CARDIFF UNIVERSITY
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ENERGY EFFICIENCY DESIGN OF RESIDENTIAL BUILDINGS IN NORTH CHINA CITIES

A thesis submitted to the Cardiff University, in fulfilment of the requirement for the degree of Doctor of Philosophy

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Abstract:

With the rapid growth of housing development in China, energy inefficiency in domestic architectures is becoming a crucial problem for the nation's sustainable development. At present, the average energy consumption of housings in North China cities is three times that in developed countries. The energy conservation regulation introduced by the government requires 65% heating energy saving in dwellings compared with the 1980's standard. However most of the current buildings cannot meet that regulation; the problem is mainly due to the lack of detailed technology and construction requirements, and difficulties in relation to enforcement.

The main aim of this research is to investigate the potential of using environmental design strategies to increase the energy efficiency of residential architectures in North China cities while provide reasonable comfort conditions. Literature review, on-site observations, field experiments and computer simulation were used. The field experiments were conducted in five flats in Tianjin and Xi'an cities to assess their thermal performance. Thermal simulations by using the building energy model HTB2 were employed to analysis these designs, and what improvements can be reasonably achieved, in line with China's targets for reducing housing energy demand by adapting certain environmental design strategies.

The findings of this work showed that with the adaptation of environmental design strategies, significant improvements of energy efficiency of residential buildings in North China cities can be achieved and considerable portion of energy can be saved. The most effective parameter in heating reduction is improve thermal insulation, having 50mm and 100mm polystyrene insulation achieved reductions of 26.5% and 38.8% respectively. Reduce the infiltration rate is the second most effective method, limit the air change rate to 0.5 ach reduced 21.6% of the heating demand from the existing condition. The parameters that reduce most cooling demand are having a reasonable window area and night time controlled ventilation—the reduction rate is around 23% and 13% respectively. Moreover, combining appropriate design parameters will maximise their effectiveness in energy reduction. Having parameters including appropriate glazing ratio, improve insulation of the building envelope, reduce infiltration etc. will enable case studies to match the 65% saving regulations straightforward and the cooling load was also substantially reduced. Moreover, by following further modification suggestions, the energy reduction rate reached 90%.

Considerable reduction in energy use and carbon emission can be achieved in North China cities and other places experiencing similar climates, by adapting the suggested design strategies. The findings of this research could help the decision-makers and architects to improve thermal performance and energy efficiency of both existing housings and future designs.

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CHAPTER ONE: INTRODUCTION

1.1 Research Background

This research attempts to explore the environmental design strategies to increase the energy efficiency of domestic buildings in North China cities while providing reasonable comfort conditions. The findings of this research intent to be able to identify the most effective strategies that can improve the energy efficiency, fulfil the government's energy saving regulation and achieve further reductions of energy consumption in residential architectures, increasing the awareness of design with respect toward local climate, emphasizing the importance of environmental design principles and strategies in existing and future domestic buildings in North China and other cities, or countries that experience similar climatic conditions.

With the rapid growth of housing development in China, energy inefficiency in housing is becoming a crucial problem for the nation's sustainable development. During the past two decades, China's economy has grown at an enormous speed after the reform of its' economy system (Yao et al. 2005). In order to house the nation's 577 million-plus urban inhabitants and meet their pursuit for better living conditions, a great number of housing projects were built in China's urban area to meet the ever growing demand, which generated numerous large scale urban developments and made housing construction one of the nation's prime industries. Every year, about a quarter to a third of the whole nation's investment went to the real estate market (Ma 2006), the number of new residential units built each year in urban areas is 4–7 million, which is about five times higher than the United States (Glicksman et al. 2001).

Nevertheless, with the vast growing pace, there is not enough attention being given to environmental design in dwellings. Due to the massive growth of the buyer's market, the developers' paid attention to only the quantity of domestic buildings rather than the quality of their design; the cost and construction speed of projects are the only factors that the developers care about (Chu 2007; Nie 2001). Traditionally, Chinese residents lived in low-rise courtyard buildings with communal green spaces, designs of those domestic buildings were simple but in harmony with the local climate situation, making effective use of available natural resources, such as natural ventilation and solar heating (Blaser 1995; Golany 1992; Li 2006). In contrast, the new buildings that are being built by today's commercial firms are generally poorly duplicated, foreign style, high-rise structures with little climate considerations, which fail to accommodate the local climates of each region in China. As a result, new houses in China cannot cope with the external environment, and hence a lot of energy needs to be consumed to provide indoor comfort conditions. People also have to purchase artificial equipments such as additional heaters, or air conditioning units and electric fans to maintain the comfort condition of their homes throughout the year, according to the data from China Bureau statistics, the amount of such equipment is growing rapidly in Chinese household.

The lack of environmental consideration during the design and construction period have made domestic buildings very energy inefficient, with the average energy use in residential architectures in China three times that in developed countries with similar climates (Lu 2005; Qiu 2005). The excessive use of energy is becoming a heavy burden to China's development and contributing to the increasing amount of greenhouse gas emission.

In order to reduce the energy used in houses and follow a more environmentally conscious path than in earlier developments in the Western world, the Chinese government pledged to implement a sustainable development strategy, giving further priority to urban housing development and the improvement of living conditions. The strategy setup for the 10th Five Year Plan (2000-2005) requires that new domestic buildings in North China to have a 50% of heating energy saving compared with those finished before 1980 (Yao et al. 2005). The updated strategy required the saving rate for new buildings from 2006 onwards to be at least 65% of heating energy compare with the 1980's standard (Chen et al. 2004; Qiu 2005; Sun 2008).

However, the majority of newly constructed buildings cannot fulfil this regulation (Qiu 2005). The unsuccessfulness of the implementation is largely due to the lack of detailed technology and construction requirements, and demonstration in the design and construction stages (Liao 2006). Therefore, for the purpose of investigating to what extent energy savings are achievable, this research analyzed a series of design parameters and strategies and their effects on the energy efficiency of buildings. It aims to provide information and guidance for the future application of housing energy savings in North China.

Environmental design is the ideal way to achieve the nation's energy saving objective for buildings. By introducing construction materials that have better thermal properties; adapting passive heating and cooling design schemes; and making the best use of natural resources, the energy load in housings could be reduced significantly. Moreover, the comfort condition in well passive designed houses will be far better than those that purely rely on artificial equipments. The chance for sustainable improvement could not be better; the pace of change in China is accelerating, and developers and consumers must be fast learners. There are many technical opportunities to reduce the energy consumption in new residential units while provide comfortable and spacious features. These opportunities should be seized now while many new buildings are under construction. A significant amount of energy could be saved if there was enough awareness of environmental design principles in the early stages of the design process (Salmon, 1999; Perry et al 1997; Givoni, 1994; Yao, 2002). For instance, if each Chinese household can reduce energy use by 1% each year, the total amount of electricity saved is equal to the same amount that the 'Three Gorge Power Plant' can generate a year (Liu 2005).

1.2 Research Aim and Objective

The importance of China's role in sustainable development has now been broadly acknowledged by the world; sustainability in Chinese domestic architectures is a crucial part in the country's future progress. Therefore, the research challenges the possibility of creating a constructive, understanding, environmental design scheme in North China cities with cold winters and hot summers. Moreover, the product of this research intends to help the decision-makers and architects to improve thermal performance and energy efficiency of both existing housing stocks and future designs. This might be the most time-saving and convenient way in China's pursuit of sustainability.

Environmental design guidelines and standards for domestic buildings are widely used in developed countries; however, there is still a lack of research attention in this field for developing countries like China. Against this background, the main aim of this research is: "**To investigate the potential of using environmental design to increase the energy efficiency of residential architectures in North China cities while provide reasonable comfort conditions.**"

Improved thermal insulation of building envelopes; passive solar energy systems; energy conservation principles; controlled ventilation and many other factors need to be investigated in order to find sound answers to the central research questions that are listed below:

1. To what extent do the existing domestic buildings in North China cities cope with the local climate?

2. To what extent can environmental design strategies improve the energy efficiency of housing in that area?

3. What are the most efficient design parameters in reducing the heating and cooling energy demand?

4. What environmental design strategies can be combined to fulfil the requirement of the 65% heating energy reduction, and how can they be implemented to achieve further reduction?

By achieving the main aim of this research and finding answers for the research questions, a number of objectives were derived. The main objectives of this research are as follows:

1. To investigate, through a literature review, the domestic building development in China, especially in the northern cities.

2. Analyze the climate in that region by studying the weather conditions in typical cities, in order to categorize the climate characters and suggest possible design considerations accordingly.

3. To conduct a field study with the purpose of forming first-hand knowledge, the current condition of the existing housing buildings in that area.

4. To conduct field experiments to assess and evaluate the thermal performance and other related data of the case studies.

5. To identify, through a literature review, the environmental design strategies that could be used to modify the design, with the aim of improving the condition of interior spaces of existing and future housing buildings.

6. To carry out computer simulation experiments to evaluate the thermal performance of the existing domestic buildings, and to predict the effectiveness of various environmental design modifications when applied to the same design.

7. To produce design guidelines and recommendations for housings applicable to that climate in general, and for North China cities in particular.

To sum up, energy conservation in Chinese residential buildings merits attention due to China's large population; the increased standard of living; and the high volume of construction. China has a crucial position in the world's sustainability approach and the battle against global warming, not only because of its huge energy use at present, but also because of the greater potential of the increasing energy demand in the future. Serious consideration must be given to sustainable design in dwellings where significant savings could be achieved through relatively simple modifications. Therefore, there is a significant responsibility for both authorities and architects, who design and manage the living environments, to take the responsibility to reduce the demand for energy use in buildings and to supply people with a better living environment through providing building design with a greater respect for local climate conditions.

Environmental design is an important issue in domestic buildings in North China to reduce the energy to the level required by the government, or even have a further saving. As mentioned before, researchers claimed that the energy efficiency could be significantly increased by applying appropriate environmental design principles during the design and construction processes. This research will focuses on the domestic buildings that are located in North China's central cities. Research questions are going to be studied and answered through literature review, field study, on-site measurement and computer simulation, for the purpose of fulfil the main aim of this research.

It is intended that the conclusions and findings of this research will help architects and decision-makers to provide the society with domestic buildings that can fulfil the energy regulation easily and utilize natural resources, in order to provide adequate indoor thermal conditions whilst conserving energy.

1.3 Research Scope

Due to the variation in climatic characteristics in China, the research is going to be based on the conditions of North China, more specifically the Zone II among the 'Architectural Zoning' in China (architectural zoning will be described in Chapter Three), which experiences a hot summer and a long cold winter.

The research is also limited to medium to high-rise domestic buildings. Forms of dwelling vary with their location and the time period they were built; at present, the most popular type of development is multi-story buildings that usually have more than 20 floors (Chen 2004). As mentioned previously, the current design of such buildings are just simple copies of the 'modern' designs and have ignored the response to the local climate. Therefore, a series of sustainable design modifications must be adapted.

1.4 Research Methodology

The carrying out of this research is achieved by four main methods, namely: literature review; on-site observation; field experiments; and computer simulation.

1.4.1 Literature Review

The theoretical foundation for research has been obtained by a series of literature reviews related to the climatic characteristics of China, the development history of domestic buildings and housing systems in North China, and environmental design strategies for dwellings, etc. A sound knowledge of the related information contributes to a better understanding of the research problems and some suitable design strategies can also be acquired by case studies of advanced examples.

1.4.2 On-Site Observation

Field studies give the research a first-hand impression of the current conditions of the existing domestic buildings and contextual data that could be gathered, with such observations serving as yet another source of evidence in a case study (Yin 1994). The main objective was to describe the existing conditions of the buildings.

1.4.3 Field Measurements

Field experiments are one of the most effective research methods that provide data that demonstrates the current circumstances of the existing conditions (Yin 1994). Field experiments were carried out in five housing projects in Tianjin and Xi'an cities. Selected flats in each building were monitored during the field study , in order to evaluate and assess their thermal performance. The air temperature inside and outside the buildings, the indoor environmental temperatures and the relative humidity were recorded, room surface temperatures of internal and external walls, outdoor global horizontal solar radiation were also documented, evaluated and assessed. All these measurements are intended to provide valuable information of the current thermal comfort condition of residential buildings. Moreover, the data will also be used to assist the calibration of computer models used in the thermal simulation and predictive modelling, enabling the predicted results to be directly compared to those measured.

1.4.4 Computer Simulation

Thermal modelling of the case studies is also a useful and an innovative method in this research. Few intense researches have been done to use thermal simulations tools to select the appropriate passive strategies, and assess the effectiveness levels of them on dwellings in North China cities. ECOTECT and HTB2 are two advanced computer modelling programmes that have been used to conduct the simulation experiments. HTB2 is the revised version of the Heat Transfer through Building program, developed at the Welsh School of Architecture (Alexander 1996). ECOTECT is compiled by Square One research and the Welsh School of Architecture at Cardiff University (Marsh 2005). The data obtained from the above methods successfully demonstrate the dimensions of the research problem, its justification and the possible answers to the research questions. The main aims of computer modelling in this research are:

1: to produce comparisons in obtained data between the on-site measurements and the predictive results.

One objective of using comprehensive computer models of measured buildings is to compare and correlate measured data with the results from simulations, in order to gain a better understanding of the models themselves and greater confidence in the applicability of computer modelling to reality (Mardaljcvic 1995), and to apply to the research of energy efficiency housing design in North Chinese cities. Furthermore, after the results measured in the field study and those from the computer simulation have been confidently proven, the next stage is to use these models to test the energy reduction effectiveness of a wide range of different environmental design strategies, aimed at improving energy efficiency and thermal performance of domestic buildings in North China cities.

2: to evaluate the thermal performance of the case studies.

After calibrating the thermal models, the energy performance of the case studies were then evaluated, their current energy efficient level was evaluated by comparing against the same model geometry with the building material in 1980's regulations' standards. Moreover, the current problems in the existing design, and the main sources of heat gains and losses, are analyzed.

3: to predict and compare the effectiveness of environmental design strategies, when applied to the case studies, to suggest design modifications.

Various environmental and energy conservation design strategies were applied to thermal models of the case study buildings to demonstrate the effectiveness level of each strategy individually, in order to prioritise the application of most appropriate parameters and suggest adequate combination of design packages. Furthermore, the next step in this investigation was to assess the improvements in thermal performance and the annual energy savings of the modified case studies, which combined with the selected design packages to achieve the 65% heating energy saving regulation and even achieve a further saving.

Data collected through the above research methods was used to create a presentation which could clearly demonstrate the effect on the energy performance and other benefits if environmental design strategies were introduced into existing and future domestic buildings.

1.5 Structure of the Thesis

Chapter One is an introduction to the research, which defines the problem and background. It also sets out the aims, objectives and significance of the study as well as the scope and limitation. The research methodology and structure of the thesis are also outlined.

Chapter Two presents an analysis of the cause and effect of global warming, the climate and energy problems faced by the world and China, and their actions toward sustainable development. The study also explains the reason for the fast growth of housing developments in recent years, the energy inefficiency problems caused during that process, the importance of energy efficiency in dwellings in North China cities and the corresponding regulations towards the heating energy reduction.

Chapter Three describes briefly the geographical and climatic features of China in general and of the 'Architecture Climate Zone II' in detail. Environmental conditions that buildings in this region experience throughout the year were carefully studied and analyzed by using climate design tools; suitable passive design strategies for that climate were also introduced.

Chapter Four discusses the theoretical background and reviews the literature in the field of human's response to thermal comfort. It also looks at the environmental and human factors including adaptive comfort theory that are affecting thermal comfort and introduces the possible ranges for thermal comfort for North Chinese cities.

Chapter Five describes the field work which was taken in Tianjin and Xi'an cities, including the information and characters of the selected five case studies, and presents the measured indoor thermal data and external climate conditions. Current thermal conditions of the case studies were assessed by analysis the measured data.

Chapter Six covers the description of the simulation tools used in this research, followed by the modelling and predictive performance results of the case studies. A comparison between the predictive data produced by the modelling tools and the data obtained by the field experiments is included in this chapter. The benefits of the advanced thermal modelling tools are also introduced.

Chapter Seven discusses and examines a range of available environmental design methods, their effectiveness and interactions between parameters are examined, in order to select the most appropriate ones that most effective and can be applied to China under the current economical and technology standard.

Chapter Eight outlines the application of various design strategies suggested from previous tests and examined their effectiveness in heating and cooling energy reduction by applying them to all case studies. The most appropriate strategies are selected to form the two recommended design packages, focusing on achieving the bottom line of the 65% heating reduction and further greater savings in residential buildings, are generated.

Chapter Nine discusses the main findings and conclusions of this thesis with the purpose of answering the main questions of the research. Energy efficiency housing design guidelines, recommendations and recommended areas of interest for future research, are also presented.

CHAPTER TWO: GLOBAL WARMING AND SUSTAINABLE DEVELOPMENT

2.1 Introduction

This chapter introduces the cause and consequences of the global warming effect that the whole human race is facing and the history of actions towards sustainable development in the built environment. Moreover, the importance and history of sustainable development in China is also discussed, including the possible negative effects of energy inefficiency on the economic and social development, and the energy conservation regulation for North China cities which requires the 65% heating energy saving, in dwellings compared with buildings in 1980's.

2.2 Cause and Effect of Global Warming

Today, the entire industrialized world acknowledges that environmental problems are indeed very serious. Over the past few decades, concerns about the global warming and environmental damage based on excessive energy use, had become dominant. The amount of energy used has grown enormously in the last 50 years and the majority of this consumption is based on fossil fuels, which is causing a significant change in the composition of the atmosphere and thus is leading to very serious consequence: global warming.

2.2.1 Reasons for the Changing Climate

The increased concentration of greenhouse gases in the atmosphere, resulting from human activities and energy consumption, is trapping more and more heat than it used to, hence causing the temperature to rise steadily in recent years and cause the global warming (IPCC 2007). Figure 2.1 (Hansen 2007) illustrates the process of change in yearly world temperature compared with the average between 1960 and 1990; we can see a clear increase since the 1980's. Besides, research shows that in the 20th century the global net temperature on the earth's surface has risen by about 0.6°C, and it is now rising at such a speed that it will reach 3°C in 100 years, however, the situation seems to be much worse than the scientists expected; the exceptionally hot summer of 2003 warned people that the pace of this warming is faster than predicted, even in the previous worst case scenarios (Roaf et al. 2005).

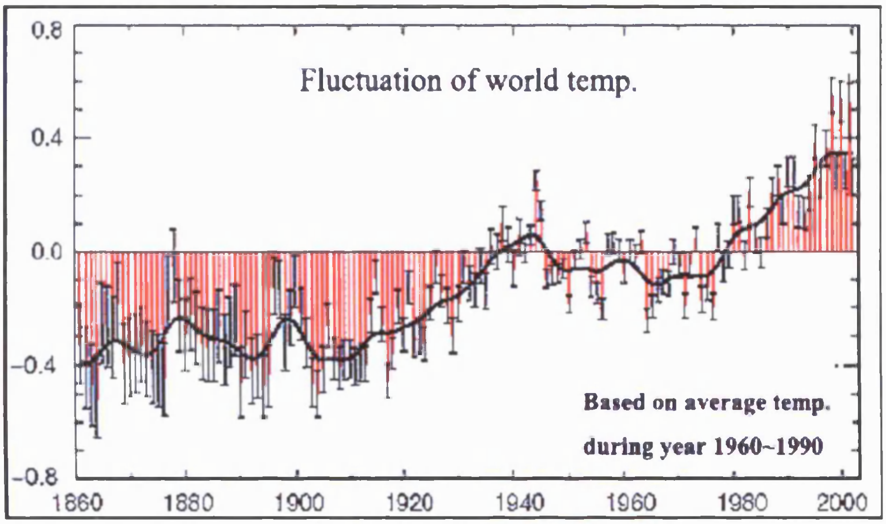


Figure 2.1: Fluctuation of World Temperature. After Hansen

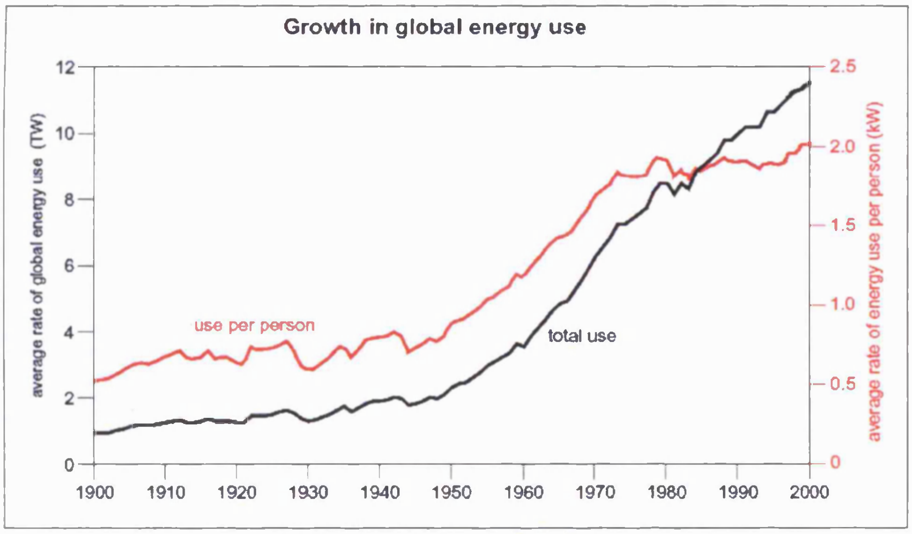


Figure 2.2: Energy Consumption Growth in 20th Century. Source: (ESRU 2002)

The 'greenhouse effect' plays a crucial role in the world's atmosphere and temperature; it is a natural process which can keeps the air warm and protects the surface from overheating by the sun at the same time. During the long history of nature, the atmosphere has formed a balance with the density of greenhouse gas in the air, hence together they can keep the global environmental system balanced and developing. However, with the discovery and the wide use of fossil oils since the mid-19th century, the amount of energy use in the world has increased dramatically. Figure 2.2 represents the trend of energy use, both total and per capita use. It is clear that throughout the world, from 1900 to 2000, the energy consumed had increased nine fold in the last century, with the major growth after 1950 (ESRU 2002).

Inevitably, the increased use of carbon based energy, like fossil oils and coal, led to the rise of greenhouse gas emissions. The total amount of CO_2 emissions was huge; it has greatly increased the concentration in the global atmosphere in the recent two centuries, and has broken the sustainable balance formed by nature throughout history. Statistics from the United Nations Environment Programme (UNEP 2005) revealed that atmospheric CO_2 has increased from a stable pre-industrial concentration of about 280 ppmv to about 367 ppmv at present (ppmv= parts per million by volume). The CO_2 concentration data from before 1958 is from ice core measurements taken in Antarctica and from 1958 onwards, are from the Mauna Loa measurement site. It is apparent that the rapid increase in CO_2 concentrations has been occurring since the onset of industrialization in last century (figure 2.3).

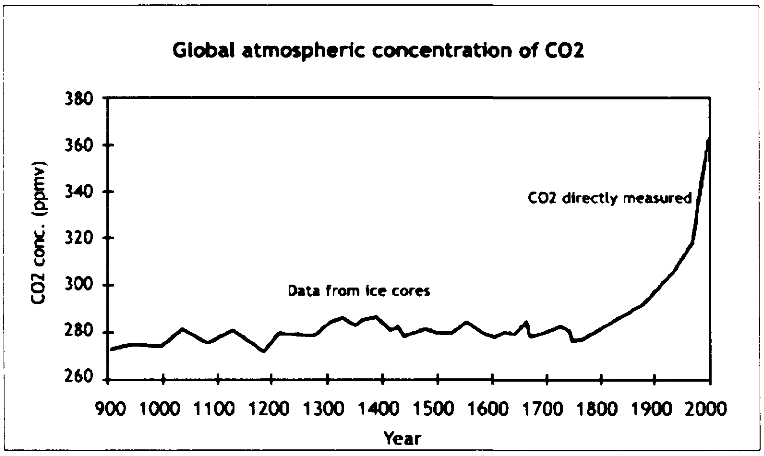


Figure 2.3: Increase of CO_2 Concentration in Atmosphere. Source: (UNEP 2005)

The increasing CO_2 emissions will lead to significant climate change: CO_2 forms an increasingly dense layer that still allows solar radiation into the earth's atmosphere, but as the thickness is increasing it prevents more and more heat from radiating back out into space, and so the bounced heat warms the lower atmosphere; this is the process that is changing our climate.

2.2.2 Effects of Global Warming

The warming of the world's climate is inevitably going to lead to the rise of the sea levels and changes in the weather patterns, among other terrible events (Tom 2000). Moreover, the developing countries are the hardest hit: extremes of climate tend to be more intense at low latitudes and in poorer countries that are less able to cope with climate disasters (POST 2006). People in the developing countries are already dying in large numbers because of extreme weather caused by climate change, whilst people in developed countries, living on cheap and abundant resources, keep generating the carbon dioxide that is warming the world.

Our everyday life will be affected by climate change, from the regions and houses we live in, to the air we breathe and the food we eat—even the effectiveness of our jobs. Statistics show that built environments are responsible for producing over half of all climate change emissions; modern buildings become more and more energy-wasteful and damaging to our future generation's planet, therefore, it has posed a challenge for architects: how to accommodate within such rapid changes and make people "stay comfortable, safe and ultimately survive in the changing climate"? (Roaf et al. 2005)

Introducing sustainability into buildings and energy use could help deal with this situation. The concept of sustainable development could contribute greatly to the improvement of the global living environment. Moreover, it could also overcome the conflict between environmental protection and economic growth (Sadownik 1998).

2.3 Global Actions towards sustainability:

2.3.1 Process Since 1970

The 1970's was the time when the environmental problem was first noticed in history; scholars and experts began to concentrate on ways to reduce the pollution and slow down the climate change. Later, some organizations and groups were set up to deal with the environmental problem. A series of actions and protocols came thereafter; the key actions in history are listed below:

The first book concerning environmental problems and that called for sustainability was published in 1972. It was written by Edward Goldsmith and his colleagues and was named "A Blueprint for Survival". The book contains a diagnosis of our rising environmental ills and the framework for curing them, and asked for some essential changes in people's actions towards the global environment, including a general plea for the application of ecological views to deal with the approaching global environmental crisis. It was a good starting point for drawing people's attentions to flesh out the details of a manifesto for sustainability at that time (Irvine 2001).

Then in mid 1980's, by using scientific calculation methods and simulation tools, some reports on the warming climate began to show what was actually happening in the measured record. It is the first time people found clear evidence of the increasing temperatures and the frequency of extreme weather events; people began to notice that the climate was changing more than its natural variability, which is more than the world can tolerate (Roaf et al., 2005).

In 1987, the World Commission on Environment and Development (WCED), which was set up in 1983, published the "Brundtland Report, Our Common Future". The Report stated that critical global environmental problems were primarily the result of the mass amount of energy consumption and industry production. The major contribution of this report is that it developed the principles for sustainable development and it was the first time that the concept of sustainability was brought to the general public. The concept is widely accepted in present academic fields: "*sustainable is a development which meets the needs of the present without* *compromising the capacity to meet the needs of future*" (WCED 1987).

In 1992, at the Earth Summit conference in Rio de Janeiro, the United Nations Framework Convention on Climate Change (UNFCCC) and 'Agenda 21' was approved. These treaties are comprehensive plans of actions to be taken globally, nationally and locally by organizations of the United Nations system, Governments, and major groups in every area, to call for industrialized countries to reduce their damage to the atmosphere. This conference was introduced to the global media and the concept of environmental protection was known and adopted by the world.

2.3.2 Kyoto Protocol

Based on the inspirations of Rio's Earth Summit, on 11 December 1997, more than 160 nations met in Kyoto, Japan, to negotiate binding limitations on greenhouse gases. The outcome of the meeting was the Kyoto Protocol, in which the nations should limit their greenhouse gas emissions, relative to the levels emitted in 1990 to be specific, and reduce worldwide greenhouse gas emissions to 5.2% below 1990 levels, between 2008 and 2012. It is an international treaty intended to bring countries together to reduce global warming and to cope with the effects of temperature increases that are unavoidable after 150 years of industrialization (Michael 1999).

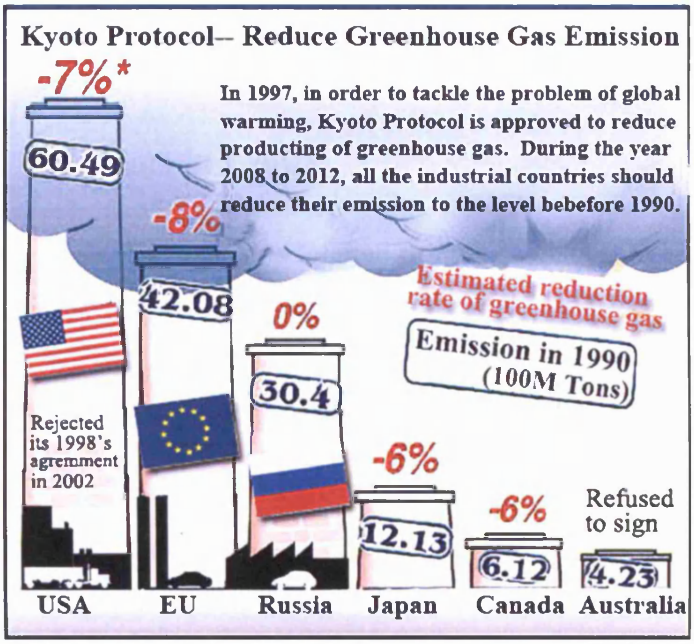


Figure 2.4: Kyoto Protocol, after (Xu 2004)

This first-time agreement asked whole industrialized nations to make legal regulations to reduce greenhouse gas emissions. Countries that approve the Kyoto Protocol will reduce emissions of greenhouse gases (mainly CO_2) that contribute to global warming. Reductions vary from country to country, according to its pollution levels, as shown in Figure 2.4. Moreover, the countries are allowed to use emissions credits, trading to meet their obligations, if they maintain or increase their greenhouse gas emissions.

China signed the pact in 1998 and approved it to be effective on 3 September 2002 and agreed commit to the following strategies (Wu 2005):

1. To place restrictions on their biggest polluters
2. To manage transportation to reduce emissions from automobiles
3. Make better use of renewable energy sources, i.e., solar power, wind power and bio-diesel, in placement of fossil fuels

Based on the ideal EIA (Energy Information Administration) Reference Case till year 2010, reductions in CO_2 emissions will result in between 18% and 77% less coal use, and between 2% and 13% less petroleum use, than projected.

2.4 Energy Problems in China

In recent years people in China have suffered from the high cost of energy needed in their home to provide the necessary conditions of comfort, and high loads through air conditioning in housings at night during the summer period have made brownouts, and blackouts, very common across China, particularly in the economically advanced cities (Lang 2002).

2.4.1 Increasing Demand

Although China has a large amount of various sources of energy resource storage, nevertheless if we compare this with the huge land area and a population around 1.5 billion, the national average per capita resource reserves are far less than the global average; the fossil oil and natural gas reserves are only 11% and 4.3% of global average per capita (Shoucong 2006). Therefore, as mentioned by Yao (2007), China's fast-economic growth has been pressurising the nation's already strapped supplies of energy and resources. It is clear that China's economic development will maintain the high speed for at lease one or two decades, and together with strapped supply of energy and resources, its energy consumption will inevitably rise due to the increasing amount of development and construction. However, without proper consideration of sustainable improvement, energy consumption is increasing at a faster rate than China's domestic economic improvement. Figure 2.5 compared the increase rate of gross domestic product (GDP) and energy consumption in recent years (Resource from National Bureau of Statistics of China), and it is evident that the growth of GDP development in China is steady at a rate of around 8% to 9% a year.

On the other hand, the increase rates of energy usage were always growing at a faster rate, especially during years 2002 to 2005. In 2005, economic growth was 9% more than previous year but power consumption grew 15% more than in 2004; the largest gap appeared in 2003 and the energy use rate increased by over 7 percentage points faster than GDP improvement. Therefore to find appropriate ways to sustain the fast economical development while not using energy excessively can be a very beneficial development path for China.

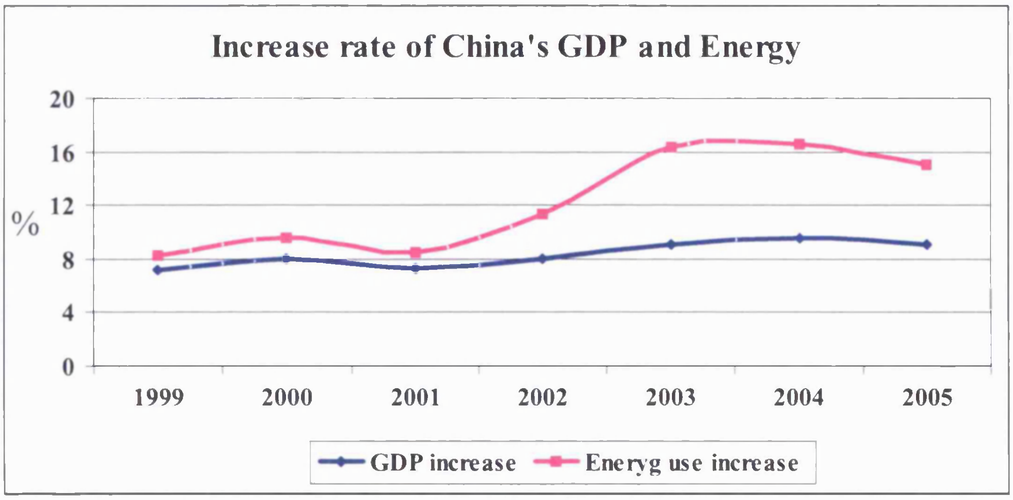


Figure 2.5: Increase Rate of GDP and Energy Use, source: (Bureau of Statistics 2006)

The increasing energy demand had grown far beyond the amount that China could produce, therefore a large amount of energy relied merely on imported resources. For instance, according the Chinese Statistic Year book published by Chinese National Statistical Bureau (2007), 40% of the increase in global oil harvest was sent to China. China consumed 230 million tons of fossil oil in 2004, 150 million of which was bought from other nations; moreover, it is predicted to continue at this level till 2020. China will use at least 500 million tons of oil per year, 80% of which will depend on imported resources.

Furthermore, China's energy production pretty much depends on the burning of coals and fossil oils, the environmental consequences of which reach far beyond its borders—China is second only to the United States in greenhouse gas emissions. Figure 2.6 demonstrates the major CO_2 emission countries for that year (Bureau of Statistics 2007).

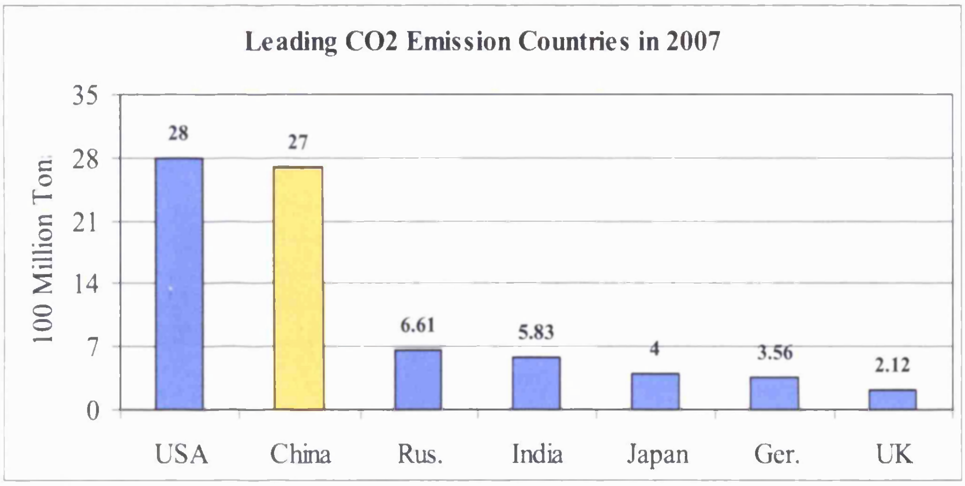


Figure 2.6: Major CO_2 Emission Countries, source: (Bureau of Statistics 2007)

2.4.2 Effects of Excess Energy Consumption

Too much energy use in domestic sectors has created major bottlenecks in many sectors of the Chinese economy. According to the records of the China Environment Yearbook (Brill et al 2005), China's power shortage reached 30 million kilowatts in 2004. Brownouts and blackouts have been very common across China, particularly in the economically advanced cities in recent years, at the peal time during the summer nights when most homes operate air conditioners. Figure 2.7 shows the number of provinces with a shortage of power supply in the recent five years. There were 16 provinces—which is approximately half of the total 34 provinces in the nation—that had experienced a limited energy supply in 2001 and the number jumped by 20% to 24 in 2005.

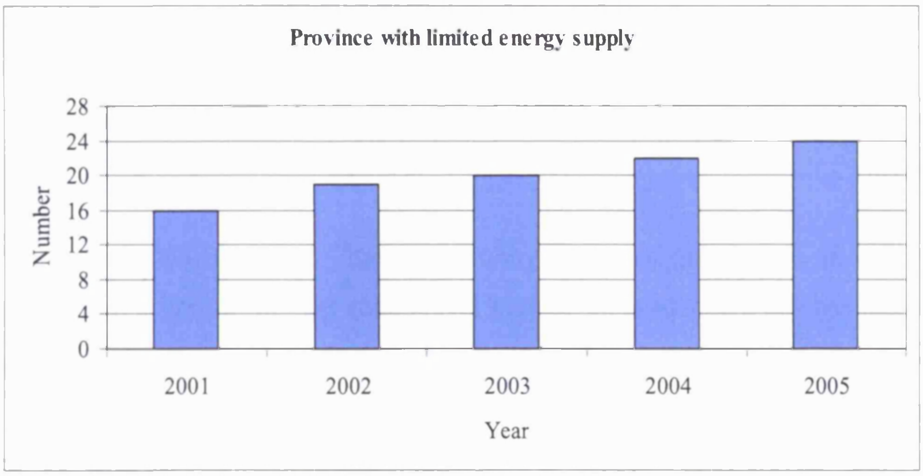


Figure 2.7: Number of Provinces with Limited Energy Supply. Source: (Brill et al 2005)

The insufficient energy supply causes many social and economical problems. First of all, it reduces the efficiency of the industry and economy progress; for instance, according to the publication of Liu & Diamond (2005), the GDP growth lost of China due to its lack of power is estimated to be around 0.5 percentage point in 2004. Secondly, the lack of energy stimulates the energy price, and this will increase substantially the living costs of the people in urban areas. The insufficient energy supply in households will also bring down the comfort level of people's living place, hence having a series of negative effects on comfort and health. Thirdly, it might bring China unpredictable political situations. In Wenmu Zhang's publication of the energy safety issue of China, it is projected that over 45% of China's petroleum and natural gas will depend on imports from abroad in less than ten years (Zhang 2003), because the energy producing nations in the world are always involved in political conflict and even battles, anything that affects the global energy market will lead to serious problem for China.

Besides the oil and gas, the overuse of coal resources has also caused serious trouble more than air pollution. Due to the lack of proper technology and safety control, the number of accidents in coal mines in China is the highest in the world, the death of coal miners in the accidents account for almost 80% of the total deaths in the world, in that area. Most coal mines are exploited by hand digging and the average production rate is only 1/40th of the mine workers in America who use machinery instead. Moreover, when producing a million tons of coal there are, on average, four mining deaths and this number is 100 times more than USA (Chen 2005).

2.4.3 Housing Based Energy Use

During the past two decades, China's economy has been growing at an enormous speed after the reform of market economical system. Consequently, this has increased not only urbanization speed, but also the living standard for Chinese people. More and more people choose to live in urban areas and are seeking a more comfortable living environment. According to the China Statistical Yearbook 2007, the urbanization rate rose from 18% in 1978, to 44.9% by the end of 2006 (Bureau of Statistics 2007) (Figure 5.18).

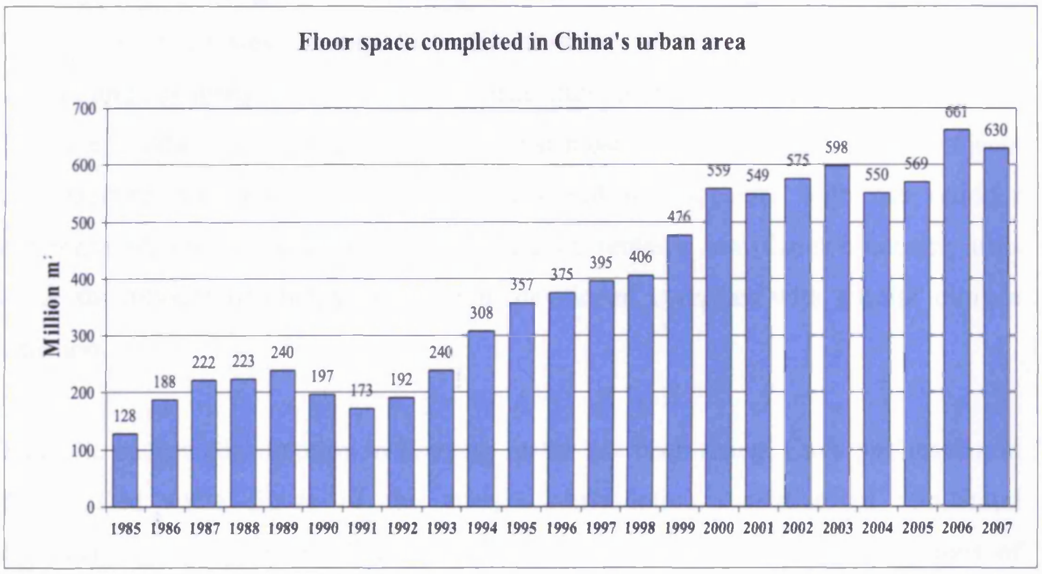


Figure 2.8: Floor Space Completed in Urban Areas. Source (Bureau of Statistics 2007)

Therefore, in order to house the nation's 577 million-plus urban inhabitants and meet their demand for better living condition, a great number of housing projects were built in China's urban area to meet the ever growing demand; this generated numerous large scale urban developments and made housing construction one of the nation's prime industries (Wu 2001). According to the publication of China Real Estate and Housing Research Association, more than one trillion Yuan (about 84 billion British pounds) are put into real estate every year in China every year (Yi 2006), which is about a quarter of the whole nation's investment; the number of new residential units built each year in urban areas was 4–7 million, which is about five times higher than the United States (Glicksman et al. 2001). Figure 2.8 above demonstrates the increase of floor area finished in recent years; one can see that the floor space completed in urban area had grown five-fold from 128 million m^2 in 1985 to 630 million m^2 in 2007, the data are from China Statistical Yearbook 2007.

The amount of construction of residential architectures is increasing at an amazing speed in China, however, considerations toward the local climate and sustainable strategies were neglected due to the great demand in the market (Sun 2008). According to Baoxing Qiu (2005), the deputy minister of the China Ministry of Construction, emphasis has been on the speed of the construction, and not enough on the design of buildings that are energy efficient and provide good environments for their occupants; instead, cheap, fast built modular 'modern' housing dominates the market and has spread nationwide, with little attention to the impact of the climate. In the same publication he also pointed out that most of the ongoing housing projects and existing domestic buildings in China fail to cooperate with the outdoor environment, and the level of energy efficiency remains low, China's housing uses triple the amount of energy as those in developed countries with similar climate situation.

Thus the energy consumption in housing sector has been rising, Cai's publication in 2006 listed some figure of the energy consumption condition of residential architectures in China, in 2002 residents consumed about 170.33 million tons of standard coal, which accounted for 10.4% of the nation's energy consumption. More specifically, the percentage of oil used by residents grew from 2.4% in 1990 to 6% in 2002. The power consumed by residents accounted for 7.7% of the total in 1990; 12.3% in 2002; and by the end of 2003, Chinese domestic buildings used about one fifth of the nation's energy consumption and was responsible for over 30% of the CO_2 produced (Cai 2006). Moreover, a big portion of the housing consumed energy are through the space heating, according to Jiang Yi (2006), space heating energy in North China cities account for 36% of the total energy consumed by domestic architectures, it is the largest component of the energy share.

The analysis above indicates that the housing is an important factor that contributes to the energy problem of China; therefore, how to raise sustainability in residential buildings in order to improve their efficiency of energy use is crucial to both China's development and the world's environmental health. Without incentives, knowledge and the capacity to build energy efficient buildings, China's residential development is very likely to follow the path of the Western world, leaving the following generations a vast problem to deal with. Moreover, how to effectively reduce the heating demand in North China cities also merit more attention as it consumes more than a third of the total energy.

2.5 China's Sustainable Development

China is in great need of sustainable strategies in the built environment. Not only to improve the domestic economy and people's life quality, but also to reduce the huge impact that China's unsustainable development will have on the planet. Therefore, the Chinese government is paying more attention to environmental issues, general energy efficiency policies are being made to make buildings use less energy and the use of renewable energy is also encouraged. However, in reality, the results are not so optimistic.

2.5.1 History of Development

The government's concern of the energy issues started in the 1980's. The first remarkable investment program was carried out during the Sixth 'Five-Year Plan' (1980-1985), which provide about 10% of the funding from energy supply investment to support the research of energy conservation (Levine 1996). The development continued through the Seventh 'Five-Year Plan' (1986-1990) and through the early 1990's when the ratio declined to near 8%, however the absolute amount of investment still increased Yao (2005). In May 1991 in Beijing, ministers from Energy Departments of 41 developing countries including Brazil and Saudi Arabia, gathered together and published the 'Beijing Declaration', announcing their concerns about global environmental issues (Speed 2004).

The Chinese government signalled its official commitment to sustainable development after the 1992 Rio Earth Summit. After agreeing to perform according to the requirement of Agenda 21, the People's Congress decided to workout 'China Agenda 21', which was the fundamental document for China's sustainable progress and set out basic goals for the plan. In the near future (1994 to 2000) the emphasis was set to settle the stand out crisis between environment and development, and lay out foundations for future developments. In 2000 to 2010, the emphasis is to finish transforming from the heavy consumption mode to a more sustainable progress, and to regulate social behaviour and economic system to act toward that way as well and after 2010, the aim is to maintain the economic improvement within the capability of environment and resource, and to contribute to the global environment progress (Lin 1999).

With the inspiration of 'China Agenda 21', a large body of environmental laws and policies has since been promulgated, leading some analysts to observe the "greening" of the Chinese state. China signed the United Nation Framework Convention on Climate Change in 1990 and decided to participate in the Kyoto Protocol, which was signed in 1998 and approved it to be effective since 3rd Sep. 2002 (Speed 2004). Environmental reporting in the newspapers is also on the rise. According to Lin (1999), surveys show that while on average Chinese newspapers carried only 125 articles on environmental issues in 1994, the number had risen up to 630 by the end of 1999. Television and radio programs about the environment have also become common features. As a result, a "green speak" has entered the Chinese vocabulary.

2.5.2 Environment and energy conservation policies in housing

It is good to see China is making more efforts toward the sustainable development; the attention to building energy conservation has also been increased. A series of building energy standards have been formulized since 1986 and addressed the importance of energy efficiency and renewable energy in the built environment (Wu 2003). The 'Energy conservation design standard for heating new residential buildings (JGJ26-95), (Ministry of Construction 1996) is the major building regulation related to the housing design standard in North China cities.

The regulation addressed the standard of the thermal properties of building envelopes. in its previous version, JGJ26-86, U value in this Standard is 0.91 W/m2 K for a roof, an external wall is 1.28 W/m2 K and a window is 6.40 W/m2 K in the Beijing and Tianjin area. JGJ26-95 proposed a requirement of the U value to be 0.6–0.8 W/m2 K for a roof, an external wall is 0.82–1.16 W/m2 K and a window is 4.0 W/m2 K in the Beijing and Tianjin area.

With the improvement of the building regulation, the energy efficiency of the residential buildings have been increased in recent years. However, there still exists a big gap in energy efficient building design between China and the developed countries in the world. Below table compares the U-value of building envelope requested in building code of North China with above countries (Canadian Codes Centre 2005; Ministry of Construction 1996; Office of Deputy Prime Minister 2006; The German Energy Agency 2007), one can notice the big gap of the building code, for instance, the U-value of external walls of China is three the amount of other countries.

	External wall	Window	Roof
China (JGJ26-95)	0.82–1.16	4.0	0.6–0.8
UK (Part L 2006)	0.30- 0.35	1.8-2.2	0.16 - 0.25
Germany (EnEV 2002)	<0.35	<1.7	<0.25
Canada (MNECB 2005)	<0.37	1.4-2.7	0.14-0.29

Table 2.1: Compare of U-value of building envelope

Therefore, in order to match the standard of developed countries, additional methods should be considered when designing new buildings and modifying existing ones, not only to fulfil the building code but also need to minimize the energy demand of residential buildings.

2.5.2.1 Domestic Building's Heating Energy Saving Regulation

In order to meet the requirement in the above mentioned documents, China is formulating detailed policies in built environments to fulfil its obligations under the convention. With the great annual growth of energy consumption, the government of China is particularly conscious of the importance of saving energy through the built environment, with domestic buildings, in particular. According to the Chief Engineer of the China Building Technology Development Centre, China has turned to contributing to sustainable development by improving house building technology in recent years. One example is, during the ongoing 19th session of the Governing Council of the United Nations Human Settlements Program, the head of the Chinese delegation reported China's guideline of sustainable housing development, including stepping up urban and rural housing infrastructure development; enhancing pollution control and environmental protection; and improving urban and rural ecological environments, in order to establish environmentally sound human settlements (UN-HABITAT 2003).

As discussed in preceding context, about 36% of energy consumption in dwellings in China is by through space heating in North China cities therefore the government is paying extra attention toward that factor. In the 10th Five Year Plan (2000-2005) of China, energy saving regulation in dwellings was clearly set, it requires a 50% energy saving in new residential buildings that compared with the standard of building finished before 1980 (Building code JGJ26-95) (Lang 2002; Yao et al. 2005). Furthermore, according to the 'Guidance for Developing Energy Efficiency Residential and Public Architecture' published in 2004, the saving rate for big cities in North China is expected to rise by 15% up to 65% from 2005 till the end of 2010, and this, for all cities in China, is expected to rise to 65% till 2020 (Qiu 2005; Sun 2008). At that time, energy consumed in housings will be the same as the standard of present developed countries with similar climates, and the reduced CO_2 emissions will be equal to the total amount produced by the whole of the UK.

Besides this, the government also applied other actions that would contribute to energy conservation, one of which is to increase the energy price in order to reduce the waste of energy by consumers in all building types. Moreover, people have been encouraged to take energy conservation principles into consideration before constructing new buildings; the media has also been highlighting this problem to explain how people might cooperate with the government to reduce energy consumption by a target amount by 2010.

However, the implementation of the policy has not been very satisfactory, largely due to the lack of detailed technology and construction requirements and difficulties in relation to enforcement in the design and construction stages (Sun 2008). Therefore, for the purpose of investigating to what extent energy savings are achievable, this research analyzed a series of building parameters and construction technologies in their effects on the energy efficiency of buildings. It aims to provide information and guidance for the future application of housing energy savings in North China.

Sustainable housing design could contribute to the fulfilment of the energy saving regulation and to reduce energy demand. This can be achieved through introducing construction elements with higher levels of thermal insulation, reduce building's air infiltration and adapt passive heating and cooling design schemes. Moreover, thermal comfort in passive design housing has the potential to be better than those that purely rely on mechanical heating, ventilating and air conditioning systems.

2.5.2.2 Current issues

Although the regulations and policies have been published for some years, the situation is still not optimistic as the effectiveness was not as expected. The preceding discussion also indicated that to promote the energy efficiency in residential architectures is not a simple issue, there are many factors that play important roles in this task, such as tighter legislation, stronger building control as well as enforcement from social and economic forces, however, for this thesis, the focus is on the technical related issues that related to the design.

Although the higher requirement in building regulation and the improvement of construction technology has improved the energy efficiency of housings in China, however, such progress is far from enough, as mentioned before, average space heating and cooling energy consumption in China is still tripled that of the developed countries with similar climate situations(Qiu 2005; Sun 2008).

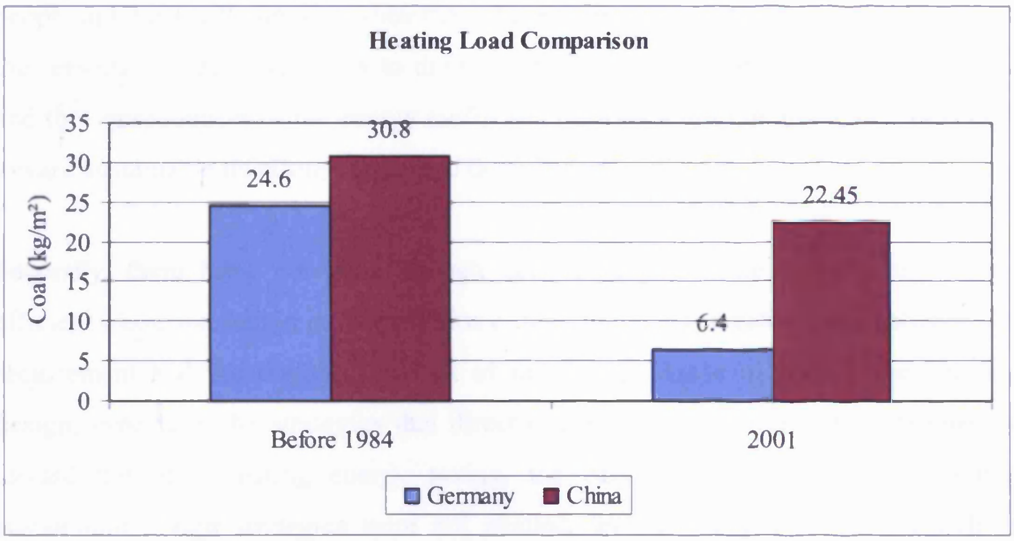


Figure 2.9: Heating Energy Comparison of China and Germany, after HuiYu

Figure 2.9 is a comparison of the housing heating load in North China and Germany, which has a similar climate situation. It is clear that at present domestic buildings in North China use far more energy in heating the room. In 2001, the average coal amount used per square metre in China was 22.45 kg and the amount in Germany was 6.4 kg, which is 70% less. However, according to the records before 1984, the amount of coal used in heating was 30.8 kg and 24.6 kg, respectively (HuiYu 2006). Possible reasons for the negative response of the sustainable strategies in China are listed below:

First of all, the awareness of the importance of the energy efficiency housing is still low among the developers, architects and even the occupants. Therefore, during the enormous growth of the real estate market, concerns from developers and architects are mainly in the quantity but not quality of the buildings; hence lots of buildings were designed and constructed without considering the local climate. In most cities, the 'Sustainable Housing' always works as an experimental unit and demonstration, little effort was paid to the application in the mass construction. On the other hand, for the buyers, due to the lack of awareness about the importance of sustainability and environmental issues, the most important factor they considered when purchasing houses are still the price; energy efficiency is not one of the decisive factors that people in China will consider when they chose their apartments. Based on this, one of the reasons for this research is to draw people's awareness of the current problems and the consequences of the energy inefficient housing and to improve their devotion toward sustainable dwelling design and development.

Secondly, there have not been enough deep attempts in the research of energy efficiency housing design in North China cities and this has created a gap between the requirement and the reality. The lack of detailed guidance of sustainable housing design, especially the strategies that directly link with the government's regulation toward the 65% heating energy saving, the easy, adaptive and simple to use sustainable design strategies were not studied, let alone applied. The research is intended to provide design guidance of sustainable housing design for North China cities, the outcome will cover the general guidance at all stages during design and construction, and the detailed design strategies that can fulfil the saving requirement.

2.6 Conclusion

This chapter analyzed the cause and consequences of global warming and stated the importance for China to limit the energy consumption in domestic buildings. Being a country that has the biggest population and producing the second largest amount of CO2, China is inevitably one of the most important characters in the battle against global warming.

The excessive energy demand has raised many problems for China's economic and social development. Environmental awareness is becoming one of the most critical factors in China. Chinese government has been trying to reduce the energy use in buildings in recent years by providing related building legislation, improve social awareness and enforcing economical means, all these factors play important roles in the pursuit of sustainable development.

The focus of this thesis is the issues related to domestic building design in North

China cities to reduce the space heating demand. The discussion in this chapter showed that the amount of housing construction is growing at an amazing speed but the energy efficiency of them, remains low, moreover, as discussed before, over a third of the housing based energy use in China is through space heating in North China cities hence reducing the energy used in that factor is extra important.

It is clear that energy inefficiency is one of the major problems that need to be solved; the application of the 65% heating energy savings in dwellings in North China cities must be completely fulfilled. However, the current compliance of that regulation is not optimistic, and pressure resulting from inefficient use of energy will continue to exist. As the largest building construction country, adaptation of effective energy saving design strategies, based on China's climate, appears crucial. Domestic buildings should be built with respect to the local climate, utilizing natural recourses to cool and heat the interior spaces with the aim of energy efficiency. Achieving this goal will contribute to preservation of the environment for the coming generations while living in healthy and comfortable housing buildings.

The next chapter is going to be the study of climate characters of North China, for the purpose of understanding the climate better and finding appropriate design and modification strategies for housing design.

CHAPTER THREE: CLIMATIC CHARACTERISTICS AND ANALYSIS OF CHINA

3.1 Introduction

As Koenigsberger (1973) mentioned, climate is '*an integration of time of the physical state of the atmospheric environment, characteristic of a certain geographical location*', it is one of the most influential factors that may affect buildings performance and the comfort of those who use them. Housing architecture should be designed to harmonise with the local climate in China, satisfy the occupants and be energy efficient. As Markus mentioned in his book, understanding and analysing the local climate of a region and the thermal comfort requirements are perhaps the most important stages in the environmental design (Markus et al. 1980). Thus it is necessary to study the background information of China and its climate, especially the area that this research is going to be concentrated on.

Since the weather situation has a great impact on sustainable building strategies, there are variations in the sustainable treatment of buildings from one region to another to provide appropriate responses to the existing climate; hence, this research is limited to the new domestic buildings in North central China, to be more specific, climate Zone Two in 'China Building Climate Zoning' (GB50178-93). Therefore this chapter intends to demonstrate the main climatic and geographical characteristics of China in general and North Central area in more detail as the selected region of this research. Climate analysis by using climate design tools was also introduced.

3.2 Location and Geographical Characteristics

3.2.1 Size and Location

The People's Republic of China is located in Eastern Asia, covering five time zones from latitude 53°30' to 4° north and longitude 73°40' to 135°05' east (Fig 3.1). Today it occupies approximately 9.6 million square kilometres (3.7 million square miles) or nearly one quarter of Asia's land, making it almost the same size as the whole European continent (Bureau of Statistics 2005).

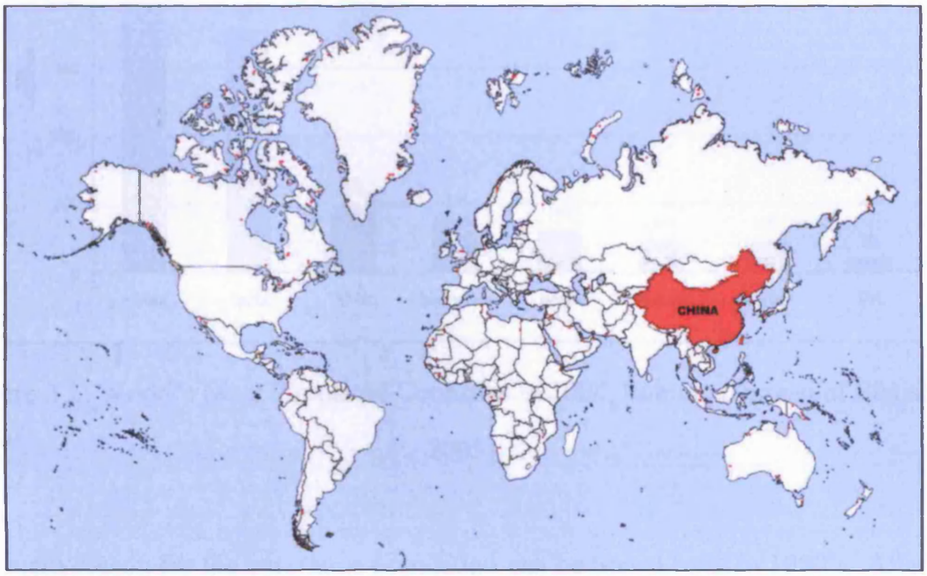


Figure 3.1: Location of China in World Map. Source: World Atlas, 2005

China, with more than 1.3 billion people, is the most populated country in the world (Figure 3.2); however, averaged by the huge land area the overall population density of the country is somewhat over 110 people per square kilometre, which is only about one-third of Japan and less than many other countries in the world. Regional variations, however, are dramatic as over 90% of the Chinese population live on less than 40% of the land, mostly in economically advanced cities, therefore the importance of energy efficiency dwellings in cities are especially essential.

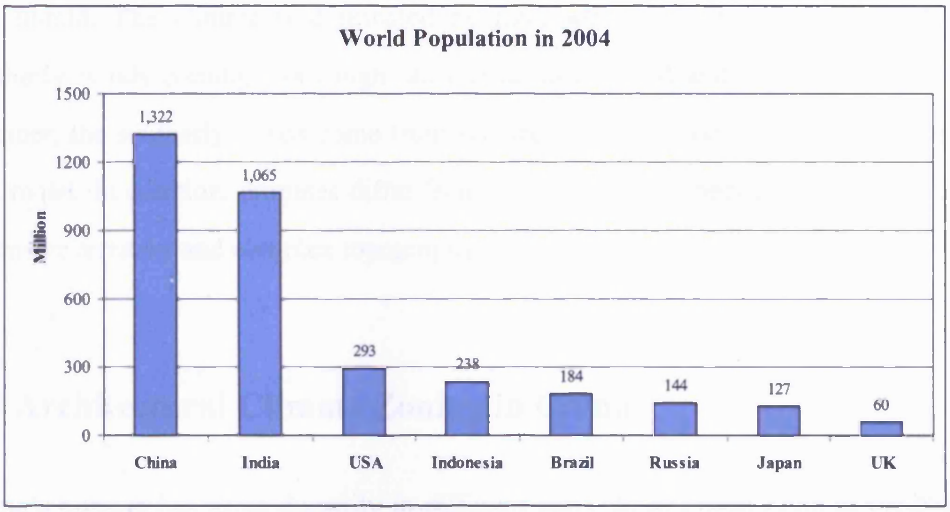


Figure 3.2: World's Most Populated Countries in 2004. Source: (Bureau of Statistics 2005)

The main reason for the enormous population can be traced back to 1950's. After the 1949 revolution, the Chinese government encouraged its people to have large families in order to increase the workforce that had been depleted by years of war. However, production and modernization speed could not keep up with the growing population, thereby forcing a change in government policy; an extensive birth control program has been in effect since the late 1970's. Nowadays, city-dwellers are required to adhere to the one-child policy, and even in the countryside families can rarely have more than two children; therefore the average household population is three.

3.2.2 Regions and Climate

China is the world's third largest country after Russia and Canada, covering many degrees of latitude with complicated terrain; therefore its climate varies radically, ranging from extremely dry, desert-like conditions in the North and West, to the rain and heat of the tropical monsoons in the South and Southeast. Generally, in Northeast China, summers are short but there is much sunshine, while winters are long and cold; in South China, the winters are mild and humid, and the long summers are burning and humid. The climate is dominated by monsoon winds in the winter, and the northerly winds coming from high latitude areas are cold and dry; whereas in the summer, the southerly winds come from sea areas at lower longitudes and are warm and moist. In addition, climates differ from region to region because of the country's extensive territory and complex topography.

3.3 Architectural Climate Zoning in China

China's climate has great disparity in different parts, from Frigid Zone in the North part, to Semitropical Zone in the South part; therefore the environmental strategies also vary from place to place. In order to distinguish the different climate zones in China and define their impact on architecture design, the Minister of Construction published the "Criterion of Architectural Climate Zoning". For the purpose of using the climate resource appropriately and preventing its negative effect, the regulation gives general requirements in the architecture design of each zone (Yao et al. 2002). It is the primary requirement in design and construction for both domestic and industry architectures.

Basic weather characteristics in different zones were studied, including their location, climate information and natural resources. Some issues in architecture, like the traditional and present housing types, are also going to be discussed. However, since this research is based on the North central Chinese cities, namely climate Zone Two, only the details of that region has been listed in this section: the information of other regions are listed in the appendix A1.

3.3.1 Zoning Definition and Climate Summary

The definition standard of the zoning is complicated and detailed; generally, it is based on local climate statistics of average temperatures in January and July, the average relative humidity in July, the yearly rain amount and the number of days per year that the average temperature is below 5°C and higher than 25°C (GB 50178-93)(Ministry of construction 1994). The definition also depends on other accessorial standard factors, such as geographical status and solar radiation, etc. Based on this criteria; China is divided into seven general architectural climate zones (Figure 3.3). The climate characteristics and representative cities of each zone are listed in the table below (Table 3.1).

Figure 3.3: Chinese Architectural Climate Zoning. Source: (Department of Architecture Construction of China 1994)

Moreover, there is another zoning definition that is also being used which divides China into five climate zones (GB 50176-93), that definition simplified the definition criteria and only follows the average temperature in January and July and the number of days per year that the average temperature is below 5°C and higher than 25°C. Based on that definition, the zone VI and VII was combined into the zone I and the rest zoning definitions remain the same. The two zoning standard were based on the same basic criteria and is compatible with each other (Liu 2005) and this study followed the first standard as it covers more detailed climate information. Moreover this study is focused on the situation in climate zone II, which covers exactly the same region in both definitions.

Zone	Basic climate data	Accessory information	Covering area and typical cities
I	January temperature ≤-10 C° and July temperature ≤25 C°, Average Humidity in Jul. ≥50%	Yearly rain amount between 200~800 mm, days that temperature below 5 C° is more than 145	Northeast China: Shenyang, Changchun
II	January temperature between -10~0 C°, July temperature between 18~30 C°	Days that temperature above 25 C° is less than 80, days that temperature below 5 C° is between 145~90	North China: Beijing, Tianjin
III	January temperature between 0~10C°, July temperature between 25~30 C°	Days that temperature above 25 C° between 40~110, days that temperature below 5 C° between 90~0	South central China: Shanghai, Nanjing
IV	January temperature between >10C°, July temperature between 25~29 C°	Number of days that temperature above 25 C° is larger than 100	Southeast China: Taibei, Haikou
V	January temperature between 0~13C°, July temperature between 18~25 C°	Number of days that temperature below 5 C° is between 0~90	Southwest China: Kunming
VI	January temperature between 0~-22 C°, July temperature between <18 C°	Number of days that temperature below 5 C° is between 90~285	West China: Lasa.
VII	January temperature between -5~-20 C°, July temperature ≥18 C°, average Humidity in Jul. ≤50%	Yearly rain amount: 10~600 mm, days that temperature above 25 C° is less 145, temperature below 5 C° is between 110~180	Northwest China: Urumchi

Table 3. 1 : Climate Summary and Typical Cities of Chinese Climatic Regions

3.4 Climatic Character of Zone Two

Analysis climate characteristics of this zone and the study their possible effects on building and sustainable design, is an essential step in this research. The situation of the whole area is studied and data from some typical cities is selected to represent the condition.

3.4.1 Location and Background

Climate Zone Two, which is the region of interest in this thesis, is located in central East China (Figure 3.4), covers six provinces including the capital city Beijing. The total size is over 1.1 million square kilometres, which is 11.5% of the size of China with more than 320 million people living there and it's about 25.6% of the whole population.

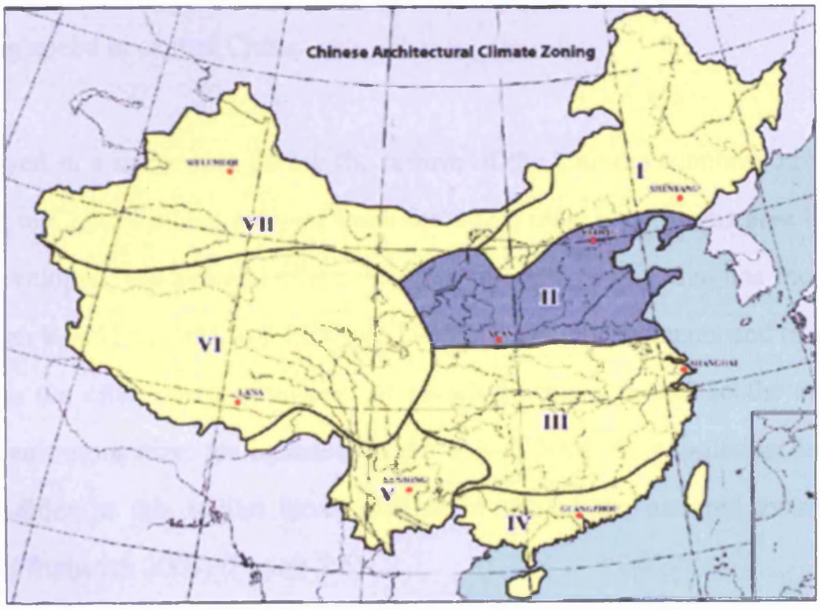


Figure 3.4: Climate Zone II. Source: (Department of Architecture Construction of China 1994)

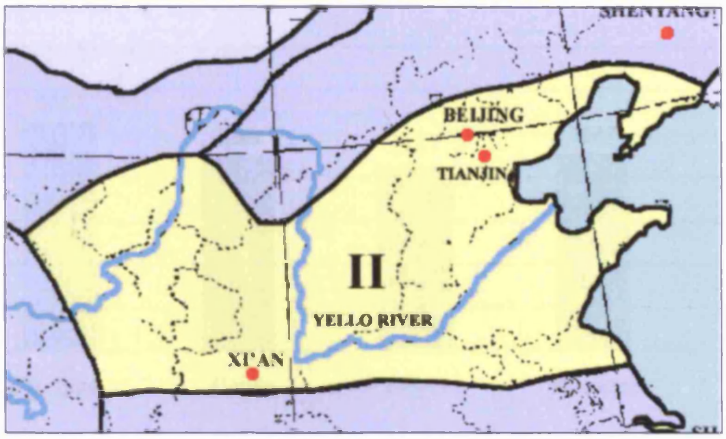


Figure 3.5: Major Cities in Zone II. Source: (Department of Architecture Construction of China 1994)

As can be seen in Figure 3.5, the Yellow River, the second longest river in China, flows across this region; and many important cities are located here: Beijing, the capital city, which is economically highly developed; Tianjin, one of the four municipalities of China; and Xi'an, the historical city, which has the fastest developing speed in central China.

Cities played in a major role during the reform of the Chinese economy process and, according to China's statistical year book for 2005, most cites in this area have been greatly developed; the average urban dwellers' income in this area has increased by 237%, from ¥ 4651 in 1995 to ¥ 11000 in 2005. These improvements and the facilities have made the cities more attractive for people to move to and so the cities have grown to enormous size: for instance, at the end of 2004 the population densities in most big cities in this region have doubled or tripled the national average value (Bureau of Statistics 2005) (Figure 3.6).

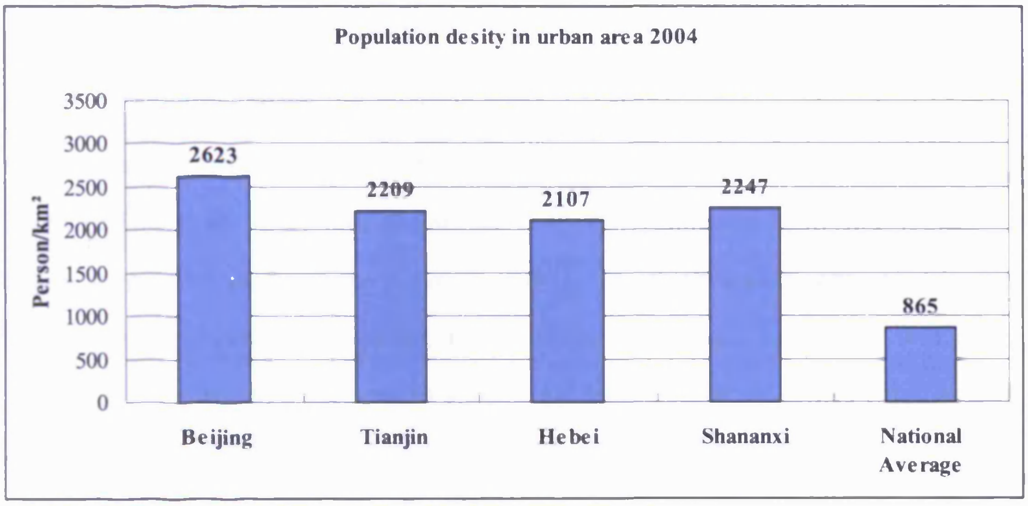


Figure 3.6: Population Density of Urban Areas. Source: (Bureau of Statistics 2005)

Driven by the increasing demand of people and the pressure to accommodate the increasing amount of urban population, there is an essential need to construct new dwellings;, hence there have been many erections of mass scale residential architectures in big cities, especially in recent years. The housing floor area completed in Beijing in 1998 was 22 million m^2 and the number grew to 45 million m^2 in 2005 (Bureau of Statistics 2006). If the sustainable housing design strategies could be formulated and integrated during the design and mass construction processes, the energy saving could be vast.

3.4.2 Climate Analysis

The climate in this region is extreme as it experiences hot summers and cold long winters; these conditions make it extremely difficult to produce energy efficient buildings. The analysis of such climates reveal the difficulties that one needs to face in order to design sustainable residential architectures that provide thermal comfort for its occupants, and climate design tools were used to help appreciate the climate condition more, and generate possible design suggestions for buildings in this region.

3.4.2.1 Air Temperature and Heating Degree Days

Air temperature is determined by the cooling and heating rate of the earth's surface. A warm surface heats the direct contact air layer by conduction, and then it heats the upper layers by convection (Givoni, 1981). It is obviously one of the most fundamental indicators of climate. Fluctuations or changes in climate will almost always be reflected in variations in surface air temperature; in general, this area has hot summers and long freezing winters with strong solar radiation all year.

