D group.

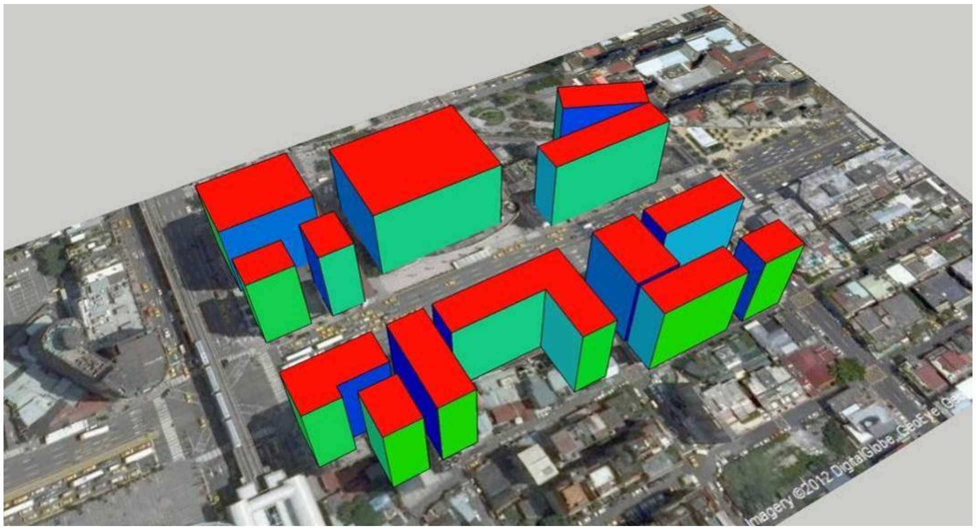


Figure 5.52 The visualized results for the Commercial-L-D group along Chung Hsiao East Road.

5.5.3 Commercial-Small-Unregulated

The Commercial-Small-Unregulated (Commercial-S-U) building group depicts traditional commercial blocks in Taipei (Figure 5.53 & 5.54). They are generally 5 storeys in height and located in very high density areas, and sometimes mixed with residential buildings.

Figure 5.53 An existing Commercial-S-U group at Shih Lin Night Market. (Source: Geo Force Technologies 2012)

Figure 5.54 A 3D model for the Commercial-S-U group at Shih Lin Night Market.

From the simulation result (Figure 5.55 & 5.56), the incidental gain is the major heat source, which is 5.5 times the solar gain. Moreover, the ventilation and fabric gain fluctuate throughout a year. Although the cooling demand is needed throughout the whole year, from December to February, the "loss" of fabric overpasses the cooling gain to help to balance the heat. Additionally, compared with the simulation result of Commercial-S, there are two different points worth noting. The first is the proportion of the solar gain. For Commercial-S-U building groups, the solar gain only occupies a small part, but for Commercial-S building prototype, it is close to the incidental gain. The second is the change of the ventilation gain. During the summer time, it becomes much higher than the rest of the year.

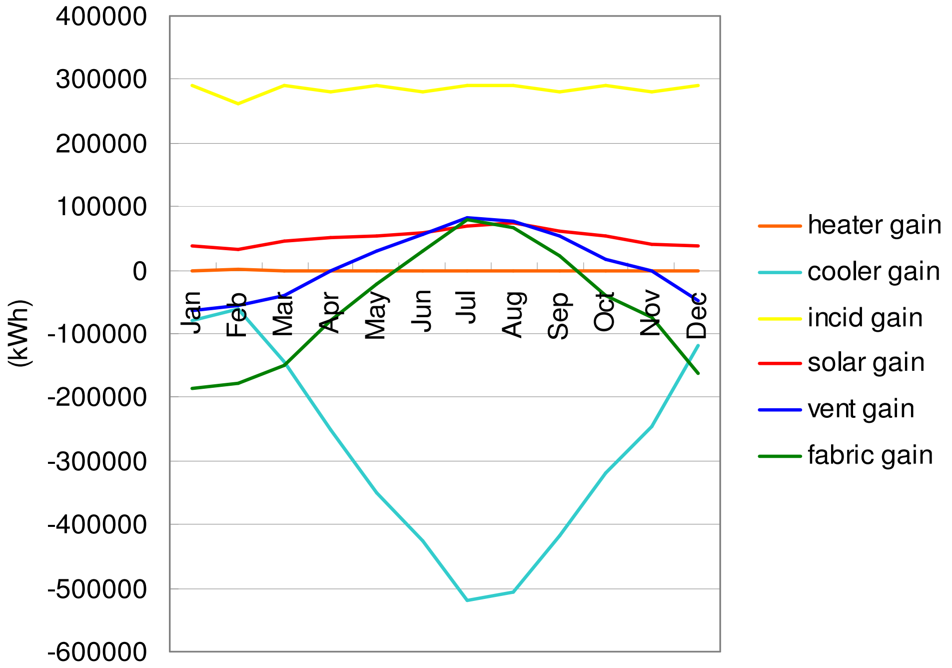


Figure 5.55 The annual heat gain by sections for the Commercial-S-U group.

Figure 5.56 The visualized results for the Commercial-S-U group at Shih Lin Night Market.

5.5.4 Commercial-Small-Regulated

The Commercial-Small-Regulated (Commercial-S-R) group are the other common traditional commercial group which can be seen throughout the city (Figure 5.57 & 5.58). Their building heights are various, but they are usually located in rectangle blocks and well-defined development areas.

From the simulation result, the incidental gain is the major heat source, which is 6.5 times greater than the solar gain (Figure 5.59). As Commercial-S-U, the ventilation and fabric gain fluctuate through a year and the cooling demand is needed throughout the whole year. In January and February, the "loss" of fabric becomes the major cooling source. Additionally, due to the uneven buildings height and the self-shading brought by themselves, the solar radiation of roofs would be various (Figure 5.60). Additionally, compared with the simulation result of Commercial-S, there is one interesting point worth noting. The proportion of the total heat for the solar gain of Commercial-S-R buildings groups is much lower than Commercial-S building type.

Figure 5.57 An existing Commercial-S-R group at Hsi Men Ting. (Source: Geo Force Technologies 2012)

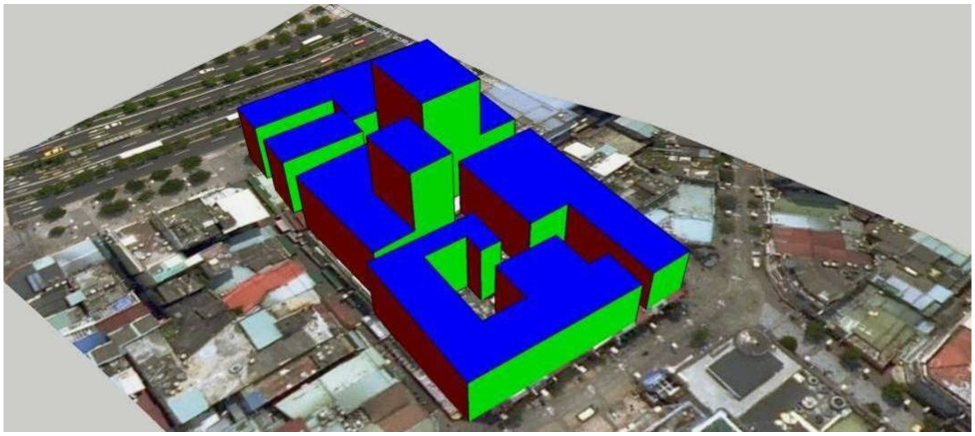


Figure 5.58 A 3D model of a Commercial-S-R group at Hsi Men Ting.

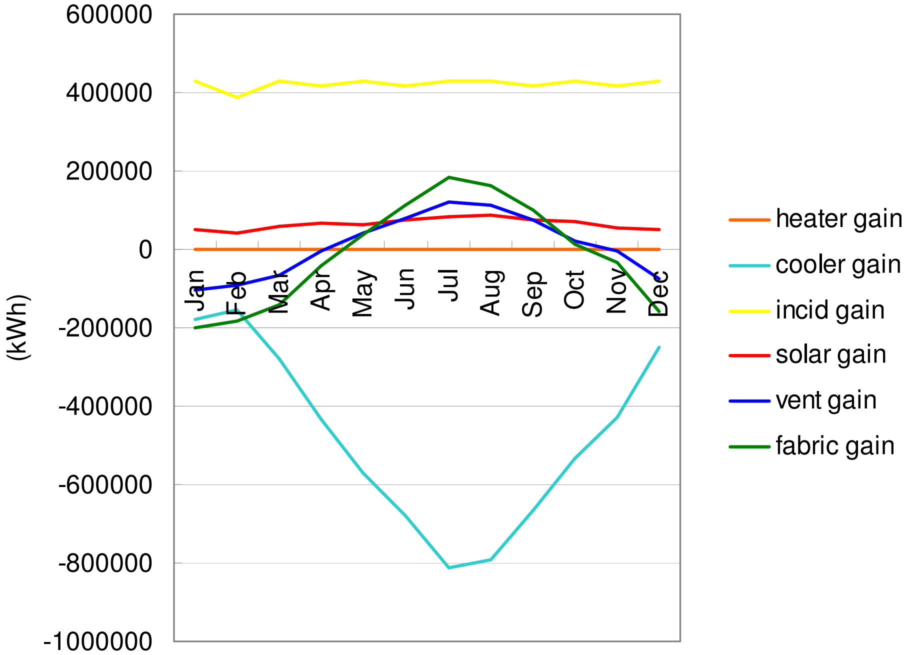


Figure 5.59 The annual heat gain by sections for the Commercial-S-R group.

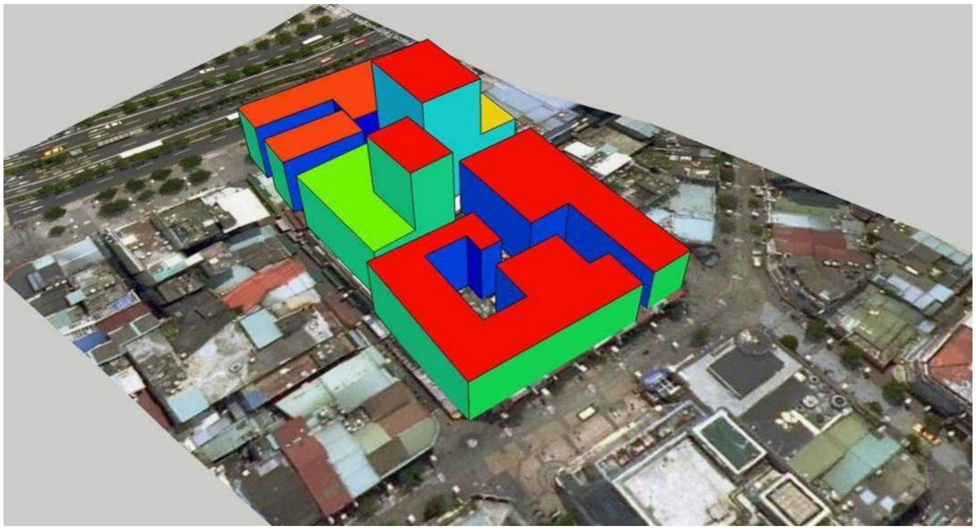


Figure 5.60 The visualized results for the Commercial-S-R group at Hsi Men Ting.

5.5.5 Residential-Large-Community

The Residential-Large-Community (Residential-L-C) building group depicts the new living spaces for Taipei citizens (Figure 5.61 & 5.62). They are built by following some design principals; higher building height, bigger public open spaces, multi-types of housing, and sharing public infrastructures.

Figure 5.61 An existing Residential-L-C group at a community in Nan Kung District.

Figure 5.62 A 3D model of a Residential-L-C group at a community in Nan Kung District.

From the simulation result (Figure 5.63 & 5.64), the incidental gain is the highest heat source every month except July. Moreover, the ventilation and fabric gain are quite varied in their seasonal impacts. Additionally, the heating demand is needed from December to March. And, except the solar gain, the monthly change and proportion of the heat gains are similar to the simulation result of Residential-L.

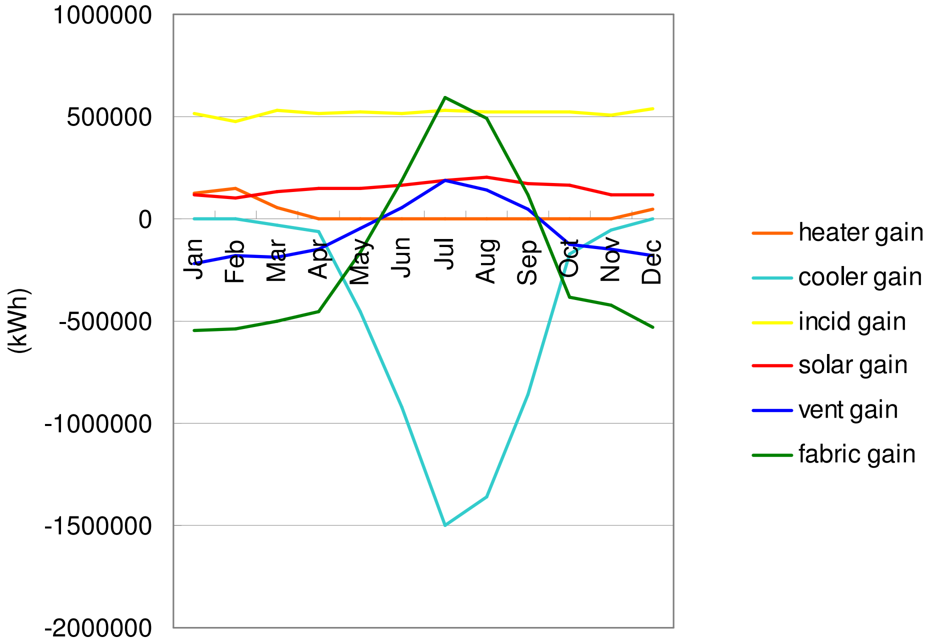


Figure 5.63 The annual heat gain by sections for the Residential-L-C group.

Figure 5.64 The visualized results for the Residential-L-C group at a community in Nan Kung District.

5.5.6 Residential-Medium-Terrace

The Residential-Medium-Terrace (Residential-M-T) building group depicts dwellings from an earlier era (Figure 5.65 & 5.66). They are generally built symmetrically with 4 or 5 storeys height and a shared public stairwell in the middle.

Figure 5.65 An existing case of a Residential-M-T group at housing along Chung Yang Rd.. (Source: Geo Force Technologies 2012)

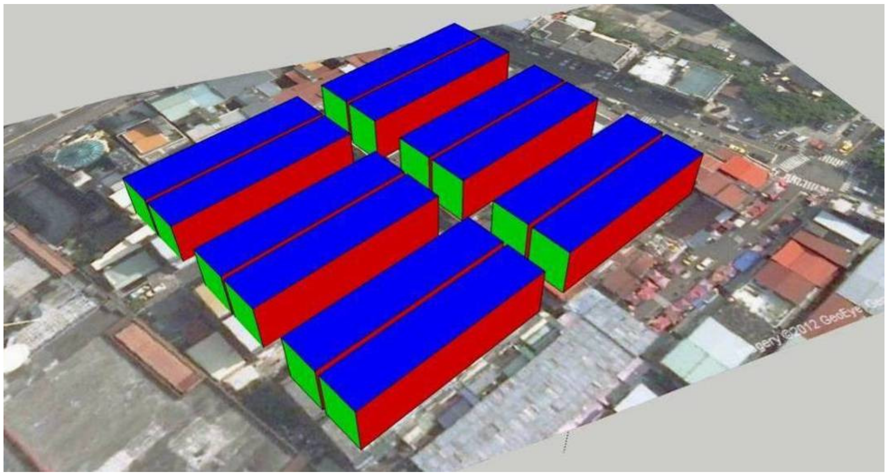


Figure 5.66 A 3D model of the Residential-M-T group at housing along Chung Yang Road.

From the simulation result (Figure 5.67 & 5.68), the incidental gain is the largest heat source every month except July and August. Similar to the Residential-L-C group, the ventilation and fabric gains vary greatly in their seasonal impacts.

Additionally, the heating demand is required from December to March. And, compared with the simulation result of Residential-M, the proportion of the total heat for the solar gain of Residential-M-T building groups is lower than Residential-M building type.

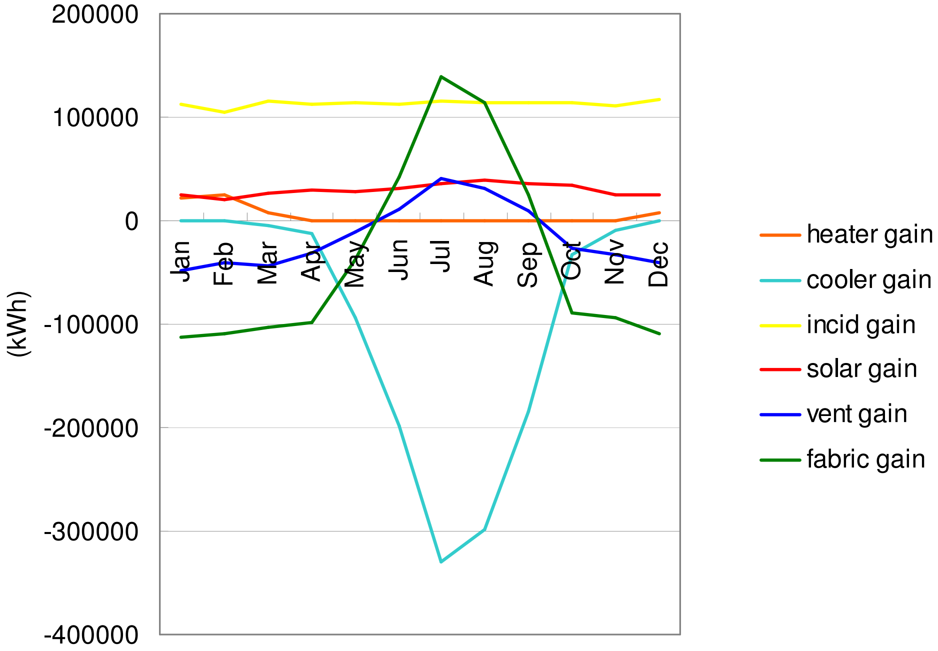


Figure 5.67 The annual heat gain by sections for the Residential-M-T group.

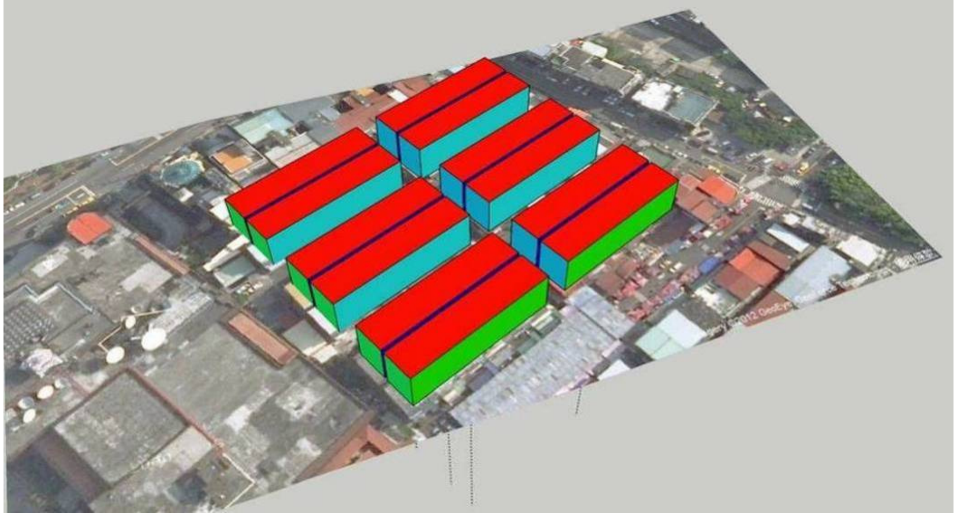


Figure 5.68 The visualized results for the Residential-M-T group at housing along Chung Yang Road.

5.5.7 Analysis and discussion

After the modelling of different building groups, it is clear to understand their energy performance and the changes occurring at different scales and the alterations caused by a different urban situation. There are some important discussions as follows.

Firstly, for both commercial and residential buildings, the incidental gain plays a more important role in the energy consumption for buildings groups than for a single building prototype.

Secondly, the average cooling load of building groups are lower than the ones of building types. The cooling load of Residential-L, -M and -S groups are 94.91, 69.20 and 93.59 kWh/m²/yr respectively. But, the energy needs of Residential-L-C and -M-T are merely 60.83 and 44.59 kWh/m²/yr (Table 5.10). For commercial buildings, the need of Commercial-L and -S are 297.13 and 356.07 kWh/m²/yr, but the needs of these Commercial building groups are much lower.

Month	Cooling load (kWh/m²/yr) of building groups					
	Commercial-L-S	Commercial-L-D	Commercial-S-U	Commercial-S-R	Residential-L-C	Residential-M-T
Jan	-13.49	-12.40	-6.96	-7.56	0.00	0.00
Feb	-12.03	-9.77	-5.72	-6.31	0.00	0.00
Mar	-16.30	-13.94	-11.92	-12.15	-0.46	-0.10
Apr	-20.23	-18.07	-19.77	-19.53	-1.07	-0.25
May	-24.24	-22.13	-26.84	-26.17	-5.35	-3.36
Jun	-26.81	-24.91	-32.24	-31.24	-10.22	-7.65
Jul	-30.61	-28.76	-38.92	-37.42	-16.05	-13.44
Aug	-30.13	-28.25	-38.02	-36.49	-14.67	-11.99
Sep	-26.47	-24.70	-31.52	-30.64	-9.65	-6.86
Oct	-23.19	-21.23	-24.64	-24.36	-2.50	-0.76
Nov	-20.03	-18.00	-19.28	-19.31	-0.87	-0.17
Dec	-15.46	-13.13	-10.1	-10.63	0.00	0.00
Total	-258.99	-235.29	-265.94	-261.80	-60.83	-44.59

Table 5.10 A list of monthly cooling loads for single use building groups.

Thirdly, the simulation results indicate that the average cooling demand of the Commercial-L-S group is slightly higher than for the Commercial-L-D group (Table

5.10). The difference implies that density might be one of the variables to cause variation. However, due to the complexity of the simulation engine and big differences in geometric characteristics between these models, it is hard to judge which variable creates the most variation.

Fourthly, the simulation result reveals that the cooling demand of the Residential-L-C group is 16 kWh/m^2/yr higher than for the Residential-M-T group, which means that the modern living style environment would also bring higher energy requirements. It is well-known that a residential community can offer better living qualities, such as broader views, larger green landscapes, bigger open spaces at ground floor levels, more complete infrastructure, and higher security. However, in terms of reducing energy demand, the energy performance of the new residential buildings is worse than the traditional terrace buildings in Taipei.

5.6 Simulation for blocks and districts

In Taiwan, most urban areas are controlled and regulated by the Urban Planning Act. Taipei and other big cities particularly obey individual and more specific regulations. In Taipei, considering the lifestyle of Taiwanese people, most urban areas are defined by containing various usage types in one block. The mixed residential and commercial land usage of buildings brings convenience. On the contrary, small sections of areas with building groups assigned for single use purposes, like those presented in the previous sections, are set for specific development functions.

In this section, four typical blocks and districts in Taipei are selected to be the experimental subjects, which are respectively located in Chung-Shan District, Ta-An District, and Sung-Shan District. These subjects contain different types of buildings within them. For modelling at urban scale, the detailed building characteristics of rooftops, balconies, and illegal extensions, have been ignored in order to simplify the model and speed up the computing process. Rejecting such specific information has been proved to not sacrifice the accuracy of simulation results at regional scale by adopting the method in this research through a series of testing.

In the each of the following sections, an aerial map of the blocks and a drawing of a 3D model head the presentation, which are then followed by the results of the simulation, including a figure and a visualized image. The simulation results would help to identify some potential variables and show the average energy consumptions of commercial and residential buildings. Moreover, they would be compared with practical measurement figures to cross-check the reliability and validity of the simulation method.

5.6.1 Blocks in Chung-Shan District

Blocks in Chung-Shan District represent typical commercial blocks in Taipei (Figure 5.69 & 5.70). They generally have similar building height, coverage rate, and building floor ratio. From the simulation result, it is clear to see the roofs of lower buildings and the facades in comparatively high density areas would accept less solar radiation (Figure 5.71). For the overall cooling and heating demands, July is the month when the cooling demand is needed the most (Figure 5.72). In contrary, for commercial blocks, there is virtually no need for heating.

Figure 5.69 The aerial map: Blocks in Chung-Shan District. (Red: Commercial use; Yellow: Residential use) (Source: Geo Force Technologies 2012; Modified by Lin 2013)

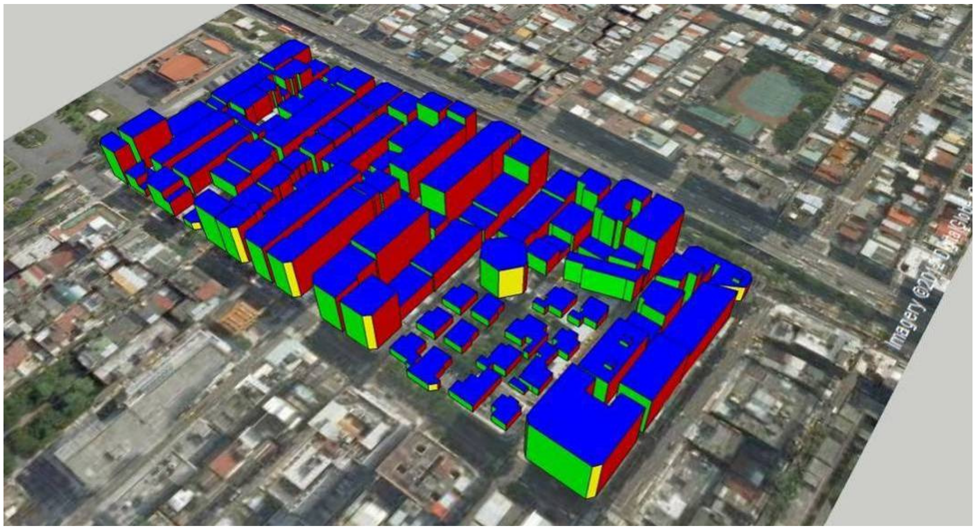


Figure 5.70 A 3D drawing of blocks in Chung-Shan District.

Figure 5.71 The visualized result of blocks in Chung-Shan District.

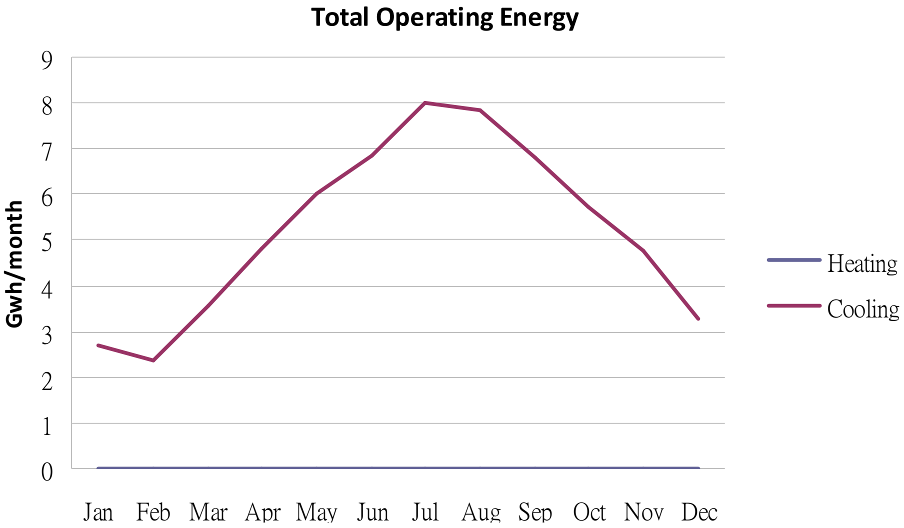


Figure 5.72 The total operating energy of the whole model in Chung-Shan District.

5.6.2 Blocks in Ta-An District

Blocks in Ta-An District represent typical mixed use blocks in Taipei (Figure 5.73 & 5.74). This kind of district generally has various commercial and residential buildings. In this case, there is one modern residential community at the north-western corner, several traditional residential blocks in the middle, and different types of commercial buildings along the big roads.

Figure 5.73 The aerial map: Blocks in Ta-An District. (Red: Commercial use; Yellow: Residential use; Green: Parks) (Source: Geo Force Technologies 2012; Modified by Lin 2013)

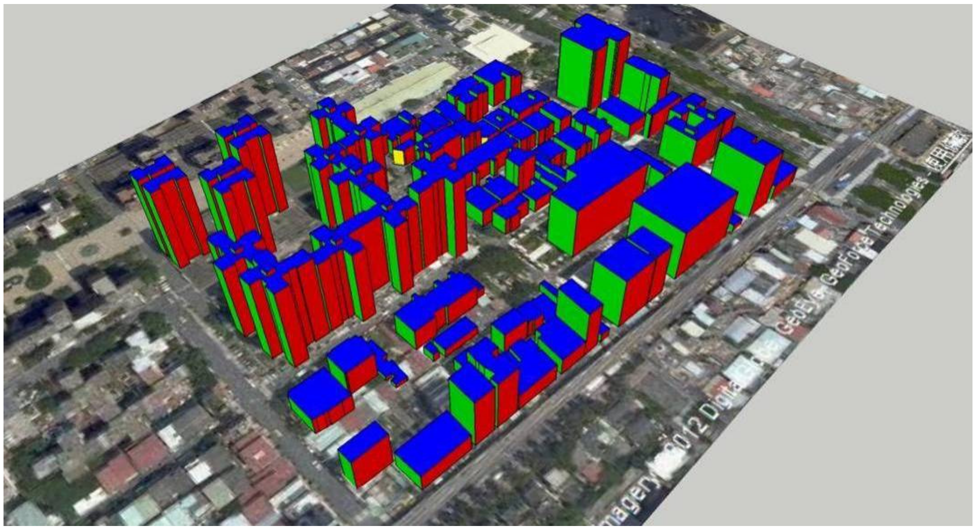


Figure 5.74 A 3D drawing of blocks in Ta-An District.

From the simulation result, it is clear to see the differences of the solar radiations of the roofs (Figure 5.74). The solar radiation of facades would be various depending on the surrounding environment and orientation. The facades of commercial buildings along the big road and facing the south obviously get more solar radiation. For the overall cooling and heating demands, July is the highest month when the cooling demand is needed (Figure 5.75). However, for mixed use blocks, there is a need for heating from December to March.

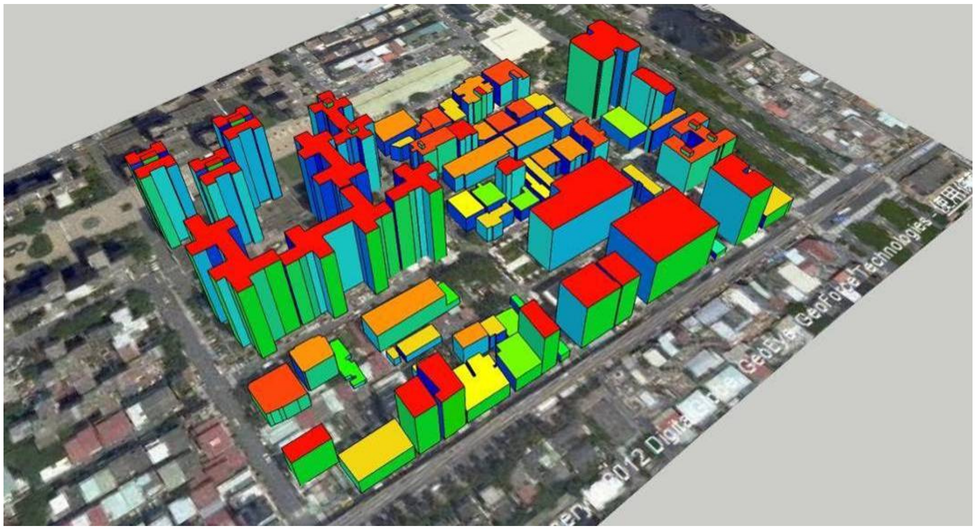


Figure 5.75 The visualized result of blocks in Ta-An District.

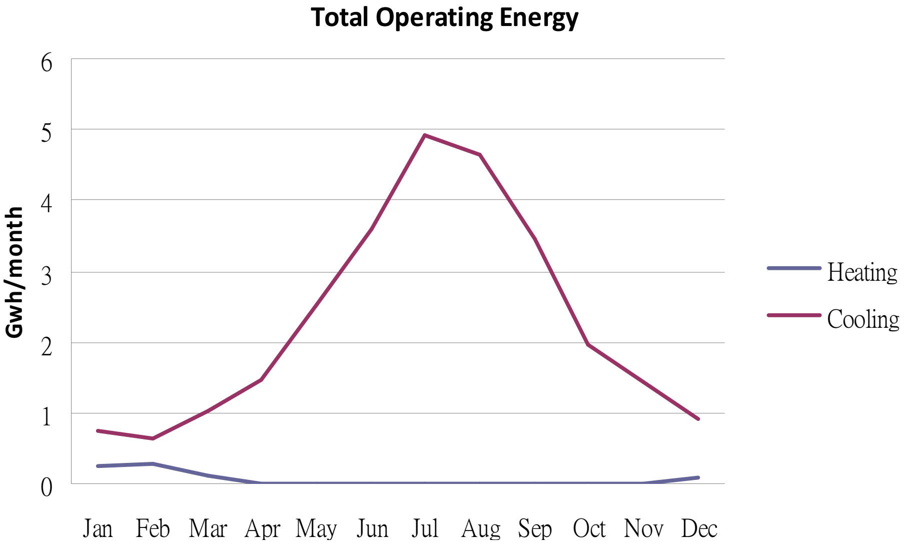


Figure 5.76 The total operating energy of the whole model in Ta-An District.

5.6.3 Blocks in Sung-Shan District

Blocks in Sung-Sang District (Figure 5.76 & 5.77) represent other typical mixed use blocks in Taipei. This kind of district generally has similar commercial and residential buildings. Compared with the buildings in Ta-An District, the buildings in this case are much more consistent.

Figure 5.77 The aerial map: Blocks in Sung-Shan District. (Red: Commercial use; Yellow: Residential use) (Source: Geo Force Technologies 2012; Modified by Lin 2013)

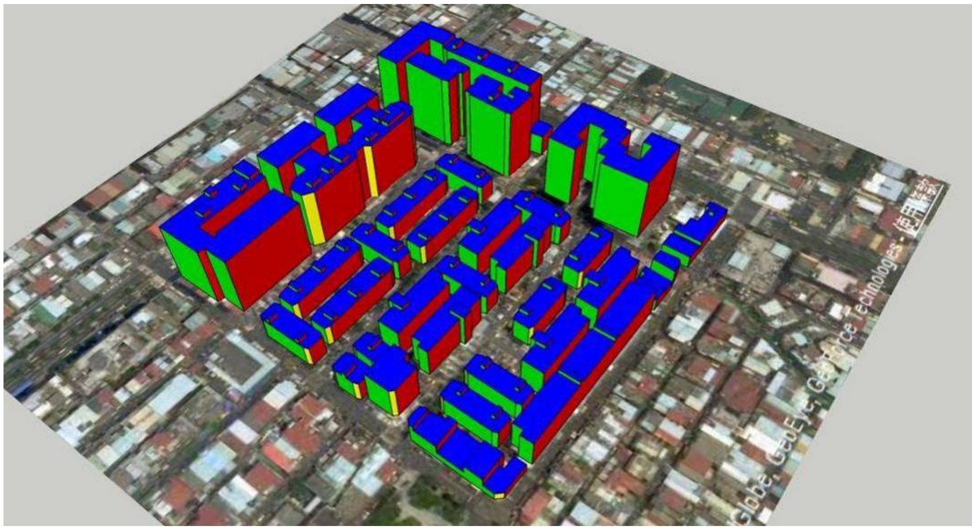


Figure 5.78 A 3D drawing of blocks in Sung-Shan District.

From the simulation result, as shown in blocks in Ta-An District, it is easy to see the differences in the solar radiations of the roofs and the facades (Figure 5.78). For the overall cooling and heating demands, July is the highest month when cooling demand is required (Figure 5.79). Moreover, there is little need for heating from December to March for buildings in Sung-Sang District.

Figure 5.79 The visualized result of blocks in Sung-Shan District.

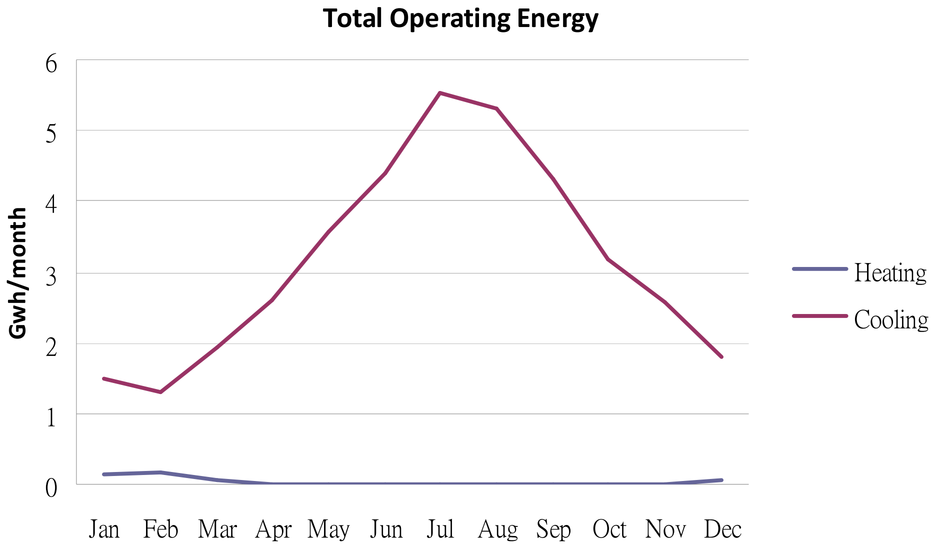


Figure 5.80 The total operating energy of the whole model in Sung-Shan District.

5.6.4 Several blocks in Ta-an District

Several blocks in Ta-An District (Figure 5.80 & 5.81) are located in the central urban environment of Taipei, which roughly covers 0.82 km^2. This district has various blocks and buildings, including commercial, public, residential, school and parks.

