Passive Design Strategy on Residential Buildings for Sustainable Development of Lhasa

李, 恩
九州大学大学院人間環境学府空間システム専攻

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Disssertation

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Passive Design Strategy on Residential Buildings for Sustainable Development of Lhasa

Summary

Environmental issue is one of the biggest problems in the world. According to the experiences of developed countries, the environmental load growth is always the result of developing. With the increasing of the environmental problems, it is easy to assume that if the developing countries follow the track of developed ones, the global environment faces more serious damage. This research aims to find one of the solutions for developing cities to control the environmental load by passive design strategy.

This research takes Lhasa as the example city to study the passive design strategy. The reason is that Lhasa's climate has abundant solar radiation in winter, so there is a possibility to reduce the considerable heating energy consumption by only passive design and the current energy balance shows Lhasa faces serious power shortage due to the developing. With the building information from the field survey, the passive design characteristics in Lhasa are studied by simulation and the effects of passive design methods are clarified. By the combinations of the passive design methods and the corresponding additional costs, the passive design strategies are proposed and each of the effectiveness is verified in the future scenario study by simulation. The result shows that Lhasa city can get a sustainable development with few heating energy increasing by the proper passive design strategy.

This dissertation consists of six chapters. The chapter outlines for this dissertation are described as follows;

Chapter 1 shows the research background and purpose of the whole research.

Chapter 2 shows the necessary information of Lhasa for this research. In this chapter, the climate, energy condition, economic situation and development of the residential buildings are grasped by the documents investigation. The climate condition shows that it is a good choice to use abundant solar energy to save heating energy. The power supply condition shows that Lhasa already faces seriously electricity shortage. The development of the residential buildings and the economic growth show that the fossil fuel consumption growth in the future cannot be avoided. All these information indicate the necessity and the priority of passive design.

Chapter 3 shows the field survey which has been implemented in Lhasa. The purpose of the field survey is to grasp the building information such as the plan, material, structure and envelope thermal performance for the simulation setting in Chapter 4, and to grasp the living style information such as the people number of a household, daily schedule and home appliances for the simulation setting in Chapter 5. The field survey shows the possibility of energy saving by applying passive design strategy because the existing buildings originally have the conception of passive design.

Chapter 4 shows the passive design characteristics study. The effects of passive design factors are classified for making the passive design strategy in Chapter 5. By the comparison of heating energy consumption between three types of residential building, it is clear that more than 27% energy consumption can be reduced by add sunroom, and 56% energy can be reduced by the combination of sunroom and north balcony. Among all envelope thermal performance design factors, the windows type has the strongest influence to energy, especially the low-e windows. Adding insulation also has good energy saving effect (17% reduction for direct solar gain type), however, its thickness does not have large influence.

Chapter 5 proposes the passive design strategy for Lhasa city by the combined consideration of both passive design effect and the corresponding extra cost. Through the scenario study, effectiveness of the strategy is verified by simulation. At the same time, the whole process of making the strategy is shown. Following methods are recommended as passive design strategy according to the cost-effectiveness analysis: 2cm insulation layer, double glass, north balcony, low-e windows. By applying the strategy proposed in the thesis, 64% heating energy can be reduced in 2030. This result also shows that the way of making passive design strategy can be applied to other developing cities and useful for the local government to plan policies to control the environmental load of residential buildings by the proper passive design.

Chapter 6 summarizes conclusions of proceeding four chapters as the general conclusion and proposes some recommendations for future work.

Contents

Chapter 1

1. Introduction

Chapter 1. Introduction

1.1 Research background

No doubt that the environmental load and energy nowadays are two of the biggest problems all over the world. The Climate change; which was noticed from the 50th of 19th century; and the oil crises at 1973 are examples of this problem. For the human being's future, the sustainable development is considered to be one of the most important common topics in the world. Up to now, for this common target, some agreements and necessary procedures with world-wide cooperation are in progress, and the technical researches about the new energy and environmental load controlling draw more attentions.

Generally, the aim and the result of social development are to improve common people's living quality. However, this improvement always indicates energy requirement increasing. Fig.1-1 shows the schematic diagram of society development and the corresponding environmental load.