Figure 3.7 shows the average monthly mean dry bulb temperatures in typical cities over a period of ten years, from 1996 to 2005. It is obvious that cities here experience hot summers and long cold winters. The summer season starts in June and ends in September; in these three months the mean maximum temperatures range between 25°C and 28°C, with a daily maximum reported around 35°C. From November to mid-March the next year, the temperature is quite low and the coldest month is January, when the monthly average temperature is around -3°C.

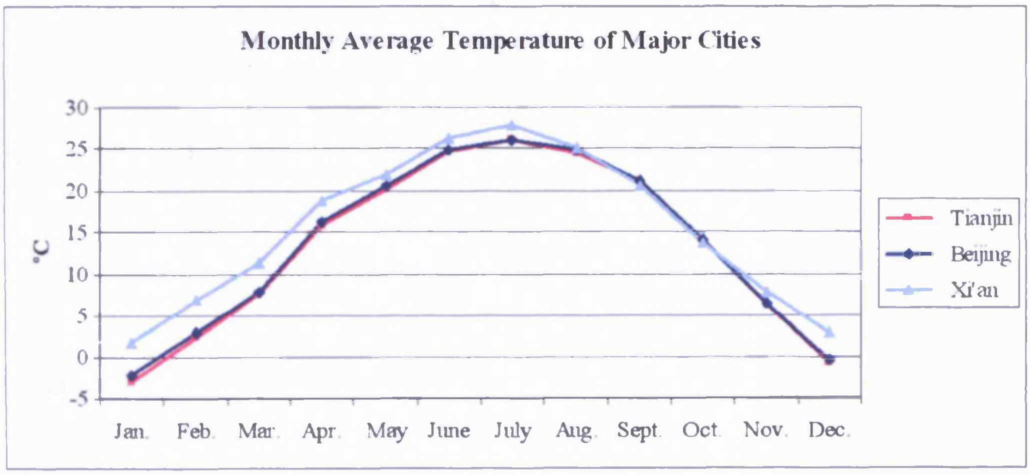


Figure 3.7: Monthly Temperature of Major Cities from 1996 to 2005. Source: (Bureau of Statistics 2005)

The extreme climates in summer and winter in this region have severe implications on the performance of poorly designed buildings; if environmental considerations are not implemented during the building design stage, it is likely to result in providing poor thermal conditions, or having a high energy use in order to maintain the indoor conditions.

Another crucial factor that can represent the climate condition is the Heating Degree Days (HDD), it is determined by the deference between the average external air temperature and a threshold temperature and the number of days that the external temperature that is lower than the threshold value. The external threshold temperature is normally defined as a temperature when it can be assumed that if the outside temperature is beyond this value then no heating is normally required. The interior spaces of the building can normally be heated passive by solar radiation and internal gains from occupants and equipments. In most countries including China, the value is defined as 18 °C (Ministry of construction 1996; Martinaitis 1998), however, there are exceptions, for instance, reference temperature in the UK is 15.5°C (Carbon trust 2007). Moreover, one has to be aware that the threshold temperature is not the desired indoor temperature, it is the representative data that is designed to reflect the demand to heat a home or other building types.

The heating degree day is mostly used to represent the severity and duration of cold weather, the colder the weather the higher the degree day value (Carbon trust 2007). Table below listed the heating degree days in North China (Data from Chinese building regulation JGJ 26-95) and some European countries (World Resource Institute 2003[1]).

[1] The data in this report is calculated with the threshold temperature of 18 degrees in all countries.

Country	Number of Heating Degree Days
Beijing	2450
France	2478
United Kingdom	2810
Germany	3252
Switzerland	3419
Sweden	4375

Table 3. 2 : Heating Degree Days Compare

From the data one can notice that the number of heating degree days in North China cities is at the similar range as France and UK and is much lower compare with Germany, Switzerland and Sweden. However, as mentioned in Chapter two, the average energy consumption of residential architecture in China is much higher than that in European countries, the above analysis hence indicates that such difference is not caused by the cold temperature, the possible reason lies in the building itself.

3.4.2.2 Relative Humidity

Relative humidity is the ratio of actual water vapor pressure to the saturation water vapor density under the current temperature (Goulding et al. 1992). Relative humidity displays variations within this region; generally in the summer period the humidity is high with an average of 60% to 70%, whilst in the winter period the humidity drops to below 55%, with the lowest value always appearing in February and March. The monthly relative humidity data for the ten-year period is shown in Figure 3.8.

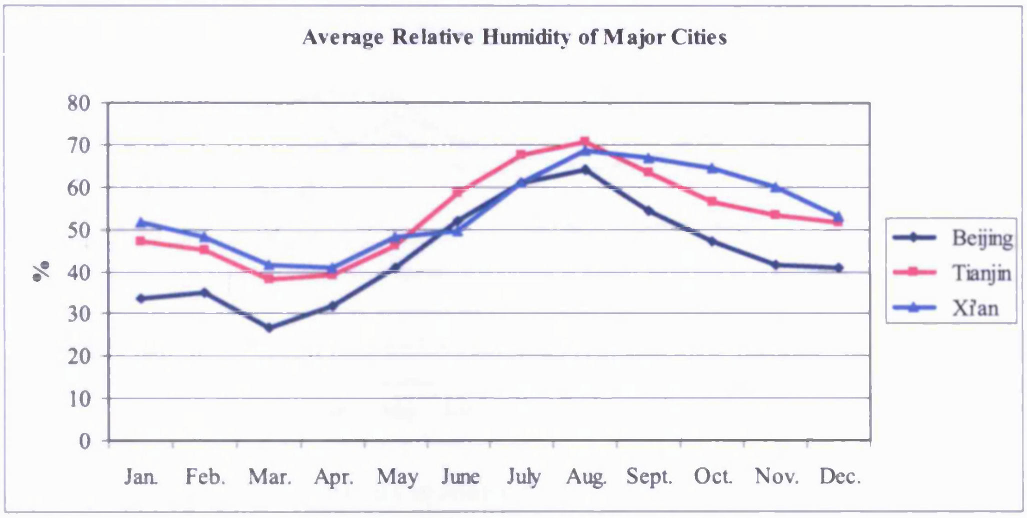


Figure 3.8: Monthly RH of Major Cities from 1996 to 2005. Source: (Bureau of Statistics 2005)

Architects and engineers should introduce applicable design strategies to increase indoor moisture in the air during winter time, and in summer to subtract the humidity of the microclimate and enclosure spaces of domestic buildings.

3.4.2.3 Solar Radiation

Solar radiation and sunshine duration provide information regarding the length of the day and cloudy periods when the intensity of radiation decreases (Szokolay 2004). In this region, the average yearly total sunshine time is between 2000 and 2800 hours, which means there are about 40-60% of sunny days a year. Figure 3.9 represents the conditions of the past ten years; the hours were longest in May ranging from 7 to 8.2, and lowest was in December, with an average value of less than 4.5 hours a day.

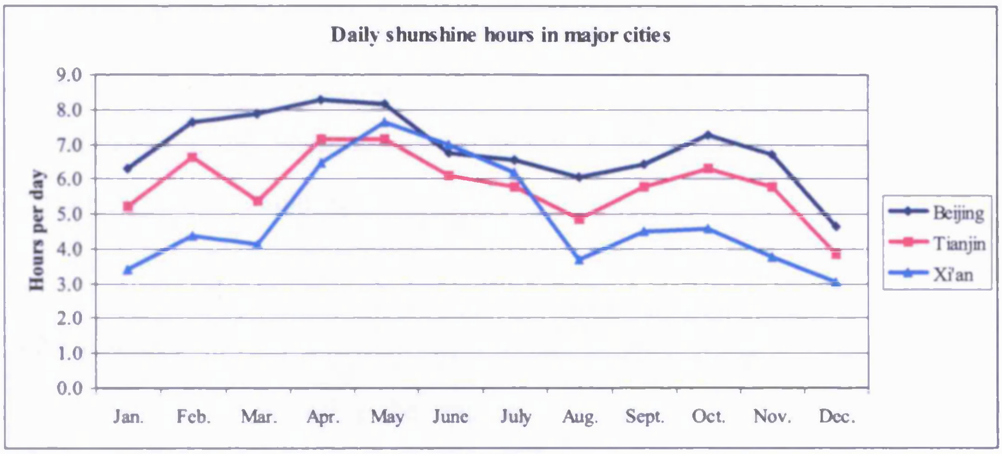


Figure 3.9: Daily Sunshine Hours in Major Cities from 1996 to 2005. Source: (Bureau of Statistics 2005)

Figure 3.10 demonstrates the average daily horizontal solar radiation amount in 2002. The lowest values appeared in December and the peak values were recorded in May or June, with the value varying according to the latitude location of cities.

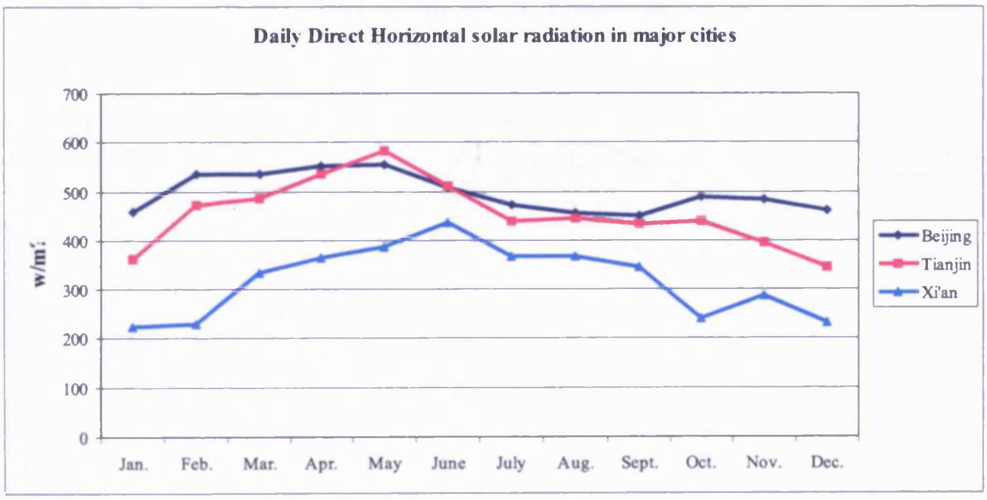


Figure 3.10: Average Daily Solar Radiation in Major Cities in 2002. Source: (U.S. Department of Energy 2006)

Therefore, according to the climate zoning regulation published by the Department of Architecture Construction (Department of Architecture Construction of China 1994), buildings in this area need to consider the influence of the strong solar radiation and heat gain through the constructions; domestic building design should take this into consideration and find possible ways to minimize the impact of direct and reflected solar radiation on the buildings.

3.4.2.4 Rainfall

Rainfall mainly occurs during the summer and autumn seasons, and snow in the winter period can also bring water to the region. It rains about 60 to 100 days a year and the total rain amount is around 300-1000mm, with the maximum daily rain amount being about 200-300mm. Figure 3.11 shows the monthly rain amount in major cities in this area: it can be seen that July and August have more rain than other months, with maximums amount ranging from 100-120mm; January and December are the driest months with generally less than 10mm rain.

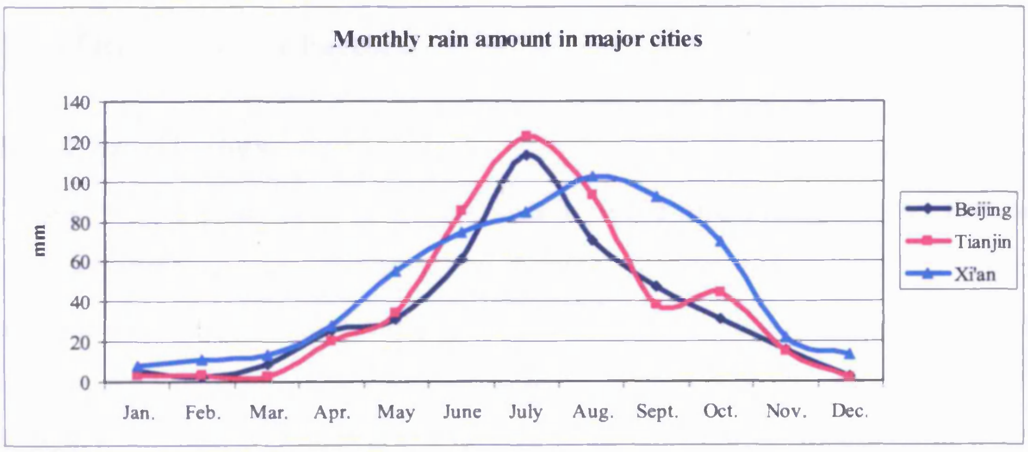


Figure 3.11: Average Monthly Rain Amount in Major Cities from 2000 to 2005
Source: (Bureau of Statistics 2005)

Generally, the water resource in North China cities is in severe shortage (Ministry of Water Resource of China 2000), hence the consideration of water conservation, like harvest rain water, should be adapted.

3.4.2.5 Wind

Wind has a direct effect on the micro-climate and indoor condition of buildings. According to the data from Bureau of Statistics, in this region, the winds blow from the North during December to February, and in the remaining period the wind direction is from the South. In some cities in eastern parst of the region, the wind normally blows from the East due to local geographical conditions. The average monthly wind speed is 1-4m/s, with the windy period being from March to May when the average wind speed is up to 2-5m/s. Periods of heavy winds are about 5 to 25 days and some cities in the western parts have about 50 days a year.

The planning of residential buildings should be made according to the local wind conditions, in order to avoid the North wind in the winter and use the summer breeze from the South to increase the chance of natural ventilation.

3.3.3 Other Related Factors

3.3.3.1 Social Factors

Traditionally, typical housing in this area is wood structured, and the famous courtyard housing style "Siheyuan", was very common here in the old times, especially in Beijing and Taiyuan. Another very distinctive housing type is the cave house in the Shanxi province; details of those buildings will be introduced in Chapter 5. At present there is not much of this kind of building left in cities because wood materials cannot last for a long periods, and the newly developed housings are primarily built with concrete and steel.

As mentioned above, the lack of water resource is one of the most apparent characters of this area: water resource is not satisfactory in both quality and quantity, and the storage per capita in this area is only one third of the national average. The eastern part, where the economical development is more advanced, has an even worse situation because of the pollution caused by the heavy industries, which resulted in a large part of the resource being unsuitable for use in daily life. Therefore, water saving methods and equipments should be introduced to built environments during the design and construction process. Moreover, this part of China is the prime coal producing area; therefore, the main energy resource is based on coal industry, and the overuse of coal has already damaged air quality in coal producing cities and led to related health issues, thus bringing energy conservation strategies could also reduce the pollution and health problems.

Data from Bureau of Statistics (2005) also showed that income distribution in this part also varies greatly, with some wealthy places like Beijing and Tianjin city having an average per capita income of £1,142 and £818 respectively— which is much higher than the average national value of £675; however, in places like Xi'an and Gansu provinces, the average income is only near £530, therefore the increasing energy bill of the home had increased the burden of the low income people. Cutting energy bills for homes also increases the possibility for people to purchase products to help improve the quality of their lives.

Most provinces in this part of China had experienced rapid economic progress in the past two decades; therefore the old cities are being changed into larger and more modern ones, and there is a substantial amount mass scale residential buildings being erected. The common housing being developed in this region is high-rise building clusters, with inside facilities for each household and most of the new development has their own fence outside, which detaches them from the street. According to the report from real estate branch in 2004 (City Express 2005), typical floorage that people here expected was roughly 100 m^2 and the favourite layout was three rooms plus a living room. The medium-rise buildings are preferential, but due to the land price and other reasons, recent developments were high-rise buildings that are generally over 20 floors high. However, due to the lack of sustainable strategies during design and construction process, most of buildings perform poorly in terms of thermal comfort, which has caused great energy inefficiency and demanded huge amounts of artificial heating or cooling equipment (Chen et al. 2004).

3.3.3.2 Corresponding Regulation

The buildings here should satisfy the occupier's need of warmth and keep both the house and people at an appropriate comfort condition during the winter. Therefore, the heating and building envelop should be designed with care, and houses in Zone Two also need to consider preventing overheat in the summer period. Secondly, housing layouts have to have an optimal response to local climate in order to gain enough natural sunlight and ventilation. Moreover, they should also guard against the cold winds in the winter season and rainstorms in the summer.

Considering the climate, all the buildings in this area are required to be equipped with central heating for cold winters; different areas can have their own regulations about the heating period, but generally it is from mid-November to mid-March each year. Moreover, most places also need to use air conditioning systems in the burning hot summer. These systems have resulted in buildings in this area having the greatest energy consumption through HVAC systems; therefore the Ministry of Construction (MOC) has put much more emphasis on this area than other places in the nation. Buildings here are asked to make maximum use of their natural resource, i.e. solar energy and natural ventilation, etc., and adapt passive strategies in order to reduce heating and cooling loads, hence cutting the energy consumption and household energy cost.

As described in the previous chapter, the demand for heating energy reduction is mainly focused on this area and North East China The general requirement for this area is to reduce the heating cost, and also give considerations to cutting down the cooling load. It is expected that compared with the energy standard of housings in the 1980's, the new buildings from 2006 will use 65% less heating energy.

3.4 Climate Design Tools

The main aim of this research is to find the most appropriate, applicable and efficient design strategies for North China, and understanding the climate conditions better will help in achieving this objective. The climate design tools can analyze and display the climate characteristics, and be used to assist at the early design stage of climate integrated design, providing the designer with a better chance of understanding the advantages and limitations of the climate.

Mahoney's Tables is a traditional tool that is still useful today, and it will be used in this research as well. On the other hand, the presences of model simulation tools gives the user the chance to analyze climate conditions faster and more accurately, and provides a better visualization, including 2D and 3D graphs. The WeatherTool V2.0 computer program, built in Ecotect, was designed to be used to analyze hourly based weather data.

3.4.1 Analysis though Mahoney Tables

The Mahoney Tables (Koch-Nielsen 2002) provide a guide to design in relation to climate using readily available climatic data. By following a step by step procedure the designer is led from the climatic information to specifications for optimal conditions of layout, orientation, shape and structure needed at the sketch design stage. It bases temperature and humidity as its main factors, and along with supplementary information of rainfall amount and wind direction, it describes the thermal stress of each month and expresses the climate as an indicator, which is finally used to suggest a general solution in terms of climatic design consideration for a specific building on the site, such as form, orientation, opening size, etc.

After plotting climate data for typical cities in climate Zone Two in China (example of Mahoney table is listed in the Appendix A2), following recommendations relate to building design parameters were generated:

- Compact courtyard planning
- Medium openings, 25 - 40%
- Heavy internal and external walls; over 8 hours' time lag
- Heavy roofs; over 8 hours' time lag

3.4.2 Analysis Through WeatherTool

Modern tools like Ecotect WeatherTool can turn the numbers and tables of data into vivid 3D graphs, as well as wind roses and sun-path diagrams. Weather data of those cities were acquired from the 'Energy Plus' website and then transferred into a format that is readable in WeatherTool. Major cities in climate Zone Two share a similar climate profile, therefore this chapter mainly uses the weather file for Beijing as its demonstration; the description of Tianjin and Xi'an city can be found in the Appendix.

3.4.2.1 Visualization of Data

One of the causes of energy inefficiency building design is the lack of understanding (or misunderstanding) of the local climate. The main key features of WeatherTool is the way it allows you to visualise weather data; for instance, presentation of the climate data on a weekly summary basis gives designers a quick and easy understanding of the climate conditions and identify its main characters hence they will be prepared for the environmental strains that may occur. Moreover, instead of indentify the data factors one after another, the presentation allows one to visualise the full range many factors of climate data at once.

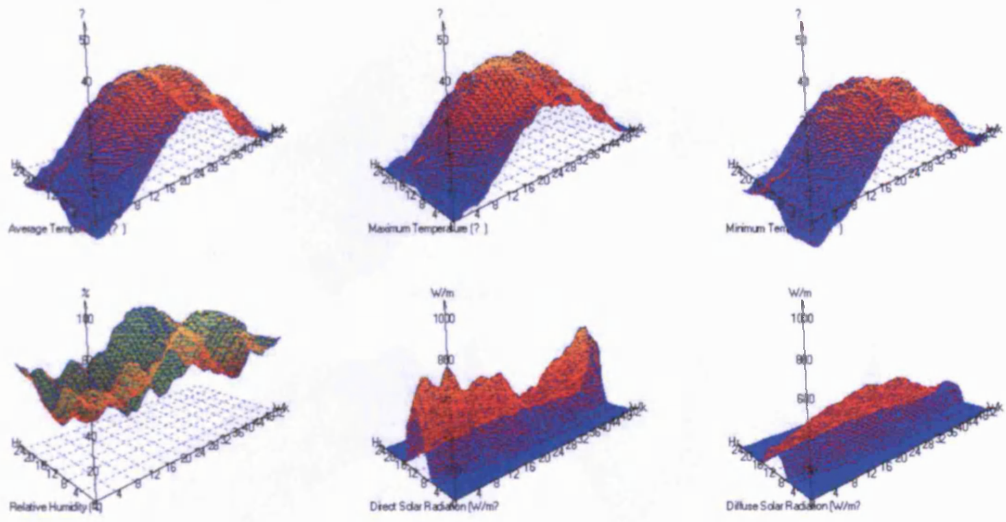


Figure 3.12: Weekly Climate Summary of Beijing, using WeatherTool in Ecotect

Moreover, visual comparison of the weekly climate summary between the site climate and other cities can demonstrate the climate character better. The graphs below compared the temperature and humidity of Beijing and European cities; it is clear that Beijing has very high temperatures in summer period and the winter temperatures reach minus values, whilst relative humidity is low all year long. Again, the comparison proved that the climate conditions in North central China are extreme and environmental considerations need to be adapted to ensure buildings in this area minimize the energy use while providing adequate comfort.

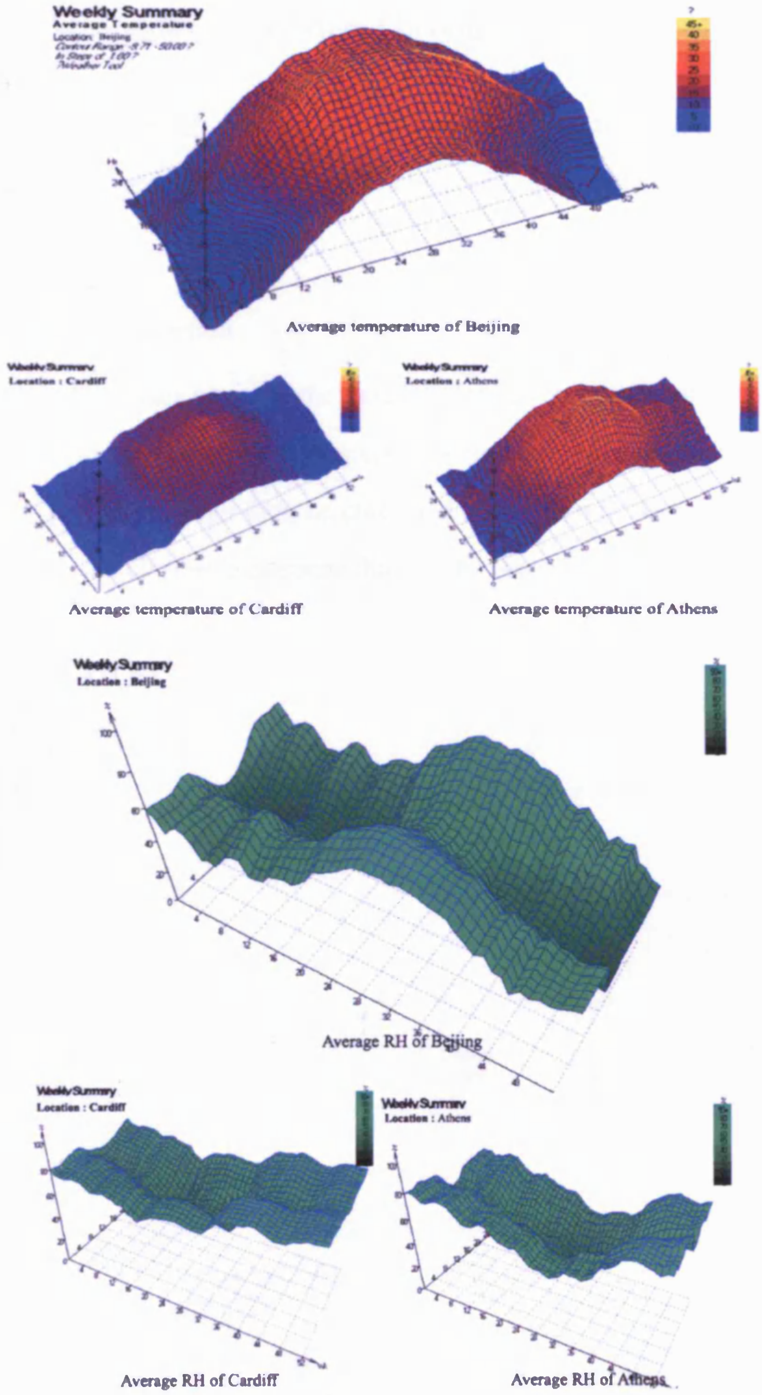


Figure 3.13: Comparison of Weekly Average Temperature and RH in Three Cities, Using WeatherTool in Ecotect

3.4.3 Design Strategies Generated Through WeatherTool Analysis

Besides presenting climate data in 3D graphs, WeatherTool also embeds some traditional methods that can provide deep analysis of the climate.

3.4.3.1 Climate Classification

Climate classification can position the yearly climates into different categorises, by overlaying the monthly maximum temperatures and humidity on the psychometric chart. All parts of the year can then be classified into different zones, which can help people to identify the climate conditions throughout the year.

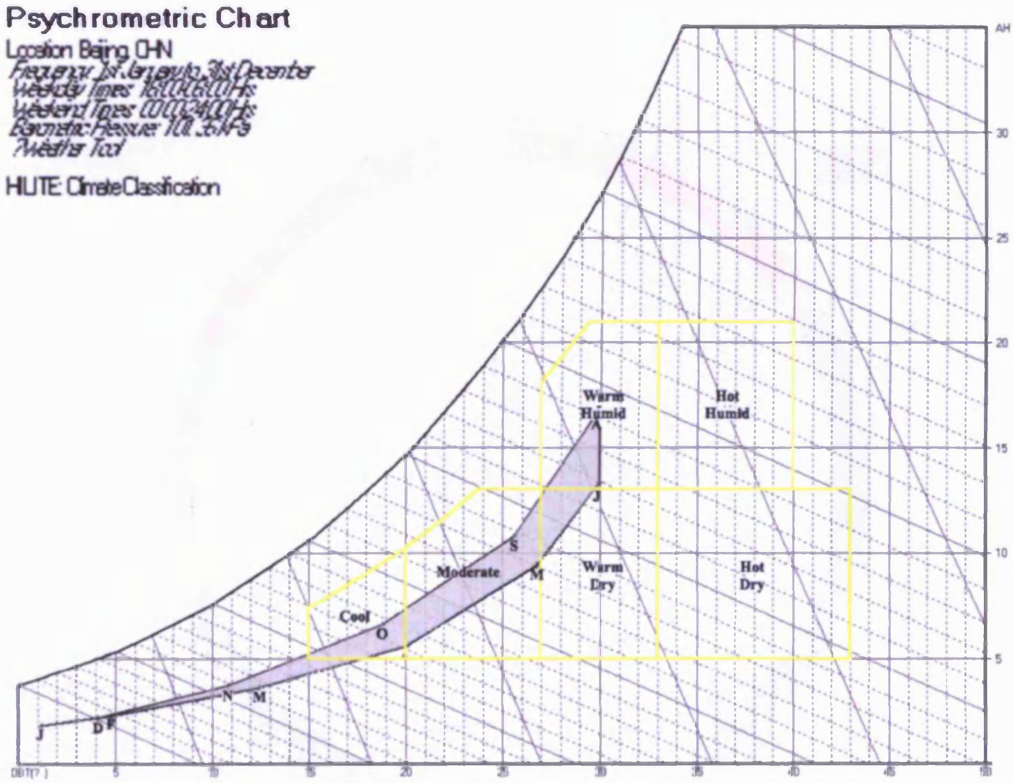


Figure 3.14: Climate Classification of Beijing, using WeatherTool

Figure 3.14 represents the result of this analysis for Beijing. One can see that weather in May and September are moderate whilst the rest of year is either too hot or too cold.

The extreme conditions always happens in January, February and December when the air temperature drop to a very low level, thus the climate can be considered as a dry climate with freezing winters and hot summers.

3.4.3.2 Optimum Solar Orientation:

The WeatherTool features can plot the solar radiation values for the overheated/ under-heated periods during the year at different orientations. The basic method is to calculate the solar radiation on a $1m^2$ vertical surface over 360 degrees under that climate. This can help to determine the unwanted solar radiations in summer. Figure 3.16 shows that the best optimum orientation for Beijing is 160° to 180°, so buildings should be arranged toward the North-South orientation in order to maximise the natural solar energy.

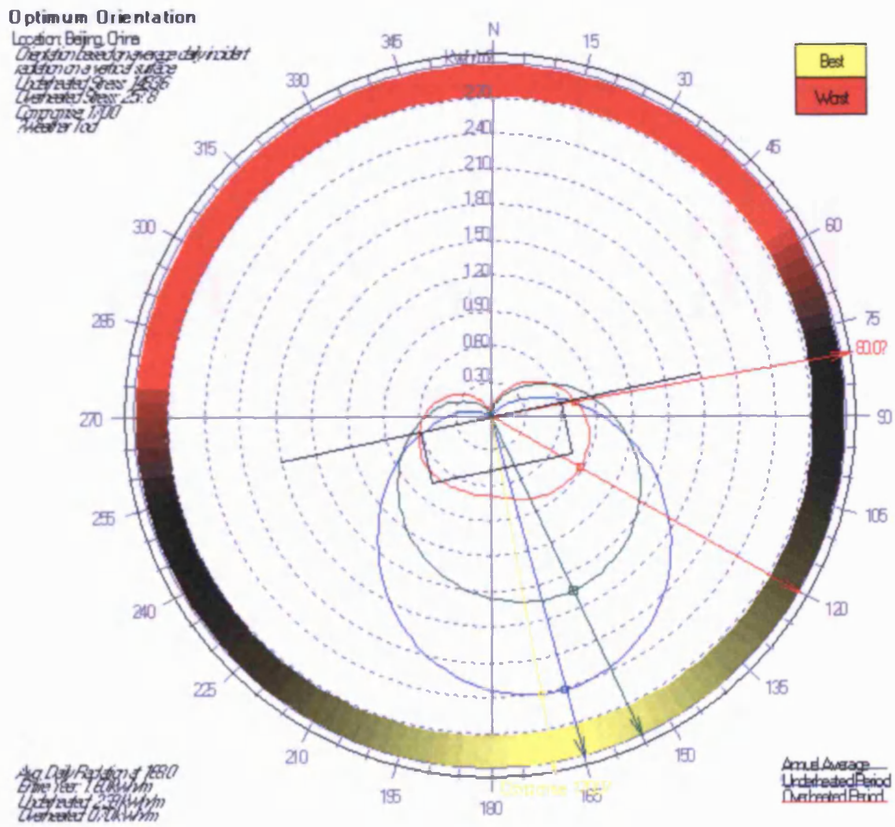


Figure 3.15: The Optimum Solar Radiation for Beijing, using WeatherTool

3.4.3.3 Passive Design Strategies Analysis

The Psychometric Analysis Chart developed by Szokolay in 1987 is the basis of WeatherTool's calculation methods (Marsh 2004). The benefit of the chart is that it can determine the potential effects of a series of passive design strategies, so one can acknowledge the most effective methods to improve the thermal comfort in this climate. It can also be used to generate possible combinations of strategies by comparing the percentages of comfort time, before and after. Figure 3.17 compares the improvements in comfort percentages by adapting a series of passive design strategies. Considering their effectiveness and adaptability, possible combinations could be: natural ventilation, thermal mass effects, night-purge ventilation and passive solar heating.

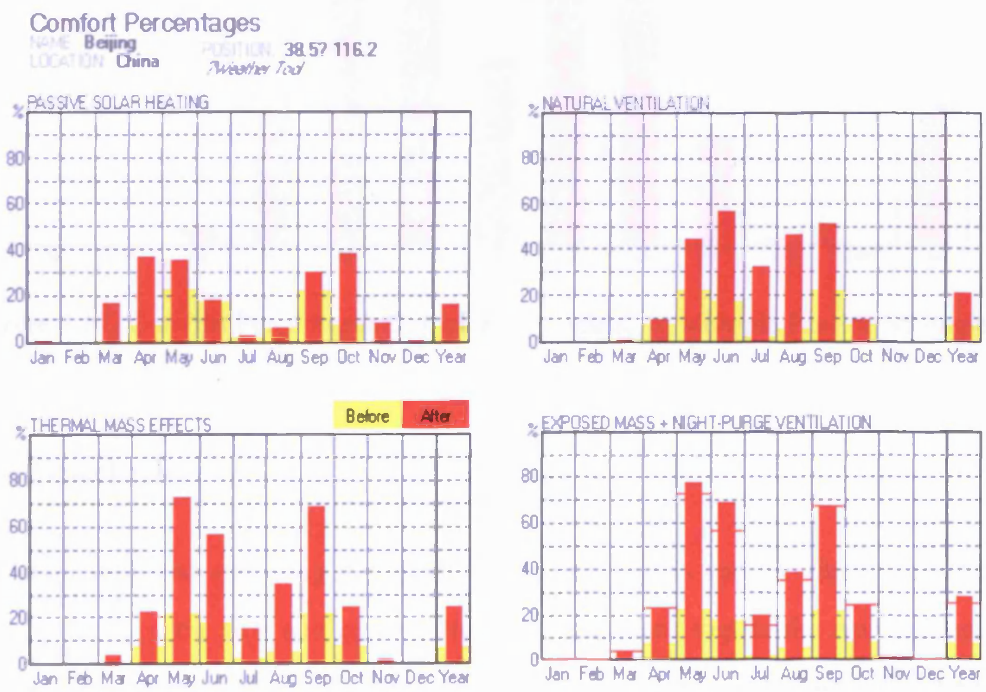


Figure 3.16: Comfort Percentages Before and After Using Different Passive Strategies.

By combining the appropriate strategies mentioned above, it can be seen from the graph in Figure 3.18 that the comfort percentages in summer were greatly improved;

however, in the winter period the situation cannot be completely solved by using those methods. Passive strategies and improved insulation properties of the building skin should be adapted.

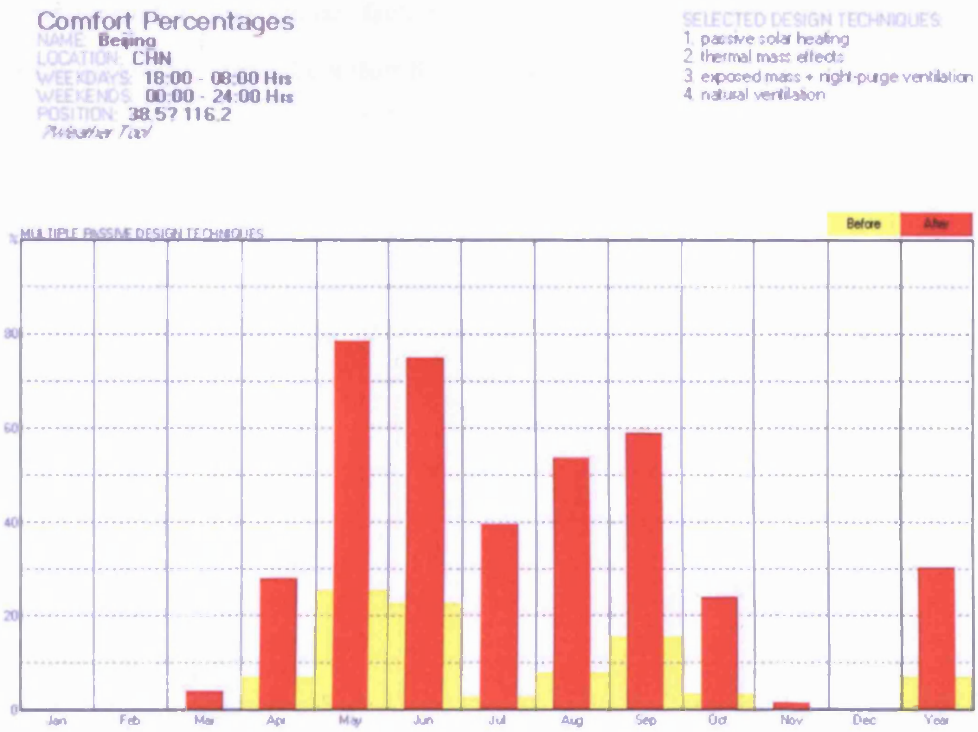


Figure 3.17: Comfort Percentages Compared by Adapting Multiple Passive Strategies

3.5 Conclusion

Understanding and analyzing the local climate of a region and its' thermal comfort requirements, is the first and perhaps the most important step in the environmental design. This chapter studied the main climatic and geographical features of different climatic zones in China, Zone II in particular. The analysis showed that this cold protection is very necessary for the buildings in this area and also not to neglect the protection from summer overheating. The study also found that the heating degree day value of North China is no greater than European countries and hence the excessive use of energy in building in China can be concluded as the fault due to building design and construction. Moreover, by using climate design tools, possible environmental design methods were also suggested.

The next chapter will focus on the thermal comfort condition of buildings, including the environmental and human factors affecting thermal comfort and introduce the possible ranges for thermal comfort for North China cities.

CHAPTER FOUR: THERMAL COMFORT CONDITIONS FOR BUILDINGS

4.1 Introduction

As Fanger (1970) mentioned, people spend most of their lives in man-made spaces therefore the indoor environment has a great impact on the occupants, including their heath and productivity, etc. Consequently, achieving a high quality internal space has long been one of the most dominant issues during architecture design; it is also generally accepted that thermal comfort is an important factor of the indoor environment quality, as most peoples direct senses are related to the surrounding thermal environment.

In order to achieve thermal comfort, certain factors such as air temperature, air velocity and relative humidity, etc., have to match within specified ranges, which is often referred to as the 'comfort band' (Fahad 2005). The following chapter aims to explain the indoor thermal comfort of humans and the important factors that determine its criteria.

4.2 Thermal Comfort

4.2.1 Definition

The research in interior thermal comfort has been an ongoing area in environmental science; many researches have been done in order to find the determinate criteria of human's comfort condition. All the studies share a common understanding that people should be satisfied with their buildings and live in a comfortable indoor environment, as a man's intellectual, manual and perceptual performance is improved when he feels neither cold nor warm (Fanger 1970).

Thermal comfort is defined in British Standard BS EN ISO 7730 as: '*that condition of mind which expresses satisfaction with the thermal environment.*' Givoni (1976) also believes that thermal comfort is '*the absence of irritation and discomfort due to heat or cold, and as a state involving pleasantness*'. Alternatively, it is the state where the person is entirely unaware of their surroundings, neither considering whether the space is too hot or too cold (Strathclyde 2007). All these and other definitions of thermal comfort represent and emphasise one concept: that thermal comfort is a condition in which the individual feels neither too cold nor too warm whilst wearing an amount of clothing suitable to the task they need to perform.

4.2.2 Factors Affecting Thermal Comfort

There are several environmental factors that affect thermal comfort. Six important factors are shown in Figure 4.1: air temperature, mean radiant temperature, humidity and air velocity (air movement) and personal factors such as metabolic heat (activity level) and clothing insulation of individuals (Konya 1980).

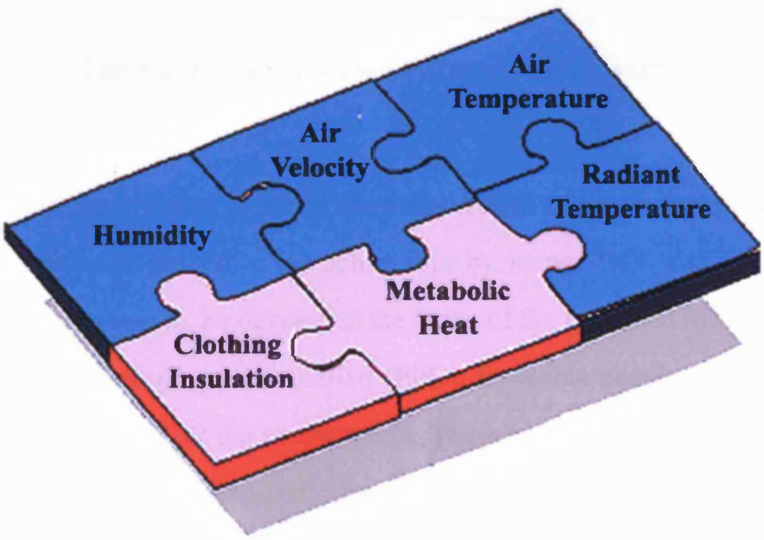


Figure 4. 1: Six Important Factors of Thermal Comfort. Source: (Health & Safety Executive 2007)

However, the response of the individual human body to the thermal environment might be a personal response, which may vary from culture to culture according to the difference in physical condition and physical activity. Although during Fanger's test in 1970 he found that there is no significant difference in comfort perception due to geographical location, season, age, gender, body-build and ethnic origin of the group (Fanger 1970), we still cannot determine a range of conditions where all people using the same room feel comfortable.

Scale value	Sensation
+3	• Hot
+2	• Warm
+1	• Slightly warm
0	• Neutral comfort
-1	• Slightly cool
-2	• Cool
-3	• Cold

Table 4. 1: Thermal Sensation Scale – A Seven Point Psychological Scale

The approach of determining at which state that a high percentage of people will fell comfortable has been proven to be achievable by using PMV and PPD votes. In Fanger's previous research, he developed the index of the Predicted Main Vote (PMV) and the Predicted Percentage Dissatisfied (PPD), to enable people to categorize and report their feelings towards the environment. These two votes have been used as the basis of the International Standard Organization ISO-7730 to evaluate moderate thermal environments. Table 4.2 shows the thermal sensation scale of thermal comfort developed on Fanger's experiment; the diagram shows the relationship between PMV and PPD (ASHRAE 2005).

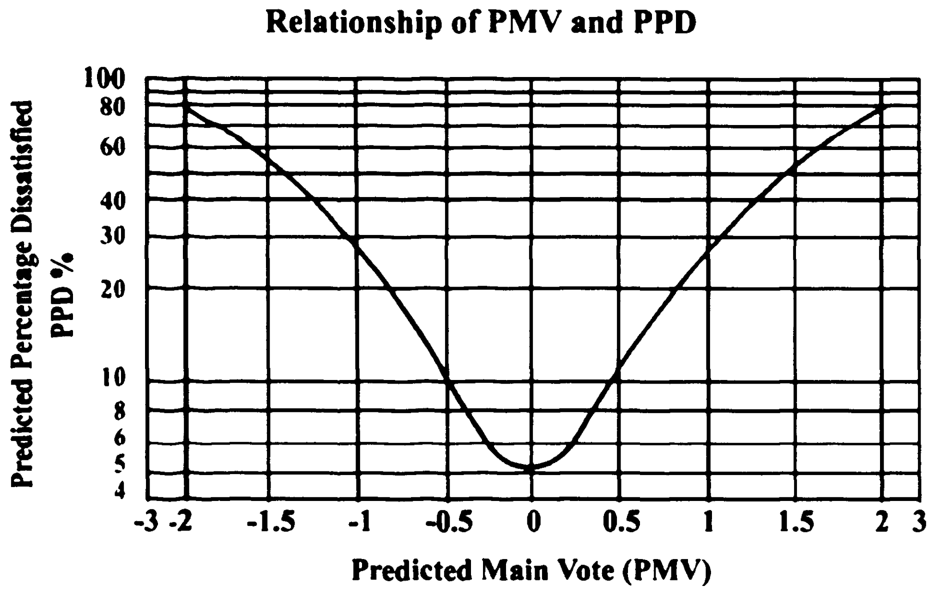


Figure 4. 2: The Relationship of PMV and PPD. Source: (Fanger 1997)

The best that people can realistically hope to achieve is a thermal environment that satisfies the majority of people in the space, or put more simply, 'reasonable comfort'. Fanger (1970) claimed that, in general, a comfort zone is an environmental situation in which 80% of the occupants feel satisfied with their environment, and the HSE (Health & Safety Executive) in the UK also considers 80% of occupants as a reasonable limit for the minimum number of people who should be thermally comfortable in an environment (Health & Safety Executive 2007).

However, most of the previous researches are focused on office work places, and there is not enough literature in the area of residential architecture. One of the fundamental reasons for this is because the peoples' activities and clothing levels are quite flexible at home: occupant can easily change their clothes and have independent control of heating or cooling equipments to improve the thermal comfort level of their homes. The following sections will try to address the important factors that affect the thermal comfort conditions in domestic architectures, particularly under the condition of Chinese cities. Features like heat-balance and heat-exchange between people and the environment, environmental and personal factors that influence the thermal comfort in homes, will be discussed in following sections.

4.2.3 Adaptive comfort

Adaptive comfort is also an important factor that influences people's perception of thermal comfort. People have a natural tendency to adapt to changing conditions in their environment. This natural tendency is expressed in the adaptive approach to thermal comfort (Nicol and Humphreys 2002). The basis of this theory is developed from Humphreys' Adaptive Principle: "*If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort*" (Humphreys 1997).

Previous research work indicated that people seem to be able to tolerate a wider range of indoor temperature in natural ventilated buildings than air-conditioned ones (Brager and de Dear 2001). Similar statement was also made by Baker and Standeven (1995) that when people have a possibility to control their environment (being able to open a window, for example) they are more easily to be thermally satisfied.

Therefore, if the design of dwellings in China can provide occupants the chance to adjust the indoor conditions to suit themselves then the need to use artificial cooling methods to achieve thermal comfort can then be effectively reduced. The adjustment includes the use of shading, opening the windows to increase the air movement etc.

Though the adaptive method is proven to be quite useful in reducing summer cooling demand, however there is little support showing this will work in winter. The choice to adapt to cold environment is limited, people can only wear more cloth or to increase body metabolic rate by shivering (however, this can also be considered as thermal discomfort). The preceding literature review shows that there is little evidence to suggest that wider tolerance of thermal conditions is expected in very low temperature (Brager and de Dear 2001). Therefore the building design should aim to be able to provide an indoor condition at a range that the majority people will feel comfortable and also provide opportunities that allow people to modify it based on their requirement.

To sum up, the study of adaptive comfort indicated that it is more efficient in reducing cooling demand and building design should provide its occupants adequate opportunities to adjust indoor conditions. There is no evident showing such effect is adequate in winter and the reasonable comfort should be provided through building design.

4.3 Environmental Factors

Air temperature, mean radiant temperature, relative humidity and air velocity are environmental factors that have a major influence on thermal comfort. Correct combination of levels of the environmental factors can enhance the thermal comfort.

4.3.1 Air Temperature

Air temperature plays the most important role in contributing to thermal comfort because it affects the rate of heat transfer between humans and their environment. Since the value is always measured with mercury or glass thermometers, it is called the Dry Bulb temperature (DBT). There is no exact ideal temperature that everyone will feel comfortable, the CIBSE guide (CIBSE 2006) recommended the general comfort indoor air temperature to be 19° C to 23° C in winter, and in summer the value should not exceed 27°C. Table 4.2 is the guidance published by the Canadian Centre for Occupational Health and Safety, which shows the appropriate level of temperature and human activities. Since China does not have detailed comfort regulations, the regulation in Canada where the climate condition is similar to Northern Chinese cities, can be viewed as a general guidance.

Temperature (°C)	Appropriate Activities
25	Optimal for bathing, showering.
24	People feel warm, lethargic and sleepy.
22	Optimal for unclothed people.
21	Most comfortable year-round indoor temperature for sedentary people or for performance of mental work.
18	Physically inactive people begin to shiver. Active people are comfortable.

Table 4. 2: Summarizes of Typical Responses to Various Temperatures. Source: Canadian Centre for Occupational Health and Safety

4.3.2 Mean Radiant Temperature

Mean radiant temperature (MRT) is the weighted average temperature of the surrounding surfaces of a space (Givoni 1981). It is responsible for the occupants' heat loss and heat gain by radiation, thus affecting his thermal comfort. It should be noted that the MRT, which is dependent on the indoor air temperature, should be kept equal or close to the air temperature, but not more than 3°C below it, otherwise the space will be 'stuffy' (McMullan 2002).

4.3.3 Relative Humidity

Relative humidity (RH) is the term that defines the amount of water vapour, as a percentage of the total vapour amount, which can be held in the air at a given temperature (Givoni 1981). It is a primary factor affecting the heat exchange between a body and the surrounding air by evaporation.

Martin Evans (Evans 1980) claims that relative humidity also relates to peoples health;

a RH value lower than 20% can cause discomfort due to the dryness in the air and will lead to cracked lips and sore throat; and a value over 90% will make people feel damp. A similar issue was also mentioned in the CIBSE guide (CIBSE 2006) as it recommended an optional range of RH of between 40% to 70%; any value above or below this appears to lead to illness.

4.3.4 Air Velocity

The movement of air helps to achieve comfort. For example, during overheated periods if the air temperature is less than the skin temperature, the air velocity improves the heat convection level to the environment. It also helps the skin to increases heat loss by evaporation, if the air humidity is lower than the skin humidity. Having an appropriate air velocity is important in dwellings; when air speed is too low, it may create a feeling of stuffiness, but an uncomfortable feeling will also occur if the air movement in the room is too big. Besides, ventilation can bring fresh air in the room, and night ventilation should be used to cool the structure of domestic buildings.

Table 4.3 describes how human occupants react to various conditions of room air motion based on Evans' (1980) previous research.

Air Speed (m/sec)	Typical effect on man
0 to 0.25	Some might complaint about stagnant air
0.25 to 0.5	Movement not noticeable except at low air temperatures
0.5 to 1.0	Feels fresh at comfortable temperatures, but may feel draughty at cool temperatures
1.0 to 1.5	Generally favourable at comfortable or warm temperatures
1.5 to 2.0	Draughty even at comfortable temperatures
2.0 Above	Acceptable only in extreme climate when no other relief is available

Table 4. 3: Various Air Movement Conditions for Thermal Comfort, after Evans

4.4 Individual Factors

Metabolic rates (activity levels) and clothing levels also play important roles in peoples thermal comfort, as they define the skin temperature and the insulation level of the skin and environment.

4.4.1 Human Metabolic Rate

4.4.1.1 Activity Levels

Every living human being produces heat at different rates through biological processes and metabolism is the term that represents this (Givoni 1981). The rate of the heat generated by a body depends on activities done by individuals (ASHRAE, 2001). As expressed in Figure 4.4, the metabolic rate of the body increases with activity, and the more active the body is, the more heat is produced. This has a significant effect on thermal comfort as it is a major cause of the heat produced within a human body.

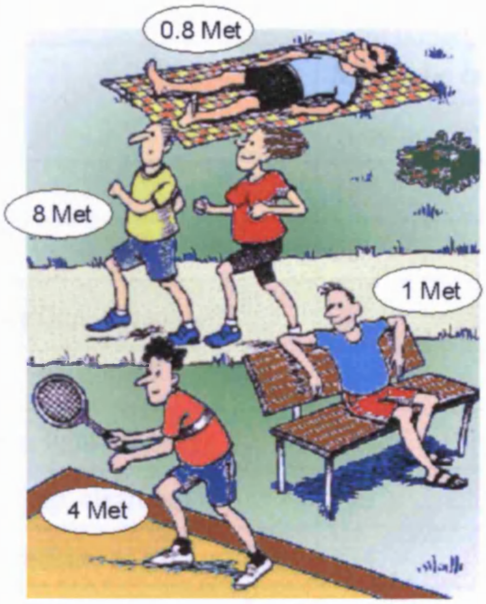


Figure 4. 3: Different Metabolic Rates Associated with Different Activities. Source: (Luma Sense Technology 2005)

The 'met' unit is used to determine the metabolic rate in ISO 7730. One 'met' is equal to 58.2 watt/m^2; the metabolic rates of different activities are showed in Table 4.4. People in their homes, in general, are considered to perform at sedentary activity levels, although this might vary in different rooms and during different periods. As a result, attention should be paid throughout the design process to reduce or reuse heat gain from human bodies and other subjects inside rooms.

Activity	Metabolic rate	
	W/m^2	Met
Reclining	46	0.8
Seated quietly	58	1.0
Sedentary activities (dwelling, school, office,)	70	1.2
Standing relaxed	70	1.2
Light activities (standing, light industry)	93	1.6
Medium activities (standing, cleaning)	116	2.0
High activities (heavy machine or garage work)	174	3.0

Table 4. 4: Metabolic Rates of Different Activities. Source: (ISO 7730)

4.4.1.2 Heat Balance and Heat Transfer

When the human body produces heat, it transfers the heat with the surrounding environment in order to maintain the body temperature within a comfortable range of between 35°C to 37°C. When the sum of the heat produced within a living human body and the amount of heat lost from the body is zero, the status is called heat balance. Heat loss and heat gain can occur through heat-exchange mechanisms such as conduction, convection, radiation and evaporation.

The first mechanism of heat exchange is conduction. According to McMullan (2002), conduction is 'the transfer of heat energy through a material without the molecules of the material changing their basic position'. The rate of the heat transferred by conduction is based upon various factors, such as the energy gradient, the surface area of contact and the thermal conductivity of the materials. As a result, care must be taken when choosing finishing materials for the floors and walls of domestic buildings.

The second mechanism is convection, where the body exchanges heat through the surrounding air. Temperature differences between air and the skin (or the clothing surface), and the air exchange rate, are two main factors that escalate the heat gain or loss from the body (Konya 1980). The body loses heat by convection if the temperature of the surrounding air is less than the skin temperature, and vice versa. Therefore, if the room air is beyond comfort level, then reducing the area of a body exposed to the surrounding air can minimize the amount of heat loss through convection. For example, people who live in hot climate such as Tianjin and Xi'an City should wear light, loose clothes during the overheated periods, to gain advantage of the convection and evaporative processes in order to lose body heat.

The third mechanism of heat transfer is radiation. Radiation is the electromagnetic energy emitted by objects in the form of photons and waves (Wikipedia). The texture and colour of the surfaces affect the rate of heat exchange. Rough surfaces, for instance, absorb and release more heat than flat surfaces. Hard-textured and dark coloured walls or roofs are good absorbers and good emitters of heat. On the other hand, smooth and white-coloured surfaces are poor absorbers and emitters.

Evaporation is the heat exchange process when the human body consumes heat to evaporate sweat, or when the skin surface is wet (Thomas 2006). Evaporation of sweat from the skin can extract some of the skin's temperature, which helps the body to feel cold.

4.4.2 Clothing Insulation

Clothing interfaces with the heat exchange processes of body surface and the surrounding environment, as it works as a layer of insulation that separates the skin from the surrounding environment, decreasing the sensitivity of the skin to temperature fluctuations. It is important to identify how the clothing may contribute to thermal comfort or discomfort.

Clothing is a potential cause of thermal discomfort, as wearing too much clothing may cause heat stress, even if the surrounding environment is not considered warm or hot. If clothing does not provide enough insulation, the wearer may be at risk from cold injuries such as frost bite, or hypothermia in cold conditions. Clothes are one of the easiest parameters that can be adapted and adjusted by an individual in order to achieve thermal comfort within given conditions (Luma Sense Technology 2005). One may add layers of clothing if you feel cold, or remove layers of clothing if one feel warm. Actions can be carried out by residents according to climate, such as removing some garments in summer or putting on jumpers in winter. However, it is very difficult to assume an accurate value of clothes, as this can vary from culture to culture. The choice of clothing is influenced by social and cultural factors, such as fashion, custom or religion.

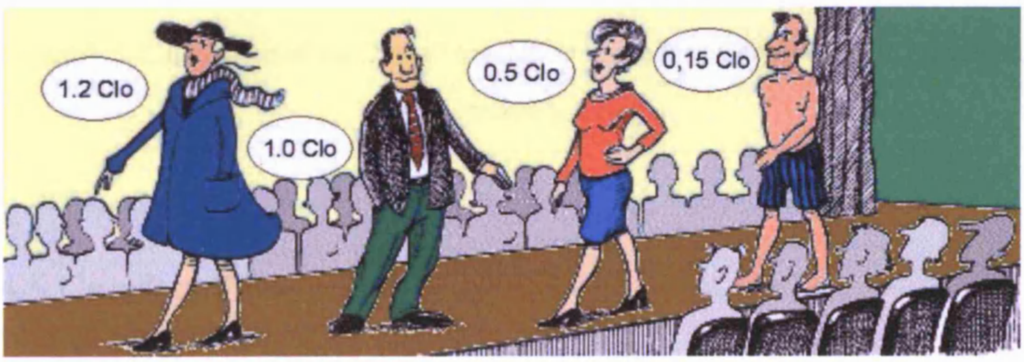


Figure 4. 4: Insulation Values for Typical Combinations. Source: (Luma Sense Technology 2005)

The unit which has been used to describe the factor of clothing thermal comfort is known as the insulation value (clo): basic measurement for the thermal properties of clothing. A naked person has a clo value of 0.0 and someone wearing a typical business suit has a clo value of 1.0, but the person needs to be comfortable at 21 °C, where relative humidity is less than 50% (Marsh 2004). An overall clo value of a person can be calculated by simply taking the clo value for each individual garment worn and simply adding them together. One clo unit equals 0.155 m^2K/W of insulation, and normally the value ranges between 0 clo to 4 clo (McMullan 2002). Figures 4.5 and 4.6 show the clo value of different types of clothes and typical combinations in altered occasions. These values can be directly applied to China where people wear similar clothes as in European countries.

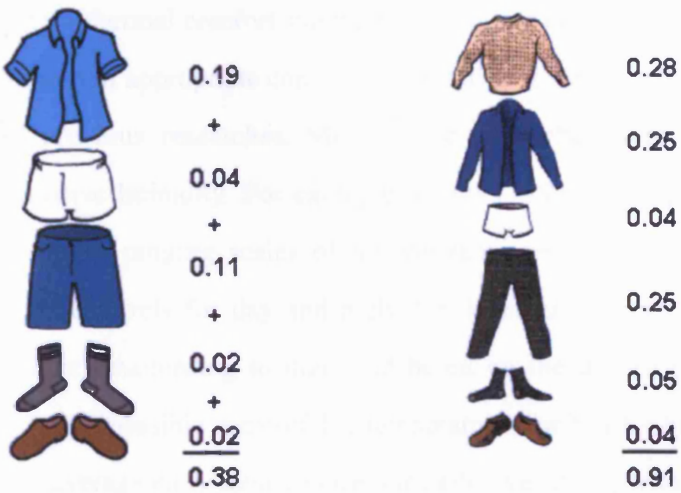


Figure 4. 5: Calculation of the Overall Insulation Value for a Certain Clothing Garment. After Innova booklet.

4.5 Comfort Zone

As mentioned at the beginning of the chapter, thermal comfort is a concept that depends on human experience—it is impossible to find an informal condition that can satisfy every single occupant. The theory of 'comfort zone' can only be considered as a relative concept. The graphs referenced in this chapter also only demonstrated the relationships of certain factors that can give a comfortable feeling to a majority of people.

In 1958, McFarland (McFarland 1958), defined comfort as an environmental condition where more than 50% of the occupants feel neither cold nor warm, and do not need to adjust their environment. However, as mentioned in section 4.42, Fanger claimed that a comfort zone is defined as an environmental condition in which 80% of the occupants feel satisfied with their environment (Fanger, 1970). The range of the comfort zone varies among indices and scales, and there are no rigid boundaries for thermal comfort.

China does not have a thermal comfort standard for building design (Yao et al. 2002), therefore the definition of appropriate comfort band in this research was based on the suggestions from previous researches. Most of the researches were based on air temperature and relative humidity. For example, Evans (1980) developed a comfort zone scale, which gives ranging scales of the desirable temperature for sedentary activities with clothing levels for day and night for different seasons, based on the relative humidity level. According to that (and based on the discussion in section 3.4.2.2 in chapter 3), the possible comfortable temperatures for North Chinese cities in the cooling season (average daily temperature normally over 25°C) with high relative humidity (50% to 70%) should be between 26°C to 29.5°C during the day, and 25°C to 28.5°C during the night. During the heating period (normally from November to March each year) room temperatures should be maintained around 22.5°C to 18 °C and 20 °C to 16 °C, at day and night respectively. A detailed description is provided in Table 4.5. Another interesting finding from the graph is that in cold seasons, the humidity has little effect on comfort.

The data from the graph indicates that night comfortable temperature in winter period can be a bit lower than day-time, however, most of the existing heating system currently being used in North China cities do not have control of the operating temperature, therefore the consideration of the indoor temperature was assumed to be maintained at the same level all day long in further part of the thesis.

	Heating season*		Mild period**		Cooling season***	
Average RH%	Day	Night	Day	Night	Day	Night
0-30	22.5-18	20-16	30-22.5	27.5-20	32.5-29.5	29.5-27.5
30-50	**22.5-18**	**20-16**	**28.5-22.5**	**26.5-20**	30.5-28.5	29.5-26.5
50-70	22.5-18	20-16	**27.5-22.5**	**26-20**	29.5-26	28.5-25
70-100	22.5-18	20-16	27-22.5	24.5-20	29-25	28-24

* Warm winter cloth and thick bedding **Light summer cloth and a blanket at night
***light summer cloth and a sheet at night

Table 4. 5: Comfort Zone Limits. After Evans.

By using the above suggested value ranges and the recommendations from the related researches in North China cities (Li and Zhu 2005; Yang and Feng 2000; Zhao 2005), the appropriate winter indoor temperature should be controlled around 21°C and summertime indoor temperature should be controlled around 26°C. However, this can only be a guidance for the research further on, such as calculation of heating and cooling load to maintain indoor conditions in above ranges, as it is not sufficient to define an absolute comfort zone for everyone. As Baker (Baker 1994) insisted '*...comfort is a far more holistic experience, being dependent upon the interaction of many environmental factors, the variability and options that the environment offers, and the ability of the occupant to determine those options...*' Moreover, due to the lack of information in thermal comfort studies in developing countries like China, it is even more difficult to determine specific comfortable limits of air temperature and relative humidity.

4.6 Conclusion

This chapter studied people's concepts and perception toward thermal comfort conditions, important factors including temperature, air movement etc. were discussed. The study of adaptive thermal comfort theory showed that people have a natural tendency to adapt to changing conditions in their environment and preceding literature indicated that providing modification possibility can reduce cooling demand.

Together with the findings in Chapter Three, it is clear that the natural climate of North China is extreme (with cold winter and hot summer), and in most periods the natural environment is outside of the required comfort zone the majority of the time. Giving the consideration of the climate conditions, it is necessary to use the help of artificial equipment, like central heating systems or electric fans and air conditioners, to assist in maintaining the indoor comfort condition. Hence, extra precautions are needed to be considered during the design process in order to minimise the use of such energy and to try to achieve thermal comfort for dwellings with environmental design methods.

Moreover, although there is no absolute universal comfort temperature, the study suggested that the possible comfortable indoor temperature for winter is about 21°C and 26°C for summer. Therefore, the energy consumption predictions that will be discussed and examined in the following chapters are with regards to the amount of energy required to achieve, or maintain, the temperature ranges mentioned above.

The next chapter is the field study of current existing dwellings in North China cities, to investigate their current indoor thermal conditions. The study also includes measuring and analyzing the local external climate condition in winter.

CHAPTER FIVE: FIELD STUDY

5.1 Introduction

A field study is a useful way to answer research questions related to the thermal performance of current residential architectures in North China. This chapter describes the methods, processes and main findings of the field study, which was carried out in five domestic buildings in Tianjin and Xi'an cities in North China in the winter period (from the end of 2005 to the beginning of 2006).

The field study process included on-site observation and field measurements, both are considered as traditional and effective ways of research methodology (Gomm et al. 2000; Yin 2003). Site observations intended to collect building information including building construction information and surrounding context situation. Field measurements aimed to investigate internal spaces, assess and collect the cases thermal conditions including temperature, humidity and wall surface temperatures, and moreover, local weather data including temperature and solar radiation were also collected.

5.2 Objectives of the Field Study

Although with advanced computer simulation software it is possible to predict more precise internal thermal situations than before, they take place in artificially suggested situations. However, through field studies, it is possible to find out the real situation 'as they naturally occur' of the buildings in their context (Denscombe 2003) and obtain the measurement outside the 'purpose-built' laboratory (Robson 2002). Furthermore, results from on-site measurement can also validate and justify the computer model by comparing on site measurements with the computer simulation results.

The objectives of the field study are:

1- To investigate the current housing development situations in North China cities and identify possible problems that lead to energy inefficiency;

2- To evaluate the thermal performance of modern housing by measuring and assessing the thermal comfort statistics in case studies, including the internal temperature, wall surface temperature and relative humidity;

3- To measure the outdoor climate data during the period of indoor measurement.
4-Recorded data will be used as a validation criterion for future computer thermal modelling

Achieving the objectives will provide this study with adequate information that is needed to help achieving the main aim of this research. The findings of building and climate information could also assist the future computer simulations. It is also hoped that the results of the field experiments will help architects and decision-makers in China to have a better understanding of the current thermal conditions of domestic architectures in that area.

5.3 Processes of the Field Experiments

5.3.1 Time and Scale of Field Experiments

The field study was conducted from the end of October 2005 to the end of February 2006. Conducting the field experiments in wintertime is important because the major concern of energy efficiency in residential architectures in this area is how to effectively reduce household heating load. Monitoring the thermal condition in the winter period can assess the residential buildings current thermal performance toward the local climate situation, and hence help to identify current problems and determine possible solutions. However, due to the limitation of time and funding, the summer conditions of the case studies were not measured; the summer cooling load will be predicted from thermal modelling once the building model is calibrated.

The number of case studies has been limited to five, due to the limitation of time and equipments. Another important reason for measuring a relatively small amount of layouts is to focus in depth into each study. As Gomm (2000) mentioned, '"case study" refers to research that investigates a few cases in considerable depth, '*...the most difference of case study and social survey relates to the number of cases investigated and the amount of detailed information that the researcher collects about each case studied... whilst many social surveys gather only a relatively small amount of data from each case.*'

5.3.2 Selection Criteria of Case Studies

Select appropriate projects and getting permission to access and record measurements were the first steps in the field study. However, this was not an easy task. First of all, house is personal property, measuring data inside it correlates with privacy issues, therefore it was hard to find a large variety of choices since it is quite difficult to persuade owners to agree with the experiment in their homes, as they are concerned that the experiments would affect their privacy. Secondly, the building for the case study also need to be able to provide stable and safe locations for the data loggers to ensure them can record realistically the indoor condition without been hampered.

Fortunately, this field study also served as part of the co-operation research projects of the Welsh School of Architecture with Tianjin University (Li and Jones 2005) and Xi'an University of Architecture and Technology (Li et al. 2006). Support was provided by those universities, hence the author was able to acquire local housing development information and gain relatively convenient access to some of the buildings. Tianjin and Xi'an cities are appropriate for the location of the case studies as they are representative of cities in climate Zone Two; both are high in density and have similar climate conditions.

With the help from the above mentioned universities, after a number of visits to the related sectors, plans of the field experiments were approved and permission was granted to some housing projects.

Five adequate high-rise domestic buildings with good experimental environments were selected as case studies. The criteria selections are as follow: first, they are all medium to high rise residential architectures representing the typical context of contemporary housing design and thus fulfil the objectives and meet the scope of the field work. Secondly, the buildings represent the common situations like construction materials and building features of North China cities, like the 200mm concrete external walls with simple insulation. Thirdly, the owners are fully support of the measurements and can ensure the equipment to be placed in a secure location.

The first three case studies were in the XinYuan Cun housing project in Tianjin city and the subsequent two studies were in Xi'an city. The selection of case studies were intended to cover the current situation in housing design in that area with as much variety as possible: the buildings vary in design, construction and materials. All buildings were finished within last 8 years; the oldest one was constructed and occupied in 2000; and the newest cases, which were in Tianjin city, were finished at the end of 2005 and were unoccupied during the period of the field study.

The first measurement was a three days' pilot test from 30th October to 2nd November in the first case study (a one bedroom flat) in Tianjin City. The purpose of this short period test is to make sure all the loggers can work within the situation and to clarify to what extent the plan of measurements can work. After that, the following four measurements were taken between January and February 2006: about one week was given to each layout in order to plant and collect the experimental devices; details of the measurements are mentioned in Sections 5.5 and 5.6.

5.3.3 Experimental Method

5.3.3.1 Internal Measurement

A number of instruments were placed in different spaces in each case study buildings to record air temperature, the globe temperature, and relative humidity and wall surface temperatures in the flats were also measured, with the exception of case study five, as the owner refused to have sensors adhered to the walls. Data loggers were placed either on desks or stands in the selected spaces to record the environmental conditions; they were placed away from direct solar radiation, and were placed at the same height level in order to record the thermal status at the same condition.

It was not possible to measure all the rooms in every flat due to the limitation of time and the number of data loggers required. The research is about residential architecture, thus the concern was to assess the thermal performance in occupied spaces; therefore, the recording devices were placed in bedrooms and living rooms, without taking account of other spaces, such as the bathroom, kitchen, etc. The loggers inside the spaces were placed as close to the centre as possible in order to minimise the interference from nearby surfaces; such locations were also intended to avoid direct solar radiation through windows on the measurement sensors. Moreover, bead thermostats were stuck on the internal side of the external and internal walls to record the temperature on different surfaces.

The sensors were set to monitor at a fifteen minute intervals for twenty-four hours over seven days. The use of fifteen minute intervals allowed loggers to record rapid changes in conditions; any suspicious event that led to an abnormal recording could then be checked against chronologically proximate data. Furthermore, in order to categorize, data loggers for each space, in each case study, were put into a plastic bag marked with the name and the purpose of testing. When the data loggers were put into the rooms, the name and number of the logger was also recorded on the AutoCAD plans of the layouts.

After placing experimental devices in each case study, access to these buildings was arranged with permission. Regular inspections by the author and colleagues were allowed throughout the monitoring periods to check whether the logging devices were working properly, and also to check any circumstances that might interfere with the recordings that could lead to errors.

5.3.3.2 External Climate Measurement

External climate data including air temperature, relative humidity and direct horizontal solar radiation values were measured during the process of the case studies. The purpose of these measurements was to use the results, together with the recorded indoor environment situation, to assess the thermal performance of case studies; moreover, the external climate data was also used as climate information input for future computer simulation.

Sensors for external conditions were placed at the top of the tallest buildings that the author was able to access in each city; the purpose of this was to exclude the overshadow effects of the solar and temperature recordings. A plastic lantern and an iron plate were used as protection for the data loggers as it could maintain the loggers connected with the external environment and at the same time protect them from rain and direct sunlight. Full details of the measurement equipment will be introduced in the following sections.

5.4 Equipments

The Welsh School of Architecture at Cardiff University has provided several pieces of equipment to carry out the experiments for this study. A number of Gemini temperature and humidity data loggers, three Squirrel Eltek loggers with bead thermostats, a pyranometer and an infrared surface temperature measurement tool, were taken to China for this purpose. All the equipment was battery powered. All loggers were in frequent use by the staff and student in Welsh School of Architecture and have been constantly calibrated.

5.4.1 Gemini Tiny Data Loggers.

Gemini Tinytag Ultra and Tinytalk data loggers were used to evaluate the thermal performance of the selected residential buildings.

The Gemini Tinytalk data logger (Figure 5.1) is a small, lightweight, cell-contained device with an 1800 reading memory and log rates of between 1 second to 4.5 hours. It is used to record environmental data inside and outside buildings with up to 3 years of battery life. It can also be used in other fields, such as industries and food transportation. In this study it was used in the internal spaces to measure the globe temperatures of the interior spaces in all case studies.

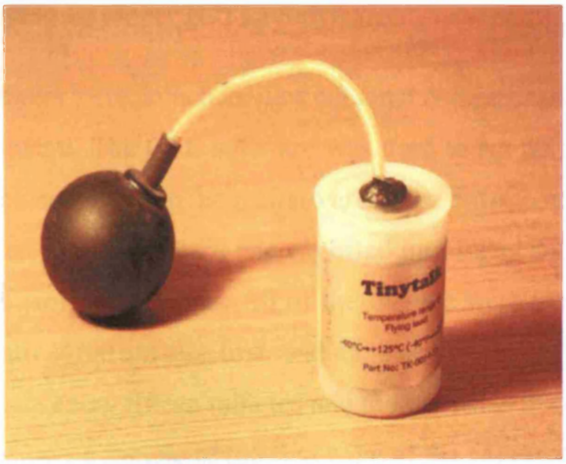


Figure 5. 1: Gemini Tinytalk Data Logger. Source: author.

Another type of Gemini tiny data logger is the Tinytag Ultra (Figure 5.2 left); this has the ability to measure air temperature and relative humidity (RH) at the same time in two separate charts. It can measure air temperatures from -30°C to +50°C and RH from 0% to 95%, which is suitable for the environmental situation in China at that period. Tinytag Ultra has a memory of 1800 readings and programmable alarms. It has a logging rate from 1 second to 10 days with minimum, maximum and actual readings, plus up to 5 years battery life. Moreover, the Gemini Tinytag Plus (Figure 5.2 right) has the same features as the Tinytag Ultra, but is different in shape.

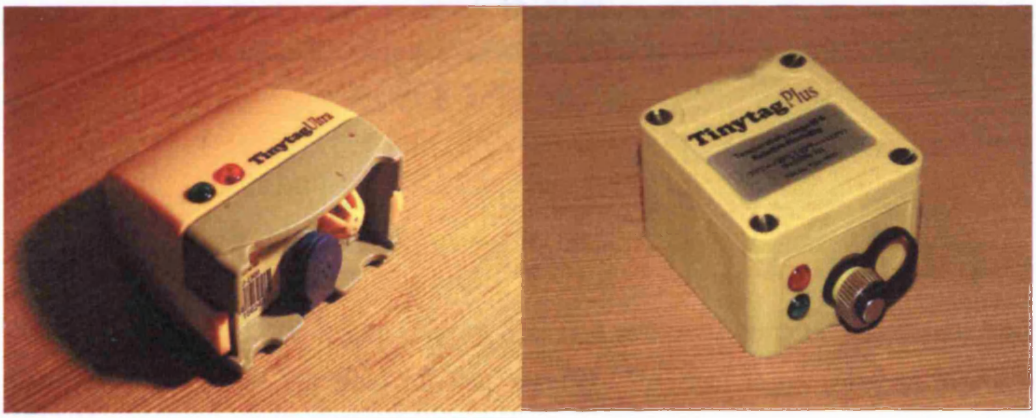


Figure 5. 2: Tinytag Ultra and Tinytag Plus for Air Temperature recordings. Source: author.