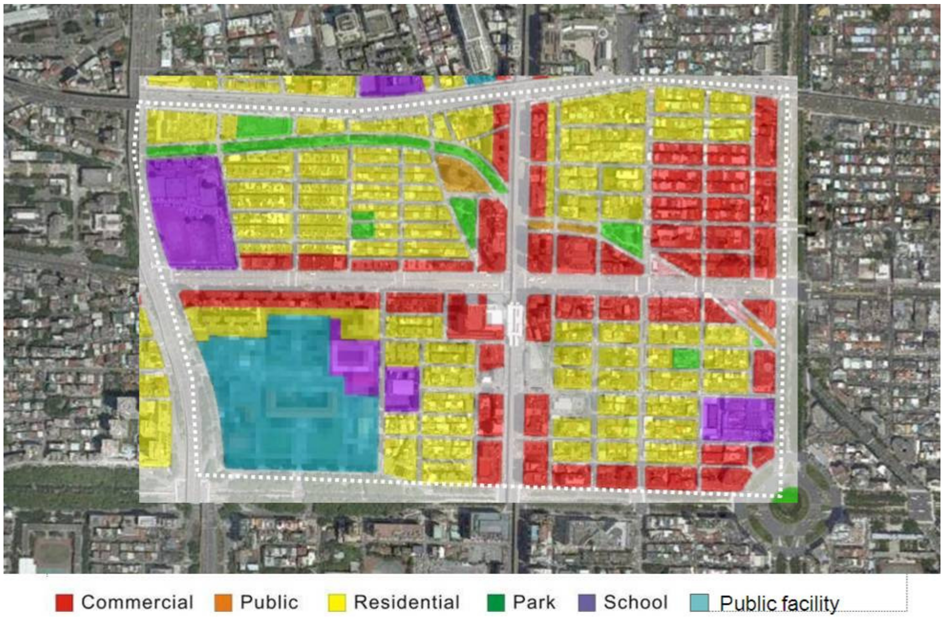


Figure 5.81 The aerial map: Several blocks in Ta-An District. (Source: Geo Force Technologies 2012; Modified by Lin 2013)

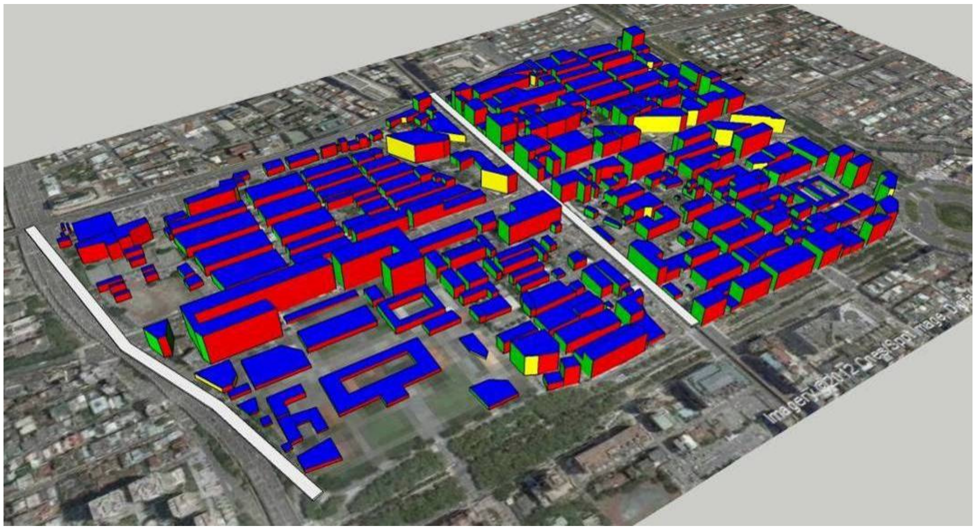


Figure 5.82 A 3D drawing of several blocks in Ta-An District.

From the simulation result, the differences between the solar radiations of the roofs and the facades still exist (Figure 5.82). For the overall cooling and heating demands, July and August are the two highest months when the cooling demand is needed (Figure 5.83). Compared with the cooling demand, the heating demand is much less on average.

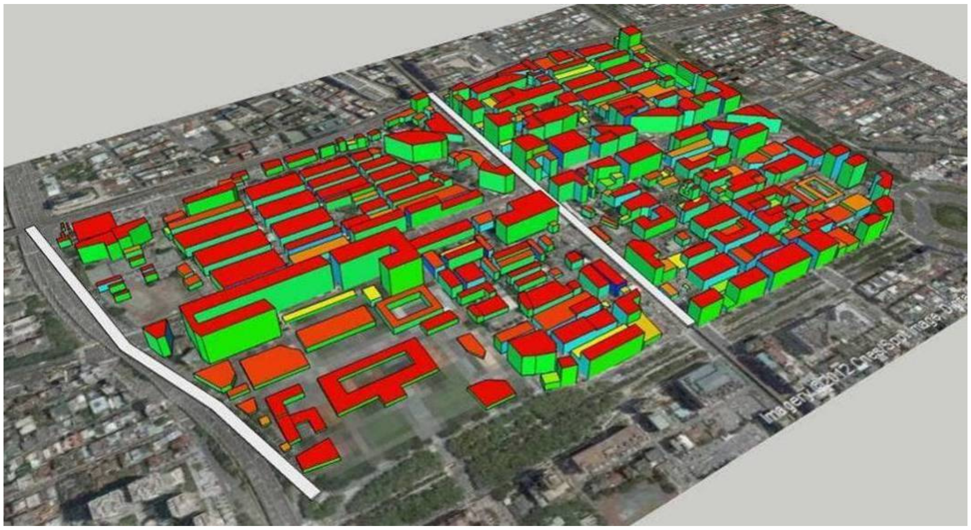


Figure 5.83 The visualized result of several blocks in Ta-An District.

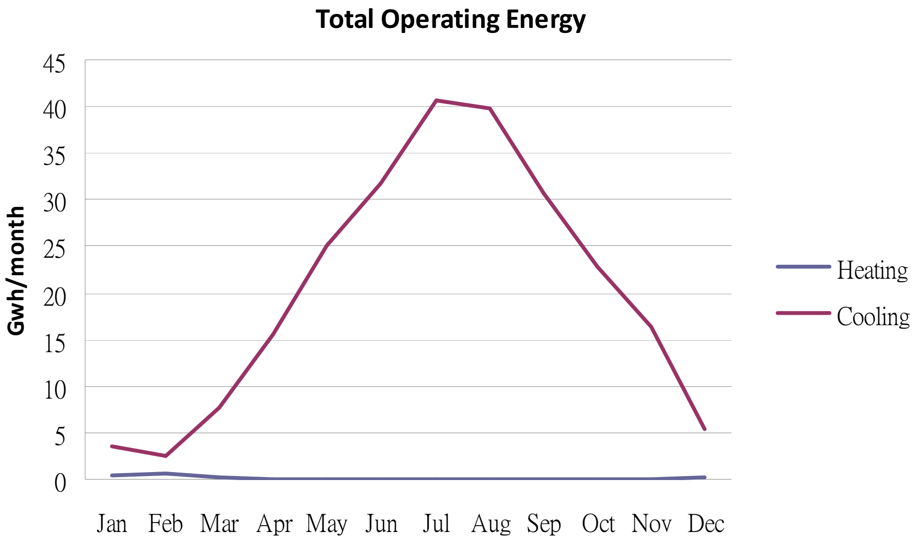


Figure 5.84 The total operating energy of the model in Ta-An District.

5.6.5 Analysis and discussion

The modelling in this section helps to figure out the general cooling and heating demands of typical blocks and districts in Taipei. Moreover, compared with the previous modelling, the differences of energy demand of commercial and residential buildings can be identified. Furthermore, the results point out some potential impact factors, such as land usage.

Firstly, for all block modelling results, the lower energy demands occur in December, January, February and March. However, the same period is the only time requiring heating demand, even though the need is very low. On the other hand, July is the month when cooling machines are needed to reduce the heat the most through a year in Taipei.

Secondly, according to simulation results, the value of the average energy use of commercial buildings in these districts, 253.67 kWh/m^2/yr, is close to the results of modelling for building groups (Table 5.11). On the other hand, for residential buildings, the average cooling load is only 38.84 kWh/m^2/yr, which is much lower than Residential-L-C and Residential-M-T building groups.

		Cooling load ($kWh/m^2/yr$)	Heating load ($kWh/m^2/yr$)
Blocks in Chung-Shan District	Overall	254.04	0.00
	Commercial	254.04	0.00
	Residential	-	-
Blocks in Ta-an District	Overall	115.74	3.04
	Commercial	263.92	0.01
	Residential	58.62	4.20
Blocks in Sung-Shan District	Overall	171.87	1.93
	Commercial	264.62	0.00
	Residential	48.49	4.49
Several Blocks in Ta-an District	Overall	154.37	1.06
	Commercial	252.02	0.00
	Residential	34.81	2.36
Overall	Commercial	253.67	0.00
	Residential	38.84	2.75

Table 5.11 A list of average cooling and heating demands of blocks.

Thirdly, the differences of energy demand among the models might be influenced by community patterns, orientation of buildings and blocks, block scale, land use, and external shading. In these four models, a higher energy demand comes together with a higher commercial land usage proportion of blocks. However, the simulation results only indicate the differences of energy performance of buildings at different scales that exist. The real reasons should be discussed separately by purifying the complexity of the models and focusing on only one variable. More specific discussions for individual variables would be preceded by the next phase of simulation.

5.6.6 Measurement vs. Simulation

The energy usage of buildings has two sides, demand and supply. The energy demand refers to the thermal output involved in heating, cooling, small power and lighting consumptions. The energy supply refers to the "delivered energy", which means the energy supplied to the buildings. The differences between the energy demand and supply aspects are caused by related system performance, including efficiency of ventilation and small power facilities, and the Coefficient of Performance (COP) of heating and cooling equipments. Moreover, the energy supply is also described in Primary Energy (PE) terms, which relates to the energy content in the fuel used and fuels for electricity production at power stations. The CO2 emissions are those associated with the PE use (Jones et al. 2011) (Figure 5.85).

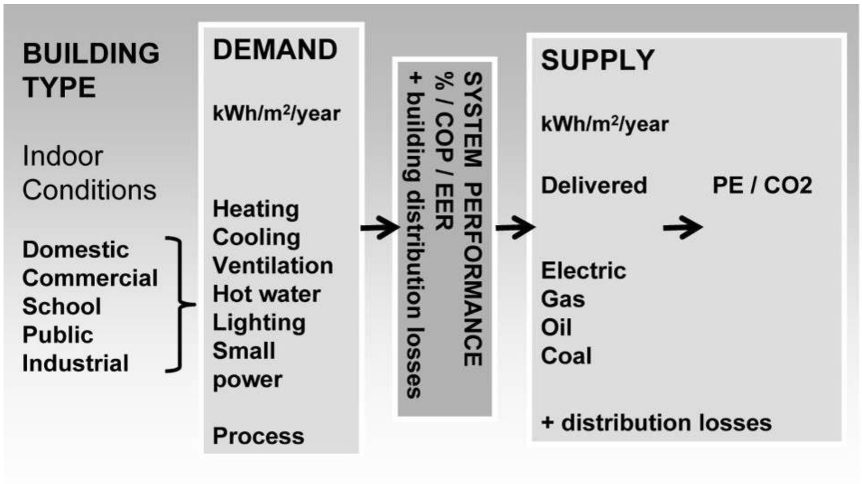


Figure 5.85 Summary of energy terminology (Source: Jones et al. 2011).

Simulation is one of the methods to understand the energy demand side. Solid default settings can help researchers predict energy requirements precisely. On the other hand, practical measurement and investigation are some of the useful ways to know the energy supply. In this section, the previous studies are reviewed first and compared with the information of the modelling results. This process is needed to check their accuracy and confirm the validation of the technical tools.

To begin with, according to the thesis of Kao (2005) and report of the Bureau of Energy in Taiwan, the electricity use proportion of different buildings can be checked in Table 5.12. For domestic buildings, small power consumed almost half of the use; lighting occupied roughly one third; AC systems and heating became the smallest part. Furthermore, the annual electricity consumption of residential houses in Taiwan was 32.1 to 41.8 kWh/m^2/yr, which is much lower than the average of Taipei, 58.32 kWh/m^2/yr. On the contrary, for non-domestic buildings, AC systems should be responsible for most of the energy consumption, followed by lighting.

Non-domestic group	Building type	AC System (%)	Lighting (%)	Elevator (%)	Piping (%)	Others (%)
Assembly	Museum	54	24	8	6	8
Commercial	Shopping mall	56	29	5	3	7
	Hotel	50	29	6	7	8
	Office	41	40	8	4	7
	Department	44	37	8	6	5
Commercial average		49	32	7	5	7
Institutional	School	44	35	4	6	11
	Research institution	48	19	3	5	25
	Hospital	53	20	5	5	17
	Government	46	33	8	4	9
Institutional average		48	27	5	5	15
Domestic group	Building type	AC System (%)	Lighting (%)	Small power & Others (%)	Annual electricity consumption (kWh/m^2/yr)	
Residential	Community (apartment and terrace)	22	27	51	41.8	
	Single building	18	34	48	32.1	
Residential average		20	30	50	-	

Table 5.12 Electricity use of different kinds of buildings in Taiwan. (Source: Bureau of Energy, Ministry of Economy, R.O.C. 2002; Kao 2005)

Next, the measured electricity should be calculated with the Coefficient of Performance (COP) to understand how much energy they really offer. In other words, the electricity what the machines need will not completely be transferred into energy. For commercial buildings in Taipei, there are many kinds of AC systems, including central, packaged and window type AC systems. Each of them uses different kinds of machines, which makes them have various COP (Table 5.13). Central AC systems with water cooled machinery own the highest efficiency. But it does not mean the system is the best choice for all commercial buildings. In general, the intermediate values of COP for AC systems in commercial and residential buildings are roughly four and three.

AC system		COP
Central AC system	Water cooled	4.45 - 6.10
	Air cooled	2.79
PAC (packaged air conditioner)	Water cooled	4.13
	Air cooled	3.18
WAC (window type air conditioner)	Console type	2.91 - 3.10
	Split type	3.06 - 3.33

Table 5.13 The COP minimum requirement of three different cooling systems in Taiwan. (Source: Ministry of Economic Affairs, R.O.C. 2005)

For commercial buildings, COP is the figure to judge the efficiency of a chiller, not the whole AC system. Therefore, it is necessary to consider the electricity for the other parts, including water pump, cooling towers, AC box and fans. Overall, 60% of electricity would be used for activating chillers and 40% would be used for pumps, towers and fans (Table 5.14).

	Chiller	Chilled water pump	Condenser water pump	Cooling towers	AC box & Fans
Electricity Consumption Proportion (%)	60	11	13	3	13

Table 5.14 The electricity consumption proportion of a central AC system in Taiwan. (Source: Ministry of Economic Affairs, R.O.C. 2005)

Next, the average illumination of lighting in Taiwan for commercial spaces is roughly 800 Lm/m^2 and 150 Lm/m^2 for residential house (Lin 2005), both of which are higher than the requirement of the CNS 12112 standard (2009) (Appendix A). Most commercial and office buildings in Taiwan use T4 fluorescent tubes, which have higher luminous efficacy. The majority of residential buildings use 45.5% fluorescent tubes, 34% incandescent and 20.4% energy saving light bulbs (ibid.). According to Lin's investigation and the default setting associated with the diary of lighting (Table 5.4), the electricity demand and heat output of lighting for commercial and residential buildings can be calculated as follows.

Lastly, Chen (2006) measured residential buildings in 23 blocks which are spread across seven different districts in Taipei. In the research, the author analyzed the relationship between the electricity use and the building type, orientation, storey and road width. Furthermore, he found that the general annual electricity usage of residential houses in mixed land use blocks in Taipei was 58.32 kWh/m^2/yr. And the usage of the residential community type was slightly higher than other building types, which showed agreement with the comparison of Residential-L and Residential-M prototype simulation results. Additionally, Kan (2009) undertook a series of field work experiments which analyzed the electricity use samples offered by Taiwan Power Company and concluded that the overall average electricity usage of commercial buildings in Taipei was 215.6 kWh/m^2/yr.

For energy demand and supply calculation, the results of Chung-Shan, Ta-An, Sung-Sang Blocks and Ta-An District modelling in this research are applied to compare with the practical measurement undertaken by Chen in 2006 and Kan in 2009. These four areas include the majority of research objects covered in Chen and Kan’s research. The detailed information involved in each block and overall consumption figures can be checked in Table 5.11. Based on the background of living style and related facility data presented earlier, the connection between the energy demand and electricity supply could help to illustrate the differences between modelling and measurement (Table 5.15 & 5.16). For commercial buildings, the simulation result is located in a reasonable range. Furthermore, if we calculate the energy supply according to the average COP of the central AC systems of commercial buildings in Taiwan (four), the total energy supply is 211.17 kWh/m^2/yr, which is very close to the measurement figures. On the other hand, for residential buildings, the simulation result is slightly higher than the measurement. In short, through the comparison, the validation and accuracy of technical tools are strongly confirmed because both the simulation results for the energy demand of residential and commercial buildings are pretty close to the real situation.

Sections	Energy calculation						Measurement (kWh/m^2/yr) (Kan 2009)	
	Energy demand			Energy supply (kWh/m^2/yr)				
	Energy output		COP					
Cooling	253.67 kWh/m^2/yr		2.79-6.10 (60%)	Chiller	90.92 - 41.59	151.53 - 69.32	Chiller	63.39
			(40%)	Others	60.61 - 27.23		Others	42.25
Lighting	15.15 W/m^2	Heat output = 46.75 W/m^2	-	66.18			68.99	
Small power & Others	17 W/m^2		-	39.29			40.96	
People	14.6 W/m^2		-	-			-	
Total	-			256.91 – 174.79			215.6	

Table 5.15 The electricity consumption calculation of commercial buildings in Taipei. (The simulation results are marked in the bold framed square.)

Sections	Energy calculation					Measurement (kWh/m^2/yr) (Chen 2006)
	Energy demand			Energy supply (kWh/m^2/yr)		
	Energy output		COP			
Cooling	38.84 kWh/m^2/yr		2.91-3.33	Chiller	13.35 – 11.66	11.66
Heating	2.75 kWh/m^2/yr		1	2.75		-
Lighting	5.32 W/m^2	Heat output = 13.32 W/m^2	-	16.60		17.50
Small power & Others	3 W/m^2		-	27.67		29.16
People	5 W/m^2		-	-		-
Total	-			60.37 – 58.68		58.32

Table 5.16 The electricity consumption calculation of general residential buildings in Taipei.

5.7 Conclusion

This chapter aims to understand the energy performance of general building, group, and district types in Taipei through the simulation. The process not only presents the energy performance of various kinds of buildings, but also recognizes the differences among the buildings at different scales. Additionally, the simulation helps to imply several potential variables of energy demand of buildings and verify the accuracy of the calculation engine by comparing the results with practical measurement. Several important achievements and conclusions are listed as follows.

Energy performance and potential strategies

The detailed energy performance of all building prototypes, blocks, and districts can be checked in the previous discussion sections. Here are the important conclusions and perspectives.

1. These nine different prototypes can be classified into two groups due to their different energy usage proportion types; non-domestic and domestic groups. Assembly, Institutional, Commercial, and Industrial buildings belong to non-domestic buildings; the rest of the building types belong to the domestic group. For the former, a cooling need exists throughout the whole year, particularly from April to November. For the latter, the cooling need is only during the summer time and the differences between the seasonal effects on this group are obvious.

2. Depending on the different prototypes, the main heat sources are varied. The incidental gain overwhelms the other heat sources for all building types except Others. It occupies the annual total heat gain from 52.75% to 84.08%. Solar gain is the second greatest heat source, which occupies 14.34% to 43.75% (Table 5.9). The heat associated with ventilation and infiltration would offer heat for none-domestic building groups. In contrast, the heat would lose in that way for domestic buildings. Moreover, the heat transmitted through fabric would help the majority of buildings emit extra heat from interior spaces.

3. Based on the simulation results, the potential strategies applied to reduce the energy use of different kinds of buildings should be varied. The strategies involved in reducing the incidental and cooling gains are critical for all kinds of buildings. But, the strategies for solar gain would not make a big difference for the Assembly buildings. Moreover, the strategies involved in ventilation gain should be applied to Industrial and Institutional buildings. Also, for Commercial-S, Institutional, Residential-L, -M, -S, and Others buildings, it is considerable to focus on the fabric gain.

Differences among the cooling demand of building prototypes, building groups and districts

In general, the average cooling demand of building groups are lower than the ones of building types. This phenomenon could be seen in both residential and commercial buildings. For residential buildings, their average cooling demand at urban scale is much lower than the ones at smaller scales. The demands of residential buildings at building, group and district scales are 88, 58 and 39 kWh/m^2 /yr respectively, which decrease by 34% and 56% at group and district scales. However, the value of the average cooling demand of commercial buildings in districts is close to the results of modelling for building groups. The demands of them are 301, 255 and 254 kWh/m^2/yr at building, group and district scales (Table 5.17).

Moreover, because of the additional consideration of over-shading in group and district modelling, the differences prove its solid impact and importance. Furthermore, the over-shading has strong connection with solar gain. Therefore, due to the higher proportion of solar gain of all heat sources in residential buildings, it is clear to observe the larger reduction of them than the commercial buildings.

	Commercial		Residential	
	Cooling demand (kWh/m^2/yr)	Heating demand (kWh/m^2/yr)	Cooling demand (kWh/m^2/yr)	Heating demand (kWh/m^2/yr)
Prototypes	301	0	88	4
Groups	255 (-15%)	0	58 (-34%)	4
Districts	254 (-16%)	0	39 (-56%)	3 (-25%)

Table 5.17 Differences among the energy demand of commercial and residential buildings of prototypes, groups and districts.

Validation of technical tools

The technical tools applied in this research are still at an early development stage, and integrate three different updated tools, namely HTB2, Virvil Plugins and SketchUp. However, by comparing the simulation results of both commercial and residential buildings with the practical measurement undertaken by Chen (2006) and Kan (2009), the validation of the method is confirmed and the accuracy of it is highly reliable.

An example of using the bottom-up engineering method

Taipei, as the capital of Taiwan, is a high-density city with more than 2.6 million citizens. With the rising consciousness of sustainable development and limited energy sources, the government and most of the people realized the importance of sustainability. Before giving practical suggestions about how to improve the built environment, a basic understanding of it at different scales is critical. Due to the lack of fundamental research involved in the energy performance of buildings, this research firstly observes the urban environment and classifies buildings into nine types, then defines the background of these prototypes. The default settings of fundamental information involved in diary, building, and interaction of heat, could be defined according to national statistics, building codes, practical measurement and design principals. Secondly, the simulation can be done at different levels to learn more about the energy performance of buildings, groups, districts, and even cities. In short, the simulation result and process not only revises the energy performance of buildings, but also shows how a bottom-up engineering method works.

Chapter 6

SIMULATION FOR BETTER STRATEGIES

SIMULATION UNDERTAKEN TO REVEAL IMPORTANT VARIABLES FOR THE ARCHITECTURES AND EXAMINE VARIOUS DESIGN STRATEGIES FOR SUMMARIZING GUIDELINES FOR TAIPEI

SIMULATION FOR BETTER STRATEGIES

6.1 Introduction

Decreasing the CO2 emissions of Taiwan is the national goal for city development. However, the requirements of the present green building regulation, EEWH-BC, and the Master Plan and the Detailed Plan of urban planning are obviously not ambitious enough to control the situation, which has been introduced in Section 3.4. Although the local government had tried to set up lots of political strategies to reduce CO2 emissions for industries and change the electricity structure, the strategies related to architectures are comparatively fewer, particularly for changes to the existing environment.

The research questions are:

"How and what can we do to implant or transform the strategies which we apply to new building projects to make them relevant to the existing ones? Furthermore, what are the most useful and effective strategies?" and

"The review of research related to sustainable development shows that a focus of sustainable research shifts from the building scale to the regional scale. What are the differences for those design strategies when they are applied to a single building or groups? Should we pay attention to different issues when facing different scale projects?"

In order to answer these questions, the aim of this chapter is to simulate and analyze critical variables at both building and urban scales, with different strategies for recognizing the degrees of their impact of energy demand and supply. Moreover, the objectives of this chapter are to summarise the related strategies from the conclusion of reviewing, to simulate and discuss the important variables and design strategies for the buildings in Taipei, to figure out the differences among strategy compositions, and to conclude the useful strategies for Taipei accounting for different building types and scales. Overall, this chapter is divided into several parts, deeper discussion of national goals, simulation and analysis of variables and selected design strategies, examination of packages of strategies and conclusion (Figure 6.1).

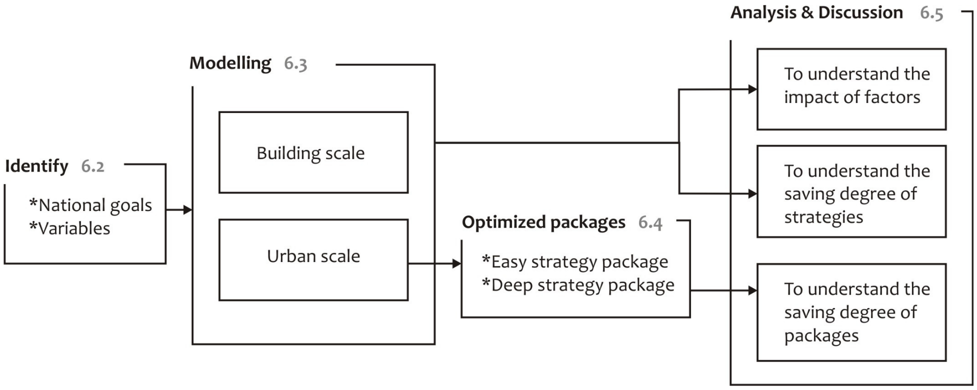


Figure 6.1 Framework of modelling in phase two.

6.2 National goals and selected variables

In this section, the goal of the local government of Taiwan would be presented first. Furthermore, the related design strategies to decrease energy use which will be examined in this research would be summarized.

6.2.1 National goals

Executive Yuan of Taiwan (行政院) announced that there would be a Sustainable Energy Policy Convention in 2008. The goal of it was to propose a return to year 2000 CO2 emissions levels by 2025, and ultimately halve those emissions levels again by 2050. Based on this context, Taiwan produced 11.17 MT/capita/yr of CO2 in 2008, which equalled 257 million tons. But in 2000, the figures were only 9.67

MT/capita/yr and 219.4 million tons. In other words, Taiwan should at least reduce 35 million tons, namely 13.6%, to achieve the mid-term goal and 147 tons, namely 56.8%, to achieve the long-term goal. The overall expected decreasing trend can be seen in Figure 3.13.

However, in order to attempt to understand how much the energy consumption of different kinds of buildings should be reduced in a city, related data is required, including total floor areas of different buildings and different regions, average energy use intensity (EUI) of all building sectors, and CO2 emissions of produce, maintenance, renovation, and demolition of construction. Additionally, the local government gave simple formulas for understanding and calculating the relationship between the electricity usage of buildings and CO2 emissions, as below. However, the formula is only useful for single building calculation because the related data needed for massive building calculation are still incomplete.

> Energy saving (kWh) = Floor area (m^2) X EUI (kWh/m^2/yr) X a (Saving proportion, %) (Ministry of the Interior 2011)
>
> CO2 reduction (kg) = Energy saving (kWh) X 0.62 (kg/ kWh) (ibid.)
>
> The CO2 emission factor, 0.62, refers the total CO2 emissions (kg) produced by 1 kWh electricity, which would be varied depending on the annual use. In 2005, the figure was 0.63; in 2009, it was 0.61.

Because of the lack of related data and researches in Taiwan, it is impossible at the moment to set up goals which precisely match the national goals for the energy use reduction proportion of the architectures in Taipei. Therefore, in the following simulation, the overall proportion of CO2 emission reduction in the middle and long term, 13.6% and 56.8%, would be the standards for testing different variables and strategies.

6.2.2 List of selected variables

In chapter two, the literature involved in sustainable design strategies at urban and building scales has been classified and listed (Table 2.7). For the issues at macro and micro urban scales, except the ones related to density, microclimate, renewable energy, urban pattern and buildings forms, they are hardly to be examined because the technical tools only can do the quantitative calculation and analysis. For the issues at building scale, most of the strategies would be examined for further improvement, particularly for the ones they contain have been transplanted into the official regulations in Taiwan. Although this study will not examine all issues related to sustainable strategies in the table, it still attempts to delve deeper into a stricter discussion, through the use of simulations, about the issues strongly related to urban and building design and the reduction of energy use. According to them, important issues and variables are selected for further discussion in this research (Table 6.1).

Scale	Issues	Variables
Urban	Density	High or low intensity development (7)
	Microclimate responsive design	1. Over-shading (9) 2. UHI effect mitigation, such as landscape, planting, etc. (10)
	Renewable energy application	Solar PV application in urban areas (11)
	Urban pattern	1. Urban fabrication (8) 2. Building arrangement in blocks (8) 3. Usage proportion of blocks (6) 4. Orientation of district (3)
Building	Building form	1. Building shape (2) 2. Wall-to-Volume ratio (2) 3. Orientation of façade and building (3)
	Construct and materials	1. Shading devices (9) 2. Insulation - U-Value of walls, windows and roof (5)
	Fenestration and ventilation	Glazing ratio (4)
	Living style	1. Efficiency of AC system (1) 2. Lighting usage (1) 3. Temperature setting (1)

Table 6.1 The selected design strategies for simulation in this research. (The numbers in brackets are the sequence of the following sections.)

At urban scale, most scholars believe that compact urban development is the most important principal of sustainable development, which can lead to higher energy efficiency, shortened transportation distances, lower construction costs and other benefits. In addition to density, urban fabrication and building in blocks would also affect the energy performance of the architectures enormously (Jones et al. 2001; Stromann-Andersen and Sattrup 2011). Moreover, incorporating microclimate responsive design is another strategy to balance the negative influence brought by urbanization. All these issues are inevitably selected for further discussion accounting for the different weather and built environments in Taipei.

On the other hand, for buildings at building scale, shape, fabric, fenestration and ventilation are four of the greatest impact design variables for the energy performance of buildings (Szokolay 2004). The shape of buildings emphasizes wall-to-volume ratio and orientation; fabric is involved in shading and insulation; fenestration and ventilation talks about size, position, and orientation of windows. Moreover, living style is another important issue because the incidental gain dominates heat sources in many kinds of buildings in Taipei, which has been proved in the previous chapter.

6.3 Simulation for variables

Succeeding the previous section, it is necessary to examine various variables and design strategies in detail. In each section, there are three parts, the introduction of variables and related strategies, input setting, and simulation at both building and urban scales, and the analysis and discussion of the results. The total simulation process is drawn in Figure 6.2.

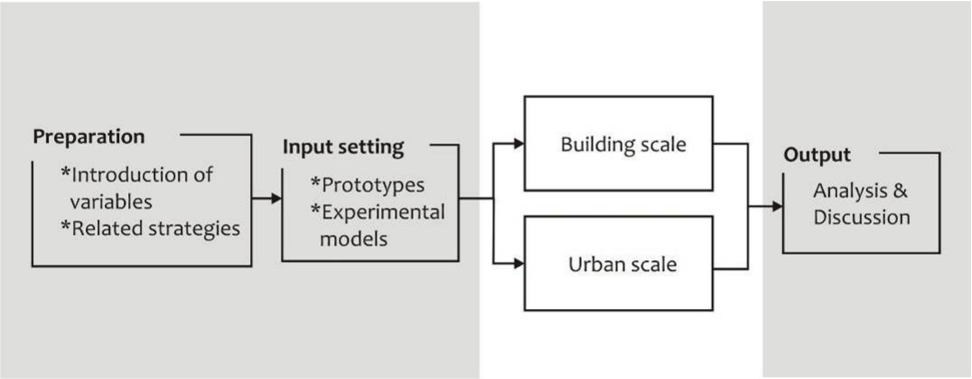


Figure 6.2 The process of modelling for variables and related design strategies.

6.3.1 Living style

Living style concerns the schedule of daily life associated with lighting and equipment usage. Moreover, in order to consider the interior situation together, this research put the equipment efficiency with them together. Schedule of daily life is deeply rooted in a local culture that is extremely difficult to change. But, the lighting and equipment usage and efficiency can be modified by adopting passive design and technological improvement.

First of all, passive design strategies can help buildings reduce their dependence on equipment. For lighting, more light can pass from the outdoor environment to the interior space to decrease the lighting usage, particularly for deep plan spaces. Similar strategies are abundant, such as changing ceiling geometry (Ahmed et al. 2009), decreasing the lighting areas by using sunlight and arranging suitable types of lamps at appropriate distances (Figure 6.3) (Lin 2003). Moreover, the colours of lights and environmental background could enforce the lighting effect (Lee 2002). For cooling systems, low temperature air flows can be guided to decrease interior temperatures or help to bring the heat of waste air away (Lin 2009a). Additionally, modifying the control of AC systems is another method. In Taiwan, people have got used to setting their AC systems at 23°C, however it is strongly recommended to adjust them from 26°C to 28°C (Ministry of the Interior 2013).

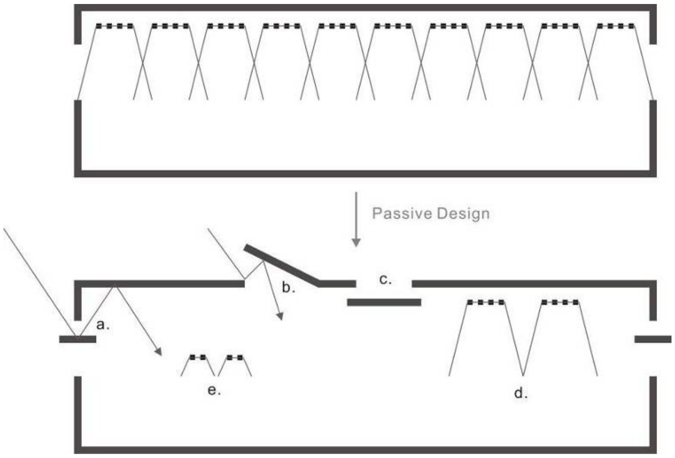


Figure 6.3 The application of passive lighting design (a. Reflecting sunlight into deeper plan spaces; b. Changing ceiling geometry; c. Using skylight; d. Arranging lamps at appropriate distances; e. Collocation with devices for specific purpose).

Secondly, technological improvement can bring more efficient equipment that increases the COP of AC systems. This method is particularly useful for commercial buildings; changing pipe and fan arrangements or using better ventilation systems is one of these strategies (Lin 2009a). Moreover, the application of automatic sensor controls can shorten operation times.

In this section, Commercial-L and Residential-L prototypes are taken as case studies for modelling at building scale. As shown in the previous paragraph, passive design can shorten the operation time and decreasing the requirement of lighting. Moreover, technical improvement methods can help to reduce the lighting requirement through increasing the luminous efficiency and luminaire efficacy, adopting auto-sensing devices, and enhancing maintenance (Lee et al. 2010; Lin 2009b). In the default setting of modelling for lighting, Lux and operation time are two variables to control the lighting performance. For commercial and residential buildings in Taiwan, the average measured Lux is usually above 750 and 150 respectively (Lee 2002) (Appendix A). Lee (2002) suggests the minimum of Lux in commercial and residential buildings could be close to 400 and 70 Lm/m^2. Therefore, there are five hypothesized different degrees to reduce lighting requirements through the application of related passive design strategies for commercial and residential models (Table 6.7).

Buildings	Variables	Pack A (Prototype)	Pack B	Pack C	Pack D	Pack E
Commercial	LUX (Lm/m^2)	800	700	600	500	400
	Operation time (hr/wk)	84	77	70	63	56
	Heat output (W/m^2)	15.15	13.26 (-1.89)	11.36 (-3.79)	9.47 (-5.68)	7.58 (-7.57)
Residential	LUX (Lm/m^2)	150	130	110	90	70
	Operation time (hr/wk)	60	56	52	48	44
	Heat output (W/m^2)	5.32	4.61 (-0.71)	3.90 (-1.42)	3.19 (-2.13)	2.48 (-2.84)

Table 6.2 The changes of LUX, operation time and heat output of lighting for Commercial-L and Residential-L prototypes.

From the simulation results, those strategies involved in cutting lighting usage successfully decrease the total energy consumption. For commercial buildings, the reduction of cooling demand could reach 33 kWh/m^2/yr with a potential electricity saving of 44 kWh/m^2/yr (Figure 6.4 & 6.5). 33 kWh/m^2/yr cooling demand equals to 8.25 kWh/m^2/yr of electricity supply on the condition that the COP of AC systems of commercial building is 4.

On the other hand, for residential buildings, there is a 13 kWh/m^2/yr difference in cooling demand between the best and the worst situations (Figure 6.6 & 6.7). Additionally, 11 kWh/m^2/yr of electricity can be saved. A 13 kWh/m^2/yr cooling demand reduction equals to a 4.33 kWh/m^2/yr electricity reduction. Moreover, there is a slightly increased trend for heating requirement. However, the total annual energy demand for this is still decreasing.

In short, the direct saving for electricity is much more than the indirect saving for cooling demand caused by lighting usage. And, lighting control has been proved as a potential strategy to save energy for both commercial and residential buildings in Taipei.

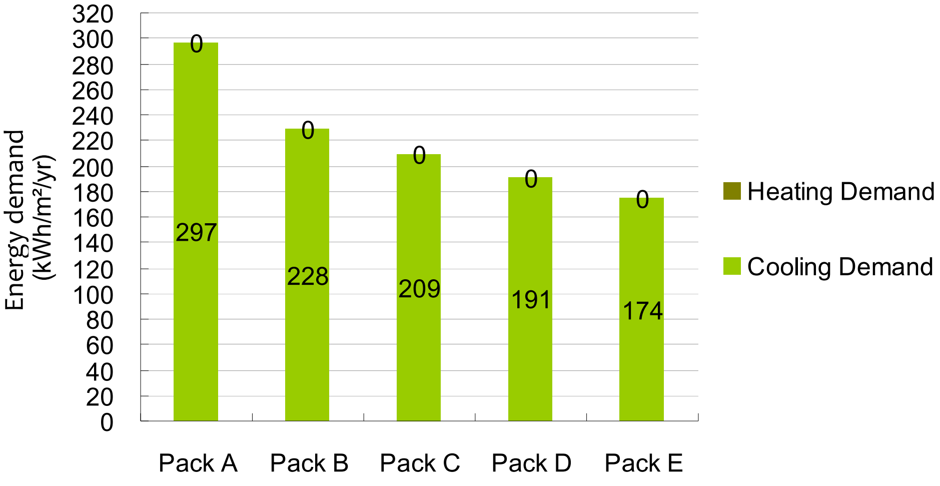


Figure 6.4 The comparison of cooling and heating demands accounting for the decreased lighting requirement, operation time and internal heat output of the Commercial-L prototype.

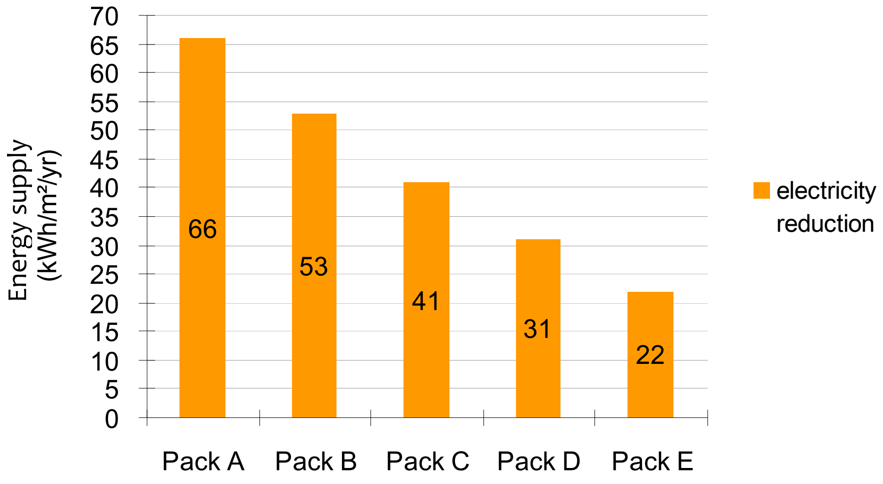


Figure 6.5 The comparison of electricity reduction accounting for the decreased lighting requirement, operation time and internal heat output of the Commercial-L prototype.

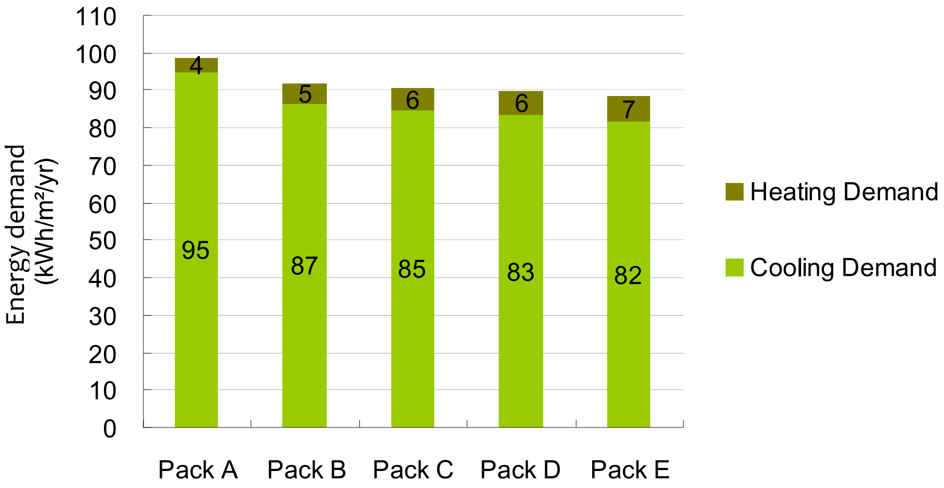


Figure 6.6 The comparison of cooling and heating demands accounting for the decreased lighting requirement, operation time and internal heat output of the Residential-L prototype.