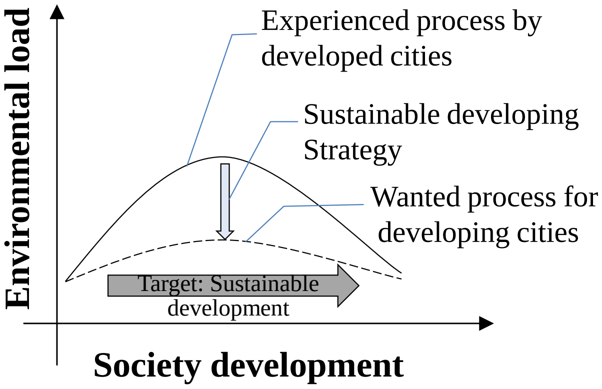

Fig.1-1 Schematic diagram of society development and the corresponding environmental load

According to the experience of developed countries, the environmental load growth is always the result of the developing process. Afterwards, the world paid more attention to this issue and invented more developed technology to control it. Environmental load in most of the developed countries were under controlled and then got reduced gradually. Therefore, developed countries have experienced the environmental load procedure of low-high-low. In Fig.1-1, the black solid curve shows this procedure.

As for the developing countries, because of the technical and financial limitations, the environmental controlling was not handled as well as the developed countries did. With the increasing of the environmental problems, it is easy to assume that if the developing countries following the track of developed ones, global environment will face more serious damage. Therefore, solving the contradictions between social development and environmental issues for the developing areas is a meaningful topic as well as an urgent target. In Fig.1-1, the dash line shows the targeted development procedure of developing countries, this curve is more flat than the black solid one, which means the developing areas should not track the old way of developed countries and should have a developing procedure with few environmental load increasing.

According to the previous background, it is clear that this research will focus on the sustainable developing strategy for developing cities. For a better understanding of the research target, it is necessary to make the definition of the developed/developing cities clear.

First, we need to know the developed/developing countries definition. According to the explanation of Wikipedia, developed countries are the countries with higher level of economy development, technologies and living quality. Developing countries has an opposite definition of developed countries [1]. Some other international organizations have the similar definitions, such as "high income economies", "very high area from human development index" and so on.

The developed countries distributed mainly at North American, Europe, Oceanic, part of Asia, totally 41 countries and areas, according to the combined information from World Bank, International Monetary Fund and the CIA World Fact book [1].

In general, developed countries have developed cities. And developing countries have different stages of development. Therefore, some cities in developing countries had reached the high level of development, but most of their cities are still under development.

Fig.1-2 shows the human development indicators world map [2]. The very high areas can be considered as the developed countries. The other countries are developing ones. From the map, it is easy to notice that, the number and area of developing countries are more than the developed ones. This map confirms again that it is an urgent task to control the environmental load from developing cities during their developing procedure.

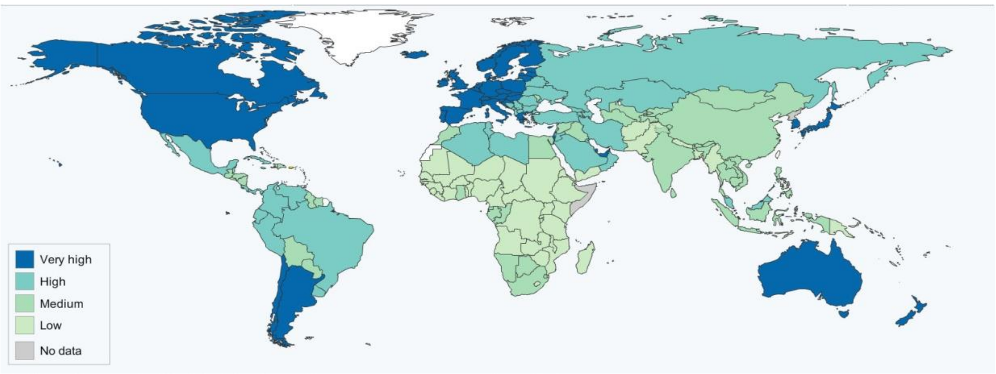

Fig. 1-2 Human Development Indicators World map [2]

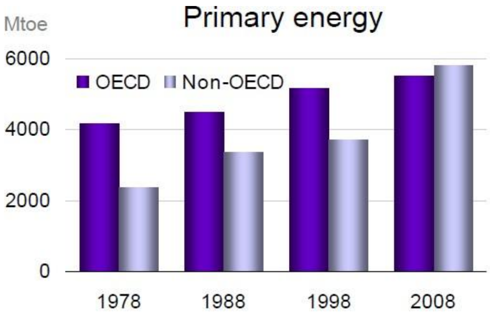

Fig. 1-3 OECD and Non-OECD Primary Energy Consumption [3]

Environmental load has a close relationship with the primary energy consumption, especially the fossil fuel consumption. Fig.1-3 shows the primary energy consumption comparison of OECD countries and the Non-OECD countries, which is considered to be developed countries and developing countries, respectively. From the figure, we can conclude that the primary energy of Non-OECD countries was beyond the OECD countries in 2008. It is expected that the whole world will face serious energy and environmental problems, if sustainable developing strategy will be not applied in the developing countries.