5.4.1.1 Gemini Tinytag Explorer (GTE) Software

The Gemini data loggers were launched via a personal computer using Gemini Tinytag Explorer (GTE) software. The GTE software was used to set up the loggers to begin logging and to download data from them afterwards. The downloaded data was viewed, saved, printed, copied to the clipboard and exported into Excel software in order for it to be translated into tables and charts. All of the loggers were instructed to delay the start of recording until 11:00 am as a first reading. They were also instructed to record the environmental data every fifteen minutes and to stop when the devices became full of data. Figure 5.3 shows a sample of the first page of the GTE software after the data was downloaded off the external recording of a Tinytag Ultra logger in the first case study.

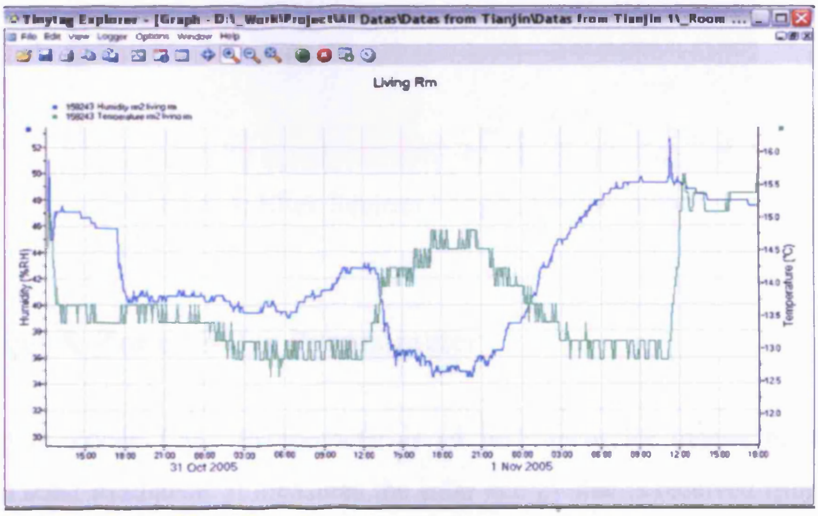


Figure 5. 3: Tinytag Explorer

5.4.2 Eltek Squirrel Logger

The Eltek Squirrel Data logger (Figure 5.4) is a compact, portable instrument with many applications in the field of data logging. The data is recorded by using a transducer to convert the data into electrical outputs. It accepts a wide range of input sensors, including temperature, humidity, RH, pulse, frequency and digital inputs, all of which can be configured and displayed locally using the Squirrel panel controls, or it can be displayed remotely using Eltek's "Darca" software, which is designed to run on a Windows equipped computer system. The logging rate can be set from 1 second to daily basics. Moreover, the logger has many input channels and up to 2 million readings, which enables it to connect with many measuring equipments at the same time. In the field study, one Eltek logger was place at the top of a building to record horizontal solar radiation; two were used indoor to record the surface temperatures.

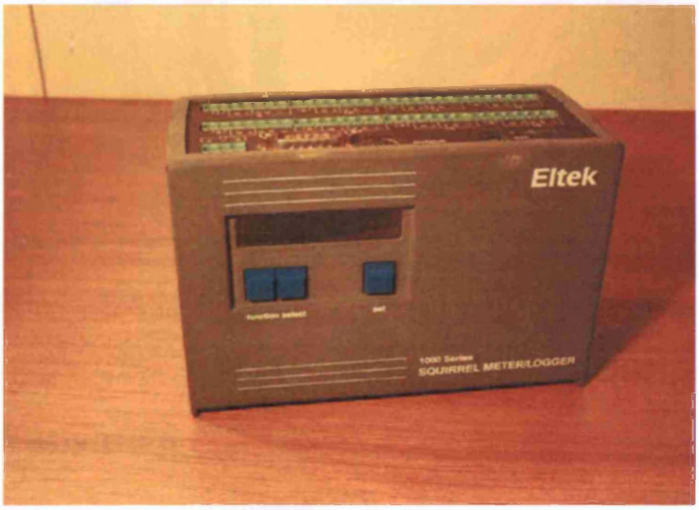


Figure 5. 4: Eltek Squirrel Logger. Source: author.

5.4.3 Kipp & Zonen Solar Pyranometer

The Kipp & Zonen CM5 Pyranometer is an instrument for measuring the direct horizontal solar irradiance. It measures the solar energy that is received from the total solar spectrum and the whole hemisphere (with 180 degrees field of view). It has a thermopile, whose warm junctions are attached to a black surface housed within a double glass dome; incident radiation on it causes produce an output voltage which the data logger converts to Watts per meter squared. The pyranometer is designed for continuous indoor and outdoor use. It measures irradiance up to 2000 W/m² and operating temperature ranges are between -40 to +80 °C. It also has a weatherproof connector which is supplied pre-wired with 10m of signal cable for simple installation, and in this case, the cable was connected to Eltek logger.

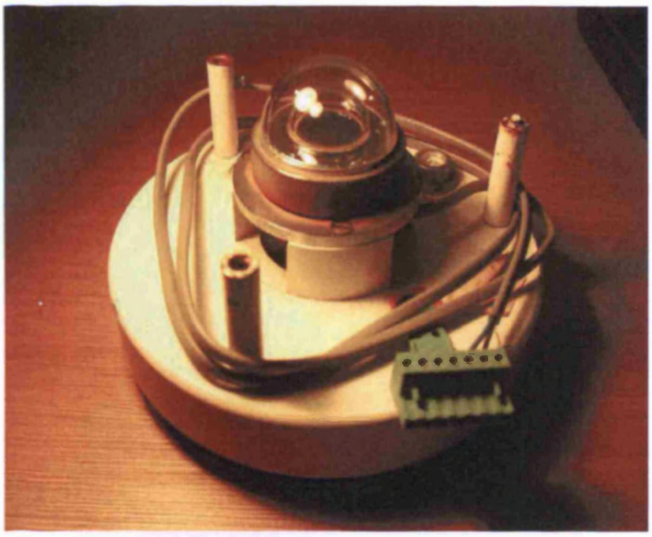


Figure 5. 5: Kipp & Zonen Solar Pyranometer. Source: author.

5.4.4 Raytek Minitemp

The Raytek MiniTemp is a pocket-sized temperature thermometer, which has a fast and instant way to measure the surface temperature of different elements. It is easy to use—just point, shoot and read the temperature on the large backlit display. It can be adapted into many areas, from surface temperatures of electrical equipment to automotive engines. In the field study, this non-contact thermometer is used to measure the surface temperatures of the central heating equipment in the rooms and also to generally check the indoor floor and surface temperatures. It is powered by a 9-volt battery and display temperatures in either °C or °F, and can work in temperature ranges from -18°C to 260°C.

Figure 5. 6: Raytek Minitemp. Source: author.

5.4.5 Personal Computer

A personal computer was used to set and download the recording data from the data loggers, and Microsoft Excel was used to analyse and demonstrate the graphical charts of the results that were obtained.

5.5 Case Studies in Tianjin City

5.5.1 Project Information

The case studies in Tianjin are selected from building numbers 5 and 6 in the Xinyuan Cun project, which is located in the south-west part of Tianjin city (Figure 5.7). It is a mixed development which includes six high-rise buildings: four of which have 29 floors and two which have 24 floors; and one 9 storey mid-rise building. All of the buildings are north-south facing, with 5° west offset. Part of the project was finished at the end of 2005 and three typical layouts of the finished buildings 5 and 6 (Figure 5.8) were selected and measured. The period of monitoring of the three studies in Tianjin is listed in Table 5.1.

Figure 5. 7: Location of Xinyuan Cun Project.

Figure 5. 8: Site Layout.

	Measurement period
Case study one (pilot study)	30^{th} Oct - 1^{st} Nov 2005
Case study two	2^{nd} - 9th Jan 2006
Case study three	3^{rd} - 9th Jan 2006

Table 5. 1: Measurement Periods of the Case Studies in Tianjin

5.5.2 Outdoor Climate Data Measurements

The loggers were placed on the very top of the building at the Department of Architecture in Tianjin University; the height of the building is approximately 23m that is, 7 floors (Figure 5.9). The location was carefully selected; the building was the tallest building in that area, therefore there was no shadow cast on the roof, and so the solar pyranometer could record the actual readings without being affected by shadows. Furthermore, the access of the roof was also strictly controlled, with the only door having access to the roof being locked; only the author and colleagues were allowed admission to check the logging situation during the measurement.

Figure 5. 9: Loggers were placed on top of the building

The outdoor temperature and humidity measurements needed to be taken at a location away from direct solar radiation. Thus a plastic lantern was used as cage for the Gemini Tinytag data loggers; the cage could maintain the loggers connected with the external environment and at the same time, protect them from rain and direct sunlight (Figure 5.10). Furthermore, an abandoned chimney was used as a surface in which to place the sensors, and a shelf was used to protect the Eltek sensors from direct sunlight or rain (Figure 5.11). An iron plate was put over the solar logger to protect the sensors from overheating (Figure 5.12).

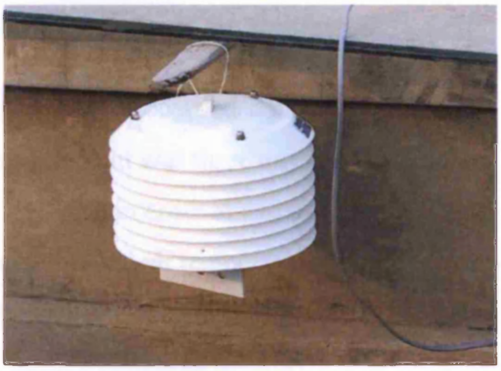


Figure 5. 10: Lantern with Tinytag Loggers

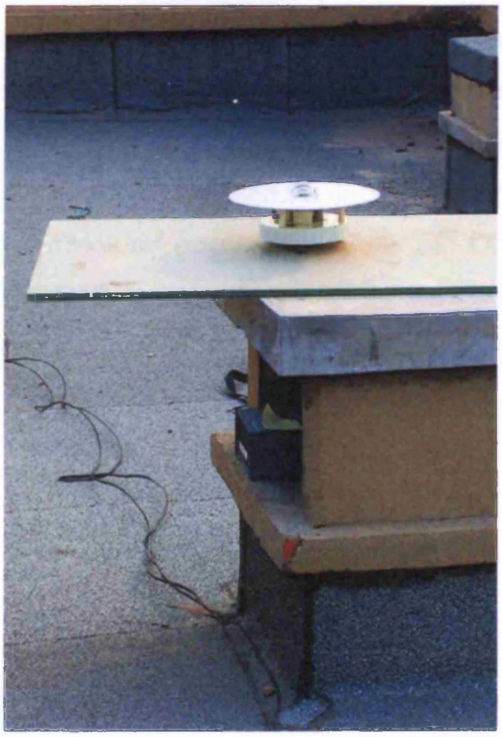


Figure 5. 11: An Abandoned Chimney was used to Place and Protect the Loggers

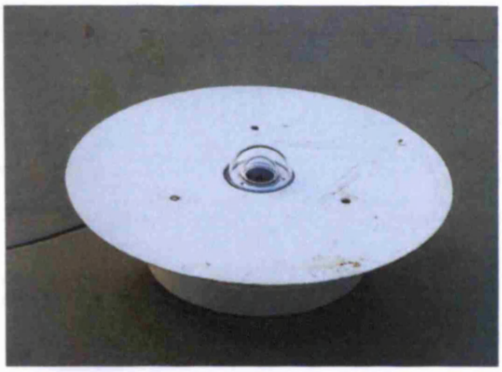


Figure 5. 12: Solar Pyranometer

5.5.2.1 Recorded Climate Data for Pilot Studies

Figures 5.13 and 5.14 show the recorded data during the first case study in Tianjin; although the indoor measurement was three days, climate data was recorded for a week (from 28th Oct to 3rd Nov 2005) in order to assess the outdoor climate conditions during that period. It can be seen that the air temperature is cold in October, and the difference between day and night was more than 10°C.

The average air temperature was about 14°C and the daily peak value always appeared around 2 pm, but never exceeded 21°C. The average relative humidity was around 44%; however, this seemed to fluctuate greatly with the weather, as maximum and minimum values of 73% and 24%, respectively, were recorded. Moreover, the solar power potential was very strong; the average direct solar radiation in daytime (from 7:00 hours to 19:00 hours) was more than 230 W/m² and the maximum reading during the time of indoor measurement was 534W/m² (recorded at 12:00, 28th Oct 2005). The range of measured data fits the expectation and represents the normal climate conditions of North China in this period.

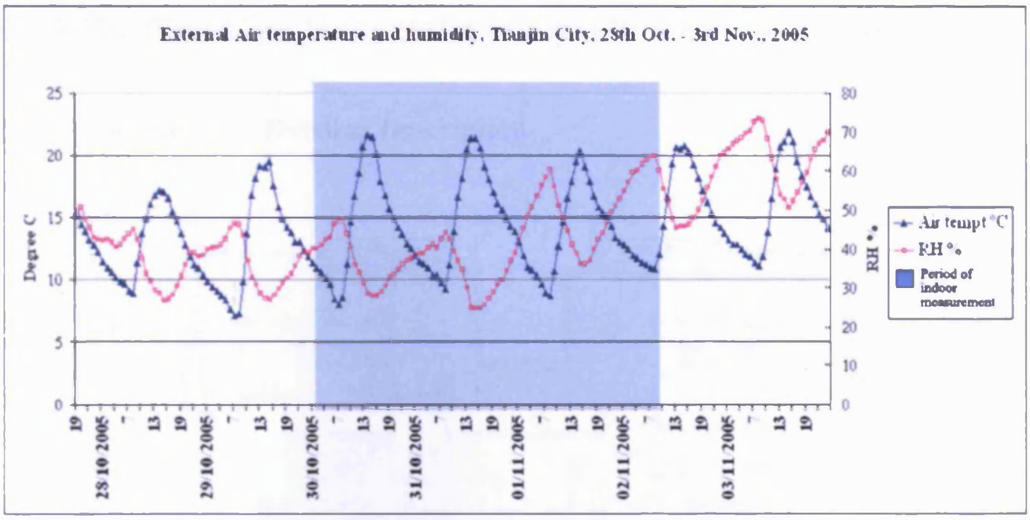


Figure 5. 13: Air Temperature and Relative Humidity in Tianjin City, Oct-Nov 2005

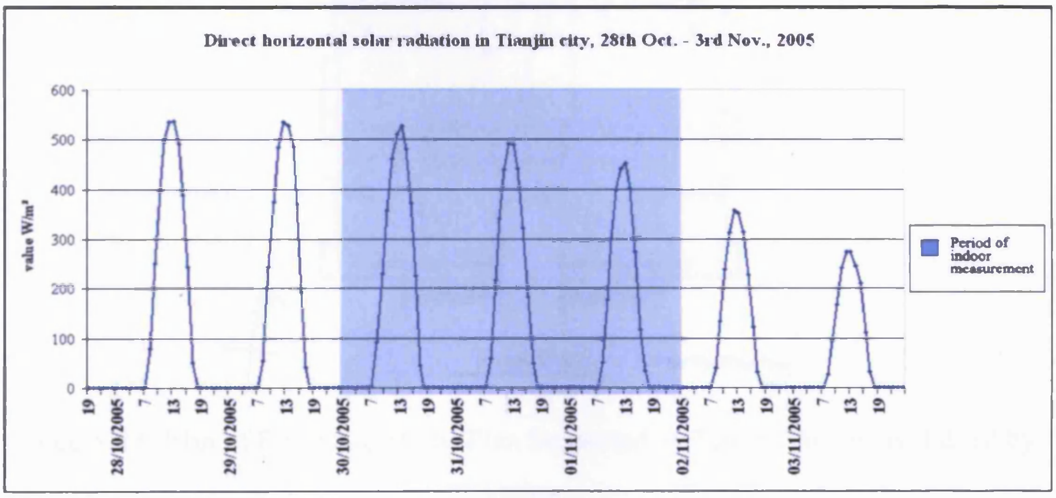


Figure 5. 14: Direct Horizontal Solar Radiation in Tianjin City, Oct-Nov 2005

5.5.3 The First Case Study (Pilot Study) (30th Oct to 1st Nov)

5.5.3.1 Location and Building Description

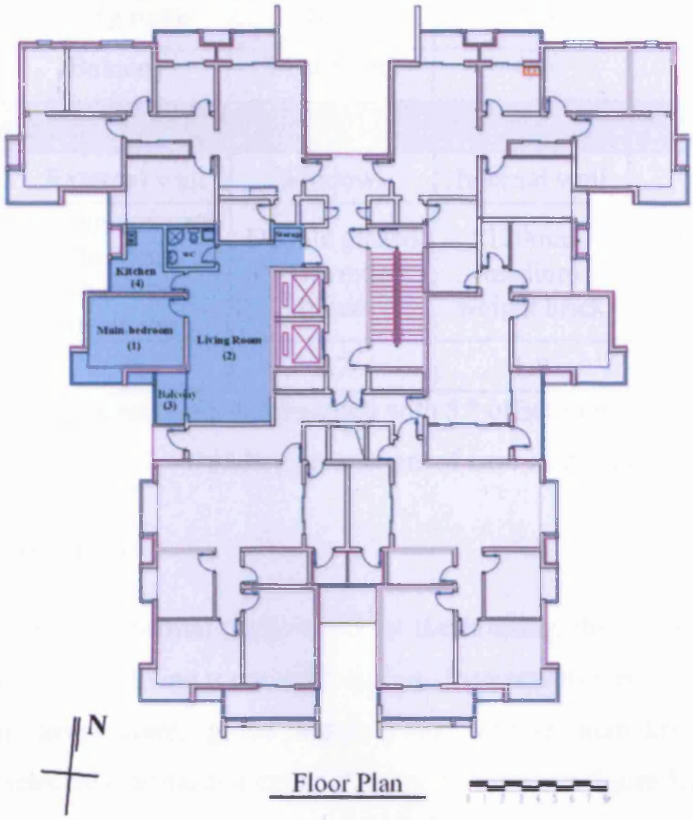


Figure 5. 15: Plan of First Case Study, Plan Supported by Tianjin University, Edited by Author.

The first case study flat was in building No.5 in the Xinyuan Cun project, which was built in 2005, with measurements taken from 30th October to 1st November 2005. The layout selected was a one bedroom plan on first floor, on the west side of the building. The rooms in this layout are mainly facing west and the only room with a south opening was the main bedroom (Figure 5.15). Information of the room parameter and building materials information are listed in table below.

Room information				
Location	Room	Orientation*	Floor area m²	Glazing ratio %
1st Floor	Main Bedroom	South-West	21.8	44.1
	Living room	N/A	29.8	N/A
	Balcony	West-North	4.4	65.0
Material information				
Element	External wall	Windows	Internal wall	Floor
Material	200mm concrete with 25mm Polystyrene Insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
U-value	0.75	2.7	1.9	1.9

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 2 : Building parameters of case study one

5.5.3.2 Monitored Spaces

In order to evaluate the thermal performance of the housing, the focus is on internal thermal conditions of the living room and bedroom. Instruments were placed in the flat to monitor air temperature, globe temperature, relative humidity and surface temperature of selected internal and external walls. As shown in figure 5.16 four sets of Tinytag Ultra data loggers were placed in the bedroom, living room and the balcony, measuring at intervals of 15 minutes. In addition, the Eltek data loggers were used to measure the walls' surface temperatures in the living room and bedroom, at 15 minute frequencies (figure 5.17).

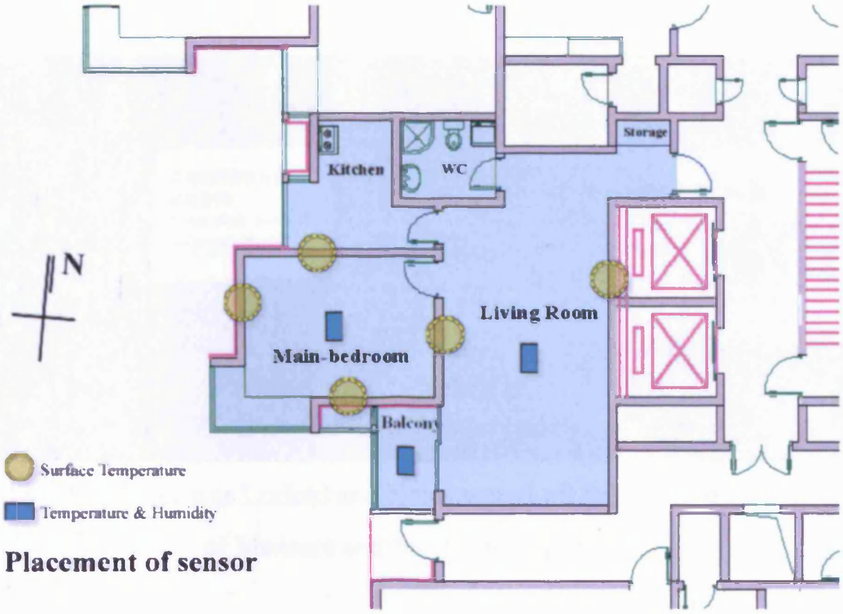


Figure 5. 16: Placement of Logger in Case Study One

Figure 5. 17: Bead Thermostats were Stuck on External and Internal Walls to Record their Surface Temperature

All of the windows and doors were closed during the times of measurement, in order to achieve a better measuring situation and also to ensure the security of the loggers (figure 5.18). Moreover, as the flat had just been completed, there was no occupant and the heating system was not in use during that period, so the internal gain was considered to be zero. All of the sensors were placed as close to the centre of each room as possible, in order to prevent direct solar radiation coming through the windows onto the measurement sensors (Figure 5.19).

Figure 5. 18: Main Door was Locked and Notes were Left to Ensure Both the Accuracy of Measure and Safety of Loggers.

Figure 5. 19: Loggers Placed on a Wood Stand in the Centre of Main Bedroom

5.5.3.3 Recorded Results

The data loggers were collected from the selected spaces after the experiment. They recorded indoor conditions of the first case study for three days (from 30th October to 1st of November). Afterwards, they were connected, to GTE software to offload their recorded data. The data was converted into hourly values, in order to be easily compared with the simulation results in further chapters. The data was checked at both scales and there were no noticeable variations between each other. The following graphical charts represent the results obtained from each space.

5.5.3.3.1: Main Bedroom

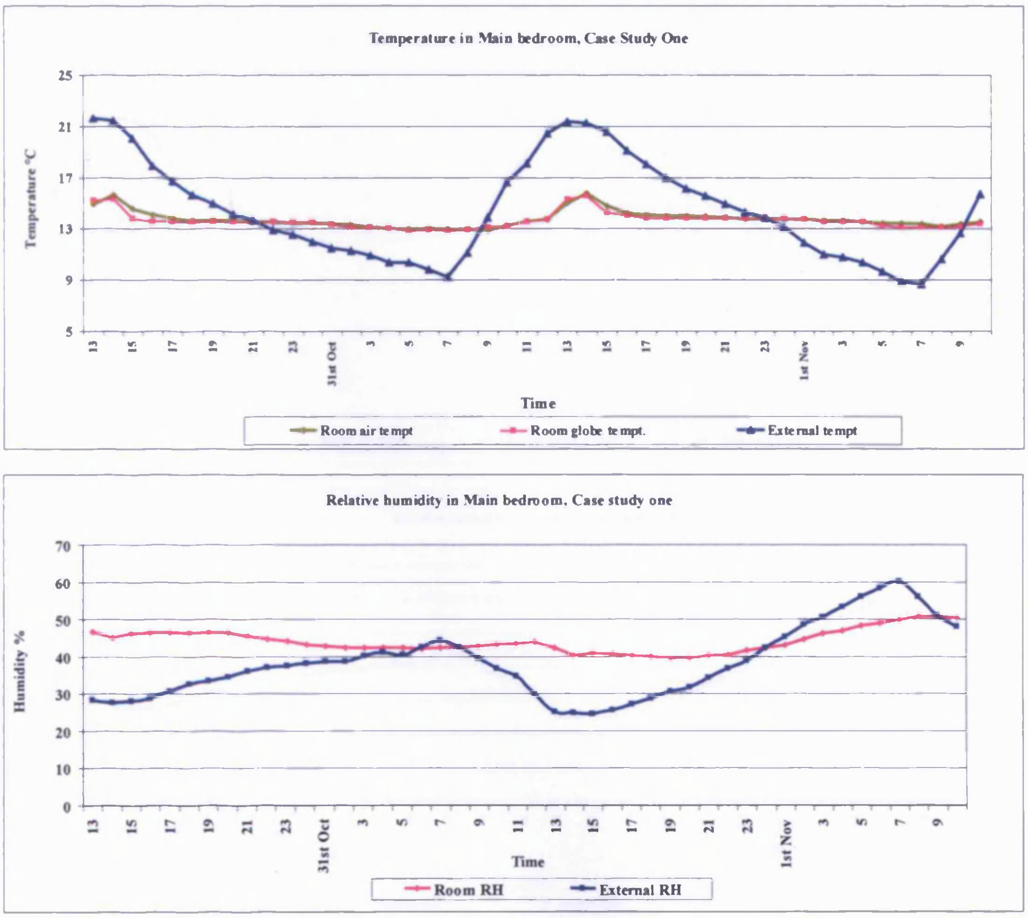
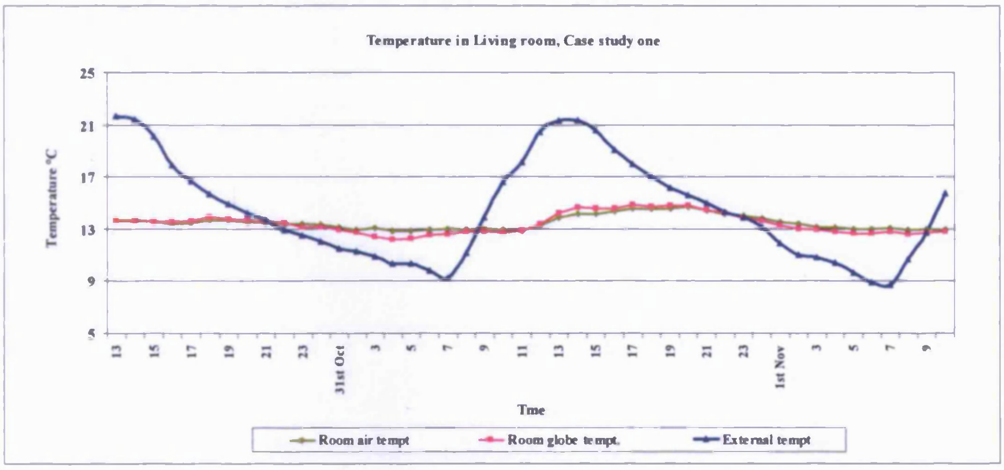


Figure 5. 20: Temperature and Humidity of the Main Bedroom in the First Case Study

From the comparison with the external conditions during the same period, it can be seen that the indoor relative humidity remained stable when compared with the variation of the external data. The room air and globe temperatures also did not change significantly; however, there was a small increase together with outside temperature at noon time, mainly due to the large area of west-facing window. The average indoor temperature is almost the same as external condition, probably due to the unsatisfactory insulation of building envelope. The main bedroom was south-west facing on the west side of the building. The maximum air temperature reached 15.6°C and the minimum reading is 12.8°C; the number for globe temperature is within the same range which is 15.8°C and 12.9°C, respectively. For the RH, 50.6% was the maximum recording and 39.4% was the minimum.

5.5.3.3.2: Living Room



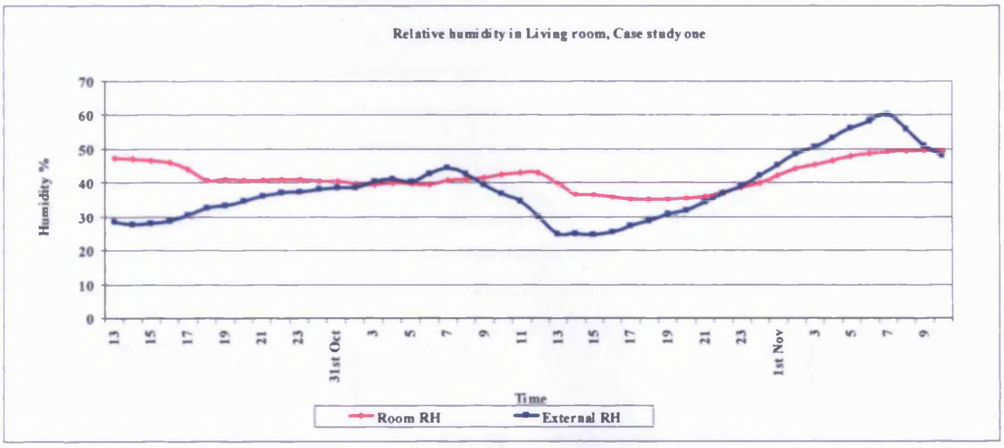


Figure 5. 21: Temperature and RH in Living Room in the First Case Study

As there is no glazing area or external wall in this space, the temperature in living room was not greatly affected by the external climate. The living room was in the middle of the layout and did not have any external surface or opening. The maximum air temperature reached 14.7°C and the minimum was 12.8°C; the reading of globe temperature is within the same range which is 14.9°C and 12.2°C, respectively. For the RH value, the indoor conditions reacted more to the external conditions compared with the bedroom: 49.4% was the maximum and 35.0% was the minimum.

5.5.3.3.3: Balcony

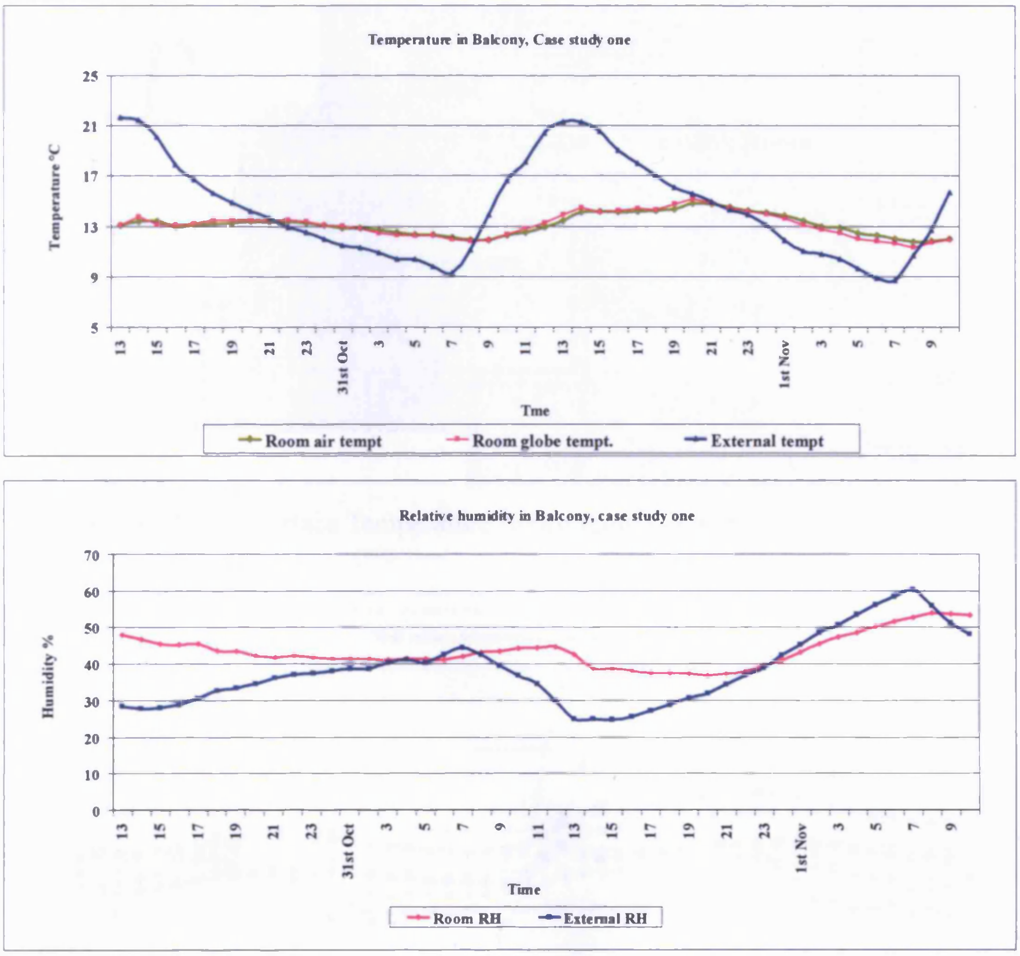


Figure 5. 22: Temperature and RH on Balcony in the First Case Study

The balcony faces west and has large amount of window area; due to the heat loss via the large opening space, the internal temperature was lower than other spaces and was affected more by the external situation. The maximum air temperature reached 14.8°C and the minimum was 11.7°C; the reading of globe temperature was within the same range, which was 15.2°C to 11.3°C. Moreover, the second highest temperature in the whole flat appeared here in the afternoon, due to the solar radiation on the west side at this time. The RH value showed a related reaction toward the external conditions, 53.7% was the maximum and 36.8% was the minimum.

5.5.3.3.5. Surface Temperature

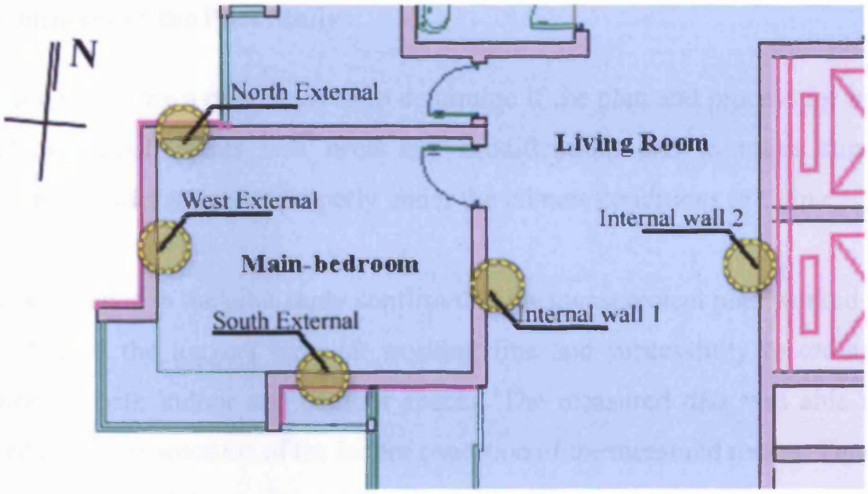


Figure 5. 23: Surface Temperature Measurement in the First Case study.

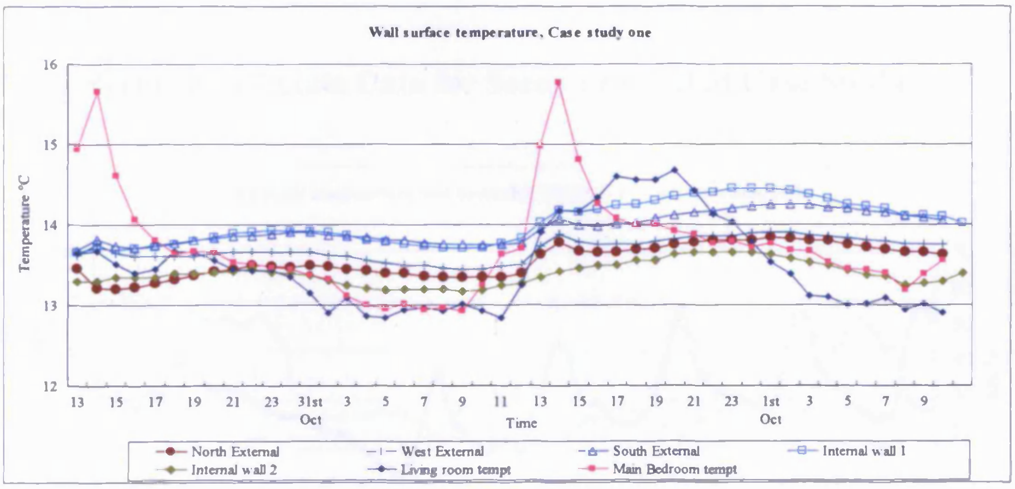


Figure 5. 24: Surface Temperature in the First Case study

The inside surface temperatures of both external and internal walls were measured in order to assess the insulation properties of the construction. All of the test points were situated at the same height level and located away from direct sunlight. Figure 5.24 shows that internal wall one had the highest surface temperature, the average reading was 14.1°C. The external walls with direct solar radiation also had relatively higher surface temperature than others; the average temperatures of south and west facing walls were 13.9°C and 13.7°C, respectively. Internal wall two was the coldest surface with an average reading of 13.4°C; a possible reason for this is that it was not insulated as it is an internal wall; however, this wall was connected to unheated spaces.

5.5.3.4 Summary of the Pilot Study

The purpose of having a pilot study is to determine if the plan and process for indoor and outdoor measurements will need any modification, and to make sure the measurement sensors can work properly under the climate conditions in China.

The results obtained in the pilot study confirm that the measurement plan worked well, and also that all the loggers were all working fine and successfully recording the information of both indoor and outdoor spaces. The measured data was able to be interpreted as a representation of the indoor condition of the measured rooms. Thus, the pilot study gave confidence for continuing with the same measurement plan and process for the other case studies.

5.5.4 Recorded Climate Data for Second Period of Case Studies

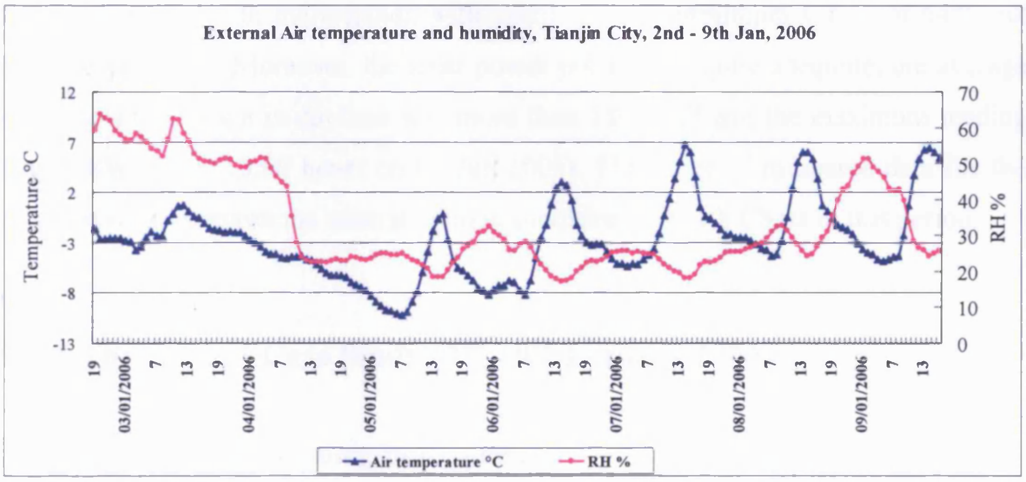


Figure 5. 25: Air Temperature and Relative Humidity in Tianjin City, Jan 2006

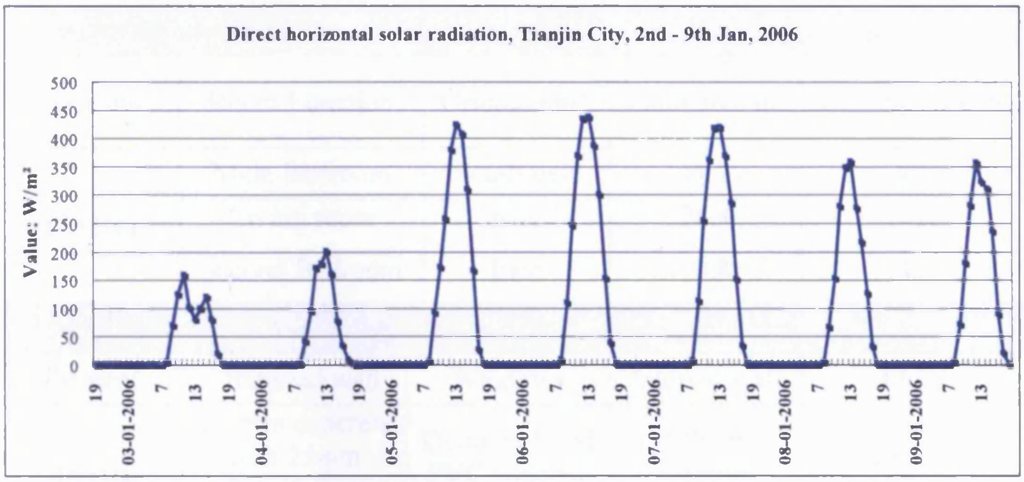


Figure 5. 26: Direct Horizontal Solar Radiation in Tianjin City, Jan 2006

Figures 5.25 and 5.26 show the data recorded during the period of the second case study in Tianjin (from 2nd to 9th Jan 2006). It is evident from the diagram that the winter period is very cold in that area; the average external temperature in that period was about -3.0°C; the daily peak value always appeared in the afternoon and the value never exceeded 5.6°C. The average relative humidity was around 33%; however, it seemed to fluctuate greatly with the weather, with maximum and minimum values of 64% and 17%, respectively. Moreover, the solar power potential is quite adequate; the average direct solar radiation in daytime was more than 180W/m² and the maximum reading was 438W/m² (at 13:00 hours on 6th Jan 2006). The range of measured data fits the expectation and represents normal climate condition of North China in this period.

5.5.4 The Second Case Study (2nd - 9th January 2006)

5.5.4.1 Location and Building Description

The second case study was a two bedroom flat situated on the fifth floor, on the east side of building No 5 in the XinYuan Cun project. The rooms in this layout mainly face east and the only room with south openings is the main bedroom. The measurements were recorded between the 2nd and 9th January 2006; the central heating system was in operation, with all doors and windows kept closed. Information of the room parameter and building materials information are listed in table below.

Room information				
Location	Room Function	Orientation*	Floor area m²	Glazing ratio %
6^{th} Floor	Main Bedroom	South-east	18.2	46
	Living room	N/A	26.4	N/A
	Second Bedroom	East	10.8	45
Material information				
Element	External wall	Windows	Internal wall	Floor
Material	200mm concrete with 25mm Polystyrene Insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
U-value	0.75	2.7	1.9	1.9

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 3 : Building parameters of case study two

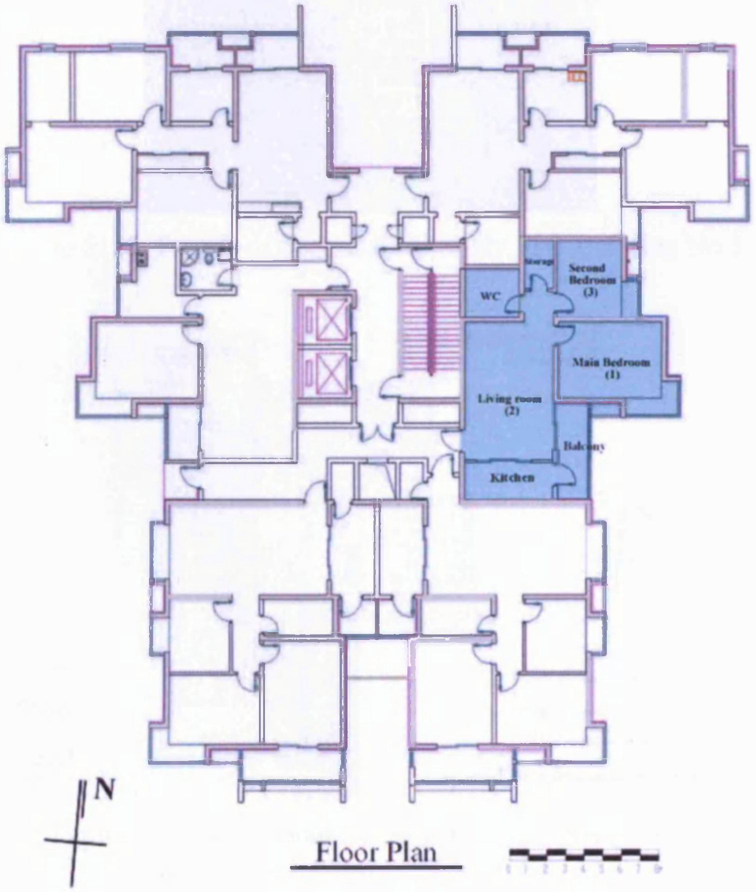


Figure 5. 27: Plan of Second Case Study, Drawing Supported by Tianjin University, Edited by Author.

5.5.4.2 Monitored Spaces

Two bedrooms and the living room were measured in this flat (figure 5.28). Three sets of Tinytag data loggers were placed in the two bedrooms and living room, measuring at intervals of 15 minutes to record air temperature, globe temperature, relative humidity and the surface temperature of selected internal walls, along with the temperature of the inner surfaces of external facing walls in the main bedroom (Figure 5.29 and 5.30).

Figure 5. 28: Facade of Second Case Study Flat, Building No.5

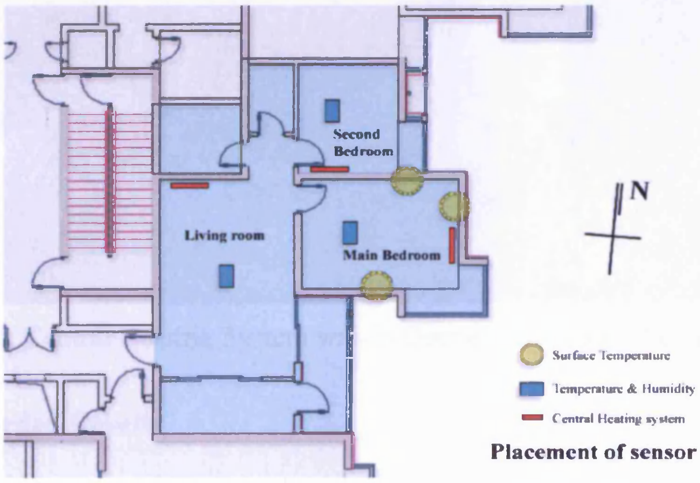


Figure 5. 29: Placement of Logger in Case Study Two

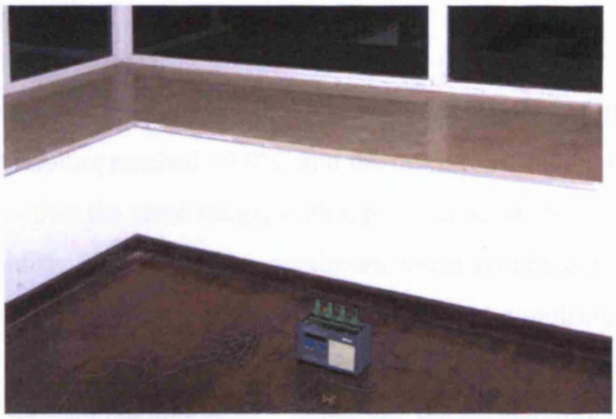


Figure 5. 30: Loggers Placed in Main Bedroom to Measure Surface Temperature

The heating system was switched to level 2 (out of 5) in every room (figure 5.31); the purpose of this was to compare the results with case study three, to represent the effective level of the heating system to the indoor temperature. The operation temperatures of the heaters' surfaces were also recorded for future computer simulation. All of the sensors were placed as close to the centre of each room as possible to prevent direct solar radiation coming through the windows.

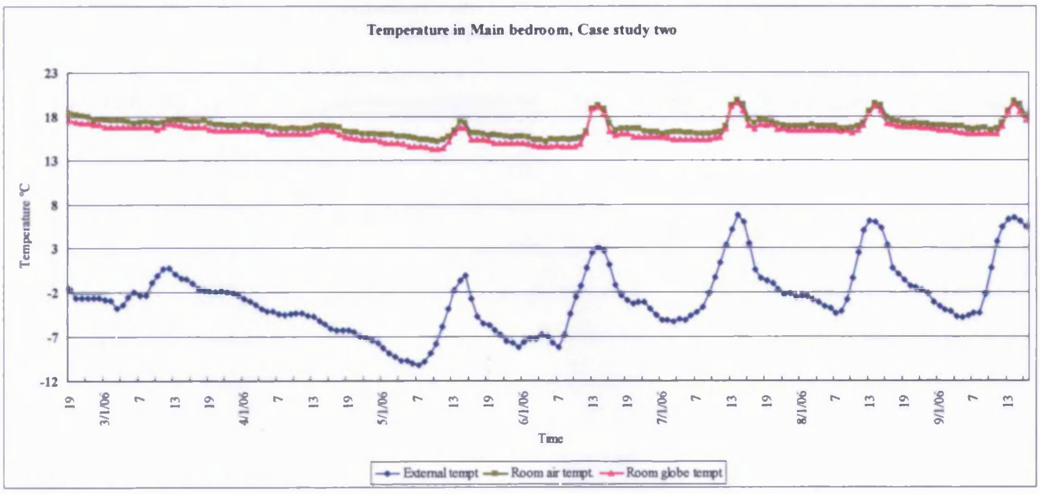
Figure 5. 31: Central Heating System was in Operation and Switched to Same Level

5.5.4.3 Recorded Results

Data loggers were collected from the selected spaces after completion of the experiment. They had been recording the indoor conditions of the second case study for over seven days (from 2nd to 9th Jan). The following graphical charts (Figures 5.32, 5.33 and 5.34) show the results obtained from each space.

5.5.4.3.1: Main Bedroom

The main bedroom was south-east facing on the east side of the building. The maximum air temperature reached 19.9°C and the minimum reading was 15.1°C; globe temperature was within the same range, with a peak value of 19.5°C and low value of 14.2°C. For humidity, 28.5% was the maximum value recorded and 13.0% was the minimum value. From the comparison with the external condition during the same period, it can be seen that with the heating system, indoor temperature remained high and relatively stable, ranging within 5°C; moreover, the temperature increased together with outside temperature at noon, mainly due to the large area of south-facing window. The indoor relative humidity remained low and stable regardless of the drastic change on the outside.



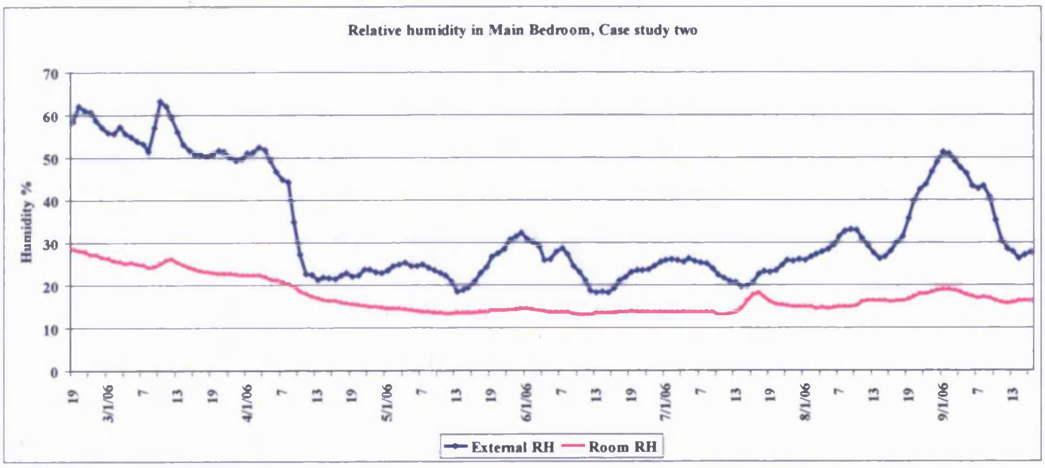


Figure 5. 32: Temperature and RH in the Main Bedroom in the Second Case Study

5.5.4.3.2: Living Room

The living room was in the middle of the layout and did not have any external surfaces or openings; hence the room was warmer than other spaces in the flat. As there was no glazing area or external wall in this space, the temperature in living room was not greatly affected by the external climate. The maximum air temperature reached 21.0°C and the minimum was 18.3°C; the reading of globe temperature is within the same range which was 19.8°C and 17.2°C, respectively. The sudden drop of air temperature on the afternoon 7th Jan. might be caused by the owner went to the flat during that time and opened the window; the effect was also reflected in the rise of RH value in the same time. Indoor humidity remained low, 29.5% was the maximum value recorded and 13.1% was the minimum value.

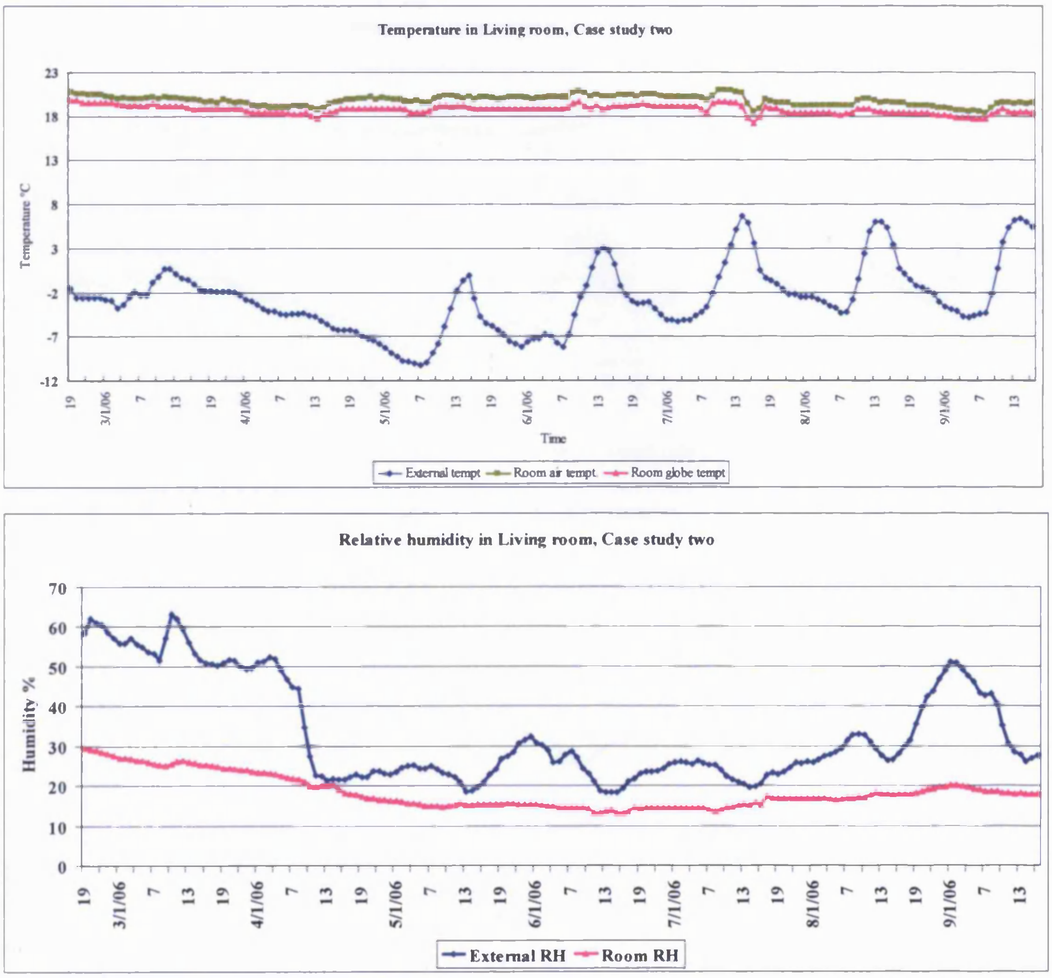
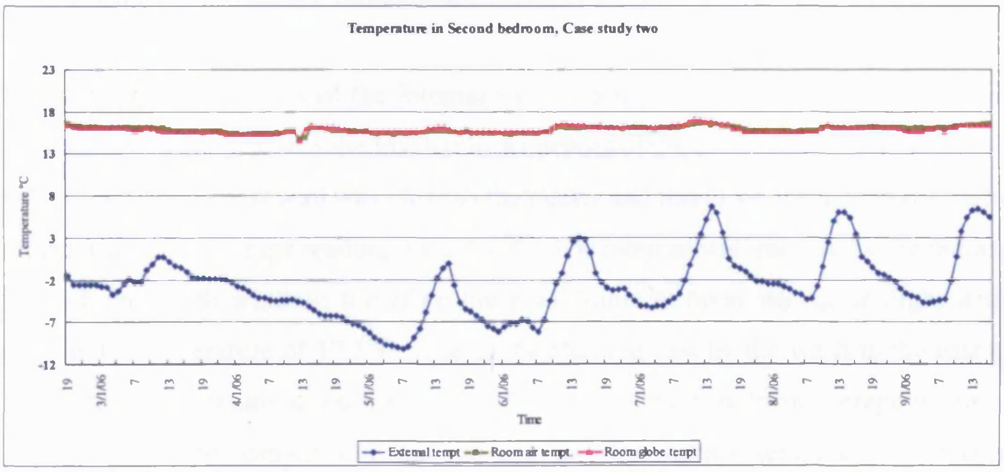


Figure 5. 33: Temperature and RH in Living Room in the Second Case Study

5.5.4.3.3: Second Bedroom

The second bedroom room was east facing. The maximum air temperature reached a maximum of 16.5°C and the minimum was 14.7°C; the reading of globe temperature was within the same range, which was 17.0°C and 14.5°C, respectively. For humidity, 28.7% was the maximum value recorded and 14.9% was the minimum value. From the comparison with the external condition during the same period, it is evident that the temperature and relative humidity were low and relatively stable when compared with external environment.

One noticeable feature is that the sudden drop of air temperature at 4th Jan, possible reason is that the owner went to the flat during that time and opened the window; the effect was also reflected in the rise of RH value in the same time.



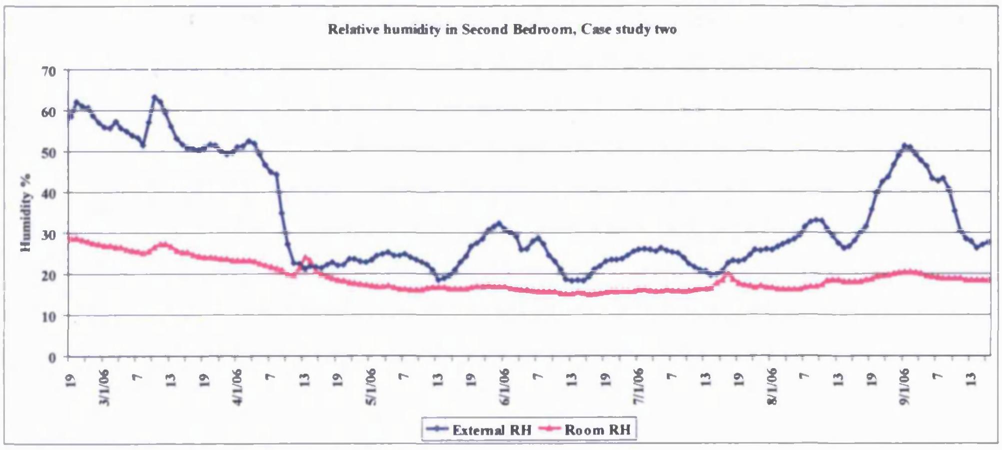


Figure 5. 34: Temperature and RH in Second Bedroom in the Second Case Study

5.5.4.3.4: Surface Temperature

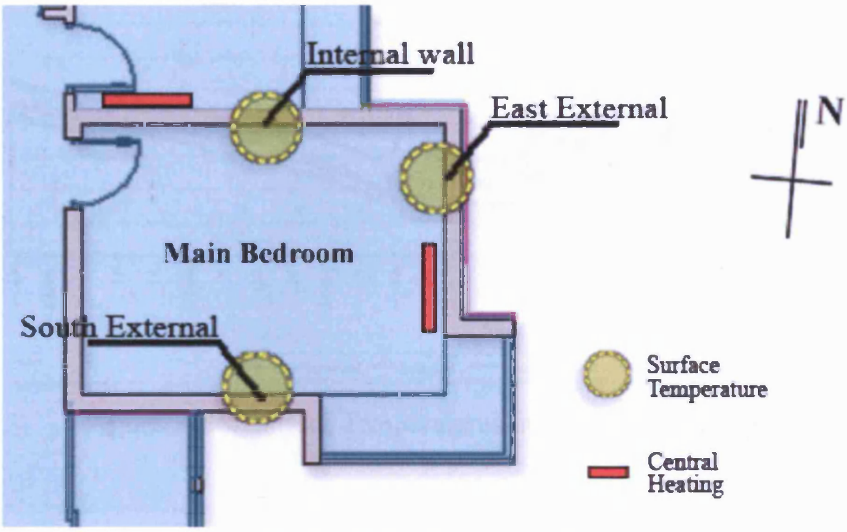


Figure 5. 35: Surface Temperature Measurements in the Second Case study

The surface temperatures of the internal side of both external and internal walls were measured in order to assess the insulation properties of the construction. The sensor that was placed on the east wall was close to the heater and therefore resulted in the highest temperature; the average reading was 15.8°C. The internal wall received solar radiation through the south window, therefore the peak value at noon was quite high, with a maximum temperature of 17.5°C. Due to the shading cast by the walls to the east and above, the temperature of south facing wall was the lowest, with an average reading of 15.2°C. From the comparison, one can see that the surface temperatures remained stable at daily ranges, compared with the room air temperature and the surfaces not next to the heater were about 1 to 2°C colder than the room temperature.

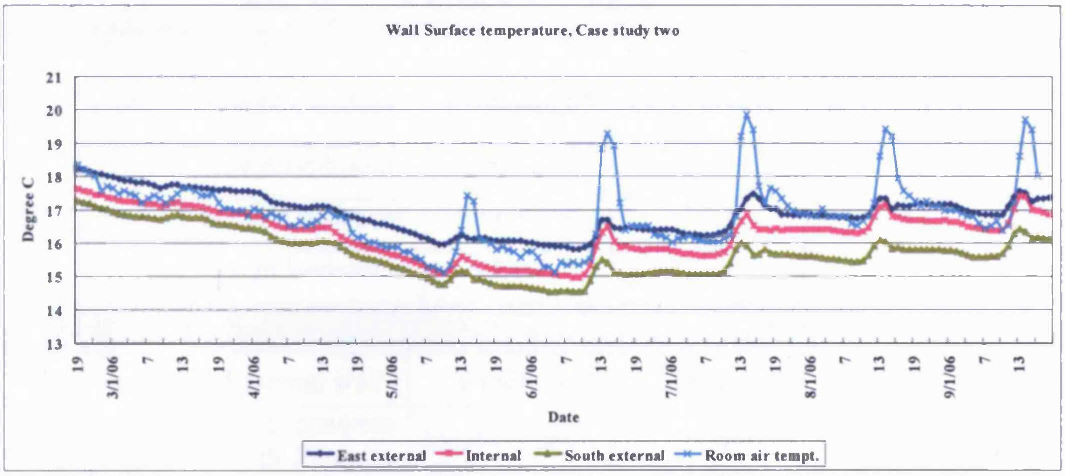


Figure 5. 36: Surface Temperatures in the Second Case Study

5.5.5 The Third Case Study (3rd to 9th January 2006)

5.5.5.1 Location and Building Description

The third case study was a three bedroom flat on twentieth floor, on the south-east side of building No 6 in the XinYuan Cun project. The measurements were recorded from 3rd to 9th January 2006; in that period, the central heating system was in operation, with all doors and the majority of windows being kept closed. The main bedroom and the second bedroom are both south facing; the rest of the rooms face east. Information of the room parameter and building materials information are listed in table below.

Room information				
Location	Room Function	Orientation*	Floor area m²	Glazing ratio %
20th Floor	Main Bedroom	South	25.9	45
	Second Bedroom	South-east	16.4	42
	Third Bedroom	East	11.8	40
Material information				
Element	External wall	Windows	Internal wall	Floor
Material	200mm concrete with 25mm Polystyrene Insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
U-value	0.75	2.7	1.9	1.9

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 4 : Building parameters of case study three

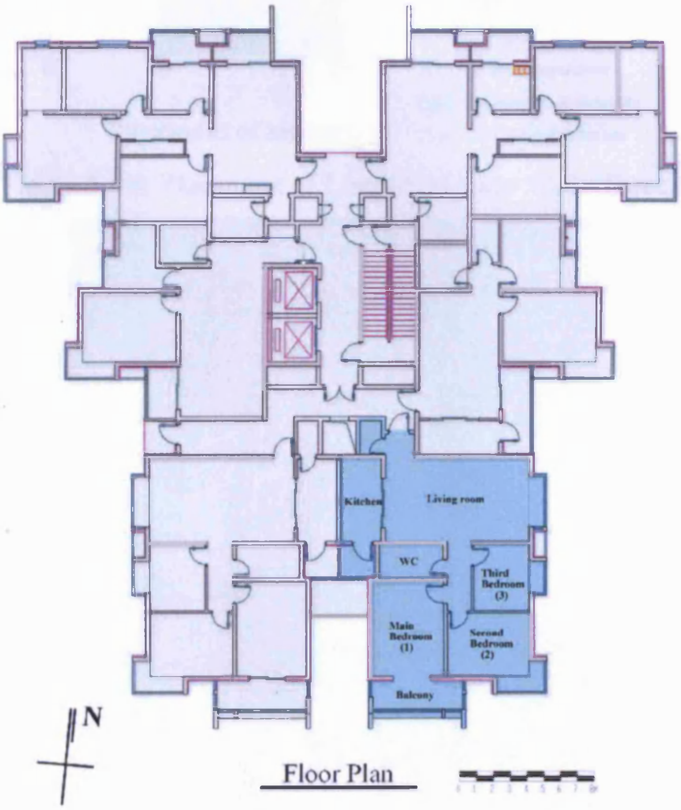


Figure 5. 37: Plan of Third Case Study, Drawing Supported by Tianjin University, Edited by Author.

5.5.5.2 Monitored Spaces

Three bedrooms were measured in this flat. The instruments were placed to monitor air temperature, globe temperature (except in the third bedroom), relative humidity and the surface temperatures of selected walls.

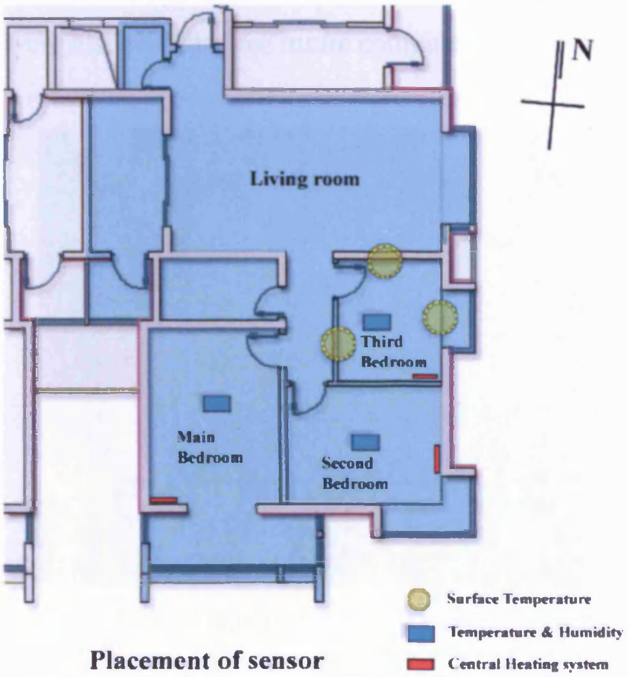


Figure 5. 38: Placement of Loggers in Case Study Three

Figure 5. 39: Facade of Third Case Study Flat, Building No. 6

There were no permanent occupants in this flat, however, the owner did make a number of visits. The central heating system and solar radiation was the only heat gain source. The heating system was switched to full power in every room in order to make a comparison with the second flat in case study two. The operation temperatures of the heaters' surfaces were also recorded for future computer simulation.

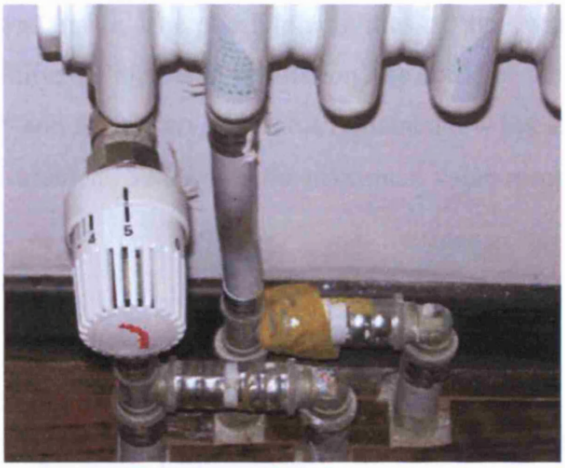


Figure 5. 40: Settings of Central Heating System

5.5.5.3 Recorded Results

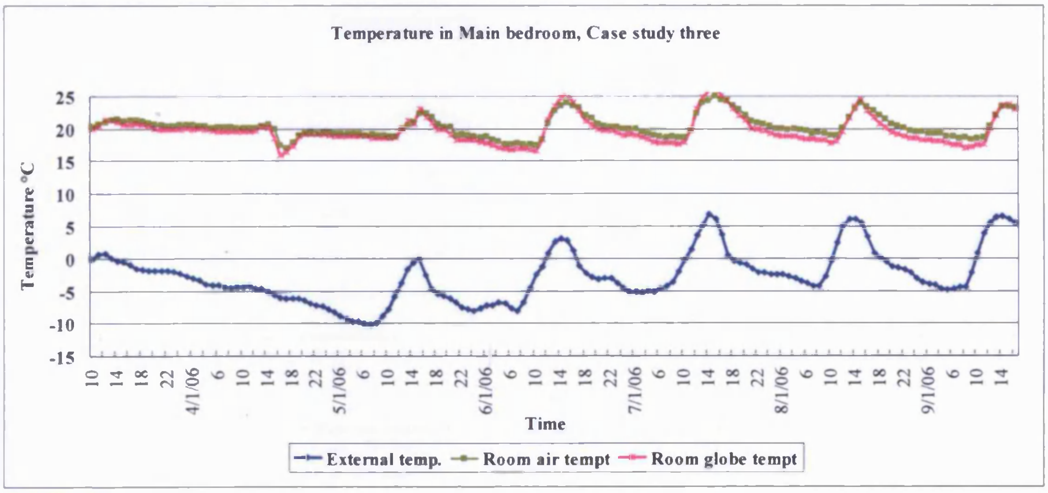
Data loggers were collected from the selected spaces after completion of the experiment. They had been recording the indoor conditions of the third case study for a week (from 3rd to 9th Jan 2006). The measured temperature were higher than case study two because the heater was on full power.

The following graphical charts (Figures 5.41, 5.42 and 5.43) show the results obtained in each space. However, the owner visited the flat several times during the measuring period without notification, which has caused some uncertainty with the recordings, especially with the humidity.

5.5.5.3.1: Main Bedroom

The main bedroom was south facing on the south-east side of the building. From the comparison with the external condition during the same period, it can be seen that indoor temperature remained high because of the heating system. Moreover, the temperature increased together with outside temperature at noon, mainly due to the large expanse of south facing window with balcony. The maximum air temperature reached was 25.0°C and the minimum reading was 17.0°C; globe temperature was within a similar range, with a peak value of 26.3°C and a low value of 15.9°C.

Another noticeable feature was the sudden drop of the temperature between 1600 and 1800 hours on 4th January; it is suspected that the owner visited the flat and opened the window whilst he was inside. The possible activities of the owner also affected the indoor relative humidity; the increased ventilation rate could be the possible reason for the jump between 4th and 5th January, the value remained low but stable during the rest of period of the measurement, 32.0% was the maximum value recorded and 15.9% was the minimum value.



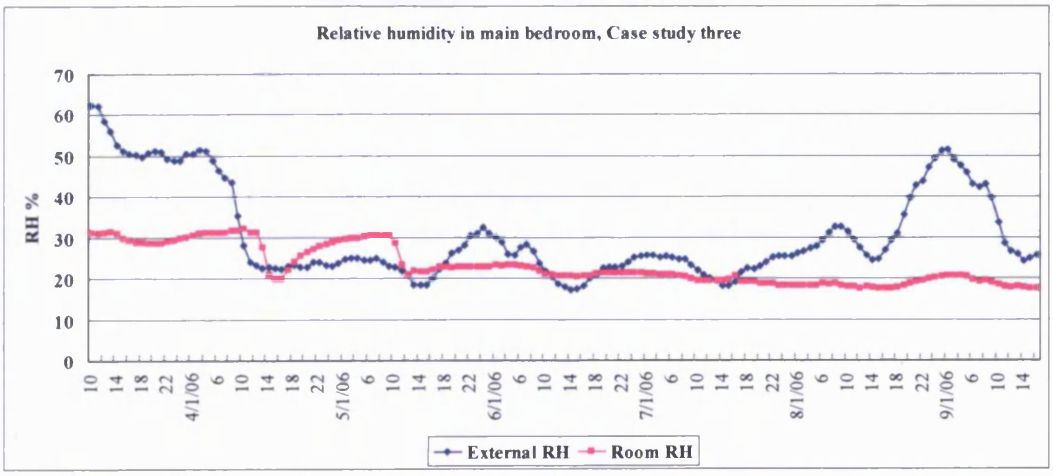


Figure 5. 41: Temperature and RH in the Main Bedroom in Third Case Study

5.5.5.3.2: Second Bedroom

This room is located at the south-east corner of the building, with a large opening area to both the south and east. The room temperature was affected by the solar radiation through windows and the peak value always appears around 14:00 hours. The maximum air temperature reached 25.5°C and the minimum was 18.5°C; the reading of globe temperature is within the same range which was 25.9°C and 18.1°C, respectively. For humidity, 32.0% was the maximum value recorded and 16.1% was the minimum value. The indoor humidity remained stable, however the humidity level was affected by the activities in the flat, with a similar pattern appearing in the same period like the main bedroom. Another noticeable feature is that the daily dips of RH value correspond to the period of peak room temperatures.