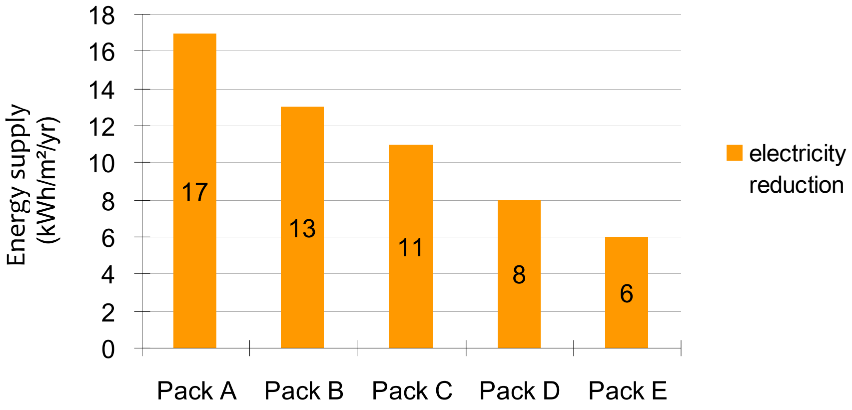


Figure 6.7 The comparison of electricity reduction accounting for the decreased lighting requirement, operation time and internal heat output of the Residential-L prototype.

Next, the temperature setting of HVAC systems plays an important role in saving energy. The Commercial-L and Residential-L prototypes are taken as subjects and simulated in different situations. There are six different popular settings for AC systems observed for commercial buildings in Taiwan from 23°C to 28°C; 18-23°C, 18-24°C, 18-25°C, 18-26°C, 18-27°C, and 18-28°C (Lin 2009a). And there are three settings for residential prototypes from 26°C to 28°C; 18-26°C, 18-27°C, and 18-28°C (ibid.). For both of them, the heating system would be activated if the indoor temperature is lower than 18°C. And the AC system would be activated if the indoor temperature is higher than the temperature setting point.

From the simulation results (Figure 6.8 & 6.9), for both commercial and residential buildings, the degree of saving is enormous and consistent. If citizens can modify the temperature setting of AC systems to 28°C, which the government strongly suggests, the total energy demand can be reduced by 30% at least. The decrease in cooling demand can reach 98 kWh/m^2/yr for commercial buildings and 36 kWh/m^2/yr for residential buildings. Without any further investment, changing the temperature setting of HVAC systems could be seen as one of the most useful strategies to reduce the energy demand of commercial and residential buildings in Taipei.

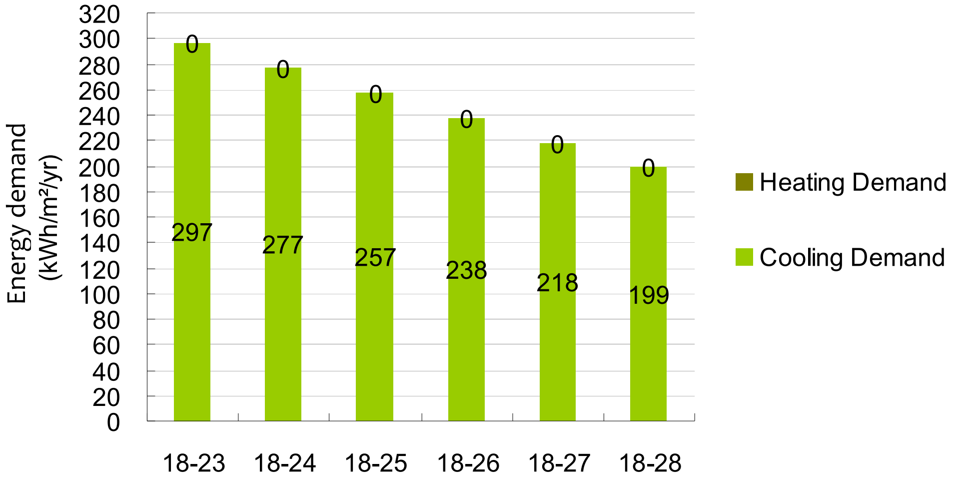


Figure 6.8 The comparison of changing the temperature setting (°C) of HVAC systems for the Commercial-L prototype.

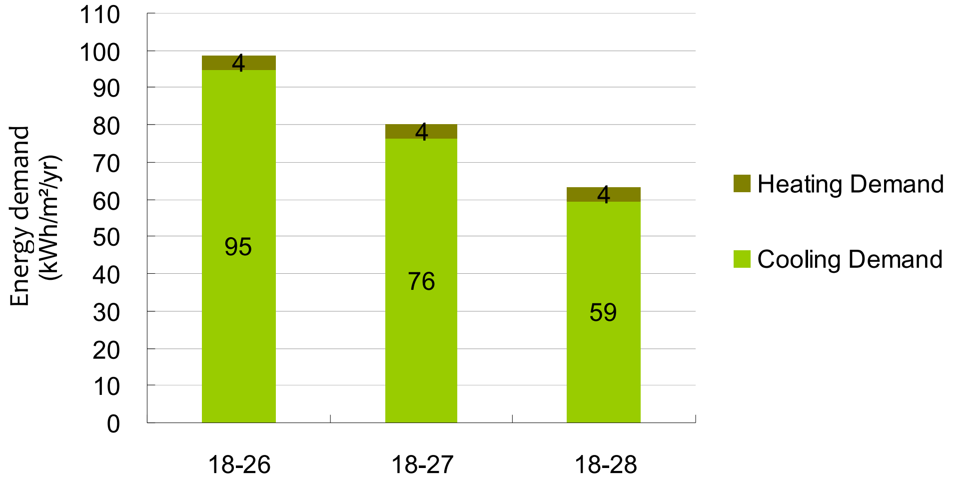


Figure 6.9 The comparison of changing the temperature setting (°C) of HVAC systems for the Residential-L prototype.

Next, the COP of AC systems can help to decrease the energy supply aspect. In this part, the simulation results of the original prototypes of Commercial-L and Residential-L are taken to be calculated with different COP of AC systems in order to compare the differences of their electricity supply requirements. Due to the updated technical development, the expectation of COP systems in commercial buildings is six; it is five for residential buildings. Based on the calculation results (Figure 6.10 & 6.11), the COP of AC systems can decrease half of the cooling supply for commercial buildings and it only reduces 13 kWh/m^2/yr for residential buildings.

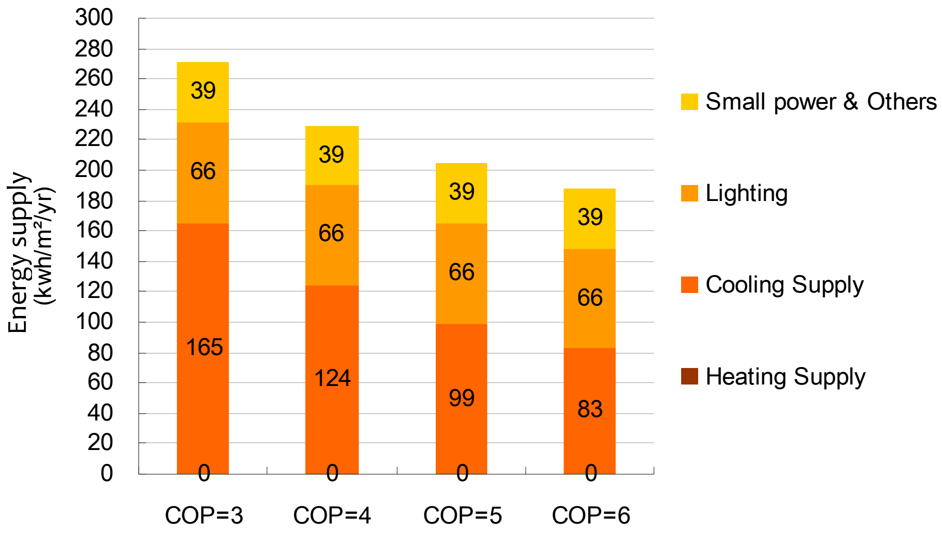


Figure 6.10 The comparison of COP improvements to the AC systems of the Commercial-L prototype.

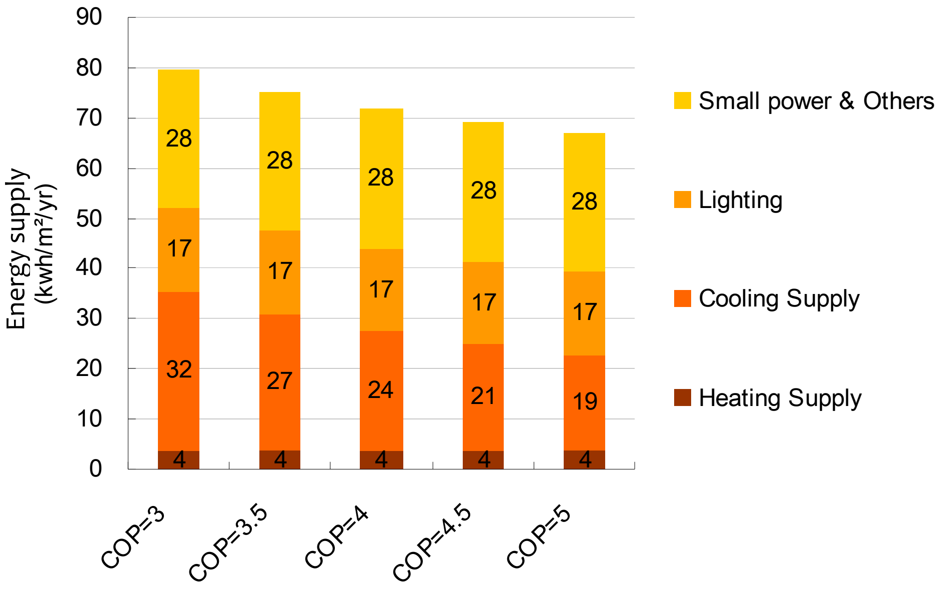


Figure 6.11 The comparison of COP improvements to the AC systems of the Residential-L prototype.

Lastly, five different packages of those strategies involved in living style for commercial and residential buildings are composed and examined by applying them at building (Figure 6.12 & 6.13) and urban scales (Figure 6.14 & 6.15). At building scale, Commercial-L and Residential-L prototypes are the subjects; at urban scale, blocks in Chung-Shan and Ta-An Districts are taken as the subjects.

On the one hand, for a single commercial building, the total energy supply should be decreased by more than two thirds, namely 182 kWh/m^2/yr, of the present situation ideally. The decrease of lighting requirement, temperature setting changes and COP of AC system improvement all contribute to the reduction. For a single residential building, the total energy supply can decrease by 27 kWh/m^2/yr compared to the present situation. Generally speaking, changes involved in living style are practical for decreasing the energy demand and supply for both kinds of buildings at building scale.

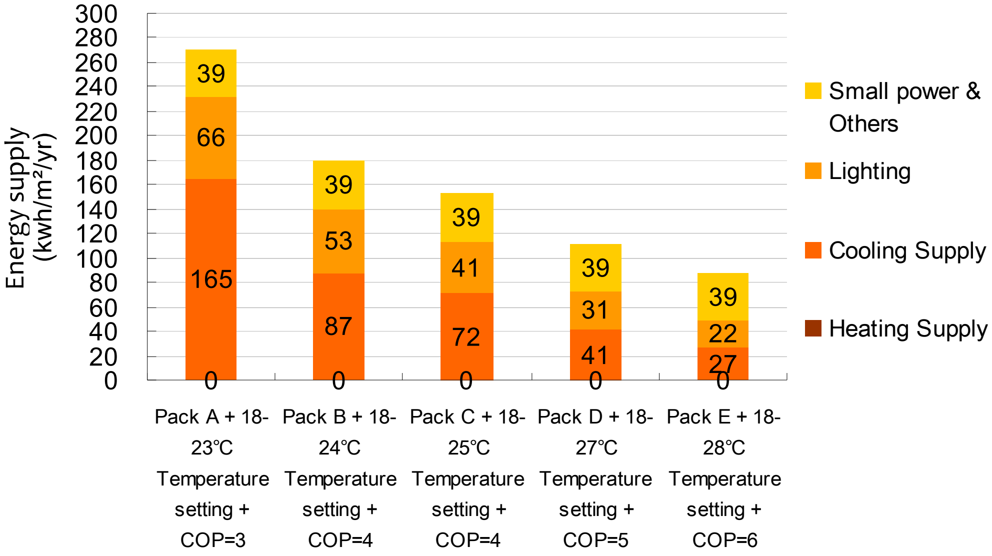


Figure 6.12 The comparison of living style changes for the Commercial-L prototype.

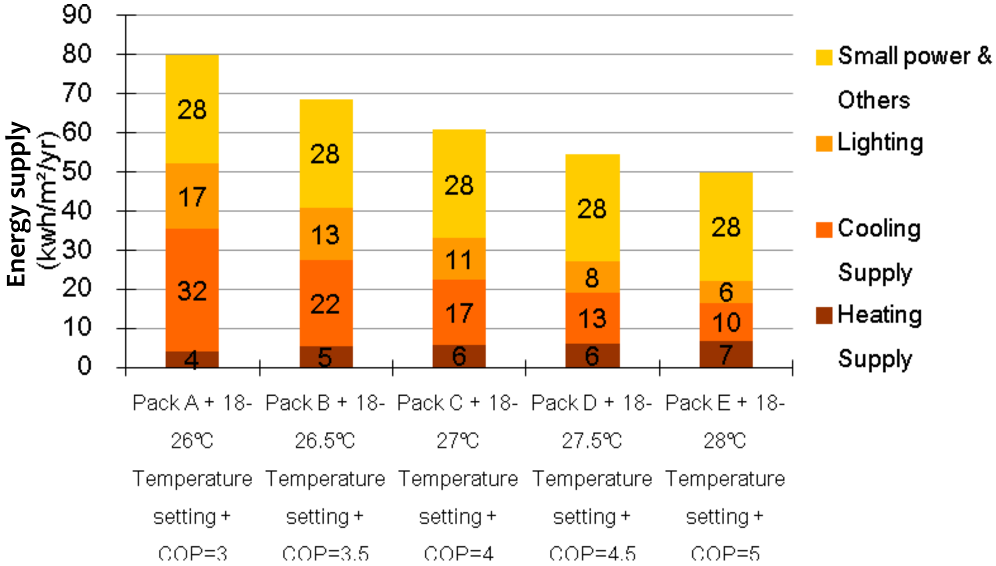


Figure 6.13 The comparison of living style changes for the Residential-L prototype.

On the other hand, the reduction degree of energy supply for buildings at urban scale is less than the buildings at building scale. For commercial buildings in Chung-Shan District, 160 kWh/m^2/yr energy would be saved by the best strategy packages. For residential buildings in Ta-An District, the reduction comes to 23 kWh/m^2/yr.

In short, both simulations at building and urban scales have proved that the living style is one of the most important issues to reduce the energy demand and supply. Without investing lot to construct advanced district facilities, educating citizens and promoting new concepts about living style, including reduction of lighting use, improving the AC system and changing the temperature setting of HVAC systems, would be effective to save energy.

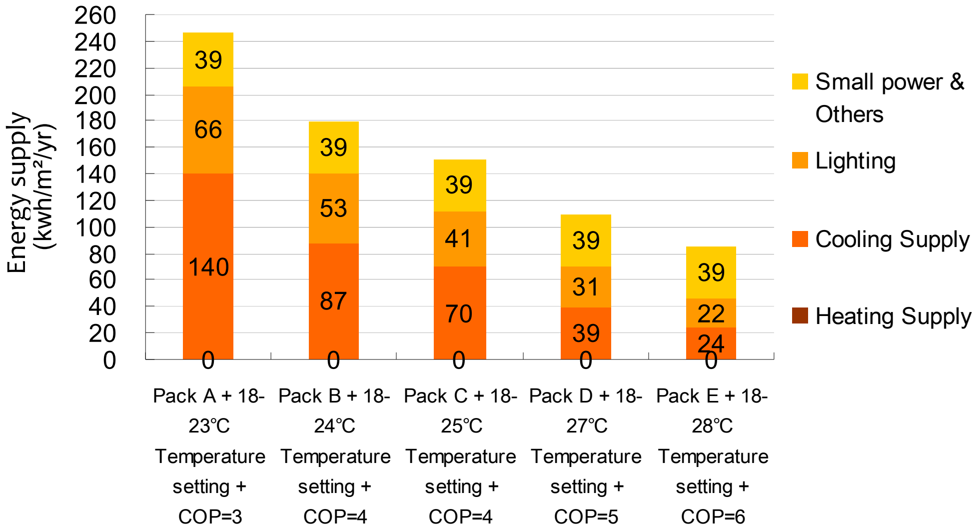


Figure 6.14 The comparison of living style changes for the commercial buildings in blocks in Chuang-Shan District.

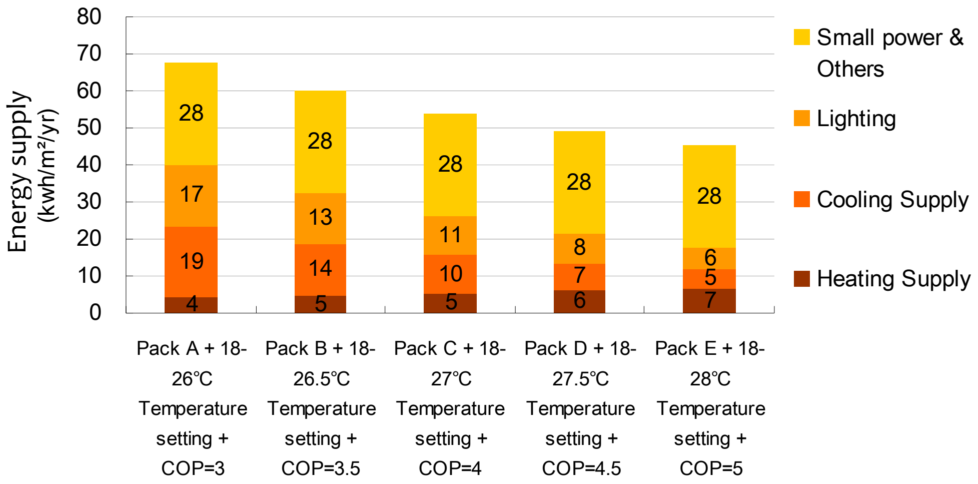


Figure 6.15 The comparison of living style changes for the residential buildings in blocks in Ta-An District.

6.3.2 Building form

In an existing city, most land has already been occupied, but there are still some empty places or redevelopment zones. Although the focus of this research is on the existing environment, it is impossible to completely ignore the issues related to new architectures, such as building form and block patterns.

The form of a building covers lots of variables, including wall-to-volume ratio, building shape, height and orientation. In this section, these variables would be examined separately with simple and clear commercial or residential prototypes, but merely at building scale.

6.3.2.1 Wall-to-volume ratio

Wall-to-volume ratio is one of the most important things and should be designed carefully (Adolphe 2001; Ratti et al. 2005). Lin (2003) introduced the concept to Taiwan and took an office building as an experimental subject, which was designed as four different kinds of forms with the same volume. He found that the annual cooling demand would grow if the building had higher wall-to-volume ratio, no matter how the orientation of building axis was located.

In order to recheck the conclusion of Lin's research, five similar commercial building prototypes are created with the same volume, but with different wall-to-volume ratios (Figure 6.16). Prototype Bld_1 has a square floor plan; the aspect ratio of the floor plan of Bld_2 and _3 is one to two; the aspect ratio of Bld_4 and _5 is one to four. All of them share the same situation and are simulated without considering surrounding areas.

The simulation result does support Lin’s opinion, the wall-to-volume ratio of commercial buildings plays a more important role in energy consumption than the buildings orientation (Table 6.3). The building with a square floor plan requires 270.19 kWh/m^2/yr. The average energy demand of buildings with one to two aspect ratio is 271.82 kWh/m^2/yr. And the buildings with one to four aspect ratio needs 278.09 kWh/m^2/yr. From the table, it is clear to see the differences caused by the wall-to-volume ratio are bigger than the ones caused by the orientation.

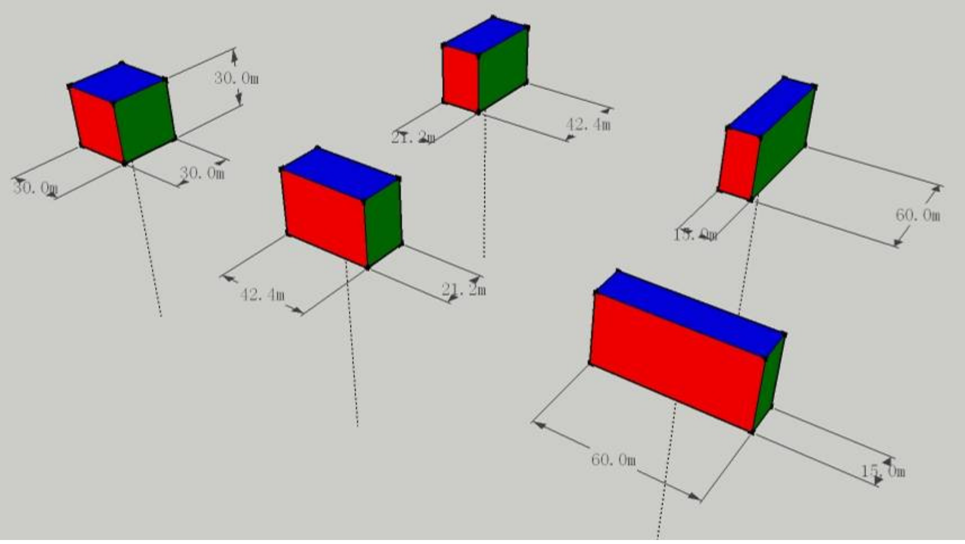


Figure 6.16 A 3D model of different commercial building forms with the same volume, but different wall-to-volume ratio.(The left to right at the bottom row are Bld_1, _ 2, _4;The left to right at the upper row are Bld_3 and _5)

	Bld_1	Bld_2	Bld_3	Bld_4	Bld_5
Wall-to-Volume (m^2/ m^3)	0.1667	0.1746	0.1746	0.2000	0.2000
Orientation	-	N-S	E-W	N-S	E-W
Cooling demand (kWh/m^2/yr)	-270.19	-270.94	-272.70	-276.09	-280.08
		-271.82		-278.09	

Table 6.3 The energy demand of different commercial building forms with the same volume.

6.3.2.2 Building shape

There are numerous different kinds of building forms existing in Taipei. By observing the practical situation, six typical forms are built for modelling; rectangle-shaped, left-handed L-shaped, right-handed L-shaped, U-shaped, T-shaped, and Courtyard (Figure 6.17 & 6.18). Each of them would be simulated in four main orientations and with consideration of self-shading.

Their average annual cooling loads are presented in Table 6.4. Combing these modelling results with the previous modelling, the square shaped building with the lowest wall-to-volume ratio has the least cooling demand. In contrast, the U-shaped building with the highest wall-to-volume ratio consumes more energy than the others. Moreover, among the four building forms with the same wall-to-volume ratio, 0.2, the rectangular building performs poorly due to the lack of self-shading. Additionally, although the courtyard building has higher wall-to-volume ratio than most buildings, its cooling demand is only slightly higher than the T-shaped building.

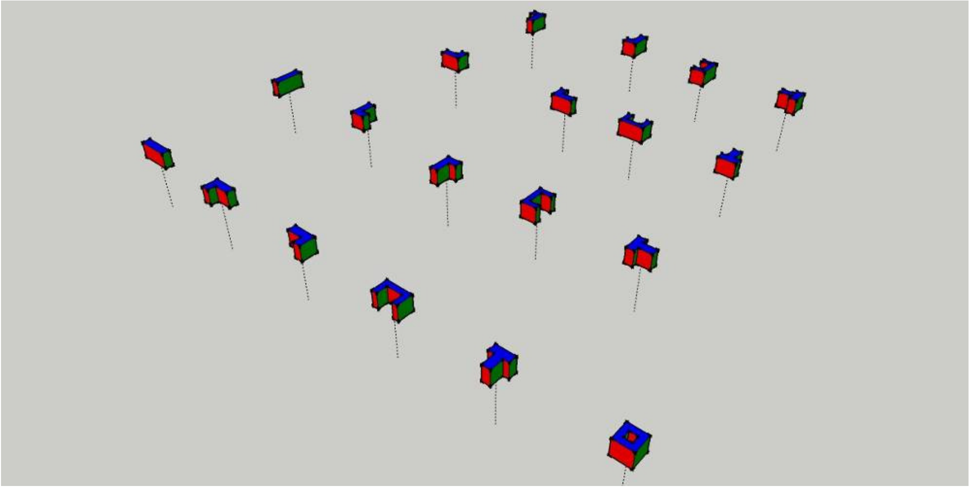


Figure 6.17 Six most popular building forms in Taipei; rectangle-shaped, L-shaped (left & right-handed), U-shaped, T-shaped, and Courtyard.

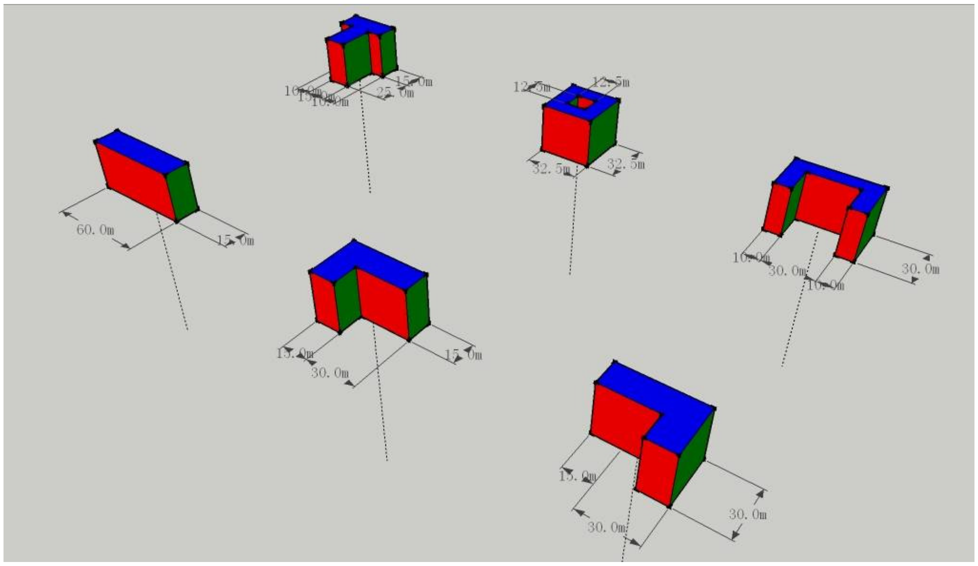


Figure 6.18 Six most popular building forms in Taipei; Rectangle-shaped, L-shaped (left & right-handed), U-shaped, T-shaped, and Courtyard.

	Square-shaped	Rectangle-shaped	Left-handed L-shaped	Right-handed L-shaped	U-shaped	T-shaped	Court-yard
Wall-to-Volume (m^2/ m^3)	0.1667	0.2000	0.2000	0.2000	0.2556	0.2000	0.2333
Solar gain (kWh/ m^2/yr)	33.51	41.50	39.53	39.27	49.38	39.21	39.92
Cooling demand (kWh/ m^2/yr)	-270.19	-278.09	-275.87	-275.60	-284.81	-275.51	-275.57

Table 6.4 The cooling demand of six popular commercial building forms with the same volume.

6.3.2.3 Form with different orientation, height, and wall-to-volume ratio

In this section, the research scope is extended to a new level and adds building height as another variable. The five commercial building prototypes what used in section 6.3.2.1 are applied for further simulation and they would be simulated with different height, from 5 to 40 floors (Figure 6.19).

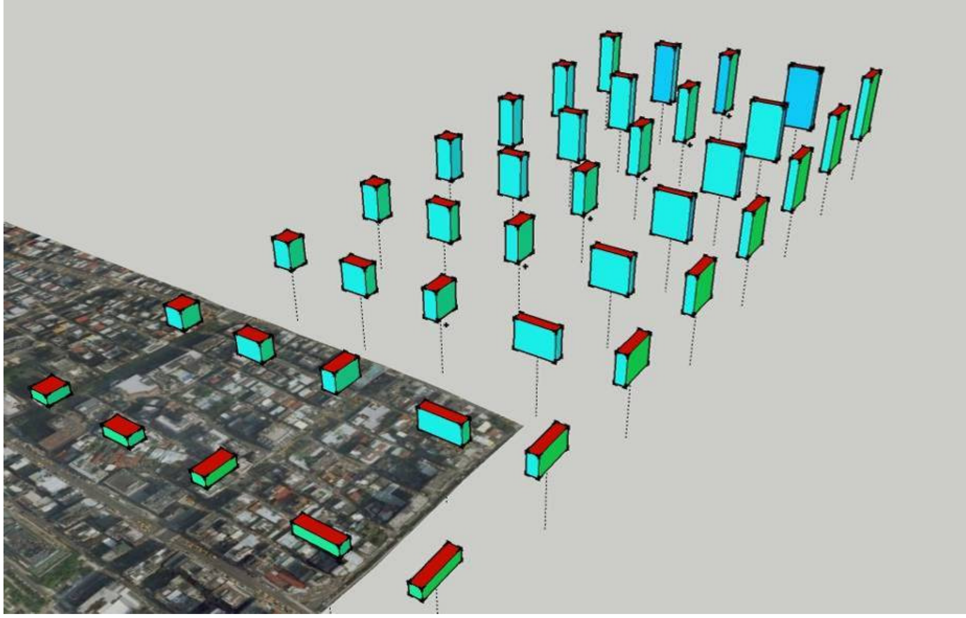


Figure 6.19 Modelling for five typical commercial building forms with different height and orientation. (Left to right in row:1,2,3,4,5)

Lin et al. (2005) asserted that wall-to-volume ratio decides the cooling demand of buildings, and thought that orientation and building height have no influence. Generally, this modelling result presents that the wall-to-volume ratio dominates the energy performance of commercial buildings in Taipei. But, once the buildings are higher than 20 storeys and toward south-north direction, their performance would be better than square ones (Figure 6.20). In other words, appropriate wall-to-volume control can practically reduce the cooling demand, but it is not the only variable. In that particular situation, the reduction brought by a low wall-to-volume ratio would be overwhelmed by the orientation which made the buildings have large façade areas mainly facing toward South. The reason is the proportion of facades facing toward east and west are considerably smaller and that makes the total volume of solar radiation of Model 20F-2 close to 20F-1. Moreover, the gaps of the average solar radiation between them are getting bigger for higher buildings (Table 6.5). In short, through the modelling related building form, wall-to-volume ratio definitely is one of the most important variables for the energy consumption of buildings which should be carefully designed by architects. But, in particular situations, the building orientation would decrease the total solar radiation and make the cooling demand decrease.

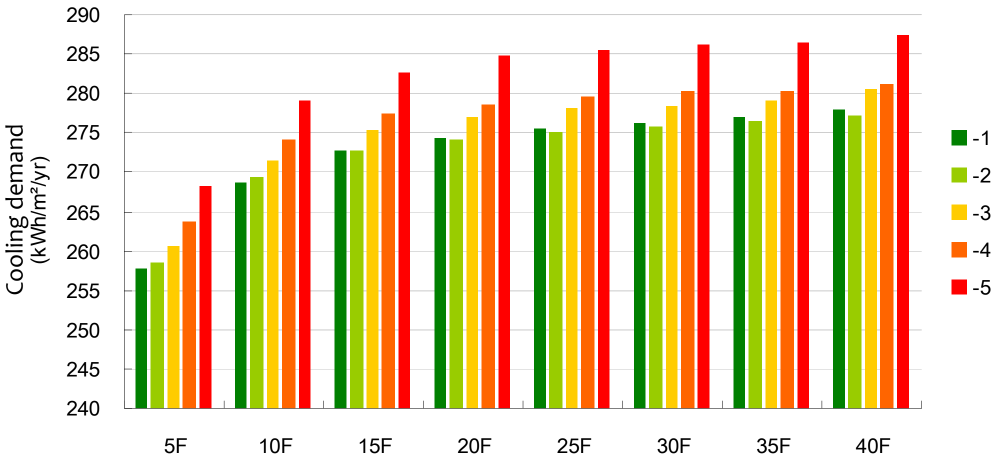


Figure 6.20 The cooling demand of five typical commercial building forms with the same volume, but different height and orientation.

Prototype (Orientation)	Wall-to-Volume (m^2/ m^3)	Solar radiation		Cooling demand (kWh/m^2/yr)
		Average (kWh/m^2/yr)	Total (kWh/ yr)	
10F-1	**0.1667**	**816**	**3671798**	**268.7**
10F-2 (SN)	**0.1747**	**792**	**3739244**	**269.3**
10F-3 (EW)	0.1747	815	3847532	271.5
10F-4 (SN)	0.2000	767	4140126	274.0
10F-5 (EW)	0.2000	817	4410349	279.1
20F-1	**0.1500**	**744**	**6027829**	**274.4**
20F-2 (SN)	**0.1581**	**710**	**6058511**	**274.2**
20F-3 (EW)	0.1581	744	6355978	277.0
20F-4 (SN)	0.1833	689	6817729	278.6
20F-5 (EW)	0.1833	757	7489645	284.8
30F-1	**0.1444**	**715**	**8365200**	**276.2**
30F-2 (SN)	**0.1525**	**677**	**8361820**	**275.7**
30F-3 (EW)	0.1525	711	8779775	278.5
30F-4 (SN)	0.1778	661	9520608	280.3
30F-5 (EW)	0.1778	727	10465409	286.2
40F-1	**0.1417**	**714**	**10916964**	**277.9**
40F-2 (SN)	**0.1497**	**674**	**10895046**	**277.2**
40F-3 (EW)	0.1497	714	11547244	280.4
40F-4 (SN)	0.1750	650	12279757	281.3
40F-5 (EW)	0.1750	719	13585720	287.4

Table 6.5 The relationship of cooling demand and variables related to building form, including orientation, wall-to-volume ratio and solar radiation.

6.3.3 Orientation

There are three parts to the orientation issue; orientation of façade, orientation of building and orientation of block. The modelling for façades can recognize the ones which would accept more solar radiation and help architects focus on shading design for them. The building modelling clarifies the relationship with orientation and solar gain and cooling demand. The modelling for blocks aims to find out the impact of orientation upon buildings at urban scale.

6.3.3.1 Orientation of façade

Assuming the general solar radiation of a southern façade during May to October in Taiwan as 1.00, the east, west, north, and horizontal elevation would be 1.24, 1.24, 0.81, and 2.78 respectively (Lin 2003). However, Lin calculated the solar radiation in an ideal situation without considering cloudy days and long-term weather data. Therefore, the same model is applied and examined in eight main directions to get more precise and practical figures (Table 6.6). The solar gain of the west, east and the roof are 1.05, 1.40, and 2.34 times that of the south elevation. Moreover, for the other four directions, north-west, north-east, and south-west would receive more heat than the south façade. According to this finding, the green building regulations in Taiwan should require architects to carefully design the roof, E, SE, S, SW, W, and NE façades. The north-eastern façade is suggested to be added to the present building design regulations.

Orientation	E	SE	S	SW	W	NW	N	NE	Roof
Solar radiation from May to Oct. (S=1.00) (Lin 2003)	1.24	-	1.00	-	1.24	-	0.81	-	2.78
Solar radiation from May to Oct. (S=1.00) (This research)	1.40	1.27	1.00	1.04	1.05	0.96	0.91	1.23	2.34
Solar radiation through a year (S=1.00) (This research)	1.09	1.12	1.00	0.92	0.85	0.76	0.73	0.91	1.81
Solar radiation from May to Oct. (kWh/m^2/6-months) (This research)	451	409	322	336	340	310	294	395	754
Solar radiation through a year (kWh/m^2/yr) (This research)	846	869	773	711	655	588	567	700	1398

Table 6.6 The solar radiation of different façades of buildings in Taipei.

6.3.3.2 Orientation of building

According to the solar gain results for the nine prototypes presented in the previous chapter, the buildings with longer façades facing south or north always received less solar gain than the ones facing east and west. In this section, Institutional and Residential-M prototypes are taken as examples. The difference between them appears more obvious because of their high aspect ratio of floor plan, which could be interpreted as the high envelope proportion of a rectangle plan. For Institutional buildings, the difference of solar gain between two individually oriented buildings in August can reach 1241 kWh and the difference in annual solar gain is 2.72 kWh/m^2/yr (Figure 6.21). For the Residential-M prototype, the difference in solar gain in August is 626 kWh and the annual difference is 2.10 kWh/m^2/yr (Figure 6.22). The annual cooling load increases by 2.80 kWh/m^2/yr for the institutional prototype and by 4.57 kWh/m^2/yr for the Residential-M prototype. In short, for buildings in sub-tropical zones, building orientation has positive correlation with solar radiation, which means more solar gain would cause a higher cooling load. This result implies that the best orientation of buildings in Taiwan is facing south or north, which generally meets the design suggestions of the Technical handbook for Green Building Design in Taiwan (ABRI 2005).

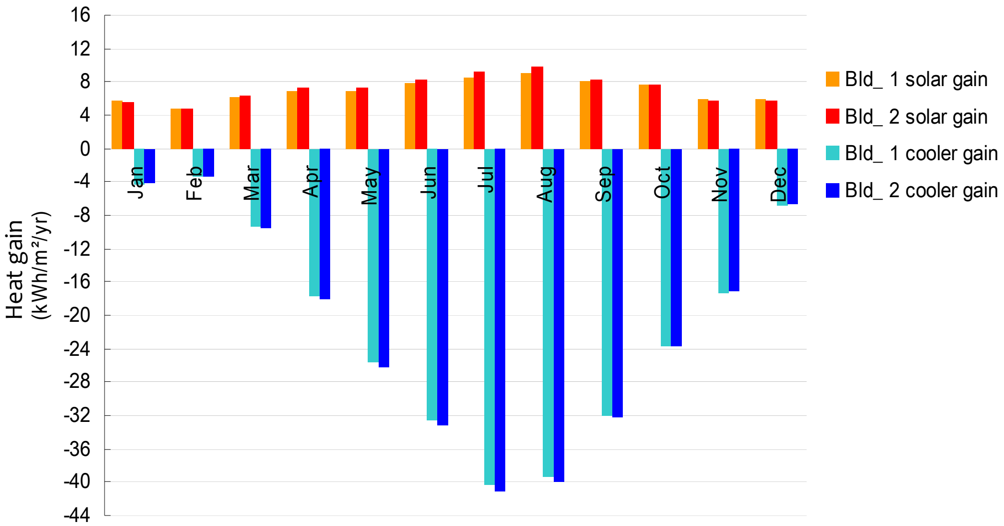


Figure 6.21 The difference of solar and cooler gain between prototype Bld_1 and Bld_2 of Institutional building prototypes.