The important topic that affects the total social energy consumption is both developed and developing countries is for the building sector.

From the past researches [4][5][6], we can conclude that the energy consumption in buildings takes large proportion in the total social energy consumption at both China and USA, top two primary energy consumption countries. In the year 2010, in China, the building energy consumption took 28% in the social energy consumption; in USA, this value is 41.1%. The fact proved that energy consumption in building is one of the key control elements for the society sustainable development. This research focuses on the building energy saving.

The outdoor climate condition has different degrees of deviation from human thermal comfort zone, in most of areas in the world. Of course, the deviation can be fixed by devices, however, no matter what kind of devices were used but they need energy to work. This is also the reason why heating/cooling energy consumption is considered to be one of the most important sources in building energy consumption.

And, the definition of passive design is to adjust the deviation by optimizing building design elements like, plan, elevation, section, materials and so on. Therefore, the work period and the thermal load of the active devices can be controlled in a low level. Compared with the active devices design, passive design has a lower financial burden and also a good energy saving effect.

Based on the previous analysis, we can conclude that to find the effective passive design is one of the coping strategies in building field for environmental and energy problems in developing cities.

The passive design strategy in this thesis points to finding a passive design method with good energy reduction effect and the low cost. This is different with the passive design measures. Moreover, for different scenarios in the future, the different passive design strategies will be proposed. The scenarios include new constructed buildings in the further future and also the renovating of the existing buildings in the near future. The strategy is studied for the local government as one of the solutions toward sustainable development.

This research takes Lhasa as an example to study the passive design strategy for its sustainable development in the future. Then, the procedure of making passive design strategy method proposed in this research can be applied to other developing cities for their sustainable development in the future.

1.2 Research purposes and significances

1.2.1 Research purposes

Passive design in architecture is one of the effective methods to reduce the environmental load without high cost. However, as we can see from Fig.1-2 that different developing cities have different developing stages. There would be of course difficulties in applying the same technologies or strategies used in the developed countries directly. But, with a proper method or combination of technologies, it could be possible to develop the target cities as sustainable ones.

In this research Lhasa will be taken as an example to carry on the passive design strategy study. The process to install the appropriate passive design methods according to the economic growth is necessary to spread the strategies into corresponding developing cities.

The purpose of this research is shown as following:

(1) To draw up the passive design strategy based on the target city’s future economic growth and passive design effect;

(2) To grasp the energy reduction effect of strategy based on the future forecast;

(3) To show the process of making passive design strategy clearly.

1.2.2 Research significances

The significances of this research have the following aspects.

(1)The passive design strategy proposed in this thesis can support the sustainable development on residential building field in Lhasa.

(2)The methodology and research flow of residential building passive design strategy proposed in this thesis can be applied to other developing cities. So the building energy consumption in the target developing cities can be controlled to a lower level.

Except these two points, there are also some other significances.

(3) With a clear understanding of the architectural form's effectiveness to the heating energy consumption, the architects in Lhasa can get a clear definition of the energy saving capacity for architectural form design in Lhasa city;

(4) The thesis gives the envelope thermal performance design elements' effect to heating energy consumption. The results can provide the local architects a clear understanding for using materials during the envelope design.

1.3 Previous researches

Passive design is an interdisciplinary subject. From the description of U.S. Department of Energy, passive solar design takes advantage of a building's site, climate, and materials to minimize energy use [7]. Also, by the explanation of Wikipedia, passive solar building design has been developed for buildings to be inhabited by humans or animals from a combination of climatology, thermodynamics, fluid mechanics/ natural convection, and human thermal comfort based on heat index, psychometrics and enthalpy control [8]. Both of the two definitions show that the passive design is an interdisciplinary subject. And it is going along with other subjects.