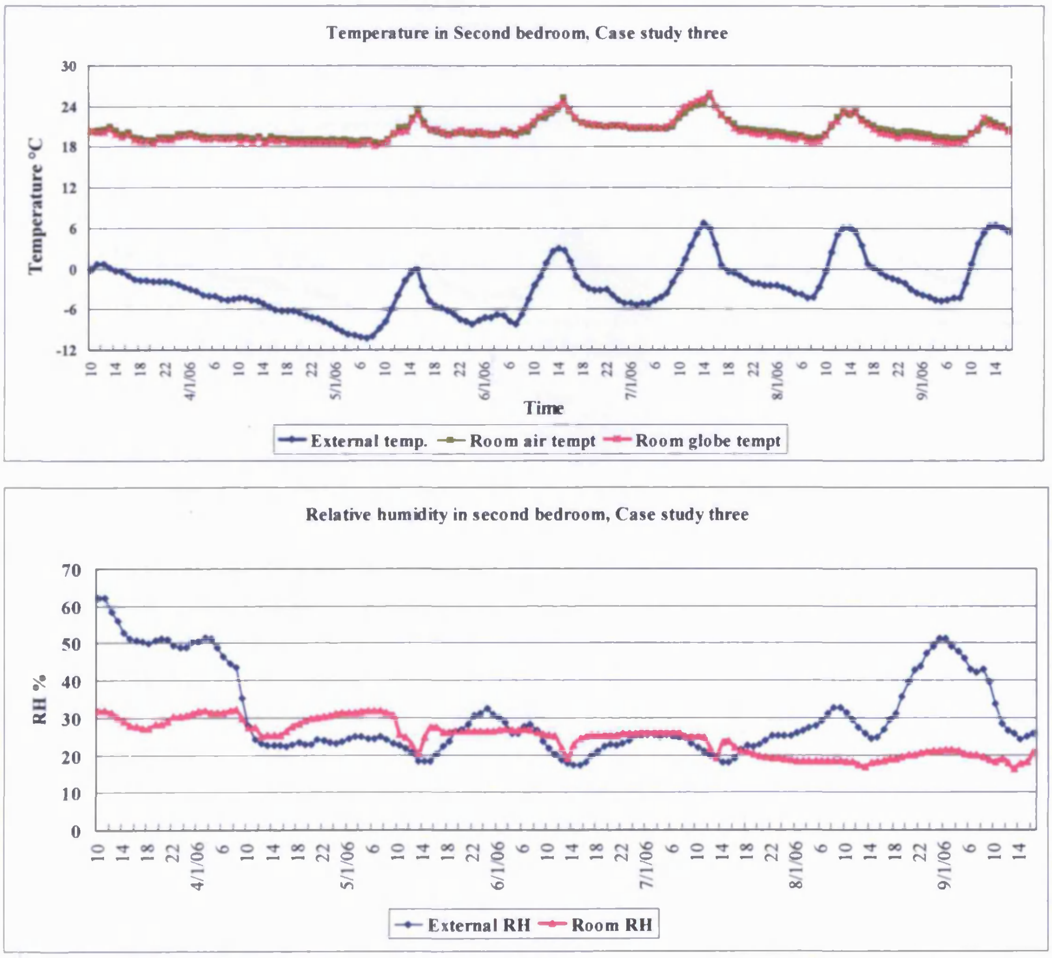
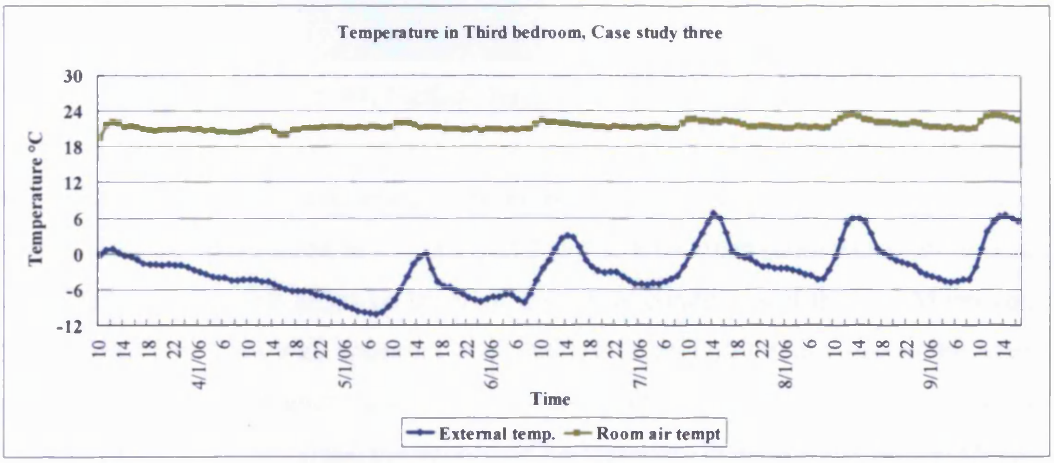


Figure 5. 42: Temperature and RH in Second Bedroom in the Third Case Study

5.5.5.3.3: Third Bedroom

The third bedroom room is east facing. From the comparison with the external condition during the same period, it is evident that the temperature was stable and the highest reading appeared in morning at around 10:00 Hours, due to the solar radiation through the east facing glazing. Some small dips of temperature, drops around 1°C, were probably caused by the opening of the windows by the owner. The maximum air temperature reached 23.3°C and the minimum was 19.6 °C. Humidity varied from the maximum of 33.6% to the minimum reading of 14.9%. However, there were three major dips in the relative humidity and the data cannot be interpreted directly, as the changes were not reflected in temperature. A possibly reason for this might be the effect from human activities.



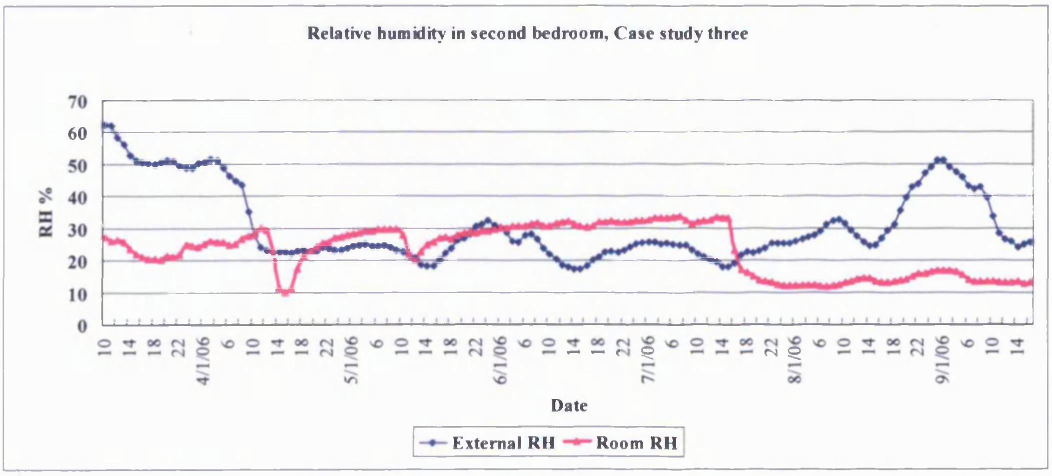


Figure 5. 43: Temperature and RH in Third Bedroom, the Third Case Study

5.5.5.3.4. Surface Temperature

The inside surface temperatures of both external and internal walls were measured in order to assess the insulation properties of the construction.

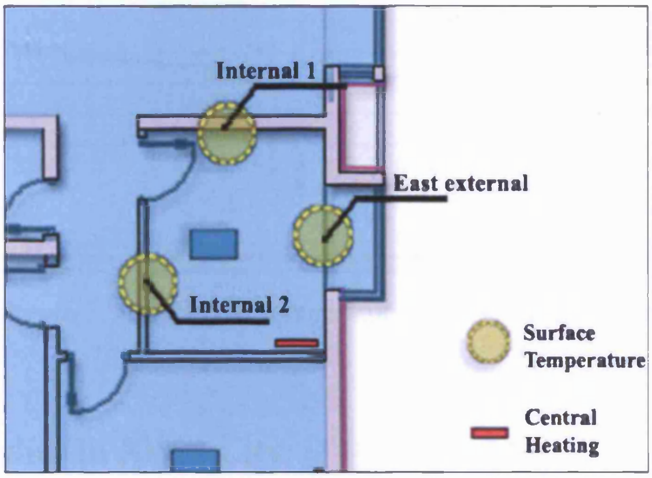


Figure 5. 44: Surface Temperature Measurements

From the measurements it is clear that the external wall had the lowest temperature and is the main heat loss source, as it was about 2 to 5°C lower than room temperature. The possible reason for this might be the poor insulation conditions of the flat. Moreover, the peak value of this wall appeared at around 10:00 to 11:00 hours, due to the solar radiation from east. Higher surface temperatures were recorded in the internal walls without external surface areas; the heat could be preserved in these walls and kept them much warmer than the constructions with external surfaces. The average temperature of internal walls one and two were 21.8°C and 21.0°C.

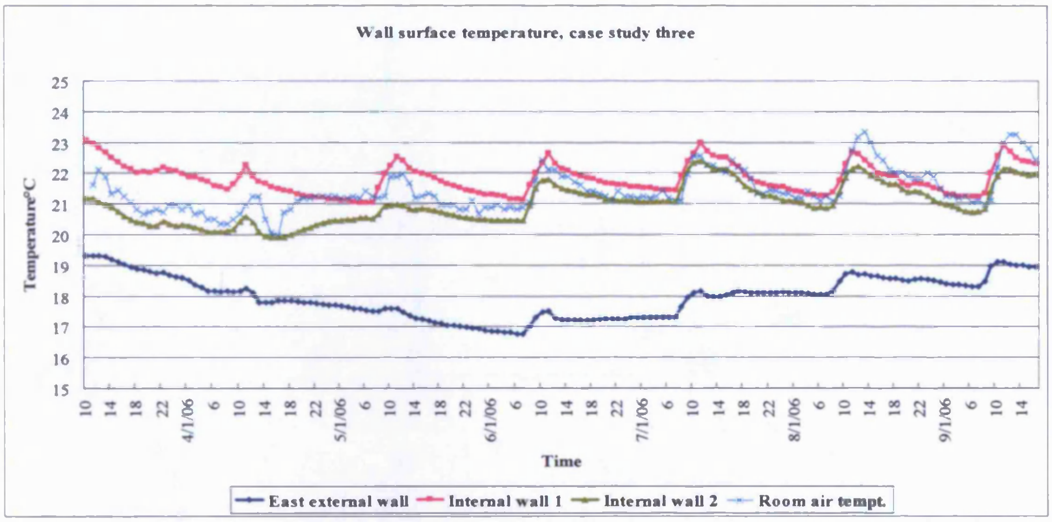


Figure 5. 45: Surface Temperature in Case Study Three

5.6 Case Studies in Xi'an City

5.6.1 Project Information

The studies in Xi'an city were included as part of the EU Asia Pro Eco project, participated by Cardiff University and Xi'an Architecture and Technology University in 2006 (Li 2006). During the process, two typical apartments were measured to assess their energy performance in relation to the current building code, and to measure the internal thermal conditions in order to provide data to inform the modelling process.

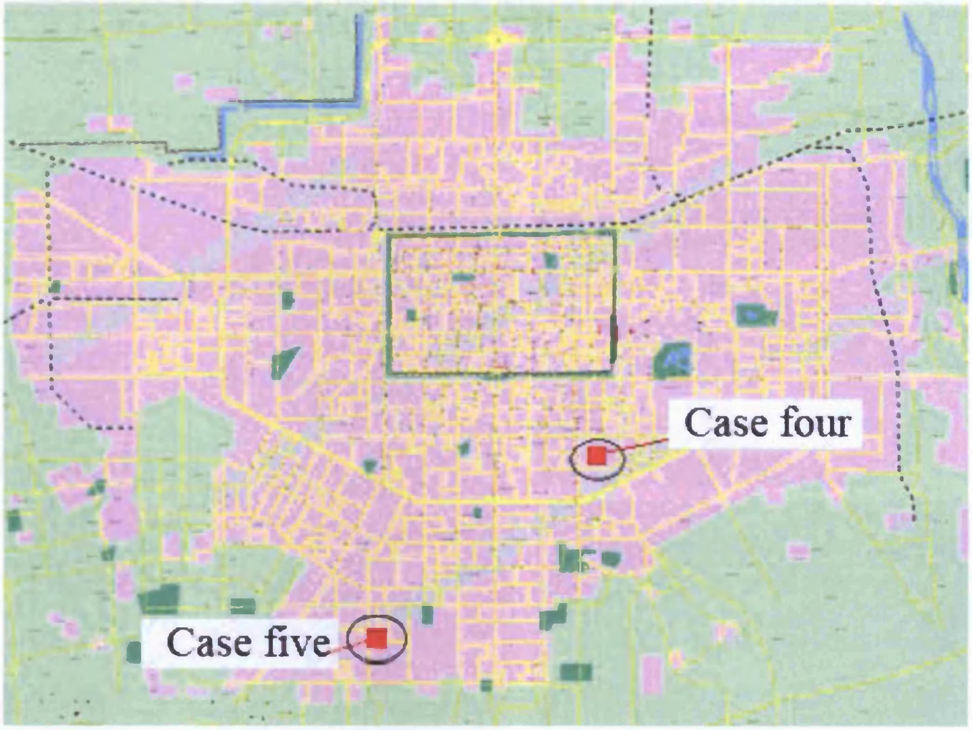


Figure 5. 46: Location of Case Studies in Xi'an

Case study four is located in the south downtown area; it is a seven floor residential development that was built in 2000. Case study five is located in the south-west of the city; it is a fourteen floor residential building that was completed in 2005. Case study four was measured from 13th to 20th January 2006, and case study five was measured from 14th to 22nd January 2006. Locations of the cases are demonstrated in the figure 5.46.

5.6.2 Outdoor Climate Data Measurements

The data loggers were placed on the top of main building of department of architecture in Xi'an University of Architecture and Technology (Figure 5.47); this is the tallest building in that area, with a height of approximately 20 metres. The reason for choosing this location was to ensure there would be no shadows cast on the roof, therefore the solar pyranometer could record the actual readings without being affected. Besides, the access of the roof was also strictly controlled; the only door that could access the roof was locked, with only the author and colleagues being allowed access to check the logging situation during the measurement period.

Figure 5. 47: Loggers Placement

The outdoor temperature and RH measurement needed to be taken at a location away from direct solar radiation, thus a plastic lantern was used as cage for the Gemini Tinytag data loggers. This ensured that loggers remained connected to the external environment, but at the same time protected from rain and direct sunlight; a plastic basin was used to protect the loggers from water and snow (Figure 5.48).

Figure 5. 48: Protections of Loggers from Environment.

5.6.2.1 Recorded External Data for the Period of Case Studies

Figures 5.49 and 5.50 show the recorded external climate data during the case studies in Xi'an. The measurement period of the whole project was almost two months (from mid-January to the end of February 2006.). The data presented here covers the period of the forth and fifth case studies, and the rest data can be found in the appendix B.

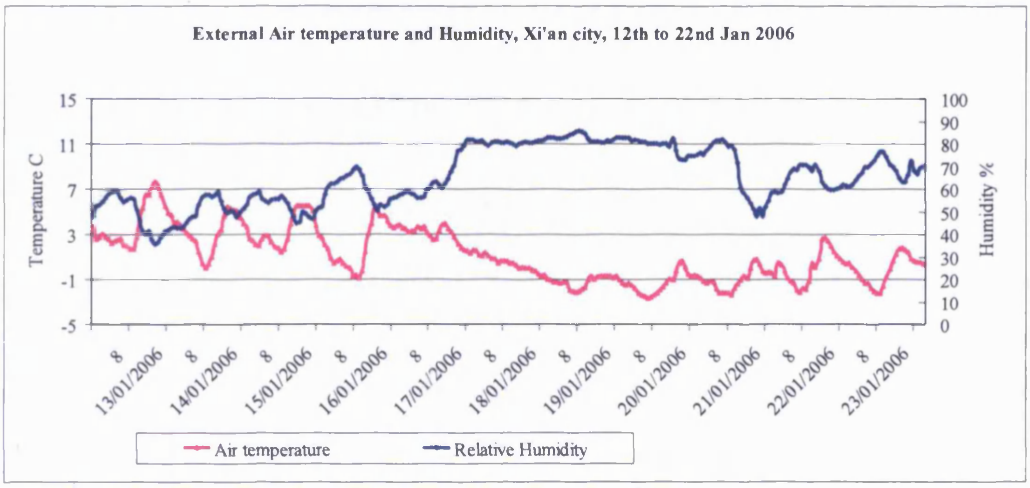


Figure 5. 49: Air Temperature and Relative Humidity in Xi'an City, Jan to Feb 2006

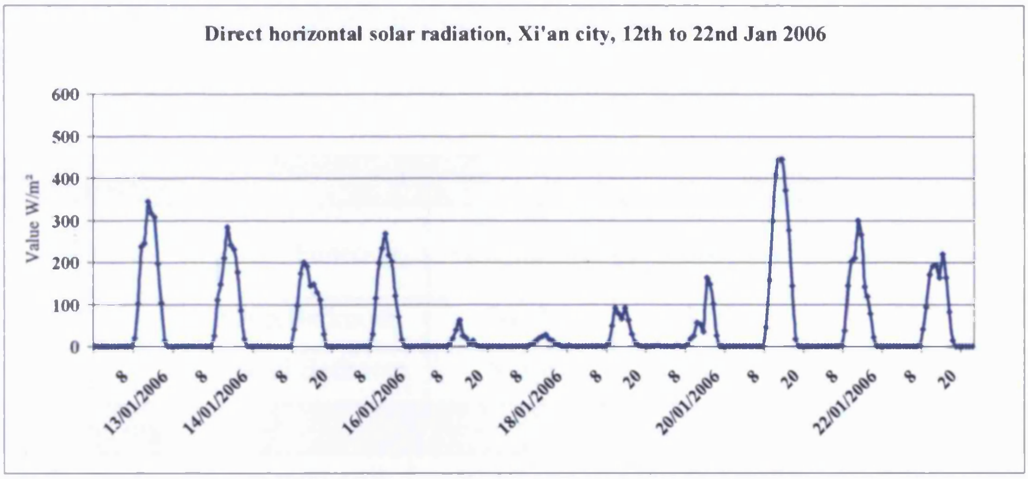


Figure 5. 50: Direct Horizontal Solar Radiation in Xi'an City, Jan to Feb 2006

From the summary, it can be seen that the air temperature is low and there was a steady drop from 16th January as the readings fluctuated between -3°C to 9°, average value was about 1.3°C and the daily peak value always appeared around 15:00 hours and never exceeded 9°C. The average relative humidity was around 44%; however, it seemed to fluctuate greatly with the weather, with maximum and minimum values of 86% and 36%, respectively. Moreover, due to the two cloudy days on 17th and 18th January, the average direct solar radiation in daytime (from 8:00 hours to 20:00 hours) was about 101 W/m², and the maximum reading during the time of indoor measurement was 445W/m² (recorded at 13:00, 21st January 2006). However, the solar radiation for the rest of the measurement period was abundant, with the average value over 140 W/m² (see Appendix for details).

5.6.3 Case Study Four (13th to 20th January 2006)

5.6.3.1 Location and Building Description

Case study four was the flat 502 in building No 30 in Xi'an Architecture and Technology University, which was built in 2000. The measurements were recorded from 13th to 20th January 2006. The layout selected was a two bedroom flat on the second floor, on the east side of the building. The flat is north-south orientated and the only room with a south opening is the main bedroom, there was one people who is living there, however, two guest came and stayed in the flat after the measurement started. Information of the room parameter and building materials information are listed in table below.

Room information				
Location	Room Function	Orientation	Floor area m²	Glazing ratio %
2nd Floor	Main Bedroom	South	15.1	22.2
	Second Bedroom	North	11.7	20.0
Material information				
Element	External wall	Windows	Internal wall	Floor
Material	200mm concrete	single glazed metal window frame	120mm medium weight brick	100mm concrete board and 10mm tile
U-value	1.15	6.40	1.90	2.27

Table 5. 5：Building parameters of case study four

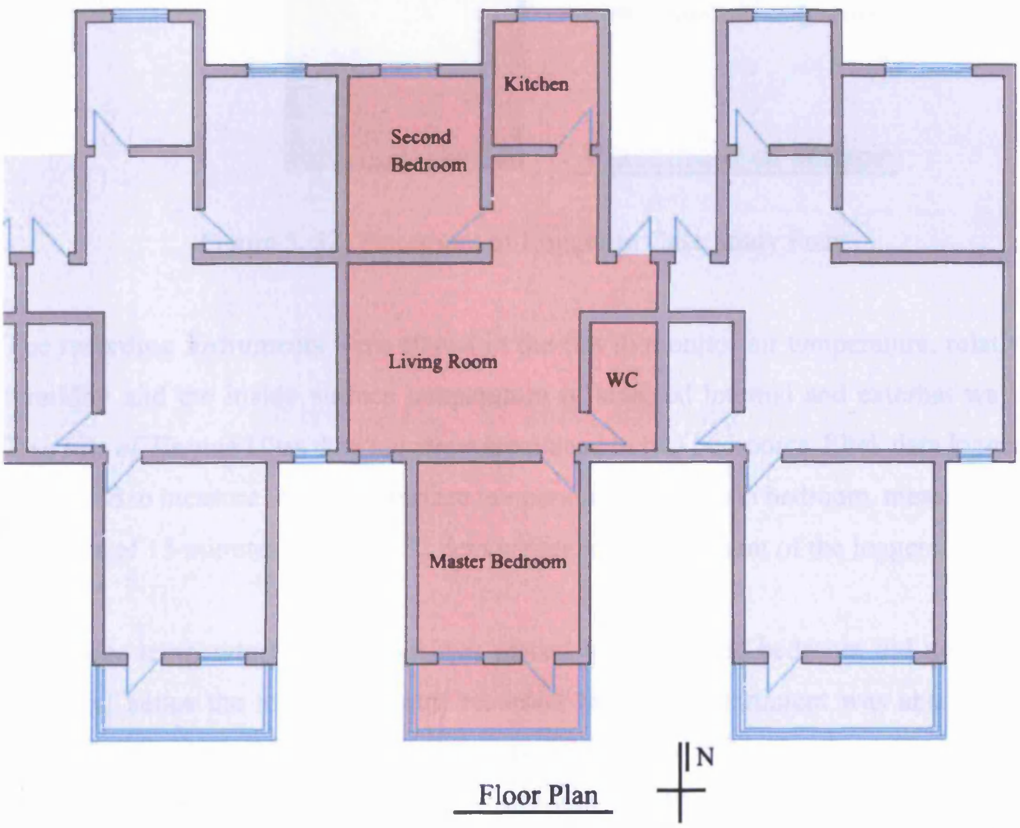


Figure 5. 51: Plan of Case Study Four based on the survey, Drawn by Author.

5.6.3.2 Monitored Spaces

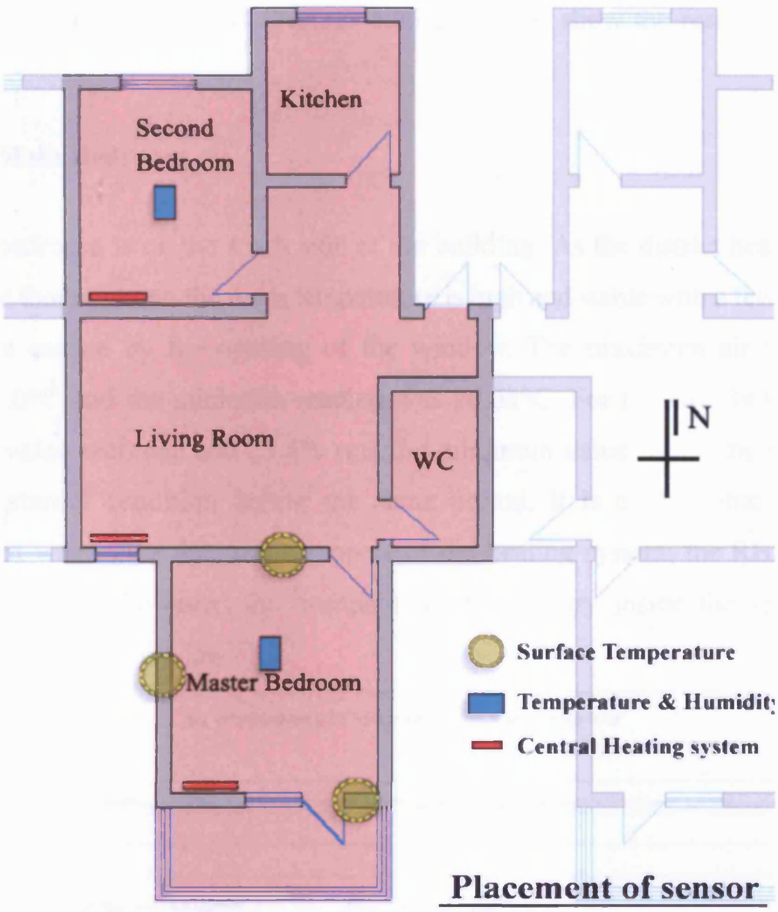


Figure 5. 52: Placement of Logger in Case Study Four

The recording instruments were placed in the flat to monitor air temperature, relative humidity and the inside surface temperature of selected internal and external walls. Two sets of Tinytag Ultra data loggers were placed in two bedrooms. Eltek data loggers were used to measure the walls' surface temperature in the main bedroom, measuring at intervals of 15 minutes. Figure 5.52 demonstrates the placement of the loggers.

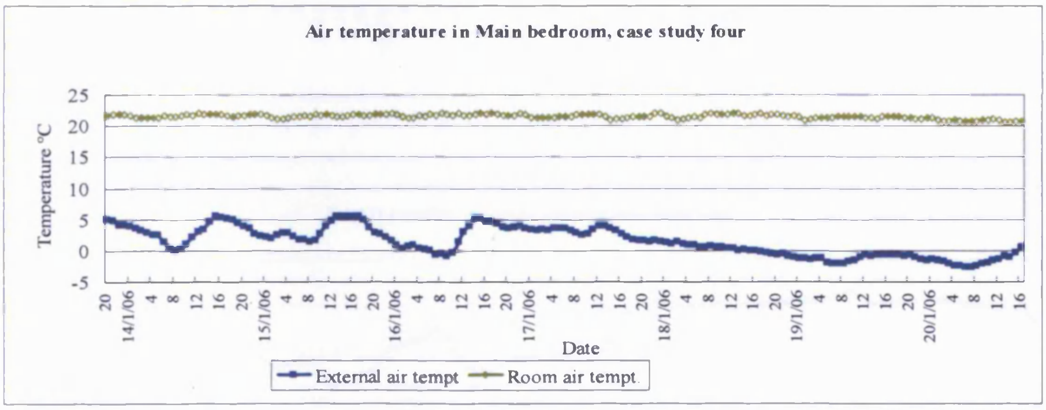
The globe temperature sensor that was placed in the second bedroom did not work properly; hence the measured result recorded from this instrument was abandoned. Furthermore, the owner had two guests staying in the second bedroom after commencement of the measurements, which caused difficulties for the measurement and the analysis of the results.

5.6.3.3 Recorded Results

The following graphical charts (Figures 5.53 and 5.54) show the results obtained in each space.

5.6.3.3.1: Main Bedroom

The main bedroom is on the south side of the building. As the district heating was in operation at that moment, the room temperature is high and stable with a few dips in the temperature caused by the opening of the window. The maximum air temperature reached 22.0°C and the minimum reading was 20.63°C. For the RH, 34.9% was the maximum value recorded and 25.4% was the minimum value. From the comparison with the external condition during the same period, it is evident that the indoor environment was stable due to the support of the heating system; the RH value also remained constant, however, the occupant might feel dry inside the space as the humidity value was quite low.



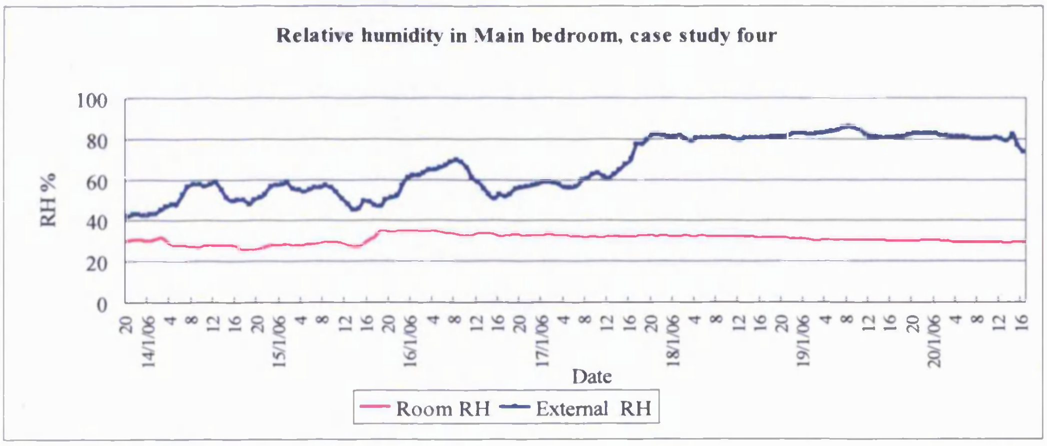
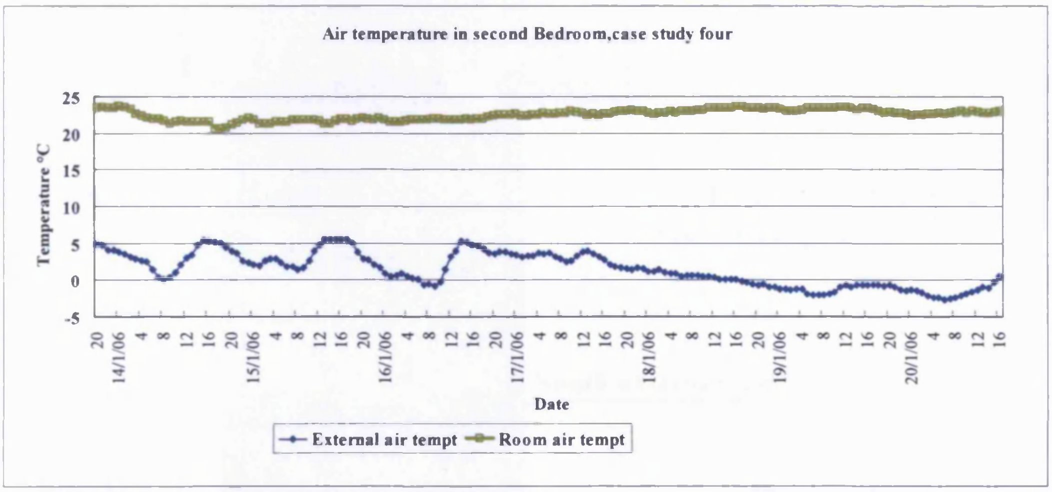


Figure 5. 53: Temperature and RH of the Main Bedroom in the Fourth Case Study

5.6.3.3.2: Second Bedroom

The second bedroom faces north. The maximum air temperature reached 23.7°C and the minimum was 20.63°C. For the RH value, 37.9% was the maximum value recorded and 25.6% was the minimum value. The higher start of both data was due to the owner cleaning the room for their guests. The guests came on 16th January, so the temperature and the humidity increased together; the higher rise in humidity on that day resulted form the drying of the guest's clothes in the room.



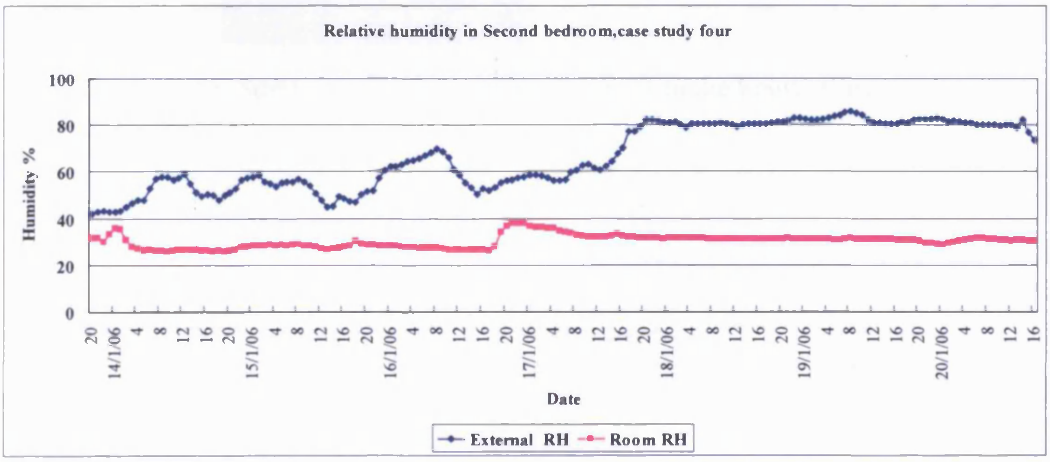


Figure 5. 54: Temperature and RH Value of the Second Bedroom in the Fourth Case Study

5.6.3.3.3: Surface Temperature

The inside surface temperatures of both external and internal walls in main bedroom were measured in order to assess the insulation properties of the construction. All of the test points were positioned at the same height level and located away from direct sunlight. The test point layout is shown in Figure 5.55. However, the sensor on the west wall was broken by the owner; hence the data recoded was abandoned.

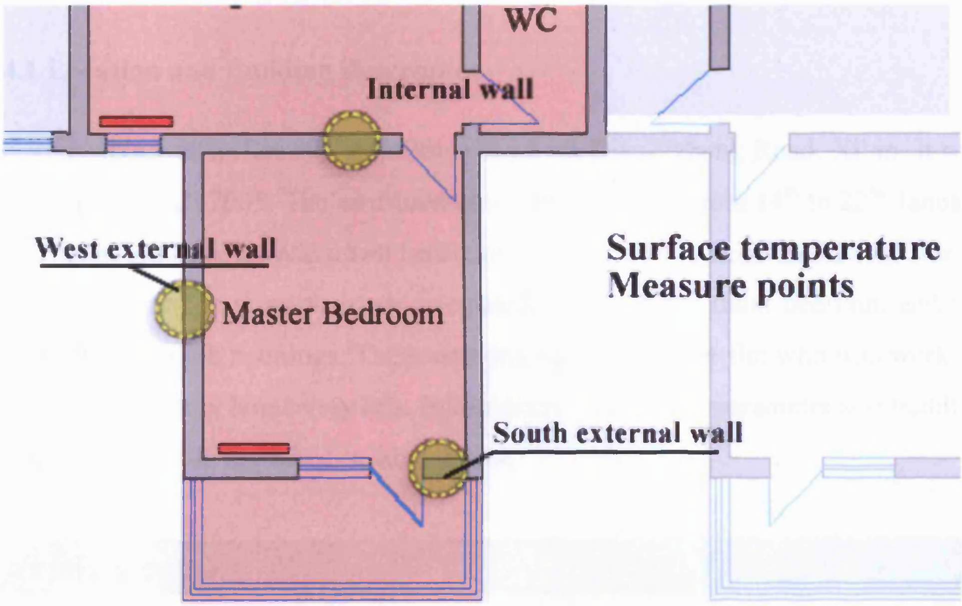


Figure 5. 55: Surface Temperature Measurement in the Fourth Case Study

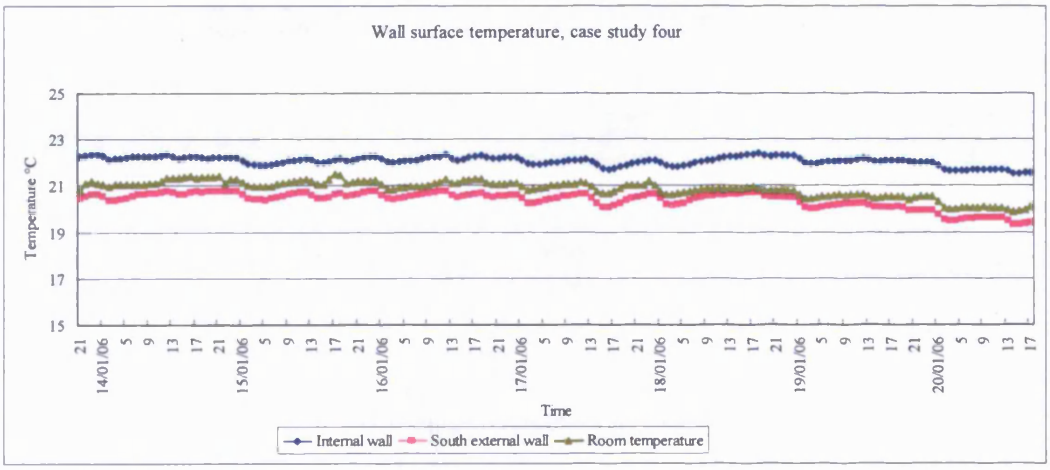


Figure 5. 56: Surface Temperature in the Fourth Case Study

Figure 5.56 summarizes the measurement results, it shows that the internal wall had the highest temperature; the average reading was 22.1°C. However, the wall that connected to the balcony was much colder as it is not insulated and the balcony has no heating system. The average reading of the south external wall temperature was only 20.4°C; this value is also lower than room temperature.

5.6.4 Case Study Five (14th to 20th January 2006)

5.6.4.1 Location and Building Description

Case study five was in flat 602 in building No 6 on DianZizheng Road, Xi'an. It was completed in March 2005. The measurements were recorded from 14th to 22nd January 2006. The layout selected was a two bedroom flat on the sixth floor on the east side of the building. The flat is north-south orientated, and both the main bedroom and the living room has south openings. There was one occupant in the flat who was working full time and was only home very late. Information of the room parameter and building materials information are listed in table below.

Room information				
Location	Room Function	Orientation*	Floor area m²	Glazing ratio %
5th Floor	Main Bedroom	South-west	17.3	44.2
	Second Bedroom	North-west	12.5	47.5
	Living room	South	19.5	N/A
Material information				
Element	External wall	Windows	Internal wall	Floor
Material	200mm concrete with 25mm perlite insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
U-value	0.90	2.70	1.92	1.90

Table 5. 6 : Building parameters of case study five

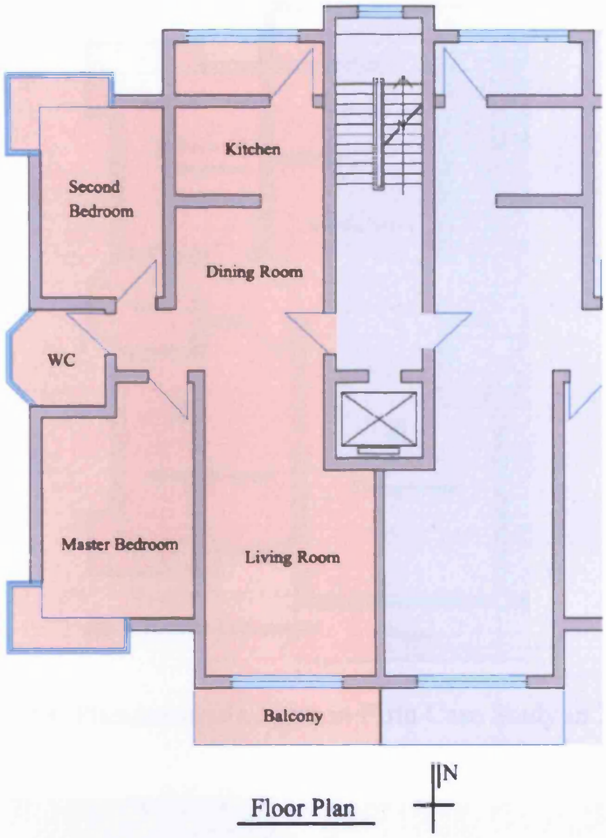


Figure 5. 57: Plan of Fifth Case Study Based on the Survey, Drawn by Author

5.6.4.2 Monitored Spaces

Two bedrooms and the living room were measured, with instruments placed in the flat to monitor air temperature, globe temperature and relative humidity at intervals of 15 minutes. Figure 5.58 and 5.59 demonstrates the placement of the loggers.

Figure 5. 58: Placement of Logger in Fifth Case Study in Xi'an

Figure 5. 59: Loggers Placed on a Night Stand in Second Bedroom and Tea Table in Living Room

5.6.4.3 Recorded Results

The following graphical charts (Figures 5.60, 5.61 and 5.62) show the results obtained in each space.

5.6.4.3.1: Main Bedroom

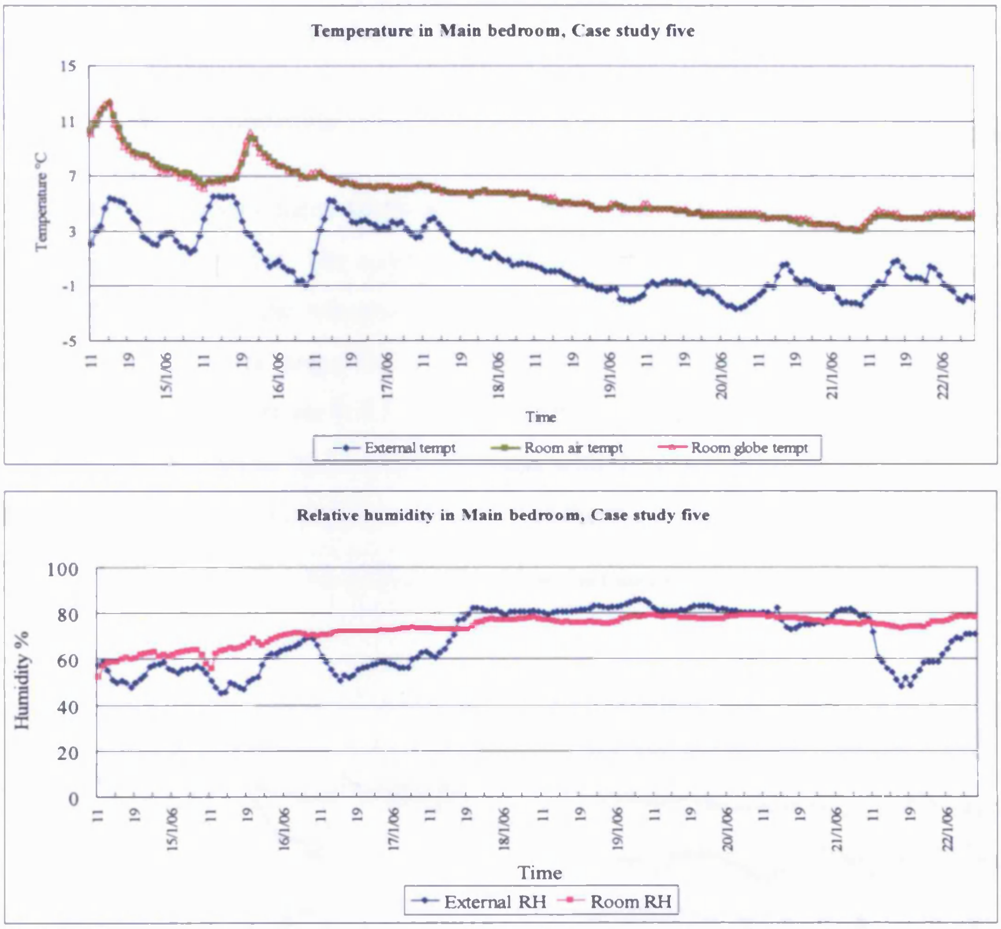


Figure 5. 60: Temperature and RH Value of the Main Bedroom in the Fifth Case Study

The main bedroom is on the south-west side of the building. The flat did not have a central heating system and all rooms were maintained by air-conditioning. There was only one occupant in the flat who was working full time and was only home very late. Therefore, the air conditioning was seldom used and windows were only opened for a very limited amount of time for ventilation and fresh air. The room temperature was quite low due to the absence of the heating system, the only high period was in the two days over the weekend (14th and 15th January 2006), when owner used the air-conditioning while she was home; however, the temperature dropped immediately due to the heat loss through the large glazing area and the external walls. The maximum air temperature was 12.30°C and the minimum reading was 2.95°C; the globe temperature of the room was in a similar range with a peak value of 12.43°C and a low value of 3.1°C. The low temperature made the relative humidity level high and had a steady increase toward the external, 78.93% was the maximum value recorded and 51.95% was the minimum value.

5.6.4.3.2: Second Bedroom

The second bedroom faces north-west; the room was left empty and the doors and windows were all shut. The room was very cold and the maximum air temperature recorded was 5.6°C; the minimum reading was 1.45°C. The globe temperature of the room was in a similar range with a peak reading of 5.3°C and a low reading of 1.5°C. There was a slight increase in the air temperature in the afternoons from the west facing window. The RH value had a steady increase with the external condition, 71.63% was the maximum value recorded and 49.75% was the minimum value.

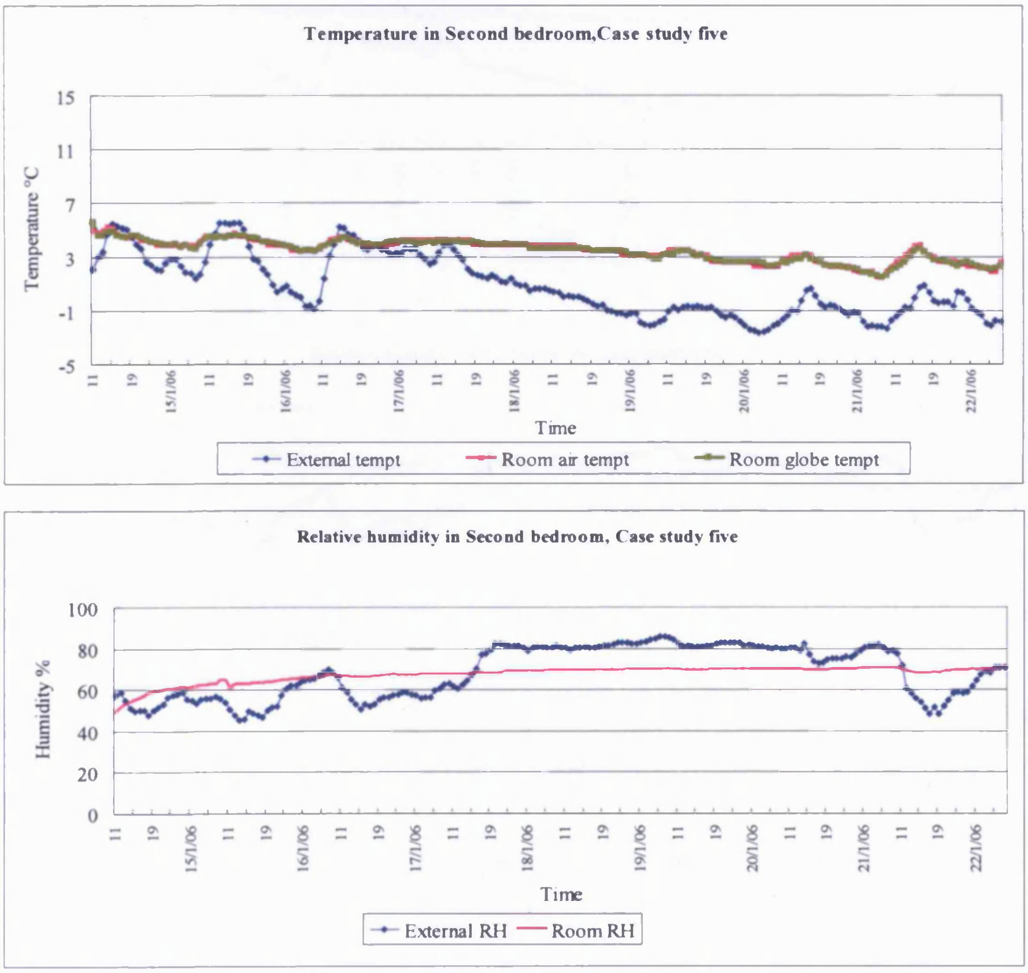
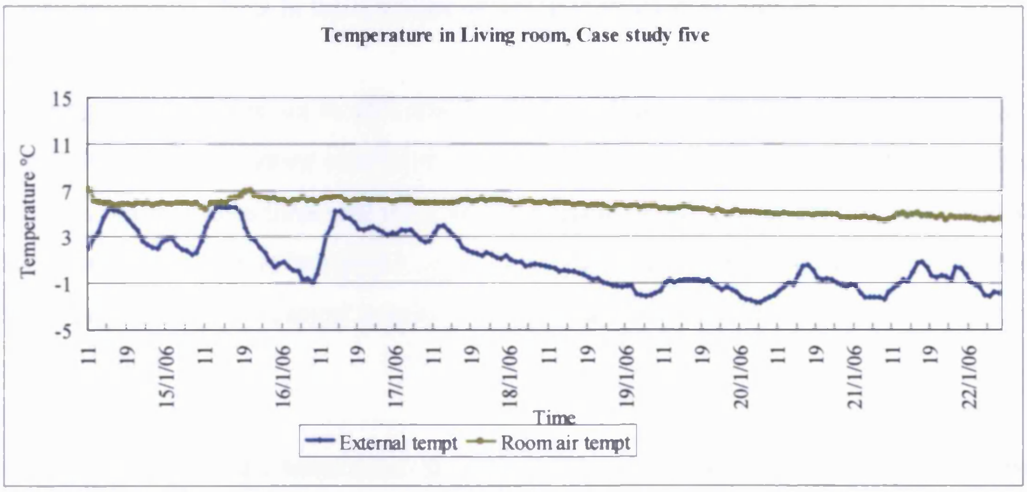


Figure 5. 61: Temperature and RH Value of the Second Bedroom in the Fifth Case Study

5.6.4.3.3: Living Room

The living room faces south, with a balcony attached; the room was seldom used during the period. The temperature was very stable with a slight decrease together with the external temperature drop. The maximum air temperature was 7.03°C and the minimum reading was 4.40°C. The RH value also remained stable, except for the 15% dip caused by the window opening on 15th January 2006; 85.55% was the maximum value recorded and 66.05% was the minimum value.



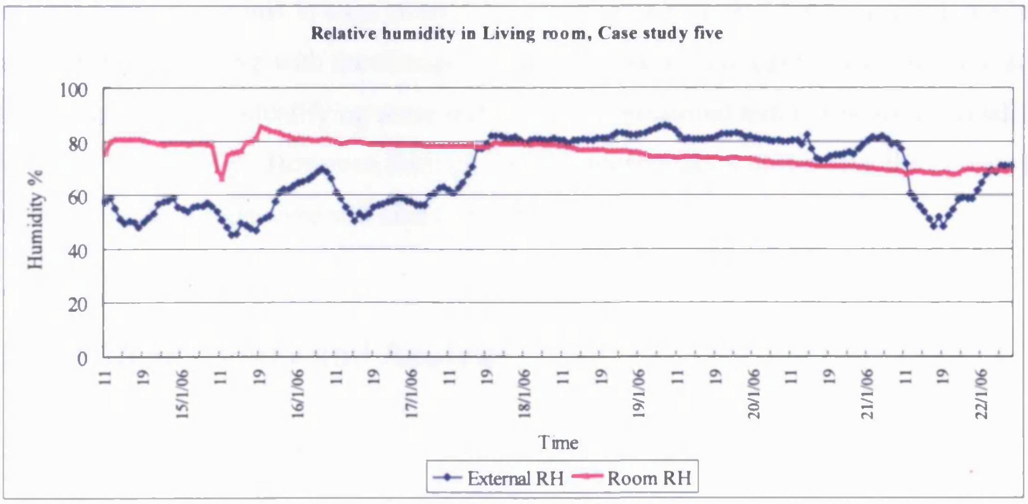


Figure 5. 62: Temperature and RH Value of the Second Bedroom in the Fifth Case Study.

5.7 Measurement Discussion

The selection of the five case studies attempted to cover as a large a variety as possible, under the conditions of availability and character. All of the buildings vary in design and they represent the typical condition of contemporary residential buildings in North China cities. As confirmed in the pilot case study (the first measurement), the plan and process of the field study was well-made, the positioning of the loggers and the data measurement was successful; only two sensors failed to work properly, but this did not cause any major effect in the outcome of the field study measurements.

Heating systems were set to different levels in each case study in order to investigate their effect on the indoor condition. Case studies one and five did not have heating systems; case studies three and four had the heating on full power continuously, whilst the heating was only at half power in case study two. The purpose of such settings was to assess the effect of central heating system on the buildings' indoor conditions in the winter period.

Nevertheless, there are some issues that affected the measurements: the operation of the central heating systems in case studies two, three and four, and the air conditioner in case study five, along with the changed occupancy patterns in case study four have all caused problems in identifying some features in the measured indoor results, especially the relative humidity. However, through intense interpretation of the data, the issues of the current dwellings were still able to be identified.

5.8 Data Summary and Analysis

5.8.1 Data Summary

This chapter discusses the main findings of the field measurements that were carried out during the field study in five existing residential buildings in Tianjin and Xi'an cities. These case studies were monitored during the winter period at fifteen minutes intervals for twenty-four hours over a week, in order to evaluate their thermal performance including air and globe temperature, relative humidity and surface temperature.

External condition including air temperature, relative humidity and solar radiation were also recorded. The results of these measurements form a picture of the existing performance and conditions of the current dwelling, the following tables and graphical charts summaries the obtained data.

Measurement summary of case study one

Room information					
Location	Room Function	Orientation *	Floor area m²	Volume m³	Glazing ratio %
1st Floor	Main Bedroom	South-West	21.8	61	44.1
	Living room	N/A	29.8	86.4	N/A
	Balcony	West-North	4.4	12.8	65.0

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 7 : Building parameters of case study one

Summary of measurement (measurement period 30th Oct-1st Nov)						
Room.	Air temperature °C	Relative Humidity %	Globe temperature °C	Surface temperature °C	External Temperature °C	External RH %
	Min/Max/Ave	Min/Max/Ave	Min/Max/Ave	Min/Max	Min/Max/Ave	Min/Max/Ave
Main Bedroom	12.9/15.8/13.7	39.4/50.6/44.0	12.8/15.6/13.6	12.9/14.3	8.7/21.6/14.4	24.6/60.2/38.2
Living room	12.8/14.7/13.5	35.0/49.4/41.6	12.2/14.9/13.4	13.0/14.7		
Balcony	11.7/14.8/13.2	36.8/53.7/43.4	11.3/15.2/13.1	N/A		

Table 5. 8: Measurement summary of case study one

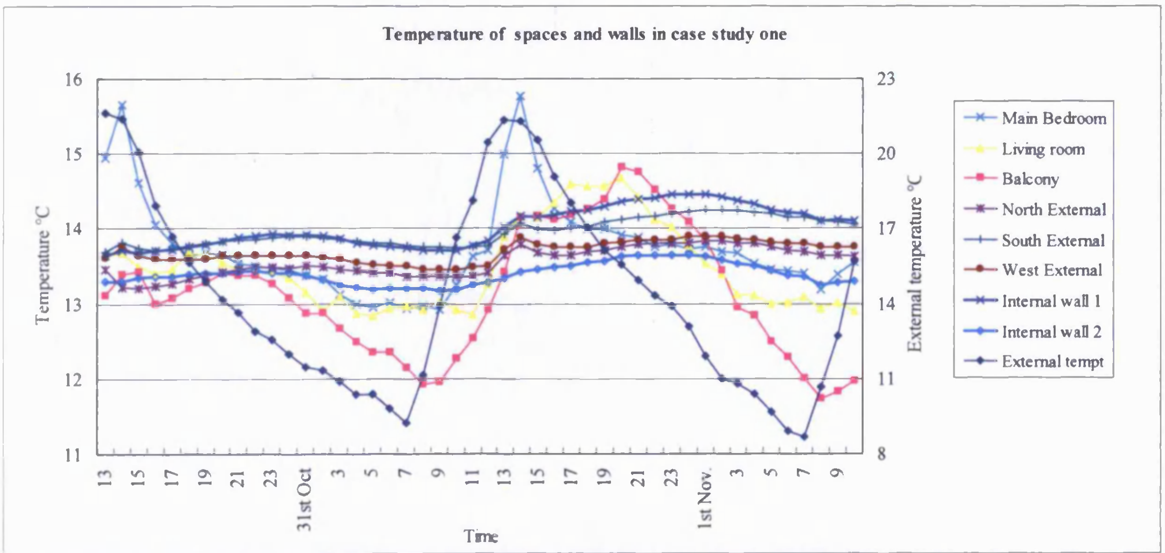


Figure 5. 63: Measurement summary of case study one

Measurement summary of case study two

Room information					
Location	Room Function	Orientation*	Floor area m²	Volume m³	Glazing ratio %
6th Floor	Main Bedroom	South-east	18.2	58.2	46
	Living room	N/A	26.4	76.6	N/A
	Second Bedroom	East	10.8	33.9	45

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 9 : Building parameters of case study two

Summary of measurement (measurement period 2nd - 9th Jan.)						
Room	Air temperature °C	Relative Humidity %	Globe temperature °C	Surface temperature °C	External Temperature °C	External RH %
	Min/Max/Ave.	Min/Max/Ave.	Min/Max/Ave.	Min/Max	Min/Max/Ave.	Min/Max/Ave.
Main Bedroom	15.1/19.9/16.8	13.0/28.5/17.2	14.2/19.5/16.2	14.9/18.2	-10.3/6.68/-2.8	18.3/63.2/33.5
Living room	18.4/21.0/19.8	13.1/29.5/18.4	17.2/19.8/18.7	N/A		
Second Bedroom	14.7/16.5/15.8	14.9/28.7/19.2	14.5/17.0/15.8	N/A		

Table 5. 10: Measurement summary of case study two

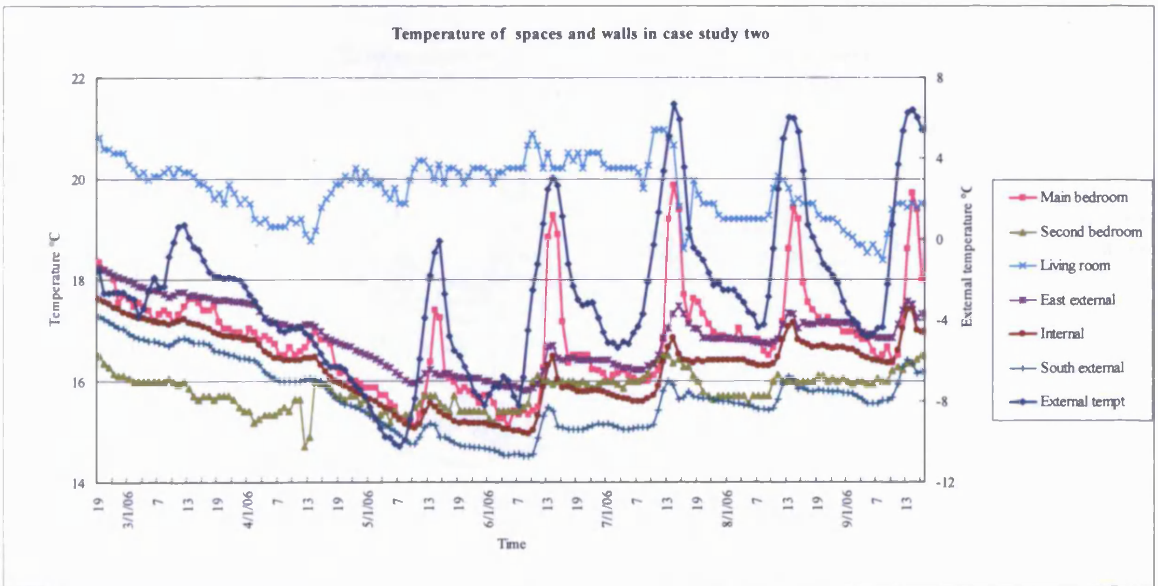


Figure 5. 64: Measurement summary of case study two

Measurement summary of case study three

Room information					
Location	Room Function	Orientation*	Floor area m²	Volume m³	Glazing ratio %
20th Floor	Main Bedroom	South	25.9	75.3	45
	Second Bedroom	South-east	16.4	45.4	42
	Third Bedroom	East	11.8	33.2	40

* The whole building is south-north orientated with 5 ° offset to west

Table 5. 11 : Building parameters of case study three

Summary of measurement (measurement period: 3rd to 9th Jan)						
Room	Air temperature °C	Relative Humidity %	Globe temperature °C	Surface temperature °C	External Temperature °C	External RH %
	Min/Max/Ave.	Min/Max/Ave.	Min/Max/Ave.	Min/Max	Min/Max/Ave.	Min/Max/Ave.
Main Bedroom	16.9/25.0/20.3	17.5/32.0/22.9	15.9/25.0/20.3	N/A	-10.3/6.68/-2.8	18.3/63.2/33.5
Second Bedroom	18.5/25.5/20.5	26.1/32.0/24.6	18.1/25.9/20.2	N/A		
Third Bedroom	19.6/23.3/21.4	9.8/33.6/23.0	N/A	16.8/22.4		

Table 5. 12: Measurement summary of case study three

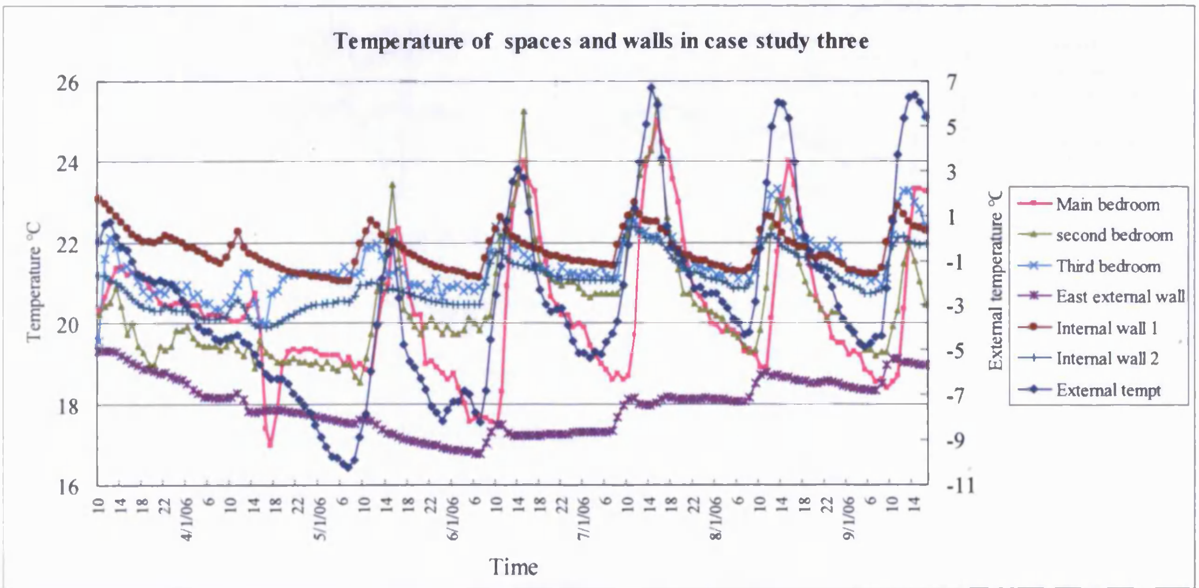


Figure 5. 65: Measurement summary of case study three

Measurement summary of case study four (in Xi'an)

Room information					
Location	Room Function	Orientation	Floor area m²	Volume m³	Glazing ratio %
2nd Floor	Main Bedroom	South	15.1	42.3	22.2
	Second Bedroom	North	11.7	32.8	20.0

Table 5. 13 : Building parameters of case study four

Type and summary of measurement (measurement period 13th -20th Jan)					
Room	Air temperature °C	Relative Humidity %	Surface temperature °C	External Temperature °C	External RH %
	Min/Max/Ave.	Min/Max/Ave.	Min/Max	Min/Max/Ave.	Min/Max/Ave.
Main Bedroom	21.0/22.0/21.6	25.4/34.9/30.7	19.3/22.1	-2.7/5.5/0.8	35.8/85.7/65.3
Second Bedroom	20.6/23.7/22.1	25.6/37.9/30.16	N/A		

Table 5. 14: Measurement summary of case study four

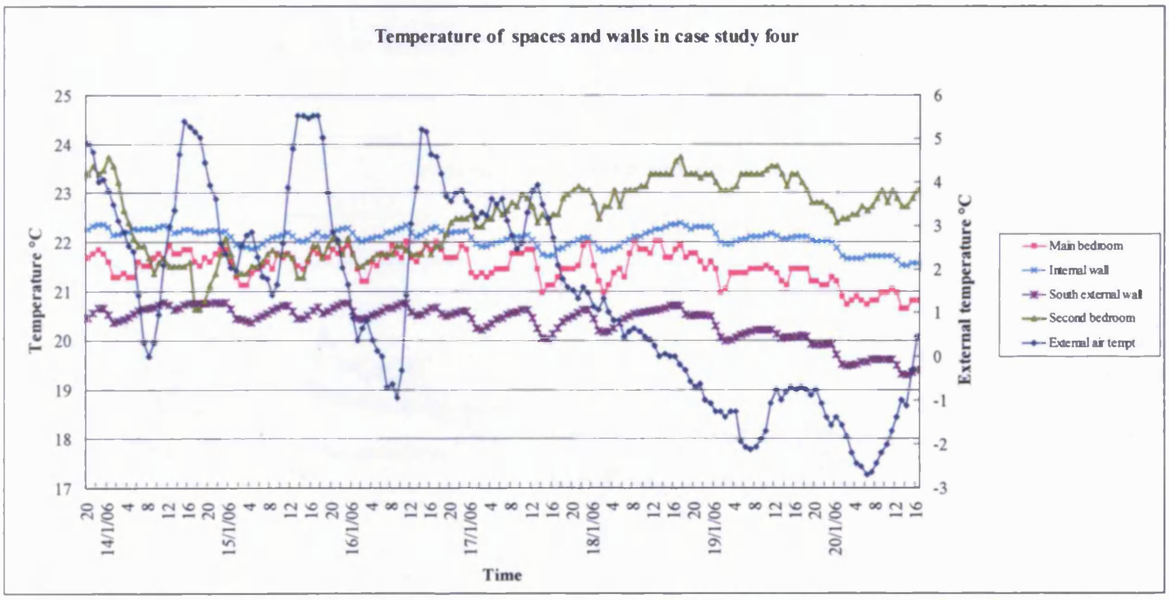


Figure 5. 66: Measurement summary of case study four

Measurement summary of case study five (in Xi'an)

Room information					
Location	Room Function	Orientation	Floor area m²	Volume m³	Glazing ratio %
5th Floor	Main Bedroom	South-west	17.3	48.4	44.2
	Second Bedroom	North-west	12.5	34.4	47.5
	Living room	South	19.5	56.5	N/A

Table 5. 15 : Building parameters of case study five

Type and summary of measurement (measurement period 13th -20th Jan)						
Room	Air temperature °C	Relative Humidity %	Globe temperature °C	Surface temperature °C	External Temperature °C	External RH %
	Min/Max/Ave	Min/Max/Ave.	Min/Max/Ave.	Min/Max	Min/Max/Ave	Min/Max/Ave
Main Bedroom	2.95/12.3/5.6	52.0/78.9/72.7	3.1/12.4/5.7	N/A	-2.7/5.5/0.8	45/85.7/68.3
Second Bedroom	1.5/4.9/3.4	49.8/71.6/67.5	1.5/5.3/3.5			
Living room	4.4/7.0/5.6	66.1/85.6/75.7	N/A			

Table 5. 16: Measurement summary of case study five

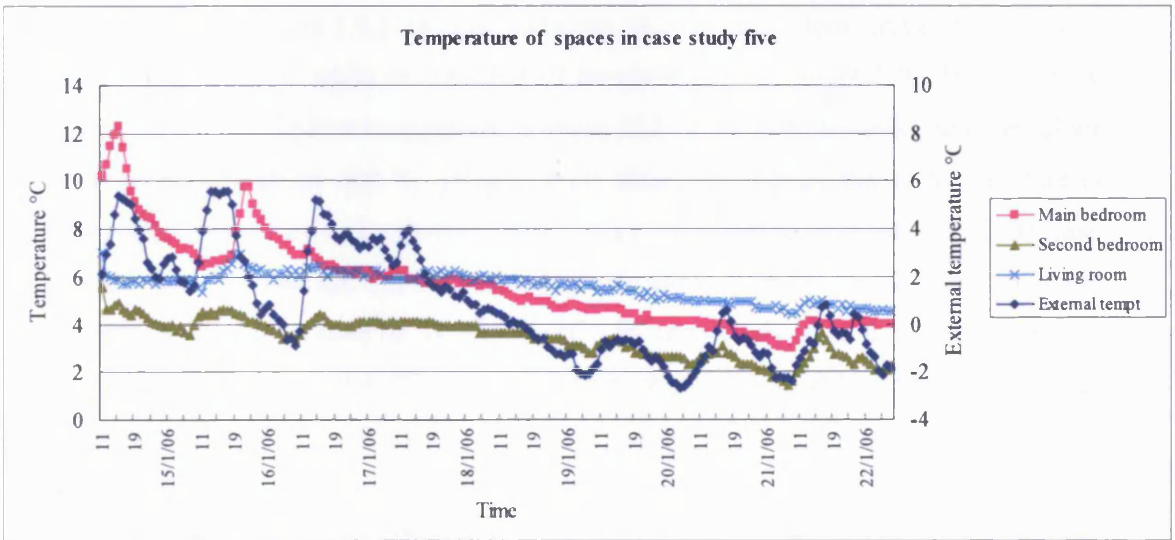


Figure 5. 67: Measurement summary of case study five

5.8.2 Data analysis

The major findings of the data are as follow:

The summaries of the external climate data showed that the winter temperature in North China cities is very low; the average external air temperature in Tianjin dropped from 14.4°C from the end of October to -2.8° C at the beginning of January. The external air temperature in Xi'an in mid-January was about 0.8°C. The range of measured data fits the expectation and description of the previous chapter of the climate zoning and represents the normal climate conditions of North China in this time of the year. Apart from the cold temperature, high values of solar radiation were recorded in both cities, with the peak hourly value of direct solar radiation around 400 to 500W/m^2 appeared around at 13 o'clock daily. The findings of the climate condition indicated the demand for cold protection in building design such as heavy insulation. Moreover, it also indicates the possibility to use solar radiation to passively heat the spaces, or to generate power.

The room temperature measurement results were summarised and listed in the tables and graphs in section 5.8.1. In case study one, the average indoor temperature is about 13.2 °C to 13.7 °C while the external air temperature is about 14.4 °C. In case study two, the average indoor temperature is about 15.8 °C to 19.8 °C while the external air temperature is about -2.8 °C. In case study three the average indoor temperature is about 20.3 °C to 21.4 °C while the external air temperature is about -2.8 °C. In case study four the average indoor temperature is about 21.6 °C to 22.1 °C while the external air temperature is about 1.1 °C. In case study five the average indoor temperature is about 3.4 °C to 5.6 °C while the external air temperature is about 0.8 °C.

An apparent issue is the affect of central heating system on the indoor temperature, Table 5.17 lists the average air temperature took from the bedrooms in all buildings. From the data it seemed that the heating systems of the case studies are able to maintain the room temperatures at a relatively comfortable value, for instance, the heating systems in case studies three and four were operating at full power; hence the reason they achieved the highest temperature around 20-22°C while the average external temperature was about 0.8 to -2.8 °C. On the other hand, the case study five, which had similar construction materials but was without heating systems, had an average air temperature of only 3.4°C (in the unoccupied north bedroom) while external air temperature was about 0.8 °C, this indicated the possibility to improve the building design and the thermal property of the building envelope to improve its ability to buffer the external climate passively to reduce the heating demand. Furthermore, the current district heating system is operating 24 hours continuously; it shows the possibility of changing such system to period heating could reduce the total heating energy demand.

Case No.	Average Measured values in bedrooms	Average External temperature	Room parameters	
	Temperature °C	Temperature °C	Glazing ratio %	Orientation
1*	13.6	14.4	44	SW
2	16.8	-2.8	46	SE
3	20.3	-2.8	45	S
4	21.5	1.1	22	S
5*	3.4	0.8	48	NW

Table 5. 17: Summary of Measurements in Bedrooms

* Flats without heating

Furthermore, the reduced heating output will have a negative impact of indoor temperature. As mentioned before in this chapter, the heating system in case study two was set at a lower output levels during the measurements in order to assess the effectiveness of the level of heating to the space condition. From table 5.17 it can be seen that the indoor air temperature in case study 2 was about 4 to 5 °C lower than case 3 and 4 that had full heating systems run at full power. Therefore how to effectively reduce the heating output whist not reducing the indoor comfort condition will be investigated in the further part of this research.

As mentioned before, the running heating system kept the indoor temperature at a relatively stable condition, however, this had also made it difficult to identify the affect of building parameters on indoor temperature such as the material of building envelope and room orientation. However, some effect can still be spotted in the cases without heating. First of all, building form and orientation had a notable impact on the indoor conditions; the measured results in case study one showed that the daytime peak indoor temperature in bedroom with south east window is about 2 degrees higher than living room, which did not have any openings (see figure 5.63). In case study five, during the period that the air-conditioning was not used, the temperature in south-facing room is about 2 degrees higher than north facing room (see figure 5.67). Secondly, the lack of consideration of the building arrangement meant that houses failed to gain from passive energy like solar heating; in case study one, for example, the maximum temperature outside was about 6°C higher than the internal temperature in the room at the same time (see figure 5.63). Therefore, in the building design process, room should be placed toward the unobstructed south in order to maximise the solar gain.

Window design is also a problem; all the spaces in the case studies had very large glazing areas, especially those completed after the year 2000, which is case studies one, two, three and five (see table 5.17). Although cannot be represented fully from the measured data, it can be safely assumed that the single glazed window in case study four, and the normal double glazing windows in the other case studies, are likely to become a prime source of heat loss during the freezing winter in North China. In addition, the large windows might also create overheating problems for the summer period, as there is no passive shading system for the windows. A smaller, well insulated window, with an appropriate shading design, should be adapted in this region.

Table 5.18 summarizes the measured results of surface temperature. The average temperatures of the inside surfaces of external walls were normally 1-2°C lower than that of internal walls in heated flats. The biggest gap appeared in case study three, where the average temperature difference between the internal walls and the east-facing external walls was 3.1°C. Giving consideration to the size of external walls, it can be predicted that they are going to be a prime source of heat loss from the building. Another low surface temperature was found in the case studies where the internal walls connected to the unheated area like balcony, elevator shafts or corridors, for instance in case study four, the internal wall that connected to the balcony was about 1.7 °C colder than normal internal walls. Those walls were not insulated since they were not directly connected to outside space; however, those unheated spaces also have undesirable thermal situations. Therefore it suggests that thermal insulation on the walls connected to the unheated spaces should also be considered in domestic architectures.