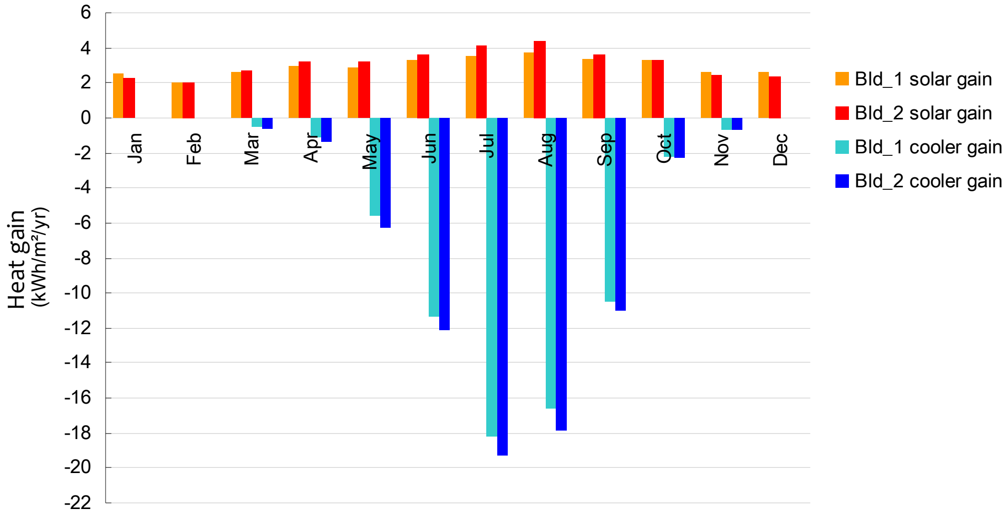


Figure 6.22 The difference of solar and cooler gain between prototype Bld_1 and Bld_2 of Residential-M building prototypes.

Furthermore, Ecotech supplies the best building orientation strategy for Taipei by calculating annual wind and solar radiation distribution together. According to the calculation result, the best orientation of buildings in general is toward 7.5 degrees south-east (Figure 6.23).

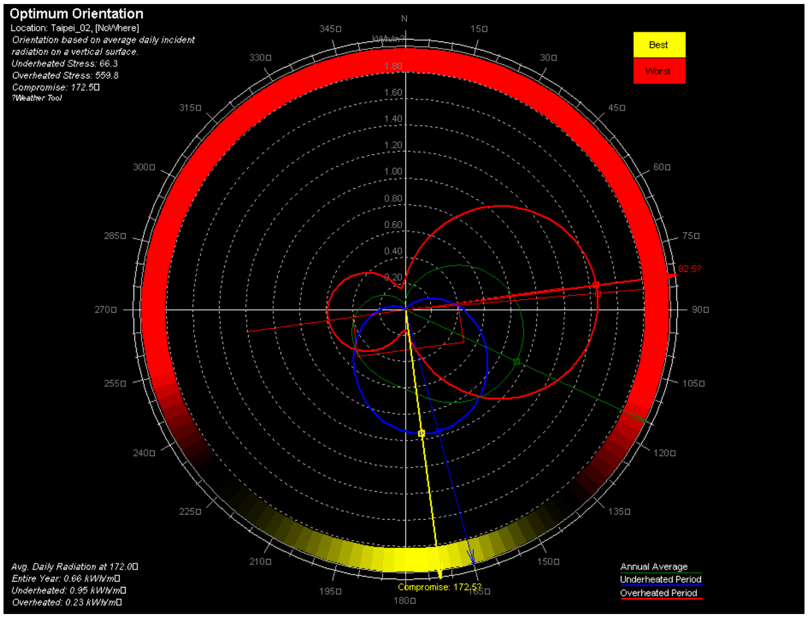


Figure 6.23 The ideal orientation of buildings in Taipei based on Ecotech's calculation engine (The yellow colour indicates the best; the red is the worst).

6.3.3.3 Orientation of block

The orientation of buildings had been proved critical for the energy performance of a single building in the previous sections. Based on institutional and residential prototype modelling, if the main axis of a building faces toward the south or north the building can consume much less energy during the summer time. Moreover, according to the modelling result of building height and building forms, the importance of building orientation would become more obvious for high-rises. However, when numerous units exist in a city, they would affect each other, by offering over-shading, blocking light accessibility, and changing the wind directions for example. The interaction may or may not change the influence of orientation. Therefore, in this section, it is necessary to discuss the issue at urban scale and examine the differences between a single building and a whole block.

Here, several blocks in the Ta-An District are taken as experimental subjects for modelling at urban scale. The direction of the whole model would be changed to summarize the solar radiation and compare the average cooling demand. As Table 6.7 shows, there are differences among the solar gains of the façades of all the buildings in all four main directions, but their annual average cooling demands are close to each other, only 2 kWh/m^2/yr maximum differences. Although the subject model is not a square model and the total areas of different façades are various, the results prove that the complexity of an urban pattern may decrease the impact of building orientation and suggests that the block orientation is not as important as individual building orientation. Theoretically, if all the orientation of buildings in Ta-An District can be relocated toward the south or north, the degree of energy consumption saving might be larger. However, for the practical environment, it is impossible to identify the most ideal arrangement. In short, orientation is undoubtedly important for a single building, but not for buildings at urban scale, particularly for buildings in the existing urban environment.

Direction District Faces	Solar radiation of façade facing different directions (kWh/m²/yr)					Cooling demand (kWh/m²/yr)
	E	S	W	N	Top	
Ta-An District (north) (Practical situation)	578	562	472	389	1264	154
Ta-An District (east)	577	562	463	397	1261	155
Ta-An District (south)	554	528	436	366	1238	153
Ta-An District (west)	583	568	461	388	1262	155

Table 6.7 The solar radiation of different façades of blocks in Ta-An District accounting for orientation in four main directions and cooling demand.

6.3.4 Glazing ratio

In Taiwan, glazing ratio has been seen as one of the most important issues for building design. Lin (2003) took a ten-storey commercial building and examined the relationship between glazing ratio and cooling demand. The simulation concluded that once the glazing ratio of the buildings in the southern city of Taiwan, Kaohsiung, increases by 1%, the cooling demand would also rise 1%. The research additionally indicated that there is no difference whether the building is decorated with normal glass windows or Low-E glass windows. On the other hand, EEWH-NC (2009) suggests that the glazing ratio should be under 25% for residential buildings and 35% for office buildings in Taiwan to avoid getting too much solar radiation.

Here, the Commercial-L and Residential-L prototypes are taken as experimental subjects and examined with 10% to 90% window glazing ratio for all façades. The simulation result points out that cooling demand will increase with a higher glazing ratio, and that the increase is a linear growth (Figure 6.24). A 10% increase in the glazing ratio of a commercial building would cause a 7 to 8 kWh/m^2/yr cooling load increase, or 2.17% to 2.97% of the whole need; a 10% increase in the glazing ratio of a residential building would cause a 3 to 4 kWh/m^2/yr cooling gain increase, or 3.5% to 4.8%. As the results show, the increase for commercial buildings is more marked than for residential buildings. In general, for commercial and residential buildings in Taipei, glazing ratio has a positive correlation with the cooling demand of buildings.

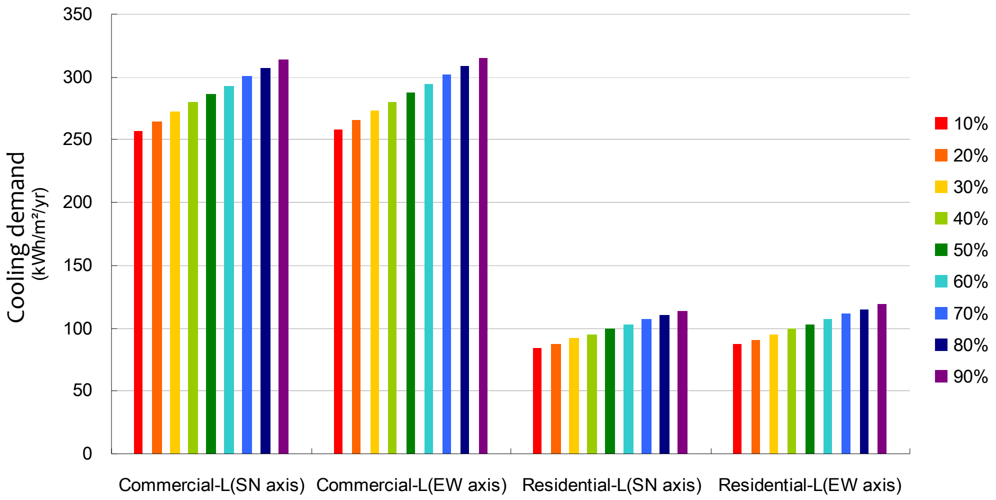


Figure 6.24 The cooling demand of Commercial-L and Residential-L buildings with different glazing ratios.

On the other hand, through the observation of the building environment in Taipei, it is not hard to find that most residential buildings have simple shading devices, but they are rare for the majority of commercial buildings, particularly for curtain wall buildings. Therefore, it is necessary to undertake deeper research for commercial buildings at building and urban scales. The Commercial-L prototype and the blocks in Chung-Shang District are the subjects.

The grouping effect of commercial blocks in Chung-Shang District reveals a difference in the trend brought by altering the glazing ratio. The increase is not as steep as that for a single commercial building (Figure 6.25). Considering the impact of over-shading for the urban scale model, a 10% increase of glazing ratio for commercial blocks only leads to roughly a 3 kWh/m^2/yr cooling demand increase. In other words, at urban scale, the glazing ratio is not as important as it is at building scale. However, careful glazing ratio control is still critical for saving energy for buildings at building and urban scales in Taipei.

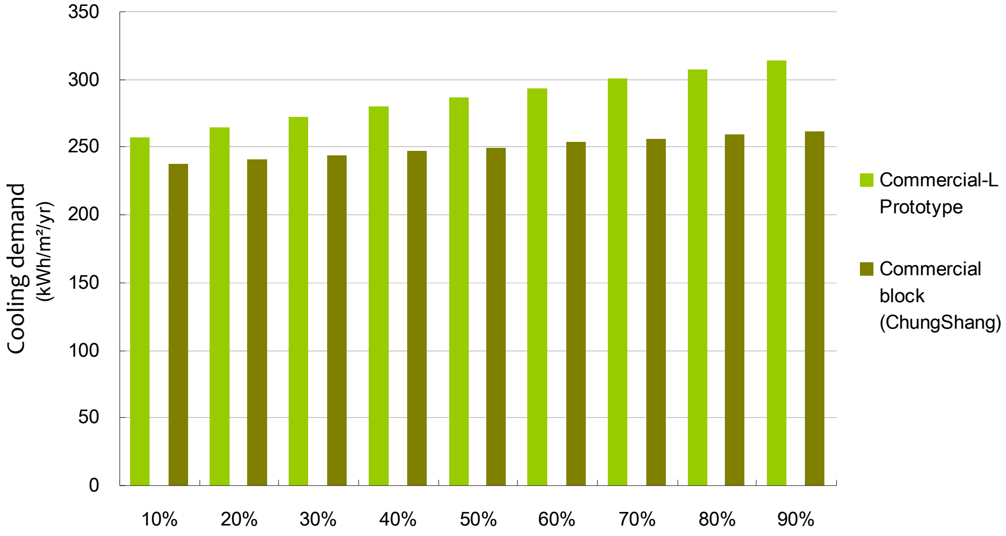


Figure 6.25 The cooling demand of Commercial-L and commercial blocks in Chung-Shang District, with different glazing ratios.

6.3.5 Insulation

Insulation has been a major research issue in Taiwan for a long time. For the present green building design code (2009), the U-Value of roofs is required to be designed to be under 1.0 W/m^2.k for residential and commercial buildings and should avoid any horizontal openings in the roof. Additionally, for huge volume buildings, e.g. assembly and commercial buildings, the U-Value of façades cannot exceed 3.5 W/m^2.k. Moreover, ABRI suggests that the U-Value of external walls should preferably be below 2.5 W/m^2.k in Taiwan. These standards for walls and roofs have been proved to make buildings keep heat outside of the interior spaces effectively. However, the U-value of windows is not regulated in Taiwan yet. Lin (2005) claimed that it is not necessary to equip buildings with double glazed or Low-E windows because these kinds of windows contrarily would keep too much heat inside, thus increasing the cooling load. This section tries to settle the argument and examine further the changes brought by the improvement of U-Value for buildings at urban scale.

Here, the Commercial-L, Residential-L prototypes and the Sung-Shan District model are taken as experimental subjects. Moreover, they would be simulated in two different situations; the default material and construction settings for commercial and residential buildings, and one improved version, which upgrades the U-Value of walls, windows and roofs. The U-Value of walls, windows and roofs for the default settings of commercial buildings are 1.15, 2.8 and 1.01 respectively (Table 5.1), but those of the improved edition are 0.7, 1.26 and 0.67. The U-Value of walls, windows and roofs for the default setting of residential buildings are 3.34, 5.41 and 1.16 W/m^2.k respectively (Table 5.1), but those of the improved edition are 2.05, 3.34, 0.67 W/m^2.k.

On the one hand, the modelling result at building scale presents that the improved version of insulation does not help commercial buildings to decrease their annual cooling demand (Figure 6.26). The over-protective layouts of buildings keep too much heat in and lead to higher energy demand during the winter time. Additionally, the increased cooling demand during the winter time balances the decrease during the summer time. For residential buildings, the better insulation version can slightly lower the annual total energy demand (Figure 6.27). Moreover, the improved edition of building layouts reduces the necessity to heat residential buildings during the winter time. In the test, the differences brought by the changes of U-Value of buildings are not obvious.

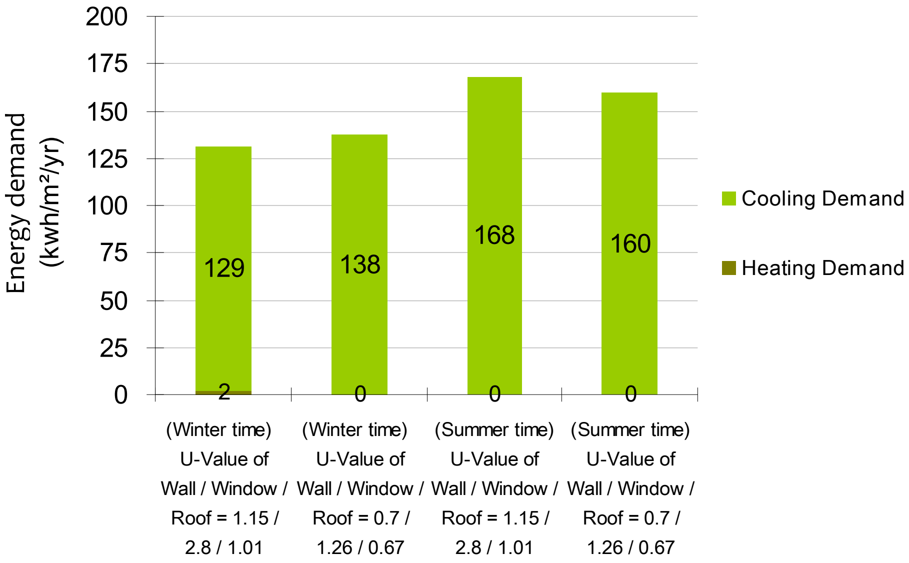


Figure 6.26 The energy demand of present and improved insulation layouts of commercial buildings during the winter and summer periods.

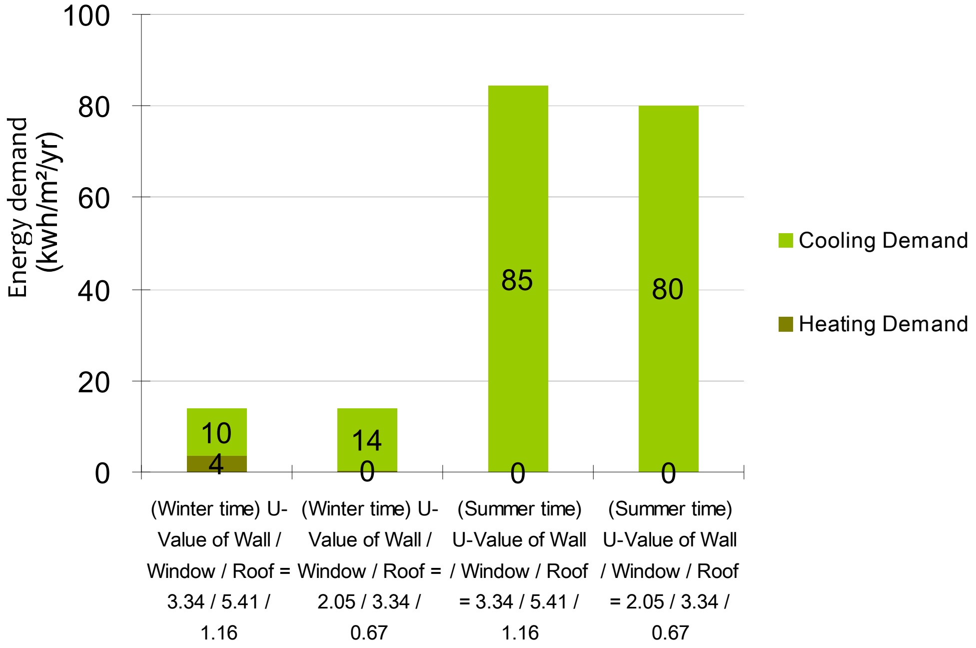


Figure 6.27 The energy demand of present and improved insulation layouts of residential buildings during the winter and summer periods.

On the other hand, the urban scale modelling presents utterly different results. The saving degrees of both commercial and residential buildings in Sung-Shan District double the figures at building scale. According to the annual energy demand analysis, commercial buildings can reduce 3 kWh/m²/yr (Figure 6.28); residential buildings can reduce 10 kWh/m²/yr (Figure 6.29). The simulation result at building scale presents that the different layouts of walls, windows and roofs cannot help commercial buildings to save energy. But at urban scale modelling, it makes practical savings for both commercial and residential buildings. The simulation result shows that the buildings with improved insulation layouts make interior spaces stay in the comfortable temperature zone longer, and that is the reason why the total annual energy demand would be decreased.

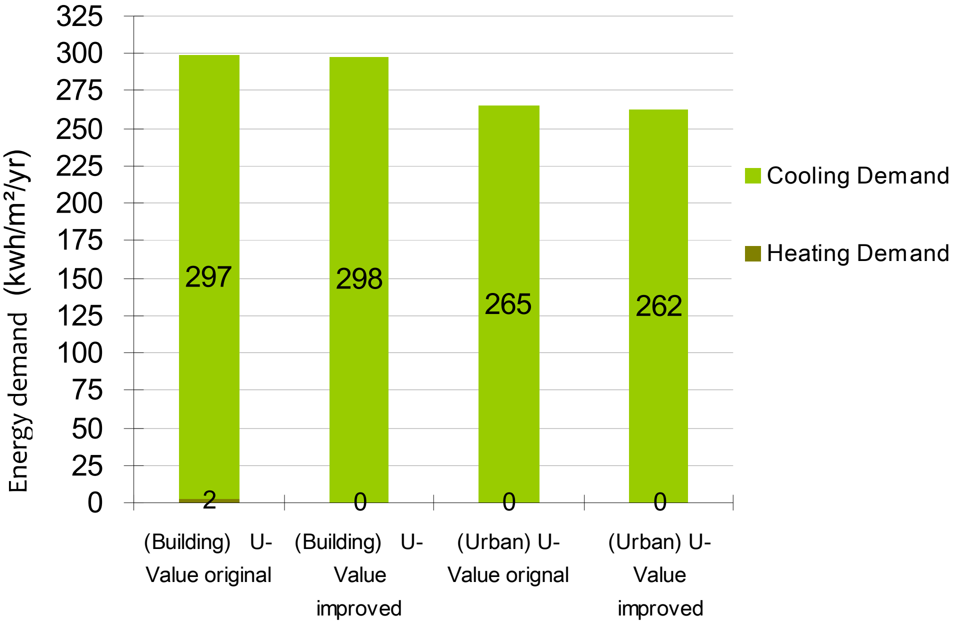


Figure 6.28 The annual energy demand of present and improved insulation layouts of commercial buildings at different scales.

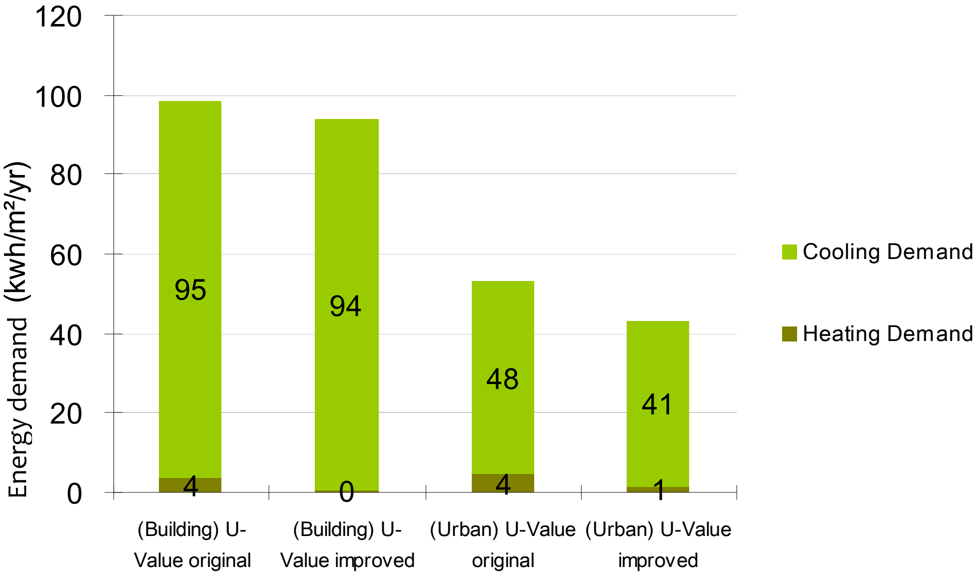


Figure 6.29 The annual energy demand of present and improved insulation layouts of residential buildings at different scales.

6.3.6 Usage proportion of blocks

Previous research indicates that the electricity usages of blocks are various depending on the proportion of commercial building types and average building height. In Chen's research (2006), he believed that the commercial building proportion should be more responsible for the energy consumption of blocks in Taipei than other variables. Through the analysis of the data and energy performance of all district models, the simulation results show agreement with Chen's conclusion (Table 6.8). The proportion of commercial floor areas has a positive correlation with the total cooling load of blocks. Due to the comparatively much higher average energy consumptions of commercial buildings than others, the modelling result and conclusion are predictable and reasonable. In terms of the dominance of commercial buildings, the strategies of saving energy for blocks involved in commercial usage should be paid more attention.

Models	Commercial floor areas (%)	Average building height (m)	Cooling demand (kWh/m^2/yr)
Blocks in Chung-Shan District	100	18.09	254
Blocks in Ta-An District	28	23.46	116
Blocks in Shung-Shan District	57	25.64	172
Several blocks in Ta-An District	55	20.77	154

Table 6.8 The average cooling demand of blocks in Taipei and their site characteristics.

6.3.7 Urban density

Dense urban environments are expected to decrease cooling demand due to the massive shading areas and restricted solar radiation access. Besides, better social interaction, lower cost public transportation and infrastructure are side-benefits brought by dense development. However, it may increase the lighting requirement which will contribute to the cooling load in hot weather areas. Furthermore, access to daylight, potentially high solar radiation, dust and health problems are all important issues related to density.

This section only simply considers the relationship of cooling demand of buildings and the urban density in order to figure out the potential impact factors. According to the Taipei land use zoning map (Figure 6.30), in central urban areas, the land usage of blocks generally could be classified into three typical types, commercial usage, residential usage, and mixed usage (Figure 6.31). The blocks along big roads usually have comparatively dense usage and would be combined with some small areas containing schools, public infrastructure, and open spaces.

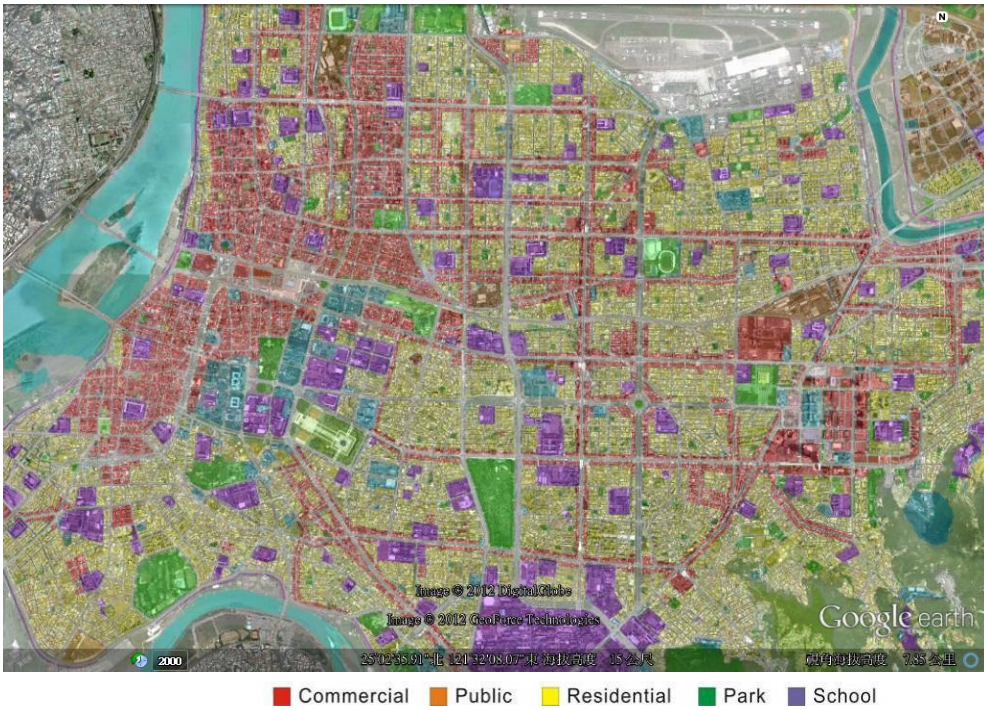


Figure 6.30 Taipei land use zoning map. (Taipei City Government & Steven Ho 2008)

Land type	Residential				Commercial				Public	School
	R1	R2	R3	R4	C1	C2	C3	C4		
Floor area ratio (%)	60	120	225	300	360	630	560	800	400	240
		R2-1 160	R3-1 300	R4-1 400						
		R2-2 225	R3-2 400	-						
Building coverage ratio (%)	30	35	45	50	55	65	65	75	35	35

Table 6.9 Regulations for floor area ratio and building coverage ratio of different land use zoning. (Taipei City Government)

Here, in order to understand the relationship between the density and the energy performance of different land usage types, three areas composed of several blocks are selected to depict commercial, residential and mixed-use types. The first depicting commercial use is located in the north-east corner of the Chung-Shan District. The second is the whole Shung-Shan district, which depicts mixed usage. The Third depicting residential use is located in the east part of the Ta-An district. Furthermore, according to the regulations of floor area ratio and building coverage ratio (Table 6.9), different development intensities are defined and applied to these models. This modelling assumes the building coverage is fully used and the buildings are constructed according to different floor areas. In addition, these models would be compared with the models in a practical situation (Table 6.10).

Figure 6.31 Land use zoning map of blocks in Chung-Shan, Shung-Shan and Ta-An Districts (Left to right). (Taipei City Government)

The simulation result demonstrates the relationship between the density and the energy demand depending on the different types of block (Figure 6.32 to 6.34). Apparently, except for the practical situation, the energy demand would climb along with the density no matter what kind of block type is concerned. The differences are more obvious for the residential blocks in Ta-An District. Although the cooling demand grows with the density, the overall increasing trend shows inconsistency and seems to have limitations. On the other hand, for mixed use and pure residential blocks, the energy demand of the practical situation is 1.5 times higher than the 100% developed situation. The sharp increase in energy demand of the practical situation does not depict a misunderstanding of the density and is only due to the subject having a comparatively much higher wall-to-volume ratio (Table

6.11), and that has been proven to have a huge influence for the energy performance of buildings.

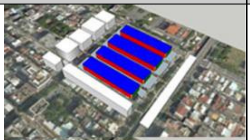
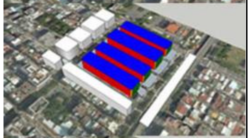
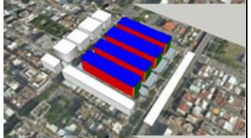
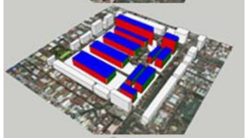
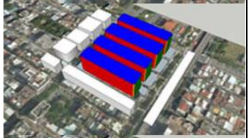
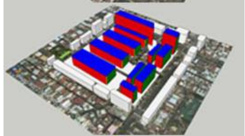
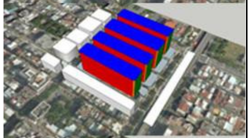
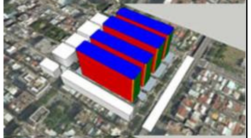
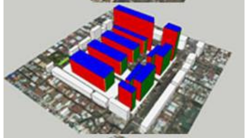
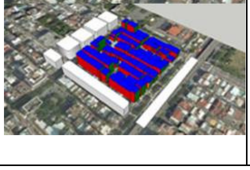
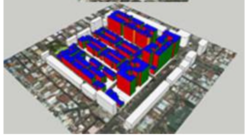
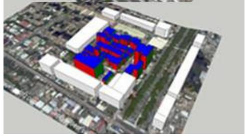
Development intensity (%)	Commercial blocks in Chung-Shan District	Mixed use blocks in Shung-Shan District	Residential blocks in Ta-An District
60 %			
100 % (Maximum of present regulations)			
140 %			
180 %			
220 %			
300 %			
86.63% / 179.62% / 160.76% (Practical situation)			

Table 6.10 Modelling for different development densities. (Take fully developed area as 100%)

Additionally, access of sunlight is another important variable that should be considered together with the density. In Taiwan, every room is required to have at least one hour a day of access to sunlight (CPAMI 2012). At over three times the present development intensity regulated in the building codes, some spaces would not satisfy the requirement. Therefore, the development density should be limited to under 300% development intensity unless adopting a better urban pattern or applying advanced technology.

Commercial blocks in Chung-Shan District			
Development intensity (%)	Wall-to-Volume ratio (m^2/ m^3 * 100)	Average solar radiation ($kWh/m^2/yr$)	
		Roofs	Walls and Windows
60 %	13.07	1385	572
86.63% (Practical situation)	20.58	1262	332
100 %	10.30	1394	573
140 %	9.18	1398	575
180 %	8.63	1398	584
220 %	8.16	1398	595
300 %	7.70	1394	589
Mixed use blocks in Shung-Shan District			
Development intensity (%)	Wall-to-Volume ratio (m^2/ m^3 * 100)	Average solar radiation ($kWh/m^2/yr$)	
		Roofs	Walls and Windows
60 %	21.01	1361	553
100 %	17.46	1364	552
140 %	15.88	1361	536
179.62% (Practical situation)	24.04	1282	421
180 %	15.00	1347	529
220 %	14.47	1340	500
300 %	13.79	1308	507
Residential blocks in Ta-An District			
Development intensity (%)	Wall-to-Volume ratio (m^2/ m^3 * 100)	Average solar radiation ($kWh/m^2/yr$)	
		Roofs	Walls and Windows
60 %	27.60	1356	544
100 %	23.44	1349	541
140 %	21.75	1344	540
160.76% (Practical situation)	33.84	1274	368
180 %	20.77	1331	542
220 %	20.15	1321	542
300 %	19.42	1306	531

Table 6.11 The detailed information and general simulation result of blocks involved in different development densities in three different districts.

In short, based on the simulation result, there is a completely opposite opinion to one that says high density development lowers energy demand. On the contrary, lower density development in Taipei can consume less energy on average, particularly for residential blocks. However, the extremely high density development seems to have limitations. The most appropriate density can not only be defined according to the cooling and heating demands, but should be re-examined together with other important issues, such as Wall-to-Volume ratio, transportation, infrastructure construction, social interaction or sunlight accessibility.

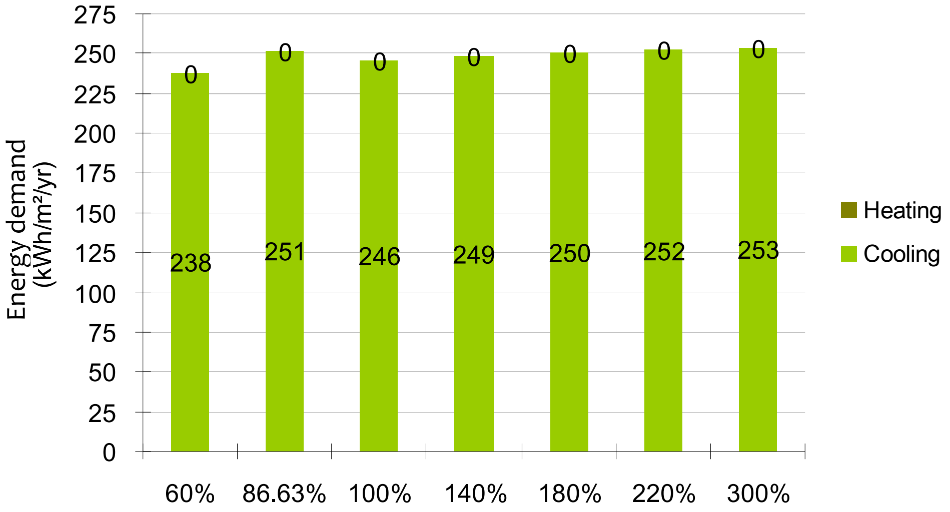


Figure 6.32 Heating and cooling demand of different development densities of blocks in Chung-Shan District.

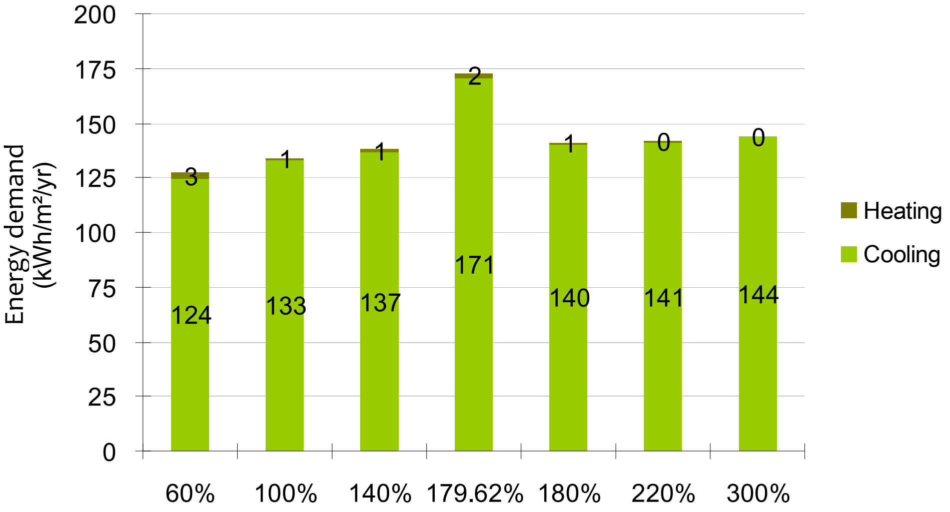


Figure 6.33 Heating and cooling demand of different development densities of blocks in Shung-Shan District.

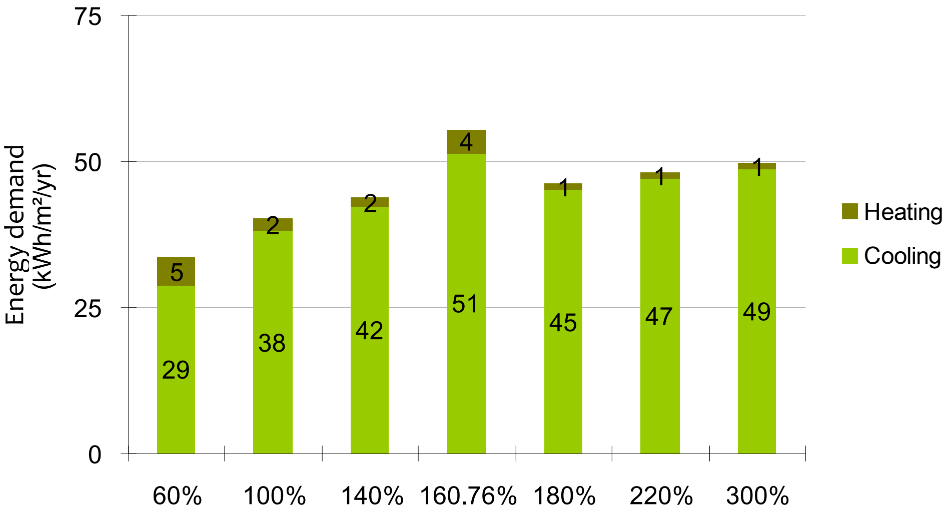


Figure 6.34 Heating and cooling demand of different development densities of blocks in Ta-An District.

6.3.8 Fabrication of blocks

The fabrication of blocks has been seen as another important variable which impacts upon the energy performance of architectures. Sattrup and Stromann-Andersen (2012) created six general urban building patterns with different plot ratios and forms according to their observation in Copenhagen. They focussed on the relationship between the models and their energy performance and concluded that the surface-to-floor ratio has a greater influence than compactness if the buildings have well insulated façades. They also (2011) found that the urban canyon factor is one of key variables for energy use in blocks. They believed that if the surrounding area of a building is transformed into a dense environment, the energy consumption of the building would increase by up to 30% with some variation for buildings with different orientations. Moreover, Cheng et al. (2006) created eighteen models in Switzerland to examine how their building forms and density would affect openness at ground level, daylight factor on building façades and PV potential on building envelope. They concluded that scattered horizontal layouts, flexible building height and low site coverage are preferable. However, as Oke said (1988), there is no universal or single optimum geometry due to the infinite compositions of various climate contexts, urban geometries, and design objectives. In short, depending on the different backgrounds and weather styles of cities, the strategies should be adjusted by considering the local environment.

In this section, through the observation of the urban fabrication of Taipei, the focus would be on two issues, block pattern and surrounding road width. In addition, some models are created to depict typical residential block patterns in Taipei and simulated with practical weather data. Moreover, the Residential-M prototype is applied as the basic unit to compose these block models.

First of all, the most common residential block pattern in Taipei is composed of a row of residential houses with small alleys between them (Figure 6.35). With different axes of terrains, there are two types which will be called Fabrication-1 & 2. Secondly, for some blocks, the open space is shaped into a courtyard for occupancy. The one which is half-closed by houses is called Fabrication-3; the other which is totally closed is called Fabrication-4. Thirdly, in order to leave more space at ground level, modern construction prefers to increase the height of buildings as shown in Fabrication-5 & 6. In short, their development density is the same, but their various patterns make them require energy demand differently (Table 6.12).

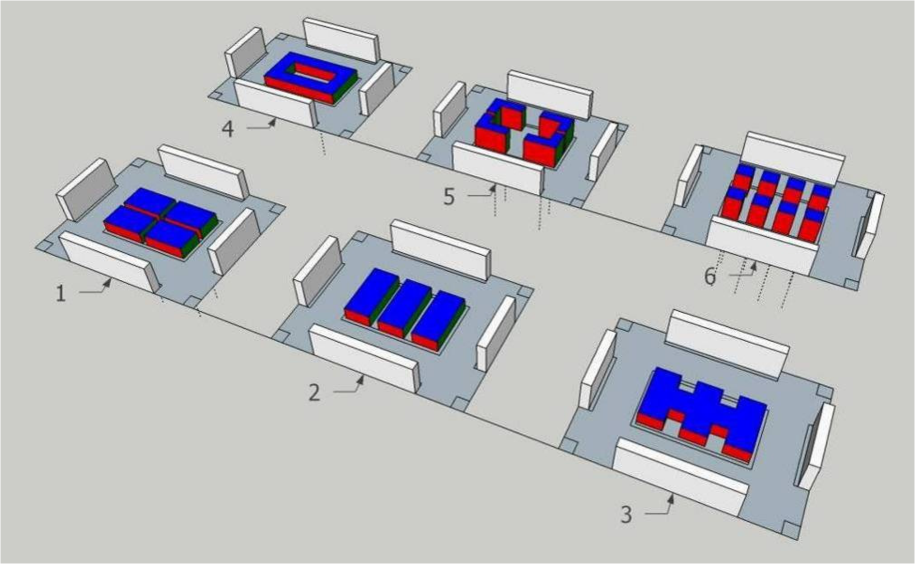


Figure 6.35 Six different typical residential block types in Taipei.