Case	Average wall surface temperature (C°)	
	Internal wall	External wall
1	14.1/13.3*	13.5
2	16.2	15.3
3	21.1	18.0
4	22.1	20.4**
5***	N/A	

Table 5. 18 : Summary of wall surface temperature

* Internal wall connected with unheated spaces

** Walls connected to unheated Balcony

*** No surface temperature was measured in case study five

5.9 Conclusion

This chapter discussed the field study and presented the measured data. The data measured including indoor air and globe temperature, relative humidity, wall surface temperature, measured external climate data including air temperature, relative humidity and solar radiation.

The sources of heat losses and gains were not measured in the case studies; therefore in order to do further investigations of the case studies, computer modelling and thermal simulations are needed. The next chapter will discuss the process of the thermal modelling and the validation of the thermal models of the case studies. The results generated from simulations will be compared with the measured data. In order to ensure the data have the same climate input, the external data measured in Tianjin and Xi'an cities will be used.

CHAPTER SIX: COMPUTER THERMAL MODELLING

6.1 Introduction

The use of simulation and analysis software is becoming increasingly common in all stages of the building design process; design tools can reduce the complexity of the underlying system equations in an attempt to lessen the computational load and the corresponding input burden placed on users (Clarke 2001). Thermal modelling tools can predict and monitor the thermal environment of modern low energy buildings, investigating the detailed workings of a building, incorporating the many aspects of thermal transport and gain (Alexander and Jones 1996). With the advances in computing technology, instead of doing the calculation manually, computer modelling has become widely used for providing accurate and detailed predictions of building energy performance and indoor comfort conditions.

Therefore, in order to test the thermal performance of exiting domestic buildings in China and to determine how their energy performance might be enhanced by applying sustainable design strategies, HTB2 and ECOTECT were selected to model the geometry of the buildings and to investigate the thermal performance of the case studies.

6.2 Thermal Analysis

6.2.1 Aim and Objectives

Simulation programs can predict the indoor condition and energy demand of buildings and can also identify the potential problems. Moreover, users can investigate to what level the efficiency of the design modifications are, so the appropriate improvements or modification of design could be made (Chung et al. 2005). Thus, it is important to select the appropriate tools for the simulation of different perspectives, and the computer models also need to be validated.

The main aim of the thermal analysis is to test and demonstrate the important role that environmental design strategies play in cutting down the energy demand in contemporary domestic buildings in China. In order to achieve this aim, a number of objectives were set as follows:

1 To evaluate models and check their application to this area by assessing the agreement levels of on-site measured data and modelling results from selected case studies.

2 To evaluate and analyse the thermal performance of the existing domestic buildings that were selected as case studies in Tianjin and Xi'an cities.

3 To investigate the sensitivity of important model parameters on the effect of indoor temperature and space load.

4 To test the effectiveness of a group of passive design strategies by applying them individually to the same model.

The study of this chapter will fulfil the first objective and the remaining three objectives will be discussed in Chapters 8 and 9.

6.2.2 Thermal Analysis Methods

Traditionally, thermal analysis means the mathematical calculation of the interplay of thermal processes based on the construction and user pattern information of certain projects, which was previously carried out manually. However, manual calculation is a time consuming process and requires a great deal of knowledge in mathematics and physics. Another drawback of this method is that when a large number of inter-related processes occur in parallel in buildings, the amount of calculation would then be enormous, and processing such a large amount of data manually would be virtually impossible (Clarke 2001).

Fortunately, with the merit of the development of computer technology, there are a number of computerised models for thermal analysis that have been developed over the past few decades and are now widely used for the prediction of indoor thermal condition and energy consumption. Moreover, with the development of more intuitive user interfaces, these can be readily used by architects and engineers to quickly estimate the thermal conditions and compare the effects of many small changes to the building design (Crawley et al. 2005).

Thus, to achieve a high level of confidence in the thermal analysis of domestic buildings in North China cities, appropriate tools should be selected. The section below explains the selection criteria and gives a general description of the tools used in this research.

6.3 Thermal Analysis Tools

6.3.1 Choice Criteria of Computer Modelling Programs

There are several criteria one should consider when choosing an appropriate simulation program to achieve the main aims of a building design or research project. The type of information needed from the model and the validity and accuracy of the program are the most important factors. Software has its pros and cons, and different tools may cover different areas. In addition, the accessibility and familiarity to the model and the accessibility to the technical support are also important (Abanomi 2005). A report called 'Contrasting the Capabilities of Building Energy Performance Simulation Programs', was published in 2005 by the US Department of Energy (DOE), listed and graded the twenty most popular simulation tools and test simulation results in different areas (Crawley et al. 2005).

Based on the above criteria, HTB2 and ECOTECT thermal modelling computer programs have been chosen for performing the simulation experiments in this research. Both programs are widely used in the field of architecture and building science research, both within the UK and overseas. ECOTECT was used to draw the geometry of the domestic building. It has the capability to export the input data to other simulation modelling programs, such as HTB2. Both programs were used to evaluate the thermal model of the case studies. However, HTB2 was used later in all the simulation experiments for the energy demand related calculations.

HTB2 was selected for this research because it can fulfil the objectives of the modelling and it has been used successfully in a number of design projects and research studies (Jones and Alexander 1999). In addition, HTB2 has also been subject to external examination, validation and appraisal. It has been tested using the main four methods for validation, which are open inspection, analytical, empirical and inter-model. In the inter-model method, for example, a number of test case studies were applied to HTB2 as well as other industry standards, such as ESP, BLAST, DOE2, and TRNSYS, etc. The comparison of the results from the BESTTEST that has been adopted by ANSI/ASHRAE 140-2001 shows that HTB2 provides average results when compared with the other standards and is also used as a method for HKBEAM (Alexander and Jones 1996). In addition, the dynamic thermal model HTB2 has been tested and successfully used on many occasions, including research and consultancy projects in North China to evaluate the thermal performance of houses (Li and Jones 2005; Li et al. 2006).

ECOTECT is a building analysis application that was complied by Square One research and the Welsh School of Architecture at Cardiff University. It is a simulation program as well as a design tool, which provides users with a comprehensive range of performance analysis and simulation functions on a designer-friendly 3D modelling interface. It is very helpful to users, especially for architects who want to test alternative design parameters at any stages of a buildings design (Marsh 2004). Additionally, another important feature of ECOTECT is that it can export geometry to a number of other tools' calculating engines, which makes it easier to carry out our simulations using different tools.

As mentioned previously, there is a large range of available software to choose from; for example, 'Energy plus' is a very powerful simulation tool in energy consumption prediction, however, the choices used were within the tools that were developed at the Welsh School of Architecture, as all of the software had already been proven to be accurate and valid in a number of previous PhD students' works (Abanomi 2005; Al-Oraier 2005; Green 2004.). Moreover, it was also more convenient to have the program developers at the school to provide adequate support and advice, which will make the learning process relatively easier.

6.3.2 Tools Description

6.3.2.1 Heat Transfer in Buildings (HTB2)

HTB2 is a finite model developed at Cardiff University that is intended for the simulation of the energy and environmental performance of existing buildings and building in the design process. It is a revised version of the Heat Transfer through Building program (HTB) that was developed in 1971 (Alexander 1996). Being an investigative research tool rather than a simple design model, HTB2 was designed to '*investigate aspects of thermal transport and to assess fabric conduction, ventilation, insulation, heating and incidental systems*' (Alexander and Jones 1996). It is able to demonstrate comprehensive operation predictions of internal environment conditions and energy demands of a building, during both the design stage and its occupancy period.

It also predicts the influence levels of fabric, ventilation, solar gains, shading, incidental gains and occupancy pattern, on the thermal performance and energy use of a building for the purpose of '*... providing scientists/programmers, perhaps working with a research architect or design team, with a flexible tool for studying the detailed operation of a building on a short time scale, of minutes rather than hours...*' (Alexander 1996).

HTB2 is an investigative research tool rather than a simple design model. By providing users with a wide range of information, including interior air and radiant temperatures, fabric temperatures, heating system use and zone-to-zone energy flow, it helps users to evaluate the thermal performance and the energy load levels in a building design.

6.3.2.1.1 Principles of the Model

In HTB2, interior spaces in a building are considered to be linked to each other and to the external environment by walls, doors, windows and ventilation paths; ventilation can also be set between zones. The heating, ventilation and air conditioning systems (HVAC) operate under a controlled and networks of incidental heat sources are the major factors that affect the building's thermal performance. These thermal factors generate heat fluxes, air movements and moisture movements which directly affect the temperature and humidity levels of the indoor spaces (Alexander 1996).

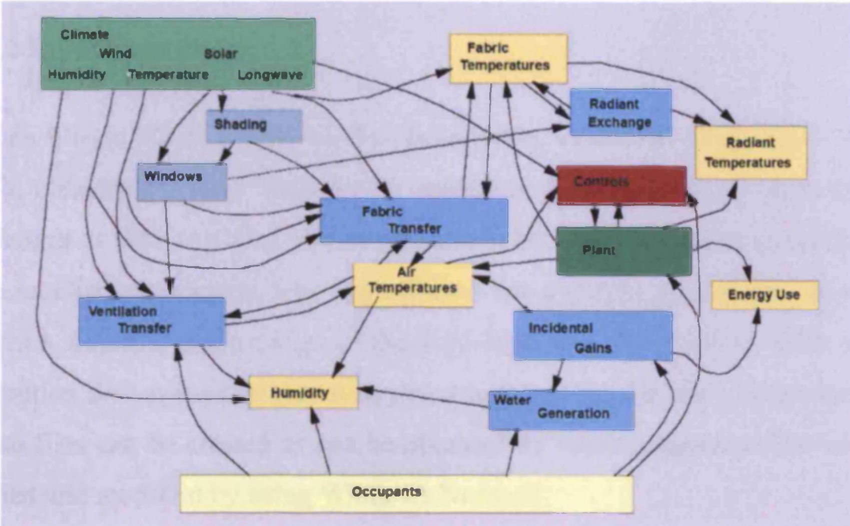


Figure 6. 1: Fundamental Building Processes and Interactions

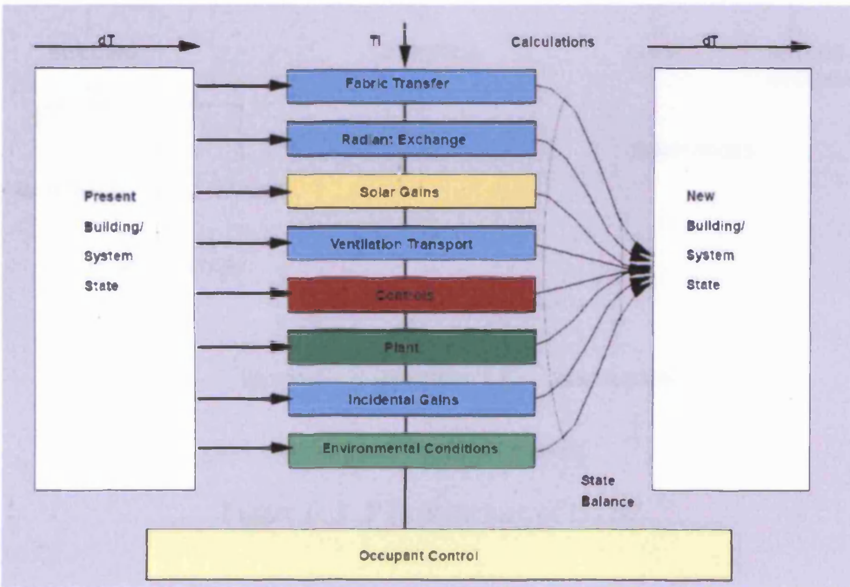


Figure 6. 2: Partitioning of Time and Processes

The complex links of interactions in Figure 6.1 represent the thermal behaviour of a building in HTB2 setting. The program divides time into intervals and assumes that each heat transport mechanism remains constant and independent of the others during that time interval (see Figure 6.2). A new set of conditions are calculated at the end of each interval throughout the run. The time interval, which is normally less than one minute, helps to achieve more accurate and detailed results.

6.3.2.1.2 Input Data Files

Input data files in HTB2 are gathered at three levels, as shown in Figure 6.3. The top-level file contains the basic information needed to organise the simulation run, such as the length of time segment, the subsystems to be used, the names of the data files and the required output data. The second-level file contains general data in the main subsystems included in the names of the third-level file. The third-level file contains the definition data related to the subsystems required for the run (Alexander, 1996). All these files can be created or can be obtained by editing standard files which can be opened and modified by using Windows Notepad.

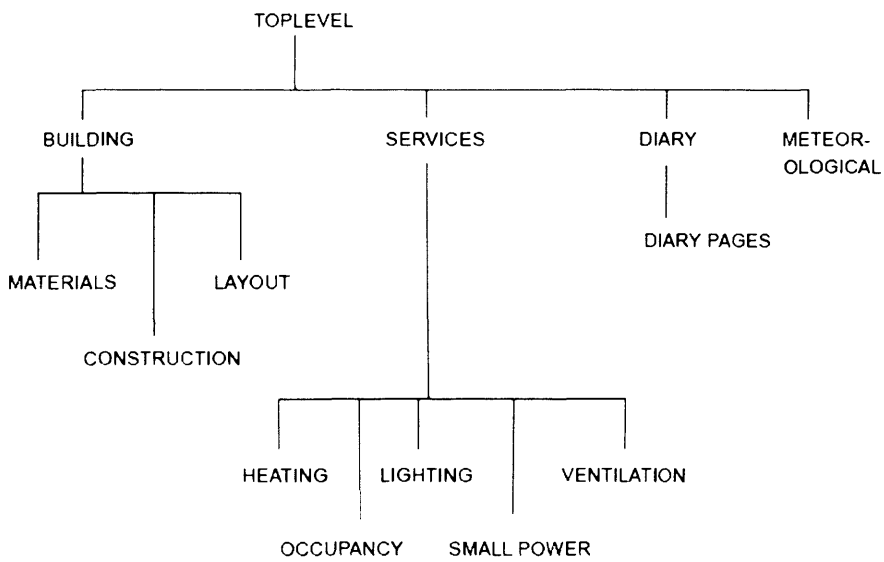


Figure 6. 3: File Structure of HTB2

6.3.2.1 3 Output Data Files

There are six types of output data that HTB2 produces for each run. The output data files summarised by Alexander (1996) are as follows:

1 LOG FILE - typically the screen output created during the ru., This output type warns of errors during the input and run stages, and marks the progress of a run.

2 INFO FILE- contains run information, such as filenames, space volumes and element types. It is created immediately after the input stag, and is useful in checking input integrity. For instance, a standard U-value is calculated for each construction type, which can then be compared against expectations.

3 REPORT FILE – also called 'BLOCK REPORT', it records interval averages of key data resulting from the simulation. The default interval is hourly, although this can be altered to any interval up to the sum of a whole year.

4 PROFILE FILE – records instantaneous temperature and heat flux profiles through selected building elements at selected intervals or as triggered snapshots.

5 LOGGER FILE – records instantaneous data asynchronously, when the value of (user) selected variables change by more than a specified amount.

6 SAVE STATE FILE - records the fabric temperature conditions each midnight. This file is not meant to be an "output" as such, but rather to be a means of restarting a simulation from a known point, it can be set with the !DEFINE RESTART command of the Top-level file.

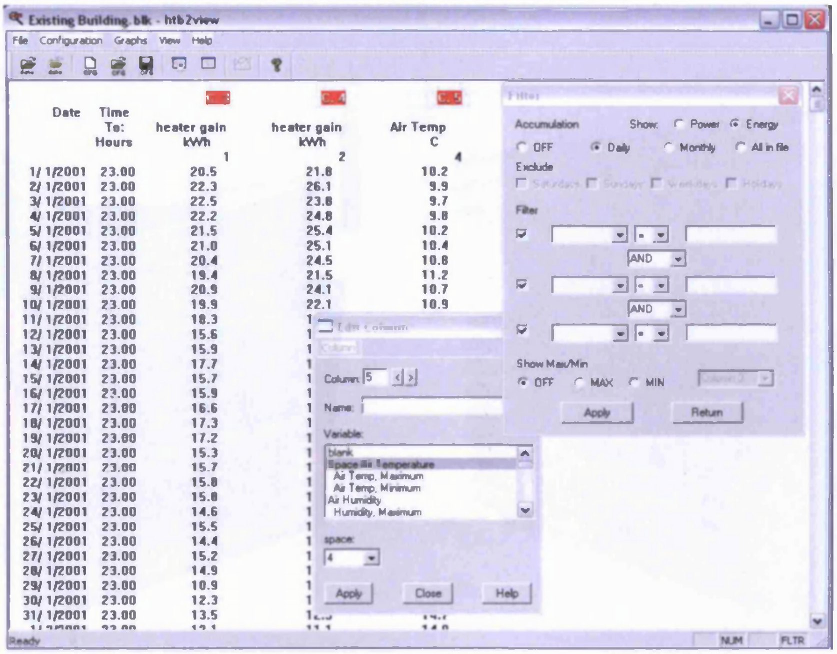


Figure 6. 4: Interface of HTB2 View

The first two standard outputs record the processes of the simulation run and the remaining four outputs, which are optional, can be selected as required in the top-level file along with the data required in each type. The Report File, also known as *.BLK file, is the most commonly used file as it contains all the simulation results. It can be opened by a program named HTB2VIEW; the basic interface of the viewer is demonstrated in Figure 6.4. By adding more columns, it is possible to view the results of selected calculations for each space separately; and moreover, the results can be displayed at different interval values and with different units, power or energy, for instance. The displayed results can then be exported to an Excel spreadsheet for further analysis.

6.3.2.2 ECOTECT

ECOTECT is a building analysis application that is based on a 3D modelling interface. The unique feature is: '...a software package with a unique approach to conceptual building design. It couples an intuitive 3D design interface with a comprehensive set of performance analysis function and interactive information display' (Marsh 2000).

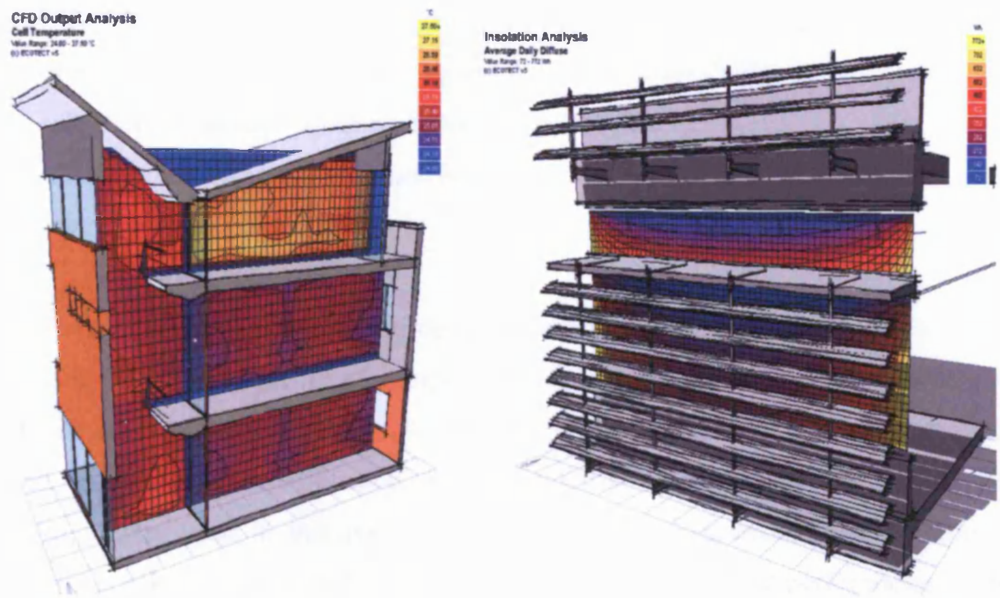


Figure 6. 5: Internal Temperature and Solar Access Analysis in ECOTECT

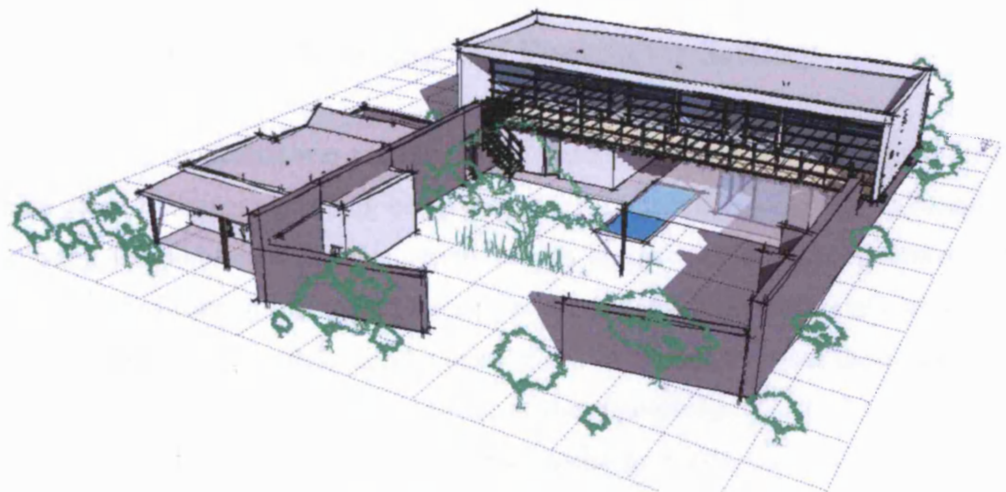


Figure 6. 6: Model Example in OpenGL View in ECOTECT

This program has useful features that can provide extensive simulation functions and simplify the simulation processes; it reduces the complexity of building data input and can generate and represent the resulting data in a more vivid way. Furthermore, it can load the calculation results from other tools, such as CFD and Radiance, and demonstrate them in a grid-based analysis system (Marsh 2004). Figure 6.5 and 6.6 demonstrate the modelling and analysing samples.

ECOTECT is capable of doing a large range of simulation, including:

- *generate interactive sun-path diagrams for instant overshadowing analysis*
- *calculate the incident solar radiation on any surface*
- *calculate monthly heat loads and hourly temperature graphs for any zone*
- *export to the HTB2 program*

However, ECOTECT is a piece of developing software; hence there are some issues in the accuracy and transfer of geometry. Also, if the user needs more accurate and detailed results in a specific area, one normally need to transfer the model to other tools, and additional modification of the transferred model is then needed. For this reason, it was used in this research for creating building geometries, performing climatic analysis of case study cities and predicting the thermal performance of the case studies; the models were then exported to the HTB2 program for the energy demand analysis.

6.4 Comparative Modelling and Parameter Settings

Comparative modelling was used to validate and verify the computer models for the case study buildings, including comparisons of the geometry of computer models to existing buildings and the simulation results against recorded measurements. As temperature is one of the major factors that determine the perception of comfort and heating/cooling energy demand, the comparison of measured indoor temperature and surface temperature data, with the result of the simulations, was used as a means to prove the validity and correctness of the model to reality. However, as there are uncertainty factors that might affect the accuracy of both measurement and prediction of the data (such as the affect by the occupant's activity), it is impossible to expect a perfect match between predicted and measured data. As mentioned by Joe Clarke (2001), although absolute accuracy is often desired, in practical model and simulation there need to be a certain level of tolerance of the difference as long as it show sufficient degree consistence between the results from measurement and simulation. In previous PhD works using HTB2 (Abanomi 2005; Al-Oraier 2005) in Welsh school of architecture, the variation between measured and predicted air temperature appeared to be in a range of between 1 to 5 °C.

6.4.1 Weather Data

The indoor conditions of residential buildings are more affected by the outdoor climate than by the occupants and other internal heat gains (Zhu and Lin 2004), therefore, having accurate climate files that correctly represent the external condition is crucial for the purpose to realistically produce the simulation of indoor condition. The completed weather files for Tianjin and Xi'an City are acquired from the database of the U.S. Department of Energy (2006), and the data was supported by Meteorological Stations in those two cities.

However, the acquired data was based on the average value over the past five years and due to the expected variation in the climatic conditions during recent years, those weather files are clearly not applicable for the comparison simulation purpose; to compare the predicted and monitored indoor air temperature when the external temperatures are not the same, is clearly not valid. When calculating the indoor temperature of the models, the climate data HTB2 considers is the external air temperature and solar radiation. Therefore, the measured on-site climate data in that specific period was used to replace the existing climate data from past average values. The purpose of this is to represent the conditions during the measurement as much as possible; the measured data including air temperature and solar radiation were manually applied to the weather file of Tianjin and Xi'an City. Site wind condition like wind speed and direction were not measured as HTB2 and Ecotect do not consider wind data in its thermal related simulation hence this does not affect the result at all. However, in reality the site wind condition will affect the infiltration rate of the building and hence in their future development the tools need to consider means to incorporate site wind condition into their calculation method.

6.4.2 Building geometry and zoning division

Geometries of the case studies were constructed in ECOTECT and based on the construction drawings supported by local Construction Administrations. The processes started by drawing the geometry of the building model in ECOTECT (see Figure 6.7). Each space in the building was drawn as a thermal zone and each zone was given a name and code to clarify and organise the output data. The second step was to specify all the element materials that were used in the construction of the existing domestic buildings.

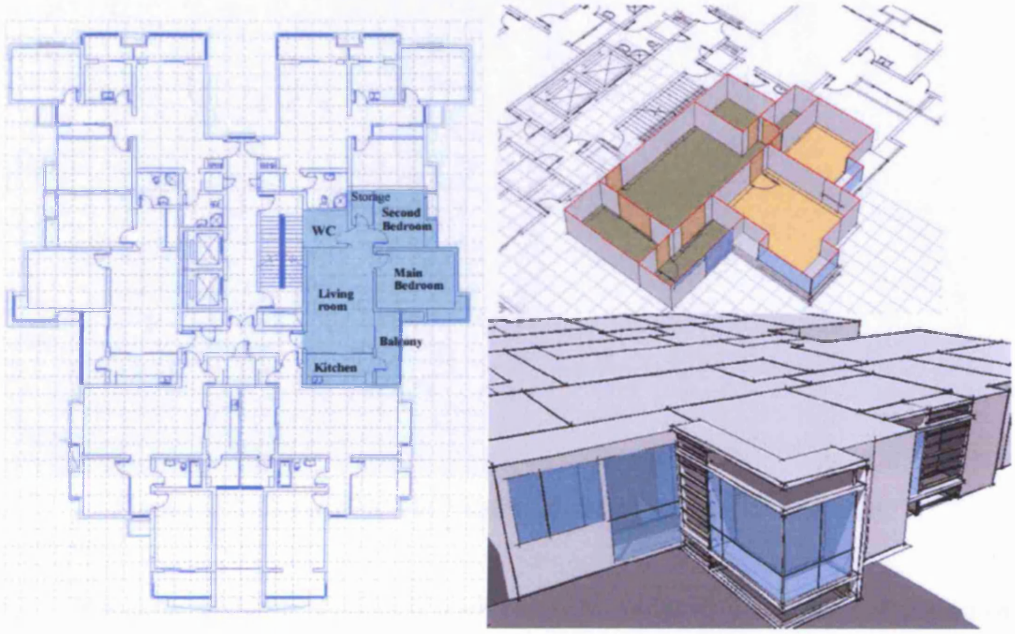


Figure 6. 7: Modelling Process in ECOTECT

Both HTB2 and ECOTECT consider a completed thermal model as a cluster of 'thermal zones' and the thermal property settings, and simulation results, are also linked with each zone. Therefore, in order to achieve accurate results, zone dividing of the model layout is an important process. Basically, each room should be considered as connected thermal zones; in some cases, spaces with supplementary functions can be merged into one in order to save calculation time.

The modelling process of case study two in ECOTECT (plan as demonstrated below) was used here to demonstrate the procedure (see Figure 6.7). Firstly, the CAD drawing of the layout plan is imported into ECOTECT, and then the flat was divided into different zones according to their functions; in this case, each room was considered as a thermal zone, the only exception is the living room which was merged with the entrance area as there was no partition between them. After separating the thermal zones, the geometries of the model were then constructed according to the dimensions: windows and doors were inserted; the rest of the building was modelled as well, the purpose of which was to keep the general volume in the same scale in order to achieve more accurate results (see Figure 6.8).

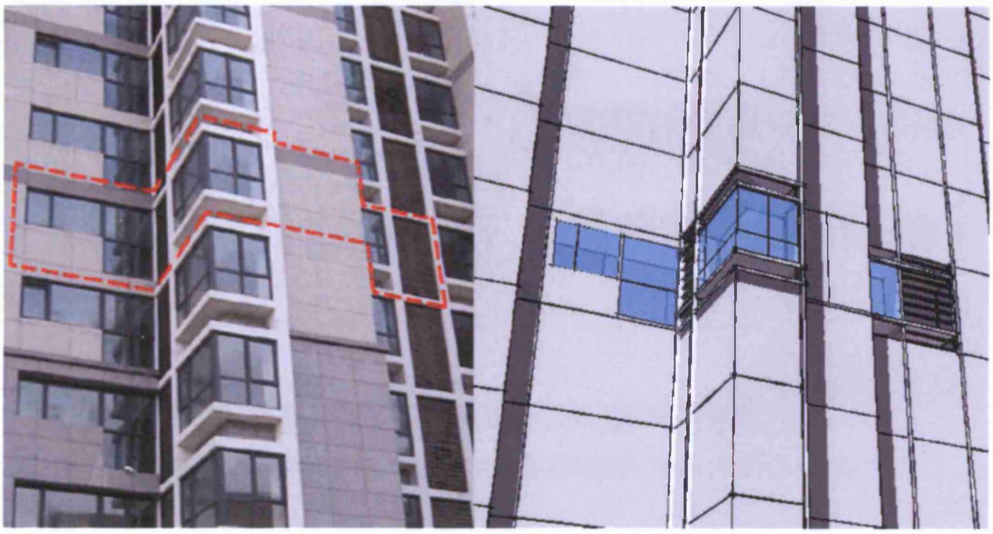


Figure 6. 8: Comparison of Model Geometry with Real Situation

During the creation of the model geometry, it is essential to check the connection of zones and surfaces. With the ECOTECT interface this can be done easily, the 3D visual representation of zones and surfaces during the data input process allows the user to ensure the correct geometric definition, and the function 'Calculate Inter-Zonal Adjacencies' can locate any possible issues that might affect further analysis (see Figure 6.9).

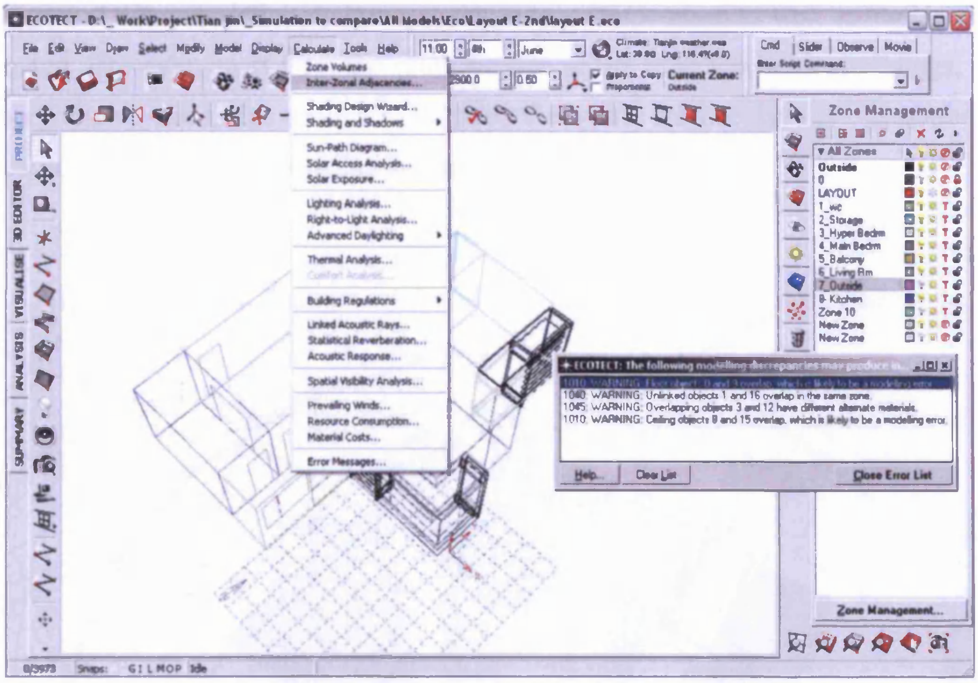


Figure 6. 9: Zones and Surface Adjacency Check in ECOTECT

Matching the model geometry with the actual appearance is important, as the computer model needs to maintain the same building scale. The appearance also has a direct relationship to the shading effect of the windows and walls.

6.4.2.1 Site Solar Condition Analysis

After the building geometry is correctly created, it is possible to check the overshadow condition and solar accessibility of the project. Solar accessibility is an important index for building planning, however, during the master plan process of the case studies, it appeared that insufficient attention was given to the orientation and content of the site, and the necessary distance between buildings for adequate sunlight access for habitable rooms was also not properly considered. These resulted in the inadequate use of solar energy and overshadow effects between each building. Moreover, the situation will worsen if the building has a complex shape and façade due to the possible self-shading effect. Figures 6.10 and 6.11 demonstrate the site content of the case studies in Tianjin; Figure 6.10 is the 1300 at summer solstice (21st June) and it is quite clear that except for some self-shading effects, most of the glazing areas are exposed to direct sunlight, because there was no passive shading design and this will definitely increase the indoor temperature as well as the cooling demand. However, apart from the south surface of the front row of the buildings, no other building can assess enough sunlight on the winter solstice day (21st December), because of the interactive shading and self-shading effect.

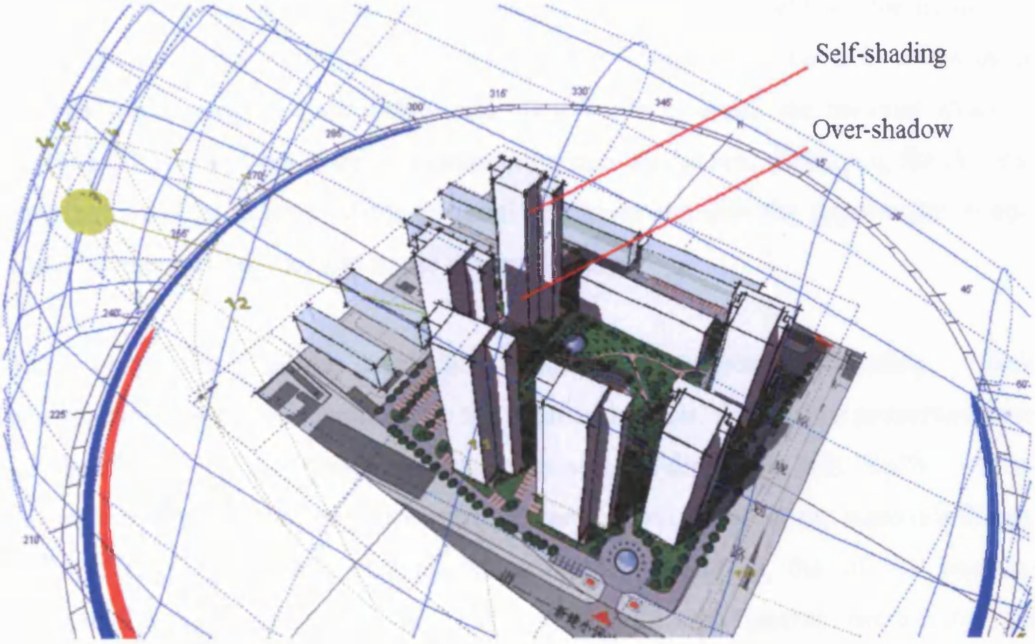


Figure 6. 10: Sun-path and Shadow Analysis on Summer Solstice Day.

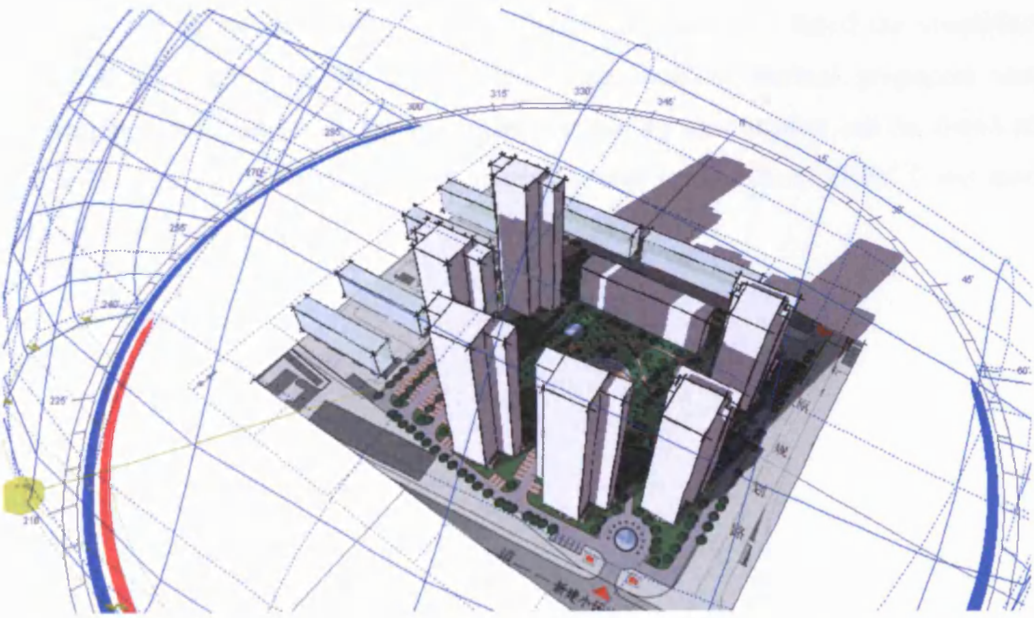


Figure 6. 11: Sun-path and Shadow Analysis on Winter Solstice Day.

6.4.3 Material Definition of the models

In order to achieve high accuracy in modelling predictions, the properties of building materials should be set correctly according to the existing condition; the modelling tools provide a large material database to choose from and one can also create other materials according to the building information. For example, the material editor in ECOTECT displays the material construction in a dialog box, displaying the thermal information of each layer of the material and gives the user the opportunity to edit material in current model and in the general library.

All materials used in the case study buildings were created according to their construction information supplied by the local authorities; the thermal properties were all checked with the suggested values in China's building code (GB 50176 – 93) to ensure the values are correct, the materials were then created in the materials library that ECOTECT provides. At this stage, each element of the of the building construction has a material file that contains the information needed for the simulation run, such as the U-value, admittance, solar absorption, transparency, thickness and weight. Figure 6.12 indicates the 'Material Dialog' box of the thermal property and layer information of the material and table 6.1 listed the simplified material information of the case studies; the detailed thermal properties and construction information of the materials used in the case studies can be found in Table 9.1 and 9.2 in Chapter 9. All materials were created in ECOTECT and then transferred into HTB2.

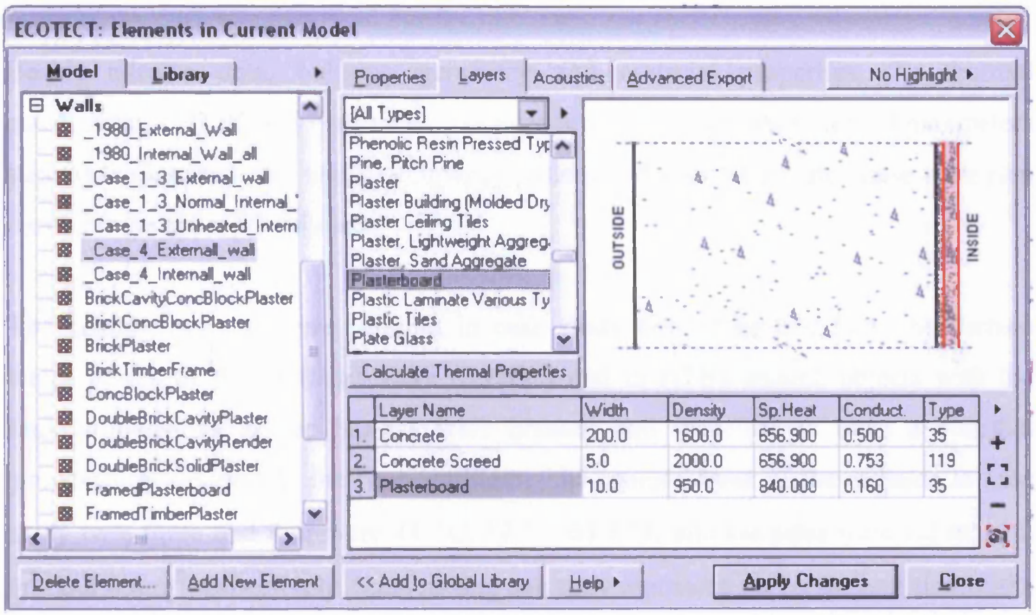


Figure 6. 12: Material Library Dialog in ECOTECT

Material information of all case studies					
		External wall	Windows	Internal wall	Floor
Case 1-3	Material	200mm concrete with 25mm Polystyrene Insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
	U-value	0.75	2.70	1.90	1.90
Case 4	Material	200mm concrete	single glazed metal window frame	120mm medium weight brick	100mm concrete board and 10mm tile
	U-value	1.15	6.40	1.90	2.27
Case 5	Material	200mm concrete with 25mm perlite insulation	Double glazed PVC window frame	120mm medium weight brick	100mm concrete board and 25mm wood floor
	U-value	0.90	2.70	1.92	1.90

Table 6. 1: Thermal Properties of the Models

6.4.4 Thermal Parameter Settings

Beside climate data, building geometry and material properties, the thermal calculation of HTB2 and Ecotect also require information of other thermal parameters such as the internal gain level, occupancy pattern and ventilation rate, these were also needed to be appropriately set.

The heating systems were running in case study two, three and four, the surface temperatures of the radiators were recorded and in HTB2 model, objects with the same dimensions as the heaters were created and were set to have a constant temperature to simulate the room radiator. The temperatures of the radiator in case study two, three and four were 44 °C, 57 °C 63.5 °C and the sizes were 1.2 m^2, 1.2 m^2 and 0.8 m^2 respectively. Such setting can only represent the basic condition of the heating system as they were considered to be running at a constant temperature all day long, although theoretically the heating system were supposed to work like that however, the possible minor fluctuations of the heating systems during its operation is impossible to represent. This might lead to some difference between the simulated data and the measurement.

The indoor conditions of residential buildings are more affected by the outdoor climate than by the occupants and other internal heat gains (Zhu and Lin 2004), domestic architecture has much lower internal gain compares with other building types as the occupant density and their activities in a certain flat will remain relatively stable and the amount of electrical equipments is also much less when compared with non-domestic buildings (Givoni 1994); hence, the impact of internal gains toward the heating and cooling demand is not as great as other building types. However, the internal gain values and occupant patterns still need to be appropriately set to ensure realistic values are input.

The occupant number and occupied time is recorded during the measurement, the first three case studies in Tianjin were unoccupied during the measurements, hence the internal gain and occupancy were considered to be zero. Case four have one occupant and the owner left home at 8 in the morning and came back at 8 at night in weekdays and at home all day in weekends. Case study five also had one occupant and she left home at 8am and came back 9pm to in weekdays and stayed home all day in weekends, however, the occupants' behaviours at home such as opening the window cannot be simulated and thus might lead to potential inaccuracy of the analysis. The internal gain level was not measured in the latter two case studies; a 5w/m2 was used to represent the heat gain level from the equipment, this value is deemed to be adequate for residential buildings and also during the site visit there were not any abnormal heat-emitting objects.

The ventilation rates were not measured in the case studies as there was not adequate equipment to do that task. The settings set based on previous literature and author's assumption. In Gao ping's (2002) previous research work, 'Calculating air infiltration in multi-storied buildings', the ventilation rate recorded by using CO_2 tracing showed that the overall ventilation for buildings with single glazed windows is about 2 ach, and with the improvements in construction technology in China in recent years, the value of 1.0 ach is achievable in recent constructions with double glazed windows (Lv 2006). Therefore, overall ventilation rates for case studies in Xi'an were set at 2 ach and 1 ach in cases four and five respectively, to realistically represent the operation condition of the building; case four had a higher infiltration rate because it was single glazed.

The above values are adequate for occupied buildings, but the first three case studies in Tianjin were unoccupied during the measurements and windows and doors were kept closed, hence a low rate of air change should be used to represent the background infiltration. Graph below showed the result of predicted temperatures by using two air change rates in the bedroom in case study one: 0.25 and 0.5, from the comparison it can be seen that the result by using 0.5 ach showed a closer agreement to measured data than 0.25 ach, therefore the 0.5 ach was used in the first three case studies.

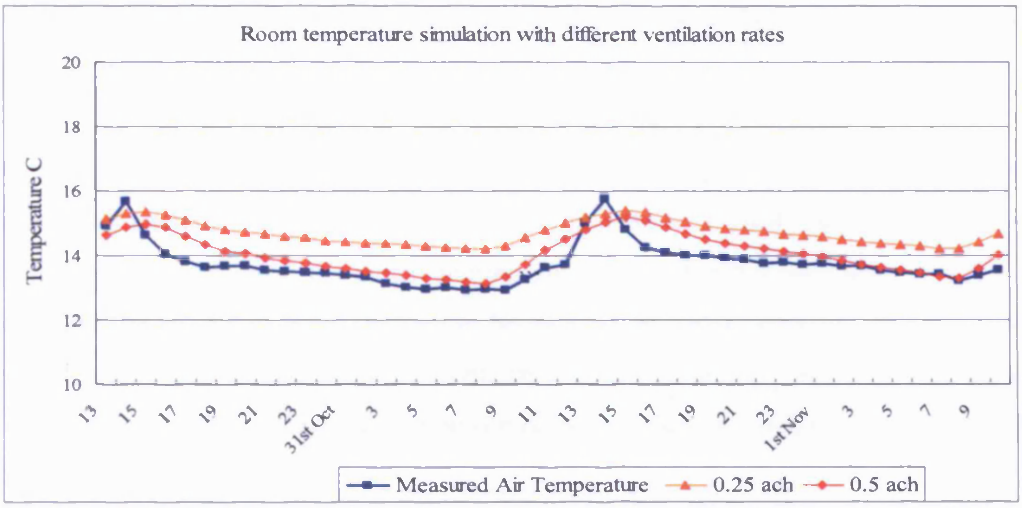


Figure 6. 13: Room temperature simulation with different ventilation rates

All mentioned parameters are listed in table 6.2 below, all the parameters were set in ECOTECT zone management dialog, and the settings can be transferred into the HTB2 tool correctly.

	Case 1 to 3	Case 4	Case 5
Occupant	None	1	1
Internal gain	None	5 w/m2	5 w/m2
Occupant period	None	8pm to 8am in weekdays and all day in weekends	9pm to 8am in weekdays and all day in weekends
Air change rate	0.5 ach	2 ach	1 ach

Table 6. 2: Thermal Parameter Setting of the Models

6.4.5 Simulation Limitations

The predicted results from HTB2 and ECOTECT were used to compare against measured temperature data. However, as mentioned before, expecting the absolute agreement between predicted and measured data is not realistic, as there are unknown parameters of the model that might affect the accuracy of the analysis. Moreover, due to the limitations and calculation methods of the tools, ECOTECT and HTB2 were used for different data comparisons in different cases. The limitations of the simulation are:

1. The important parameters for the simulation like building geometry, material information, external climate data and occupant period were know and correctly input in the models. However, the exact internal gain and infiltration rate were unknown, although the input data were deemed to be reasonable and adequate, they might lead to potential errors in the analysis. Furthermore, the occupants' behaviours at home such as opening the window cannot be simulated and thus also might lead to potential inaccuracy of the analysis.

2. The temperature generated in ECOTECT is environmental temperature, so it has to be compared with the globe temperature measured; and for HTB2, the predicted results has to be compared against the air temperature measured in those rooms.

3. ECOTECT cannot simulate temperatures in rooms with central heating systems, its HVAC system is limited to air-conditioning and it will keep the room strictly at a steady temperature. On the other hand, HTB2 can create objects with a constant temperature and that can be used to simulate the room radiator (details of the settings can be found in the Appendix C). However, this also cannot fully represent the condition, as mentioned before...

4. ECOTECT cannot generate an object's surface temperature so the comparison can only be with the simulation in HTB2.

6.5 Modelling Results

The comparison between the predicted and monitored indoor temperature and surface temperature of the five case studies will be investigated here; the purpose is to assess the level of agreement between the modelling output data and on-site measurements results. Moreover, as mentioned in Section 6.5.1, the measured external climate data was converted into applicable weather files for the tools and was used for the comparison. The beginning and finishing period of measurements were eliminated from the comparison in order to avoid the effects of the author placing and collecting the loggers. The data was listed in an Excel spreadsheet for comparison; in some graphs, the external conditions were listed in the secondary axis on the right, in order to distinguish from the main data. Thermal parameters settings of the models are listed in Table 6.2 (see Section 6.4.4.2 for the description of the settings), the summary of the comparison of simulated and measured data is listed in table 6.3 at the end of this chapter.

6.5.1 The First Case Study

The first case study is an unoccupied and unheated apartment. The total measurement was three days and the measured results from the bedroom and living room were used for the comparison. The comparison of the predicted and measured surface temperatures was of the internal side of the south and east external walls.

As there is no unpredictable parameter like user pattern or equipment use, the predicted indoor air to and from HTB2 and the environment temperature from ECOTECT, compared well with the measured data, the difference normally within +/- 1°C; the larger difference appeared on the balcony, possible reason is the solar radiation through the large glazing area has caused the unbalanced temperature distribution during the measurement. Likewise, the predicted surface temperatures also matched the measured data.

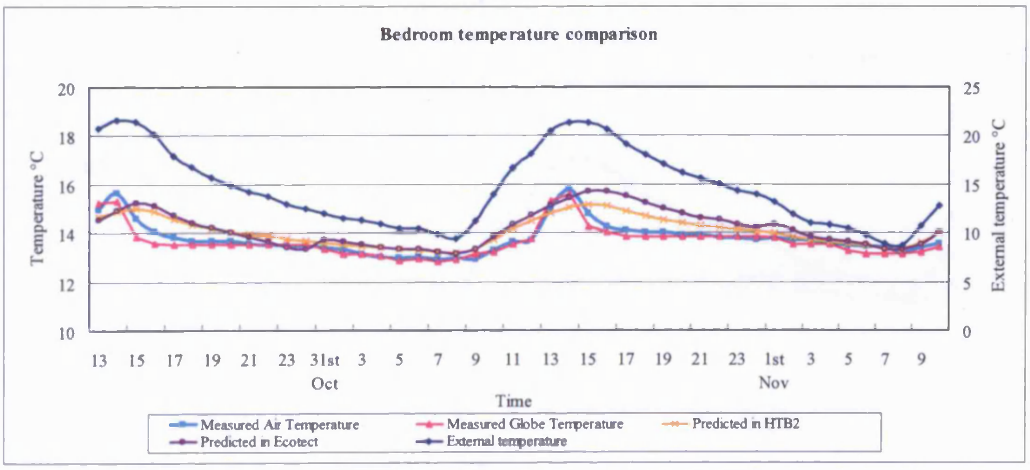


Figure 6. 14: Temperature Comparison in Bedroom, Case Study 1

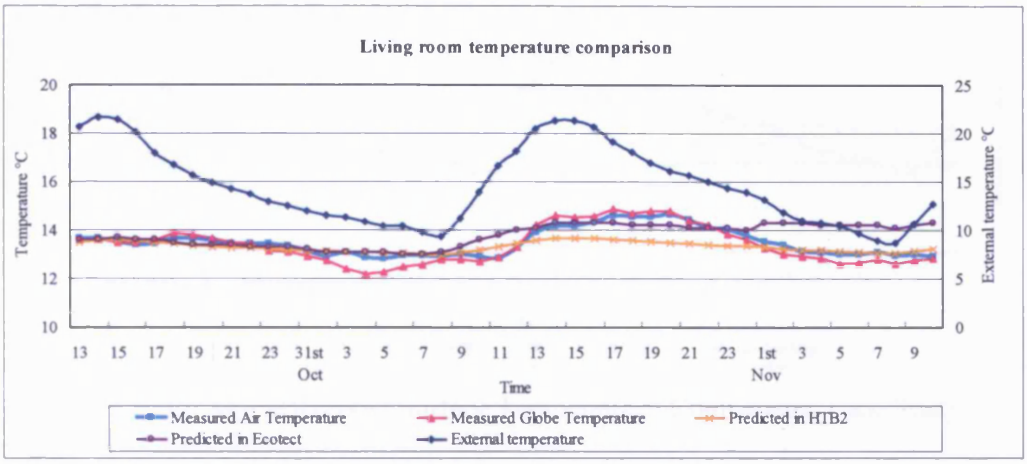


Figure 6. 15: Temperature Comparison in Living Room, Case Study 1

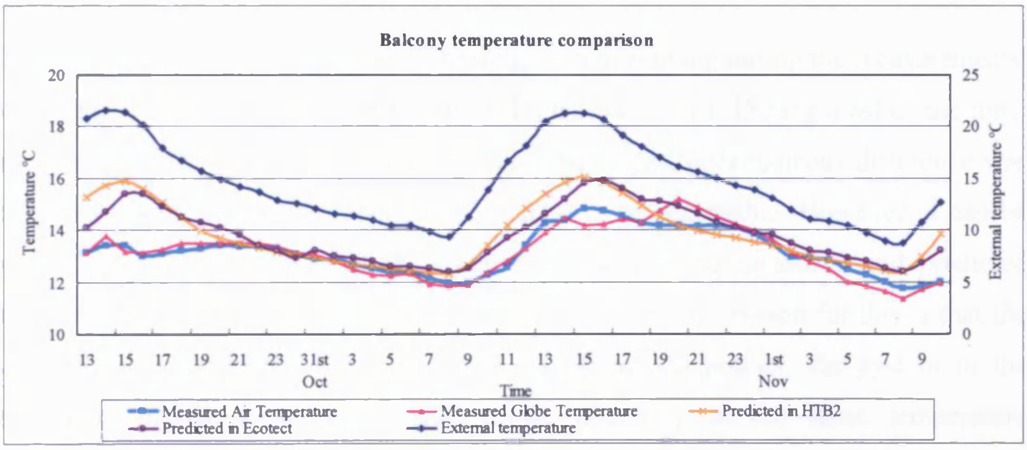
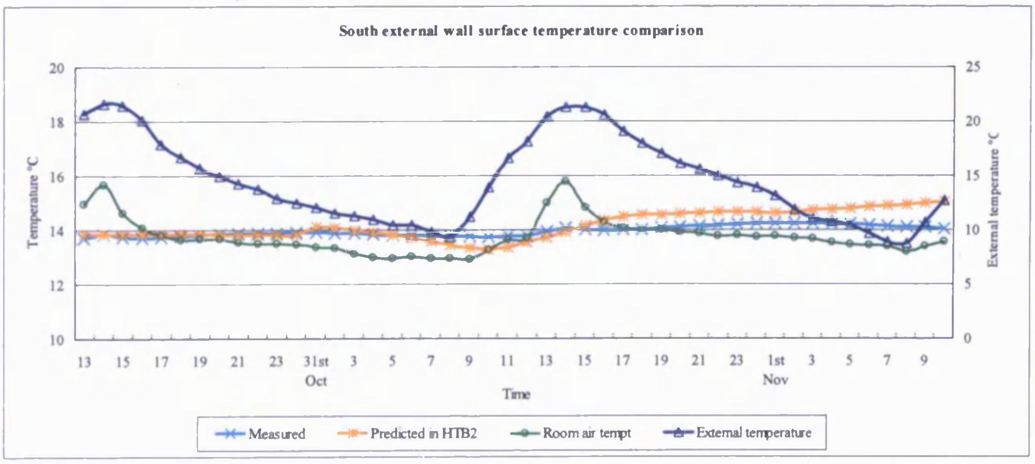


Figure 6. 16: Temperature Comparison on Balcony, Case Study 1



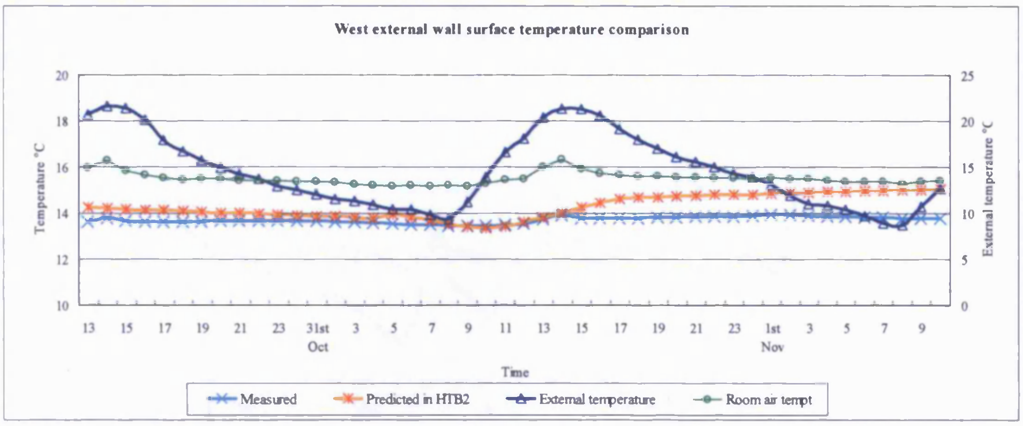


Figure 6. 17: Main Bedroom Surface Temperatures Comparison, Case Study 1

6.5.2 The Second Case Study

The second case study had a central heating system running during the measurements, therefore, only the predicted results from HTB2 were used. During most of the time, the general differences were about 1 °C and the largest instantaneous difference was still less than 2.5 °C, these results are deemed to be acceptable. However, it can be noticed from the results, that the difference between the measured and predicted temperature s are larger than the first case study. The main reason for this is that the operation of the district heating system is difficult to predict; the system in the simulation needs to be considered to be operating at the same temperature continuously and the possible variation of the heating supply cannot be fully represented.

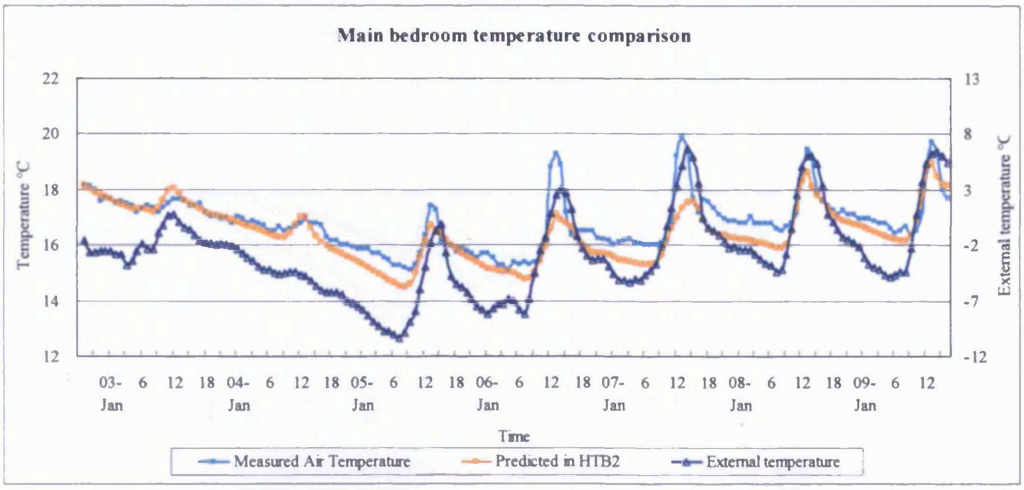


Figure 6. 18: Temperature Comparison in Main Bedroom, Case Study 2

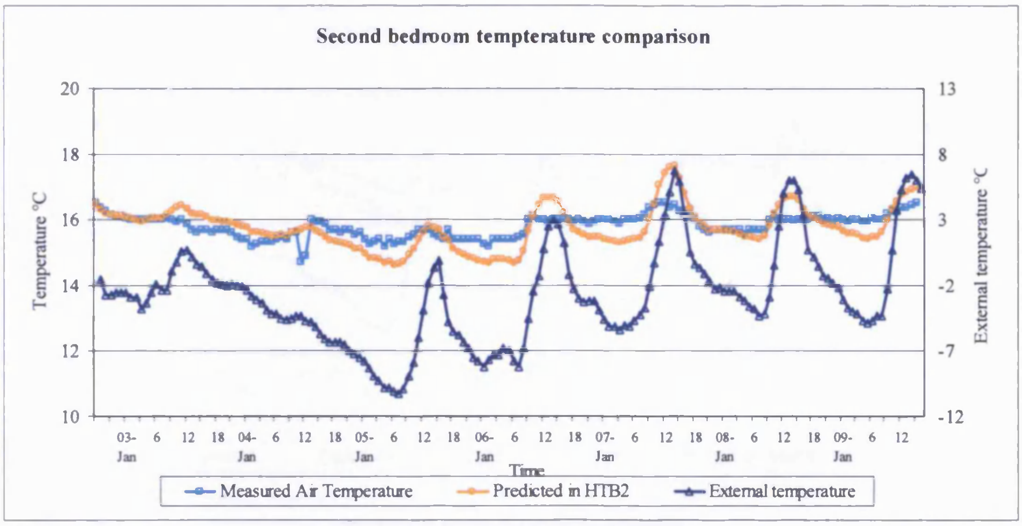


Figure 6. 19: Temperature Comparison in Second Bedroom, Case Study 2

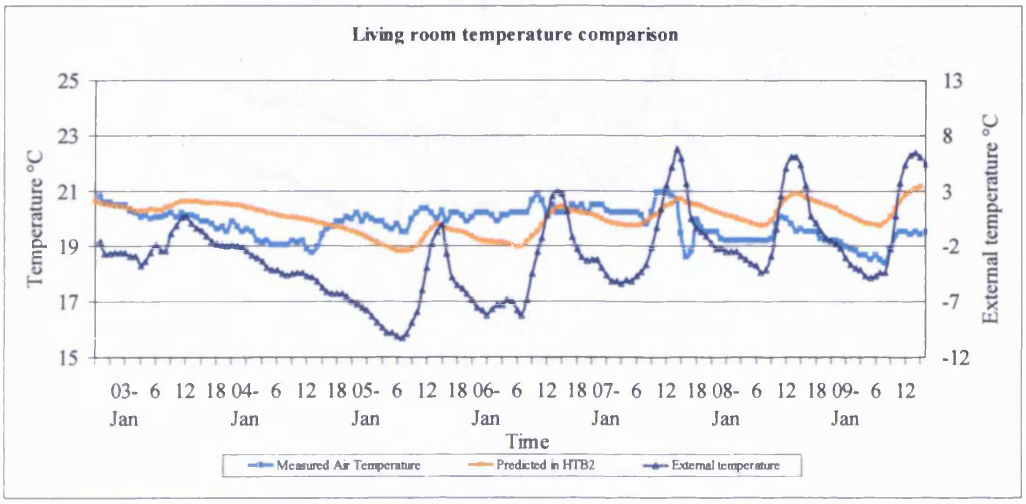
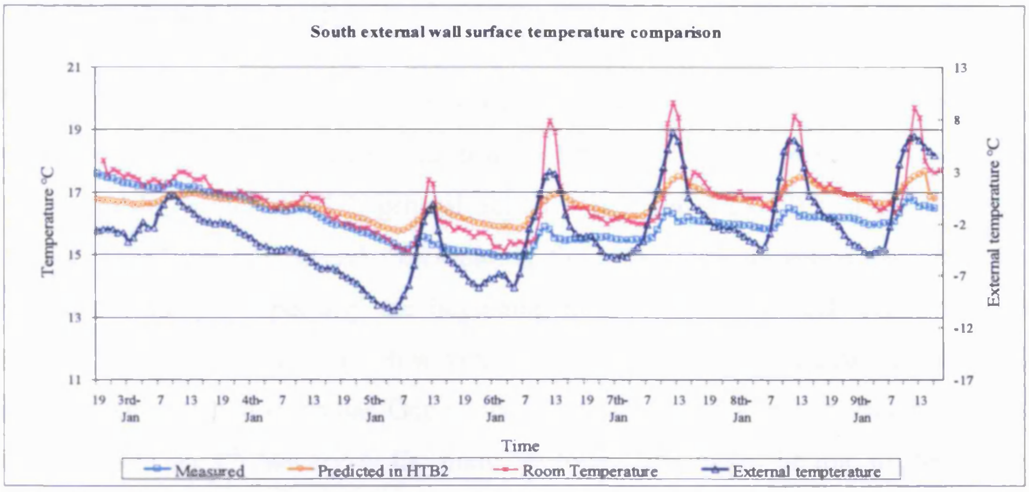
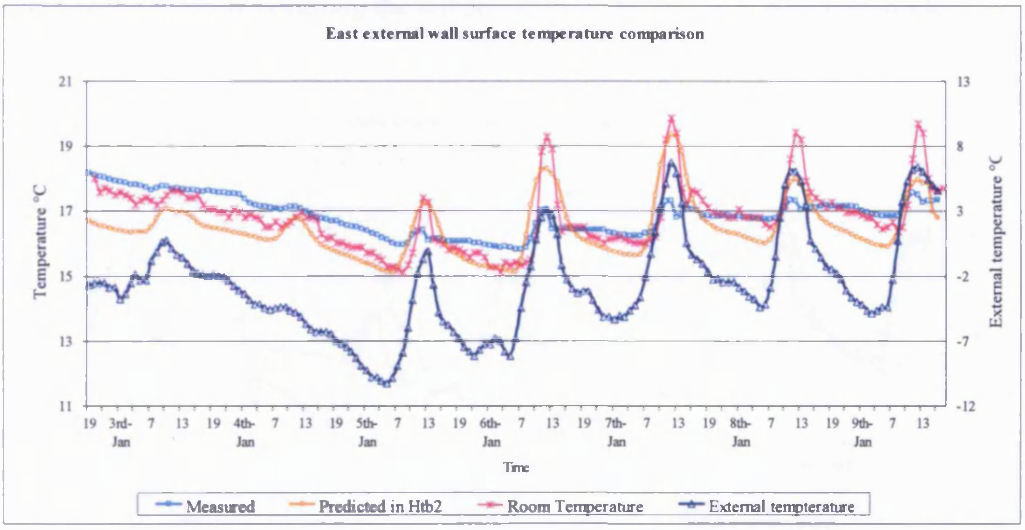


Figure 6. 20: Temperature Comparison in Living Room, Case Study 2





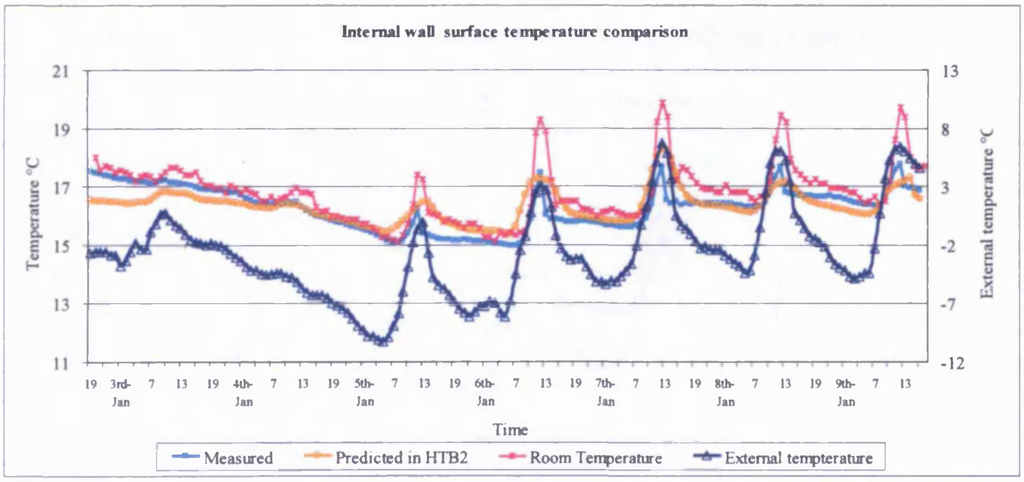


Figure 6. 21: Main Bedroom Surface Temperature Comparison, Case Study 2

6.5.3 The Third Case Study

The third case study had a central heating system running during the measurements, therefore, only the predicted results from HTB2 were used. For the same reasons mentioned in Section 6.5.3.2, general gaps are between 1 to 2 °C; in addition, the owner visited the flat several times during the measurements which disturbed the recorded readings, especially the beginning part of the data, such effect and be noticed from the comparisons. However, during the rest period the data matched well and the general trend is similar. One noticeable fact is the sudden temperature drop at around 1800 on 4th January in the main bedroom; this might be due to the owner entering the room and opening the window during the period that he was inside.

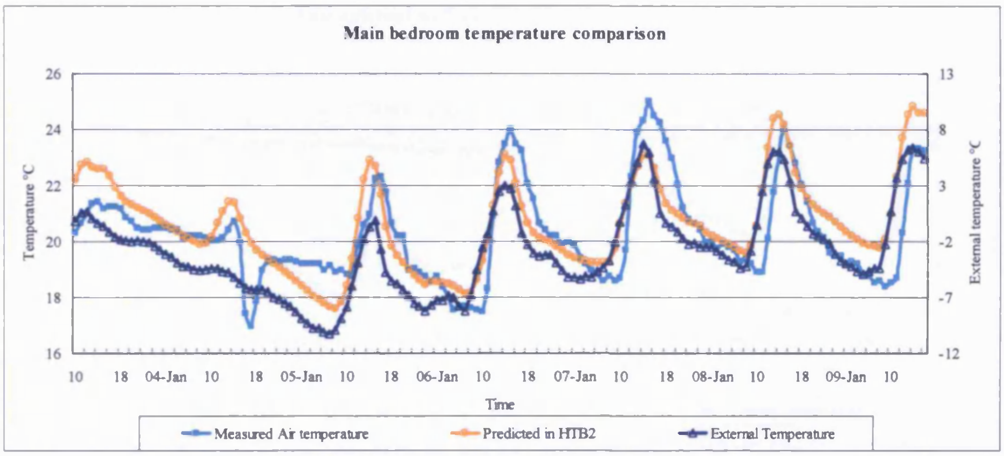


Figure 6. 22: Temperature Comparison in Main Bedroom, Case Study 3

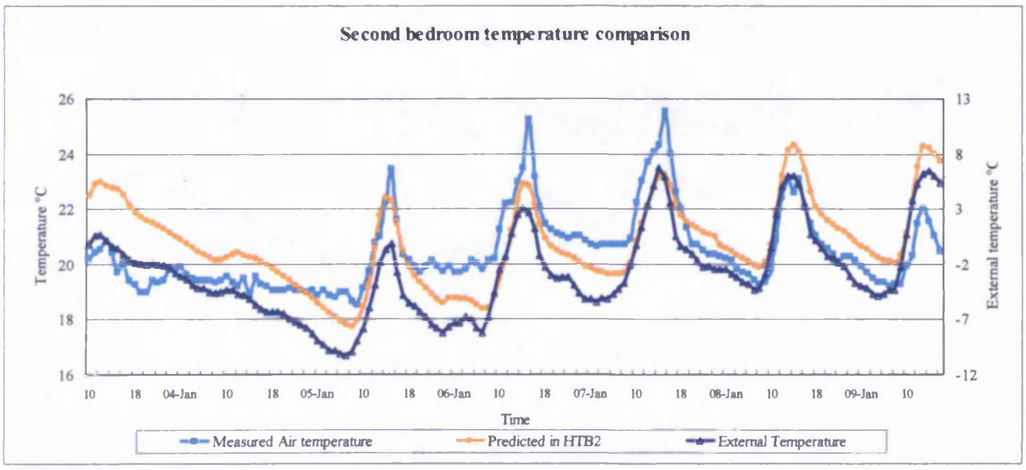


Figure 6. 23: Temperature Comparison in Second Bedroom, Case Study 3

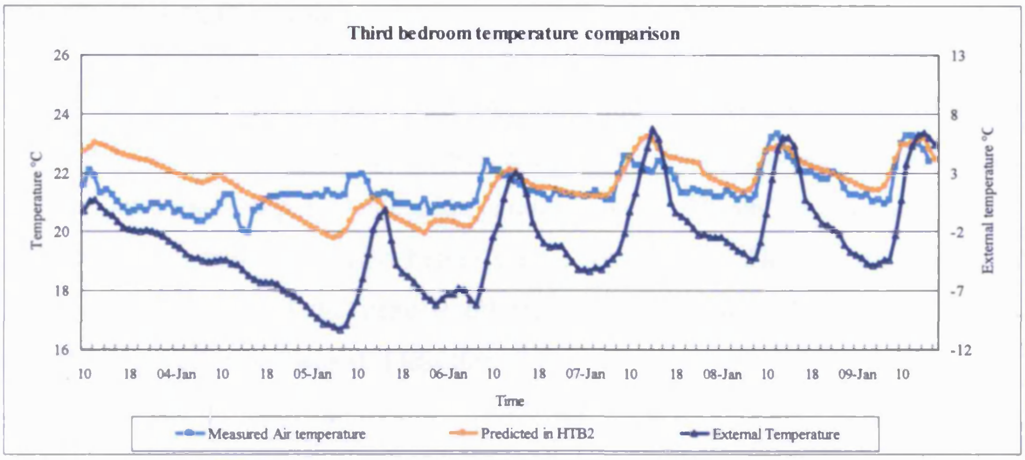


Figure 6. 24: Temperature Comparison in Third Bedroom, Case Study 3

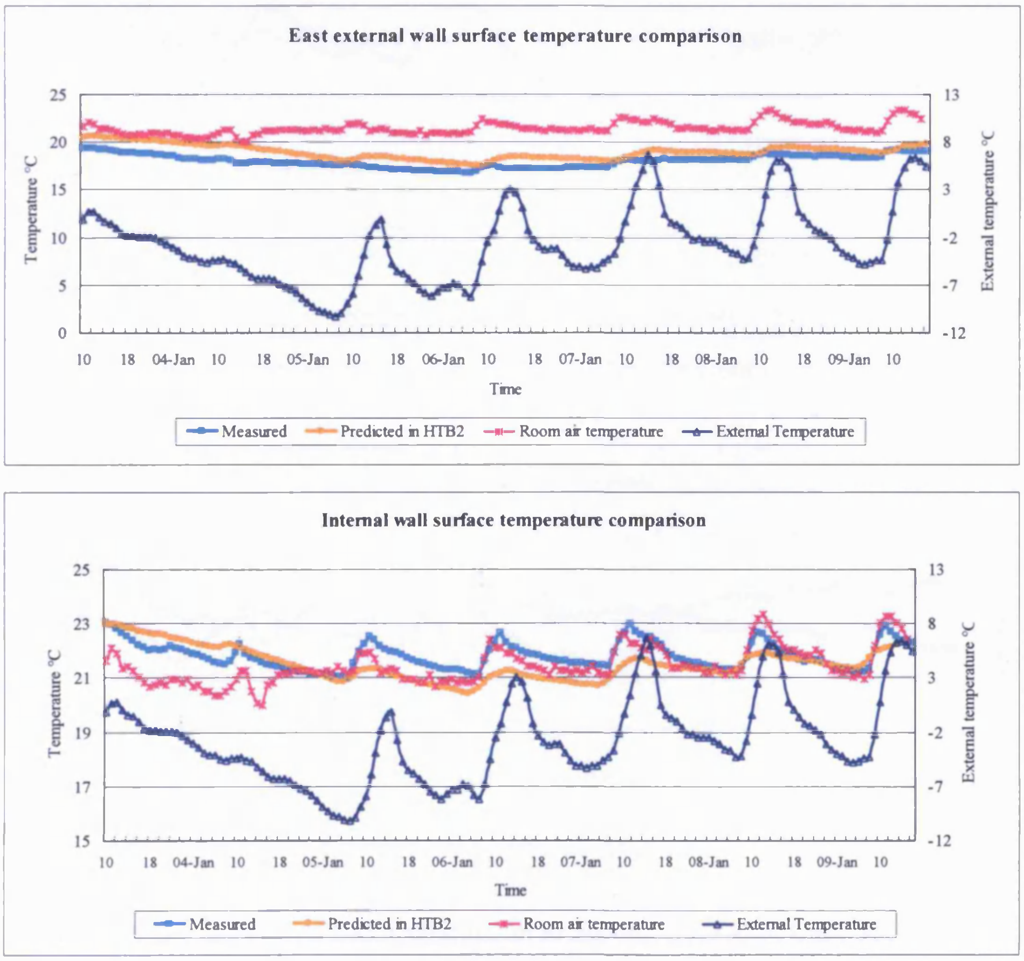


Figure 6. 25: Comparison of Surface Temperature in Third Bedroom, Case Study 3

6.5.4 The Fourth Case study

This is the most difficult case to simulate; the number of occupants changed as the owner had guests staying during the period, therefore, setting the appropriate scheme for occupancy and equipment operation is quite difficult. Hence, the data used for the comparison was from the period before the guests arrived. The data matched well during that period, and the general differences are below 1 °C and the largest instantaneous difference was still less than 2°C.