Residential Block Types	Wall-to-volume Ratio (m^2/ m^3* 100)	Volume Rate (%)	Building Coverage Ratio (%)	Average Building Height (m)	Average Cooling Demand (kWh/m^2/yr)
Fabrication -1	27.51	288.85	72.21	12	28.76
Fabrication -2	26.11	270.80	67.70	12	29.41
Fabrication -3	24.05	255.89	63.97	12	27.49
Fabrication -4	27.00	247.25	61.81	12	30.42
Fabrication -5	38.25	288.85	36.11	24	57.26
Fabrication -6	41.47	283.11	35.39	24	57.19

Table 6.12 The related information of six residential block types, including wall-to-volume ratio, average building height, building coverage ratio, volume rate and their cooling demand.

Additionally, the models would be located on four different sites with 8, 15, 20, and 30 meter width roads surrounding them, all models would have 10 storey high buildings on all four sides (Figure 6.36). These four different types of surroundings are the most popular situations in Taipei and the road widths are defined based on urban master plan regulations. Through the simulation, it indicates how the road width affects the energy performance of different types of residential blocks in Taipei.

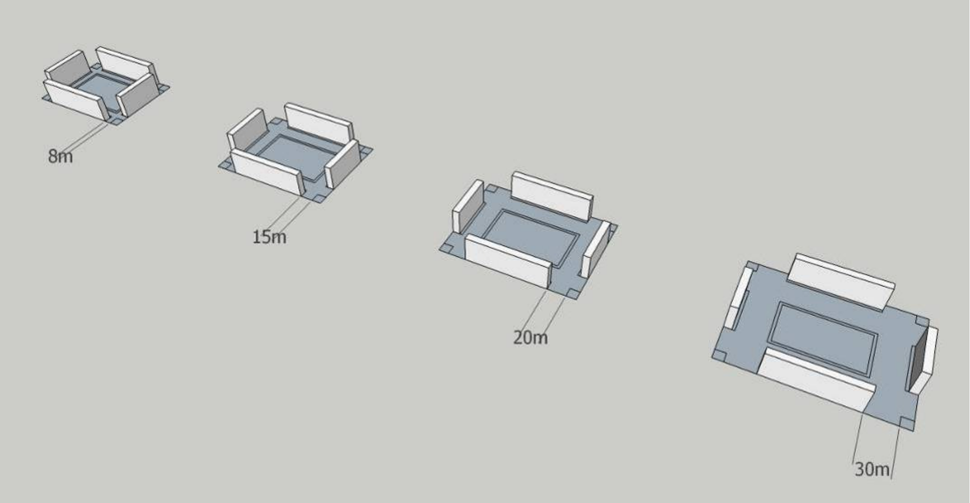


Figure 6.36 Four different kinds of surrounding situations of residential block types.

The simulation result indicates several critical points (Figure 6.37). First of all, for residential blocks, urban fabrication would affect their energy performance enormously. The pattern of urban fabrication can be quantified by several variables, including wall-to-volume ratio, volume rate, building coverage ratio, and average building height. The changing trend of cooling demand is similar to the average building height and the wall-to-volume ratio. The higher figures of these two variables make residential buildings consume more energy. On the other hand, although lower building coverage ratio can leave more public space at ground floor level, it also causes higher energy consumption. Additionally, among these variables, volume rate which can be taken as the development intensity of blocks, is the most tricky one. There is no absolute rule of its relationship with cooling demand. Take Fabrication-1 and -5 for example, which share the same development strength. In this case, different arrangement of buildings leads to different areas of open space and the cooling demand of Fabrication-5 doubles that of Fabrication-1. In general, lower wall-to-volume ratio, lower average building height, and higher building coverage ratio can help to decrease the cooling demand of residential blocks in Taipei.

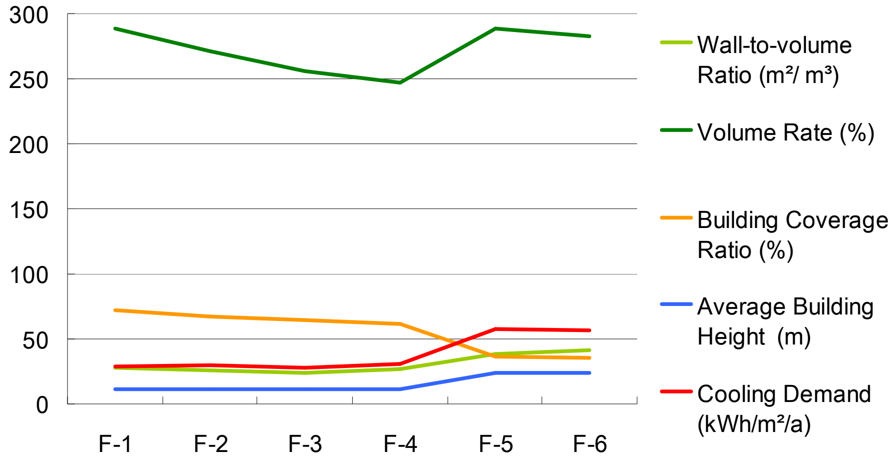


Figure 6.37 The annual average energy performance and related information of six different types of residential blocks.

Secondly, Chen (2006) asserted that it is the road width surrounding blocks that would affect the energy demand of buildings in blocks. He classified the road width of blocks in Taipei into four groups, under 10 meters, from 10 to 20, from 20 to 30, and above 30 meters. Moreover, Chen stated that blocks surrounded by under 10m width roads consume much less energy than the others. Furthermore, there is no big difference in the cooling demand of blocks surrounded by 10m to 20m and 20m to 30m width roads. In contrast, the blocks with greater than 30m width roads would need much more energy. However, there are numerous uncontrollable variables in his investigation, such as different block patterns, orientation, and building composition of blocks.

The modelling in this research simply put the same block into the same location, but with different surrounding situations. From the simulation results, blocks with larger road widths definitely consume more energy because of less over-shading from surrounding buildings (Figure 6.38). As long as the highway situation satisfies the basic requirements of transportation, narrowing down the road width would be a good strategy to reduce energy demand for residential buildings in Taipei.

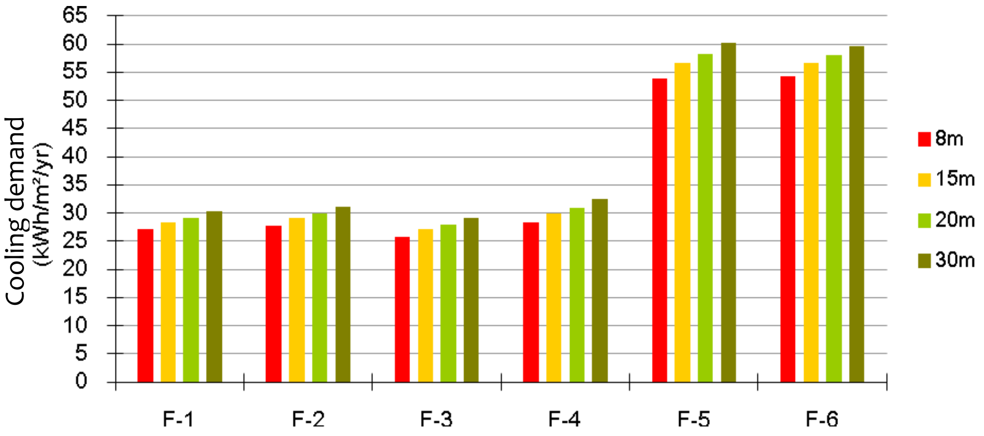


Figure 6.38 The annual average cooling demand of residential block types with different road widths and fabrication.

6.3.9 Shading

Shading is an important and complicated issue, particularly for cities in hot and wet climates. This section aims to examine the relationship between shading and energy demand for buildings at building and urban scales, and is divided into three parts; shading devices for a single building, shading devices at urban scale, and over-shading.

6.3.9.1 Shading devices for a single building

Shading devices are the second most important variable to affect the cooling load for a single building in Taiwan, next to glazing ratio (Lin et al. 2005). Due to various building types, interior situations and construction materials, there are numerous ways to use shading devices to decrease the percentage of cooling demand. In 2004, Lin measured a five square meters room in a commercial office with three popular shading device methods used in Taiwan, including horizontal, vertical and grid shading (Table 6.13) (Appendix B). The author concluded that shading devices are the most needed for façades facing toward a southern direction. Additionally, he believed that horizontal shading is comparatively more effective for all external walls than vertical shading, except toward the north. On the other hand, this issue for domestic buildings in Taiwan is relatively unimportant. The first reason is the glazing ratio of domestic buildings is usually smaller than that of non-domestic buildings. The second reason is most of the residential buildings in Taiwan are equipped with balconies and located in high density blocks surrounded by narrow width roads.

Therefore, based on Lin's research conclusions and the observation of the practical normal situation in Taipei, this research focuses on the impact of shading devices for commercial buildings and takes the Commercial-L prototype as the experimental subject at building scale. The building model is set up with horizontal shading devices on the south, east or west façades or with vertical shading devices on the north façades to examine the different impact effects caused by shading devices. The detailed information and simulation results can be seen in Figure 6.39.

Orientation	South	West	North	East
No shading	1653	1985	1467	1713
Horizontal shading	**1442** **13%**	**1773** **11%**	1365 7%	**1541** **10%**
Vertical shading	1483 10%	1582 7%	**1341** **9%**	1609 6%
Grid shading	1347 18%	1673 16%	1281 13%	1462 15%
Default setting	Space: 5m x 5m Floor height: 3.6m Window area: 3m x 2m Shading depth: 4:1			

Table 6.13 The energy demand (Mcal/yr) and saving degree (%) of commercial spaces in Taipei with different shading devices. (Source: Lin 2004)

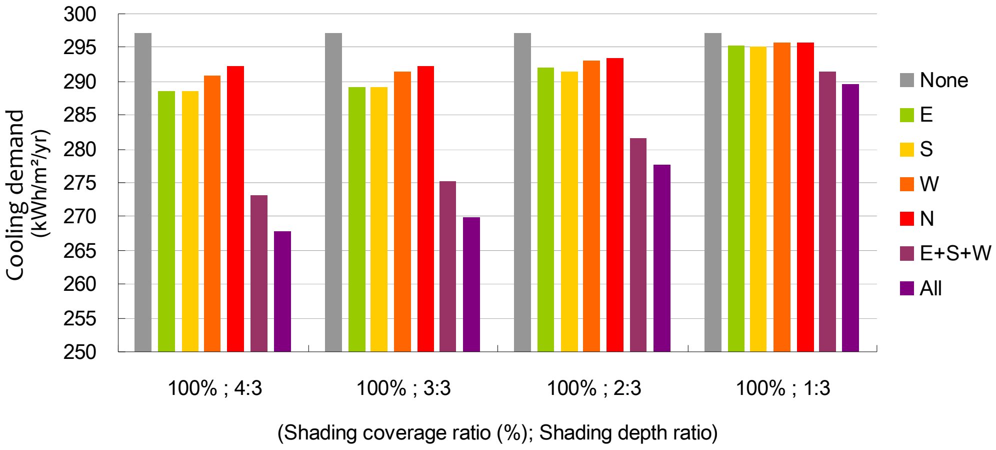


Figure 6.39 The cooling demand of the Commercial-L prototype with shading-devices on different directions of façades and with different shading depth ratio (Appendix B).

There are several findings from the simulation. First of all, the shading devices installed on the south or east façades of commercial buildings resulted in a reduction in cooling demand, more so than for devices installed on the other main directions. Secondly, the saving degree brought by a shading device on only one façade of the building is limited. In that situation, the biggest difference between buildings with and without shading devices is within 10 kWh/m²/yr. However, if the building is equipped with shading devices on the south, west, and east façades at the same time, the reduction of cooling demand is obvious and can reach 24 kWh/m²/yr. Thirdly, the shading depth ratio plays an important role in saving energy. Although the façades are fully covered by shading devices, they may not work effectively if their shading depth ratio is too small. Based on the simulation, it is suggested that the shading depth ratio of commercial buildings in Taipei should be greater than 2:3. In short, according to the simulation related to the shading device at building scale, commercial buildings in Taipei are better equipped with shading devices on the south, east and west façades, and the shading depth ratio should not be lower than 2:3. Moreover, if these requirements could be satisfied, the commercial buildings could save at least 15.6 kWh/m²/yr in cooling demand, namely 5.21% of total consumption.

6.3.9.2 Shading devices at urban scale

In this section, the shading device issue would be discussed further by considering the impacts brought by over-shading. Over-shading can not only affect the function of self-shading and shading devices, but also offers more shading for buildings located in urban areas, which indirectly leads to solar gain and cooling demand reduction.

Following the conclusion of the previous section, the importance of the shading devices on the south façades of commercial buildings is critical. Therefore, the Commercial-L building prototype is taken as an experimental subject and simulated in different surrounding situations and equipped with different façade shading coverage and shading depth ratio devices. Through the observation of the central urban environment in Taipei, the prototype is designed to be surrounded by 13 storey high commercial buildings, but equipped with different numbers of horizontal overhangs (33%, 67% or 100% coverage of the façade area) on the south façade from the top. Moreover, there is a 10 storey high building opposite the prototype, which is separated by different width roads, from 15 to 50 meters (Figure 6.40 & 6.41). The setting of distances between buildings all refers to the Taiwan Province's Enforcement Rules of Urban Planning Law (CPAMI 2013).

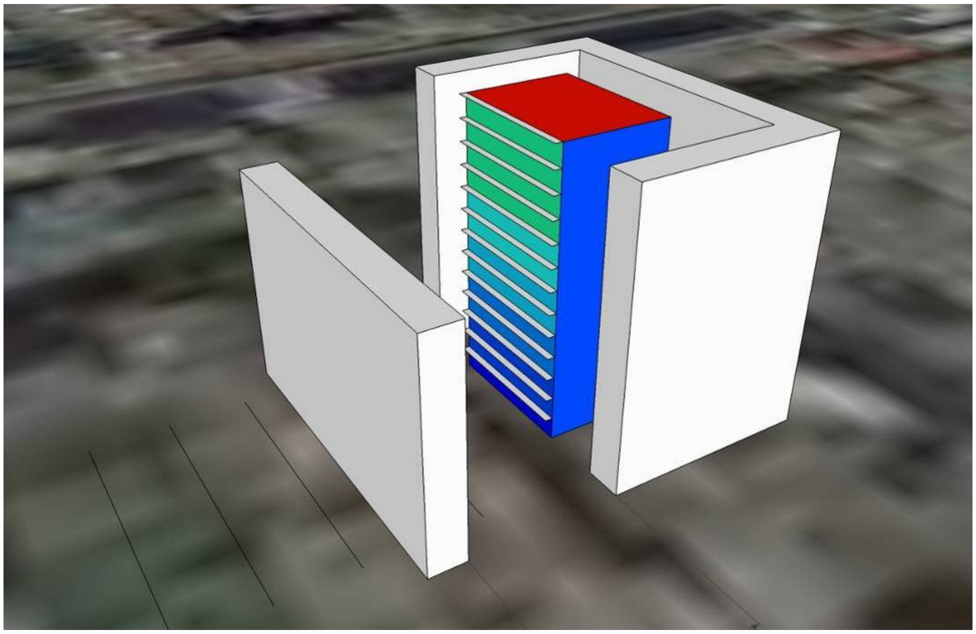


Figure 6.40 The Commercial-L prototype located in a particular urban environment with horizontal overhangs on the south façade.

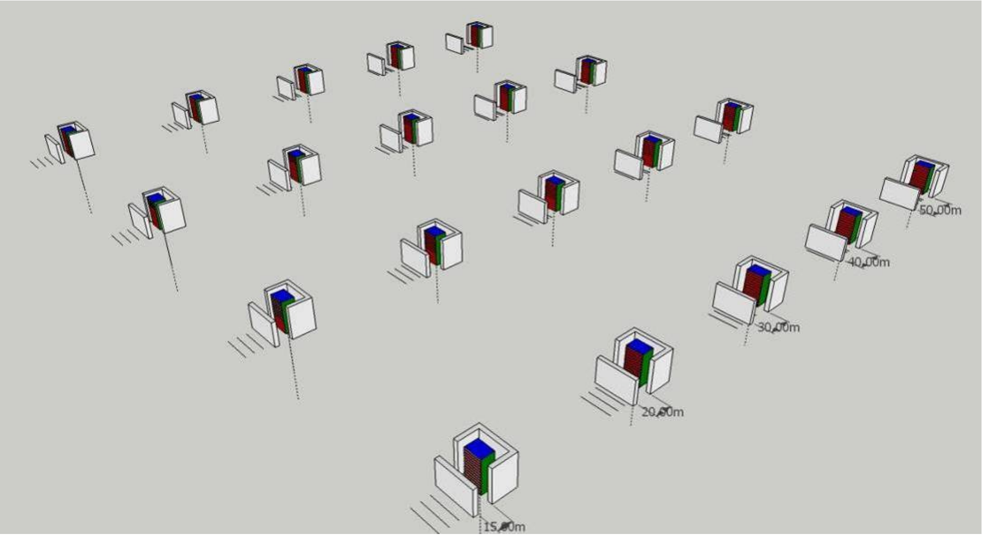


Figure 6.41 The commercial prototypes are all surrounded by 13 storey high buildings and face south, but are equipped with different numbers of horizontal overhangs and different road widths.

First of all, in the modelling, the functionality of the shading device would definitely be affected by the surrounding environment. For the situation set in this modelling, larger coverage façade overhangs lead to reduced cooling demand, but the saving degree brought by shading devices would become smaller for lower storey façades (Figure 6.42 & 6.43). Take buildings with a 2:3 shading depth ratio but different coverage ratios as an example. No matter how wide the roads they face are, the cooling demands of buildings with one third of their façade covered by shading devices are 4 kWh/m²/yr less consumptive than the buildings without any shading devices. But the cooling demands of buildings with two thirds of their façade covered by shading devices are only 2 kWh/m²/yr less consumptive than the buildings with one third of their façade covered by shading devices. The smaller saving degree occurs because the surrounding buildings offer partial shading for the lower storeys of the façade.

Secondly, the buildings surrounded by narrower width roads consume less energy, particularly for the ones surrounded by less than 30m width roads. From the simulation result, once the distance between two buildings is over 40m, over-shading would lose its function to offer shading for other buildings. Therefore, the cooling demands of the buildings facing 40m and 50m width roads are close.

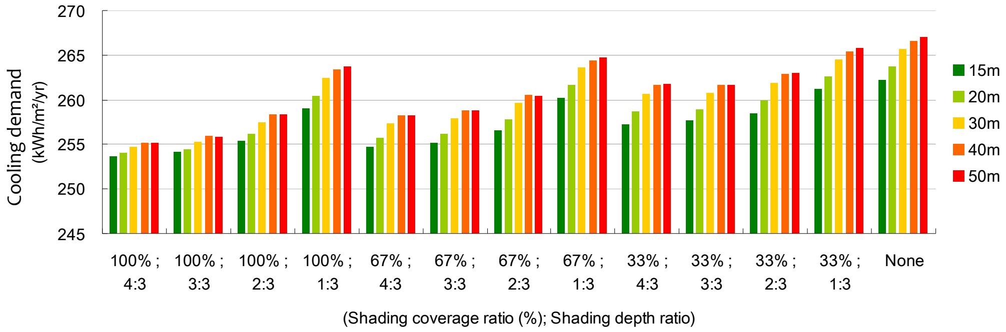


Figure 6.42 The cooling demand of commercial buildings with different shading coverage ratios of their south façades and shading depth ratio in different surrounding situations in Taipei.

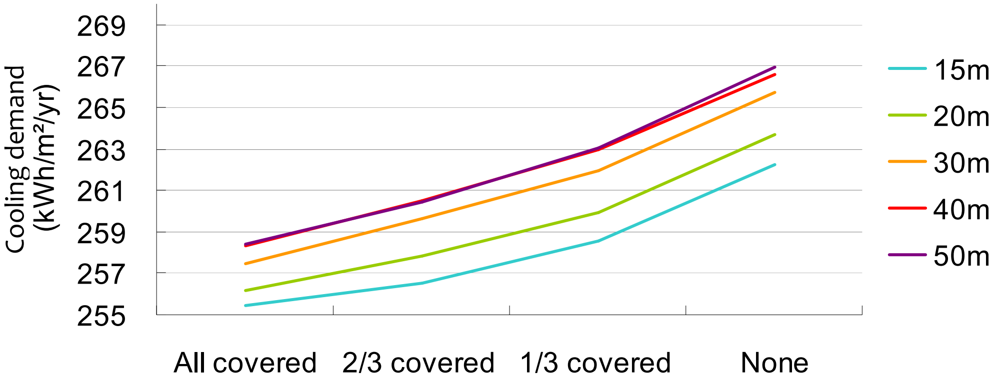


Figure 6.43 The cooling demand of commercial prototypes equipped with 2:3 shading depth ratio devices and with different coverage ratios of overhangs and surrounded by different width roads.

Thirdly, over-shading can replace a large part of the function of shading devices for commercial buildings in Taipei. Combing with the simulation results of the previous modelling, a single building without any shading device would require 297 kWh/m²/yr cooling demand. However, the buildings without any shading devices located in the model setting situation of this section would only consume 265 kWh/m²/yr on average. In other words, over-shading reduces 32 kWh/m²/yr of the cooling demand by blocking solar radiation. On the other hand, for the buildings fully equipped with 4:3 shading depth ratio devices, the shading devices can only add another 10 kWh/m²/yr of cooling demand reduction. Apparently, the saving degree brought by shading devices is much less than by over-shading for buildings in urban environments.

Fourthly, in comparison with the simulation of commercial buildings in the block and district modelling, the average cooling demand of commercial buildings in Taipei is lower than the modelling in this section. In other words, the complicated practical situation would produce more over-shading than the simple modelling in this section. Thus, the importance of its impact for saving energy demand of buildings in Taipei can not be ignored.

6.3.9.3 Over-shading

Succeeding the previous modelling, there is no doubt that over-shading can practically reduce the energy demand of blocks and districts in Taipei. By comparing the results of simulations with and without shading calculations for models at urban scale, it becomes easier to recognize the impact of over-shading. Here, several blocks in Ta-An District are taken as examples (Figure 6.44). The solar gain reduction related to over-shading occupies 21% to 25% of the total monthly solar gain, which can help to decrease the cooling demand of buildings from 3% to 5%. Furthermore, a similar reduction could be seen in all of the block and district modelling in this research. As the Figure 6.45 shows, there is a correlative relationship between solar gain reduction and cooling demand reduction. Each fifty thousand kWh/yr of solar gain increase would roughly make one GWh/yr of cooling demand increase. In short, the simulation results reveal that decreasing solar gain of buildings at urban scale is one of the most important strategies for reducing energy consumption.

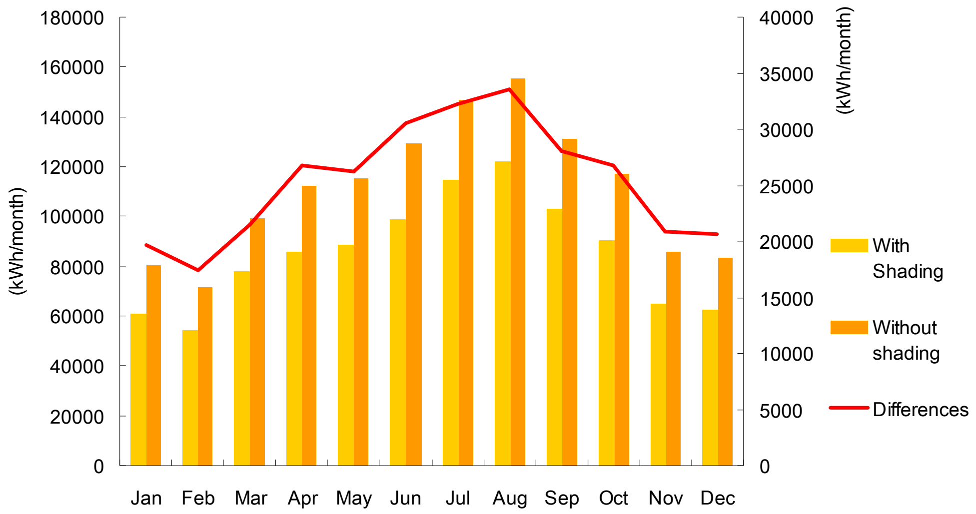


Figure 6.44 The differences in solar gain for the Ta-An District model with and without calculating shading. (Left Y-axis shows units of total solar gain; Right Y-axis is the differences.)

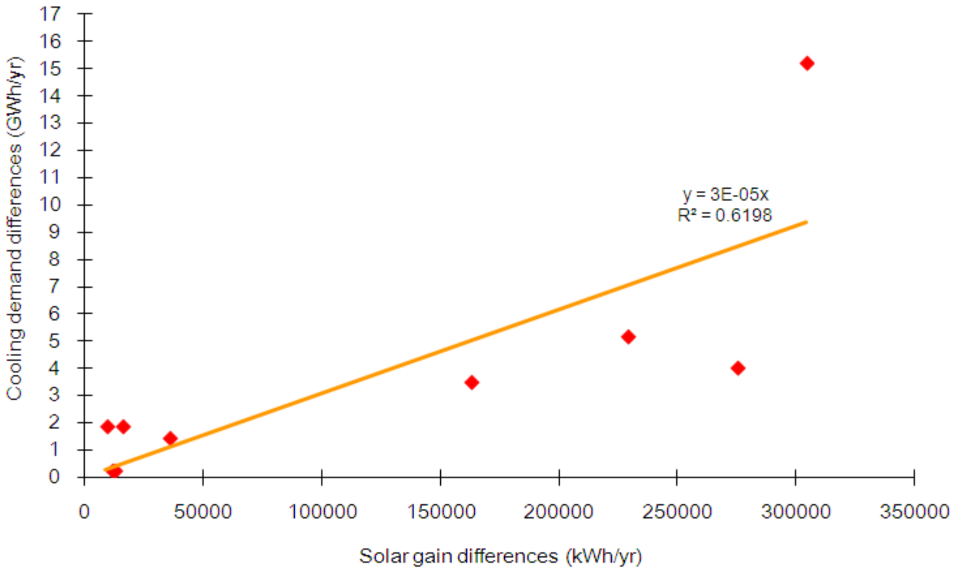


Figure 6.45 The regression analysis of the relationship of solar gain differences and cooling demand decrease of all block and district modelling in this research.

6.3.10 Urban heat island effect

The urban heat island effect (UHI) creates various negative impacts upon the built environment, including higher temperatures, lower humidity, decreased solar radiation, more cloud cover, a slight increase in rainfall, lower wind speed, and air pollution (Landsberg 1981; Lin 2009). Furthermore, according to the report of the Taiwan Power Company, the electricity consumption of AC systems in urban areas will increase by 6% if the outdoor temperature in city centres becomes 1°C higher than suburban areas (Lin 2009a). Lin (2009a) asserted that until now, there have been no agreed measurements of the UHI effect because it is easily affected by wind direction, terraces, water, roads, seasons, and time. Fortunately, there are abundant researches offering numerous practical strategies to mitigate the UHI effect. Replacing hard pavements with whiter or low reflective materials is the most effective tactic. Additionally, increasing planting, leaving ventilation pathways, and applying green rooftops and green walls are also good strategies (Lee 1999). If a city adopts some of the UHI mitigation strategies, the overall urban environmental temperature will decrease enormously which in turn leads to indirect energy consumption reduction.

In this section, according to the previous investigation undertaken in Taipei, several blocks in Ta-An District are taken as experimental subjects in different hypothesized degrees of temperature reduction in order to discover how these changes to the external urban environment would impact upon the cooling demand of buildings. First of all, the weather data offered by U.S. Department of Energy (USDE 2000) are adopted because the information was measured at the elevation of six meters above sea level, which is believed to consider the UHI effect. By passing, the data is referable and applied for many different kinds of energy calculation engines, such as Energy Plus. Secondly, in 2009, Lin investigated the Taipei central urban environment and observed that the UHI effect strength can reach 4.9°C at midnight during the summer time. The smallest difference, which occurred at noon in winter, was only 1°C (Lee 1999). Based on these statistics, the five different degrees of temperature reduction are set (Figure 6.46 & 6.47).

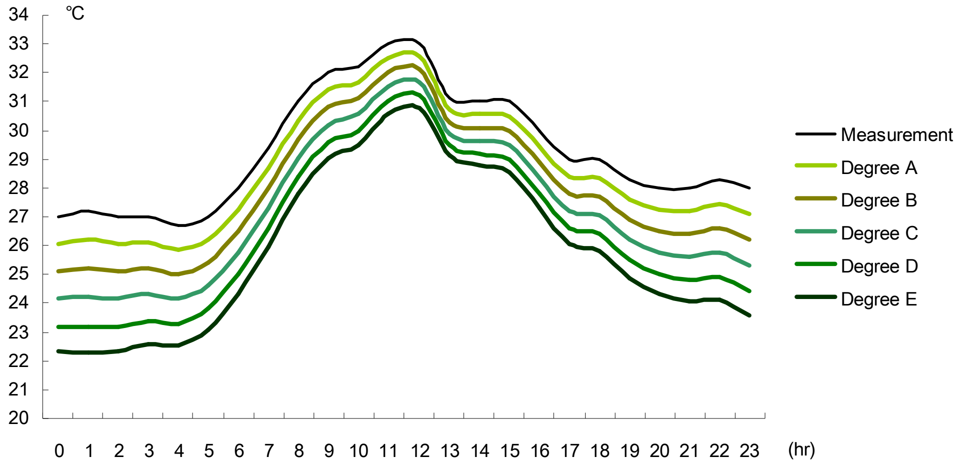


Figure 6.46 The hourly hypothesized outdoor temperature reduction in 14th July.

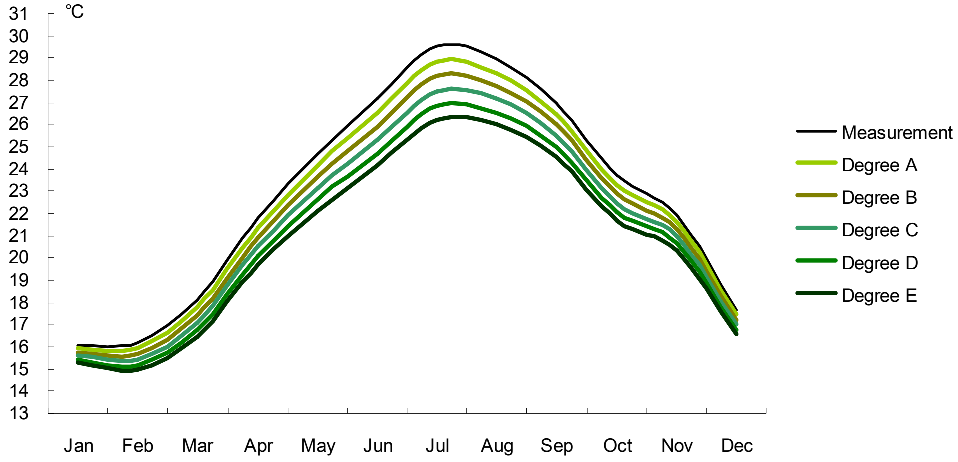


Figure 6.47 The monthly hypothesized outdoor temperature reduction.

The simulation result shows that a one degree Celsius decrease leads to almost a 10% energy demand reduction for residential buildings and a 2.25% reduction for commercial buildings (Figure 6.48 to 6.50). Overall, for blocks in Ta-An District, each degree Celsius increase requires an extra 18.27% in energy demand, which is almost double that of the prediction asserted by the Taiwan Power Company. In short, the impact of the UHI effect may have a much greater importance than previously thought for Taipei City. Therefore, the related mitigation strategies for the UHI effect are critical, not only to give a more comfortable outdoor environment, but also to significantly help to reduce the energy demands of buildings, particularly residential ones.

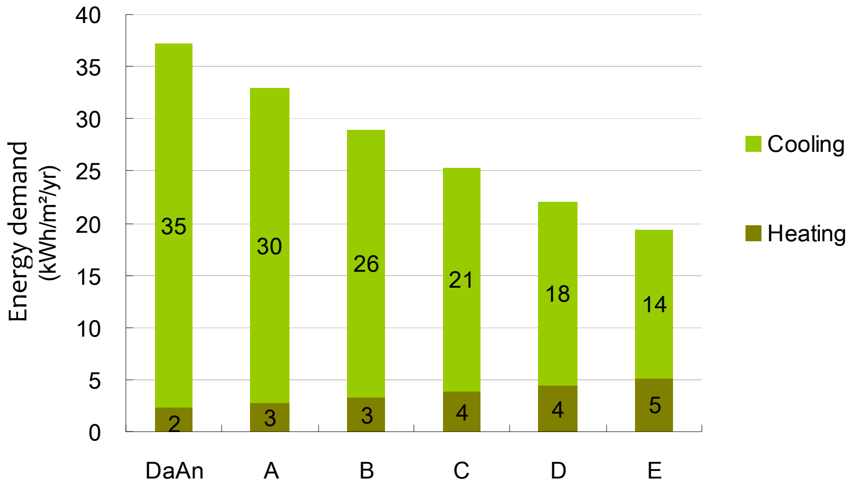


Figure 6.48 The annual cooling and heating demands of residential buildings in Ta-An District accounting for the different strength of the UHI effect in Taipei.

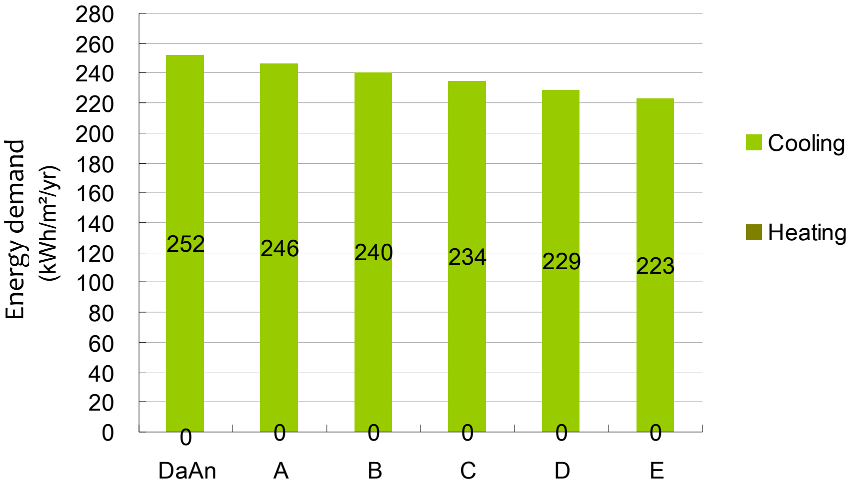


Figure 6.49 The annual cooling and heating demands of commercial buildings in Ta-An District accounting for the different strength of the UHI effects in Taipei.

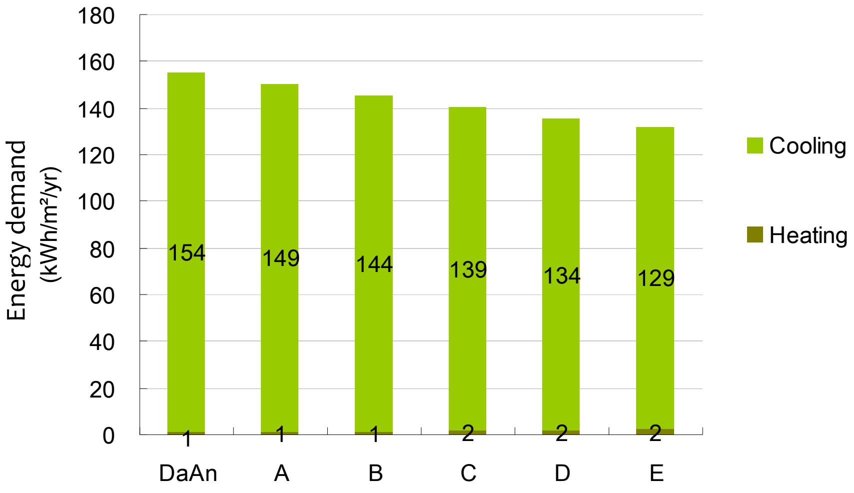


Figure 6.50 The average annual cooling and heating demands of Ta-An District accounting for the different strength of the UHI effects in Taipei.

6.3.11 Renewable energy application

Renewable energy systems can be applied at building and community scales in the urban environment or developed based on off-site grid resources (Jones et al. 2011). Solar PV and thermal water, wind, biomass, and hydroelectric systems are the most common renewable energy systems. However, the advantages and disadvantages of each system are various. Jones et al. (2011) believed that the solar system would be one of the most applicable systems for building integrated design, but with its low efficiency of between 10% to 15%, it is much less effective that wind power's 60% efficiency.

Next, according to the analysis of Chen et al.'s research (2010), the energy reserves of wind, solar and hydro systems are much larger than other renewable energy systems in Taiwan. The energy reserves of wind and solar energy systems are much more abundant than other systems, which are 29.9 kWh/d/p (per day per person) and 24.27 kWh/d/p respectively. Apparently, both of them are potentially developable in Taiwan.

In short, due to the limited land availability and highly developed urban environment, the installation of solar PV systems is the best and most applicable way forward for the existing building environment in Taipei. For a hot and wet weather zone such as Taiwan, solar PV panels not only offer electricity, but also help to decrease the solar radiation reflected by roofs and walls. Therefore, this research only focuses on the application and potential of solar PV systems.

There are two kinds of methods to predict the potential electricity output of solar PV systems which have been conducted by two research teams in Taiwan. By applying the simulation information to the formulas, the potential benefits of PV system application for the four district models can be calculated and predicted.

First of all, based on Chen et al.'s research (2010), the potential electricity output can be calculated by the district population and the average reserves of solar PV systems, 24.27 kWh/d/p.

(Area: km^2) x (Density of the city: people/km^2) x 365 x (Reserves: 24.27 kWh/d/p) =
(Annual electricity output of PV systems: kWh/yr)

For blocks in Chung-Shan District:
0.0658 x 16318 (Density of Chung-Shan District) x 365 x 24.27

Secondly, Yue and Huang (2011) focused on PV system application and predicted the potential of it based on land use analysis. They used the urban planned districts (Central Weather Bureau, CWB 2005) and national statistics (CEPD 2007; CPA 2009) to deduct developed floor area for PV panel installation. Following the solar-architectural rules of thumb for BIPV potential calculation (IEA 2002), a utilization factor of 0.4 was suggested to calculate the potential rooftop area, which considers building construction area (HVAC installation, elevators, terrace, etc.), the impact of over-shading and the use of available surfaces for other purposes. Furthermore, Yue and Huang (2011) used the formula of the annual electricity output (kWh) of PV systems (Hinrichs et al. 2006; IEA 2002; Technological Center of Solar Photovoltaics of the Industrial Technology Research Institute, TCSP 2005) to predict the total and average output of cities in Taiwan.

(Designated area: m^2) x (Exploitation ratio: %) x (Actual building coverage ratio: %) = (Developed floor area: m^2)

(Developed floor area: m^2) x (Potential rooftop area for installation ratio: 0.4) = (Potential rooftop area: m^2)

(Potential rooftop area: m^2) x (Annual solar radiation: kWh/m^2/yr) x (Module efficiency: %) x (Aggregative coefficient: %) = (Annual electricity output of PV systems: kWh/yr)

For Taipei:
(Potential rooftop area) x (Annual solar radiation) x 19.3 % (Rentzing, 2009) x 0.75 (TCSP, 2005)

For blocks in Chung-Shan District:
37406.08 (Developed floor area) x 0.4 x 1237.88 (Annual solar radiation) x 19.3% x 0.75

Based on those researches, the potential of PV application for the four district models in two methods are calculated (Table 6.14). The predictions for the potential of solar PV systems in urban areas in Taipei based on Yue and Huang's research are very low, mostly under 5 kWh/m^2/yr. The only exception is Chung-Shan District because the commercial blocks in it have a higher coverage ratio and lower proportion of roof area to total floor area. Although the prediction of the potential electricity output of solar PV systems, according to these two methods, have huge differences, the figures can still give reliable ranges of the potential for different urban areas.