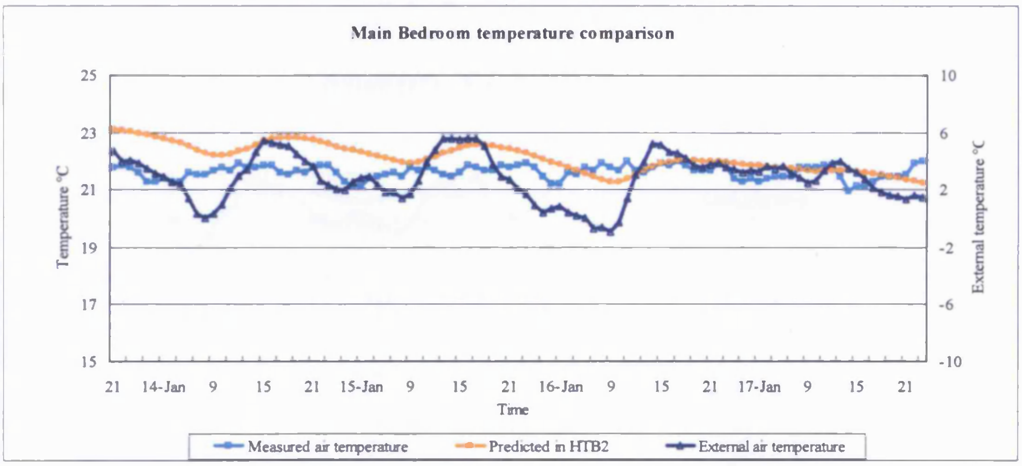


Figure 6. 26: Temperature Comparison in Main Bedroom, Case Study 4

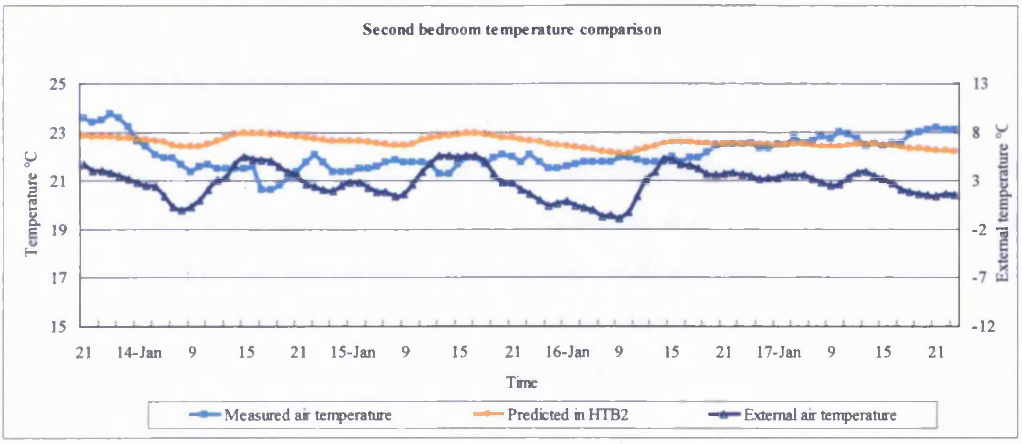
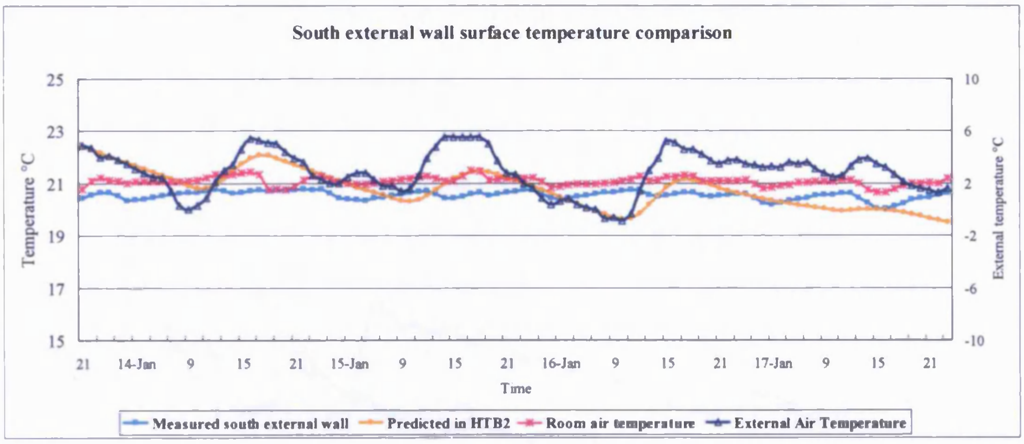


Figure 6. 27: Temperature Comparison in Second Bedroom, Case Study 4



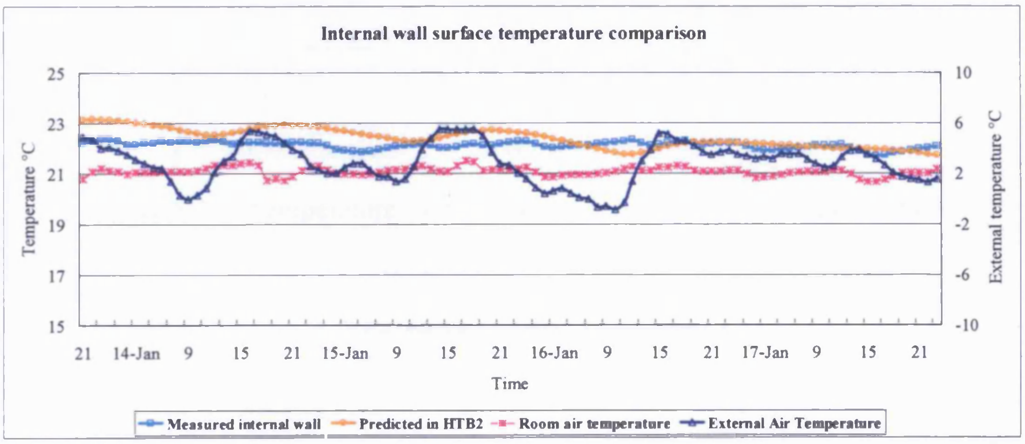


Figure 6. 28: Comparison of Surface Temperature in Main Bedroom, Case Study 4

6.5.5 The Fifth Case Study

This flat was also occupied when measured, however, there was only one occupant and the occupant period is very regular; moreover, there was no central heating system in the flat—all the rooms were equipped with air conditioning system—and the north bedroom was left empty and without any internal gain source. The surface temperature was not measured, as the owner refused to have the loggers placed on the walls.

The best match from the results is in the north bedroom, as there is no unpredictable parameter; the difference of the measured and predicted data in the main bedroom are bigger, especially on 14^{th} and 15^{th} January, the sudden rise of the measured temperature, as explained in Section 6.6.4.3 in Chapter 6, was caused by the operation of the air-conditioning system.

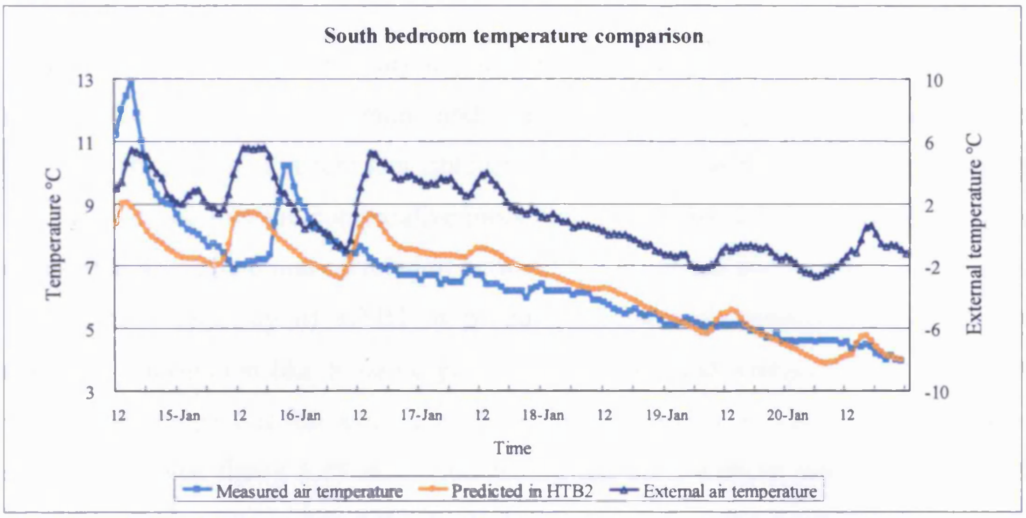


Figure 6. 29: Temperature Comparison in South Bedroom, Case Study 5

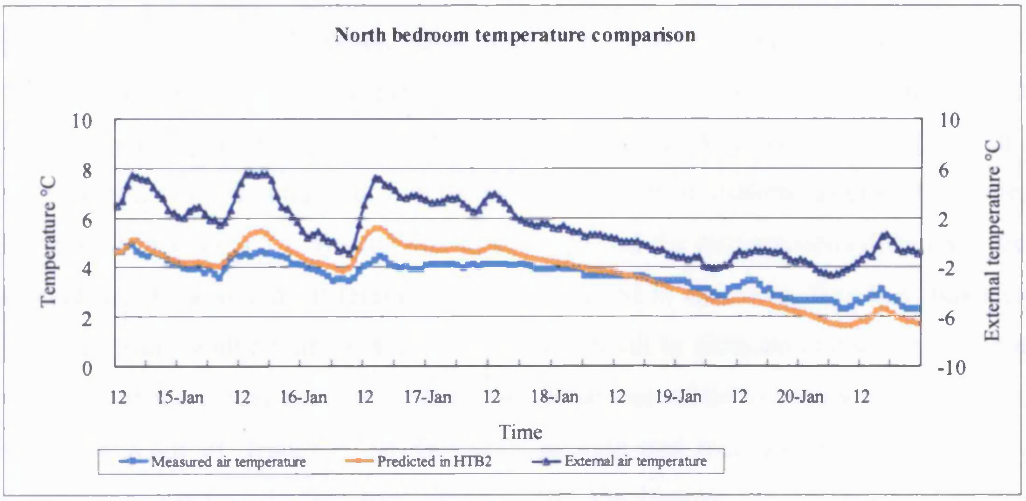


Figure 6. 30: Temperature Comparison in North Bedroom, Case Study 5

6.6 Discussion

Table 6.3 represents the summary of the measured and predicted data from all case studies; the minimum, maximum and average values of room and wall surface temperatures are listed. From that table and the graphs presented in preceding section 6.5, one can see that the comparative modelling in the five cases studies all showed reasonable agreement and correlation between the predicted and measured data. This showed the capability of HTB2 in producing reasonable predicted results when adequate information like building geometry, material and weather data is correctly input. One evidence is that in Case study one (see section 6.5.1) and North bedroom in case five (see figure 6.29 in section 6.5.5), the ones without heating system and occupant, the results matched the best, during most time the predicted data match well with the measurement and the difference normally within +/- 1°C.

However, as mentioned before, some unknown parameters have caused a certain amount of inaccuracy of the predictions as bigger gaps between simulations and recorded data appeared in some instance. One apparent factor is the heating system, for instance, case two and three had the same construction material as case study one, the graphs in section 6.5 showed that in some period the instantaneous difference are around 2.5 °C, a similar difference was also noticed in case four, thus this indicates that the spaces with heating system are more difficult to simulate due to the possible variation of the actual heating system. The behaviour of the occupant also caused a certain amount of disagreement between simulate and measurement, in the south bedroom in case study five (see figure 6.28), the biggest gap appeared when the occupant operated the air-conditioning, moreover, in case study two and three, there were sudden drops in measured temperature (see figure 6.18 and 6.21) due to the fact that the owner visited the flat although the promised not to and opened the window during their stay. However, from the data there is no evident that the unknown of exact internal gain level is causing inaccuracy, largely owning the fact that the internal gain level in residential buildings is relatively low, but in modelling buildings with greater internal gain source, this value must be measured in detail.

Generally, the variation range can be considered as acceptable since there are uncontrollable factors that may affect the accuracy of both measurement and predicted results. This gives confidence that thermal simulation tools, like HTB2, hence, it can be used to do parametric studies that are aimed at identifying the most beneficial energy saving measures for these apartments.

Analysis of results from the simulations indicate that HTB2 is capable of modelling the performance of buildings to a satisfactory level of accuracy when providing adequate information like geometry, material and climate data, moreover, as mentioned in section 6.4.4 some reasonable values can be input when certain parameters are not measured. However, although there is no direct evident showing the error caused by those unmeasured parameters like infiltration and internal gains, one must bear in mind that they are all contributing to the overall disagreement of predicted and measured data and might lead to potential errors of analysis. The most apparent effects of the unknown parameters on the results are from the heating system and the people's behaviour, therefore, in other cases when a more detailed simulation result is required, those parameters should be measured in detail, furthermore, this also indicates the need to develop simulation tools to ensure them can appropriately reflect such parameters and also provide user a better chance to set the variables.

Besides indentifying the importance of heating system and people's behaviour in the simulation, the study also revealed the limitations of ECOTECT in the prediction of energy related parameters; however, it still achieved good agreements with the measured data under the free-running circumstances as shown in Section 6.5.3.1. Hence, the main use of this tool was to generate and transfer the geometry of the model to HTB2 for energy-related analysis and simulations.

	Measured air/surface temperature °C	Predicted air/surface temperature °C
	Min/Max/Ave	Min/Max/Ave
Case study one		
Main Bedroom	12.8/15.6/13.6	13.1/15.2/14.0
Living room	12.8/14.7/13.5	13.0/13.7/13.3
Balcony	11.7/14.8/13.2	12.3/16.0/13.8
South external wall	13.7/14.3/14.0	13.3/15.0/14.1
West external wall	13.5/13.9/13.7	13.3/15.0/14.3
Case study two		
Main Bedroom	15.1/19.9/16.8	14.2/18.3/16.1
Living room	18.4/21.0/19.8	18.8/21.1/20.0
Second Bedroom	14.7/16.5/15.8	14.7/18.9/16.2
South external wall	14.9/17.6/16.1	15.8/17.7/16.6
East external wall	15.8/18.2/16.9	15.1/19.4/16.5
Internal wall	15.0/17.8/16.3	15.4/18.3/16.3
Case study three		
Main Bedroom	16.9/25.0/20.3	18.6/23.3/20.5
Second Bedroom	18.5/25.5/20.5	17.4/22.5/19.5
Third Bedroom	19.6/23.3/21.4	19.8/23.2/21.6
East external wall	16.8/19.3/18.0	17.5/20.6/18.9
Internal wall	21.0/23.7/21.8	19.9/21.0/22.6
Case study Four		
Main Bedroom	21.0/22.0/21.6	21.2/23.1/22.1
Second Bedroom	20.6/23.7/22.1	22.1/22.9/22.6
South external wall	20.0/20.8/20.3	19.5/22.4/20.8
Internal wall	21.7/22.4/22.1	21.7/23.2/22.4
Case study Five		
Main Bedroom	3.0/12.3/5.6	3.0/8.5/5.7
Second Bedroom	1.5/4.9/3.4	1.3/5.6/3.5

Table 6. 3: Summary of Measurements and Prediction of Case Studies

6.7 Conclusion

The aim of this chapter is to validate the model by assessing the agreement levels of on-site measured data and modelling results from case studies. This aim was successfully achieved. The comparative modelling in the five cases studies all showed reasonable agreement and correlation between the predicted and measured data.

Advance simulation tools provide people with a better chance for analysis the thermal conditions of buildings more easily and more accurately. Parameters for the simulation like building geometry, material information, external climate data and occupant period were know and correctly input in the models. Moreover, the data analysis indicated that the uncontrollable data like the possible variation of heating system and occupant's behaviours is causing variations between the predicted data with the measured. The differences between the measured and predicted data were within 1°C in cases without heating system and occupant and the value was about 2.5°C in occupied and heated buildings. Such data indicates that the important roles that those factors are playing and how to measure them appropriately needs to be investigated in future research work.

The work in this chapter confirmed that the HTB2 model is able to accurately predict the indoor thermal conditions and can be used in the detailed analysis in further chapters, the models of the case studies were accurately constructed and therefore are able to be used for further investigations. However, the exact internal gain and infiltration rate were unknown, although the input data were deemed to be reasonable and adequate, they might lead to potential errors in the analysis. Furthermore, the occupants' behaviours at home such as opening the window cannot be simulated and thus also might lead to potential inaccuracy of the analysis. Beyond that, the discussion in this chapter also suggested the future development of the tools is needed in order to reflect better the important variables such as people's behaviour and central heating systems.

CHAPTER SEVEN: POTENTIAL ENVIRONMENTAL DESIGN STRATEGIES

7.1 Introduction

The aim of this chapter is to discuss the factors that affect the energy efficiency of residential architectures in North China cities. A range of possible sustainable design strategies available were discussed, more importantly, the interactions between the strategies' parameters and the applicability under the climate, technical and economical condition in China were also studied in order to provide a holistic view of those methods.

The strategies that have close interaction with each other will be discussed together. Discussing the interactions of strategies is quite important, one must be aware of the importance of incorporating environmental design strategies into the built environment as well as their possible effect before apply them into the case studies, having a comprehensive view of the methods will help one to find the appropriate combination to maximise the effect rather than compromise it.

In order to achieve a better understanding of the strategies and to identify the thermal tool's sensitivity toward the strategies, some design schemes were tested on a simplified basecase model through thermal simulation in HTB2, in order to examine their effectiveness on maintaining the comfort level and reduce the energy demand in domestic buildings. This study is the follow up of the findings of housing condition and development history based on previous chapters, the purpose is to generate possible design modification which will feed into Chapter 8, in which those possible strategies will be applied to the case studies to improve their energy efficiency.

Studies from previous chapters indicated that the current designs of domestic buildings fail to cope with the local climate, hence, lots of additional energy needs to be consumed in order to maintain the indoor comfort level. As mentioned in previously, under the circumstances of the vast housing development in China, saving energy through the housing sector has become essential and the government has become aware of the significance of promoting energy conservation design strategies in residential architectures.

A large amount of energy could be saved if houses were built with respect to the local climate and enough attention was given to environmental design strategies during the early stages of design. Not only will it be beneficial to the sustainable development in China, but also to the global environment. Moreover, when searching for suitable design strategies, converting environmental design strategies from vernacular buildings in North China is an important criteria,, as mentioned by Yingxin Zhu (2004), a researcher at Tsinghua University, Beijing: '...it is more efficient to combine the advantages from both the successful Chinese traditional buildings and the experiences of developed countries to develop the sustainable buildings in China'.

7.2 Importance of Environmental Design for Houses:

The CIBSE Guide (2006a) defined environmental design as *'...design that provides the required interior environment and services with minimum energy, use, in a cost effective and environmentally sensitive manner'*. In the era before the introduction of air-conditioning systems and other electrical equipments, environmental design principles and strategies were essential because they were the only way to maintain thermal comfort for occupants, which is why, as mentioned in Chapter 5, many environmental design concepts can be traced from the local traditional building designs.

Buildings in China are becoming major consumers of energy; China's buildings sector currently accounts for 23% of China's total energy use and is projected to increase to one-third by 2010 (Yao et al. 2005), and as mentioned in Chapter 2, Chinese domestic buildings used about one-fifth of the nation's energy consumption and was responsible for over 30% of the CO_2 produced (Yu 2005). Moreover, the rising energy bill and the need to purchase additional equipments is also becoming an extra heavy burden for households, especially for the working class.

Secondly, another aspect, apart from the energy point of view, is to maintain the sustainability in urban culture. Adapting the environmental design strategies from traditional dwellings is also important in maintaining the cities' architectural heritage, as mentioned by Roger Zetter (2006):

'*... the globalisation of architectural styles, building technologies and urban spaces has dramatically impacted city design in the developing world..... Unique built environments are being removed from their context and replace by global forms and designs which are often poorly adapted to local needs and conditions...*'

Last but not least, the environmental design of housing also has a direct connection in improving the occupants' heath and living quality. The house is the place where people spend the majority of their time, to live and rest; achieving a better thermal comfort of the dwellings will provide occupants with a healthy and comfortable living place. Furthermore, according to Yao Runming, De Dear (1991) claimed that well designed buildings can create internal conditions that occupants find more pleasant than those found in some air conditioned buildings (Yao 2002).

7.3 Possible Environmental Design Strategies

Environmental engineering had taken its place in building design around the 19th century (Hawkes 2002). Hence, there is a large and increasing amount of literature on domestic energy conservation technologies. In order to establish the range of options that is applicable to domestic buildings in Northern China, the factors that affect their thermal performance need to be studied. The main sources of heat gain or losses also need to be identified.

7.3.1 Identifying Sources of Heat Gains and Losses

In order to apply appropriate environmental design strategies and design modifications to the case studies in this research, it is necessary to study the energy end use distributions and the contribution to heat gains and losses of different building components. Studies from previous research is presented here with the intention of helping to understand the energy consumption factions in housings, and the factors that contribute to energy consumption.

7.3.1.1 Energy consumption breakdown

Figure 7.1 used in Yao's previous publications (Yao et al. 2005) demonstrates the percentage breakdown of residential energy consumption in China. One can see that space heating and cooling accounts for the largest household energy use of 65 %; heating for water is 15%, electric lighting and cooking account for 14% and 6%, respectively. Therefore, finding effective ways to reduce space heating and cooling energy in housings will be an important factor in shrinking the major household energy consumptions.

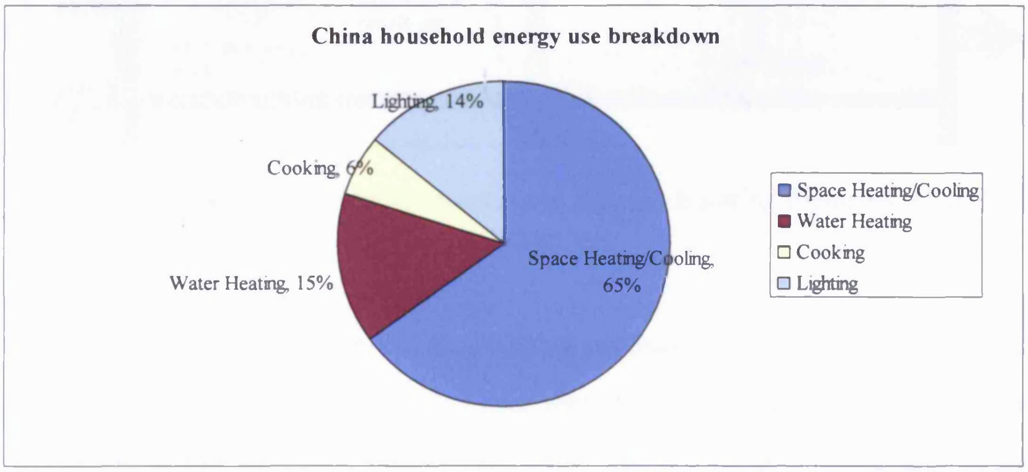


Figure 7.1: China Household Energy Use Breakdown

7.3.1.2 Sources of Heat Gains and Losses

During a previous research project undertaken at the Welsh School of Architecture and at Xi'an Architecture and Technology University, the sources of passive heat gains and losses in current domestic buildings in North China cities were examined by using the HTB2 modelling (Jones and Wang 2007). The thermal modelling tool is able to predict the breakdown of passive heat gain or loss through construction elements throughout the year; hence, the thermal performance of current design can be viewed, and this provides a valuable guidance for this research by determining what areas merit deep investigation. Figure 7.2 represents the summary of detailed breakdown.

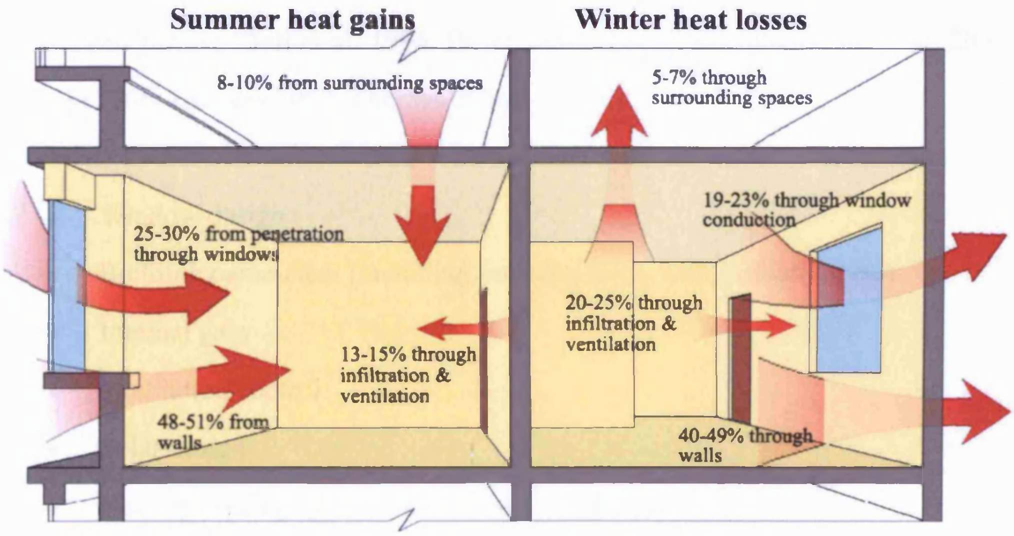


Figure 7.2: Breakdown of Heat Gain and Loss through Building Elements, after Phil Jones

From Figure 7.2, one can see that the building envelope is the largest source of heat gains or losses; hence, the upgrading of their thermal properties will play an important role in improving buildings' energy efficiency. The second dominant source is the glazing area; an appropriate glazing ratio and passive shading design should be adapted in order to reduce the summer solar penetration and winter heat transmission. There is also a considerable amount of heat gains and losses through infiltration and conduction to surrounding unheated or un-cooled spaces; therefore, limiting the air infiltration and the insulation of walls connected to those spaces must also be considered.

7.3.2 Suggested environmental strategies

Figures 7.1 and 7.2 show that the major energy consumption in houses is through space heating and cooling, and the thermal properties of the building envelope, window design parameters, ventilation control and insulation to surrounding unheated or un-cooled spaces, are the major factors that dominate the heating and cooling demand. After an in depth study of some cases of low energy building (Li 2006, 2007) and literatures on the most important strategies that affect space heating or cooling requirements, the following environmental design areas have been selected to be investigated further (Bell et al. 1996; Borer and Harris 2005; Glicksman et al. 2001; Gonzalo 2006; Hawkes 2002; Thomas 2006):

- Window design
- Building parameters (including building form, wall insulation, etc)
- Internal gain
- Ventilation control
- Solar design
- Heating/cooling system efficiency

There are many detailed strategies in building and system design within the above suggested fundamentals. As mentioned at the beginning of this chapter, those strategies will be discussed based on their efficiencies and applicability to residential buildings in North China cities. Moreover, the applications of detailed environmental designs heavily depend on the local climate conditions and indoor environment and comfort requirements (Perry and McClintock 1997), hence it is also important to select the appropriate ones under the criteria of climate circumstances and housing development history of China, in order to achieve the maximized effects; therefore, the results from the analysis of climate and traditional housings presented in Chapters 3 and 5 have also been used as important selection criteria during the investigation.

7.4 Discussion of Design Strategies

The discussion of above suggested strategies will be carried out in this section, the interactions between the strategies' parameters and their applicability under the climate, technical and economical condition in China are the main focus.

Applying environmental design strategies will improve the energy efficiency of buildings, however, simply adding strategy one after another without the awareness of the interaction of them will sometimes compromise the efficiency and sometimes will even cause negative effects. For instance, the heavily insulated building is very likely to have overheating problems in summer period if there is no appropriate consideration in passive shading or natural ventilation design. Therefore the discussion is intended to investigate the interactions of the suggested methods and find appropriate combinations that can maximise the effectiveness of strategies.

As have been mentioned many times in this thesis, the application of possible environmental design strategies during the early stages of building design will effectively reduce the overall energy consumption. As Goulding (1992) claimed, '*...the best opportunities for improving a building's energy performance occur early in the design process when basic decisions are made concerning the site, orientation, configuration and passive solar strategies...*'. If designers do not realise the potential for energy saving during the initial phase, the opportunity to make significant savings by relatively simple adjustments to the design will be lost, and this will result in the need for increasingly sophisticated or costly efforts to modify the design at further stages. The conceptual graph created by Andrew Marsh (see Figure 7.3) also demonstrates this understanding; one can see that if the environmental design strategies can be adapted during the conceptual design process, a higher effectiveness and a lower cost will be achieved.

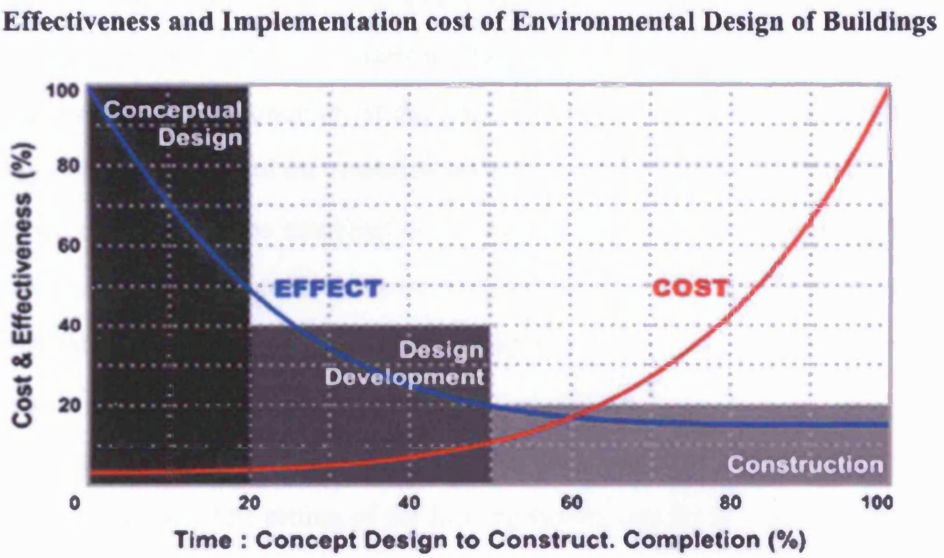


Figure 7.3: Effectiveness and Implementation Cost of Environmental Design of Buildings, after Andrew Marsh

In order to select appropriate environmental design strategies to improve the energy efficiency of the case studies, possible strategies will be introduced and discussed in the following sections. Moreover, in order to assist in checking the effectiveness level of the strategies on the building's energy and thermal performance and determining their applicability in China's conditions, some strategies will be examined by being applied at different parameter degrees of a basecase test cell model. The use of simplified basecase models is a useful way to examine the effectiveness level of the possible design strategies and the tools sensitivity toward the parameter. This method has been successfully used by a number of previous researchers in similar research areas at the Welsh School of Architecture (Abanomi 2005; Al-Oraier 2005).

The basecase model was setup based on the author's experience of the common practice construction information in north China; the wall is 200 mm thick with a U-value of 1.2 W/m²K, the window is a double glazed aluminium frame with a U-value of 2.7 W/m²K, and the window–to-wall ratio is 20%. To represent the condition of the occupied building, the basic ventilation rate was set at 1 air change per hour (ach) and the internal gain from the occupant and equipment were set at 5 w/m² and the occupancy period was set to be from 6pm to 8am in weekdays and all day at weekends. Additionally, in order to asses the heating and cooling load demand that will be needed to maintain the indoor condition of the flats at a comfortable range, the heating and cooling system was set and the operation set point was set to be 26°C and 21°C; the set points were defined by the combination of suggestions from reviews of literature and the previous research works in this area (see Section 5.5. 6.7.2 in Chapter 4), and the climate data of Tianjin was used. The heating system was set up to be continuously running in order to represent the current continuous district heating system, and the cooling system operating period was assumed to be from 6pm to 8am on weekdays and all day at weekends. The setting of the heating system and the cooling system was to represent the people's control over the air conditioning system. Furthermore, the same heating and cooling system settings will also be used during the simulation of all case study models in Chapter 9; detailed settings will be listed there as well.

7.4.1 Design Parameters Related to Building Skin

The building skin, or building envelope, is the totality of the building elements that separate the indoor environment of the building from the outdoor environment; it is the selective pathway for a building to work with the climate—responding to heating, cooling, ventilating and natural lighting needs (U.S. Department of Energy 2006a). Consisting of the building's roof, walls and windows, the skin controls the flow of energy between the interior and exterior of the building, hence playing a major role in achieving climate-responsive residential buildings (Oral et al. 2004).

The analysis result in Figure 7.2 in section 7.3.1 showed that the external wall is responsible for about 50% of the heat gains and losses in residential buildings in North China, moreover, analysis of the data from field study also indicate the need to improve the thermal properties of the building envelope to buffer the external climate more passively (see section 6.6.8 in chapter 6). The skin of building should control physical environmental factors such as heat, light and wind, in order to create comfortable conditions for the user whilst minimising energy consumption. In addition, as mentioned by Fuller (Fuller et al. 2005), an energy efficient building envelope should also take advantage of positive climate attributes that could improve the interior environment.

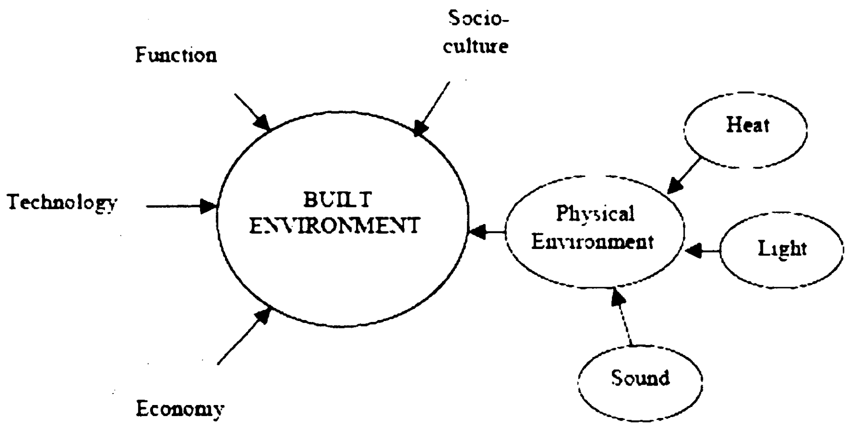


Figure 7.4: Parameters with Influence on the Design of Building Envelope. Source: (Oral et al. 2004)

Oral (2004) suggested that the building envelope should be designed with respect to various determinants, such as environmental, technological, socio-cultural, functional and aesthetic factors (see Figure 7.4). The attention of this section, however, is to emphasise the design response of building envelope to the local environment in multi-floor residential architecture design, in order to achieve energy efficiency. The focus will be on the following design parameters that have a direct influence on a building envelope design, which are:

- Building Form and Orientation
- Fenestration and Window design

- Wall Insulation
- Thermal Mass Structure

The above factors will be discussed and some test through the basecase model will be used to examine to what extent they affect the energy performance of the buildings. However, discussions of roof and ground floor properties will not be carried out in this study as they do not have as much impact on multi-story building as they do on low-rise houses.

7.4.1.1 Building orientation and glazing ratio

Building orientation is an important aspect that affects the building thermal performance; the energy demand in rooms will depend on its orientation in relation to the seasonal and daily sun path (Givoni 1976). An effective design should make sure that the building is properly orientated to ensure the best use of solar radiation heat gains and day lighting, whilst minimising the undesirable excess solar gain in summer and heat loss in winter. Moreover, appropriate orientation arrangement also assists in the design for natural ventilation, the main openings should avoid the main wind direction in winter period while maintain the possibility to incorporate the summer natural ventilation to reduce the cooling demand.

An appropriate building orientation can make the best use of solar radiation as heat source for buildings. ECOTECT WeatherTool is a useful tool in determining the building's best orientation according to the local climate and sun path diagram. The calculation process of the appropriate orientation in North China was introduced in Chapter 3, and the suggested orientation is north-south. Moreover, the study of the vernacular dwellings in North China also found that such orientation has long been preferred. The study of the sun path indicates that the low angle of the sun's altitude makes the penetration to south windows in the winter period very favourable for the source of passive heating; the high solar angle also makes it easy to use shading systems to minimise the impact of overload solar radiation, hence, subsequently reducing the cooling load (Goulding et al. 1992).

The above discussion indicated the great influence of the building orientation on the window design. Due to its high thermal transmission rate, the heat gain/loss through windows per unit area is much higher than through walls or roofs (Givoni 1994; Hestnes et al. 1997). Therefore the amount and type of glazing are important in terms of energy efficiency for buildings (Yao et al. 2002) and the selecting the appropriate amount of glazing area of a façade should be decided according to building's orientation.

During the field study of current housing projects in northern China, it was found that most new housing projects have large window to wall ratios, the glazing area are equally distributed at all four directions and no passive shading systems were combined; for instance, most of the rooms in the case studies (except in Case Study 4) had glazing ratios greater than 40%, the largest value even reached 48% (see Section 5.7.1 and Table 5.13 in Chapter 5). Sun penetration in the summer through the exposed window areas is one of the major sources of thermal overheating discomfort, which can cause additional cooling energy. Moreover, without proper treatment of window insulation, the large exposed window area is also one of the major sources of heating energy loss. Below computer presentation image of the case studies in Tianjin shows the large glazing areas of the buildings.

Figure 7.5: Computer Expression of the Large Glazing Area of Case Studies in Tianjin City. Source: Department of Architecture, Tianjin University

The relationship between energy use and the glazing–to-wall ratio were studied using HTB2, in order to demonstrate the impact of orientation on glazing ratio. The basecase model was simulated with different glazing ratios facing the four cardinal directions. The results are presented in Figures 7.6 and 7.7, and they showed that with the increase of glazing-to-wall ratio, the cooling and heating load will rise accordingly in all four orientations. The increase rate of cooling load is more apparent than heating, for example, the cooling load in the west facing room is 16 kWh/m2 when the window is 10% of the wall area and the load increased to 52 kWh/m2 when the glazing ratio was 90%. The heating load in the north facing room increased from 177 to 220 kWh/m2 when the glazing ratio rose from 10% to 90%.

The simulation results also showed that southern rooms have a better energy performance in winter and rooms facing north also need less cooling in the summer. This is due to the high sun angle on the south and the small amount of direct solar gain on the north. The east and west orientations suffer from a low sun angle in the morning and evening, respectively, and this therefore caused poor energy performance throughout the year. Consequently, a south-north orientation is preferable in northern China, and positioning rooms with more activities and long usage times in the south should be achieved as much as possible. The result from simulation confirmed the discussion above that the South-North orientation is suitable for the climate of North China

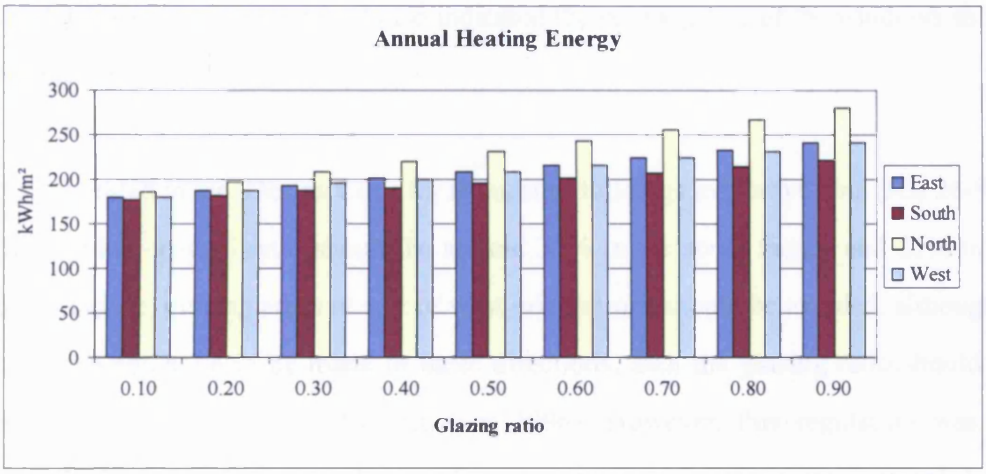


Figure 7.6: Relationship of Heating Load and Glazing Ratio

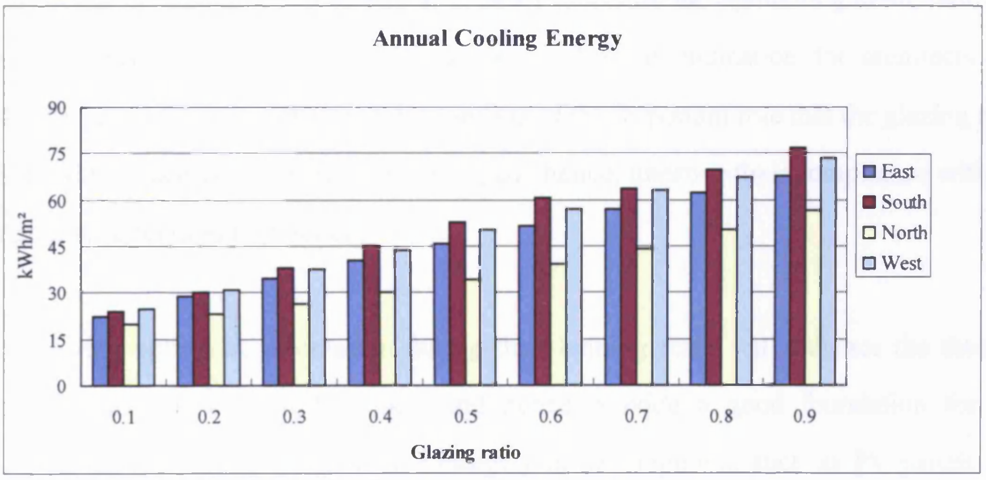


Figure 7.7: Relationship of Cooling Load and Glazing Ratio

However, one may argue that the increase in the window area will lead to more solar heating, however, as suggested by Hastings and Wall (2007), a 'net heat gain' in winter can only be achieved by using windows that have a U-value less than 0.8 w/m²k, otherwise the heat gain through the windows will not be able to offset the heat loss. The data from the simulation also indicated the same effect, although the south façade had lowest heating demand in winter among all the orientations, but still the heating demand increased at a liner rate with the enlargement of the glazing ratio. Considering the current construction technology in China, the use of such highly insulated windows is not realistically applicable at present. Therefore, in considering energy efficiency, the glazing ratios of the case studies should be reduced; the study of the climate of north China cities in Chapter 3 also indicated the opening size of the windows should be medium.

As suggested in the 'Design Code for Domestic Buildings in North China (JGJ 26-95)', the window-to-wall ratio should be around 35% in the south façade and 25% in the north façade; glazing areas at east or west orientations should be avoided, although, if the openings have to be made in these directions, then the glazing ratio should not exceed 30% (Ministry of Construction 1996). However, this regulation was not complied with well during the building design practice, hence stronger regulation enforcement should be implemented in order to ensure the optimum glazing ratio can be achieved. The above analysis can be used as an indication for architects and developers to achieve a better understanding of the important role that the glazing ratio is playing in achieving energy efficiency, and hence, improve their compliance with the national regulation in practice.

Achieving optimistic orientation during the planning stage will enhance the thermal performance of the building skin and hence provide a good foundation for the application of further sustainable strategies in development, such as PV panels and attached sunspace (Schittich 2003). The detailed discussion of using optimum orientation to achieve passive solar heating and generating solar energy will be carried out in further sections within this chapter (see Section 7.4.5). However, the relationship of the glazing ratio and the indoor lighting condition was not investigated as the main aim of this research was on the space heating and cooling energy, the possible issues that might relate to the indoor lighting conditions will be considered in further work after this research.

7.4.1.2 Window insulation and shading design

The window system plays an important role in sustainable housing design. Previous analysis results (see Figure 7.2) indicate that the inadequate insulation level of the windows also makes it a major source of heat loss in winter. Moreover, solar penetration through windows in the summer is a major reason for the building's cooling demand; the solar heat gain can elevate a building's indoor temperature and cause overheating in summer. As claimed by Givoni (1994), heat gains and losses through windows depend greatly on their size and orientation, The building's transparent elements should be designed with the aim of maximising the useful solar heat gain in winter, while minimising summer heat gains and winter heat losses; variables type of window and its associated shading configurations, are tested in this section.

7.4.1.2.1 Window insulation

Most existing domestic buildings are still using single glazed windows, and as a result, they are suffering from the winter heat loss and air leakage (Jones and Wang 2007). Figure 7.11 shows the unsatisfactory window and wall condition of a residential building in 1980's. Therefore, updating window systems to double glazed windows can reduce thermal transmission through the glazed areas. This is very important in the long and cold winters experienced in northern China, and furthermore, it can also reduce the air transmission with external spaces.

Figure 7.8: Out-dated Building Construction. Source: Author

In addition, in developed countries the thermal property of double glazed windows is far better than those in China. The common overall U-value for double glazed windows is around 2.7 W/m²K (GB50176) in China, while in the UK the value of low-e double glazing windows is about 2.0W/m²K (UK Part L).

Figure 7.12 compares the annual heating and cooling load of basecase models at four cardinal orientations with different glazing types. Three different window materials were used in the computer model; the single glazing window has a U-value of 6.4 W/m²K (value set according to China Building Regulation GB50176), normal and low-e double glazing windows have U-values of 2.7 and 2.0 W/m²K, respectively. One can see that by switching from single glazed windows to double glazed windows, the space heating energy can be reduced by around 10 to 12%. Moreover, an additional 6 to 7 % of heating demand will be reduced when adapted to low-e double glazing, and the overall saving of low-e windows over single glazed windows is about 15%. Hence, replacing the current single glazed windows with double glazed windows will effectively reduce the heating load in buildings. Furthermore, by adopting the UK standards, the space heating energy can be further reduced.

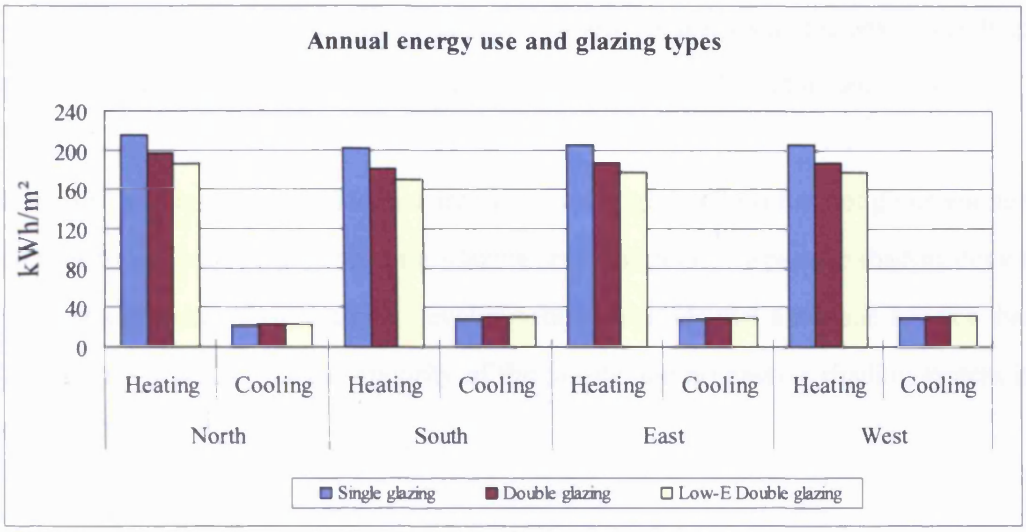


Figure 7. 9: Energy Use for Different Glazing Types

It is clear that updating the window insulation have an apparent effect on reducing heating demand, however, from figure 7.12, it can also be learnt that the cooling demand has increased together with the insulation improvement. This is because the summer heat gain in rooms cannot be passed out easily in better insulated windows. Giving the consideration that improve the window insulation is a necessary step in improve the energy efficiency of the dwelling design, finding methods that can adequately reduce the effect of the increased summer heat gain is essential. One effective solution will be using passive shading device to eliminate or reduce the summer solar penetration before it enters the interior spaces, moreover, the night purge ventilation can also be employed to remove the heat stored in the room (Borer and Harris 2005). Both methods will be discussed in further sections of this chapter.

7.4.1.1.2 Shading design parameters

Solar gain through windows is a major component of the total heat gain of housing (Givoni 1994). Minimising this heating source in summer through the use of shading devices is therefore of primary importance in reducing buildings' cooling demand. A shading system is an effective way of reducing undesired solar heat gains in summer, which can improve the thermal comfort in summer and reduce the need for mechanical cooling. Furthermore, as mentioned in previous section, using shading device can help to reduce the increased cooling demand caused by improved window insulation.

However, contemporary residential architecture design in China has not given enough consideration to the protection of the glazing areas; normally no passive shading device is designed, figure 7.10 is a new development of a residential area, one can see that glazed area accounts for the majority of the facade and no passive shading system is provided.

Figure 7.10: New housing development in Beijing. Source: Author

A shading system is a building element that keeps the sun off the building envelope at desired times of the year. It is a very effective way to reduce indoor air temperature; moreover, it is a major architectural feature and provides one of the main ways to '*...articulate the façade of a building...*' (Lechner 1991).

Appropriate shading design can avoid direct solar radiation during the overheated period in summer and allow it into rooms during wintertime when it is desired (Jian and Jiang 2001). Generally exterior shades and high reflective glazing are more effective than interior shades and heat absorbing glass, because they can exclude sunlight before it reaches the building envelope (Clark et al. 2006; Hawkes 2002). The shading device should be designed to allow winter solar gains to enter the room in order to contribute to spatial heating, as well as ensuring a good level of daylight in winter. An example of an appropriate shading design is demonstrated in Figure 7.8.

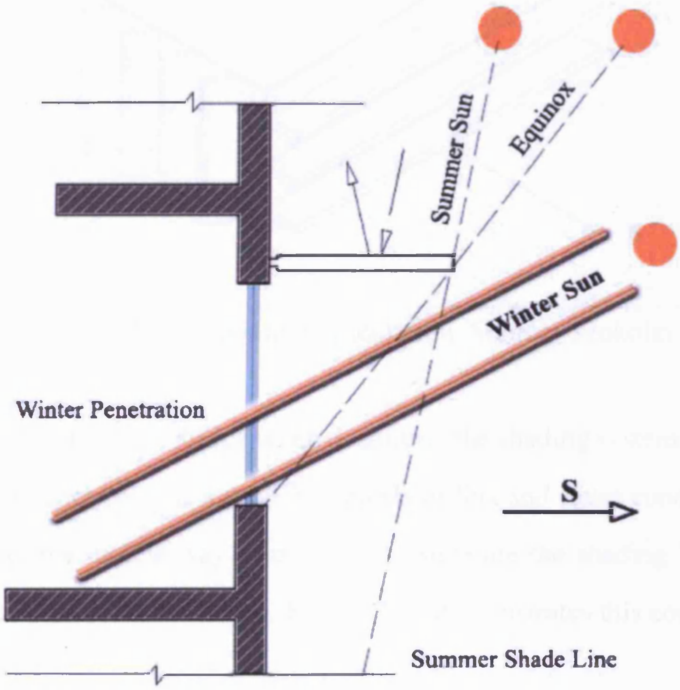


Figure 7.11: Shading Design Example, after Szokolay

The design of the shading device should be carefully considered according to the local climate condition, latitude and façade orientation, in order to eliminate summer penetration and allow winter sun to access deep inside rooms. The type of external shading is determined by its orientation; horizontal overhang is generally more effective in the south, whilst vertical fins are better for the east and west (Givoni 1994; Szokolay 2004). Moreover, a combination of both horizontal and vertical fins can also be used to provide full protection for the windows (Abanomi 2005; Jian and Jiang 2001). However, there is no uniform shading shape that can be effective on windows regardless of their locations, instead, the size and shape of the shading element should be generated based on the local climate and sun path diagram as well as the building's characters.

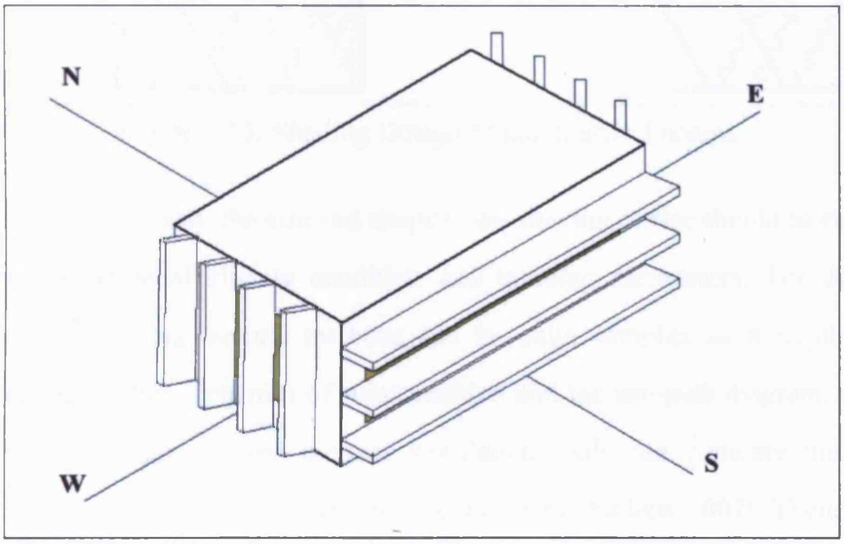


Figure 7.12: Shading Types and Orientation. Source: Szokolay (2004)

In addition, another factor to notice when designing the shading system is to ensure the shading board will not become a source to trap heat flux and cause conduction through external surface; the easiest way to do so is to separate the shading board from the attached surface area (Thomas 2006). Figure 7.13 demonstrates this concept.

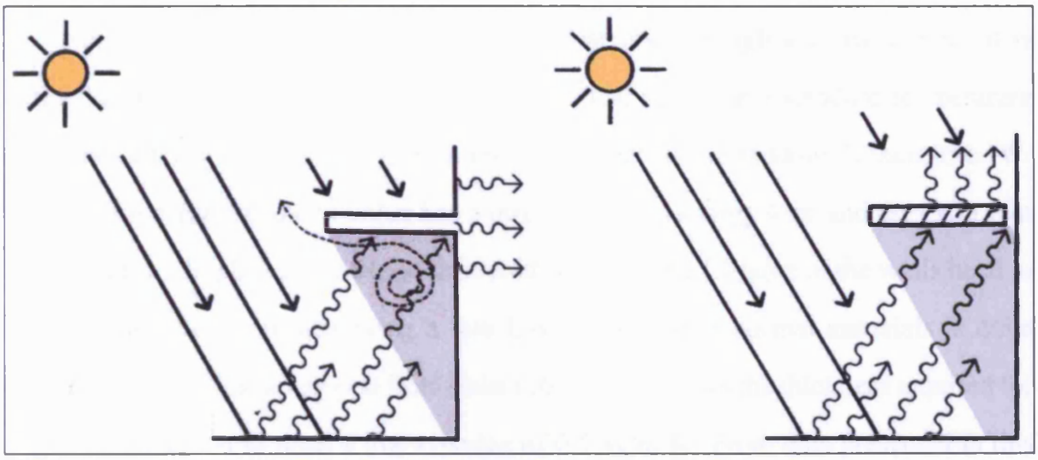


Figure 7.13: Shading Design Method, after Thomas

As mentioned previously, the size and shape of the shading device should be calculated according to the local climate condition and building parameters. The design of shading devices using manual methods can be quite complex as it requires deep understanding of the mechanics of solar position and the sun-path diagram, whereby the advanced computer-based thermal simulation tools can generate the passive shading systems accurately for very specific purposes (Andrew 2007). Therefore, the appropriate shading design for the case studies will be introduced in the following chapter; the size of the shadings will be suggested using thermal prediction tools, namely, the Shading Mask program in HTB2 (SHADE.EXE) and ECOTECT shading design calculation.

7.4.1.2 Wall Insulation related parameters

Wall insulation can reduce the amount of heat lose through the building fabric to a very low level; it is a major component of any energy saving design strategy (Marsh 2005). As described in the beginning of this chapter, walls with external surfaces are the main source of heat loss in winter and can also contribute to summer heat gains (see Figure 7.2) hence having appropriate insulation is a fundamental factor in energy efficiency design of residential buildings in North China cities.

The word 'U-value' is used to describe the heat loss through a construction, it is defined as the amount of heat (in Watts) that is lost per m^2 at a standard temperature difference of 1 degree Kelvin. The international unit of the U-value is therefore 'W/(m^2K)'. It is clear that the U-value has a direct effect on energy loss, and the extra cost that it leads to, in places that experience cold winters. The U-value of the walls need to be really low, however, achieving a low U-value by using normal materials is quite difficult. Table 7.2 is developed from Feist (2007), and shows the thickness required for a wall construction to meet a low U-value of 0.5 W/m^2K. From data presented in this table, it can be seen that a by using normal construction materials, the low U-value can only be achieved if the wall construction was very thick; a reasonable thickness of the components is only available if a good insulating material is used.

Material Types	Heat Conductivity W/(m.K)	Thickness (mm) needed to meet U=0.50 W/(m^2K)
Solid brick	0.800	1500
Hollow brick	0.400	750
Concrete Cinder	0.335	610
Typical insulation material	0.040	80
Highly insulation material	0.025	50
Vacuum insulation	0.008	16

Table 7.1 : Material Properties and Thickness, after Feist

During the long and cold winter periods in North China, it is important for buildings to have adequate cold protection. In order to minimise the demand of the heating system and make sure the heat gain from the radiators can be kept in the desired spaces, insulation of the building envelope is quite important (Wang et al. 2003). The study at the beginning of this chapter showed that more than half of the winter heat losses are through the exposed external walls and surrounding unheated spaces, hence, the thermal insulation on those elements is crucial in achieving energy efficiency of residential buildings.

However, as mentioned by scholars (Lang 2002; Rousseau and Chen 2001), insulation materials have not been adequately used in housings in North China cities. Most of the existing buildings were constructed with double brick or concrete walls and were built without using any insulation. The research work of Lang Siwei showed that the wall U-values of these buildings were about 1.6 to 1.2 w/m²k, which is more than three times higher than the value of the UK, where there is a similar winter climate. Among the case study buildings, Case Study 4 was constructed in 2000 and built without any insulation; Case Study 5 was constructed in 2005 and had 25mm expanded perlite insulation at internal side of the exposed walls; the cases in Tianjin were built between 2005 and 2006, and had the best insulation materials, which was 25mm polystyrenes at the external surface of exposed walls. Although the data showed that with the progress of construction standard, recent constructed residential buildings, especially the high standard ones, started to put insulation materials on the external walls, the building envelope is still unable to properly buffer the external climate in winter.

From the result in the field study in Chapter 6, surface temperatures of walls that are connected to the external environment are about 3°C lower than those of the internal walls and the room air temperature, especially for external walls without long periods of solar radiation. For instance, the east facing wall in Case Study 3 had a temperature difference of more than 4°C from the room air temperature, therefore, the insulation level of the building façade must be improved. Moreover, the insulation is not only required on the external surfaces of buildings, the walls that connect to the uncontrolled spaces, such as stairs or elevator shafts, also need to be insulated. The analysis in Figure 7.2 showed that the heat gain and loss to surrounding uncontrolled spaces accounted for 5 to 10% of the total amount; measurements from the field study also showed that the internal walls connected to uncontrolled spaces had a lower surface temperature than exposed façades. All these indicate that the insulation level of the exposed walls and walls connected to unheated internal spaces, need to be improved.

There are many insulation materials that are being used in the developed countries. The insulation material that is suitable for China must have a low thermal conductivity and must be available, and affordable, under the current technology and economical standard for China. Moreover, as claimed by Wu Xueling (2007), the choice of the insulation material should be easy to be adapted in the current building construction process, otherwise the saving target will be compromised by the lack of technology. For instance, Wu mentioned that in some cities in North China there were some attempts to put insulation materials in the inner space of the external walls, however, this method requires quite delicate construction techniques which the current standard in China is unable to provide. Buildings constructed based on this method are still suffering from the problems like thermal bridge and condensation, therefore, this construction method is not encouraged by the local authorities in North China cities. The wall construction of housing in China is generally 200 mm in-situ concrete, or prefabricated concrete frames with brick infill (Phil et al. 2007); thermal insulation can, therefore, only be normally applied to the internal or external surface.

As has been claimed and proved by many scholars in their previous research (Borer and Harris 2005; Richartz 2007; Yuan 2008; Zhang 2002), insulation applied externally is generally more effective than insulation applied to the internal surface, although it would be more expensive and require a larger depth of construction. It is easier to prevent thermal bridging as the whole wall is wrapped in an insulation layer, and the inner 'heavy-weight' skin can provide stable indoor temperatures during the winter. Also, it provides additional protection for construction elements and does not reduce the floor area of the rooms.

The suggested insulation material is polystyrene board; it is currently the most common insulation material in China. It has been widely used as building insulation materials in all kinds of architectures (Xiaoqian et al. 2005), being reasonably priced and having good thermal resistance, As described in the Chinese building code GB 50176, the thermal conductivity of polystyrene board in China is 0.042W/mK. The general sizes of the available polystyrene board in China are based on the module of 25mm thickness (Fuller et al.; Zhang 2002), Moreover, previous research work by Wu Xueling and Zhang Yunping, who investigated the application of polystyrene board as external insulation materials, also suggested that the maximum thickness of the board should not exceed 100mm as the cost and production time for board thicker than this would be subsequently increased, it is also more likely to have cracks on the external surface during use (Wu and Xu 2007; Zhang 2006).

In order to test the effects of energy reduction using polystyrene board insulation, simulation of the basecase model was carried out in HTB2. Polystyrene board was added at the external walls of the model and the thickness of board was increased in steps of 25mm, up to a maximum thickness of 100mm.

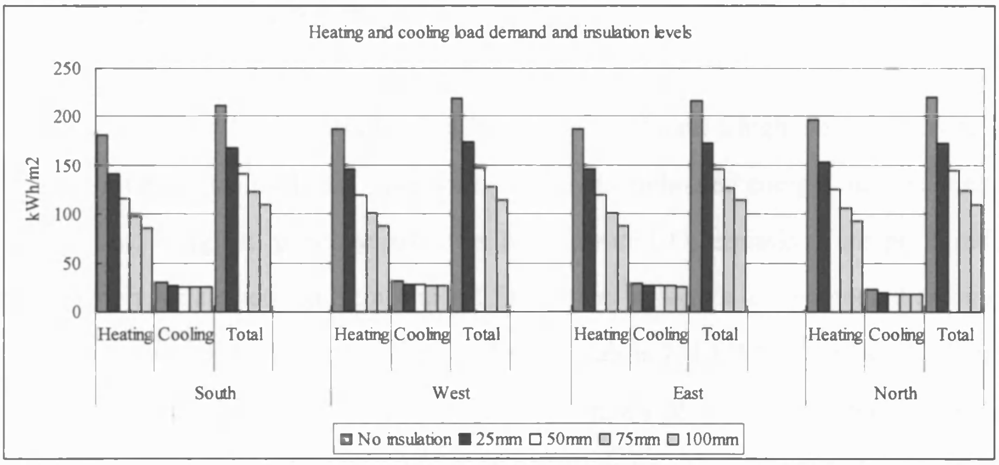


Figure 7.14: Heating Energy in Relation to External Insulation

Figure 7.14 represents the results for the relationship between the different levels of thermal insulation and energy use. Polystyrene board was selected as the insulation material, with a thermal conductivity of 0.042W/mK and its density is 30kg/m^3. From the graph, one can see that the reduction of the heating demand showed a linear trend together with the increase of insulation level. It can also be identified that the saving declined for every increment in the thickness of the insulation, which can be explained by the 'rule of diminishing returns', which was discovered from the research work of R. J. Fuller (2005). Similar reduction patterns also appeared in the cooling demand.

One can also conclude from the graph that the increase of insulation from 0 to 25mm, and from 25 to 50 mm, had a more apparent reduction in total demand than the further increase in the insulation level. Therefore, these two values should be considered first when the funding for the building design and construction is limited. However, in Zhang Yunping's research, it was suggested that an insulation level of no less than 30mm was the minimum requirement for buildings in North China; therefore, the 50mm polystyrene board will be considered as the minimum insulation thickness. Moreover, the board with the maximum thickness of 100mm will also be considered as the higher level of the design modification of the case studies, as it provides the highest available insulation level.

However, one must bear in mind that polystyrene board have a high embodied energy. Although the use of insulation saves many times its embodied energy, materials that require less energy to generate and thus have lower CO_2 emissions are preferred; generally, materials derived from mineral fibres tend to have a low embodied energy, for instance, the embodied energy for rockwool slab is 231 kWh/m^3, which is about one- fifth of expanded polystyrene board (1126 kWh/m^3) (Woolley and Kimmins 2000). The use of rock wool should be encouraged wherever possible, however, at the current condition, polystyrene is still the first choice when selecting the insulation material as it is easier and cheaper to make, and it requires less technology to install. All these characters make it more suitable to be widely applied.

7.4.1.3 Thermal Mass and heating regime

This section will discuss the thermal mass effect and its implication with the heating regime. The effect of thermal mass on the indoor thermal comfort and its interaction with the period heating scenario will be investigated.

7.4.1.3.1 Thermal mass of building envelope

Thermal mass is the capacity of objects to store the heat gain in the building envelope; When correctly incorporated in building constructions, it can be a useful method of controlling the flow or storage of heat in order to maintain the thermal comfort and an effective means to reduce the need of artificial heating or cooling (Roaf 2005).

This method is most effective in hot and dry climates with big temperature difference day and night (Givoni 1994). The heavy thermal mass can provide an opportunity for the building envelope to store the heat received from outside in the structure for some time, and release most of the heat back to the external when the external temperature is lower at night. Figure 7.15 demonstrates the reaction process of thermal mass construction in the summer period. One can see that in the day time, the building envelope keeps storing the heat from the external environment; the most percentage of heat gain will be stored in the construction until it reaches the limit of thermal capacity. There will be a slight amount of heat transferred to indoor space when the temperature of the construction becomes higher than the indoor temperature, and the indoor air temperature will start to rise to its peak value. However, as soon as the external temperature starts to drop, most of the heat stored in the building envelope elements will be passed to the external environment.

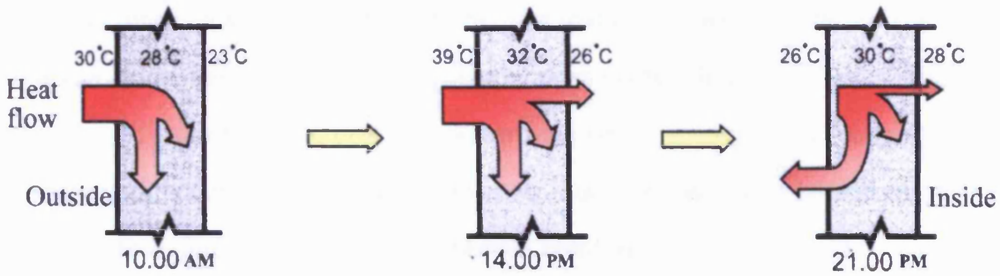


Figure 7.15: Thermal Mass Effect, after Koch

The tests of the effect of thermal mass on the building envelope to the indoor environment were carried out using HTB2; the basecase (facing south) was applied with 200mm, 400mm and 800mm concrete as wall construction. The results of indoor temperature on the hottest days of the year (15th and 16th July) are shown in Figure 7.16. From the results one can see that by using thicker walls, the summer room temperature could be effectively reduced, by using 400mm and 800mm wall, the reduction of peak indoor temperature was about 0.7 and 2 degrees respectively. Another effect is that the heavy thermal mass can maintain the room temperature to a more stable range, the daily variation of temperature was more 4 degrees when using 200mm wall and the value was reduced to 3.5 degrees by applying 400mm wall and 2 degrees by using 800mm wall.

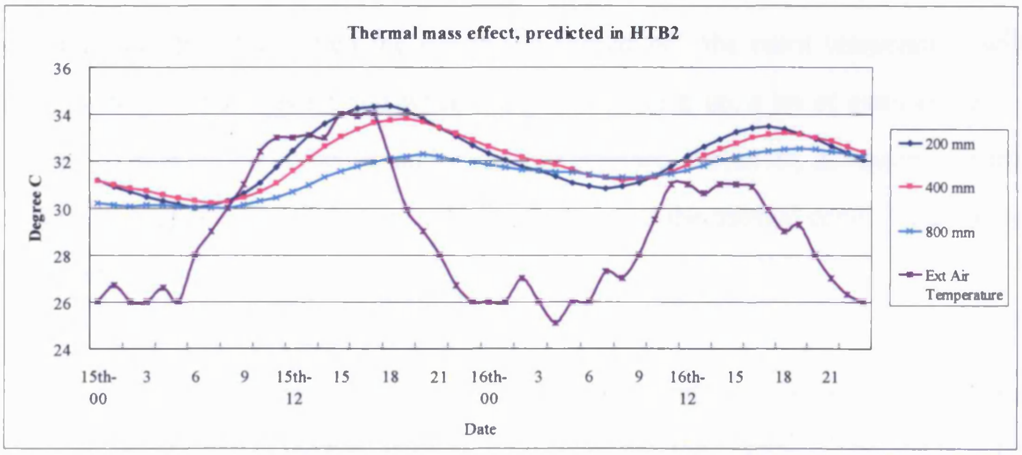


Figure 7. 16: Thermal Mass Effect in Reducing Summer Room Temperature

Moreover, one can also interpret from the data that the indoor temperature kept rising for a few hours even the external air temperature started dropping, this is due to the heat released from the structures that is warming up the indoor temperature, therefore providing night ventilation to remove the heat stored in the constructions will provide extra benefit in improving the indoor thermal comfort.

7.4.1.3.2 Heating regime scenario and thermal mass

As mentioned before, the dwellings in North China cities are all equipped with central heating systems that run at 24 hours all the time, lots of suggestion from researchers have been made, arguing that it should be changed to period heating that can be controlled based on the requirement of individual household (Xia 2006). This is deemed to be a reasonable requirement that can reduce the heating output.

However, some scholars expressed their concerns of the actual efficiency of the change of heating regime (Jiang 2006). As the change from continuous heating to period will require quite a substantial amount of work like installing the heating metre to every household and add manual control to the exiting radiators, hence the effect of such changed must be studied carefully. One major concern is that the giving current construction technology of China, the building envelope cannot buffer the external climate well, therefore when the heating is turned off, the room temperature will quickly drop to a low point and when the heater is back on, a lot of extra energy is needed to heat up the structure and room temperature, moreover, as heating up the room will require some time, hence during that period the thermal comfort cannot be provided to the occupants.

The use of thermal mass might help to reduce such negative effects, heavy thermal mass can store some of the heat from internal space heating, therefore after the heating is turned off the heat stored in the mass can keep the indoor temperature at a higher level and prevent it from dropping too fast. In order to test such effect, HTB2 simulation is used to study the interaction of thermal mass and period heating. In the basecase model, the heater was set to be running from 1800 pm to 0800 am next morning to represent the condition that occupant have heater on when they are at home, the operating temperature is 21 degrees.

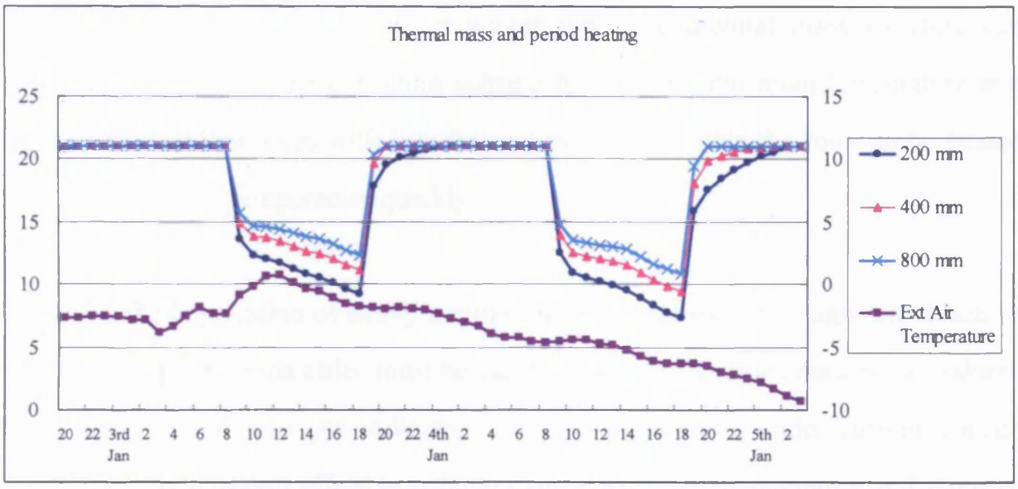


Figure 7. 17: Thermal Mass and Period Heating

From the result one can see that when the radiator was turned off, the room temperature all dropped immediately as the external air temperature is quite low, the interior temperature of building using 200mm concrete external walls was always 2 and 3 degrees lower than rooms with 400mm and 800mm external walls. Moreover, when the heater was back on, it took about 4 hours for the room temperature to be heated back to the comfort region, however for rooms with heavier thermal mass, the time required to heat up the room was within two hours.

The results from the simulation indicated that under the current building condition, simply change the heating supply to period heating might have negative effects of indoor thermal condition. It can also be concluded that the thermal mass have a positive effect in the application of period heating, rooms have a heavy thermal mass is able to maintain the room temperature at a higher level hence the time and energy to heat up the room when the heating is back on can be effectively reduced.

To sum up, the discussion and simulation in this section indicates the positive effects of thermal mass in improving energy efficiency and indoor thermal comfort conditions. In summer period, rooms with heavy thermal mass can have a relatively lower and more stable indoor temperature as it releases large amount of heat gain back to into the external environment. In winter time, the thermal mass structure can improve the effect of period heating scheme by maintain the room temperature at a higher level than the ones with less thermal mass and enable the room to be heated back to the desired temperature quickly.

However, the application of heavy thermal mass structures to the high-rise domestic buildings in north China cities must be careful, the related issues must be considered when apply it into use. As indicated from the simulation, under current climate conditions, the apparent effect in reducing summer indoor temperature and improve the effect of period heating can only be achieved by using walls with a thickness of about 400mm or 800mm, and having a wall that thick might require a big change of current construction technology. Besides, the extra thick wall will also affect the size of the indoor spaces. Hence this method does not seem to be easily applicable for the mid or high-rise dwellings in north China cities in practice. The reduction of summer temperature and be achieved by using passive shading devices and the performance of the period heating can also be achieved through better building insulation. However, if possible, during the indoor decoration process, materials with a large thermal capacity can be used to store the solar heat gain in winter daytime and then released back into the interior during the night, but those materials must be isolated from direct solar penetration in summertime, otherwise they will become another source contributing to the cooling demand.

7.4.2 Design parameter related to Ventilation

Ventilation, as defined in ASHRAE Standard (2004), is that air used for providing acceptable indoor air quality. It is the simplest strategy for improving comfort when the indoor temperature, under still air movement, seems to be too high (Givoni 1994).

When people are present in their homes, ventilation is especially necessary for comfort and life support by bringing in fresh air; limiting the concentration of carbon dioxide and removing odours caused by cooking or smoking. However, the air exchange process, through ventilation and infiltration is another way that heat escapes from houses. As mentioned by Borer and Harris (2005), more heat can be lost in well insulated houses through ventilation and infiltration than through fabric. Furthermore, in some extreme climates, direct air exchange with the external environment in the summer period will also bring the heat inside the dwelling spaces. The common ventilation rate measure is the number of times the whole interior volume of air is replaced per hour, and is called air changes per hour (ach /h). As suggested by Brown and Dekay (2001) achs of 0.5 to 1.5 are common in modern flats.

7.4.2.1 Ventilation control

7.4.2.1.1 Natural ventilation

Natural ventilation should be considered during the building design in order to deliver treated natural air to spaces which may passively heat, cool, humidify and dehumidify the spaces (Raja et al. 2000).

The design of ventilation systems in housing should provide for good indoor air quality and also exhaust summer heat gains. Normally a background ventilation rate of about 0.5 ach is sufficient to maintain the occupants' requirement for air supply (Diamond et al. 1998; Givoni 1994), but when the internal temperatures rise in the summer, typically up to about 4 ach is needed to reduce internal temperatures (Al-Oraier 2005) and this rate can be achieved, as claimed by Cynthia (2002), by opening windows in the flat. Natural ventilation in summer helps to reduce the indoor air temperature and provide a sufficient fresh air supply for occupants without using mechanical equipment. The use of natural ventilation to provide cooling in the summer period is a common strategy in residential buildings in China (Yao et al. 2002). However, it is more effective during the moderate conditions of the year, where the outdoor temperature is normally similar, or lower, than the desired temperature (Lechner 1991). The climate analysis in Chapter 3 indicated that during the summer season in North China the external daytime temperature typically ranged from 27 °C to 35 °C, and temperatures become more moderate at night, therefore, the increased night ventilation is more effective in reducing the summer cooling demand of houses in North China cities. Moreover, as mentioned in section 7.4.1.3, the natural ventilation can also improve the effect of thermal mass structure.

The design and construction of houses should utilise the natural ventilation design; building orientation and window design are the main sources for achieving natural ventilation. The orientation of the building should be designed according to local wind patterns, and attention should also be paid to the size and location of windows. Cross-ventilation should be used wherever possible, with windows on different façade orientations, which are subjected to a wind pressure gradient to ensure a good flow of air. Window openings should be controllable for different summer and winter ventilation rates. The main details of the design methods that affect indoor ventilation conditions are (Givoni 1994):

A. Geometrical configuration of the building's envelope.
B. Location and total area of openings with respect to wind direction.
C. Vertical location of openings.
D. Window types and details of their openings.
E. Interior obstructions to air flow from the inlet to outlet openings.

These factors should be considered in the early stages of building design. For instance, if there were two openings on one side, the appropriate design, as suggested by Waleed (2005), is to locate one in the central, and one at the edge of the façade, to create a pressure difference. Moreover, as claimed by Givoni (1976) and Lechner (1991), shading elements that attach to windows can also enhance the use of natural ventilation; side fins can create pressure differences of windows to encourage ventilation circulation if they can be placed on different sides of the windows. The horizontal overhang is able to increase the ventilation rate, especially if there is a gap between the building envelope and the overhang. Moreover, as mentioned in Section 7.4.1.2, this fixture can also help to remove the heat that is trapped below the shading slabs and reduce the surface temperature of the glazing areas.

7.4.2.1.2 Limit Infiltration

Instead of the use of deliberate natural or controlled ventilation strategies, air movement into buildings can also occur from uncontrolled infiltration (air leakage) of outside air through the building fabric, due to the density difference between the air in different areas (ASHRAE 2005).

In mild climates, a certain level of infiltration is helpful to fulfil the ventilation demand of spaces, maintaining a certain level of comfort when no one is at home to operate the designed controlled ventilation system. However, as the infiltration is an uncontrolled source, it is unlikely to provide sufficient air flow at the right time and in the right locations (Energy Saving Trust 2006). Moreover, under the extreme weather condition and serious pollution in northern Chinese cities, direct air change with the external environment should not be encouraged, instead, a deliberately designed ventilation system with consideration of air purity and heat recovery should be considered instead. According to Borer and Harris (2005) , infiltration is not needed; the house should only be ventilated through controlled air change:

'Ventilation is only really necessary when we artificially create a very humid micro-climate by cooking, washing or bathing. ...the basic approach is to seal up a house as tightly as is possible, and then to have plenty of opportunities to ventilate as needed...'

Figure 7.18: Out-dated Housing in 80's in Xi'an. Source: Author

As mentioned above, an air change rate of 0.5 ach will be sufficient to supply adequate air for residential building; however, with the effect of uncontrolled infiltration, the overall air change rate will be larger than it is desired to be. Therefore, minimising the infiltration will also contribute to the energy efficiency of the building, especially during the cold winter months.

Most of the existing houses in China are poorly constructed when compared to the average standard in European countries and northern America; the air leakage through cracks in the walls and unsealed window areas is likely to increase the heating demand and cause the indoor comfort problems. Data from previous research works show that the overall ventilation rate of houses constructed in the 1980s is about 2 to 2.5 ach/h, and the value for buildings with single glazed windows will be about 1.5 to 2 (Gao 2002; Jones and Wang 2007). One may argue that the increased infiltration in summer might help to remove the heat gains in summer, however, besides moving the internal heat outside, the uncontrolled air change will also bring external hot air into the building which will neutralise the positive effects; therefore, the controlled night ventilation is appreciated in the climate of northern Chinese cities.

Thus, it is clear that the draught-proofing of housings in China is one of the most beneficial energy saving measures available. Desired air change in buildings should be achieved through controlled ventilation, and the air infiltration should be minimised by designing air-tight constructions; the target rate for overall ventilation in occupied residential buildings, as suggested in CIBSE guide (1999) is 0.5 to 1.0 ach, and similar ranges were also stated in the report 'Energy efficient ventilation in dwellings' produced by the Energy Saving Trust in 2006. With the improvements in construction technology in China in recent years, the value of about 1.0 ach is achievable (Lv 2006), however, in order to achieve the lower band of the suggested rate, extra considerations should be given during the design process. Borer and Harris (2005) suggested that the major air leakage path are: window and door openings, window-/door-to-wall junctions, dry lining, suspended timber or concrete floors, pipes through floors and ceilings, electrical fittings.

7.4.2.2 Heat Recovery and Internal gains

The supply of fresh air to the occupants can normally be achieved by simply open the window, however, in winter this will affect the thermal performance of the buildings. The direct air change from a heated room to the external cold air will cause unnecessary heat loss; measured data from the field study showed that opening the window in winter period in heated room caused the immediate temperature drop (see the case study two and three in chapter 5). The hear recovery system provides an effective way to heat the incoming air by using the internal gains generated inside the house.

7.4.2.2.1 Internal Gains

Internal gain is the heat emission from occupants and equipments (such as lights) inside the rooms. The unit for internal gain is Watt per square metre (w/m2). It affects the thermal condition of spaces and has a direct connection with the thermal comfort and energy demand of buildings (CIBSE 2006). Too much internal gain will lead to the increase of indoor temperature; spaces with electrical equipments like office buildings, will normally have indoor temperatures higher than external temperatures during the summertime, due to the large amount of internal gains. Therefore appropriate control and management of the internal gain is crucial for maintaining the thermal comfort of the rooms.

However, for houses, the occupant density and their activities in a certain flat will remain relatively stable and the amount of electrical equipments is also much less when compared with non-domestic buildings (Givoni 1994); hence, the impact of internal gains toward the heating and cooling demand is not as great as other building types. As mentioned in the 'Design Code for Domestic Buildings in North China' (JGJ 26-95) (Ministry of Construction 1996), the internal gain produced from occupants and electric equipments in typical Chinese households should be considered as 3.8 w/m^2 during related thermal calculations. However, with the improvement in people's income and living standard, more and more electric equipments like TVs, recorders and computers are being introduced in housings; the amount of lighting equipment is also increasing (Bureau of Statistics 2007), therefore, in order to represent this factor, the internal gain levels of the rooms in the case studies have been set at 5 w/m^2.

The internal gain from occupant and equipment is low in housing; however the heat emitted during cooking and showering should be utilised. In traditional cave dwellings in China, the cooking is carried out indoors in the winter time and the pipes of kitchen hearth go through the heated bed (Kang element) in order to use the heat generated during cooking to warm up the bed (Golany 1992). This method is apparently not suitable to be directly applied in current modern life, however, the concept of heat recovery can be achieved through modern design strategies. To demonstrate the effect, a gas cooker and an electric shower was set in the kitchens and bathrooms of the case study models. The heat gain levels were set at 2290 and 1200, as suggested in CIBSE guide; the operating time was set to one hour each day for those equipments based on the author's experience.

When designing the space and function of buildings, appropriate zoning should be carefully considered to limit unwanted internal gains in summer; it is preferred that spaces with higher values of internal gains should be grouped together and natural ventilation systems should be ultilised to remove the heat to external spaces. In the winter period, the heat could also be used to contribute to the heating energy of the building through a heat recovery system.

7.4.2.2.2 Heat Recovery

The heat recovery is commonly associated with mechanical ventilation, and is generally called the 'Mechanical Ventilation with Heat Recovery' (MVHR) system. Normally, in a well insulated house, the majority of the heating effort goes towards warming up the ventilation air, whilst the warm air created in spaces like the kitchen and bathroom, will be transferred to outside (Borer and Harris 2005). Heat recovery systems capture heat energy from wasted air and reuse it by returning it to systems or processes. This can include heating space and water (Carbon Trust 2008).

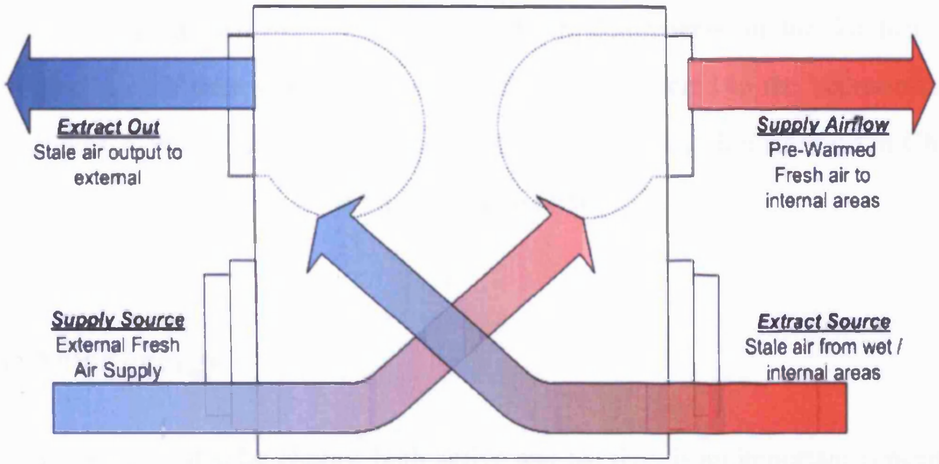


Figure 7.19: Work Flow of MVHR System (DEALEC 2007)

As described in SAP 2005 in UK, the efficiency level of the heat recovery system is about 66%, and according to Borer and Harris (2005), an effective system can pick up around 85% of the heat in outlet air to warm up the fresh air drawn from outside through the heat exchanger. Therefore, the fresh air can be warmed before it is introduced into rooms; the method is more energy effective in places with very cold winters and high level air pollutions (Gonzalo 2006). Warm air from the kitchen and bathroom will be drawn into the exchanger before being ventilated to external spaces and the heat will then be extracted. When external fresh air comes into the living space, the recovered heat will be used to warm it up; in addition,, the heat recovery system will also purify the air before passing it into the internal spaces.

The cost benefit of a heat recovery system depends largely on the type and scale of the installation, but it does gives substantial long-term energy savings. It often reduces the need to generate heat in the first place, making further energy and cost savings (Carbon Trust 2008). Many low-carbon housing projects in the UK have successfully integrated heat recovery chimneys; the BedZed project in south London, for instance. Furthermore, the 'Kang' in traditional cave dwellings in the Xi'an area are good examples of using heat generated from cooking to warm up the bed.

As mentioned in Section 7.4.2.2.2, in order to test how the heat recovery can reduce the heating energy demand, internal gains from equipments in the kitchen and bathrooms in each case study was considered to be recovered to the bedrooms and living rooms. Considering the current technology and construction standard in China, the recovery efficiency was set at the lower rate of 66%.

7.4.5 Solar energy

The adequate use of solar energy, both active and passive, is an important concept in reducing the energy consumption for spatial heating and cooling (Schittich 2003). and as claimed by Yao Runming (Yao et al. 2002), the adoption of passive solar heating/cooling concepts have been widely accepted among designers.

Solar energy is particularly appropriate as an energy source for buildings and over the last few years, considerable progress has been made in maximising its use in houses as the intensification of the global warming debate has led to increasing pressure to design buildings which make maximum use of free solar gains for heating cooling and lighting (Smith 2005). Currently, solar energy is increasingly perceived as an energy option with vast commercial potential; the international market for solar electric is currently expanding more than 20% a year (Eurobooks 1996). Solar power will play a key role in changing our energy use. Instead of contributing to the environmental problem, the built environment has huge potential to become a key part of solution (Marsh 2007).

The sun provides almost all of the world's energy needs; an extreme amount of energy falls on the earth's surface, providing warmth, wind, rain and photosynthesis (Hestnes et al. 1997; Yannas 1994). Energy from the sun is clean, renewable, free and abundant, and as said by Borer and Harris (2005), the solar energy is '*dwarfing human fossil fuel use*'. The sun provides a constant 173,000 terawatts (173,000 x 10^{12}W) of energy, whereas world fossil fuel is only 13 terawatts, so the solar energy is 15,000 times greater than our fossil fuel use. In other words, the solar energy falling on the earth in one hour is equal to the annual world fossil fuel demand (Borer and Harris 2005; HGa Consulting Engineers 1996). Therefore, using solar power will help reduce the world's dependence on fossil fuel and reduce the greenhouse gas associated with it.

As demonstrated in the Figure 7.20, only less than half of the sun's radiation is converted into heat; 30% of it is bounced back to space, reflected off snow, clouds or objects' surfaces. The amount of heat that is absorbed by objects on earth is very insignificant, most of the converted heat is lost to space, as long-wave radiation. Therefore, instead of letting that huge amount of solar power be reflected back to space, one can use passive solar design methods and solar energy devices, like PV panels, to intercept some of this solar radiation energy and turn it into something useful, like hot water, spatial heating or electricity. The results will be greatly beneficial, even if one only gets a slight proportion.

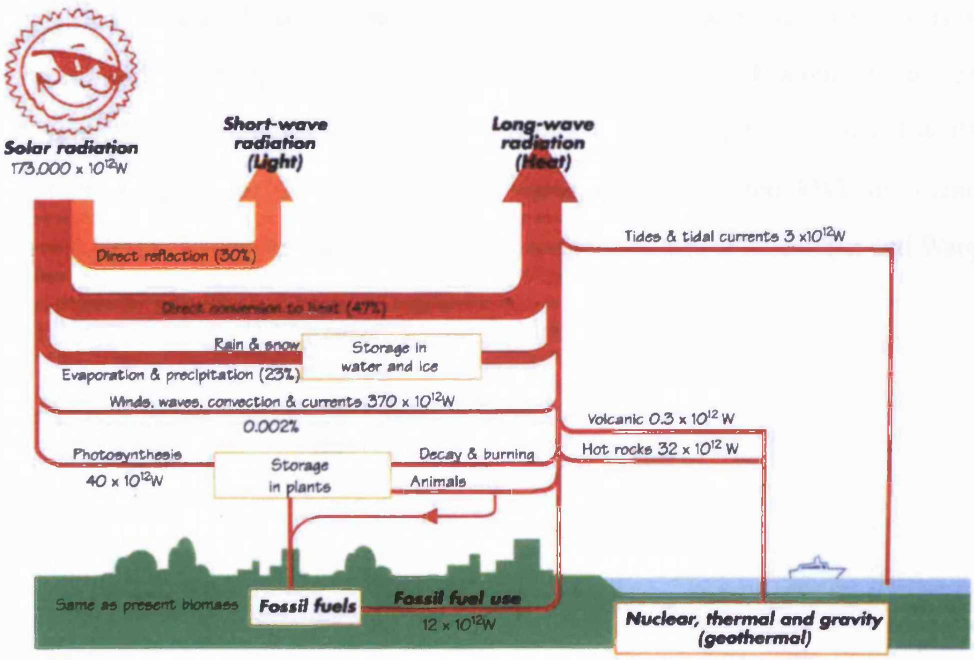


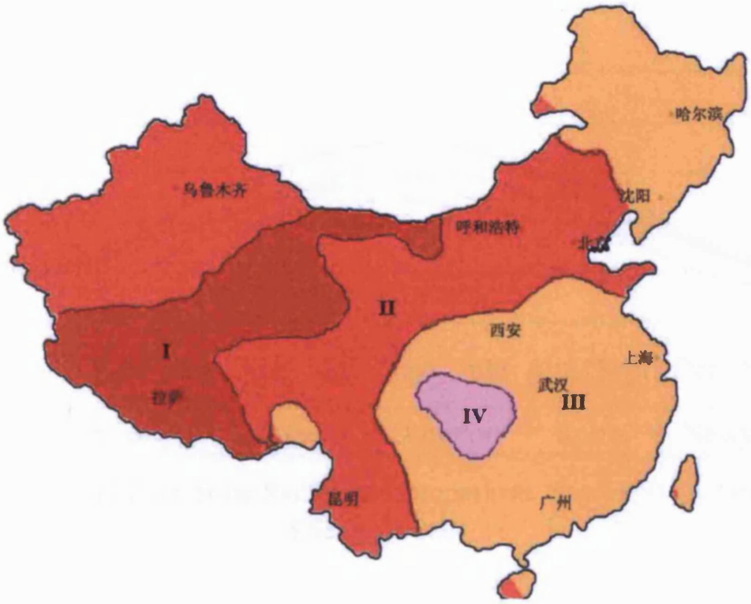
Figure 7.20: Solar Energy Distribution. Source: (Borer and Harris 2005)

The application of solar electricity is simple, silent and reliable. Unlike fossil fuels and nuclear power, solar electricity generation produces no pollution. Solar energy can provide homes with an onsite power station. It is the only electricity-generating renewable technology that can be mass-deployed in our towns and cities, where the majority of the energy is used (HGa Consulting Engineers 1996).

The study of the potential of adapting passive solar energy is important in achieving energy efficiency and thermal comfort in houses, as described by 'IES's Solar Heating and Cooling Programme's' Task 13:

'...by advance solar building technologies through the identification, development, and testing of new and innovative concepts which have the potential for eliminating or minimizing the use of purchased energy in residential buildings while maintaining acceptable thermal comfort levels...'

The full application of solar energy will displace the use of fossil fuel; in the UK for example, it is estimated that passive solar design could lead to a reduction in carbon dioxide (CO_2), amounting to 3.5 million tonnes per year in the UK alone by the year 2025 (Smith 2005). Moreover, China is also trying to establish 100,100,000 kW PV installation by the year 2030, which will generate 130 billion kWh of 'clean' electricity, similar to the capacity of 30 large coal operated power station (Li and Wang 2007).



Area	Intensity a year (kWh/m2)	Area size (% of nation)
I	> 1750	17.4
II	1400-1750	42.7
III	1050-1400	36.3
IV	<1050	3.6

Figure 7.21: Solar radiation distribution in China. Source: (Li and Wang 2007)

Figure 7. 21 demonstrates the distribution of solar energy sources in China. It is clear that solar radiation is an abundant source in China, especially in northern areas; more than 96% of the nation's land area has a yearly cumulative solar radiation between 1050 to 2450 kWh/m2 in the past 30 years. The comparison of monthly solar radiation amounts between Beijing and other European cities is demonstrated in Figure 7.22. It is clear that solar radiation in north China cities is higher than other cities with similar altitude; therefore, China has an advantage in adapting solar power sources during the building design and construction process and will achieve better results.

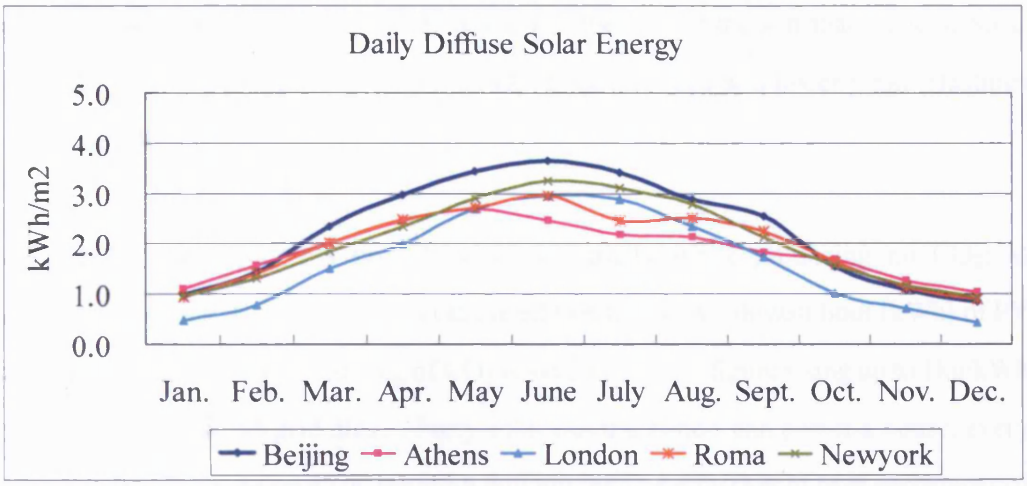


Figure 7.22: Daily Diffuse Solar Radiation Comparison. Source: (U.S. Department of Energy 2006b)

Using passive solar energy devices in this way spends the earth's 'income' rather than its 'capital'; living sustainably entails living within our means. Switching to non-polluting renewable resources and energy efficient building designs is, as said by Lord Norman Forster: '*... not about fashion, it is about survival...* '

The use of solar energy can be generally divided into thermal use of solar energy and photovoltaic (PV); and in addition, passive cooling strategies should also be considered in order to prevent overheating conditions in the summer period. Details of these strategies will be introduced in following sections.

The difference between the two types of indirect utilisation of solar energy mentioned above—thermal use of solar energy and photovoltaic (PV)—is that in thermal use solar energy, collectors transform/store solar radiation into heat, whereas PV-cells generate power out of solar radiation (Schittich 2003).

7.4.5.1 Solar-electricity and Solar Water Heating

PV materials generate direct electrical currents when exposed to light (Schittich 2003). Solar electric technology (photovoltaic or PV) uses solar cells to generate electricity straight from sunlight, as it is the light and not the heat of the sun that matters. Solar electricity will be produced even on cloudy days, although at a lower yield (Hastings and Wall 2007).

PV (photovoltaic) systems provide clean electricity while producing no CO_2; as mentioned by Sue Roaf (2005), it is estimated that for every kilowatt hour (kWh) of PV electricity that is produced, 0.6 kg of CO_2 is saved with this figure rising up to 1kg/kWh when PV replaces off-grid diesel. Forty solar electric panels can power a house, every square metre installed on a UK building will prevent the emission of over two tonnes of carbon dioxide during its 30 year lifetime (HGa Consulting Engineers 1996).

Figure 7.23: PV Cells on the Window, the BedZed project. Source: Author

Additionally, solar electric generation has the highest power density (a global mean of 170 W/m²) among renewable energies. Another benefit is that the electric is generated onsite, so the losses during the transport of energy are insignificant (transmission losses were approximately 7.2% in 1995) (Hastings and Wall 2007). An average solar electric system fitted to a home, in case of a UK home, will contribute around 43% of the average household's annual electricity needs; moreover, this technology is leading to concepts of energy surplus buildings, which generate more energy per year than they consume (Hastings and Mørck 2000).

Typical sizes of PV modules are 0.5x 1.0 m2, or 0.33 x 1.33 m2, although products larger than 1 m^2 can also be made; these modules are made up of about 40 cells (Hestnes et al. 1997). The energy generation rate is mostly determined by geographical location and the incline and orientation of the installed components. Generally, installations designed for supplementary spatial heating electricity should be orientated towards lower solar altitudes in winter, whilst installations for domestic hot water use should be orientated toward the higher solar altitudes in the summer season (Schittich 2003).

However, the price of PV cells has been, and still is, high and so its generated electricity is more expensive than grid-based sources. Fortunately, the price has been rapidly dropping for a number of years, and it is expected to drop by half by the year 2010 and the price of PV generated electricity will become similar with that of normal electricity within 20 years (Parker 2008). Furthermore, the solar panel is a one-off investment, and facilities can operate with little maintenance or intervention after the initial setup. Once the initial capital cost of building a solar power plant has been spent, the operating costs are extremely low when compared to existing power technologies.

An inexpensive method for solar energy use is solar water heating. Figure 7.1 in this chapter showed that the energy spend on water heating accounts for 15% of the whole energy demand and is the second largest use after spatial heating and cooling. So, minimising the energy expenditure in this factor by using solar water heating is also a possible way in which to contribute to energy efficiency in houses. As shown in Figure 7.24, this method has existed in China for a long period and has a long tradition in its application. Solar water heating systems have a higher efficacy than PV systems; some 20 to 50% of the monthly solar radiation incident on a collector can be delivered as useful heat output from solar water heating (Thomas 2006).

Figure 7.24: Solar Water Heating System in China. Source: (Steffen 2006)

However, in urban areas, the application of the solar water heating system is not developing very fast at the moment, only 7.6% households have solar power installed, compared with the demand of 23.2% (Investment Consultancy 2007); the lack of appropriate opportunities to install such systems during the design of high-rise housings might be the main reason.

7.4.5.2 Passive Solar Heating

Besides being converted into energy, solar power can also be used to warm up spaces in order to reduce energy consumption, especially with spatial heating. Passive solar design is the traditional technique of designing buildings to make maximum advantage of the sun's radiation for the living spaces. Through the study of the history of the residential architectures in North China, it can be learnt that solar design has been in use for a significant period; the ancient Chinese and Greeks were planning and building cities and buildings whose layout was based on what we nowadays call passive solar design, which means buildings should be designed to be oriented toward the south in order to gain maximum sunlight.

Solar gain can be divided into direct and indirect gains. Direct gain is basically radiant heat that directly penetrates a building through south-facing windows (Szokolay 2004). It can warm the interior spaces and be stored by interior surfaces such as walls, roofs, floors and furniture. It has been estimated that the sun can provide about 14% of the space heating demands on average in UK homes (Thomas 2006). Moreover, as proved by using simulations in previous parts of this chapter, under the climate condition in China, rooms facing south will also have a better thermal performance than rooms facing other directions. Indirect gain is heat collected and stored by high thermal mass construction materials, such as masonry, concrete and brick (Gonzalo 2006). A detailed description of thermal mass can be found in previous sections in this chapter. High mass walls will transfer heat from the outside environment to the interior space by conduction, radiation and convection. To increase comfort and the usefulness of solar gains, many of the house interiors include massive materials to store the heat, such as concrete floors and brick walls (Hestnes et al. 1997), as described in Section 7.4.2.3. Since the application of using very thick external walls to create thermal mass has lots of difficulties to be applied to high-rise buildings in North China cities, applying materials with high thermal capacities indoors might be an option.

Access to the sun has both psychological and physiological effects that have always been appreciated. As discussed in the preceding sections, China has an abundant amount of natural solar radiation, hence passive solar heating could be a useful method to reduce the heating demand. Figure 7.25 demonstrates the monthly total solar transmission through windows in diverse orientations; it is clear that the south facing window has a much higher solar gain in winter than in the summer period. The solar

7.4.6 Other Parameters

7.4.6.1 Effective Systems

Many effective active systems can maintain comfort levels without using energy or renewable energy, and are commonly used in houses. These are Ground Source Heat Pumps (GSHP) and Combined Heat and Power (CHP).

7.4.6.1.1 Ground source heat pump

As described by Randall Thomas (2005), heat pumps are devices that can move heat energy from one place to another. More importantly; they are able to move energy from a lower temperature to a higher temperature, and the most efficient pump is the Ground Source Heat Pump (GHP or GSHP), which originated in the 1940s. This is another technology which '*...goes back a long way but which is only now realizing its potential as technology for the future...*' (Smith 2005). The GSHP uses the stable temperature of the earth for both heating and cooling purposes by generating a stabilised temperature all year long; the prime principle is that it does not create heat, it transports it from one area to another, and it uses up to 50% less electricity than conventional electrical heating or cooling (CIBSE 2006b; Smith 2005).

Another advantage is that the ground heat pump has a higher coefficient of performance (COP) than traditional electrical heating/cooling sources, as demonstrated in Table 7.3. It is clear that the GSHP has the highest efficiency of 300 to 400%, which means that for every kilowatt of electricity generated it produces 3 to 4 kilowatts of useful heat (Borer and Harris 2005). Moreover, the theoretical COP for the heat pumps is 14 and in the near future a COP of 6 is likely to be achievable (Smith 2005).

7.4.6.2 Landscape Elements

Buildings are also influenced by their surrounding landscape elements, trees and other vegetations have an important role to play in the site layouts because of their amenity value and the effect of tempering the wind and micro climate (Thomas 2006).

Name	Period of Full leaf	Transparency (% of Radiation Passing)	
		Full Leaf	Bare Branch
Sycamore	May/August	25	65
Chestnut	Mid April/August	10	60
Birch	May/August	20	60
Oak	Mid May/Mid October	20	70
Elm	May/August	15	65

Table 7.3: Characteristics of Common Trees, after Thomas

As described in previous chapters, trees and other plants were generally used as a means to create passive shading and improve micro climate conditions in traditional dwellings in China. However, one also has to consider for deciduous trees, how long they are in leaf and how transparent they are to solar radiation, both when in leaf and bare. Trees are able to provide control of summertime solar gain in order to avoid excessive temperatures, but they also act as fixed external shading elements which will lead to a wintertime loss of passive solar gain and a year-round loss of light (Anon. 1990; Thomas 2006). Table 7.4 provides a selection of such data; however, the data listed is from the measurements of trees in the UK. It is to demonstrate the concept of selection criteria, so selecting tree types in dwelling design in China should be considered based on data from domestic tree characters.

Moreover, as mentioned before, in China the current development types are mostly medium to high-rise buildings, therefore the buildings' thermal performance will not be greatly affected by vegetation, but the landscape design will help to improve the comfort and micro-climate of the public spaces in the residential areas, as indicated through the research work carried out by Xingrong (2003). The landscape design can purify the air, reduce the summer solar radiation on the ground and can reduce the wind speed by about 40% in the winter period.

7.5 Conclusion

The study and analysis of this chapter is intended to provide a comprehensive context for the modifications of the case studies in next chapter, possible environmental design strategies were suggested and the related design parameters were discussed together.

The study at the beginning of this chapter showed that the major energy demand in residential architectures is through spatial heating and cooling, and the analysis of the passive heat gain and loss sources indicated that building envelop elements have the greatest effects on a building's thermal and energy performance; hence, appropriate consideration of those factors should be adapted of housing design process in North China cities.

Various available sustainable design strategies in housings were discussed. More importantly, in order to select appropriate methods that can be applied to the houses in North China cities, considerations of the adaptability and affordability under the current construction technology and economical conditions of China were used as the main criteria for the selection. Besides the theoretical discussion and study of the strategies, a basecase model was setup to test and demonstrate their effectiveness level in reducing heating and cooling energy demand. The results of this chapter provided the suggestions of the detailed design modifications outlined in the following chapter.

The discussion of interactions of the parameters indicated that the application of the strategies are not all straightforward as they need to consider the practical issues of the economic and construction situation of China whereas other strategies may have a different priority in the design process. Moreover, some strategies cannot be used solely as they need to be combined with other strategies to make the best use of each other. For instance, the improved window insulation has to be applied together with passive shading design to make sure the cooling demand will not be increased. A summary of this chapter and suggestions of design modifications follow:

1. China's housing is developing rapidly; however, attention paid to energy efficiency and sustainable concepts are far from sufficient. In order to achieve the objective of energy savings in housing, high quality construction and sustainable design strategies must be applied at the design stage. Environmental design can provide buildings with both energy efficiency and a more comfortable living environment.

2. The optimum orientation can reduce the energy use in buildings in North China. It is suggested that north-south orientation should be selected as much as possible, and reduce or avoid the use of glazing areas on the east-west sides. The study also showed that the too big windows are contributing to the energy inefficiency hence having the appropriate glazing according to the orientation will improve the building's energy performance.

3. Improved window insulation properties and passive shading design can make the best use of winter solar gain; avoid winter heat loss and summer overheating of rooms. The improved window insulation might lead to the summer cooling demand; hence, it needs to be used together with a passive shading system. Shading design parameters should be considered according to the orientation and local sun-path diagram.

4. Wall insulation is very effective at reducing heating energy demand in the long wintertime in North China, and external insulation should be given priorities. The polystyrene board should be used as the prime insulation material at the current conditions, as it is affordable and relatively easy to install; however, materials with less embodied energy like rock wool should also be considered wherever possible.

5. Thermal mass structure showed positive effect in improving energy efficiency and indoor thermal comfort conditions. In summer period, rooms with heavy thermal mass can maintain a relatively lower and more stable indoor temperature. In winter time, the thermal mass structure can improve the effect of period heating scheme. However, the practical issue should also be considered when apply it in practice as it requires great increase of the size of the building envelope which will affects the size of internal area and the current construction method.

6. Natural ventilation should be used in summer nights and the moderate climate periods to reduce cooling load and improve indoor comfort level. Air-tightness of the building should be pursuit with the improvement of construction technology to minimise the heating demand.

6. Winter air supply should be achieved via heat recovery system which can use the internal heat gain to preheat the incoming air. The internal gain level of houses is relatively low and stable when compared with other building types, but considerations should also be paid to reusing the heat emitted from inside the house. Using heat recovery systems can recover the heat emitted in the kitchen and bathrooms to reduce the heating demand in winter.

7. Solar panels for generating renewable onsite energy, like electricity and hot water, should be used to provide a certain amount of energy. The placement of the panels should be decided and calculated based on local sun-path diagram. Systems like the

Ground Source Heat Pump and Combined Heat Power can increase energy generating efficiency and further reduce the use of non-renewable energy.

8. Other parameters like landscape design should also be introduced in order to improve the micro-climate for the site and increase the bio-diversity.

All the tests in this chapter are intended to examine the effectiveness level of each method and the possibility of applying the methods in China. The next step is to determine how effective they are in terms of reducing the heating and cooling demand in all five case studies and how to combine them together in order to achieve the heating energy saving demanded by the Chinese government and achieve an even further saving.

CHAPTER EIGHT: DESIGN MODIFICATIONS

8.1 Introduction

As discussed and shown in previous chapters, environmental design strategies will effectively improve the energy efficiency and thermal performance of buildings. Therefore, this chapter is intended to investigate the effectiveness levels of the strategies suggested from Chapter 7, in improving the energy efficiency and thermal condition of the five case study buildings and the possible combination of certain strategy packages to fulfil the energy conservation requirement of the Chinese government. Mcreover, on top of meeting the target, it was also investigated to determine whether further reductions could be achieved through environmental design strategies.

Comparative modelling (comparing thermal performance and the energy demand of the 'before' and 'after' model) using HTB2 was adapted to the thermal models of all five case studies, in order to examine the improvement in their thermal and energy performance. Suggested appropriate strategies will be applied to the models for the purpose of studying each design parameter in relation to its impact on the energy efficiency of the case studies. Moreover, some strategies will also be applied accumulatively to assess the effectiveness of combined modification packages as the combination of strategies will help to notify the interactions of the design parameters.

Moreover, in order to test and examine to what extent the current housing design and the design modifications fulfil the heating energy saving regulation which is currently being enforced in China, heating energy demand of the five case studies were also generated based on the standard of 1980's regulation ('Reference Building'), and the outputs were used as reference values for comparison with current designs ('As Built') and buildings with suggested modifications. However, there is no regulation for cooling energy saving, hence the saving level of the cooling demand will be generated by comparison against the case studies' current conditions.

The results from the model showed clearly that the environmental design strategies will significantly improve the indoor conditions and reduce the consumption of energy in all of the case studies. The findings of this chapter intend to provide designers and decision-makers an overview of the effectiveness of environmental design in improving energy efficiency of dwelling buildings in North Chinese cities, and how to use them to achieve the 65% heating saving regulation.

8.2 Simulation Process

The simulation went through three phases. The first phase was to examine the current energy efficiency standard of the case studies. Comparative modelling was used to compare the energy performance of all five case studies, based on current designs and under the building regulations of the 1980s, in order to test to what extend they fulfil the 65% heating saving regulation. The second phase was to apply suggested design modifications to the case study models; the efficiency of individual design parameters will be examined by being applied separately to the model, in some cases the strategies will also be applied accumulatively to access the effectiveness of the combinations of strategies. The strategies were suggested according to building types and conditions and the influence of one strategy on another is also discussed when the combinations of certain strategies are needed. The results from the modified models are used to demonstrate the level of improvements from current and reference buildings. The third phase in the simulation was to rank the design parameters based on their effectiveness in improving the energy efficiency of the case studies, moreover, two design modification packages will be suggested for the purpose of meeting the regulation requirement and achieving further savings.

As explained in Chapter 7, the effectiveness of some strategies may not be able to be directly transferred into the improved thermal comfort or the reduction of energy consumption. The reasons for this are the limitation and sensitivities of the modelling tools; and more importantly, not all of the possible modifications can be demonstrated through simulation and therefore the results cannot be shown directly. One needs to interpret the results of simulation and then explain how certain strategies can be effectively adapted.

The strategies studied in this chapter were selected due to their appropriateness to the climate conditions in China; moreover, the practical application possibility was also considered, due to the technology and financial ability of the current building industry.

HTB2 was chosen to perform the energy calculation; the monthly heating or cooling load was generated in case studies under different scenarios.

Table 8.1 lists the thermal properties of the materials used in the case study models, which were obtained according to the China Thermal Design Code (GB50176-93). Table 8.2 lists the material construction information and properties of the 1980s and model of case studies; the first three cases in Tianjin have identical building material properties although they differ in design parameters, the other two cases in Xi'an have different materials as they were designed and constructed in different periods. The construction information of the 1980s building was based on the previous research by Lang Siwei (2002) and the construction information of the case studies were supplied by the local authorities in Tianjin and Xi'an cities. Some properties, like the building's top roof and ground floor slab, are not listed as all case studies are located in the middle part of the buildings; hence the effects of the top and bottom layers of the high-rise buildings are minor and can therefore be neglected.

	Thermal Conductivity W/m K	Density Kg/m3	Specific Heat J/kg.K
Glass Standard	1.05	2300	837
Polystyrene Insulation	0.042	30	1380
Brick	0.81	1800	1050
Medium Weight Brick	0.58	1400	1050
Plasterboard	0.431	1250	1088
Concrete	0.50	1600	1050
Concrete Screed	0.753	2100	650
Perlite Insulation	0.070	120	1170
Ceramic Tiles	0.309	1900	656.9
Wood Floor	0.209	825	2385

Table 8.1: Thermal Properties of the Selected Materials

The settings of the models' thermal parameters were based on the discussions in Chapter 8. The internal gain levels of the models were set to be 5w/m^2 and the occupancy periods were set to be from 6pm to 8am on week days and all day on weekends. The heating and cooling operation set points were 21 and 26°C (see Chapter 4 for details), the heating system was set to be running continuously over 24 hours to represent the current continuous district heating, and the cooling was set to be operating only within the occupancy periods in order to represent the households' control of the air-conditioning systems.

Elements	1980s	Cases 1-3 (2006)	Case 4 (2000)	Case 5 (2005)
External Wall	1 = 360 mm Brick 2 =10 mm Plasterboard	1 = 25mm Polystyrene Insulation 2 = 200 mm Concrete 3 = 5mm Concrete Screed 4 = 10 mm Plasterboard	1 = 200 mm Concrete 2 = 5mm Concrete Screed 3 = 10 mm Plasterboard	1 = 200 mm Concrete 2 = 5mm Concrete Screed 3 = 10 mm Plasterboard 4 = 25mm Internal Expanded Perlite Insulation
U-value*	1.57	0.75	1.15	0.90
Windows	Metal Frame 1 = 6mm Single Glazed Glass	PVC Frame & 1 = 6mm Standard Glass 2 = 30mm Air Gap 3 = 6mm Standard Glass	Metal Frame 1 = 6mm Single Glazed Glass	PVC Frame & 1 = 6mm Standard Glass 2 = 30mm Air Gap 3 = 6mm Standard Glass
U-value	6.40	2.70	6.40	2.70
Internal Walls Connect to Unheated Spaces	1 = 120 mm Brick 2 = 10 mm Plasterboard	1 = 10mm Plasterboard 2 = 120mm Medium Weight Brick 3 = 10 mm Plasterboard	1 = 10mm Plasterboard 2 = 120mm Medium Weight Brick 3 = 10 mm Plasterboard	1 = 10mm Plasterboard 2 = 120mm Medium Weight Brick 3 = 10 mm Plasterboard
U-value	2.62	1.92	1.92	1.92

Flat Floor	1 = 100mm Concrete Board 2 = 5mm Concrete Screed	1 = 10mm Plasterboard 2 = 100mm Concrete Board 3 = 5mm Concrete Screed 4 = 25mm Wood Floor	1= 10mm Plasterboard 2 = 100mm Concrete Board 3 = 5mm Concrete Screed 4 = 10mm Ceramic Tiles	1 = 10mm Plasterboard 2 = 100mm Concrete Board 3 = 5mm Concrete Screed 4 = 25mm Wood Floor
U-value	2.60	1.90	2.27	1.90
Ventilation Rate**	2.5	1.0	2.0	1.0
Passive Shading Device	None	None	None	None
Glazing Ratio	N/A	35-46%	22-25%	44-48%
Internal Gain	5w/m²			
Occupancy Period	6pm to 8am in Weekdays 24 Hours in Weekends			
Heating/Cooling Setpoint and Operation Time	21 °C (24 hours) and 26 °C (same as occupancy)			

* Unit in W/m²K ** Unit in air change/ hour

Table 8.2: Material Information in Simulation Models

2000, and the saving is only around 18%. The other four cases that were built during 2005 to 2006 have higher saving percentages, around 42 to 51%. It is certain that the heating energy efficiency is increasing as the technology and attention toward sustainability increased during the recent years; however, neither of the buildings achieved the saving degree required by building regulations. Moreover, even if the buildings reached the 65% of saving, the energy consumption value is till way too high when compared with the current standard in developed countries that have similar climate conditions, like the UK, Germany or Canada.

Table 8.3 compares the U-value of important building envelope elements requested in the building code of China with the countries previously mentioned above (Canadian Codes Centre 2005; Ministry of Construction 1996; Office of Deputy Prime Minister 2006; The German Energy Agency 2007). One can notice the figures the big gap in the building code; for instance, the U-value of the external walls of China is more than twice the amount of the other countries.

	External Wall	Window	Roof	Walls to Unheated Spaces
China (JGJ26—95)	0.82-1.16	<4	<0.8	<1.5
UK (Part L 2006)	0.30-0.35	1.8-2.2	0.16-0.25	0.35-0.5
Germany (EnEV 2002)	<0.35	<1.7	<0.25	<0.35
Canada (MNECB 2005)	<0.37	1.4-2.7	0.14-0.29	0.3-0.37

Table 8.3: Comparison of U-value of Building Envelope

Most of the case study buildings are considered to be representative of the highest standard of Chinese housings and they still unable to reach the government's target of 65% heating energy saving; therefore, in order to match the standard of other developed countries, additional methods should be considered when designing new buildings and modifying existing ones, not only to fulfil the building code, but also to minimise the energy demand of residential buildings.

8.3.2 Window Design

8.3.2.1 Glazing Ratio

As discussed in Chapter 7, too large glazing area will increase the heating and cooling demand. However, all case studies, except Case Study 4, have glazing ratios larger than 40% regardless of their orientation; for instance, the window to wall ratio of the north-west bedroom in Case Study 5 is almost 50% and none of the windows has any passive shading system. Moreover, as claimed in Section 7.4.1.1, under the current construction standard of China, the window insulation level is unable to achieve a 'net heat gain'; therefore, limiting the unprotected glazing areas is the first thing to do in order to effectively reduce the heating and cooling energy demand.

The glazing areas of the case studies were reduced to fulfil the range required in the building code (Design Code for Domestic Buildings in North China (JGJ 26-95)). As suggested in the previous chapter, the window-to-wall ratios of the south and north façades are reduced to 35% and 25%, respectively, and the values of the west and east façades are limited to 30%.

Figure 8.2 and 8.3 plotted the heating and cooling energy demands of the case studies using optimum glazing ratio and the energy saving rates from existing design (except Case Study 4, as its glazing ratio is within the range of the regulations). One can see that total yearly energy demands are effectively reduced by 10 to 15%; the reduction rate ranges from more than 40 kWh/m^2 in Case Study 5 to about 20 kWh/m^2 in Case Study 2. Case Study 5 had the greatest reduction as it had the largest existing glazing ratio. Having an appropriate glazing ratio is more successful in decreasing the cooling load than the heating demand, as the average cooling load was cut down by 23% whilst the heating load was reduced by about 8%; this is consistent with the results from the simulation of the basecase test model in the previous chapter.

The results of the yearly cooling and heating energy demand and the reduction rates from existing conditions are presented in Figure 8.5 and 8.6, one can see that that by adapting better insulated openings, further reductions of heating energy were achieved. An average 6.2% of the heating load was reduced by using low-E windows. However, similar with the previous test, the tightness of the windows also caused an increase in the cooling load; the averaged cooling demand increased 3.6%, however, this negative effect can be reduced by using passive shading devices.

8.3.2.3 Window Insulation and Shading Design

None of the cases studies has passive shading devices, and thus in the summer period, the excessive sun penetration through the openings will become a major source for cooling demand. Moreover, the previous test in Section 8.3.2.2 found that improved window insulation can reduce the heating load but will increase the cooling demand, due to its tightness. External shading elements should be designed carefully at the early stage of the project, and each façade should be treated separately. In addition, one should bear in mind that shadings should eliminate undesired summer solar gain, but make sure that the low angle sun in winter can penetrate the inside spaces. As mentioned in Chapter 7, the manual calculation for the dimension of the shading element can be quite complex as it requires a deep understanding of the mechanics of solar position and the sun-path diagram, whilst the advanced computer-based thermal simulation tools can generate the passive shading system accurately and easily (Andrew 2007). The shading designs for the case studies were generated using thermal prediction tools: ECOTECT shading design calculation and the Shading Mask program in HTB2 (SHADE.EXE).

ECOTECT was used to determine the appropriate size and design of the shading elements; its 'Shading Design Wizard' is able to calculate the necessary shading dimensions required for specific purposes. The target was set to eliminate the summer solar gains whilst not block solar radiation in winter when heat is required. The calculation of the optimum shading device indicated that the best performance was achieved by combining horizontal shading panels together. Whilst the horizontal panels should be larger at the south orientations, side fins should be larger at the west and east orientations. The proposed shading design parameters suggested by Ecotect

8.3.3.2 Wall Insulation

As mentioned in previous chapters, the lack of insulation level is one of the biggest problems that affect the energy efficiency of the dwellings in North China cities; the insulation level of the building envelope of the case study buildings is not enough. The lowest external wall U-value is 0.75 W/m^2K in Case Studies 1, 2 and 3; however, this is still much higher than the standard in developed countries (see table 8.3). In addition, another problem found is that walls connected to non-heated spaces are also not properly insulated; however, in regulations in the UK and other European countries, those walls should be insulated as well as the external façades.

Better thermal insulation levels are going to be introduced to the case study buildings in order to reduce their energy demand. As proved in the previous chapter, the internal insulation is not efficient and is associated with many negative effects, therefore, it is not considered during the modification and all insulations are applied externally.

As stated in Chapter 7, polystyrene board is the primary available source of wall insulation and two thickness of board (50mm and 100mm) were used respectively, to improve the thermal property of the wall construction (see Section 7.4.2.2 for details). As listed in Table 8.4, in the first construction type, the insulation material is 50mm thick polystyrene slab and the overall U-value of that material is 0.50 W/m^2K. In the second construction, a 100mm thick polystyrene board was applied at the external side of the concrete wall, and the overall U-value of that material is 0.30 W/m^2K.

Figure 8.15 showed the results of heating demand reduction by combining parameters related to building envelope design. The models were modified by combine the apt glazing ratio and double glazed windows with improved insulation. Using 50mm polystyrene board reduced about 30% of the heating energy, whilst the 100mm polystyrene insulation had a better performance by reducing 40% of the heating demand. Case Study 4 had the highest reduction rate of heating load cut at 59% and 68%, respectively, in the two scenarios as it benefits from have a reduced infiltration level (from 2.0 to 1.0 by having double glazed window) and improved insulation level of windows and walls. It indicates that by combining the appropriate design strategies, the energy efficiency of the case study buildings can be largely improved. Moreover, when compare the results in figure 8.14 and 8.15, one can also notice that having insulation achieved a more effective reduction than using apt glazing ratios.

It is also noticeable that by using the first insulation type and the window modifications, the heating demands in all case studies can be reduced to a similar level, or even less than, the required heating saving rate (the target value in the figure), and by applying higher levels of insulation, a further saving beyond the requirement of at least 15% is achievable.

So, the 50mm polystyrene insulation should be used as a bottom line when building new developments and renovating existing building stocks in order to fulfil the 65% heating energy saving requirement of the government; the 100mm polystyrene insulation should be considered if a higher energy efficiency standard is required. Moreover, though the 65% heating energy saving of the five case studies was achieved by adapting the above mentioned design modifications; however, the investigation of the energy reduction by adapting more strategies will continue, in order to examine to what extent the energy efficiency can be achieved.

The cooling load demands of the case studies and the decrease rates from the existing conditions are plotted in figure 8.17; one can see that the cooling loads were reduced by improving the insulation, about 4.8% less cooling energy is demanded in cases with 50mm insulation; however, the difference between the two construction types are modest, the average saving rate of using 100mm insulation is 6.4%. When comparing the results in figure 8.17 and figure 8.3, one can see that unlike the heating reduction,

8.3.4 Ventilation Control

Ventilation control methods, like reducing the infiltration rate and promoting night purge ventilation, will help to lift the thermal comfort in rooms whilst reducing the energy consumption. The study of adaptive comfort in chapter 4 also indicated the positive effect that provide occupancy the chance to use natural ventilation as a means to modify the indoor thermal environment will increase their acceptance range of comfort summer temperature hence to reduce the demand of artificial equipments. Achieving air tight spaces will greatly reduce the heat loss in winter and the night ventilation is more effective in cutting down the cooling demand.

8.3.4.1 Air Tightness

For well-insulated spaces, heat loss through infiltration and ventilation can be greater than through the fabric (Borer and Harris 2005); therefore, eliminating the undesired infiltration can improve the building's energy efficiency. The basic air change rates for the previous models were set to be 1 ach, as suggested in Section 7.4.4.2; however, as claimed by Givoni (1994) and Diamond (1998), in order to minimise the energy demand, the ventilation rate should be kept to a minimum requirement of 0.5 ach. Therefore, dwelling designs should attempt to limit the infiltration and only allow controlled air change for buildings to maintain the desired air supply.

In order to test such effect, the ventilation rates of the 5 case studies were reduced to 0.5 ach in order to reflect the result of limiting the infiltration to a maximum air-sealed level. The heating and cooling demands of the case studies are shown in Figure 8.20 and 8.21.

summertime will help to prevent the hot air from entering the living spaces, however, during the night time, the ventilation with the mild external air temperature will help to cool the rooms. Reducing the air exchange during night period will compromise the opportunity to use a passive cooling strategy.

Therefore, in order to achieve the optimum reduction in both heating and cooling loads, the ventilation rate should be limited to the minimum required level during the winter period and summer daytime. Natural ventilation at night time should be encouraged and such effects will be discussed in the following section.

8.3.4.2 Night Ventilation

As proved in previous studies, night ventilation is more favourable than increasing the ventilation rate all day during the summer months. In summertime, daytime temperature in cities like Tianjin and Xi'an can reach a very high level, around 37°C and far beyond the comfort band of 26°C; however, at night, the temperature drops to a milder range and is normally below 25°C. Therefore, night ventilation can be used to create a comfortable environment without consuming any additional cooling energy. Moreover, natural cool air inlets from the night ventilation can also help to remove the heat stored in the building elements, or heat emitted by household equipments, through heat exchange equipment to the outside.

Ventilation schemes are applied in the simulations, during daytime (from 7am to 10pm) the air change rate was limited to the same level of previous simulation (0.5 ach), as during this period the external air temperature is most likely to be higher than the desired value. From 10pm to 7am, the ventilation rate is changed to 4 ach in order to maximise the use of external cool air to cool down the spaces. As claimed in Chapter 8, increased ventilation can be achieved by opening windows to create natural ventilation (Cynthia Howard-Reed 2002).

Figure 8.22 compares the cooling demand of the case studies before and after the application of night ventilation. One can see clearly that the cooling load was reduced by introducing night ventilation, the reductions of the cooling demand range from 5 to

Furthermore, as described in chapter 4, the use of natural ventilation strategy will also help utilizing adaptive thermal comfort condition to reduce the demand of using artificial cooling equipments. However, this theory is not able to be represented in the simulation tools, this indicates the need to improve the tools to appropriately represent such variables.

8.3.4.3 Ventilation with Heat Recovery

As mentioned in the discussion in Sections 7.4.3, the heat generated inside the house can be used as a means of reducing the energy demand. Heat generated through activities in bathrooms and kitchens is normally transmitted directly to external spaces through window openings and extract fans. That energy can be easily recovered by using heat recovery systems (MVHR), which will effectively convert the heat in warm air from kitchen and bathroom before passing them to external environment, and the heat stored in the system can warm up the cold air before delivering it to the indoor spaces.

The effect of heat recovery systems can not be simulated directly; however, as mentioned at the beginning of the chapter, some interpretations of the process are used to demonstrate its effectiveness in reducing the heating demand. In the simulations, system heat gain levels of the kitchen and bathroom were set at 2290W and 1200W, as suggested in CIBSE guide; operating time was assumed to be one hour each day for the equipments, based on the author's experience. In each case study, 66% of heat generated in kitchens and bathrooms (settings were based on the discussions in Section 7.4.2.3) was assumed to be recovered and then delivered evenly to the bedrooms and living rooms as heat sources. The settings of this simulation were made through HTB2 and are outlined in Appendix C.

The simulation results are shown in Figure 8.24. The simulation results show that the recovered heat can replace 10 to 15kWh/m^2 heating energy, which make an average 8.6% reduction over the existing condition. Though the reduction rate is relatively low compares with other parameters like insulation or reduce infiltration, but when apply it to the well-insulated and air tight house the recovered heat will be beneficial.

The results show that by changing to period heating, the heating energy of the case studies was reduced by less than 9%. However, the reduction rate is lower than expected as the actual heating operation hours were reduced to half of the original, moreover, the effectiveness was also much lower when compare with that of other design parameters that is rested before in this chapter. The discussion in previous chapter indicated the possible reason for such a result: for normal buildings without adequate insulation and air-tightness, when the heating system is off the indoor temperature will drop to a low level; the output of heating system will increase to recover the low indoor temperature when the heating is back on, but this effect compromises the heating reduction in practice. On the other hand, for a better insulated and air-tight design, the effect of period heating simulation might be more apparent. In next section, the period heating will be combined together with thermal mass to examine the combined result.

8.3.5.2 Period Heating and Thermal mass

The discussion in section 7.4.1.3 indicated that thermal mass structure can improve the effect of period heating scheme by maintain the room temperature at a higher level than the ones with less thermal mass and enable the room to be heated back to the desired temperature quickly. Therefore the improved thermal mass structures of the case study models were combined with period heating scheme to examine their combined effectiveness. The 200mm concrete layer of the external walls of case studies was changed to 400mm and 800mm concrete to demonstrate the improved thermal mass.

To summarise, using period heating instead of 24 hour continuous heating is preferred in the residential architectures in North China cities, and people should have their own control of the heating system, just like with air-conditioning, and they should be charged according to the amount of heating they use. The basic suggestions of the operation period should be set according to the occupants' time schedule, like from 6pm to 8am on weekdays and continuously on the weekend. Moreover, since people's demands and requirements of heating levels are different, the control of the system will also give the occupants the opportunity to choose their preferred thermal condition at any time. For instance, rooms for elderly people will require longer heating periods than for working occupants, as they will occupy rooms for longer periods.

Furthermore, the simulations also suggested that the direct application of period heating to current conditions do not appear to have a great improvement, reduce the operating time to 1/2 only achieved a reduction of less than 10% in heating energy demand. On the other hand, the data also indicates the possibility to increase its efficiency by applying it in well-insulated conditions.

8.3.6 Generating Natural Energy

The tests in the previous chapters have proved that by adapting design modifications, like improving thermal insulation, optimising orientation, limiting air leakage and introducing efficient systems like heat recovery and natural ventilation, the heating and cooling energy demand of the dwellings can be reduced to a very low level. However, no matter how low the consumption is, there is still some non-renewable energy being used. Generating clean and free natural energy onsite from sun or wind will help to cut down energy demand in further steps; furthermore, these energy sources are renewable, hence, the overall impact of the building on the environment will be minimised.

8.3.6.1 Solar-electricity and Solar Water Heating

As described in Section 8.4.5, North China cities have abundant solar radiation all year long; Table 8.5 shows the daily global solar radiation and geographic information of Beijing, Xi'an and Tianjin cities; it is clear that the adequate amount of sunlight will provide a good opportunity to generate onsite solar electricity and water heating.

City	Latitude (Degree)	Average Solar Radiation (Wh/m^2)
Beijing	38.5	3835.9
Tianjin	38.9	3706.6
Xi'an	34.3	3236.9

Table 8. 5: Geographic and Solar Radiation Information of North China Cities. Source: (U.S. Department of Energy 2006)

As suggested by Borer and Harris (2005), the largest amount of solar radiation is received on the south orientation (in northern hemisphere); therefore, the solar panels should be placed toward south. In addition, the tilt of the panels also has a great impact on the performance. A study of previous research works and publications (Duffie and Beckman 1991; Lunde 1980; Schittich 2003) indicate that the optimised tilt degree to the horizontal surface of south facing panels, should be:

$$S_{opt} = \varnothing \pm 15\,° \ (\varnothing = \text{latitude of the location})$$

Therefore, the south facing panels in above mentioned cities should be tilted from the horizontal plane of 25° to 55°. In order to test the effects of different placement, simulations were carried out to test the solar radiation falling on panels tilting at different degrees, namely 25°, 55°, 0°, and 90°; the last two values are used to demonstrate the situation when the panels are fitted on a flat roof or mounted vertically on the façade. The year was divided into two periods: the winter months, when the electricity generated will supply the winter heating purpose; and during the 'rest months', when the energy generated will be used mostly for water heating.

horizontal fittings perform better in supplying domestic hot water and space heating, respectively. If possible, moveable solar panels are preferred so that the tilting degrees can be adjusted to absorb solar energy at different periods of the year.

Although solar energy has a great potential in North China cities, the temptation of generating all power required in houses through PV panels for electricity at the current stage might be unrealistic; for instance, from the previous simulations, the optimised building that can fulfil the 65% energy saving regulation will still have a total yearly electricity demand for space heating at about 9,500 kWh (average floor area of case studies is about 80m² hence the total heating demand is 80*118.6 $\approx$9500 kWh), and this would require at least 45 pieces of 175 Wp solar panels, with an area of about 45 m² for each household (calculation method referenced from Jambor (2006) and Jardine (2001)). So, for the whole building, the size of the solar panel array will be impossible to place; hence, the suggestion for current PV consideration is to maximise the roof area for PV panels in order to generate electricity for public use, like the lighting and heating for the public spaces. The PV can be applied to replace the space heating or cooling energy when the total energy efficiency is further improved.

8.3.7 Other Parameters

8.3.7.1 Ground Source Heat Pump

Ground Source Heat Pump systems have been widely used in many parts of the world, including North America and Europe, for many years (GSHP Association 2007). They are also able to be applied easily to the dwellings in North China cities, as the requirement of the installation is relatively low. As in practice, having a large public open space between a cluster of dwelling buildings in a residential community is very normal in China, the pipes of the heat pumps can be located underneath the public green spaces, like grass land or water features.

In a recent report published by the Energy Saving Trust (2007), typically GSHP systems cost more to install than conventional heating or cooling systems; however, these systems have very low maintenance costs and payback time will be no more than 20 years. Take the UK for instance, a typical 6 – 8 kW system costs approximately £7,300-£11,800 and one can save £400-£800 on heating bills by using the environmentally friendly heating; and more importantly, 2-8 tonnes of CO_2 per year can also be saved from the house. In many countries, the cost of a system can be subsidised by governmental programs, such as tax credits. In addition, by using off-peak electricity or solar power energy, the running costs of the system can also be effectively reduced (Hestnes et al. 1997).

Furthermore, if Ground Source Heat Pumps replaced the coal-powered heating system that dominates North China, the efficiency will also be more favourable. And now, there are some successful examples that have been built in China in recent years and this will be an important method in achieving sustainability in housing architecture.

8.3.7.2 Combined Heat and Power (CHP)

Although the CHP system is becoming popular in the UK and other European cities, its application in China is still currently an unexplored area. The application of the CHP has a great potential in the dwellings in North China, as it can fulfil the heating demand whilst providing adequate electric for daily use.

However, the application of a large scale CHP system should be carefully considered in China, as the large unit must be running for long periods in order to be cost-effective (about 3,500 to 4,500 hours per year), and service and maintenance for large scale is often required and quite complicated (Thomas 2006). Therefore, in China, the smaller CHPs on a community scale are favoured; installing such equipment, instead of traditional boilers, will pay back the additional costs initially incurred in 4 to 5 years, and only 2,000 to 3,000 running hours are required and the maintenance of smaller CHP systems is also more simple and easier to carry out; for example, the evaporator can be cleaned every 2,000 to 3,000 hours (which is about once a year) (Borer and Harris 2005; Thomas 2006).

8.3.7.3 Landscape Elements

As mentioned in Chapter 7, the appropriate use and planning of landscape elements, like plants and trees, can protect the buildings from the winter winds and summer solar penetration. However, in the high-rise developments in North China, shading effects from trees will affect no more than three floors; therefore, the overall cooling reduction cannot be dependent on plant shadings. However, plants and landscape elements can change the condition of the public spaces and provide occupants with a better micro-climate in the public living environment. Moreover, strategies like roof planting can also contribute to improving the roof insulation and provide rain water collection methods.

8.4 Modification Packages

The findings in previous simulations suggested that design parameters vary in their effectiveness; it was found that improve wall insulation and reduce infiltration have the most apparent effect in reducing heating demand and having apt glazing ratio and night ventilation are the most effective ways to reduce the cooling demand. It is also shown that energy demand can be effectively reduced by adapting combined modifications. Therefore the appropriate design parameters were combined to suggest two modification packages. The first one includes the above mentioned most effective methods and the purpose is to fulfil the 65% heating energy saving required by Chinese government.

The parameter selection of the first package is based on the criteria of easy adaptive and relatively low requirements that can be easily adapted during design and construction process. The second package, however, includes more complex technology and higher thermal insulation and air-tightness requirements than the first one; this is suggested for dwelling designs that require a better energy performance, although the cost of construction and requirement of attention during design will be higher than the first package.

8.4.1 Package One (For 65% Heating Energy Saving)

This modification package will be used as guidance and checklist for the design and modification of residential architectures, in order to fulfil the basic requirement of the government regulation for 65% saving over the buildings under 1980s regulation.

- Domestic buildings need to have an appropriate window-to-wall ratio (glazing ratio); the value of the south and north façades should be around 35% to 25%, respectively, and for the value for the west and east facing façades should be no larger than 30%.
- Double glazed windows must be used on all orientations; the U-value of it is 2.7 $W/m^2 K$.
- Passive shading systems should be used to create appropriate shading.
- Wall insulation should be applied on the external side of exposed walls; walls that connect with unheated spaces should also be insulated. A layer of 50mm polystyrene insulation should be used and the wall U-value is 0.5 W/m^2K.
- Rooms should be constructed to have good air-tightness. Possible air leakage sources should be checked and the air change rate for heating periods should not exceed 1.0 ach.
- Natural and night purge ventilation is recommended to use the cool air at nights and remove the heat stored in structures.

Figure 8.28 demonstrated the reduction of heating load by adapting the design modification package one. It is clear that the heating loads in all case studies were successfully reduced to below the target value, which is 65% less than its reference building in the 1980s' standard. Moreover, depending on the building design and construction period, the saving from the existing design varies in the five case studies, ranging from 30% in Case Study 3 to the highest saving of 60% in Case Study 4. The average reduction rate from the existing condition is 41%. All the buildings vary in design and building parameters; however, they all perform well under the suggested design modifications. So achieving the suggestions in 'Package One' in the building design or modification will guarantee that the purposed architecture fulfils the minimum of the national regulation.

existing condition. The lowest saving was 10 kWh/m^2 in Case Study 4, a possible reason is the higher infiltration rate (2 ach) in the existing building. However, as explained previously, the direct air exchange with the external environment in North China is not encouraged due to dust and air pollution problems.

8.4.2 Package Two (For Further Savings)

Preceding package is for the minimum requirement of the regulation however, the heating and cooling demands are still relatively high; for example the average heating and cooling demand of the case studies are about 114 and 28 kWh/m^2. In order to design and construct buildings requiring less energy, some additional strategies should be adapted. Package Two is suggested for this purpose and the detailed recommendation is as follows:

- Requirements of glazing ratios and window shading are the same as Package One.
- More improved insulated low-E windows should be used and the U-value is 2.0 W/m^{2}K.
- External walls, and walls that connect with unheated spaces, should be heavily insulated. The suggested construction is 100mm polystyrene insulation with a U-value for the wall of about 0.3 W/m^{2}K.
- Rooms should be designed to have extra air-tightness and possible air leakage sources should be checked. The overall air change rate for the heating period should not exceed 0.5 ach.
- Natural and night purge ventilation systems are recommended in order to use the cool air at night and remove the heat stored in constructions.
- A heat recovery system should be used to recover the heat from vented air, delivering and preheating fresh air.
- Onsite energy generation methods like PV solar panels, solar water heating or a ground source heat pump should be used to substitute a certain amount of the energy demand.

	1st Case	2nd Case	3rd Case	4th Case	5th Case	Average
As Built	52.8	45.6	57.9	34.3	64.3	49.6
Combined Case 1	28.7	27.4	29.3	24.9	28.1	27.7
Combined Case 2	24.2	22.5	26.4	21.2	25.5	24.0

Table 8.8: Summary of Average Cooling Energy Consumption per m² in Case Studies

Based on the data listed in figures 8.30 and 8.31, and Tables 8.7 and 8.8, it can be seen that by adapting higher construction standards and recommended strategies, the heating load can be substantially reduced. With the higher requirements, the heating demands of all the modified buildings are about 50 kWh/m², which is about 85% less than the value of the 1980s standard. The saving rate over the existing condition is about 74%. Moreover, as predicted in previous sections, the period heating system works better under these circumstances, a further 30% heating energy reduction was achieved when apply period heating scheme to cases with 'Package two' standard, with an overall heating demand is about 82% and 90% less than existing and reference building respectively. In terms of the cooling load, the improvement from the Package One was about 3 to 5 kWh/m^2, and the savings from existing buildings are over 50%.

The further reduction in the energy demand also provides a better chance to use onsite generated natural energy to cover most of the electricity demand of the buildings. After deductions, the total energy demand will be around 50 to 60 kWh/m², therefore, reasonable sized onsite energy generation methods, like PV panels and ground source heat pumps, will be able to supply a high percentage of the heating and cooling energy.

8.5 Summary

8.5.1 Effectiveness of Design Parameters:

A range of design parameters were applied to the case study models, the effectiveness of each design parameters in reducing heating and cooling energy demand was tested by using thermal simulation in HTB2. The parameters were applied to the model separately, in order to provide a general view of each design parameter in relation to its impact on the energy efficiency of the case study buildings. Moreover, some strategies were also be applied accumulatively to assess the effectiveness of combined modification packages as the combination of strategies will help one to notify the interactions of the design parameters.

Details of the suggested strategies are outlined below and the results of heating and cooling demand calculation are listed in table 8.9 and 8.10.

A. Glazing ratio: Domestic architectures need to have an appropriate glazing ratio; 30% and 20% for south and north façades, respectively, whilst for west and east facing façades, the glazing ratio should be no larger than 20%.
B. Window insulation: Double glazed windows (U-value is 2.7 $W/m^2 °K$) should be used to on all orientations as the minimum requirement; when possible, better insulated windows like Low-E windows with U-value of 2.0 $W/m^2 °K$ should be considered.
C. Window shading: A projection of 500 to 600mm on south, west and east windows should be used.
D. Wall insulation should be applied on the external side of exposed walls and walls that connect with unheated spaces, the suggested minimum construction is 50mm polystyrene insulation with 200mm concrete, the U-value is about 0.5 W/m^2K. Improved insulation level should be considered when possible; the suggested construction is 100mm polystyrene insulation with 200mm concrete, the overall U-value is about 0.3 W/m^2K.
E. Thermal mass: 400mm and 800mm thermal mass structure can be used to reduce the heating and cooling demand, it also able to improve the effectiveness of period heating. However, its effect is much less than using insulation and its related issues of construction and internal space area must be considered during application.
F. Rooms should be designed to be air-tight and possible air leakage sources should be checked. The overall air change rate for heating periods should not exceed 1.0 ach and should aim for the extra room air tightness with air change rate not exceeding 0.5 ach for heating periods.