Models	Calculation process	Output prediction	
		(GWh/yr)	(kWh/m^2/yr)
Blocks in Chung-Shan District	0.0658 x 16318 x 365 x 24.27	9.51	38.53
	37406.08 x 0.4 x 1237.88 x 19.3% x 0.75	2.68	10.86
Blocks in Sung-Shan District	0.050691 x 22548 x 365 x 24.27	10.13	45.74
	9007.13 x 0.4 x 1335.43x 19.3% x 0.75	0.70	3.15
Blocks in Ta-An District	0.078573 x 27517 x 365 x 24.27	19.15	81.22
	8069.77 x 0.4 x 1200.582 x 19.3% x 0.75	0.56	2.38
Several blocks in Ta-An District	0.823151 x 27517 x 365 x 24.27	200.65	84.98
	142683.6 x 0.4 x 1235.199 x 19.3% x 0.75	10.20	4.32

Table 6.14 The prediction of potential electricity output of solar PV systems for four blocks in four different districts in Taipei.

6.4 Package of strategies

In this section, the strategies for reducing energy demand and supply that have been discussed in the previous sections would be composed into different packages and compared with Taiwan's national mid and long-term goals.

6.4.1 Strategy composition

The majority of important variables and design strategies have been examined and discussed at both building and urban scales in the previous sections. The purpose of this section is to combine those strategies and compare their collective impacts at urban scale through the simulation. The Shung-Shan District model is taken as the experimental subject and examined with different packages of strategies composed of various parts of the design strategies. Those design strategies are generally classified into easy and deep strategy packages (Table 6.15) depending on their degree of feasibility for the existing environment.

For the easy strategy packages, there are four different packages, which are associated to lighting use, temperature setting of HVAC systems, glazing ratio, and equipment efficiency. All the details are concerned the settings of the previous simulation. For the long strategy packages, there are four different packages, which would contain the easy strategy packages and associated to UHI mitigation, insulation improvement, and Solar PV application.

Lastly, some other important issues are not included simply because they are suitable for new buildings or their timescale of achievement will be longer than 40 years for the existing environment, such as block fabrication, urban density, orientation and diverse renewable energy application. Moreover, some strategies that cannot reduce the energy demand of buildings at urban scale efficiently would be ignored, including shading device and orientation of buildings.

Package	No.	Strategies	Details
Easy	1	Lighting reduction	As Pack B in Section 6.3.1
		HVAC temperature setting change	18-26.5 °C for residential 18-24 °C for commercial
		Glazing ratio	30% for residential 60% for commercial
		Equipment efficiency (COP of HVAC)	3.5 for residential 4 for commercial
	2	Lighting reduction	As Pack C in Section 6.3.1
		HVAC temperature setting change	18-27 °C for residential 18-25 °C for commercial
		Glazing ratio	30% for residential 50% for commercial
		Equipment efficiency (COP of HVAC)	4 for residential 5 for commercial
	3	Lighting reduction	As Pack D in Section 6.3.1
		HVAC temperature setting change	18-27.5 °C for residential 18-27 °C for commercial
		Glazing ratio	20% for residential 40% for commercial
		Equipment efficiency (COP of HVAC)	4.5 for residential 6 for commercial
	4	Lighting reduction	As Pack E in Section 6.3.1
		HVAC temperature setting change	18-28 °C for all
		Glazing ratio	20% for residential 30% for commercial
		Equipment efficiency (COP of HVAC)	5 for residential 6 for commercial
Deep	1	With Short No.3 strategy package	-
		UHI mitigation strategies	As Degree A in Section 6.3.10
		Insulation improvement	U-Value of wall, window and roof =0.7, 1.26, 0.67
		Solar PV system application	25%
	2	With Short No.3 strategy package	-
		UHI mitigation strategies	As Degree A in Section 6.3.10
		Insulation improvement	U-Value of wall, window and roof =0.7, 1.26, 0.67
		Solar PV system application	50%
	3	With Short No.4 strategy package	-
		UHI mitigation strategies	As Degree B in Section 6.3.10
		Insulation improvement	U-Value of wall, window and roof =0.7, 1.26, 0.67
		Solar PV system application	75%
	4	With Short No.4 strategy package	-
		UHI mitigation strategies	As Degree B in Section 6.3.10
		Insulation improvement	U-Value of wall, window and roof =0.7, 1.26, 0.67
		Solar PV system application	100%

Table 6.15 Detailed context of easy and deep design strategy packages.

6.4.2 Analysis and discussion

From the simulation results, it is clear to understand that the strategies of easy strategy packages can successfully reduce the electricity supply to as low levels as deep strategy packages do (Figure 6.51). Furthermore, in order to achieve the national mid-term and long term goals for CO2 emission reduction, 13.6% and 56.8%, the renewable energy application should not be excluded for the long term goal. Moreover, there is no doubt that a real low carbon society would be built depending on more aggressive and comprehensive strategies.

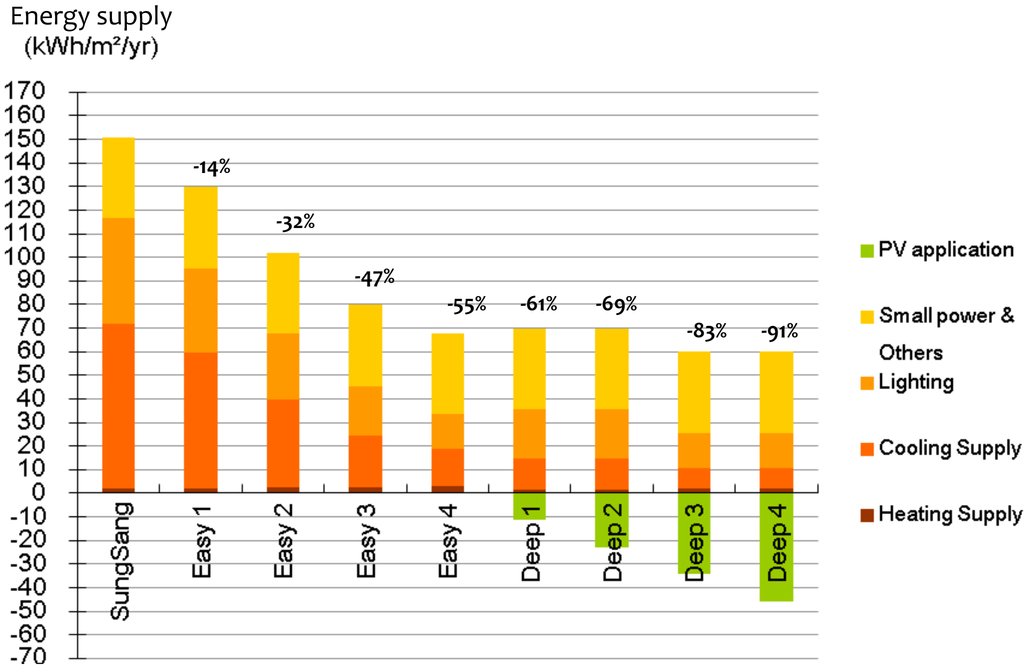


Figure 6.51 The summary of average electricity supply with different strategy packages in Sung-Shan District.

First of all, the easy strategy package No.1 depicts a new living style with changes to the temperature settings of AC systems, lighting usage and slightly improved equipments. However, without any other big investment, such as glazing and building fabrication refurbishment, it still can bring a 14% decrease, which satisfies the national mid-term goal in Taiwan. For the rest of the easy strategy packages, temperature settings of AC systems, lighting usage, and efficiency of facilities play very important roles. Additionally, strict control of glazing ratio does help decrease the solar gain of buildings to save energy. If all the buildings adopt better equipment systems and occupants can follow the new living style, 47% and 55% energy can be saved in easy strategy packages No.3 and No. 4 respectively. Through the series of strategy applications, a low energy society probably can be realized, but not a real low carbon society.

Secondly, it is the renewable energy application of solar PV systems that can shape a real low carbon living environment. The long-term strategy No.1 considers the improvement of the urban micro-climate and 25% solar PV system application in Shung-Shan District, which is based on easy strategy package No.3. The solar PV system can supply 11.44 kWh/m^2/yr on average, which is roughly 16.34% of the total energy supply. Under the similar background situation, deep strategy package No.2 calculates a 50% PV system application, which brings 22.87 kWh/m^2/yr and helps create a 69% energy reduction. Both of them satisfy the requirement for achieving the national long-term goal in Taipei. Additionally, in an ideal situation involving a 100% PV system application, almost 91% of the energy demand can be balanced.

In short, in order to achieve the national goals in Taiwan, the local government should eagerly educate citizens and promote a new living style in the short-term. In the long-term, the government has to cooperate with citizens to change the landscape and increase over-shading in the urban environment to lower the UHI effect, encourage people to use highly efficient AC systems, and subsidise house owners for the installation of solar PV systems. In addition, there are some strategies which are not included, such as density modification, control of building orientation, height and wall-to-volume ratio, and better block patterns, because for an existing environment, they are difficult to change in the short-term. However, they are still important for the long-term strategy. Therefore, for new buildings and re-built projects in urban areas, they should be considered along with the other strategies.

6.5 Conclusion

This research examined several variables and strategies related to the energy demand of buildings, including orientation of façade and building, building usage, glazing ratio, insulation, shading device and others. Moreover, this research extended the scope and scale to urban dimensions, such as building forms, block fabrication, urban development intensity, over-shading and the changes of the outdoor environment. Through a series of simulations at both building and urban scales, it is clear to understand the impacts of those variables and related strategies. In addition, the analysis of simulation results helps to determine a better development path to reduce the energy consumption of buildings in Taipei. The following are the critical conclusive points.

The impact degrees of different variables and strategies for buildings at building and urban scales in Taipei

1. Living style change is one of the most effective strategies for commercial and residential buildings in Taipei. Although the saving percentage becomes smaller for the urban scale model, it still reduces enormously. The summary of reduction percentages in different situations can be checked in Table 6.16 & 17.

Issue		Living style				
Strategies	No.	Pack A (Prototype)	Pack B	Pack C	Pack D	Pack E
	Lighting requirement (LUX)	800	700	600	500	400
	Operation time (hr/wk)	84	77	70	63	56
	Heat output of lighting (W/ m^2)	15.15	13.26	11.36	9.47	7.58
	Temperature setting (℃)	18-23	18-24	18-25	18-27	18-28
	COP of AC system	3	4	4	5	6
Building scale model		-	-33.65 %	-43.62 %	-58.73 %	-67.41 %
Urban scale model		-	-27.04 %	-38.75 %	-55.63 %	-65.27 %
(Prototype) Building scale model : Commercial-L Urban scale model : Commercial blocks in Chuang-Shan District						

Table 6.16 The reduction percentage of energy supply involved in living style for commercial buildings at building and urban scales with different strategies.

Issue		Living style				
	No.	Pack A (Prototype)	Pack B	Pack C	Pack D	Pack E
Strategies	Lighting requirement (LUX)	150	130	110	90	70
	Operation time (hr/wk)	60	56	52	48	44
	Heat output of lighting (W/ m^2)	5.32	4.61	3.90	3.19	2.48
	Temperature setting (℃)	18-26	18-26.5	18-27	18-27.5	18-28
	COP of AC system	3	3.5	4	4.5	5
Building scale model		-	-16.05 %	-23.46 %	-32.10 %	-37.04 %
Urban scale model		-	-11.71 %	-20.67 %	-27.69 %	-33.24 %
(Prototype) Building scale model : Residential-L Urban scale model : Residential blocks in Ta-An District						

Table 6.17 The reduction percentage of energy supply involved in living style for residential buildings at building and urban scales with different strategies.

2. Building form concerns wall-to-volume ratio, shape, height and orientation. Among them, the wall-to-volume ratio generally is the most important thing due to it having the high positive correlation with cooling demand based on the building simulation in this research. However, the other variables would also affect the relationship in different ways. For shape, some types of buildings can reduce solar gain by an increase in self-shading, such as Courtyard and T-shape buildings. Additionally, for commercial buildings higher than 20 storeys, orientation would be more important than the wall-to-volume ratio for energy consumptions.

3. According to the simulation for Institutional and Residential-M building prototypes and several blocks in Ta-An District, it is not too difficult to see how the orientation has a strong relationship with solar radiation. The façades facing east and south usually get much more solar gain than the others. Moreover, the solar radiation increase would cause models at building scale to have a higher cooling demand. However, the impact of urban scale modelling was very weak. In short, orientation is undoubtedly important for a single building, but not for an urban environment.

4. The simulation for glazing ratio pointed out that higher cooling gain would increase with higher glazing ratio, and the increase is a linear growth both for building and urban scale models. A 10% increase in glazing ratio for a single commercial building would cause a 7 to 8 kWh/m^2/yr cooling demand increase. For urban scale modelling, a 10% increase in glazing ratio for the commercial block only leads to a roughly 3 kWh/m^2/yr increase (Table 6.18).

Issue	Glazing ratio								
Opening percentage	90%	80%	70%	60%	50%	40%	30%	20%	10%
Building scale model	7.07 %	4.65 %	2.40 %	-	-2.36 %	-4.80 %	-7.26 %	-9.85 %	-12.47 %
Urban scale model	2.95 %	1.83 %	0.68 %	-	-1.68 %	-2.91 %	-4.16 %	-5.45 %	-6.77 %
(Prototype) Building scale model : Commercial-L (with 60% glazing ratio) Urban scale model : Commercial blocks in Chunag-Shan District (with 60% glazing ratio)									

Table 6.18 The comparison of cooling demand of building and urban scale models by different glazing ratio for commercial buildings.

5. The simulation for insulation presents different impacts brought by the changes of U-Value for walls, windows and roofs at building and urban scales. At building scale, the improved U-Value only decreases the energy demand of residential buildings by 4.9% and increases the cooling demand of commercial ones. However, at urban scale modelling, it successfully decreases the demand of both of them by 0.8% and 19% (Table 6.19).

Issue	Insulation	
U-Value (Wall / Window / Roof)	(Commercial) 1.15 / 2.8 / 1.01 (Residential) 3.34 / 5.41 / 1.16	(Commercial) 0.7 / 1.26 / 0.67 (Residential) 2.05 / 3.34 / 0.67
Building scale model	-	(Commercial) +0.0% (Residential) -4.9%
Urban scale model	-	(Commercial) -0.8% (Residential) -19.0%
(Prototype) Building scale model : Commercial-L and Residential-L Urban scale model : Blocks in Sung-Shan District		

Table 6.19 The comparison of the energy demand of commercial and residential buildings at building and urban scale models with different U-Value for walls, windows and roofs.

6. The proportion of the commercial floor areas of blocks has a positive correlation with the total cooling demand. Due to the comparatively much higher average energy consumptions of commercial buildings than other building types, the result is predictable and reasonable. In terms of the dominance of commercial buildings in Taiwan, the strategies for saving energy for blocks involved in commercial usage should be paid more attention to.

7. Depending on the modelling of three different types of districts in Taipei, cooling demand always grows with the urban density no matter what kinds of district types they are, particularly for residential blocks (Table 6.20).

Issue	Urban density					
Density	60 %	100 %	140 %	180 %	220 %	300 %
Chung-Shan District	-3.17 %	-	1.21 %	1.91 %	2.58 %	3.06 %
Shung-Sang District	-5.22 %	-	2.69 %	4.98 %	5.48 %	7.33 %
Ta-An District	-16.69 %	-	8.26 %	14.65 %	18.90 %	22.72 %
The 100% urban density is according to the definition of building regulations in Taiwan.						

Table 6.20 The comparison of the energy demand of three district types in Taipei with different development intensities.

8. Based on the simulation of different fabrications of residential blocks with the same density, wall-to-volume ratio, average building height and surround road width have positive correlations with the cooling demand of buildings. On the contrary, volume rate and building coverage ratio have a negative correlation.

9. According to the simulation related to the shading devices at building scale, commercial buildings in Taipei have to be better equipped with shading devices on their south, east and west façades, and the shading depth ratio of them should not be lower than 2:3 (Table 6.21).

Issue	Shading device at building scale					
Shading coverage ratio ; shading depth ratio	Covered façades					
	East	South	West	North	E+S+W	All
100% ; 1:3	-0.57 %	-0.63 %	-0.45 %	-0.46 %	-1.90 %	-2.52 %
100% ; 2:3	-1.70 %	-1.89 %	-1.31 %	-1.18 %	**-5.21** %	-6.54 %
100% ; 3:3	-2.63 %	-2.62 %	-1.91 %	-1.62 %	-7.37 %	-9.13 %
100% ; 4:3	-2.86 %	-2.83 %	-2.07 %	-1.62 %	-8.05 %	-9.81 %
Prototype: Commercial-L						

Table 6.21 The reduction degree of cooling demand for commercial buildings with different shading devices on different façades.

10. Through the modelling for commercial buildings at urban scale, the saving degree of cooling demand by equipping buildings with shading devices in the urban environment would be limited. On the contrary, over-shading is much more important to save energy for buildings (Table 6.22). Additionally, in order to make sure over-shading functions efficiently, the distance between two commercial buildings in Taipei should preferably be kept to within 30 meters.

Issue	Over-shading & Shading device at urban scale				
Over-shading	Road width (The buildings facing)				
	15m	20m	30m	40m	50m
Without over-shading	297 kWh/m^2/yr				
With over-shading	262 (-11.71%)	264 (-11.21%)	266 (-10.54%)	267 (-10.24%)	267 (-10.11%)
Shading device	Road width (The buildings facing)				
	15m	20m	30m	40m	50m
100% ; 1:3	-1.12%	-1.34%	-1.33%	-1.38%	-1.22%
100% ; 2:3	-2.52%	-2.98%	-3.21%	-3.26%	-3.22%
100% ; 3:3	-3.02%	-3.61%	-4.01%	-4.14%	-4.16%
100% ; 4:3	-3.17%	-3.78%	-4.25%	-4.43%	-4.43%
Prototype: Commercial-L / Surrounding situation : Figure 6.41					

Table 6.22 The reduction degree of the cooling demand of commercial buildings with over-shading from different shading devices in the practical urban environment in Taipei.

11. UHI effect mitigation strategies for changing the outdoor thermal environment have been proved to effectively decrease the cooling demand in the Ta-An District modelling (Table 6.23).

Issue	The UHI effect					
Strength	Measure-ment	Degree A	Degree B	Degree C	Degree D	Degree E
Residential buildings	-	-11.38 %	-22.02 %	-31.84 %	-40.78 %	-47.99 %
Commercial buildings	-	-2.33 %	-4.66 %	-6.99 %	-9.33 %	-11.44 %
Ta-An-L District	-	-3.30 %	-6.52 %	-9.66 %	-12.71 %	-15.38 %
The detailed temperature reduction for different degrees can be check in Section 6.3.10.						

Table 6.23 The reduction degree of energy demand for Ta-An District with different outdoor thermal environments.

12. Based on the modelling for strategy packages, in order to achieve the national goals in Taiwan, the local government should eagerly educate citizens and promote a new living style in the short-term. Moreover, the government have to cooperate with citizens to change the landscape and increase over-shading in the urban environment to lower the UHI effect, encourage people to use highly efficient equipments, and subsidize house owners to install solar PV systems. In addition, density modification, control of building orientation, height and wall-to-volume ratio, and better block pattern planning should be considered for new buildings and re-built projects in urban areas.

Strategies to reduce energy supply for new and existing buildings

This chapter examined several different kinds of strategies to figure out their impact for energy consumptions of buildings in different situations in Taipei. The detailed information can be checked in the previous paragraphs. Here, the comparison of their impact on energy supply is listed in Figures 6.52 & 6.53 (Appendix C).

First of all, for both existing commercial and residential buildings, strategies related to living style can effectively decrease the energy supply. For commercial buildings, lighting is the most important issue, which could help to decrease the energy supply from 19% to 41%. The potential reduction brought by the changes of HVAC system setting and COP improvement are considerable. For residential buildings, those three strategies are equally important.

Secondly, shading device, glazing ratio and UHI mitigation are useful for existing commercial buildings. Glazing ratio, insulation and UHI mitigation are critical for residential buildings. However, there are some differences for them at building and urban scales, such as glazing ratio and insulation.

On the other hand, compared with existing buildings, the reductions caused by related strategies for new commercial and residential buildings are less. Fabrication, referring to the pattern of blocks, is the only one exception for new residential buildings. Moreover, density might be another issue for new development areas in Taipei. But, its energy saving degree is limited.

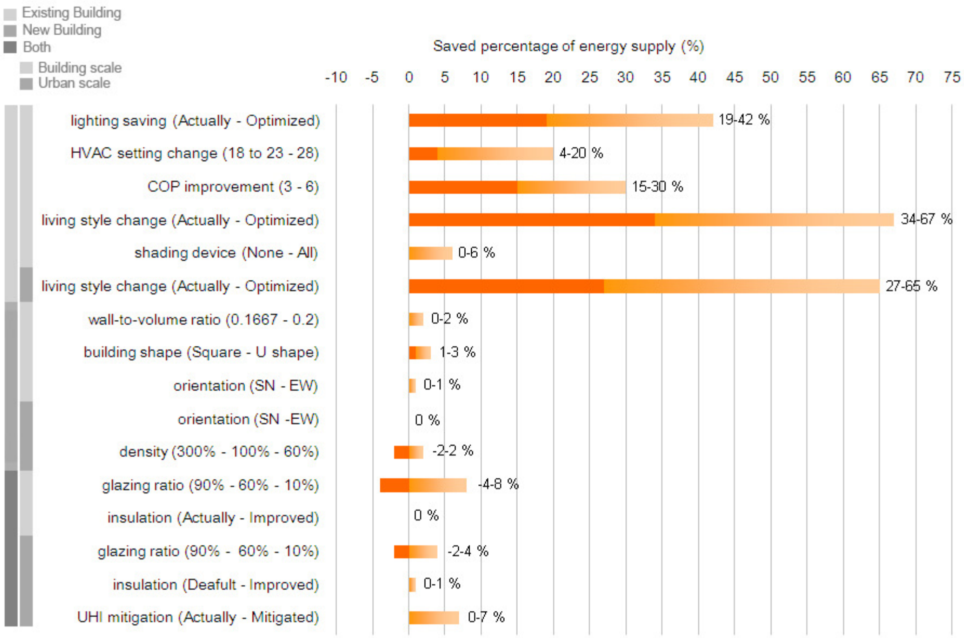


Figure 6.52 The summary of saved percentage of energy supply of different strategies for commercial buildings.

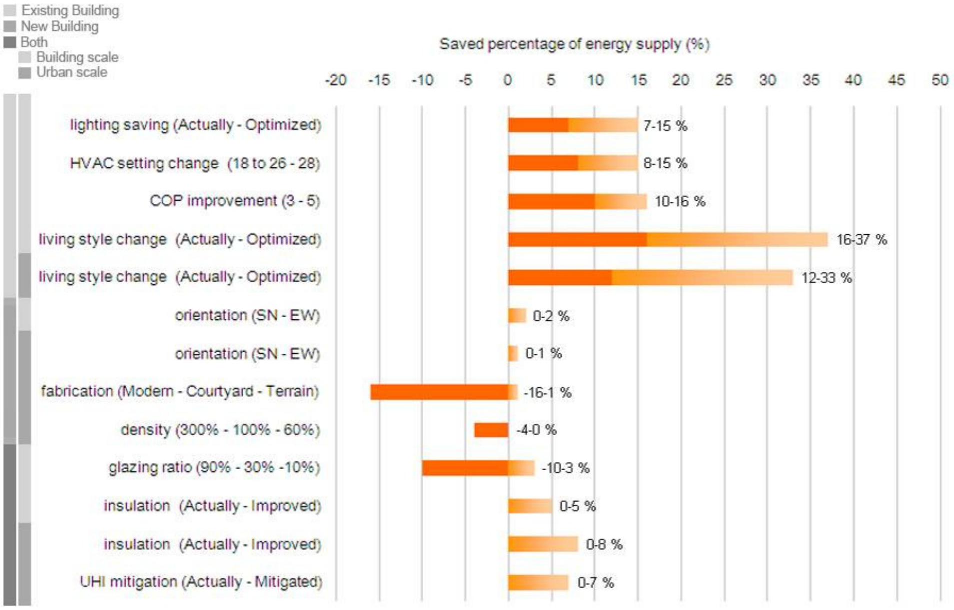


Figure 6.53 The summary of saved percentage of energy supply of different strategies for residential buildings.

Findings of design strategies through urban scale simulation

In the past, there were rarely any discussions about variables at urban scale in Taiwan because of the general ignorance about urban design and the limitations of technical tools. This research successfully extended the scope and created simulations at urban scale by applying practical situations and models. Some discoveries and new perspectives emerged to define better strategies for reducing energy demand.

On the one hand, the modelling at a bigger scale revealed some different conclusions from those at building scale, including orientation of façade or building, shading device, glazing ratio and U-Value. Orientation of façade or building is important for single building tests, which directly affect the solar radiation. However, for a group of buildings, although the eastern façades would get the most solar radiation, the difference between the total gain becomes much less.

Based on the analysis of the annual cooling demand of Ta-An District, the impact brought by orientation could nearly be ignored. Next, shading device was believed to be another important issue to save energy. But, through the modelling of shading device at urban scale, no matter where the buildings are located, the saving degree brought by increasing shading devices is limited to within 4 kWh/m^2 /yr. Next, a similar phenomenon appeared for glazing ratio. Glazing ratio was thought to be the most important thing to avoid accumulating too much solar radiation in Taiwan (Lin 2003). However, the saving degree is not as big as the expectation. But, glazing ratio control is still an important variable in Taiwan. Next, the modelling of insulation at building scale presented the minor influence of U-Value improvements to walls, windows and roofs for commercial buildings. However, the modelling at urban scale showed practical savings for both commercial and residential buildings, which could reach three and seven kWh/m^2/yr.

On the other hand, the research field involved in urban scale modelling gave some new ideas. Urban development intensity presented that higher density development would not reduce the average cooling demand. In other words, if only considering the energy issue without accounting for transportation, infrastructure and social issues, high density development may not be beneficial for the urban environment. Next, block fabrication plays an important role to affect the energy demand, which contains many variables, including wall-to-volume ratio, volume rate, building coverage ratio, average building height, and surrounding road width. Wall-to-volume ratio, average building height, volume rate and road width have a positive correlation with cooling demand. A compact, low height and reduced volume block development is preferable. Next, over-shading is another critical issue. For hot and wet weather styles, adopting appropriate strategies to increase over-shading in urban areas is essential. Next, through the outdoor thermal environment simulation, the UHI effect mitigation strategies have been proven to potentially reduce the energy requirement.

In short, the modelling at urban scale changed some of our perspectives on variables at building scale. Moreover, it added some important concepts for saving energy demand, which solidly help to complete the guideline.

Analysis and conclusion can be references for urban design principals in Taiwan.

All the simulation results presented in this research can be references for urban design in Taiwan. The two main reasons are the practical experimental subjects' setting and the urban scale discussion.

In the present public city and architecture management systems in Taiwan (Figure 3.14), urban design is not included, and is only considered by the Council of Assessment during their reviews of urban planning reports. Moreover, due to the lack of principals for urban design, various negative planning outcomes would be produced through the system (Figure 3.15). However, the majority of urban plans in Taiwan aim to achieve low carbon development. Thus, without any principals, the system definitely cannot satisfy this ambition. Although political issues are not the concern in this research, the research result still can offer some useful suggestions for committees.

Chapter 7

CONCLUSION AND RECOMMENDED FUTURE STUDIES

A PRESENTATION OF THE FINDINGS, ACHIEVEMENT, AND CONTRIBUTION OF THIS RESEARCH, AND RECOMMENDED FUTURE STUDIES

CONCLUSION AND RECOMMENDED FUTURE STUDIES

7.1 Introduction

This research discussed sustainable development around the world from many perspectives and summarized important variables and strategies according to theories and projects. Moreover, methods involved in energy calculation and the latest technical tools were deeply explored. In order to compensate for the lack of researches involved in energy performance of buildings in Taiwan and figure out the guidelines to save energy demand and supply, a series of technical methods were constructed. Through observation of practical situations and analysis of related data, and by using a set of simulation tools, the questions and objectives were answered and achieved. Additionally, the modelling results challenged existing perspectives and offered more comprehensive ideas for building and urban design in Taipei. Overall, the experience not only indicated a way to understand the energy performance of an existing environment, but also gave practical suggestions, particularly for cities in hot and wet climates.

7.2 Conclusion

This section presents the important findings and achievements of this research, which are divided into several topics; a method to understand, analyze and predict the energy performance of architectures, fundamental understanding and analysis of different types of buildings in Taipei, examination of variables for an existing environment, and sustainable development guidelines for Taipei.

7.2.1 A method to understand, analyze and predict the energy performance of architectures

1. The research process of this study presents an example of a bottom-up method with simulation for a practical city (Figure 7.1). The simulation method should be based on solid default settings of fundamental information involved in diary of living, incidental heat, materials of buildings, space layouts, and weather data. Furthermore, the information could be defined according to national statistics, building codes, practical investigation and design principals. Additionally, the simulation should be done at different scales to recognize the differences in energy performance among models.

Figure 7.1 The bottom-up method applied in this research to a building, a community, a block and to a district.

2. A large number of studies have been made of the energy performance of buildings, but little is known about energy performance at urban scale because of the obstacles the complexity of a city presents. This research successfully integrates several software, Sketch Up (@Last Software and Google), HTB2 v2.10 (WSA 2008) and Virvil Plugins v1.3 & v1.4 (WSA 2012) to consider the relationship of buildings and their surrounding situations. Moreover, with the help of improved technical tools, the method theoretically could be extended unlimitedly.

3. The simulation results were compared with measurements from previous researches to prove their validity and reliability. For commercial buildings in Taipei, the simulation result of electricity supply goes from 174.79 to 256.91 kWh/m^2/yr, and the actual measurement is 215.6 kWh/m^2/yr (Kan 2009). For residential buildings, the simulation result is 58.69 to 60.38 kWh/m^2/yr and the actual measurement is 58.32 kWh/m^2/yr (Chen 2006). The simulation result has proved that the accuracy of the simulation is extremely high.

7.2.2 Understanding and analysing different types of buildings in Taipei

1. Buildings in Taipei can be generally classified into two groups due to their different energy usage types, non-domestic and domestic. Assembly, Institutional, Commercial, and Industrial buildings belong to the non-domestic buildings group; the rest of the building types belong to the domestic group. For the non-domestic buildings group, a cooling necessity exists throughout the whole year, particularly from April to November. For the domestic group, the need is only during the summer time and the differences between the seasonal effects are enormous.

2. Depending on different prototypes, the heat sources are various. The incident gain overwhelms other heat sources for the majority of building types in Taipei except Others, occupying 53% to 84%. Moreover, solar gain is the second largest heat source, which accounts for between 15% and 44%. Moreover, the ventilation and fabric gains are varied depending on the building usage.

3. According to the simulation results, the potential strategies applied to decrease the energy demand of different kinds of buildings should be different. The strategies for reducing incidental and cooling gains are the most important for all kinds of buildings. The strategies for solar gain would also be critical for all of them except the Assembly buildings. Additionally, for Industrial and Institutional buildings, strategies related to ventilation gain are considerable; for Commercial-S, Institutional, Residential-L, -M, -S, and Others building types, focus should also be on strategies concerning fabric gain.

7.2.3 Examination of variables for architectures

1. The average energy demands of buildings at smaller scales are lower than the ones at larger scales. For cooling demand of residential buildings, their average demand at building, group and district scales are 88, 58 and 39 kWh/m^2/yr respectively. In other words, it decreases 34% and 56% at group and district scales. For cooling demand of commercial buildings, they are 301, 255 and 254 kWh/m^2/yr at building, group and district scales. Furthermore, because of the additional consideration of over-shading in group and district modelling, the differences prove its importance. Moreover, due to the higher proportion of solar gain of all heat sources in residential buildings, it is clear to observe the larger reduction of them than the commercial buildings.

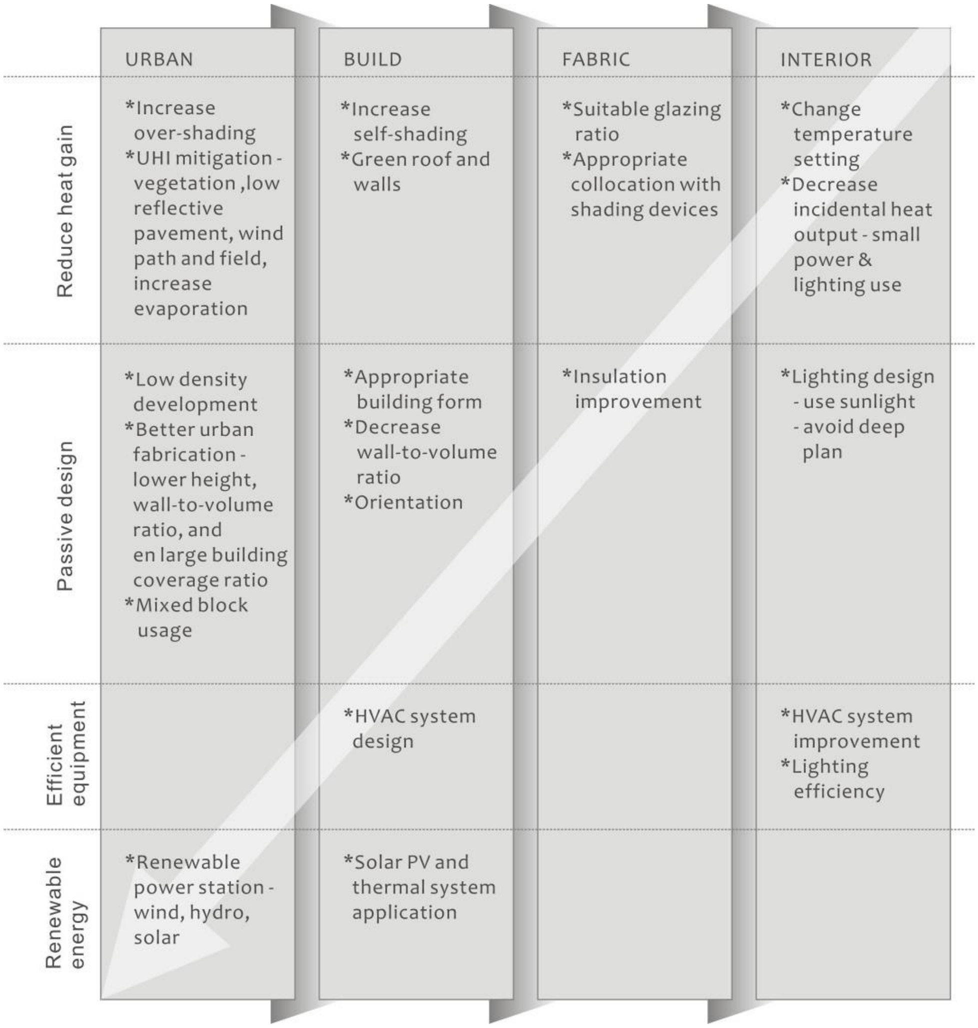
2. According to the simulation results in the second phase, in order to decrease the energy use of buildings in Taipei, lighting, facility efficiency, temperature settings of AC systems, orientation, glazing ratio, shading device, and wall-to-volume ratio are important variables for buildings at building scale. In addition, insulation is not as important as previous researches have suggested.

3. Urban development intensity, block usage type, wall-to-volume ratio, volume rate, building coverage ratio, average building height, surrounding road width, over-shading, insulation and outdoor environment are all critical variables for buildings at urban scale. To start with, higher density development would not help to reduce the average cooling demand in Taipei. Next, wall-to-volume ratio, average building height, volume rate and surrounding road width have positive correlations with cooling demand. Next, for hot and wet climates, increasing over-shading in urban areas is essential. Finally, the outdoor environment has its own potential to reduce energy requirements.

4. Orientation of façade or building is important for buildings, but it could be completely ignored for urban scale modelling. Moreover, shading device was previously believed to be another important issue to save energy for buildings (Lin 2009a). However, through the modelling at urban scale in this research, the energy saving brought by shading devices is limited. Instead, over-shading

is much more important. Additionally, the improvement of insulation may not be important for buildings according to the building scale modelling, but it can slightly decrease the energy demand of buildings at urban scale.

7.2.4 Guidelines for saving energy of buildings in Taipei



	URBAN	BUILD	FABRIC	INTERIOR
Reduce heat gain	*Increase over-shading *UHI mitigation - vegetation ,low reflective pavement, wind path and field, increase evaporation	*Increase self-shading *Green roof and walls	*Suitable glazing ratio *Appropriate collocation with shading devices	*Change temperature setting *Decrease incidental heat output - small power & lighting use
Passive design	*Low density development *Better urban fabrication - lower height, wall-to-volume ratio, and en large building coverage ratio *Mixed block usage	*Appropriate building form *Decrease wall-to-volume ratio *Orientation	*Insulation improvement	*Lighting design - use sunlight - avoid deep plan
Efficient equipment		*HVAC system design		*HVAC system improvement *Lighting efficiency
Renewable energy	*Renewable power station - wind, hydro, solar	*Solar PV and thermal system application		

Figure 7.2 Guidelines of urban and building related strategies for the architectures in Taipei.

1. For decreasing the energy demand of buildings, related strategies could be classified into four critical steps and different scale sectors. The four important steps are decreasing heat gain, applying passive design, improving equipment efficiency, and adopting renewable energy (Jones et al. 2011). The scale sectors

are urban, building, fabric and interior (Stromann-Andersen and Sattrup 2011). Firstly, decreasing heat gain is the priority to save energy. Before trying to reduce the supply aspect, it is important to cut down the demand side first. Secondly, another method to manage heat sources is through applying passive designs, which not only can decrease the energy demand of buildings before and after operation, but also can help to maximize the saving degree brought by the other three steps. Thirdly, improving equipment efficiency concerns the supply aspect. Fourthly, renewable energy application aims to offer energy to balance requirements. The detailed strategies for Taipei can be seen in the above figure showing different steps and scale sectors (Figure 7.2).

2. From the modelling of optimized strategy packages, the local government can achieve its short-term goal by eagerly educating citizens and promoting a new living style. For long-term national goal, the government has to increase over-shading in urban areas, lower the UHI effect, encourage people to use high efficient equipments, subsidize house owners to install PV systems, and undertake building retrofitting or renovation according to passive design strategies. However, for a real low-carbon city, more aggressive and comprehensive strategies should be employed.

3. All the simulation results presented in this research can be references for urban planning audits and for making urban design assessments in Taiwan. Urban design is not included in the present public city and architecture management systems in Taiwan, which is only considered by the Council of Assessment during their review of urban planning reports. Therefore, the simulation method can help to examine proposals and its conclusion can be the principals for reviews.

7.3 Recommended future studies

Through the application of modelling, this research understands, analyzes and predicts the energy performance of the architectures in Taipei. Here are some suggestions for further research.

1. The default setting of buildings in this research adopted average figures based on national statistics, the national building code, design principals and measurements taken by previous researches. The main reason for this is that this research aims to focus on the general situation in a city, not a specific building or area. However, for further researches, the variety of existing buildings should be deeply understood and investigated, including construction ages, materials, electricity usage, social connection and others. Solid fundamental background information of buildings would not only help to understand energy performance of buildings in specific areas clearly, but would also support further researchers localize related strategies.

2. The discussion scope of this research does not cover all kinds of buildings in Taipei and the subjects for modelling only depict the most general and typical building environments. Therefore, except the fundamental research to investigate the related data of buildings, more simulation for specific building types and situations should be discussed, such as high-rise buildings or traditional communities. Moreover, the guidelines for sustainable design strategies can be concluded further for various situations in Taipei instead of one general version.