Combined Case 2&period heating	34.7	34.0	32.7	35.2	32.6	33.8	83.1%

*Existing Glazing ratio of case study four is within the required range

Table 8.9: Summary of Heating Load Calculation Based on Suggested Design Parameters

	1st Case	2nd Case	3rd Case	4th Case	5th Case	Average	Reduction from Existing
Existing	52.8	45.6	57.9	34.3	64.3	51.0	0.0%
Apt glazing ratio	43.0	36.1	44.1	N/A*	41.5	41.2	23.2%
Improved window insulation	54.2	47.1	59.8	37.7	67.2	53.2	-3.6%
As built with shading	49.8	42.4	51.0	34.1	60.0	47.5	7.6%
Low_E window with shading	50.2	43.4	51.9	34.9	60.4	48.1	6.3%
50mm polystyrene insulation	49.3	43.4	53.9	33.1	62.6	48.4	4.8%
100mm polystyrene insulation	48.9	43.0	52.9	32.2	61.2	47.6	6.4%
Apt glazing ratio & 50mm insulation	38.3	32.6	38.7	32.8	38.0	36.1	25.1%
Apt glazing ratio & 100mm insulation	37.8	31.9	38.1	32.2	36.9	35.4	26.5%
400mm Thermal Mass	51.4	44.8	56.6	33.4	63.4	49.9	1.9%
800mm Thermal Mass	50.6	44.4	56.0	33.0	63.0	49.4	3.0%
Reduce air change rate to 0.5	56.5	47.4	60.0	38.3	67.3	53.9	-5.5%
Night ventilation	45.5	38.1	51.3	31.0	55.2	44.2	13.3%
Combined case 1	28.7	27.4	29.3	24.9	28.1	27.7	43.7%
Combined case 2	24.2	22.5	26.4	21.2	25.5	24.0	52.0%

*Existing Glazing ratio of case study four is within the required range

Table 8.10: Summary of Cooling Load Calculation Based on Suggested Design Parameters

The efficiencies of the design parameters are listed in below figures. Figure 8.32 shows the average percentages of heating energy saving from the existing conditions, the data in blue colour means the efficiency achieved from individual parameter and the purple ones represent the results from combined methods. From the data, one can

One noticeable feature is that applying certain strategies solely will cause the increase of cooling demand (overheating in summer), for example, improving window insulation to Low_E windows caused 3.6% increase of cooling load, moreover, reducing air change rate to 0.5 ach also increase the load by 5.5%. The explanation of such results is that the improved insulation and air tightness allow less heat to be transferred to the external environment. Hence those methods will need to be joint with other design parameters, for example, combining the passive shading design with improved insulation decreased the cooling demand about 6.3%. Furthermore, when applying the packages suggested, the demand of using air-conditioning can be reduced by between 46% and 53%, respectively.

This section summarised the effectiveness of the suggested design parameters, moreover, beside these measurable strategies, other design methods should also be considered during the design stage; for instance, the building should be designed and planned to ensure the best use of natural ventilation and solar access to maximise the natural daylight and passive solar heating. In addition, effective systems, like period heating supplied by CHP stations, PV and solar water heating panels, can contribute towards further reductions by generating onsite renewable energy resources.

8.5.2 Design packages

Data in previous section showed the high energy reduction efficiency of the suggested design packages, which are suggested to fulfil the 65% saving regulation that required by Chinese government and achieve a further saving. The discussion at the beginning of this chapter indicates that although the energy efficiency of the buildings has been improved over the 1980's standard, the current buildings still have not been able to achieve the 65% saving demanded by the government. The average saving rate of the case studies is about 41% from their reference buildings. Therefore using those packages as design guide lines will enable the buildings to fulfil the regulation and achieve better energy efficiency.

The detailed information of the packages is listed in section 8.4, summary of the design parameters and the overall heating reduction rate in relation to heating and cooling energy demand will be presented here. Table 8.9 summaries the thermal properties of the important building elements and design strategies used in the packages. From the table one can see that wall insulation, air-tightness, shading and the amount—and type— of window system are the most important factors for achieving the basic requirements of the energy saving objective, the overall reduction from reference condition is about 67%. Furthermore, having a higher standard of the before mentioned parameters and adapting effective design methods, like summer night ventilation, heat recovery and period heating schemes, will enable the domestic architectures to save about 85% heating energy. Moreover, by using period heating scheme, the reduction rates of the two packages were increase to 71% and 90% respectively. Besides the heating reduction, the two packages also successfully reduced the cooling demand of the case studies, the cooling reduction rates from existing condition is 46% and 53%. The comparison of the average heating and cooling demand and the reduction rate are listed in figure 8.34 and 8.35.

8.6 Conclusion

This chapter described the investigation of the effectiveness of suggested design strategies in reducing the heating and cooling energy of the case study buildings. The HTB2 program was used to perform the simulations, the strategies were applied to each case study both individually and combinative; comparisons of the thermal performance, heating and cooling load between the basecase and modified models were discussed. Moreover, possible design strategies that fulfil the basic energy saving requirement, and also provide further energy saving possibilities, were also outlined.

The suggested design parameters vary in their effectiveness; it was found that improve wall insulation and reduce infiltration have the most apparent effect in reducing heating demand and having apt glazing ratio and night ventilation are the most effective ways to reduce the cooling demand, those methods should be prioritised during design and construction process of domestic architectures in North China.. The discussion and simulation in this chapter also indicated that applying appropriate strategies together the effectiveness of energy reduction can be maximised. The suggested design package one enables the heating energy demand of the case study buildings to reach the regulation level required by the government. The strategies include having 50mm polystyrene insulation, overall air change rate of 1 ach and other design parameters like having an appropriate glazing ratio, well shaded and insulated windows. Moreover, by adapting a higher requirement on building envelopes, together with extra air-tightness and heat recovery systems, the energy efficiency can even achieve a much higher level in all case studies. The simulation also indicates that apply period heating scheme to the packages designs achieved a higher efficiency in heating reduction.

The simulation results show significant improvements in the energy efficiency; the application of a range of relatively simple passive design modifications can have a direct effect on reducing the buildings' heating and cooling load. All five case studies vary in design, age and construction information, but they all achieved a similar heating and cooling energy reduction, therefore, it gives extra confidence in the fact that these methods could be widely used in North China cities.

CHAPTER NINE: CONCLUSION

9.1 Introduction

This chapter presents the conclusion of this research, main findings, design recommendations of residential architectures in North China cities, benefits of this research and areas the areas where further work should be undertaken were presented.

9.2 Conclusion:

The aim of this thesis was: **To investigate the potential of using environmental design to increase the energy efficiency of residential architectures in North China cities while provide reasonable comfort conditions.** This aim was successfully achieved; the research outcome showed that the energy efficiency can be effectively increased by incorporating a range of environmental design strategies.

The indoor temperature of the five case studies in Tianjin and Xi'an cities were measured during the winter period. The average air temperature in heated rooms was about 20 to 22 °C while the average external temperature was about 1 to -3 °C. The current district heating system is operating 24 hours continuously; it shows the possibility to changing such system to period heating could reduce the total heating energy demand. The data also showed that the average air temperature in rooms without heating system and no occupants was about 3.4 °C whilst external air temperature was about 0.8 °C. This indicated the possibility to improve the building design and the thermal property of the building envelope to improve its ability to buffer the external climate passively.

The measured data was also used to compare with the predicted results from HTB2. Based on the comparison of results, there was a good agreement in all five case studies. In rooms without occupants and heating systems, the difference between predicted and measured data was always less than 1 °C, however the agreement was not that good in occupied and heated rooms, the agreement in average air temperature between the predicted results and measurements was within ±1.5 °C with differences up to ±2.5 °C, the variations were considered to be acceptable owning the fact the central heating systems and occupant's behaviours may affect the accuracy levels of both the predicted and measured data. Analysis of results from the simulations indicate that HTB2 is capable of modelling the performance of buildings to a satisfactory level of accuracy when providing adequate information like geometry, material and climate. However one must bear in mind that some unmeasured parameters like the variation of heating system and the people's behaviour are contributing to the overall disagreement of predicted and measured data. Therefore, in conditions when more detailed simulation result is required, those parameters should be measured in detail, furthermore, this also indicates the need to develop simulation tools to ensure them can appropriately reflect such parameters and also provide user a better chance to set the variables.

The analysis of the effectiveness of environmental design strategies indicated the most efficient strategies toward heating and cooling energy reductions and they should be prioritised during design and construction process of domestic architectures in North China. The most effective heating reduction factor is to improve the thermal insulation level of the building, having 50mm and 100mm polystyrene insulation achieved reductions of 26.5% and 38.8% respectively. Reduce the infiltration rate is the second most effective method, limit the air change rate to 0.5 ach reduced 21.6% of the heating demand from the existing condition. Other methods including having apt glazing ratio, improved window insulation, period heating and heat recovery also achieved the reduction rates ranging from 6.2% to 8.8%. The data also showed the parameters that reduce most cooling demand are having a reasonable window area and night time controlled ventilation—the reduction rate is around 23% and 13% respectively. Passive shading design and improve thermal insulation also achieved reductions around 4.8% to 7.6%.

Element U-values (W/m^2K) & Strategies	Package one (to meet regulation)	Package two (for further saving)
External wall	0.5	0.3
Window	D_ glazing (2.7)	D_ glazing Low-E (2.0)
Ventilation rate (Ach/h)	1	0.5
Glazing ratio	25-35% on N & S <30% on W & E	
Window passive shading	Yes	Yes
Night controlled ventilation	Yes	Yes
Heat recovery	No	Yes
Period Heating	Yes	Yes
Heating energy reduce from ref. building	67%	85%
Heating Energy (with period heating) Reduction from Reference Building	71%	90%
Cooling energy reduction from existing condition	46%	53%

Table 9. 1: Suggested Design Packages

9.3 Design Recommendation

The following design recommendations were generated based on this research, they are focused on providing the designers with useful information on energy efficiency design of residential buildings in North China cities.

Sustainable Housing Design Strategies

1 Site Analysis

Site analysis is important to explore the existing conditions, such as local climate and obstacles from existing surroundings, in order to maximise the use of natural resources.

Residential architectures in North China cities should be orientated towards the north-south direction and the location of buildings should be placed to ensure all households can achieve adequate solar access; moreover, site ventilation conditions should also be studied to offer buildings the opportunity to encourage natural ventilation.

2 Building Form and Spatial Arrangement

The current 'Dot' tower should not be encouraged as it is unable to maximize the solar access and cross ventilation to all flats on the plan. The 'Slab' shaped building is preferred in the climate of northern Chinese cities, as the rooms in this type of building have a better likelihood of being orientated towards the south, whilst rooms can also be arranged to enable the use of natural cross ventilation as a passive cooling method.

3 Window Design

The residential buildings should have an appropriate glazing ratio, which is 35% and 25% for south and north façades, whilst for west and east facing façades it should be no larger than 30%. Double glazing is a minimum standard whilst 'Low-E' windows are preferred. Appropriate window shading design should also be incorporated at south, east and west windows.

4 Building Insulation

Adequate wall insulation must be considered and should be applied to the external side of exposed walls, if possible; furthermore, walls that connect with unheated spaces should also be insulated to the same level. The insulation level is at least 50mm polystyrene.

5 Ventilation Control

Rooms should be designed to be air-tight and possible air leakage sources should be checked during construction. The overall infiltration and ventilation rate for the heating period should not exceed 1.0 ach. Natural ventilation is recommended to use at night in the summer period to cool down the internal spaces. Moreover, the study of adaptive comfort indicates that provide occupants chances to modify the internal environments will increase the acceptance range for thermal comfort hence further reduce the need for artificial equipments.

6 Heat Recovery Systems

Internal heat generated from daily activities in the bathroom and kitchen also should be recovered to preheat the inlet air in the winter period. The restored heat could also contribute to the domestic hot water in the summer period.

7 Period Heating

Period heating should replace the current 24 hours continuous heating; people should have control of the time and scale of heating they require and should be charged according to the amount of heating they use.

8 Generating Natural Energy

On-site energy generation methods like PV solar panels, solar water heating, or a ground source heat pump, should be used to substitute a certain amount of the energy demand. The placement of the collecting boards, especially the tilting degree, should be calculated according to the project location and local sun-path diagram. The optimum incline for Northern Chinese cities should be 25° to 55°.

9 Landscape Elements

Landscape elements should be planned in order to provide occupants with a better micro-climate in the public living environment. Moreover, strategies like roof planting, can also contribute to improving the roof insulation and provide an area for rain water collection.

10 Efficient Systems

If possible, efficient systems, like 'Ground Source Heat Pump' and 'Combined Heat and Power', can be adopted to generate more efficient and renewable energy supply that is necessary to the dwellings.

9.4 Benefits of this Research

The research outcome is intended to increase the attention toward energy efficiency dwelling design in North China cities. The results indicated that energy savings in line with government targets are achievable if energy saving measures is integrated into the design, and building energy models can identify the most appropriate design parameters and combined design packages for achieving these savings. Conclusions drawn from this study are to help architects and decision-makers to enforce sustainable design during the building design and construction process, in order to achieve both appropriate adaptations to the climate, as well as create a better thermal environment.

On a global scale, cutting down energy consumption and greenhouse gas emissions in housings in China will help the world to battle against the worsening climate problem. A 'less polluting' China will definitely contribute to the global action toward sustainability. Furthermore, the experience of such development will give a good example to high-density cities in other developing countries in their action to reduce energy consumption.

On a national scale, China is committed to sustainable development; the reduced energy demand in housing sectors will definitely contribute to it and release the burden of the negative effects of energy shortage on China's economical progress. The saved energy and resource will also give a substantial lift to China's further development.

On a household scale, environmental design can provide occupants with a healthy, high quality and comfortable indoor climate; meet people's expectation of better thermal comfort and living condition, and; occupants' life quality will be improved as a result of the extra money saved from the buildings running cost (heating and cooling).

9.5 Future Work

The aims and objectives in this thesis have been achieved, and during the research, some areas were found to have the potential to form the basis of future study. Furthermore, the research of sustainable building design is a big topic, other important factors should also be investigated during further research works. The suggested areas are as follows:

- It is a potential area of interest to finding appropriate ways to use computer simulation and comparative modelling methods to assess the benefit of energy and emission reduction, when applying the design strategies suggested in this research, on a city or region scale. A first step has already been taken by using a GIS based tool, Energy and Environmental Prediction model (EEP). (See Appendix D).
- The model validation process showed the impact of people's behaviour and the variation of heating system on the indoor thermal environment, it is necessary to develop the thermal simulation tools to provide appropriate response toward those parameters and also provide user a better chance to set the variables, other factors like the adaptive comfort should also be made compatible within thermal simulation.
- Investigate possible practical issues during the application of the suggested design strategies, such as the relationship of the design strategies with indoor lighting, acoustic conditions, detailed technical requirement and cost-benefit calculation of each design method. The comparison of the effectiveness of the design strategies in the thesis has provided useful information for the cost benefit calculation.
- Further study of sustainable concepts in the building construction process, such as materials embodied energy and Modern Method of Constriction (MMC). Ways to examine energy and emission of the whole lifecycle of the buildings could also be

investigated.

- After buildings have been designed and constructed following the suggested design packages, a post-occupancy comfort and energy survey should be taken to check the occupants' response and the energy consumption in reality, to see if any adaptations or modifications should be noted.
- A comprehensive investigation of the environmental design strategies in traditional architectures and measurements of the thermal condition in some traditional dwellings should be taken to compare with the current modern buildings.
- Apply the approach and methodologies of this thesis to conduct more researches to evaluate and improve the thermal and energy performance of different building types, or other climate zoning regions of China.

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Climate zone two is located in central east China (Fig 3-7), covering whole area of four provinces including Beijing, the capital city and part of other two provinces, total size is over 1.1 million km^2, which is 11.5% of the whole area of China, more than 320 million people live here and it is about 25.6% of the whole population.

Winter here is long and dry and summer time is short but hot and humid. Temperature fluctuates drastically in spring and summer; spring is windy with sand storms happening in some places, in summer and autumn time there will be lots of rainstorms and sometime even hail and thunderstorms. Rain amount is about 300~1000mm a year and overall solar radiation is 150--190w/m^2. Water amount per capita is only 400-900mm^3, which is the lowest in the nation; however, this part is the prime coal produce place in the country, especially in Shanxi province (ChinaNet, 2005).

Traditionally, typical housing architecture in this area is wood structured, and the famous courtyard housing style, "Siheyuan", is very common here in the old time such as Beijing and Taiyuan city, another very distinctive housing type is the cave house in Shanxi province. But at present there is not much this kind of buildings left because wood material cannot last for a long period and the newly developed housings are primarily built with concrete and steel.

The buildings here should satisfy the occupiers' need of warmth and keep both the house and people at an appropriate condition in winter, so the heating and building envelop should be designed with care, and houses in zone two also need to consider preventing over heat in summer period. Secondly, housing layouts have to have an optimal response to local climate in order to gain enough natural sunlight and ventilation. Moreover, they should also guard the cold wind in winter season and rain storm in summer.

Zone five is located in south China (Fig 3-10), covering whole area of Yun'nan province and part territory of other three provinces, total area is 570 thousand km^2, which is 6% of the size of china, about 60 million people live here, which is 5.1% of the whole Chinese population.

This place has an apparent three-dimensional climate; weather varies with the change of altitude. Most places have a cool summer and warm winter, and the difference between dry and humid season is quite clear. The sunshine time is short, so in some highland area the winter is quite cold. Daily temperature does not vary quite much in a year but the hotness gap during a day is large. This zone has the largest possibility to have thunderstorm in China, it could happen in every month (ChinaNet, 2005).

Abundant rain amount and lots of rivers make per capita water storage in this region three times outnumbered than the country average. Water resource is the largest energy advantages and the second is the solar energy due to the large amount of sunshine. This section has lots of ethnic minorities; many of them have their own types of residential buildings, mainly wooden or terrene. Most of them play an important role in Chinese architectural history.

In order to cooperate with the climate situation in this area, the following factors should be considerer as obligation during dwelling and building design process. First, all the buildings should meet the need of protecting from the constant rain in humid season, in addition the ventilation should also be considered, anyway the heat prevention is not needed. Secondly, in urban planning and architecture design process, one key factor is to make the buildings have good natural ventilation, especially in rainy period and important room such as main bedroom should have good orientation. Thirdly, there should be some measurements to minimise the bad effect from heavy rain during construction process.

Spacing

11,12								3	Open spacing for breeze penetration
2 -- 10								4	As 3, but protect from cold/hot wind
0,1							Y	5	Compact planning

Air movement

<table>
<tr><td>3 -- 12</td><td></td><td></td><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">6</td><td rowspan="2">Rooms single banked. Permanent provisionfor air movement</td></tr>
<tr><td rowspan="2">1,2</td><td rowspan="2"></td><td rowspan="2"></td><td>0 -- 5</td></tr>
<tr><td>6 -- 12</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="2">Y</td><td rowspan="2">7</td><td rowspan="2">Doublebanked rooms with temporary provision for air movement</td></tr>
<tr><td rowspan="2">0,0</td><td>2 -- 10</td><td></td><td></td></tr>
<tr><td>0,1</td><td></td><td></td><td></td><td>8</td><td>No air movement required</td></tr>
</table>

Openings

			0,0		0,0			9	Large openings, 40 - 80%
			11,12		0,1			10	Very small openings, 10 - 20 %
Any other conditions							Y	11	Medium openings, 20 - 40%

Walls

			0 -- 2					12	Light walls, short time lag
			3 -- 12				Y	13	Heavy internal and external walls

Roofs

			0 -- 5					14	Light insulated roofs
			6 -- 12				Y	15	Heavy roofs; over 8 hours' time lag

Outdoor sleeping

				2 -- 12				16	Space for outdoor sleeping required

Rain protection

		3 -- 12						17	Protection from heavy rain needed

LIST OF DETAILED RECOMMENDATIONS

Indicator from Table 2					
H1	H2	H3	A1	A2	A3
1			**11**	**1**	**4**

Size of opening

			0,1		0.0			1	Large 40- 80%
					1 -- 12			2	
			2 -- 5						Medium: 25 - 40%
			6 -- 10					3	Small: 15 - 25%
			11,12		0 -- 3			4	Very small: 10 - 20%
					4 -- 12		Y	5	Medium: 25 - 40%

Protection of opening

3 -- 12								6	In north and south walls at body height on windward side
1 -- 2			0 - 5						
			6 -- 12				Y	7	As above, opening also in internal walls
0.0	2 -- 12								

Protection of opening

					0 -- 2			8	Exclude direct sunlight
		2 -- 12						9	Provide protection from rain

Walls and floors

			0 -- 2					10	Light, low thermal capacity
			3 -- 12					11	Heavy, over 8 h time leg

Roofs

10 -- 12			0 -- 2					12	light, reflecting surface , cavity
			3 -- 12					13	Light, well insulated
0 -- 9			0 -- 5						
			6 -- 12				Y	14	Heavy, over 8 h time leg

External feature

				1 --12				15	Space for outdoor sleeping
		1 -- 12						16	Adequate rainwater drainage

Appendix C: Example files from HTB2

Example setting for Radiator Heating system simulation in HTB2

* Zone 1.

```
!HEATSYS '1_Main_Bedroom'
 !POWER OUTPUT = -1.0            *  Unlimited power output
 !SPLIT = 0.0, 0.0, 1.0          *  Direct output mode
 !DIRECT CONNECTIONS
    _#14 AT 0.002 = 1.0          * output to element #14 (radiator) at 0.002 m deep from
first surface
  }
!CLOCK START TIME #1 = 00:00:00 | mtwtf--  * Period heating, Monday to Friday
!CLOCK STOP TIME  #1 = 08:00:00 | mtwtf--
!CLOCK START TIME #1 = 18:00:00 | mtwtf--
!CLOCK STOP TIME  #1 = 24:00:00 | mtwtf--
!CLOCK START TIME #1 = 00:00:00 | -----ss    *24 Hours heating during weekend
!CLOCK STOP TIME  #1 = 24:00:00 | -----ss
!STAT TYPE PROPORTIONAL
!SETPOINT HEATING = 44.00           *  desired surface temperature, control temperature
                                    of first surface of element #14 at 44 degree C during
                                    the operation period
!DEADBAND = 1.0                     *  Must be associated with dead band and width
!BANDWIDTH = 2.0
!STAT COUPLING = 0.0  ,  0.0  ,  1.0
!STAT SURFACE CONNECTIONS
 _FIRST #14 = 1.0                  * Control surface temperature constant
  }
!END
```

* Zone 2.

```
!HEATSYS '2_Second_Bedroom'
 !POWER OUTPUT = 1.0
 !SPLIT = 0.0, 0.0, 1.0
 !DIRECT CONNECTIONS
    _#22 AT 0.002 = 1.0
     }
!CLOCK START TIME #1 = 00:00:00 | mtwtf--
!CLOCK STOP TIME  #1 = 08:00:00 | mtwtf--
!CLOCK START TIME #1 = 18:00:00 | mtwtf--
!CLOCK STOP TIME  #1 = 24:00:00 | mtwtf--
```

```
!CLOCK START TIME #1 = 00:00:00 | -----ss
!CLOCK STOP TIME   #1 = 24:00:00 | -----ss
!STAT TYPE PROPORTIONAL
!SETPOINT HEATING = 43.00
!DEADBAND = 1.0
!BANDWIDTH = 2.0
!STAT COUPLING = 0.0  ,  0.0  ,  1.0
!STAT SURFACE CONNECTIONS
 _FIRST #22 = 1.0
  }
!END

* Zone 3.

!HEATSYS '3_Living_Room'
 !POWER OUTPUT = 1.0
 !SPLIT = 0.0, 0.0, 1.0
 !DIRECT CONNECTIONS
     _#24 AT 0.002 = 1.0
 }
!CLOCK START TIME #1 = 00:00:00 | mtwtf--
!CLOCK STOP TIME   #1 = 24:00:00 | mtwtf--
!CLOCK START TIME #1 = 00:00:00 | -----ss
!CLOCK STOP TIME   #1 = 24:00:00 | -----ss
!STAT TYPE PROPORTIONAL
!SETPOINT HEATING = 43.00
!DEADBAND = 1.0 .
!BANDWIDTH = 2.0
!STAT COUPLING = 0.0  ,  0.0  ,  1.0
!STAT SURFACE CONNECTIONS
 _FIRST #24 = 1.0
  }
!END
```

Example setting of Heat Recovery system simulation in HTB2

```
!SMALL POWER 'COOKER'
!HEAT OUTPUT = 2290.0           * Heat emission from cooker is 2290 W
!INITIAL FRACTION = 1.0
!CONVECTIVE CONNECTIONS         * Space 1, 2, 3 (66% of heat gain split into two bedrooms
                                  and living room)
  _#1 = 0.22                    *22% goes to Main bedroom
  _#2 = 0.22                    *22% goes to Second bedroom
  _#3 = 0.22                    *22% goes to Living room
  _#5 = 0.34                    *34% stays in the kitchen
   }
!CLOCK START TIME #1 = 18:30:00 | mtwtf--   *Cooking system to be operating one hour each
                                              day
!CLOCK STOP TIME  #1 = 19:30:00 | mtwtf--
!CLOCK START TIME #1 = 18:30:00 | -----ss
!CLOCK STOP TIME  #1 = 19:30:00 | -----ss
!END


!SMALL POWER 'SHOWER'
!HEAT OUTPUT = 1200.0
!INITIAL FRACTION = 1.0
!CONVECTIVE  CONNECTIONS        * Space 1, 2, 3 (66% of heat gain splitted into two
                                  bedrooms and living room)
  _#1 = 0.22                    *22% goes to Main bedroom
  _#2 = 0.22                    *22% goes to Second bedroom
  _#3 = 0.22                    *22% goes to Living room
  _#4 = 0.34                    *34% stays in the kitchen
   }
!CLOCK START TIME #1 = 22:30:00 | mtwtf--   *Cooking system to be operating one hour each
                                              day

!CLOCK STOP TIME  #1 = 23:30:00 | mtwtf--
!CLOCK START TIME #1 = 22:30:00 | -----ss
!CLOCK STOP TIME  #1 = 23:30:00 | -----ss
!END
```

Input files in HTB2 model

The main input data files (including as built current condition, 1980's standard, modification package one and two) of case study two model were listed here as example.

Current Condition

Top level file:

!RUNID FullYear
* Setup run.
!ENABLE STANDARD SETUP
!ENABLE GROUND TEMP CALCS

!SET ORIENTATION = 5.0 *South facing, 5 degree to west
!SET GROUND FACTOR = 0.001
!SET AIR REFERENCE = 13.1
!SET GROUND TEMP = 13.1

!SET TIMESTEP = 20.0
!SET RUNLENGTH = 372,00
!SET DATE = 25/12/2000
!SET DAY = MONDAY

* Output files and data.
!OUTPUT INFO = '2nd Case As built.inf'
!OUTPUT BLOCK FILE = '2nd Case As built.blk'
!DEFINE BUILDING FILE = '2nd Case As built.bld'
!DEFINE SERVICES FILE = '2nd Case As built.srv'
!DEFINE DIARY FILE = '2nd Case As built.dyl'
!DEFINE METEOR FILE = 'Tianjin climate.met'

Building File:

* ECOTECT v5 -> HTB2 Exporter.
* DATE: Feb 21 18:47:49 2008

!PROJECTID [2nd Case]
!LOCATION = 39.90 116.40
!TIME ZONE = 120.00

* Zone 1.
!DEFINE SPACE = '1_Main_Bedroom'
!VOLUME = 58.05770
$POSITION X = 310 Y = 20

```
    $ICON = 305
!END

* Zone 2.
!DEFINE SPACE = '2_Second_Bedroom'
 !VOLUME = 33.91072
    $POSITION X = 610 Y = 20
    $ICON = 305
!END

* Zone 3.
!DEFINE SPACE = '3_Living_Room'
 !VOLUME = 76.62402
    $POSITION X = 910 Y = 20
    $ICON = 305
!END

* Zone 4.
!DEFINE SPACE = '4_wc'
 !VOLUME = 19.08191
    $POSITION X = 1210 Y = 20
    $ICON = 305
!END
* Zone 5.
!DEFINE SPACE = '5_Kitchen'
 !VOLUME = 46.59130
    $POSITION X = 1510 Y = 20
    $ICON = 305
!END

* Zone 6.
!DEFINE SPACE = '6_Storage'
 !VOLUME = 9.82372
    $POSITION X = 1810 Y = 20
    $ICON = 305
!END

* Zone 7.
!DEFINE SPACE = '7_Balcony'
 !VOLUME = 22.45472
    $POSITION X = 1510 Y = 20
    $ICON = 305
!END

* Zone 8.
!DEFINE SPACE = '8_Corridor'
 !VOLUME = 24.24594
    $POSITION X = 2410 Y = 20
    $ICON = 305
!END

* Zone 9.
!DEFINE SPACE = 'Flat_E_room1'
 !VOLUME = 41.96032
    $POSITION X = 2710 Y = 20
    $ICON = 305
!END

* Zone 10.
!DEFINE SPACE = 'Flat_E_room_2'
 !VOLUME = 28.72755
    $POSITION X = 3010 Y = 20
    $ICON = 305
!END

* Zone 11.
!DEFINE SPACE = 'Flat_E_room_3'
 !VOLUME = 42.97375
    $POSITION X = 3310 Y = 20
    $ICON = 305
!END

* Zone 12.
!DEFINE SPACE = 'Flat_E_room_4'
 !VOLUME = 36.32804
    $POSITION X = 3610 Y = 20
    $ICON = 305
!END

* Zone 13.
!DEFINE SPACE = 'Flat_E_room_5'
 !VOLUME = 107.69601
    $POSITION X = 3910 Y = 20
    $ICON = 305
!END

* Zone 14.
!DEFINE SPACE = 'Stairs_and_elevators'
```

```
 !VOLUME = 189.52464
   $POSITION X = 4210 Y = 20
   $ICON = 305
!END

* Zone 15.
!DEFINE SPACE = 'Flat_G_room__1_'
 !VOLUME = 44.75891
   $POSITION X = 4510 Y = 20
   $ICON = 305
!END

* Zone 16.
!DEFINE SPACE = 'Flat_G_room__2_'
 !VOLUME = 86.96648
   $POSITION X = 4810 Y = 20
   $ICON = 305
!END

* Zone 17.
!DEFINE SPACE = 'Flat_G_room__3_'
 !VOLUME = 31.06800
   $POSITION X = 5110 Y = 20
   $ICON = 305
!END

* Zone 18.
!DEFINE SPACE = 'Flat_G_room__4_'
 !VOLUME = 52.96951
   $POSITION X = 5410 Y = 20
   $ICON = 305
!END

* Zone 19.
!DEFINE SPACE = 'Flat_G_room__5_'
 !VOLUME = 47.31203
   $POSITION X = 5710 Y = 20
   $ICON = 305
!END

* Zone 20.
!DEFINE SPACE = 'Flat_G_room__6_'
 !VOLUME = 45.13124
   $POSITION X = 6010 Y = 20
   $ICON = 305
!END

* Zone 21.
!DEFINE SPACE = 'Flat_D_room__1_'
 !VOLUME = 50.85834
   $POSITION X = 6310 Y = 20
   $ICON = 305
!END

* Zone 22.
!DEFINE SPACE = 'Flat_D_room__2_'
 !VOLUME = 18.16529
   $POSITION X = 6610 Y = 20
   $ICON = 305
!END

* Zone 23.
!DEFINE SPACE = 'Flat_D_room__3_'
 !VOLUME = 66.57079
   $POSITION X = 6910 Y = 20
   $ICON = 305
!END

* Zone 24.
!DEFINE SPACE = 'Flat_D_room__4_'
 !VOLUME = 92.49884
   $POSITION X = 7210 Y = 20
   $ICON = 305
!END

* Zone 25.
!DEFINE SPACE = 'Flat_D_room__5_'
 !VOLUME = 40.69030
   $POSITION X = 7510 Y = 20
   $ICON = 305
!END

* Zone 26.
!DEFINE SPACE = 'Flat_D_room__6_'
 !VOLUME = 17.63743
   $POSITION X = 7810 Y = 20
   $ICON = 305
!END
```

```
* Zone 27.
!DEFINE SPACE = 'Flat_D_room__7_'
 !VOLUME = 32.15887
   $POSITION X = 8110 Y = 20
   $ICON = 305
!END

* Zone 28.
!DEFINE SPACE = 'Flat_C_room__1_'
 !VOLUME = 21.24607
   $POSITION X = 8410 Y = 20
   $ICON = 305
!END

* Zone 29.
!DEFINE SPACE = 'Flat_C_room__2_'
 !VOLUME = 100.32062
   $POSITION X = 8710 Y = 20
   $ICON = 305
!END

* Zone 30.
!DEFINE SPACE = 'Flat_C_room__3_'
 !VOLUME = 36.92105
   $POSITION X = 9010 Y = 20
   $ICON = 305
!END

* Zone 31.
!DEFINE SPACE = 'Flat_C_room__4_'
 !VOLUME = 100.96465
   $POSITION X = 9310 Y = 20
   $ICON = 305
!END

* Zone 32.
!DEFINE SPACE = 'Flat_B_room__1_'
 !VOLUME = 72.60520
   $POSITION X = 9610 Y = 20
   $ICON = 305
!END

* Zone 33.
!DEFINE SPACE = 'Flat_B_room__2_'
 !VOLUME = 50.51689
   $POSITION X = 9910 Y = 20
   $ICON = 305
!END

* Zone 34.
!DEFINE SPACE = 'Flat_B_room__3_'
 !VOLUME = 28.83236
   $POSITION X = 10210 Y = 20
   $ICON = 305
!END

* Zone 35.
!DEFINE SPACE = 'Flat_B_room__4_'
 !VOLUME = 114.66293
   $POSITION X = 10510 Y = 20
   $ICON = 305
!END

* Zone 36.
!DEFINE SPACE = 'Flat_B_room__5_'
 !VOLUME = 34.62215
   $POSITION X = 10810 Y = 20
   $ICON = 305
!END

* Zone 37.
!DEFINE SPACE = 'Flat_B_room__6_'
 !VOLUME = 37.52672
   $POSITION X = 11110 Y = 20
   $ICON = 305
!END
```

```
!MATERIALS FILE    = 'stdmat.lby'
!MATERIALS USER FILE = '2nd Case 1980s.lby'
!CONSTRUCTION FILE = '2nd Case 1980s.con'
!LAYOUT FILE = '2nd Case 1980s.lay'

!EOF
```

Construction File:

```
* ECOTECT v5 -> HTB2 Exporter.

* Material 1.
!CONSTRUCTION 'HollowCore_Plywood'
!TYPE OPAQUE
!PARTS
_ 1 = @1   0.003   0   * Plywood
_ 2 = -1   0.034   0   * Air Gap
_ 3 = @3   0.003   0   * Plywood
}
!END

* Material 2.
!CONSTRUCTION '_Case_2_External_wall'
!TYPE OPAQUE
!PARTS
_ 1 = @4   0.025   0   * Polystyrene
_ 2 = @5   0.200   0   * Concrete
_ 3 = @6   0.005   0   * Concrete Screed
_ 4 = @7   0.010   0   * Plasterboard
}
!END

* Material 3.
!CONSTRUCTION '_Case_2_DoubleGlazed_AlumFrame'
!TYPE TRANSPARENT * U value = 2.7
!PARTS
_ 1 = @8   0.006   0 0.00   * Glass Standard
_ 2 = -3   0.000179   0 0.00   * Air Gap
_ 3 = @10   0.006   0 0.00   * Glass Standard
}
!END

* Material 4.
!CONSTRUCTION '_Case_2_Normal_Internal_Wall_'
```

```
!TYPE OPAQUE
!PARTS
_ 1 = @11   0.010   0   * Plaster Building (Molded Dry)
_ 2 = @12   0.120   0   * Brick, Mediumweight
_ 3 = @13   0.010   0   * Plaster Building (Molded Dry)
}
!END

* Material 5.
!CONSTRUCTION '_Case_2_Unheated_Internal_Wall_'
!TYPE OPAQUE
!PARTS
_ 1 = @14   0.010   0   * Plasterboard
_ 2 = @15   0.120   0   * Brick, Mediumweight
_ 3 = @16   0.010   0   * Plasterboard
}
!END

* Material 6.
!CONSTRUCTION '_Case_2_Foor'
!TYPE OPAQUE
!PARTS
_ 1 = @18   0.010   0   * Plaster Board
_ 2 = @19   0.100   0   * Concrete
_ 3 = @20   0.005   0   * Concrete Screed
_ 4 = @21   0.025   0   * Wood Oak Red Black (Across Grains
}
!END

* Material 7.
!CONSTRUCTION '_Case_2_Ceiling'
!TYPE OPAQUE
!PARTS
_ 1 = @22   0.025   0   * Wood Oak Red Black (Across Grains
_ 2 = @23   0.005   0   * Concrete
_ 3 = @24   0.100   0   * Concrete Cinder
_ 4 = @25   0.010   0   * Plasterboard
}
!END

!WINDOW = 'Double Glazing'
!TRANSMISSION =
 0.49, 0.64, 0.64, 0.64, 0.64, 0.61, 0.57, 0.50, 0.36, 0.16, 0.0
!ABSORPTION =
```

0.24, 0.24, 0.24, 0.24, 0.24, 0.24, 0.26, 0.27, 0.29, 0.27, 0.0
!END

Layout File:
There are more than 300 elements in the whole model, only the elements in the Bedrooms and living rooms of case study flat were listed.

```
* ECOTECT v5 -> HTB2 Exporter.
* Externally Exposed Surfaces.

* Objects From Zone 1.

* ECOTECT v5 -> HTB2 Exporter.

* Externally Exposed Surfaces.

* Objects From Zone 1.

* Element 1.
!ELEMENT = 'Wall005'
 !CONSTRUCTION      =      2           *
_Case_2_Extenal_wall
 !AREA = 1.62
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210   Y = 20
   $ICON = 306
   $EXTERNALPOS X = 310   Y = 260
!END

* Element 2.
!ELEMENT = 'Wall006'
 !CONSTRUCTION      =      2           *
_Case_2_Extenal_wall
 !AREA = 0.18
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210   Y = 80
   $ICON = 306
   $EXTERNALPOS X = 310   Y = 260
!END

* Element 3.
!ELEMENT = 'Wall007'
 !CONSTRUCTION      =      2           *
_Case_2_Extenal_wall
 !AREA = 0.22
 !ORIENTATION = 0.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210   Y = 140
   $ICON = 306
   $EXTERNALPOS X = 310   Y = 260
!END

* Element 4.
!ELEMENT = 'Wall008'
 !CONSTRUCTION      =      2           *
_Case_2_Extenal_wall
 !AREA = 1.24
 !ORIENTATION = 270.0
 !TILT = 0.0
```

```
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210    Y = 200
   $ICON = 306
   $EXTERNALPOS X = 310    Y = 260
!END

* Element 5.
!ELEMENT = 'Wall042'
 !CONSTRUCTION      =      2          *
_Case_2_Extenal_wall
 !AREA = 2.70
 !ORIENTATION = 90.0
 !TILT = 90.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210    Y = 260
   $ICON = 306
   $EXTERNALPOS X = 310    Y = 260
!END

* Element 6.
!ELEMENT = 'Wall043'
 !CONSTRUCTION      =      2          *
_Case_2_Extenal_wall
 !AREA = 2.70
 !ORIENTATION = 90.0
 !TILT = -90.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210    Y = 320
   $ICON = 306
   $EXTERNALPOS X = 310    Y = 260
!END

* Element 7.
!ELEMENT = 'Wall044'
 !CONSTRUCTION      =      2          *
_Case_2_Extenal_wall
 !AREA = 0.90
 !ORIENTATION = 0.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210    Y = 380
   $ICON = 306
   $EXTERNALPOS X = 310    Y = 260
!END

* Element 8.
!ELEMENT = 'Wall045'
 !CONSTRUCTION      =      2          *
_Case_2_Extenal_wall
 !AREA = 0.57
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 210    Y = 440
   $ICON = 306
   $EXTERNALPOS X = 310    Y = 260
!END

* Element 9.
!ELEMENT = 'Wall046'
 !CONSTRUCTION      =      2          *
_Case_2_Extenal_wall
 !AREA = 0.90
```

!ORIENTATION = 0.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.60
!ABSORPTION LAST = 0.60
!CLASS = 4
$POSITION X = 210 Y = 500
$ICON = 306
$EXTERNALPOS X = 310 Y = 260
!END

* Element 10.
!ELEMENT = 'Wall047'
!CONSTRUCTION = 2 * _Case_2_Extenal_wall
!AREA = 0.57
!ORIENTATION = 90.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.60
!ABSORPTION LAST = 0.60
!CLASS = 4
$POSITION X = 210 Y = 560
$ICON = 306
$EXTERNALPOS X = 310 Y = 260
!END

* Element 11.
!ELEMENT = 'Wall114'
!CONSTRUCTION = 2 * _Case_2_Extenal_wall
!AREA = 7.68
!ORIENTATION = 90.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.60
!ABSORPTION LAST = 0.60
!CLASS = 4
$POSITION X = 210 Y = 620
$ICON = 306
$EXTERNALPOS X = 310 Y = 260
!END

* Element 12.
!ELEMENT = 'Wall115'
!CONSTRUCTION = 2 * _Case_2_Extenal_wall
!AREA = 5.22
!ORIENTATION = 180.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.60
!ABSORPTION LAST = 0.60
!CLASS = 4
$POSITION X = 210 Y = 680
$ICON = 306
$EXTERNALPOS X = 310 Y = 260
!END

* Element 13.
!ELEMENT = 'Wall121'
!CONSTRUCTION = 2 * _Case_2_Extenal_wall
!AREA = 3.77
!ORIENTATION = 0.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.60
!ABSORPTION LAST = 0.60
!CLASS = 4
$POSITION X = 210 Y = 740
$ICON = 306
$EXTERNALPOS X = 310 Y = 260
!END

* Objects From Zone 2.

* Element 14.

```
!ELEMENT = 'Wall029'
 !CONSTRUCTION = 2 *
_Case_2_Extenal_wall
 !AREA = 3.81
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 20
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 15.
!ELEMENT = 'Wall030'
 !CONSTRUCTION = 2 *
_Case_2_Extenal_wall
 !AREA = 0.13
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 80
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 16.
!ELEMENT = 'Wall031'
 !CONSTRUCTION = 2 *
_Case_2_Extenal_wall
 !AREA = 0.17
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 140
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 17.
!ELEMENT = 'Wall032'
 !CONSTRUCTION = 2 *
_Case_2_Extenal_wall
 !AREA = 1.62
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 200
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 18.
!ELEMENT = 'Wall036'
 !CONSTRUCTION = 2 *
_Case_2_Extenal_wall
 !AREA = 0.80
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 260
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END
```

```
* Element 19.
!ELEMENT = 'Wall037'
 !CONSTRUCTION      =      2      *
_Case_2_Extenal_wall
 !AREA = 1.36
 !ORIENTATION = 180.0
 !TILT = 90.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 320
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 20.
!ELEMENT = 'Wall038'
 !CONSTRUCTION      =      2      *
_Case_2_Extenal_wall
 !AREA = 1.36
 !ORIENTATION = 180.0
 !TILT = -90.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 380
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 21.
!ELEMENT = 'Wall039'
 !CONSTRUCTION      =      2      *
_Case_2_Extenal_wall
 !AREA = 0.80
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.60
 !ABSORPTION LAST = 0.60
 !CLASS = 4
   $POSITION X = 510   Y = 440
   $ICON = 306
   $EXTERNALPOS X = 610   Y = 260
!END

* Objects From Zone 3.

* Element 22.
!ELEMENT = 'Wall024'
 !CONSTRUCTION            =            4
*Normal_Internal_Wall_
 !AREA = 1.59
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 810   Y = 20
   $ICON = 306
   $EXTERNALPOS X = 910   Y = 260
!END

* InterZonal/Underground Surfaces.

* Objects From Zone 1.

* Element 62.
!ELEMENT = 'Wall009'
 !CONSTRUCTION            =            4
*_Case_2_Normal_Internal_Wall_
 !AREA = 9.13
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 3
```

```
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 409   Y = 20
   $ICON = 306
!END

* Element 63.
!ELEMENT = 'Floor040'
 !CONSTRUCTION = 6   * _Case1_3_Foor
 !AREA = 18.24
 !ORIENTATION = 90.0
 !TILT = -90.0
 !SPACE TO FIRST = 9
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.58
 !ABSORPTION LAST = 0.58
 !CLASS = 2
   $POSITION X = 409   Y = 80
   $ICON = 309
!END

* Element 64.
!ELEMENT = 'Ceil041'
 !CONSTRUCTION = 6   * _Case1_3_Foor
 !AREA = 18.24
 !ORIENTATION = 90.0
 !TILT = 90.0
 !SPACE TO FIRST = 8
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.58
 !ABSORPTION LAST = 0.58
 !CLASS = 3
   $POSITION X = 409   Y = 140
   $ICON = 309
!END

* Element 65.
!ELEMENT = 'Door055'
 !CONSTRUCTION      =      1            *
HollowCore_Plywood
 !AREA = 1.89
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 3
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.24
 !ABSORPTION LAST = 0.24
 !CLASS = 8
   $POSITION X = 409   Y = 200
   $ICON = 306
!END

* Element 66.
!ELEMENT = 'Wall113'
 !CONSTRUCTION              =             4
*_Case_2_Normal_Internal_Wall_
 !AREA = 4.93
 !ORIENTATION = 0.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 5
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 409   Y = 260
   $ICON = 306
!END

* Element 67.
!ELEMENT = 'Wall122'
 !CONSTRUCTION              =             4
*_Case_2_Normal_Internal_Wall_
 !AREA = 8.70
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 2
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 409   Y = 320
   $ICON = 306
!END
```

```
* Objects From Zone 2.

* Element 68.
!ELEMENT = 'Wall027'
 !CONSTRUCTION = 4
*_Case_2_Normal_Internal_Wall_
 !AREA = 5.70
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 6
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 709   Y = 20
   $ICON = 306
!END

* Element 69.
!ELEMENT = 'Wall027'
 !CONSTRUCTION = 4
*_Case_2_Normal_Internal_Wall_
 !AREA = 2.85
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 3
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 709   Y = 80
   $ICON = 306
!END

* Element 70.
!ELEMENT = 'Wall028'
 !CONSTRUCTION = 4
*_Case_2_Normal_Internal_Wall_
 !AREA = 8.70
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 7
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 709   Y = 140
   $ICON = 306
!END

* Element 71.
!ELEMENT = 'Ceil034'
 !CONSTRUCTION = 6   *_Case_2_Foor
 !AREA = 10.80
 !ORIENTATION = 180.0
 !TILT = 90.0
 !SPACE TO FIRST = 8
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.58
 !ABSORPTION LAST = 0.58
 !CLASS = 3
   $POSITION X = 709   Y = 200
   $ICON = 309
!END

* Element 72.
!ELEMENT = 'Floor035'
 !CONSTRUCTION = 6   *_Case_2_Foor
 !AREA = 10.80
 !ORIENTATION = 180.0
 !TILT = -90.0
 !SPACE TO FIRST = 9
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.58
 !ABSORPTION LAST = 0.58
 !CLASS = 2
   $POSITION X = 709   Y = 260
   $ICON = 309
!END

* Element 73.
!ELEMENT = 'Door056'
 !CONSTRUCTION = 1   *
HollowCore_Plywood
```

!AREA = 1.89
!ORIENTATION = 270.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 3
!SPACE TO LAST = 2
!ABSORPTION FIRST = 0.24
!ABSORPTION LAST = 0.24
!CLASS = 8
$POSITION X = 709 Y = 320
$ICON = 306
!END

* Element 74.
!ELEMENT = 'Wall124'
!CONSTRUCTION = 4
*_Case_2_Normal_Internal_Wall_
!AREA = 1.99
!ORIENTATION = 270.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 7
!SPACE TO LAST = 2
!ABSORPTION FIRST = 0.42
!ABSORPTION LAST = 0.42
!CLASS = 4
$POSITION X = 709 Y = 380
$ICON = 306
!END

* Objects From Zone 3.

* Element 75.
!ELEMENT = 'Floor018'
!CONSTRUCTION = 6 *_Case_2_Foor
!AREA = 26.36
!ORIENTATION = 0.0
!TILT = -90.0
!SPACE TO FIRST = 9
!SPACE TO LAST = 3
!ABSORPTION FIRST = 0.58
!ABSORPTION LAST = 0.58
!CLASS = 2
$POSITION X = 1009 Y = 20
$ICON = 309
!END

* Element 76.
!ELEMENT = 'Wall019'
!CONSTRUCTION = 5
*_Case_2_Unheated_Internal_Wall_
!AREA = 15.23
!ORIENTATION = 270.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 7
!SPACE TO LAST = 3
!ABSORPTION FIRST = 0.53
!ABSORPTION LAST = 0.53
!CLASS = 4
$POSITION X = 1009 Y = 80
$ICON = 306
!END

* Element 77.
!ELEMENT = 'Wall020'
!CONSTRUCTION = 4
*_Case_2_Unheated_Internal_Wall_
!AREA = 8.74
!ORIENTATION = 0.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 5
!SPACE TO LAST = 3
!ABSORPTION FIRST = 0.42
!ABSORPTION LAST = 0.42
!CLASS = 4
$POSITION X = 1009 Y = 140
$ICON = 306
!END

* Element 78.
!ELEMENT = 'Wall021'
!CONSTRUCTION = 4
*_Case_2_Normal_Internal_Wall_
!AREA = 3.95
!ORIENTATION = 90.0
!TILT = 0.0

```
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 5
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 1009    Y = 200
   $ICON = 306
!END

* Element 79.
!ELEMENT = 'Wall023'
 !CONSTRUCTION          =          4
*_Case_2_Normal_Internal_Wall_
 !AREA = 3.77
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 6
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 1009    Y = 260
   $ICON = 306
!END

* Element 80.
!ELEMENT = 'Wall025'
 !CONSTRUCTION          =          4
*_Case_2_Unheated_Internal_Wall_
 !AREA = 8.12
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 4
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.42
 !ABSORPTION LAST = 0.42
 !CLASS = 4
   $POSITION X = 1009    Y = 320
   $ICON = 306
!END

* Element 81.
!ELEMENT = 'Ceil026'
 !CONSTRUCTION = 6   *_Case_2_Foor
 !AREA = 26.36
 !ORIENTATION = 0.0
 !TILT = 90.0
 !SPACE TO FIRST = 8
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.58
 !ABSORPTION LAST = 0.58
 !CLASS = 3
   $POSITION X = 1009    Y = 380
   $ICON = 309
!END

* Element 82.
!ELEMENT = 'Door057'
 !CONSTRUCTION      =     1          *
HollowCore_Plywood
 !AREA = 2.31
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 7
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.24
 !ABSORPTION LAST = 0.24
 !CLASS = 8
   $POSITION X = 1009    Y = 440
   $ICON = 306
!END

* Element 83.
!ELEMENT = 'Door116'
 !CONSTRUCTION      =     1          *
HollowCore_Plywood
 !AREA = 3.15
 !ORIENTATION = 0.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 5
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.24
 !ABSORPTION LAST = 0.24
```

```
 !CLASS = 8
   $POSITION X = 1009   Y = 500
   $ICON = 306
!END

* Element 84.
!ELEMENT = 'Door118'
 !CONSTRUCTION = 1 * HollowCore_Plywood
 !AREA = 1.89
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 4
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.24
 !ABSORPTION LAST = 0.24
 !CLASS = 8
   $POSITION X = 1009   Y = 560
   $ICON = 306
!END

* Element 85.
!ELEMENT = 'Door123'
 !CONSTRUCTION = 1 * HollowCore_Plywood
 !AREA = 3.15
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 5
 !SPACE TO LAST = 3
 !ABSORPTION FIRST = 0.24
 !ABSORPTION LAST = 0.24
 !CLASS = 8
   $POSITION X = 1009   Y = 620
   $ICON = 306
!END

* Window definitions.

* Element 101.
!ELEMENT = 'Win048'
 !CONSTRUCTION = 3 *_Case_2_DoubleGlazed_AlumFrame
 !AREA = 4.81
 !ORIENTATION = 0.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0048'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #63 LAST = 1.00
 !CLASS = 6
   $POSITION X = 210   Y = 800
   $ICON = 307
   $EXTERNALPOS X = 310   Y = 260
!END

* Element 102.
!ELEMENT = 'Win049'
 !CONSTRUCTION = 3 *_Case_2_DoubleGlazed_AlumFrame
 !AREA = 3.24
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 1
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0049'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #63 LAST = 1.00
 !CLASS = 6
   $POSITION X = 210   Y = 860
   $ICON = 307
   $EXTERNALPOS X = 310   Y = 260
!END

* Element 103.
```

```
!ELEMENT = 'Win050'
 !CONSTRUCTION            =           3
*_Case_2_DoubleGlazed_AlumFrame
 !AREA = 2.87
 !ORIENTATION = 90.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0050'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #72 LAST = 1.00
 !CLASS = 6
   $POSITION X = 510   Y = 500
   $ICON = 307
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 104.
!ELEMENT = 'Win051'
 !CONSTRUCTION            =           3
*_Case_2_DoubleGlazed_AlumFrame
 !AREA = 1.48
 !ORIENTATION = 180.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 2
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0051'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #72 LAST = 1.00
 !CLASS = 6
   $POSITION X = 510   Y = 560
   $ICON = 307
   $EXTERNALPOS X = 610   Y = 260
!END

* Element 105.
!ELEMENT = 'Win052'
 !CONSTRUCTION            =           3
*_Case_2_DoubleGlazed_AlumFrame
 !AREA = 2.55
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 5
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0052'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #91 LAST = 1.00
 !CLASS = 6
   $POSITION X = 1410   Y = 80
   $ICON = 307
   $EXTERNALPOS X = 1510   Y = 260
!END

* Element 106.
!ELEMENT = 'Win058'
 !CONSTRUCTION            =           3
*_Case_2_DoubleGlazed_AlumFrame
 !AREA = 4.25
 !ORIENTATION = 270.0
 !TILT = 0.0
 !GROUND REFL = 0.2
 !SPACE TO FIRST = 0
 !SPACE TO LAST = 5
 !ABSORPTION FIRST = 0.19
 !ABSORPTION LAST = 0.19
 !EMISSIVITY FIRST = 0.00
 !EMISSIVITY LAST = 0.00
 !SHADING = 'Win0058'
 !WINDOW TYPE = 'Double Glazing'
 !PATCH TO #91 LAST = 1.00
 !CLASS = 6
   $POSITION X = 1410   Y = 140
   $ICON = 307
```

$EXTERNALPOS X = 1510   Y = 260
!END   !EOF

1980's Standard

Top level file:

!RUNID FullYear

* Setup run.
!ENABLE STANDARD SETUP
!ENABLE GROUND TEMP CALCS

!SET ORIENTATION = 5.0   *South facing, 5 degree to west
!SET GROUND FACTOR = 0.001
!SET AIR REFERENCE = 13.1
!SET GROUND TEMP = 13.1

!SET TIMESTEP = 20.0
!SET RUNLENGTH = 372,00
!SET DATE = 25/12/2000
!SET DAY = MONDAY

* Output files and data.
!OUTPUT INFO = '2nd Case 1980s.inf'
!OUTPUT BLOCK FILE = '2nd Case 1980s.blk'
!DEFINE BUILDING FILE = '2nd Case 1980s.bld'
!DEFINE SERVICES FILE = '2nd Case 1980s.srv'
!DEFINE DIARY FILE = '2nd Case 1980s.dyl'
!DEFINE METEOR FILE = 'Tianjin climate.met'

Building File:
All the zone information and geometry are same with model of Current condition

Construction File:
* ECOTECT v5 -> HTB2 Exporter.

* Material 1.
!CONSTRUCTION '_1980_Foor'
!TYPE OPAQUE
!PARTS
_ 1 = @2   0.100   0   * Concrete
_ 2 = @3   0.005   0   * Concrete Screed
}

```
!END

* Material 2.
!CONSTRUCTION 'HollowCore_Plywood'
!TYPE OPAQUE
!PARTS
_1 = @5    0.003    0    * Plywood
_2 = -1    0.034    0    * Air Gap
_3 = @7    0.003    0    * Plywood
}
!END

* Material 3.
!CONSTRUCTION '_1980_External_Wall'
!TYPE OPAQUE
!PARTS
_1 = @9    0.360    0    * Brick
_2 = @10   0.010    0    * Plaster Building (Molded Dry)
}
!END

* Material 4.
!CONSTRUCTION '_1980_Internal_Wall'
!TYPE OPAQUE
!PARTS
_1 = @12   0.120    0    * Brick
_2 = @13   0.010    0    * Plaster Building (Molded Dry)
}
!END

* Material 5.
!CONSTRUCTION '_Ceiling_1980'
!TYPE OPAQUE
_1 = @15   0.005    0    * Concrete Screed
_2 = @16   0.100    0    * Concrete
}
!END

* Material 6.
!CONSTRUCTION '_1980_SingleGlazed_AlumFrame'
!TYPE TRANSPARENT * U value = 6.4
!PARTS
_1 = @18   0.006    0 0.00    * Glass Standard
}
```

!END

!WINDOW = '6MMFLOAT'
!TRANSMISSION =
0.64 , 0.80 , 0.80 , 0.80, 0.80, 0.78, 0.75, 0.71, 0.60, 0.36, 0.0
!ABSORPTION =
0.134 , 0.12, 0.12, 0.12, 0.12, 0.14, 0.14, 0.14, 0.14, 0.15, 0.15
!END

!EOF

Layout File:
All the zone information and geometry are same with model of Current condition

Modification Package 1

Top level file:

!RUNID FullYear

* Setup run.
!ENABLE STANDARD SETUP
!ENABLE GROUND TEMP CALCS

!SET ORIENTATION = 5.0 *South facing, 5 degree to west
!SET GROUND FACTOR = 0.001
!SET AIR REFERENCE = 13.1
!SET GROUND TEMP = 13.1

!SET TIMESTEP = 60.0
!SET RUNLENGTH = 372,00
!SET DATE = 25/12/2000
!SET DAY = MONDAY

* Output files and data.
!OUTPUT INFO = '2nd Case Package 1.inf'
!OUTPUT BLOCK FILE = '2nd Case Package 1.blk'
!DEFINE BUILDING FILE = '2nd Case Package 1.bld'
!DEFINE SERVICES FILE = '2nd Case Package 1.srv'
!DEFINE DIARY FILE = '2nd Case Package 1.dyl'
!DEFINE METEOR FILE = 'Tianjin climate.met'

Building File:
All the zone information and geometry are same with model of Current condition

Construction File:

```
* ECOTECT v5 -> HTB2 Exporter.

* Material 1.
!CONSTRUCTION 'HollowCore_Plywood'
!TYPE OPAQUE
!PARTS
_ 1 = @1    0.003    0    * Plywood
_ 2 = -1    0.034    0    * Air Gap
_ 3 = @3    0.003    0    * Plywood
}
!END

* Material 2.
!CONSTRUCTION 'Pack 1_Case_2_External_wall'
!TYPE OPAQUE
!PARTS
_ 1 = @4    0.050    0    * Polystyrene
_ 2 = @5    0.200    0    * Concrete
_ 3 = @6    0.005    0    * Concrete Screed
_ 4 = @7    0.010    0    * Plasterboard
}
!END

* Material 3.
!CONSTRUCTION 'Pack 1_Case_2_DoubleGlazed_AlumFrame'
!TYPE TRANSPARENT * U value = 2.7
!PARTS
_ 1 = @8    0.006    0 0.00    * Glass Standard
_ 2 = -3    0.000179    0 0.00    * Air Gap
_ 3 = @10    0.006    0 0.00    * Glass Standard
}
!END

* Material 4.
!CONSTRUCTION 'Pack 1_Case_2_Normal_Internal_Wall_'
!TYPE OPAQUE
!PARTS
_ 1 = @11    0.010    0    * Plaster Building (Molded Dry)
_ 2 = @12    0.120    0    * Brick, Medium weight
_ 3 = @13    0.010    0    * Plaster Building (Molded Dry)
}
!END
```

```
* Material 5.
!CONSTRUCTION 'Pack 1_Case_2_Unheated_Internal_Wall_'
!TYPE OPAQUE
!PARTS
_1 = @4   0.050  0   * Polystyrene
_2 = @5   0.200  0   * Concrete
_3 = @6   0.005  0   * Concrete Screed
_4 = @7   0.010  0   * Plasterboard
}
!END

* Material 6.
!CONSTRUCTION 'Pack 1_Case_2_Foor'
!TYPE OPAQUE
!PARTS
_1 = @18   0.010  0   * Plaster Board
_2 = @19   0.100  0   * Concrete
_3 = @20   0.005  0   * Concrete Screed
_4 = @21   0.025  0   * Wood Oak Red Black (Across Grains
}
!END

* Material 7.
!CONSTRUCTION 'Pack 1_Case_2_Ceiling'
!TYPE OPAQUE
!PARTS
_1 = @22   0.025  0   * Wood Oak Red Black (Across Grains
_2 = @23   0.005  0   * Concrete Screed
_3 = @24   0.100  0   * Concrete Cinder
_4 = @25   0.010  0   * Plasterboard
}
!END

!WINDOW = 'Double Glazing'
!TRANSMISSION =
 0.49, 0.64, 0.64, 0.64, 0.64, 0.61, 0.57, 0.50, 0.36, 0.16, 0.0
!ABSORPTION =
 0.24, 0.24, 0.24, 0.24, 0.24, 0.24, 0.26, 0.27, 0.29, 0.27, 0.0
!END

!EOF
```

Layout File:

All the zone information and geometry are same with model of Current condition, except the window size as they were reduced to meet the regulation

* Window definitions.

* Element 101.
!ELEMENT = 'Win048'
!CONSTRUCTION = 3 * Pack 1_Case_2_DoubleGlazed_AlumFrame
!AREA = 2.80
!ORIENTATION = 0.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.19
!ABSORPTION LAST = 0.19
!EMISSIVITY FIRST = 0.00
!EMISSIVITY LAST = 0.00
!SHADING = 'Win0048'
!WINDOW TYPE = 'Double Glazing'
!PATCH TO #63 LAST = 1.00
!CLASS = 6
$POSITION X = 210 Y = 800
$ICON = 307
$EXTERNALPOS X = 310 Y = 260
!END

* Element 102.
!ELEMENT = 'Win049'
!CONSTRUCTION = 3 * Pack 1_Case_2_DoubleGlazed_AlumFrame
!AREA = 1.48
!ORIENTATION = 90.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.19
!ABSORPTION LAST = 0.19
!EMISSIVITY FIRST = 0.00
!EMISSIVITY LAST = 0.00
!SHADING = 'Win0049'
!WINDOW TYPE = Double Glazing
!PATCH TO #63 LAST = 1.00
!CLASS = 6
$POSITION X = 210 Y = 860
$ICON = 307
$EXTERNALPOS X = 310 Y = 260
!END

* Element 103.
!ELEMENT = 'Win122'
!CONSTRUCTION = 3 * Pack 1_Case_2_DoubleGlazed_AlumFrame
!AREA = 1.63
!ORIENTATION = 90.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 2
!ABSORPTION FIRST = 0.19
!ABSORPTION LAST = 0.19
!EMISSIVITY FIRST = 0.00
!EMISSIVITY LAST = 0.00
!SHADING = 'Win0122'
!WINDOW TYPE = Double Glazing
!PATCH TO #72 LAST = 1.00
!CLASS = 6
$POSITION X = 510 Y = 500
$ICON = 307
$EXTERNALPOS X = 610 Y = 260
!END

* Element 104.
!ELEMENT = 'Win050'
!CONSTRUCTION = 3 * Pack 1_Case_2_DoubleGlazed_AlumFrame
!AREA = 2.55
!ORIENTATION = 270.0
!TILT = 0.0
!GROUND REFL = 0.2
!SPACE TO FIRST = 0
!SPACE TO LAST = 5

```
!ABSORPTION FIRST = 0.19
!ABSORPTION LAST = 0.19
!EMISSIVITY FIRST = 0.00
!EMISSIVITY LAST = 0.00
!SHADING = 'Win0050'
!WINDOW TYPE = Double Glazing
!PATCH TO #91 LAST = 1.00

!CLASS = 6
  $POSITION X = 1410   Y = 80
  $ICON = 307
  $EXTERNALPOS X = 1510   Y = 260
!END

!EOF
```

Modification Package 2

Top level file:

```
!RUNID FullYear

* Setup run.
!ENABLE STANDARD SETUP
!ENABLE GROUND TEMP CALCS

!SET ORIENTATION = 5.0        *South facing, 5 degree to west
!SET GROUND FACTOR = 0.001
!SET AIR REFERENCE = 13.1
!SET GROUND TEMP = 13.1

!SET TIMESTEP = 60.0
!SET RUNLENGTH = 372,00
!SET DATE = 25/12/2000
!SET DAY = MONDAY

* Output files and data.
!OUTPUT INFO = '2nd Case Package 2.inf'
!OUTPUT BLOCK FILE = '2nd Case Package 2.blk'
!DEFINE BUILDING FILE = '2nd Case Package 2.bld'
!DEFINE SERVICES FILE = '2nd Case Package 2.srv'
!DEFINE DIARY FILE = '2nd Case Package 2.dyl'
!DEFINE METEOR FILE = 'Tianjin climate.met'
```

Building File:

All the zone information and geometry are same with model of current condition

Construction File:

```
* ECOTECT v5 -> HTB2 Exporter.

* Material 1.
!CONSTRUCTION 'HollowCore_Plywood'
!TYPE OPAQUE
```

```
!PARTS
_ 1 = @1    0.003    0    * Plywood
_ 2 = -1    0.004    0    * Air Gap
_ 3 = @3    0.003    0    * Plywood
}
!END

* Material 2.
!CONSTRUCTION 'Pack 2_Case_2_External_wall'
!TYPE OPAQUE
!PARTS
_ 1 = @4    0.100    0    * Polystyrene
_ 2 = @5    0.200    0    * Concrete
_ 3 = @6    0.005    0    * Concrete Screed
_ 4 = @7    0.010    0    * Plasterboard
}
!END

* Material 3.
!CONSTRUCTION 'Pack 2_Case_2_DoubleGlazed_AlumFrame'
!TYPE TRANSPARENT *U =2.0
!PARTS
_ 1 = @8    0.006    0 0.30    * Glass Standard
_ 2 = -3    0.00030    0 0.00    * Air Gap
_ 3 = @10    0.006    0 0.20    * Glass Standard
}
!END

* Material 4.
!CONSTRUCTION 'Pack 2_Case_2_Normal_Internal_Wall_'
!TYPE OPAQUE
!PARTS
_ 1 = @11    0.010    0    * Plaster Building (Molded Dry)
_ 2 = @12    0.120    0    * Brick, Medium weight
_ 3 = @13    0.010    0    * Plaster Building (Molded Dry)
}
!END

* Material 5.
!CONSTRUCTION 'Pack 2_Case_2_Unheated_Internal_Wall_'
!TYPE OPAQUE
!PARTS
_ 1 = @4    0.100    0    * Polystyrene
_ 2 = @5    0.200    0    * Concrete
```

```
_3 = @6   0.005   0   * Concrete Screed
_4 = @7   0.010   0   * Plasterboard
}
!END

* Material 6.
!CONSTRUCTION 'Pack 2_Case_2_Foor'
!TYPE OPAQUE
!PARTS
_1 = @18   0.010   0   * Plaster Board
_2 = @19   0.100   0   * Concrete
_3 = @20   0.005   0   * Concrete Screed
_4 = @21   0.025   0   * Wood Oak Red Black (Across Grains
}
!END

* Material 7.
!CONSTRUCTION 'Pack 2_Case_2_Ceiling'
!TYPE OPAQUE
!PARTS
_1 = @22   0.025   0   * Wood Oak Red Black (Across Grains
_2 = @23   0.005   0   * Concrete Screed
_3 = @24   0.100   0   * Concrete Cinder
_4 = @25   0.010   0   * Plasterboard
}
!END

!WINDOW = Double Glazing Low E
!TRANSMISSION =
 0.49, 0.64, 0.64, 0.64, 0.64, 0.61, 0.57, 0.50, 0.36, 0.16, 0.0
!ABSORPTION =
 0.24, 0.24, 0.24, 0.24, 0.24, 0.24, 0.26, 0.27, 0.29, 0.27, 0.0
!END

!EOF
```

Layout File:
All the zone information and geometry are same with model of Modification Package 1

Appendix D: Energy and Environmental Prediction (EEP) model

The Energy and Environmental Prediction model (EEP) model is a computer based modelling framework developed at Cardiff University that quantifies energy use and associated emissions for cities to help planning sustainable cities. The model is based on GIS techniques and incorporates a number of sub-models to establish current energy use and CO2 emissions produced by buildings (CRIBE 1999) and can be used to consider the integration of different design modification aspects of the findings into a larger scale. Each sub-model uses official accepted procedures to predict energy use and emissions, the model can also predict the effectiveness of future planning decisions.

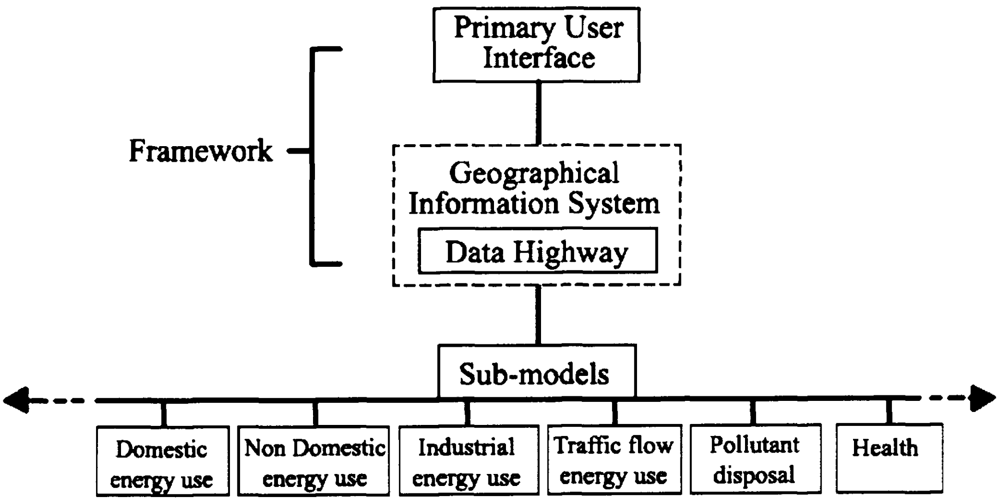

Figure 1: Framework of EEP model

Each building in the EEP model is linked through the GIS framework and can be accessed and updated from a main menu screen. It presents results in the form of thematic maps that highlight pollution or energy hotspots throughout a region. These can be used to pinpoint areas of high energy use that can be targeted for improvement.

The packages of HTB2 and Energy and EEP program can represent the summary and layout of energy use and CO2 emission condition at present in both detailed and collectively level on a GIS based system. Moreover, energy efficiency improvement of a single property or a group of buildings that can be achieved by adapting various modifications can also be represented with detail improvement information. These features will be a help to decision makers and designers in planning for sustainable development. First of all, it helps in studying current energy pattern and identifies potential problems. Secondly, the improvement of energy performance in altered building types can also be viewed, this provides users with a chance to pick appropriate methods in order to hit agreed targets. The data flow of the combined software is listed in figure 2.

Computer modelling systems can carry out a range of predictions using the same geometric description of the building. The thermal dynamic energy model HTB2 was used to predict the time varying thermal performance of buildings and EEP represents the annual energy use and CO2 emission condition

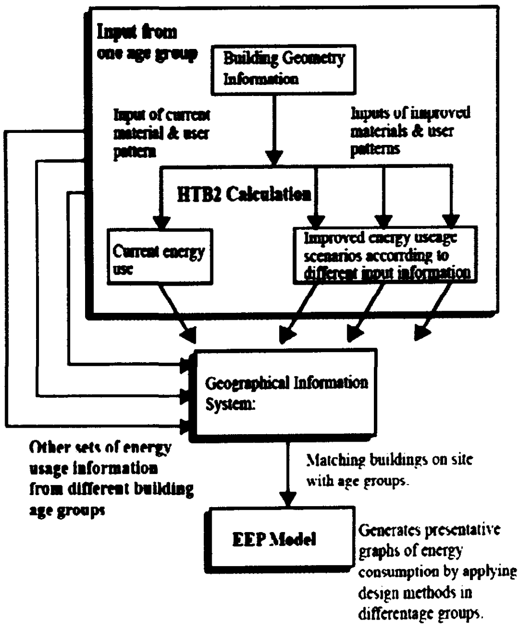

Figure 2: Data flow process of software combination

extent the current buildings perform with the energy aspect and how much they improved from the old standard and the effect of changed heating scheme, from unlimited central heating to the schemed heating.

The results of modeling using these design tools must be useful to inform the design process, and must also be able to be interpreted in a way that can inform high-level decision-making.

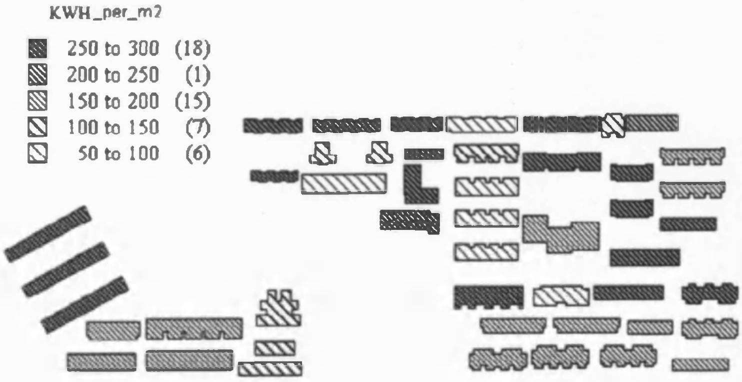

Figure 4: Current average energy usage by building

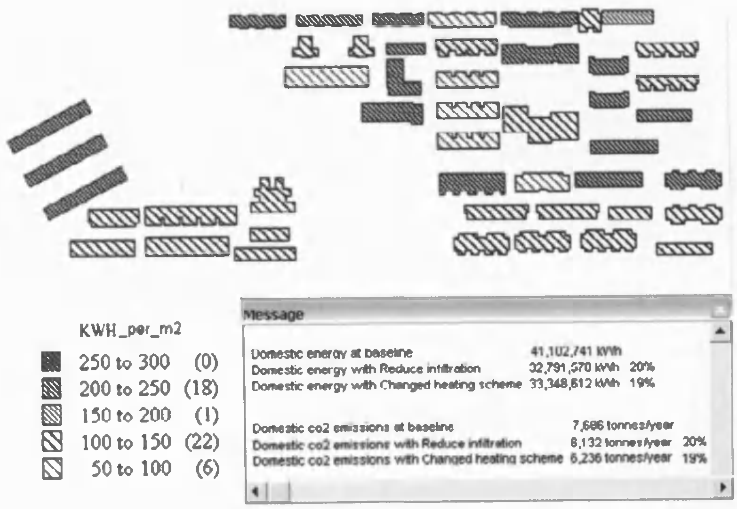

Figure 5: Improved energy efficiency