3. Technical tools should be improved continuously by considering more variables, particularly concerning microclimates at urban scale. For interior setting, more patterns can be added for residential and commercial spaces. For outdoor environment, in order to get more precise results and examine more strategies, there are lots of variables which should be calculated together, such as heat gain from transportation, wind paths and fields, and reflective ratios of pavements.

4. The bottom-up method applied in this research can be integrated with GIS system and extended to consider other important issues of the built environment and architectures, such as transportation, waste management, public infrastructure and social interaction, which could be explored further to help define the best solution for architectures.

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Appendices

TAIWAN LIGHTING STANDARDS (CNS 12112)

SHADING DEPTH RATIO

LIST OF SAVED ENERGY PERCENTAGE

CODE OF VIRVIL PLUGIN v1.4

APPENDIX A

Taiwan lighting standards (CNS 12112)

A-1 Commercial spaces

LUX	Common space	Grocery store	Supermarket	Department	Clothing	Culture	Entertainment	Special
3000	-	-	-	-	-	-	-	-
2000	Showroom		Showroom	Showroom	Showroom			Focus
1500								
1000	-			Focus Counter	Counter		Focus	
750	Focus Front-desk Packing - area	Focus	All	All	Focus Fitting - room	Showroom Focus Counter	Exhibition	Showroom
500	Lobby Elevator	Facade			Exhibition	All	All	Counter
300	Office	All	-	-		-		Reception
200	Reception				-		-	All
150	Service - spaces				All			
100	-	-			-			-
75	All							

A-2 Office spaces

LUX	Spaces			Working
2000	-			-
1500	Office Business Lobby (Daytime)			Design Draw Type Calculate
1000				
750				
500	-	Meeting room Print Control Medicine		-
300	Assembly Reception Restaurant Kitchen Entertainment Rest Guard / Security Stairs			
200		Book Facility Classroom Stairs	-	
150			Toilet Shower room Balcony Stairs	
100	Fitting room Warehouse Entrance (Parking) Service spaces		-	
75				
50	Security stairs			
30				

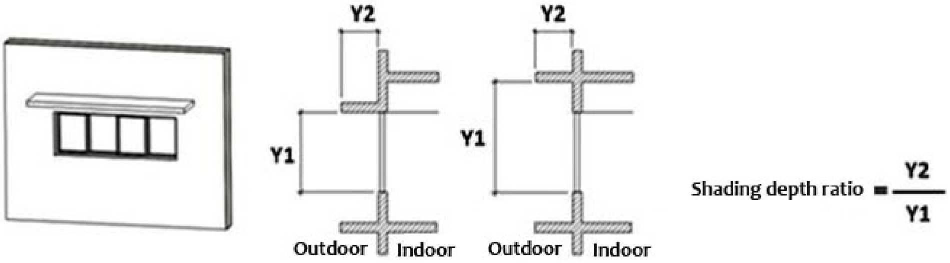
A-3 Residential spaces

LUX	Reading	Living	Kitchen & Dinning	Bedroom	Working	Bathroom	Toilet	Balcony & Stairs	Storeroom	Porch	Garage	Yard
2000	-	-	-	-	Work	-	-	-	-	-	-	-
1500												
1000												
750	Write Read			Read Make-up								
500			Sink Table			Lavatory Sink					Clean Check	
300	-	Sofa Desk										
200				-	Laundry							
150			-			All					-	BBQ
100	All	-	All		All		All					
75		All						All		Mail Bell Doorplate	All	
50					-	-			All			All
30	-		-	All			-					

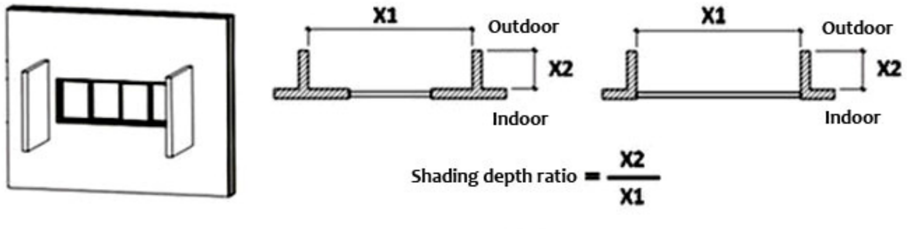
APPENDIX B

Shading depth ratio (CPAMI 2012)

B-1 Horizontal overhangs



B-2 Verticle side fins



B-3 Grid shading = (X2/X1 +Y2/Y1) / 2

APPENDIX C

List of saved energy percentage

Commercial building										
Scale	Type	Strategy (* = Prototype)	Cooling demand	Cooling supply	Lighting supply	Small power supply	Total demand	Total supply	Saved percentage of demand	Saved percentage of supply
			kWh/m^2/yr						%	
Building	Existing	lighting - package A*	297	165	66	39	297	270	0	0
		lighting - package B	228	127	53	39	228	219	-23	-19
		lighting - package C	209	116	41	39	209	196	-30	-27
		lighting - package D	191	106	31	39	191	176	-36	-35
		lighting - package E	174	97	22	39	174	158	-41	-42
		HVAC setting - 18 to 23*	297	165	66	39	297	270	0	0
		HVAC setting - 18 to 24*	277	154	66	39	277	259	-7	-4
		HVAC setting - 18 to 25*	257	143	66	39	257	248	-13	-8
		HVAC setting - 18 to 26*	238	132	66	39	238	237	-20	-12
		HVAC setting - 18 to 27*	218	121	66	39	218	226	-27	-16
		HVAC setting - 18 to 28*	199	111	66	39	199	216	-33	-20
		COP = 3*		165	66	39	n/a	270		0
		COP = 4		124	66	39	n/a	229		-15
		COP = 5		99	66	39	n/a	204		-24
		COP = 6		83	66	39	n/a	188		-30
		living style - package A*		165	66	39	n/a	270		0
		living style - package B		87	53	39	n/a	179		-34
		living style - package C		72	41	39	n/a	152		-44
		living style - package D		41	31	39	n/a	111		-59
		living style - package E		27	22	39	n/a	88		-67
Urban		living style - package A*		140	66	39	n/a	245		0
		living style - package B		87	53	39	n/a	179		-27
		living style - package C		70	41	39	n/a	150		-39

		living style - package D		39	31	39	n/a	109		-56
		living style - package E		24	22	39	n/a	85		-65
Building	New	wall-to-volume ratio - 0.1667*	270	150	66	39	270	255	0	0
		wall-to-volume ratio - 0.1746	272	151	66	39	272	256	1	0
		wall-to-volume ratio - 0.2	278	154	66	39	278	259	3	2
		building shape - Square*	270	150	66	39	270	255	0	0
		building shape - Rectangle	278	154	66	39	278	259	3	2
		building shape - L shaped	276	153	66	39	276	258	2	1
		building shape - U shaped	285	158	66	39	285	263	6	3
		building shape - T shaped	276	153	66	39	276	258	2	1
		building shape - Courtyard	276	153	66	39	276	258	2	1
		orientation - SN*	269	149	66	39	269	254	0	0
		orientation - EW	272	151	66	39	272	256	1	1
U.		orientation - SN*	252	140	66	39	252	245	0	0
		orientation - EW	253	141	66	39	253	246	0	0
Building	Both	glazing ratio - 10%	257	143	66	39	257	248	-12	-8
		glazing ratio - 20%	265	147	66	39	265	252	-10	-6
		glazing ratio - 30%	273	151	66	39	273	256	-7	-4
		glazing ratio - 40%	280	155	66	39	280	260	-5	-3
		glazing ratio - 50%	287	159	66	39	287	264	-2	-1
		glazing ratio - 60%*	294	163	66	39	294	268	0	0
		glazing ratio - 70%	301	167	66	39	301	272	2	1
		glazing ratio - 80%	307	171	66	39	307	276	5	3
		glazing ratio - 90%	314	174	66	39	314	279	7	4
Urban		glazing ratio - 10%	237	132	66	39	237	237	-7	-4
		glazing ratio - 20%	240	133	66	39	240	238	-5	-3
		glazing ratio - 30%	243	135	66	39	243	240	-4	-2
		glazing ratio - 40%	247	137	66	39	247	242	-3	-2
		glazing ratio - 50%	250	139	66	39	250	244	-2	-1
		glazing ratio - 60%*	254	141	66	39	254	246	0	0
		glazing ratio - 70%	256	142	66	39	256	247	1	0
		glazing ratio - 80%	259	144	66	39	259	249	2	1
		glazing ratio - 90%	262	145	66	39	262	250	3	2
B.		insulation - U-value*	297	165	66	39	297	270	0	0
		insulation - U-value improved	298	166	66	39	298	271	0	0
Urban		insulation - U-value*	265	147	66	39	265	252	0	0
		insulation - U-value improved	262	146	66	39	262	251	-1	-1
	New	density - 60%	238	132	66	39	238	237	-3	-2
		density - 100%*	246	137	66	39	246	242	0	0
		density - 140%	249	138	66	39	249	243	1	1
		density - 180%	250	139	66	39	250	244	2	1
		density - 220%	252	140	66	39	252	245	2	1
		density - 300%	253	141	66	39	253	246	3	2
Building	Existing	shading device - None*	297	165	66	39	297	270	0	0
		shading device - S	289	161	66	39	289	266	-3	-2
		shading device - E	289	161	66	39	289	266	-3	-2
		shading device - N	292	162	66	39	292	267	-2	-1
		shading device - W	291	162	66	39	291	267	-2	-1
		shading device - S+E+W	275	153	66	39	275	258	-7	-5
		shading device - All	270	150	66	39	270	255	-9	-6

U.	Both	UHI - measurement*	252	140	66	39	252	245	0	0
		UHI - degree A	246	137	66	39	246	242	-2	-1
		UHI - degree B	240	133	66	39	240	238	-5	-3
		UHI - degree C	234	130	66	39	234	235	-7	-4
		UHI - degree D	229	127	66	39	229	232	-9	-5
		UHI - degree E	223	124	66	39	223	229	-12	-7

Residential building										
Scale	Type	Strategy (* = Prototype)	Cooling demand	Cooling supply	Lighting supply	Small power supply	Total demand	Total supply	Saved percentage of demand	Saved percentage of supply
			kWh/m²/yr						%	
Building	Existing	lighting - package A*	95	36	17	28	99	81	0	0
		lighting - package B	87	34	13	28	92	75	-7	-7
		lighting - package C	85	34	11	28	91	73	-8	-9
		lighting - package D	83	34	8	28	89	70	-10	-14
		lighting - package E	82	34	6	28	89	68	-10	-15
		HVAC setting - 18 to 26*	95	36	17	28	99	81	0	0
		HVAC setting - 18 to 27	76	29	17	28	80	74	-19	-8
		HVAC setting - 18 to 28	59	24	17	28	63	69	-36	-15
		COP = 3*		36	17	28	n/a	81		0
		COP = 4		28	17	28	n/a	73		-10
		COP = 5		23	17	28	n/a	68		-16
		living style - package A*		36	17	28	n/a	81		0
		living style - package B		27	13	28	n/a	68		-16
		living style - package C		23	11	28	n/a	62		-23
		living style - package D		19	8	28	n/a	55		-32
		living style - package E		17	6	28	n/a	51		-37
Urban		living style - package A*		23	17	28	n/a	68		0
		living style - package B		19	13	28	n/a	60		-12
		living style - package C		15	11	28	n/a	54		-21
		living style - package D		13	8	28	n/a	49		-28
		living style - package E		12	6	28	n/a	46		-33
B.	New	orientation - SN*	67	26	17	28	71	71	0	0
		orientation - EW	72	28	17	28	76	73	7	2
U.		orientation - SN*	35	14	17	28	37	59	0	0
		orientation - EW	36	14	17	28	38	59	3	1
Building	Both	glazing ratio - 10%	87	33	17	28	91	78	-8	-3
		glazing ratio - 20%	91	34	17	28	95	79	-4	-2
		glazing ratio - 30%*	95	36	17	28	99	81	0	0
		glazing ratio - 40%	99	37	17	28	103	82	4	2
		glazing ratio - 50%	103	38	17	28	107	83	8	3

		glazing ratio - 60%	107	40	17	28	111	85	12	5
		glazing ratio - 70%	111	41	17	28	115	86	16	7
		glazing ratio - 80%	115	42	17	28	119	87	20	8
		glazing ratio - 90%	119	44	17	28	123	89	24	10
		insulation - U-value*	95	36	17	28	99	81	0	0
		insulation - U-value improved	94	31	17	28	94	76	-5	-5
Urban		insulation - U-value*	48	20	17	28	52	65	0	0
		insulation - U-value improved	41	15	17	28	42	60	-19	-8
	New	density - 60%	29	15	17	28	34	60	-15	0
		density - 100%*	38	15	17	28	40	60	0	0
		density - 140%	42	16	17	28	44	61	10	2
		density - 180%	45	16	17	28	46	61	15	2
		density - 220%	47	17	17	28	48	62	20	3
		density - 300%	49	17	17	28	50	62	25	4
		fabrication 1	29	11	17	28	30	56	-3	-1
		fabrication 2	30	11	17	28	31	56	0	0
		fabrication 3	27	10	17	28	28	55	-10	-2
		fabrication 4*	30	11	17	28	31	56	0	0
		fabrication 5	57	20	17	28	58	65	87	16
		fabrication 6	57	20	17	28	58	65	87	16
	Both	UHI - measurement*	35	14	17	28	37	59	0	0
		UHI - degree A	30	13	17	28	33	58	-11	-1
		UHI - degree B	26	12	17	28	29	57	-22	-3
		UHI - degree C	21	11	17	28	25	56	-32	-5
		UHI - degree D	18	10	17	28	22	55	-41	-6
		UHI - degree E	14	10	17	28	19	55	-49	-7

APPENDIX D

Code of VirVil Plugin v1.4

```
# Copyright Welsh School of Architecture 2011 #
# Adjusted by K. Y. Lin 2012 #
require 'sketchup.rb'
require 'win32ole'
Sketchup::require 'VirVil/progressbar.rb'
Sketchup.load('VirVil/htb2_functions')
Sketchup.load('VirVil/Areas_Total_V3')
Sketchup.load('VirVil/Attribute_Buildings')
Sketchup.load('VirVil/Explode')
Sketchup.load('VirVil/Final_Flip_V2')
Sketchup.load('VirVil/orient_faces')
Sketchup.load('VirVil/Properties_CMD')
Sketchup.load('VirVil/running htb2 V3')
Sketchup.load('VirVil/get_htb2_results')
Sketchup.load('VirVil/sky_view')
Sketchup.load('VirVil/zone_building')
Sketchup.load('VirVil/reflect_view')
@filenamecounter = 0
@totalmasknumber = 0
@shadingarr = []
Sketchup.send_action "showRubyPanel:"
plugins_menu = UI.menu("Plugins")
$virvillsubmenu = plugins_menu.add_submenu("VirVil KY")
# http://sketchupapi.blogspot.co.uk/2008/02/sharing-data-between-sketchup-ruby-and.html
$htb2_dialog = UI::WebDialog.new("HTB2 Attributes", true, "", 550, 500, 1030, 0, true)
# produce new file
def close_htb2_files()
@bldfile.close
@layfile.close
@solcfgfile.close
@heatcfgfile.close
@cfgfile.close
@topfile.close
@srvfile.close
@htrfile.close
#@lgtfile.close
@spwfile.close
#@occfile.close
@vntfile.close
```

```
@metfile.close
@dylfile.close
puts "Finished file number :" + @filenamecounter.to_s
end # close_htb2_files
#produce new file
def neednewfile()
@bldfile.puts "!MATERIALS FILE = '" + @stdmatfilename + "'"
@bldfile.puts "!MATERIALS USER FILE = '" + @usermatfilename + "'"
@bldfile.puts "!CONSTRUCTION FILE = '" + @constructionfilename + "'"
@bldfile.puts "!LAYOUT FILE = '" + File.basename(@layfile.path) + "'"
# close all the open files
close_htb2_files
filename = Sketchup.active_model.title + @filenamecounter.to_s
@bldfile = File.new("htb2file/" + filename.to_s + ".bld", "w") ##create a building file
@layfile = File.new("htb2file/" + filename.to_s + ".lay", "w") ##create a layout file
@topfile = File.new("htb2file/" + filename.to_s + ".top", "w") ##create a top file
@htrfile = File.new("htb2file/" + filename.to_s + ".htr", "w") ##create a heating file
@vntfile = File.new("htb2file/" + filename.to_s + ".vnt", "w") ##create a ventilation file
@spwfile = File.new("htb2file/" + filename.to_s + ".spw", "w") ##create a small power file
@metfile = File.new("htb2file/" + filename.to_s + ".met", "w") ##create a weather data file
@dylfile = File.new("htb2file/" + filename.to_s + ".dyl", "w") ##create a diary top file
@drydayfile_a = File.new("htb2file/" + filename.to_s + "dayA.dry", "w") ##create a diary
day file
@drydayfile_b = File.new("htb2file/" + filename.to_s + "dayB.dry", "w") ##create a diary
day file
@drydayfile_c = File.new("htb2file/" + filename.to_s + "dayC.dry", "w") ##create a diary day
file
@dryendfile_a = File.new("htb2file/" + filename.to_s + "endA.dry", "w") ##create a diary
weekend file
@dryendfile_b = File.new("htb2file/" + filename.to_s + "endB.dry", "w") ##create a diary
weekend file
@solcfgfile = File.new("output/" + filename.to_s + "_sol.cfg", "w") ##create a configuration
file
@heatcfgfile = File.new("output/" + filename.to_s + "_heat.cfg", "w") ##create a
configuration file
@cfgfile = File.new("output/" + filename.to_s + ".cfg", "w") ##create a configuration file
@srvfile = File.new("htb2file/" + filename.to_s + ".srv", "w") ##create a service file
@bldfile.puts "!PROJECTID" + " ='" + Sketchup.active_model.title + "'"
@bldfile.puts "!LOCATION = " + @latitude.to_s + " " + @longitude.to_s
@bldfile.puts "!TIME ZONE = " + @timezone.to_s
@filenamecounter += 1
end # neednewfile
#PRINT BUILDING FILE
def htb2printbld()
shadingmaskfaceslist = [ ]
shadingmaskfaceslistnames = [ ]
buildinglist = [ ]
elementnumber = 0
sol_elementcolumn = 3 # for the solar config file only want elements that have pv potential
this is for the column number
heat_elementcolumn = 3 # for the heat config file
limen = [1] # last internal mass element number
```

```
@fileindex = [] # an array to keep index of buildings files and how many building inside each
file
@bldfile.puts "!PROJECTID" + " ='" + Sketchup.active_model.title + "'"
@bldfile.puts "!LOCATION = " + @latitude.to_s + " " + @longitude.to_s
@bldfile.puts "!TIME ZONE = " + @timezone.to_s
buildingcounter = Sketchup.active_model.attribute_dictionaries['VIRVIL']['buildingcounter']
+ 1
for bld_id in 1...buildingcounter
    e = Sketchup.active_model.entities.find { |theone| (theone.typename == "Face")
&& ((theone.get_attribute "VIRVIL_BuildingID", "BldingID") == bld_id) &&
((theone.get_attribute "VIRVIL_BuildingID", "face_orientation") == "'floor'") }
    temp_face = e.get_attribute "VIRVIL_BuildingID", "faceID"
    temp_area = e.get_attribute "VIRVIL_BuildingID", "area"
    temp_orientation = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    temp_tilt = e.get_attribute "VIRVIL_BuildingID", "tilt"
    temp_height = e.get_attribute "VIRVIL_BuildingID", "BuildingHeight"
    temp_sketchup_bld_id = e.get_attribute "VIRVIL_BuildingID", "BldingID"
    temp_gr = e.get_attribute "VIRVIL_BuildingID", "glazing_ratio"
    temp_volume = e.get_attribute "VIRVIL_BuildingID", "volume"
    temp_build_type = e.get_attribute "VIRVIL_BuildingID", "type"
    temp_mass_ratio = e.get_attribute "VIRVIL_BuildingID", "mass_ratio"
    temp_floor_height = e.get_attribute "VIRVIL_BuildingID", "floor_height"
    if temp_orientation.to_s == "'floor'"
        @totalmasknumber += nofacesconnected (e)
# this cannot be larger than 255 as the htb2view can only allow 255 columns
# so this is config files 7 columns of simple buildings (this will have 255 / 7 columns * 4 shade
masks ) or one building with 145 masks
        if (@totalmasknumber >= 145)
            starttheshading (shadingmaskfaceslist,
shadingmaskfaceslistnames)
            htb2printhtr(buildinglist)
            htb2printcfg(buildinglist)
            htb2printvnt(buildinglist)
            htb2printspw(buildinglist)
            htb2printdyl
            htb2printdryday_a(buildinglist)
            htb2printdryday_b(buildinglist)
            htb2printdryday_c(buildinglist)
            htb2printdryend_a(buildinglist)
            htb2printdryend_b(buildinglist)
            htb2printsrv
            htb2printmet
            filename = Sketchup.active_model.title + (@filenamecounter -
1).to_s
            @topfile.puts "* top level run file for " +
Sketchup.active_model.title
            @topfile.puts "!RUNID " + Sketchup.active_model.title + " base
case"
            @topfile.puts "* configure model as standard..."
            @topfile.puts "!ENABLE STANDARD"
            @topfile.puts "!ENABLE VENTILATION"
            @topfile.puts "!DISABLE LIGHTING"
            @topfile.puts "!ENABLE SMALL POWER"
```

```
            @topfile.puts "!ENABLE HEATING"
            @topfile.puts "!DISABLE OCCUPANCY"
            @topfile.puts "!ENABLE REPORT ELEMENT"
            @topfile.puts "!ENABLE REPORT HEATING"
            @topfile.puts "*!ENABLE REPORT ALL"
            @topfile.puts ""
            @topfile.puts "* set up run parameters"
            @topfile.puts "!SET TIMESTEP = 20.0"
            @topfile.puts "!SET RUNLENGTH = 365,00"
            @topfile.puts "!SET FRAME=0.2"
            @topfile.puts "!SET GROUND TEMPERATURE = 18.0"
            @topfile.puts "* pick up proper start date and position met file"
            @topfile.puts "!SET DATE = 01/01/2007"
            @topfile.puts "!SET DAY = MONDAY"
            @topfile.puts "!SET START MET = 0   * i.e. skip 215  met days"
            @topfile.puts "* chose output files and data, output from start of run"
            @topfile.puts "!OUTPUT INFO = '..\\output\\" + filename.to_s + ".INF'"
            @topfile.puts "!ENABLE BLOCK OUTPUT"
            @topfile.puts ""
            @topfile.puts "*"
            @topfile.puts "!OUTPUT BLOCK FILE = '..\\output\\" + filename.to_s + ".BLK'"
            @topfile.puts "!SET AIR REFERENCE = 20.0"
            @topfile.puts ""
            @topfile.puts "* connect to further files"
            @topfile.puts "!DEFINE BUILDING FILE = '" + File.basename(@bldfile.path) + "'"
            @topfile.puts "!DEFINE SERVICES FILE = '" + File.basename(@srvfile.path) + "'"
            @topfile.puts "!DEFINE DIARY FILE = '" + File.basename(@dylfile.path) + "'"
            @topfile.puts "!DEFINE METEOR FILE = '" + File.basename(@metfile.path) + "'"
            neednewfile
            htb2printcfg_faces
            elementnumber = 0
            sol_elementcolumn = 3
            @totalmasknumber = 0
            @fileindex << bld_id - 1
            shadingmaskfaceslist.clear
            shadingmaskfaceslistnames.clear
            buildinglist.clear
            buildinglist << e
            @totalmasknumber += nofacesconnected (e)
        else
            buildinglist << e
        end #if
        toro = (@filenamecounter - 1).to_s
        e.set_attribute "VIRVIL_BuildingID", "fileID", toro
        toro2 = e.all_connected
        toro2.each do |tor|
```

```
                        if tor.is_a? Sketchup::Face
                                tor.set_attribute "VIRVIL_BuildingID", "fileID", toro
                        end
                end
                #puts @totalmasknumber
                temp_bld_id = calc_bld_id (temp_sketchup_bld_id)
                @bldfile.puts "!DEFINE SPACE" + " = 'Bld_" + temp_sketchup_bld_id.to_s
+ "'"
                @bldfile.puts " !VOLUME = " + temp_volume.to_s
                @bldfile.puts " $POSITION X = 0 Y = 0"
                @bldfile.puts " $ICON = 305"
                @bldfile.puts "!END"
                @audit_bldfile.puts      temp_sketchup_bld_id.to_s      +      ","      +
(@filenamecounter - 1).to_s + "," +temp_bld_id.to_s + "," + temp_volume.to_s + "," +
temp_height.to_s + "," + temp_build_type + "," + temp_mass_ratio.to_s + "," +
temp_floor_height.to_s + "," + calculate_building_floor_area(e).to_s
        #
                temp11 = heatoutput(e)
        #
case temp_build_type
                when "Residential"
                        con_extwall = 1
                        con_intwall = 2
                        con_roof = 3
                        con_ceil = 4
                        con_floor = 5
                        con_window = 6
                when "Industrial"
                        con_extwall = 7
                        con_intwall = 8
                        con_roof = 9
                        con_ceil = 10
                        con_floor = 11
                        con_window = 12
                when "Commercial"
                        con_extwall = 13
                        con_intwall = 14
                        con_roof = 15
                        con_ceil = 16
                        con_floor = 17
                        con_window = 18
                when "NULL"
                        con_extwall = 1
                        con_intwall = 2
                        con_roof = 3
                        con_ceil = 4
                        con_floor = 5
                        con_window = 6
                end # temp_build_type
        # ground floor
                @layfile.puts "!ELEMENT = 'Gnd floor " + temp_bld_id.to_s + "'"
                elementnumber += 1
                @layfile.puts " !CONSTRUCTION = "+  con_floor.to_s
```

```
        @layfile.puts " !AREA = " +  temp_area.to_s
        @layfile.puts " !ORIENTATION = 0"
        @layfile.puts " !TILT = " + temp_tilt.to_s
        @layfile.puts " !SPACE TO FIRST = " + temp_bld_id.to_s
        @layfile.puts " !SPACE TO LAST = 0"
        @layfile.puts "!END"
        @layfile.puts ""
        temp_ground_floor_area = temp_area;
        gnd_face_number = temp_face;
# print face details to audit file
        @audit_facefile.puts temp_face.to_s + "," + temp_sketchup_bld_id.to_s +
"," +(@filenamecounter - 1).to_s + "," + temp_bld_id.to_s + "," + temp_build_type.to_s + ","
+elementnumber.to_s + "," + con_floor.to_s + "," + temp_area.to_s + "," + "0" + "," +
temp_tilt.to_s+ ",0,0,0,0";
    # internal floor thermal mass
        @layfile.puts "!ELEMENT = 'int floor " + temp_bld_id.to_s + "'"
        elementnumber += 1
        int_floor_num = elementnumber
        @layfile.puts " !CONSTRUCTION = "+  con_ceil.to_s
        if (temp_floor_height.to_f != 0)
            temp_mass_area = calculate_building_floor_area(e) -
temp_ground_floor_area.to_f
        else
            temp_mass_area = 2
        end # if
        if (temp_mass_area.to_f <= 2)
            temp_mass_area = 2
        end # if
        @layfile.puts " !AREA = " +  (temp_mass_area).to_s
        @layfile.puts " !ORIENTATION = 0"
        @layfile.puts " !TILT = " + temp_tilt.to_s
        @layfile.puts " !SPACE TO FIRST = " +  temp_bld_id.to_s
        @layfile.puts " !SPACE TO LAST = " +  temp_bld_id.to_s
        @layfile.puts "!END"
        @layfile.puts ""
# print face details to audit file
        @audit_facefile.puts "int_floor," + temp_sketchup_bld_id.to_s + ","
+(@filenamecounter - 1).to_s + "," + temp_bld_id.to_s + "," + temp_build_type.to_s + ","
+elementnumber.to_s + "," + con_ceil.to_s + "," + temp_mass_area.to_s + "," + "0" + "," +
temp_tilt.to_s + ",0,0,0,0";
    # internal wall thermal mass
        @layfile.puts "!ELEMENT = 'int wall " + temp_bld_id.to_s + "'"
        elementnumber += 1
        @layfile.puts " !CONSTRUCTION = "+  con_intwall.to_s
        if (temp_mass_ratio.to_f!=0)
            temp_wall_mass_area = temp_volume.to_f *
temp_mass_ratio.to_f
        else
            temp_wall_mass_area = 2
        end # if
        if (temp_wall_mass_area.to_f <= 2)
            temp_wall_mass_area = 2
        end # if
```

```
        @layfile.puts " !AREA = " + temp_wall_mass_area.to_s
        @layfile.puts " !ORIENTATION = 0"
        @layfile.puts " !TILT = 0"
        @layfile.puts " !SPACE TO FIRST = " + temp_bld_id.to_s
        @layfile.puts " !SPACE TO LAST = " + temp_bld_id.to_s
        @layfile.puts "!END"
        @layfile.puts ""
# print face details to audit file
        @audit_facefile.puts "int_wall," + temp_sketchup_bld_id.to_s + ","
+(@filenamecounter - 1).to_s + "," + temp_bld_id.to_s + "," + temp_build_type.to_s + ","
+elementnumber.to_s + "," + con_intwall.to_s + "," + temp_wall_mass_area.to_s +
",0,0,0,0,0,0";
    # wall and window for each face
        list = e.all_connected
        list.each do |g|
            if g.is_a? Sketchup::Face
                temp_face = g.get_attribute "VIRVIL_BuildingID",
"faceID"

                temp_area = g.get_attribute "VIRVIL_BuildingID", "area"
                temp_orientation = g.get_attribute "VIRVIL_BuildingID",
"face_orientation"

                temp_tilt = g.get_attribute "VIRVIL_BuildingID", "tilt"
                temp5 = g.get_attribute "VIRVIL_BuildingID", "BldingID"
                temp_bld_id = calc_bld_id (temp5)
                temp_gr = g.get_attribute "VIRVIL_BuildingID",
"glazing_ratio"

                temp8 = g.get_attribute "VIRVIL_BuildingID", "volume"
                if temp_orientation.to_s == "'roof'"
                    # need to calculate the orientation as this has
been replaced

                    temp_orientation = azimuth_htb2(g.normal);
                    @layfile.puts "!ELEMENT = 'roof " +
temp_face.to_s + "'"

                    elementnumber += 1
                    @layfile.puts " !CONSTRUCTION = "+
con_roof.to_s

                    @layfile.puts " !AREA = " + temp_area.to_s
                    @layfile.puts " !ORIENTATION = " +
temp_orientation.to_s

                    @layfile.puts " !TILT = " + temp_tilt.to_s
                    @layfile.puts " !SPACE TO FIRST = 0"
                    @layfile.puts " !SPACE TO LAST = " +
temp_bld_id.to_s

                    @layfile.puts " !SHADING = 'face " +
temp_face.to_s + "'"

                    if @calc_reflections
                        @layfile.puts " !REFLECT MASK = 'face
RF" + temp_face.to_s + "'"

                    end #if @calc_reflections
                    @layfile.puts "!END"
                    @layfile.puts ""
                    shadingmaskfaceslist << g
                    shadingmaskfaceslistnames << temp_face.to_s
```

```
# print face details to audit file and solar cfg file
                                        @audit_facefile.puts temp_face.to_s + "," +
temp_sketchup_bld_id.to_s + "," + (@filenamecounter - 1).to_s + "," + temp_bld_id.to_s +
"," + temp_build_type.to_s + "," +elementnumber.to_s + "," + con_roof.to_s + "," +
temp_area.to_s + "," + temp_orientation.to_s + "," + temp_tilt.to_s+ ",0,0,0,0";
                                        @solcfgfile.puts " !COLUMN # " +
(sol_elementcolumn).to_s + "  VARIABLE # 51  INDEX #" + elementnumber.to_s + "  /FIRST
NAME 'face " + temp_face.to_s + "'"
                                        sol_elementcolumn += 1
                                        @heatcfgfile.puts " !COLUMN # " +
(heat_elementcolumn).to_s + "  VARIABLE # 46  INDEX #" + elementnumber.to_s + "  /FIRST
NAME 'face " + temp_face.to_s + "'"
                                        heat_elementcolumn += 1
                                elsif (temp_orientation.to_s == "'floor'")
                                                if (temp_face!=gnd_face_number)
# is the floor the first gnd floor which started the building, otherwise it's a new part of the
ground floor
                                                        @layfile.puts "!ELEMENT =
'Gnd floor " + temp_bld_id.to_s + " "+ temp_face.to_s + "'"
                                                        elementnumber += 1
                                                        @layfile.puts
" !CONSTRUCTION = "+  con_floor.to_s
                                                        @layfile.puts " !AREA = " +
temp_area.to_s
                                                        @layfile.puts " !ORIENTATION
= 0"
                                                        @layfile.puts " !TILT = " +
temp_tilt.to_s
                                                        @layfile.puts " !SPACE TO
FIRST = " + temp_bld_id.to_s
                                                        @layfile.puts " !SPACE TO LAST
= 0"
                                                        @layfile.puts "!END"
                                                        @layfile.puts ""
                                                        temp_ground_floor_area =
temp_area;
                                # print face details to audit file
                                                        @audit_facefile.puts
temp_face.to_s + "," + temp_sketchup_bld_id.to_s + "," +(@filenamecounter - 1).to_s + ","
+ temp_bld_id.to_s + "," + temp_build_type.to_s + "," +elementnumber.to_s + "," +
con_floor.to_s + "," + temp_area.to_s + "," + "0" + "," + temp_tilt.to_s+ ",0,0,0,0";
                                                        @heatcfgfile.puts " !COLUMN #
" + (heat_elementcolumn).to_s + "  VARIABLE # 46  INDEX #" + elementnumber.to_s + "
/FIRST  NAME 'face " + temp_face.to_s + "'"
                                                        heat_elementcolumn += 1
                                                end # if (temp_face!=gnd_face_number)
                                elsif temp_orientation.to_s == "'exposed floor'"
                                                @layfile.puts "!ELEMENT = 'Exposed
floor " + temp_face.to_s + "'"
                                                elementnumber += 1
                                                @layfile.puts " !CONSTRUCTION = "+
con_extwall.to_s
```

```
                        @layfile.puts " !AREA = " +
temp_area.to_s
                        @layfile.puts " !ORIENTATION = 0"
                        @layfile.puts " !TILT = " + temp_tilt.to_s
                        @layfile.puts " !SPACE TO FIRST = 0"
                        @layfile.puts " !SPACE TO LAST = " +
temp_bld_id.to_s
                        @layfile.puts "!END"
                        @layfile.puts ""
                        temp_ground_floor_area = temp_area;
                # print face details to audit file
                        @audit_facefile.puts temp_face.to_s +
"," + temp_sketchup_bld_id.to_s + "," +(@filenamecounter - 1).to_s + "," +
temp_bld_id.to_s + "," + temp_build_type.to_s + "," +elementnumber.to_s + "," +
con_floor.to_s + "," + temp_area.to_s + "," + "0" + "," + temp_tilt.to_s+ ",0,0,0,0";
                        @heatcfgfile.puts " !COLUMN # " +
(heat_elementcolumn).to_s + "  VARIABLE # 46  INDEX #" + elementnumber.to_s + "  /FIRST
NAME 'face " + temp_face.to_s + "'"
                        heat_elementcolumn += 1
                else
                    if (temp_gr.to_i!=100)
                        @layfile.puts "!ELEMENT = '" +
degree_to_orientation(temp_orientation,false)+ " facade " + temp_face.to_s + "'"
                        elementnumber += 1
                        @layfile.puts " !CONSTRUCTION = "+
con_extwall.to_s
                        @layfile.puts " !AREA = " +
(temp_area.to_f - (temp_area.to_f * (temp_gr.to_f / 100.0))).to_s
                        @layfile.puts " !ORIENTATION = " +
temp_orientation
                        @layfile.puts " !TILT = " + temp_tilt.to_s
                        @layfile.puts " !SPACE TO FIRST = 0"
                        @layfile.puts " !SPACE TO LAST = " +
temp_bld_id.to_s
                        @layfile.puts " !SHADING = 'face " +
temp_face.to_s + "'"
                        if @calc_reflections
                            @layfile.puts " !REFLECT MASK
= 'face RF" + temp_face.to_s + "'"
                        end #if @calc_reflections
                        @layfile.puts "!END"
                        @layfile.puts ""
                        @heatcfgfile.puts " !COLUMN # " +
(heat_elementcolumn).to_s + "  VARIABLE # 46  INDEX #" + elementnumber.to_s + "  /FIRST
NAME 'face " + temp_face.to_s + "'"
                        heat_elementcolumn += 1
                    end # (temp_gr.to_i==100)
            # if the glazing ratio is not 0 create a window
                    if (temp_gr.to_i>0)
                        @layfile.puts "!ELEMENT = '" +
degree_to_orientation(temp_orientation,false)+ " win " + temp_face.to_s + "'"
                        elementnumber += 1
```

```
                        @layfile.puts " !CONSTRUCTION = "+
con_window.to_s
                        @layfile.puts " !AREA = " +
(temp_area.to_f * (temp_gr.to_f / 100.0)).to_s
                        @layfile.puts " !ORIENTATION = " +
temp_orientation
                        @layfile.puts " !TILT = " + temp_tilt.to_s
                        @layfile.puts " !SPACE TO FIRST = 0"
                        @layfile.puts " !SPACE TO LAST = " +
temp_bld_id.to_s
                        @layfile.puts " !SHADING = 'face " +
temp_face.to_s + "'"
                        if @calc_reflections
                            @layfile.puts " !REFLECT MASK
= 'face RF" + temp_face.to_s + "'"
                        end #if @calc_reflections
                        @layfile.puts " !WINDOW TYPE =
'DBL6'"
                        @layfile.puts " !PATCH TO #" +
(int_floor_num-1).to_s + " FIRST = " + sprintf('%.2f',
(temp_ground_floor_area.to_f/(temp_mass_area.to_f + temp_ground_floor_area.to_f)))
                        @layfile.puts " !PATCH TO #" +
(int_floor_num).to_s + " FIRST = " + sprintf('%.2f',(1 -
temp_ground_floor_area.to_f/(temp_mass_area.to_f + temp_ground_floor_area.to_f)))
                        @layfile.puts "!END"
                        @layfile.puts ""
                        @heatcfgfile.puts " !COLUMN # " +
(heat_elementcolumn).to_s + " VARIABLE # 46 INDEX #" + elementnumber.to_s + " /FIRST
NAME 'face win" + temp_face.to_s + "'"
                        heat_elementcolumn += 1
                    end # if
# print face details to audit file and solar cfg file
                    @audit_facefile.puts temp_face.to_s + "," +
temp_sketchup_bld_id.to_s + "," + (@filenamecounter - 1).to_s + "," + temp_bld_id.to_s +
"," + temp_build_type.to_s + "," +elementnumber.to_s + "," + con_extwall.to_s + "," +
temp_area.to_s + "," + temp_orientation.to_s + "," + temp_tilt.to_s + "," +temp_gr.to_s+
"," + (temp_area.to_f * (temp_gr.to_f / 100.0)).to_s + "," + (temp_area.to_f -
(temp_area.to_f * (temp_gr.to_f / 100.0))).to_s + "," + con_window.to_s;
                    @solcfgfile.puts " !COLUMN # " +
(sol_elementcolumn).to_s + " VARIABLE # 51 INDEX #" + elementnumber.to_s + " /FIRST
NAME 'face " + temp_face.to_s + "'"
                    sol_elementcolumn += 1
                    shadingmaskfaceslist << g
                    shadingmaskfaceslistnames << temp_face.to_s
                end # if roof or floor or else
            end # if g is a face
        end # each g for the list of faces all connected
    else
        next
    end # if floor
    bld_id += 1
end # each e
@bldfile.puts "!MATERIALS FILE = '" + @stdmatfilename + "'"
```

```
@bldfile.puts "!MATERIALS USER FILE = '" + @usermatfilename + "'"
@bldfile.puts "!CONSTRUCTION FILE = '" + @constructionfilename + "'"
@bldfile.puts "!LAYOUT FILE = '" + File.basename(@layfile.path) + "'"
starttheshading (shadingmaskfaceslist, shadingmaskfaceslistnames)
htb2printhtr(buildinglist)
htb2printcfg(buildinglist)
htb2printvnt(buildinglist)
htb2printspw(buildinglist)
htb2printdyl
htb2printdryday_a(buildinglist)
htb2printdryday_b(buildinglist)
htb2printdryday_c(buildinglist)
htb2printdryend_a(buildinglist)
htb2printdryend_b(buildinglist)
htb2printsrv
htb2printmet
filename = Sketchup.active_model.title + (@filenamecounter - 1).to_s
@topfile.puts "* top level run file for " + Sketchup.active_model.title
@topfile.puts "!RUNID  " + Sketchup.active_model.title + " base case"
@topfile.puts "* configure model as standard..."
@topfile.puts "!ENABLE STANDARD"
@topfile.puts "!ENABLE VENTILATION"
@topfile.puts "!DISABLE LIGHTING"
@topfile.puts "!ENABLE SMALL POWER"
@topfile.puts "!ENABLE HEATING"
@topfile.puts "!DISABLE OCCUPANCY"
@topfile.puts "!ENABLE REPORT ELEMENT"
@topfile.puts "!ENABLE REPORT HEATING"
@topfile.puts "*!ENABLE REPORT ALL"
@topfile.puts ""
@topfile.puts "* set up run parameters"
@topfile.puts "!SET TIMESTEP = 20.0"
@topfile.puts "!SET RUNLENGTH = 365,00"
@topfile.puts "!SET FRAME=0.2"
@topfile.puts "!SET GROUND TEMPERATURE = 18.0"
@topfile.puts "* pick up proper start date and position met file"
@topfile.puts "!SET DATE = 01/01/2007"
@topfile.puts "!SET DAY = MONDAY"
@topfile.puts "!SET START MET = 0   * i.e. skip 215  met days"
@topfile.puts "* chose output files and data, output from start of run"
@topfile.puts "!OUTPUT INFO = '..\\output\\" + filename.to_s + ".INF'"
@topfile.puts "!ENABLE BLOCK OUTPUT"
@topfile.puts ""
@topfile.puts "*"
@topfile.puts "!OUTPUT BLOCK FILE = '..\\output\\" + filename.to_s + ".BLK'"
@topfile.puts "!SET AIR REFERENCE = 20.0"
@topfile.puts ""
@topfile.puts "* connect to further files"
@topfile.puts "!DEFINE BUILDING FILE = '" + File.basename(@bldfile.path) + "'"
@topfile.puts "!DEFINE SERVICES FILE = '" + File.basename(@srvfile.path) + "'"
@topfile.puts "!DEFINE DIARY FILE = '" + File.basename(@dylfile.path) + "'"
@topfile.puts "!DEFINE METEOR FILE = '" + File.basename(@metfile.path) + "'"
elementnumber = 0
```

```
@totalmasknumber = 0
@fileindex << bld_id - 1
shadingmaskfaceslist.clear
shadingmaskfaceslistnames.clear
buildinglist.clear
end # htb2printall function
# PRINT CONFIGURATION FILE
def htb2printcfg(buildinglist)
columncounter  = 3
requirements = [ 13, 71, 72, 73, 74, 75, 76 ]
col_title = [ " atemp", " heat", " cool", " incid", " sol", " fab", " vent" ]
@cfgfile.puts " !TITLE = ''"
@cfgfile.puts " !PAGE TEXT EXPORT"
@cfgfile.puts " !CSV UK"
@cfgfile.puts " !SET START AFTER = 0"
@cfgfile.puts " !SET STOP AFTER = 0"
buildinglist.each do |e|
        temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
        if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
                temp = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
                sketchup_bld_temp = e.get_attribute "VIRVIL_BuildingID", "BldingID"
                col_title_inc = 0
                for arequirement in requirements
                        @cfgfile.puts " !COLUMN # " + columncounter.to_s + "  VARIABLE
# " + arequirement.to_s + "   INDEX #   " + temp.to_s + "   NAME 'BLD " +
sketchup_bld_temp.to_s + col_title[col_title_inc]+"'"
                        columncounter +=1
                        col_title_inc +=1
                end # for requirements
        end # if face is floor
end # each e
@cfgfile.puts "* graph information"
@cfgfile.puts "* filter information"
@cfgfile.puts " !ACCUMULATE = MONTHLY"
@cfgfile.puts " !SHOW ENERGY"
end # htb2printcfg function
# PRINT CONFIGURATION FILE
def htb2printcfg_faces
@solcfgfile.puts " !TITLE = ''"
@solcfgfile.puts " !PAGE TEXT EXPORT"
@solcfgfile.puts " !CSV UK"
@solcfgfile.puts " !SET START AFTER = 0"
@solcfgfile.puts " !SET STOP AFTER = 0"
@solcfgfile.puts " !ACCUMULATE = MONTHLY"
@solcfgfile.puts " !SHOW ENERGY"
@heatcfgfile.puts " !TITLE = ''"
@heatcfgfile.puts " !PAGE TEXT EXPORT"
@heatcfgfile.puts " !CSV UK"
@heatcfgfile.puts " !SET START AFTER = 0"
@heatcfgfile.puts " !SET STOP AFTER = 0"
@heatcfgfile.puts " !ACCUMULATE = MONTHLY"
@heatcfgfile.puts " !SHOW ENERGY"
end # htb2printcfg_faces function
```

```
# PRINT SERVICE FILE
def htb2printsrv()
@srvfile.puts "* services file for bre " + Sketchup.active_model.title
@srvfile.puts "!SERVICEID full systems"
@srvfile.puts ""
@srvfile.puts "!HEATING FILE = '" + File.basename(@htrfile.path) + "'"
#@srvfile.puts "!LIGHTING FILE = '" + File.basename(@lgtfile.path) + "'"
@srvfile.puts "!SMALL POWER FILE = '" + File.basename(@spwfile.path) + "'"
#@srvfile.puts "!OCCUPANCY FILE = '" + File.basename(@occfile.path) + "'"
@srvfile.puts "!VENTILATION FILE = '" + File.basename(@vntfile.path) + "'"
end # htb2printall function
# PRINT HEATING FILE
def htb2printhtr(buildinglist)
@htrfile.puts "*  ideal single space heating system, fully convective,"
@htrfile.puts "*     heat to 18 oC, cool to 26 oC   0  til 24"
buildinglist.each do |e|
            temp_oreintation = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
            if (e.is_a? Sketchup::Face) && (temp_oreintation == "'floor'")
                      temp_bld_id = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
                       temp_type = e.get_attribute "VIRVIL_BuildingID", "type"
                       case temp_type
                       when "Residential"
                                   @htrfile.puts "!HEATSYS 'RESI'"
                                   @htrfile.puts " !STAT TYPE IDEAL
                                   @htrfile.puts ""
                                   @htrfile.puts "   !POWER OUTPUT = -1
                                   @htrfile.puts "   !CONVECTIVE CONNECTIONS"
                                   @htrfile.puts "      _#" + temp_bld_id.to_s + " = 1.
                                   @htrfile.puts "     }"
                                   @htrfile.puts ""
                                   @htrfile.puts "   !SETPOINT HEAT = 18.0             * start heating"
                                   @htrfile.puts "   !SETPOINT COOL = 26.0             * start cooling"
                                   @htrfile.puts "   !STAT AIR CONNECTIONS"
                                   @htrfile.puts "       _#" + temp_bld_id.to_s + " = 1.0                     *
stat monitoring space 4"
                                   @htrfile.puts "     }"
                                   @htrfile.puts "!CLOCK START TIME #1 = 00:00:00 |MTWTF--
                                   @htrfile.puts "!CLOCK START TIME #1 = 00:00:00 |-----ss
                                   @htrfile.puts "!CLOCK STOP TIME #1  = 08:00:00 |MTWTF--"
                                   @htrfile.puts "!CLOCK STOP TIME #1  = 24:00:00 |-----ss"
                                   @htrfile.puts "!CLOCK START TIME #2 = 18:00:00 |MTWTF--
                                   @htrfile.puts "!CLOCK STOP TIME #2  = 24:00:00 |MTWTF--"
                                   @htrfile.puts "!END"
                       when "Industrial"
                                   @htrfile.puts "!HEATSYS 'FACTORY'"
                                   @htrfile.puts " !STAT TYPE IDEAL                    * force to maintain
air temp."
                                   @htrfile.puts ""
                                   @htrfile.puts "    !POWER  OUTPUT  =  -1                     *  in  kw/-1  is
unlimited"
                                   @htrfile.puts "   !CONVECTIVE CONNECTIONS"
                                   @htrfile.puts "       _#" + temp_bld_id.to_s + " = 1.0                     *
convective to space 1"
```

```
                        @htrfile.puts "    }"
                        @htrfile.puts ""
                        @htrfile.puts "  !SETPOINT HEAT = 18.0          * start heating"
                        @htrfile.puts "  !SETPOINT COOL = 23.0          * start cooling"
                        @htrfile.puts "  !STAT AIR CONNECTIONS"
                        @htrfile.puts "     _#" + temp_bld_id.to_s + " = 1.0                  *
stat monitoring space 1"
                        @htrfile.puts "    }"
                        @htrfile.puts "  !CLOCK START TIME #1 = 08:00:00 |MTWTFSS
                        @htrfile.puts "  !CLOCK STOP TIME #1  = 20:00:00 |MTWTFSS"
                        @htrfile.puts "!END"
                when "Commercial"
                        @htrfile.puts "!HEATSYS 'COMMER'"
                        @htrfile.puts " !STAT TYPE IDEAL                  * force to maintain
air temp."
                        @htrfile.puts ""
                        @htrfile.puts "   !POWER  OUTPUT  =  -1                * in kw/-1 is
unlimited"
                        @htrfile.puts "  !CONVECTIVE CONNECTIONS"
                        @htrfile.puts "     _#" + temp_bld_id.to_s + " = 1.0                  *
convective to space 1"
                        @htrfile.puts "    }"
                        @htrfile.puts ""
                        @htrfile.puts "  !SETPOINT HEAT = 18.0          * start heating"
                        @htrfile.puts "  !SETPOINT COOL = 23.0          * start cooling"
                        @htrfile.puts "  !STAT AIR CONNECTIONS"
                        @htrfile.puts "     _#" + temp_bld_id.to_s + " = 1.0                  *
stat monitoring space 1"
                        @htrfile.puts "    }"
                        @htrfile.puts "  !CLOCK START TIME #1 = 08:00:00 |MTWTFSS
                        @htrfile.puts "  !CLOCK STOP TIME #1  = 20:00:00 |MTWTFSS"
                        @htrfile.puts "!END"
                when "NULL"
                        @htrfile.puts "!HEATSYS 'RESI'"
                        @htrfile.puts " !STAT TYPE IDEAL                  * force to maintain
air temp."
                        @htrfile.puts ""
                        @htrfile.puts "   !POWER  OUTPUT  =  -1                * in kw/-1 is
unlimited"
                        @htrfile.puts "  !CONVECTIVE CONNECTIONS"
                        @htrfile.puts "     _#" + temp_bld_id.to_s + " = 1.0                  *
convective to space 4"
                        @htrfile.puts "    }"
                        @htrfile.puts ""
                        @htrfile.puts "  !SETPOINT HEAT = 18.0          * start heating"
                        @htrfile.puts "  !SETPOINT COOL = 26.0          * start cooling"
                        @htrfile.puts "  !STAT AIR CONNECTIONS"
                        @htrfile.puts "     _#" + temp_bld_id.to_s + " = 1.0                  *
stat monitoring space 4"
                        @htrfile.puts "    }"

                        @htrfile.puts "  !CLOCK START TIME #1 = 00:00:00 |MTWTFSS
                        @htrfile.puts "  !CLOCK STOP TIME #1  = 24:00:00 |MTWTFSS"
```

```
            @htrfile.puts "!END"
        end #case
    end # if e is a face
end # each e
end # htb2printall function
#
# PRINT LIGHTING FILE
def htb2printlgt()
@lgtfile.puts "Lighting File"
end # htb2printall function
#
# PRINT VENTILATION FILE
def htb2printvnt(buildinglist)
@vntfile.puts "1                    * simple acr ventilation."
@vntfile.puts "*********"
buildinglist.each do |e|
    temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
        temp = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        case temp3
        when "Residential"
            @vntfile.puts  temp.to_s + "                              * space " +
temp.to_s
            @vntfile.puts "0.5  , 1.0  , 1.0            * just use infiltration rate"
            @vntfile.puts "26.0                          *   vent stat setting not used
but needed"
            @vntfile.puts "---------"
        when "Industrial"
            @vntfile.puts  temp.to_s + "                              * space " +
temp.to_s
            @vntfile.puts "0.5  , 2.0  , 2.0            * just use infiltration rate"
            @vntfile.puts "26.0                          *   vent stat setting not used
but needed"
            @vntfile.puts "---------"
        when "Commercial"
            @vntfile.puts  temp.to_s + "                              * space " +
temp.to_s
            @vntfile.puts "0.5  , 2.0  , 2.0            * just use infiltration rate"
            @vntfile.puts "26.0                          *   vent stat setting not used
but needed"
            @vntfile.puts "---------"
        when "NULL"
            @vntfile.puts  temp.to_s + "                              * space " +
temp.to_s
            @vntfile.puts "0.5  , 1.0  , 1.0            * just use infiltration rate"
            @vntfile.puts "26.0                          *   vent stat setting not used
but needed"
            @vntfile.puts "---------"
        end #case
    end # if e is a face
end # each e
@vntfile.puts "0"
```

```
end # htb2printall function
#
# PRINT Occupancy FILE
def htb2printocc()
@occfile.puts "Occupancy File"
end # htb2printall function
#
# PRINT Small Power FILE
def htb2printspw(buildinglist)
buildinglist.each do |e|
        temp_orient = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
        if (e.is_a? Sketchup::Face) && (temp_orient == "'floor'")
                temp_bld_id = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
                 temp_type = e.get_attribute "VIRVIL_BuildingID", "type"
                 temp_floor_area = calculate_building_floor_area(e);
                 case temp_type
                 when "Residential"
                         @spwfile.puts "!SMALL POWER 'including lighting occupancy and people'"
                         @spwfile.puts "      !HEAT  OUTPUT  =  "  +  (temp_floor_area  * 13.32).to_s
                         @spwfile.puts ""
                         @spwfile.puts "   !CONVECTIVE CONNECTIONS"
                         @spwfile.puts "     _#" + temp_bld_id.to_s + " = 1.0             * convective to space3"
                         @spwfile.puts "     }"
                         @spwfile.puts "!CLOCK START TIME #1 = 00:00:00 |MTWTF--
                         @spwfile.puts "!CLOCK START TIME #1 = 00:00:00 |-----ss
                         @spwfile.puts "!CLOCK STOP TIME #1  = 08:00:00 |MTWTF--"
                         @spwfile.puts "!CLOCK STOP TIME #1  = 24:00:00 |-----ss"
                         @spwfile.puts "!CLOCK START TIME #2 = 18:00:00 |MTWTF--
                         @spwfile.puts "!CLOCK STOP TIME #2  = 24:00:00 |MTWTF--"
                         @spwfile.puts "!END"
                 when "Industrial"
                         @spwfile.puts "!SMALL POWER 'including lighting occupancy and people'"
                         @spwfile.puts "      !HEAT  OUTPUT  =  "  +  (temp_floor_area  * 35).to_s
                         @spwfile.puts ""
                         @spwfile.puts "   !CONVECTIVE CONNECTIONS"
                         @spwfile.puts "     _#" + temp_bld_id.to_s + " = 1.0             * convective to space1"
                         @spwfile.puts "     }"
                         @spwfile.puts "!CLOCK START TIME #1=08:00:00 |MTWTFSS"
                         @spwfile.puts "!CLOCK STOP TIME #1=20:00:00  |MTWTFSS"
                         @spwfile.puts "!END"
                 when "Commercial"
                         @spwfile.puts "!SMALL POWER 'including lighting occupancy and people'"
                         @spwfile.puts "      !HEAT  OUTPUT  =  "  +  (temp_floor_area  * 47.25).to_s
                         @spwfile.puts ""
                         @spwfile.puts "   !CONVECTIVE CONNECTIONS"
```

```
                    @spwfile.puts "      _#" + temp_bld_id.to_s + " = 1.0                *
convective to space6"
                    @spwfile.puts "     }"
                    @spwfile.puts "!CLOCK START TIME #1=08:00:00 |MTWTFSS"
                    @spwfile.puts "!CLOCK STOP TIME #1=20:00:00  |MTWTFSS"
                    @spwfile.puts "!END"
            when "NULL"
                    @spwfile.puts "!SMALL POWER 'including lighting occupancy and
people'"
                    @spwfile.puts "      !HEAT OUTPUT = " + (temp_floor_area *
13.32).to_s
                    @spwfile.puts ""
                    @spwfile.puts "   !CONVECTIVE CONNECTIONS"
                    @spwfile.puts "      _#" + temp_bld_id.to_s + " = 1.0                *
convective to space3"
                    @spwfile.puts "     }"
                    @spwfile.puts "!CLOCK START TIME #1 = 00:00:00 |MTWTF--
                    @spwfile.puts "!CLOCK START TIME #1 = 00:00:00 |-----ss
                    @spwfile.puts "!CLOCK STOP TIME #1  = 08:00:00 |MTWTF--"
                    @spwfile.puts "!CLOCK STOP TIME #1  = 24:00:00 |-----ss"
                    @spwfile.puts "!CLOCK START TIME #2 = 18:00:00 |MTWTF--
                    @spwfile.puts "!CLOCK STOP TIME #2  = 24:00:00 |MTWTF--"
                    @spwfile.puts "!END"
            end #case
      end # if e is a face
end # each e
end # htb2printall function
#
# PRINT DIARY MAIN FILE
def htb2printdyl()
@dylfile.puts       File.basename(@drydayfile_a.path)
```

(Skip the following 364 lines for a whole year diary)

```
end # htb2printdyl function
#
# PRINT Diary Day FILE A
def htb2printdryday_a(buildinglist)
reslist= []
comlist =[]
indlist= []
buildinglist.each do |e|
      temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
      if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
            temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
            case temp3
            when "Residential"
                    reslist << e
            when "Commercial"
                    comlist << e
            when "Industrial"
                    indlist << e
            when "NULL"
                    reslist << e
            end # case
```

```
        end #if
end # each e
buildinglist.each do |e|
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        temp = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
        case temp3
        when "Residential"
                @drydayfile_a.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
        when "Commercial"
                @drydayfile_a.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
        when "Industrial"
                @drydayfile_a.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
        when "NULL"
                @drydayfile_a.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
        end # select
end # each e
for i in 0..3
        if i==0
                reslist.each do |a|
                        temp    =    calc_bld_id(a.get_attribute    "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_a.puts "00:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each a
        elsif i==1
                reslist.each do |a|
                        temp    =    calc_bld_id(a.get_attribute    "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_a.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
                end # each a
                comlist.each do |b|
                        temp    =    calc_bld_id(b.get_attribute    "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_a.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each b
                indlist.each do |c|
                        temp    =    calc_bld_id(c.get_attribute    "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_a.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each c
        elsif i==2
                reslist.each do |a|
                        temp    =    calc_bld_id(a.get_attribute    "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_a.puts "18:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
```

```
        end # each a
        comlist.each do |b|
            temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @drydayfile_a.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each b
        indlist.each do |c|
            temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @drydayfile_a.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each c
    elsif i==3
        reslist.each do |a|
            temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @drydayfile_a.puts "24:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each a
    end # if
end # for
@drydayfile_a.close
end # htb2printdryday function
#
# PRINT Diary Day FILE B
def htb2printdryday_b(buildinglist)
reslist= []
comlist =[]
indlist= []
buildinglist.each do |e|
    temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        case temp3
        when "Residential"
            reslist << e
        when "Commercial"
            comlist << e
        when "Industrial"
            indlist << e
        when "NULL"
            reslist << e
        end # case
    end #if
end # each e
buildinglist.each do |e|
    temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
    temp = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
    case temp3
    when "Residential"
        @drydayfile_b.puts "00:00:00   !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
```

```
        when "Commercial"
                @drydayfile_b.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
        when "Industrial"
                @drydayfile_b.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
        when "NULL"
                @drydayfile_b.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
        end # select
end # each e
for i in 0..3
        if i==0
                reslist.each do |a|
                        temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "00:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each a
        elsif i==1
                reslist.each do |a|
                        temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
                end # each a
                comlist.each do |b|
                        temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each b
                indlist.each do |c|
                        temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each c
        elsif i==2
                reslist.each do |a|
                        temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "18:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
                end # each a
                comlist.each do |b|
                        temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
                        @drydayfile_b.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
                end # each b
                indlist.each do |c|
```

```
            temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @drydayfile_b.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each c
    elsif i==3
        reslist.each do |a|
            temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @drydayfile_b.puts "24:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each a
    end # if
end # for
@drydayfile_b.close
end # htb2printdryday function
#
# PRINT Diary Day FILE C
def htb2printdryday_c(buildinglist)
reslist= []
comlist =[]
indlist= []
buildinglist.each do |e|
    temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        case temp3
        when "Residential"
            reslist << e
        when "Commercial"
            comlist << e
        when "Industrial"
            indlist << e
        when "NULL"
            reslist << e
        end # case
    end #if
end # each e
buildinglist.each do |e|
    temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
    temp = calc_bld_id(e.get_attribute "VIRVIL_BuildingID", "BldingID")
    case temp3
    when "Residential"
        @drydayfile_c.puts "00:00:00   !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
    when "Commercial"
        @drydayfile_c.puts "00:00:00   !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
    when "Industrial"
        @drydayfile_c.puts "00:00:00   !SET VENT RATE#" + temp.to_s + " =
0.5,2.0,2.0"
    when "NULL"
```

```
        @drydayfile_c.puts "00:00:00    !SET VENT RATE#" + temp.to_s + " =
0.5,1.0,1.0"
    end # select
end # each e
    for i in 0..3
        if i==0
            reslist.each do |a|
                temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "00:00:00    !SET VENT STATUS#" +
temp.to_s + " = ON"
            end # each a
        elsif i==1
            reslist.each do |a|
                temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "08:00:00    !SET VENT STATUS#" +
temp.to_s + " = OFF"
            end # each a
            comlist.each do |b|
                temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "08:00:00    !SET VENT STATUS#" +
temp.to_s + " = ON"
            end # each b
            indlist.each do |c|
                temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "08:00:00    !SET VENT STATUS#" +
temp.to_s + " = ON"
            end # each c
        elsif i==2
            reslist.each do |a|
                temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "18:00:00    !SET VENT STATUS#" +
temp.to_s + " = ON"
            end # each a
            comlist.each do |b|
                temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "20:00:00    !SET VENT STATUS#" +
temp.to_s + " = OFF"
            end # each b
            indlist.each do |c|
                temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "20:00:00    !SET VENT STATUS#" +
temp.to_s + " = OFF"
            end # each c
        elsif i==3
            reslist.each do |a|
```

```
                temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
                @drydayfile_c.puts "24:00:00    !SET VENT STATUS#" +
temp.to_s + " = OFF"
            end # each a
    end # if
end # for
@drydayfile_c.close
end # htb2printdryday function
#
# PRINT Diary End FILE A
def htb2printdryend_a(buildinglist)
reslist= []
comlist =[]
indlist= []
buildinglist.each do |e|
    temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        case temp3
        when "Residential"
            reslist << e
        when "Commercial"
            comlist << e
        when "Industrial"
            indlist << e
        when "NULL"
            reslist << e
        end # case
    end #if
end # each e
for i in 0..1
    if i==0
        reslist.each do |a|
            temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "00:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each a
        comlist.each do |b|
            temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each b
        indlist.each do |c|
            temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each c
    elsif i==1
        reslist.each do |a|
```

```
            temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "24:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each a
        comlist.each do |b|
            temp = calc_bld_id(b.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each b
        indlist.each do |c|
            temp = calc_bld_id(c.get_attribute "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_a.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each c
    end # if
end # for
@dryendfile_a.close
end # htb2printdryend function
#
# PRINT Diary End FILE B
def htb2printdryend_b(buildinglist)
reslist= []
comlist =[]
indlist= []
buildinglist.each do |e|
    temp2 = e.get_attribute "VIRVIL_BuildingID", "face_orientation"
    if (e.is_a? Sketchup::Face) && (temp2 == "'floor'")
        temp3 = e.get_attribute "VIRVIL_BuildingID", "type"
        case temp3
        when "Residential"
            reslist << e
        when "Commercial"
            comlist << e
        when "Industrial"
            indlist << e
        when "NULL"
            reslist << e
        end # case
    end #if
end # each e
reslist.each do |a|
    temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID", "BldingID")
    @dryendfile_b.puts "00:00:00   !SET VENT RATE#" + temp.to_s + " = 0.5,1.0,1.0"
end # each a
for i in 0..1
    if i==0
        reslist.each do |a|
            temp = calc_bld_id(a.get_attribute "VIRVIL_BuildingID",
"BldingID")
```

```
            @dryendfile_b.puts "00:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each a
        comlist.each do |b|
            temp     =     calc_bld_id(b.get_attribute     "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_b.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each b
        indlist.each do |c|
            temp     =     calc_bld_id(c.get_attribute     "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_b.puts "08:00:00   !SET VENT STATUS#" + temp.to_s
+ " = ON"
        end # each c
    elsif i==1
        reslist.each do |a|
            temp     =     calc_bld_id(a.get_attribute     "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_b.puts "24:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each a
        comlist.each do |b|
            temp     =     calc_bld_id(b.get_attribute     "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_b.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each b
        indlist.each do |c|
            temp     =     calc_bld_id(c.get_attribute     "VIRVIL_BuildingID",
"BldingID")
            @dryendfile_b.puts "20:00:00   !SET VENT STATUS#" + temp.to_s
+ " = OFF"
        end # each c
    end # if
end # for
@dryendfile_b.close
end # htb2printdryend function
#
# PRINT WEATHER DATA FILE
def htb2printmet()
if (Sketchup.active_model.attribute_dictionaries['VIRVIL']['weatherfilename'])
    weathertemp                                                              =
Sketchup.active_model.attribute_dictionaries['VIRVIL']['weatherfilename']
else
    weathertemp = "cardiff_try"
    virivl_attrib = Sketchup.active_model.attribute_dictionaries
    virivl_attrib['VIRVIL']['weatherfilename'] = weathertemp
end # weathertemp
if (@filenamecounter==1 )
    puts "Weather file " + weathertemp
end if
```

```
inmatfilename = Sketchup.find_support_file("Plugins")+ "/VirVil/htb2files/" + weathertemp
+ ".met"
in_lines = IO.readlines(inmatfilename)
in_lines.each do |e|
        @metfile.puts e
end #in_lines
end # htb2printall function
#
# PRINT CONSTRUCTION FILE
def htb2printcon()
if (Sketchup.active_model.attribute_dictionaries['VIRVIL']['confilename'])
        contemp = Sketchup.active_model.attribute_dictionaries['VIRVIL']['confilename']
else
        contemp = "standard"
        virivl_attrib = Sketchup.active_model.attribute_dictionaries
        virivl_attrib['VIRVIL']['confilename'] = contemp
end # confilename
inconfilename = Sketchup.find_support_file("Plugins")+ "/VirVil/htb2files/" + contemp +
".con"
# output the selections
puts "Construction file "+ contemp
in_lines = IO.readlines(inconfilename)
line_count = 1
@confile.puts "!MATERIALS FILE = '" + @stdmatfilename + "'"
@confile.puts "!MATERIALS USER FILE = '" + @usermatfilename + "'"
in_lines.each do |e|
        if line_count>2
                @confile.puts e
        end # line_count
        line_count +=1
end #in_lines
@confile.close
end # htb2printcon function
#
# PRINT STANDARD MATERIALS FILE
def htb2printstdmat()
          inconfilename                                              =
Sketchup.find_support_file("Plugins")+"/VirVil/htb2files/STDMAT.LBY"
in_lines = IO.readlines(inconfilename)
in_lines.each do |e|
        @stdmatfile.puts e
end #in_lines
@stdmatfile.close
end # htb2printall function
#
# PRINT USER MATERIALS FILE
def htb2printusermat()
inconfilename = Sketchup.find_support_file("Plugins")+"/VirVil/htb2files/USER.LBY"
in_lines = IO.readlines(inconfilename)
in_lines.each do |e|
        @usermatfile.puts e
end #in_lines
@usermatfile.close
```

```
end # htb2printall function
#
# START THE SHADING
def starttheshading(shadingmaskfaceslist, shadingmaskfaceslistnames)
vv = 0
pb = ProgressBar.new(shadingmaskfaceslist.length,"Making Shading masks...");
shadingmaskfaceslist.each do |s|
        pb.update(vv);
        shadingmask(s,shadingmaskfaceslistnames[vv])
        vv += 1
end #s
end # starttheshading
#
# MAIN FUNCTION
def main_virvil_function
prompts = ["Choose an angle: ","Calculate Reflections: ", "Choose Length in MM: "]
defaults = ["10","no","30000"]
list = ["10|5|2|1","yes|no",""]
#prompts = ["Choose an angle: ", "Choose Length in MM: "]
#defaults = ["10","30000"]
#list = ["10|5|2|1",""]
@results = UI.inputbox prompts, defaults, list, "VIRVILL THE HTB2 PLUGIN"
if (@results)
        virivl_attrib = Sketchup.active_model.attribute_dictionaries
        if (virivl_attrib['GeoReference'])
# for TB added this to makes sure it happens
                attribute_buildings
                if
(Sketchup.active_model.attribute_dictionaries['VIRVIL']['buildingcounter']>0)
                        @filenamecounter = 0
                        get_htb2_lat_long()
# create htb2file output and results folders
                        if !File.exist?("htb2file")
                                Dir.mkdir("htb2file");
                        end
                        if !File.exist?("output")
                                Dir.mkdir("output");
                        end
                        if !File.exist?("results")
                                Dir.mkdir("results");
                        end
                        puts "Exporting HTB2 files"
                        puts "Ray angle = "+ @results[0].to_s
                        puts "Ray length = "+ @results[2].to_s
#                       puts "Ray length = "+ @results[1].to_s
                        @ents = Sketchup.active_model.entities
                        @layers = Sketchup.active_model.layers
                        @ray_layer = @layers.add "Ray Layer"
                        @point_layer = @layers.add "Point Layer"
                        @htb2_ray_length = @results[2].to_f
#                       @htb2_ray_length = @results[1].to_f
                        @angle_step = @results[0].to_f
                        if @results[1]=="no"
```

```
                        @calc_reflections = false
                else
                        @calc_reflections = true
                        puts "Calculate the reflections"
                end # if @results[1]="no"
                # PRINTS THE TOTAL NUMBER OF RAYS
                model = Sketchup.active_model
                @totalnumberofraysperface = (360 / @results[0].to_f) * ( 90 /
@results[0].to_f)
                @totalnumberofrayspermodel = @totalnumberofraysperface *
numberoffaces(model)
                puts "Total number of rays =
"+@totalnumberofrayspermodel.to_s
                # RINTING THE FILES
                filename = Sketchup.active_model.title + @filenamecounter.to_s
                @bldfile = File.new("htb2file/" + filename.to_s + ".bld", "w")
##create a building file
                @layfile = File.new("htb2file/" + filename.to_s + ".lay", "w")
##create a layout file
                @topfile = File.new("htb2file/" + filename.to_s + ".top", "w")
##create a top file
                @srvfile = File.new("htb2file/" + filename.to_s + ".srv", "w")
##create a service file
                @htrfile = File.new("htb2file/" + filename.to_s + ".htr", "w")
##create a heating file
                #@lgtfile = File.new("htb2file/" + filename.to_s + ".lgt", "w")
##create a lighting file
                @spwfile = File.new("htb2file/" + filename.to_s + ".spw", "w")
##create a small power file
                #@occfile = File.new("htb2file/" + filename.to_s + ".occ", "w")
##create a occupancy file
                @vntfile = File.new("htb2file/" + filename.to_s + ".vnt", "w")
##create a ventilation file
                @metfile = File.new("htb2file/" + filename.to_s + ".met", "w")
##create a weather data file
                @confile = File.new("htb2file/" + filename.to_s + ".con", "w")
##create a construction file
                @constructionfilename = filename.to_s + ".con"
                @stdmatfile = File.new("htb2file/" + filename.to_s + "std.lby",
"w") ##create a standard material data file
                @stdmatfilename = filename.to_s + "std.lby"
                @usermatfile = File.new("htb2file/" + filename.to_s + "user.lby",
"w") ##create a user material data file
                @usermatfilename = filename.to_s + "user.lby"
                @dylfile = File.new("htb2file/" + filename.to_s + ".dyl", "w")
##create a diary top file
                @drydayfile_a = File.new("htb2file/" + filename.to_s + "dayA.dry",
"w") ##create a diary day file
                @drydayfile_b = File.new("htb2file/" + filename.to_s + "dayB.dry",
"w") ##create a diary day file
                @drydayfile_c = File.new("htb2file/" + filename.to_s + "dayC.dry",
"w") ##create a diary day file
```

```
            @dryendfile_a = File.new("htb2file/" + filename.to_s + "endA.dry",
"w") ##create a diary weekend file
            @dryendfile_b = File.new("htb2file/" + filename.to_s + "endB.dry",
"w") ##create a diary weekend file
            @solcfgfile = File.new("output/" + filename.to_s + "_sol.cfg", "w")
##create a solar configuration file
            @heatcfgfile = File.new("output/" + filename.to_s + "_heat.cfg",
"w") ##create a solar configuration file
            @cfgfile = File.new("output/" + filename.to_s + ".cfg", "w")
##create a configuration file
# create an audit file for the buildings and the faces
            audit_filename=          "results/"          +
Sketchup.active_model.title+"_audit_building.csv"
            @audit_bldfile = File.new(audit_filename.to_s , "w") ##create a
building audit file
            @audit_bldfile.puts          "bld_id,file_id,htb2_bld_id,volume
(m3),height (m),build_type,mass_ratio,floor_height (m),building_floor_area (m2)"
            audit_filename=          "results/"          +
Sketchup.active_model.title+"_audit_face.csv"
            @audit_facefile = File.new(audit_filename.to_s , "w") ##create a
face audit file
            @audit_facefile.puts
"face_id,bld_id,file_id,htb2_bld_id,build_type,element,construction,area  (m2),orientation
(deg),tilt (deg),glazing ratio,wall area (m2),window area (m2),window construction"
            @filenamecounter += 1
            htb2printcon
            htb2printcfg_faces
            htb2printbld
            htb2printstdmat
            htb2printusermat
            close_htb2_files
            @audit_bldfile.close
            @audit_facefile.close
            virivl_attrib['VIRVIL']['filenamecounter'] = @filenamecounter;
            puts "Total of HTB2 files = "+@filenamecounter.to_s;
            puts ""
        else
            UI.messagebox("There are no buildings in the model please
create some to model.",MB_OK)
        end                                                        #if
Sketchup.active_model.attribute_dictionaries['VIRVIL']['buildingcounter']
    else
        UI.messagebox("This model does not have a Geographic location, please
set this using the Model Info window.",MB_OK)
    end # if (virivl_attrib['GeoReference'])
end # if (@results)
end # main_virvil_function
#
# load the menus
$virvillsubmenu ? (virvill = $virvillsubmenu) : (virvill = UI.menu("Plugins"))
virvill.add_item("Attribute Buildings") { attribute_buildings }
# virvill.add_item("Zone Building") { zone_selected }
virvill.add_item("Choose HTB2 options") { choose_htb2_options }
```

```
virvill.add_item("VIRVIL THE HTB2 PLUGIN V1.4") { main_virvil_function }
virvill.add_item("Running htb2") { htb2_run }
virvill.add_item("Get htb2 results") { get_htb2_results }
virvill.add_separator
virvill.add_item("Areas Total V3") {  areas_totals }
virvill.add_item("Sky View") { sky_view_htb2 }
virvill.add_item("Reflect View") { reflect_view_htb2 }
virvill.add_item("Show HTB2 Attributes") { show_web_dialog }
virvill.add_separator
$virvillsubmenu.add_item("Explode All") { bomb_groups }
virvill.add_item("Final Flip V2") { final_flip_v2 }
cmd_bld = UI::Command.new("Building Properties") { building_properties }
cmd_bld.menu_text = "Building Properties"
cmd_bld.set_validation_proc {
		Sketchup.active_model.selection.each do |z|
				if z.is_a? Sketchup::Face
						MF_ENABLED
						break
				else
						MF_DISABLED
						next
				end # z is face
		end # selection.each z
}
cmd_face = UI::Command.new("Face Properties") { face_properties }
cmd_face.menu_text = "Face Properties"
cmd_face.set_validation_proc {
		Sketchup.active_model.selection.each do |z|
				if z.is_a? Sketchup::Face
						MF_ENABLED
						break
				else
						MF_DISABLED
						next
				end # z is face
		end # selection.each z
}
UI.add_context_menu_handler do | menu |
	menu.add_separator
	menu.add_item cmd_bld
	menu.add_item cmd_face
end # do menu cmd_face
# detect selection change and allow if a face
class MySelectionObserver < Sketchup::SelectionObserver
		def onSelectionBulkChange(selection)
				is_face = false;
				Sketchup.active_model.selection.each do |z|
						if z.is_a? Sketchup::Face
						is_face = true;
						end # z is face
				end # selection.each z
				if (is_face)
						facelist = []
```

```
                Sketchup.active_model.selection.each do |e|
                if e.is_a? Sketchup::Face
                        facelist << e
                else
                        next
                end # if e is a face
end # for # for e in facelist
# load the shading mask and send it to the dialog
# http://sketchupapi.blogspot.co.uk/2008/02/sharing-data-between-sketchup-ruby-and.html
                q = facelist[0]
                virivl_attrib = q.attribute_dictionaries
                if (q.get_attribute "VIRVIL_BuildingID", "shade_mask")
                        sol_max                                         =
Sketchup.active_model.attribute_dictionaries['VIRVIL']['solar_max'] ;
                        sol_min                                         =
Sketchup.active_model.attribute_dictionaries['VIRVIL']['solar_min'] ;
                        js_command = "passFromRubyToJavascript(\"Legend_"+
sol_min.to_s+"_"+sol_max.to_s + "\")";
                        $htb2_dialog.execute_script(js_command);
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"faceID";
                        face_for_flash = face_for_flash1.to_s
                        face_for_flash1 =  q.get_attribute "VIRVIL_BuildingID",
"BldingID";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"fileID";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"face_solar_energy";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"face_orientation";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"area";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"glazing_ratio";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        face_for_flash1 = q.get_attribute "VIRVIL_BuildingID",
"tilt";
                        face_for_flash    =    face_for_flash    +    ","    +
face_for_flash1.to_s
                        js_command   =   "passFromRubyToJavascript(\"Face_"+
face_for_flash + "\")";
                        $htb2_dialog.execute_script(js_command)
```

```
                shade_for_flash = q.get_attribute "VIRVIL_BuildingID", "shade_mask";
                model_lat = q.get_attribute "VIRVIL_BuildingID", "latitude";
                js_command = "passFromRubyToJavascript(\"Mask_"+ shade_for_flash +"_" + model_lat.to_s+"\")";
                $htb2_dialog.execute_script(js_command)
            end # if (virivl_attrib['VIRVIL_BuildingID'])
        end #if (is_face)
    end
end
# https://developers.google.com/sketchup/docs/ourdoc/appobserver
class MyAppObserver < Sketchup::AppObserver
    def onNewModel(model)
 # Here is where one might attach other observers to the new model.
        model.selection.add_observer(MySelectionObserver.new)
    end
    def onOpenModel(model)
 # Here is where one might attach other observers to the new model.
        model.selection.add_observer(MySelectionObserver.new)
    end
end
# Attach the observer.
Sketchup.active_model.selection.add_observer(MySelectionObserver.new)
# Attach the observer
Sketchup.add_observer(MyAppObserver.new)
```