Developed countries started the passive design research very early. In U.S. in May, 1976, the first passive design conference was held. In the same year, Dr. J.D. Balcomb organized the simulation program for the Trombe wall style passive solar house [9]; in 1978, he wrote the simulation software for direct solar gain style passive design house [10]; in 1980, the attached sunroom house simulation program was finished and the passive design handbook was published [11][12]. In 1982, the passive solar design journal had been released [13]. Besides, there are many practical passive design Atlases [14]. The previous works promote the development of the passive design.

In 1996, the British scholar G.S. Yakubu [15]surveyed the residents lived in the passive design buildings, the results showed, except the energy saving effect and the indoor comfort, the residents also concerned about the art of elevation. In other words, the art part of architectural design in the whole passive design procedure should not to be ignored.

In Japan, the passive design was also well developed. In 1974, Ministry of Economy, Trade and Industry carried out a *Sunshine Project*. From 1974 to 1980, the research targets laied on the collective houses and detached houses, the solar heating and the solar water heating system were the key research points [16].

As for Lhasa city, the existing passive design researches have been made mainly by Chinese researchers. Xi’an University of Architecture and Technology developed the first code for local residential building heating energy conservation. The code proposed a technical controlling index of passive and active solar energy utilization [17]. Wang Lei analyzed the effect of solar radiation on the indoor thermal load and the heating devices choice [4]. Sang Guochen analyzed the delayed action and attenuation of solid walls under the double wave effect of solar radiation and outdoor air temperature [18]. Wang Dong analyzed the effect of solar radiation to the coefficient of direction correcting factors [19]. He Quan analyzed the local residents living habitats and traditional residential building styles in rural areas in Tibet [20].

These researches made contributions to control the heating energy load of Tibetan cities by the envelope thermal design or provide a better steady calculation method. However, there are no researches that focus on the passive design strategy, which means to control the building energy consumption at different developing stages in the future. Also, these researches did not show the effectiveness of different passive design methods for different architectural forms.

In this research, both architectural form elements and the envelope thermal performance elements are considered for the passive design study. Also, in order to deal with the different developing stages in the future, the research studied the passive design strategies based on the consideration of the future economic condition.

1.4 Research flow and organization of the dissertation

In this dissertation is consists of 6 chapters. The mainly content of each one is introduced as following:

Chapter 1 is the introduction. This chapter contains the research background; purpose and significance; then, the previous researches and the organization of this dissertation.

Chapter 2 is the background of Lhasa city. The basic and necessary information of Lhasa city is introduced in this chapter. All the information is the foundation of passive design strategy study at Chapter 5. This information includes geography; climate; energy balance in the city; society and economy development; the residential building's development. Documents and statistics investigation are held in this chapter.

There are three purposes for this chapter: (1). Climate characteristics are analyzed to consider about the proper passive design method which is used in Chapter 4; (2). Energy balance analysis enhances the needs of this research; this point confirms the research background; (3). Economic development shows that it is necessary to consider about the passive design strategy from the economic point of view which is considered to be a condition for the strategic study in Chapter 5.

Chapter 3 analyzes the current residential building's condition by the field surveys. The field measurement and questionnaire were the main methods in this chapter. There are two goals in this chapter: (1). To grasp the information about typical residential building and life style in Lhasa for simulation, which is the foundation for the simulation models used in Chapter 4 and 5; (2). To grasp the actual thermal condition in the surveyed house to understand the energy increasing potential.

Chapter 4 shows the residential building passive design analysis. Three common unit types are collected to analyze the passive design characteristics. For the passive characteristics study, both the architectural form design factors and the envelope thermal performances design factors are considered. This research is considered to be the first to study the passive design with the effect of both architectural form and the envelope thermal performance in Lhasa. It also classified the effect and influence of passive design elements. In this chapter, simulation is the main method.

The purpose of this chapter is to gain the passive design characteristics for Lhasa and classify the effect of each passive design method for making the passive design strategy in Chapter 5.

Chapter 5 shows making the passive design strategy and the effect verification. In this chapter, Lhasa city's developing process is grasped by the future scenario forecasting. Then, the passive design strategies are studied by the combined consideration of both economic condition in the future and the effect of the passive methods.

The purpose of this chapter has three main points: (1). To figure out the passive design strategy according to Lhasa’s future economic growth; (2). To show the process of making passive design strategy; (3). To understand the effect of applying the strategy in Lhasa based on the future forecast.

Chapter 6 shows the conclusions and the prospects.

Fig.1-4 shows the research flow.

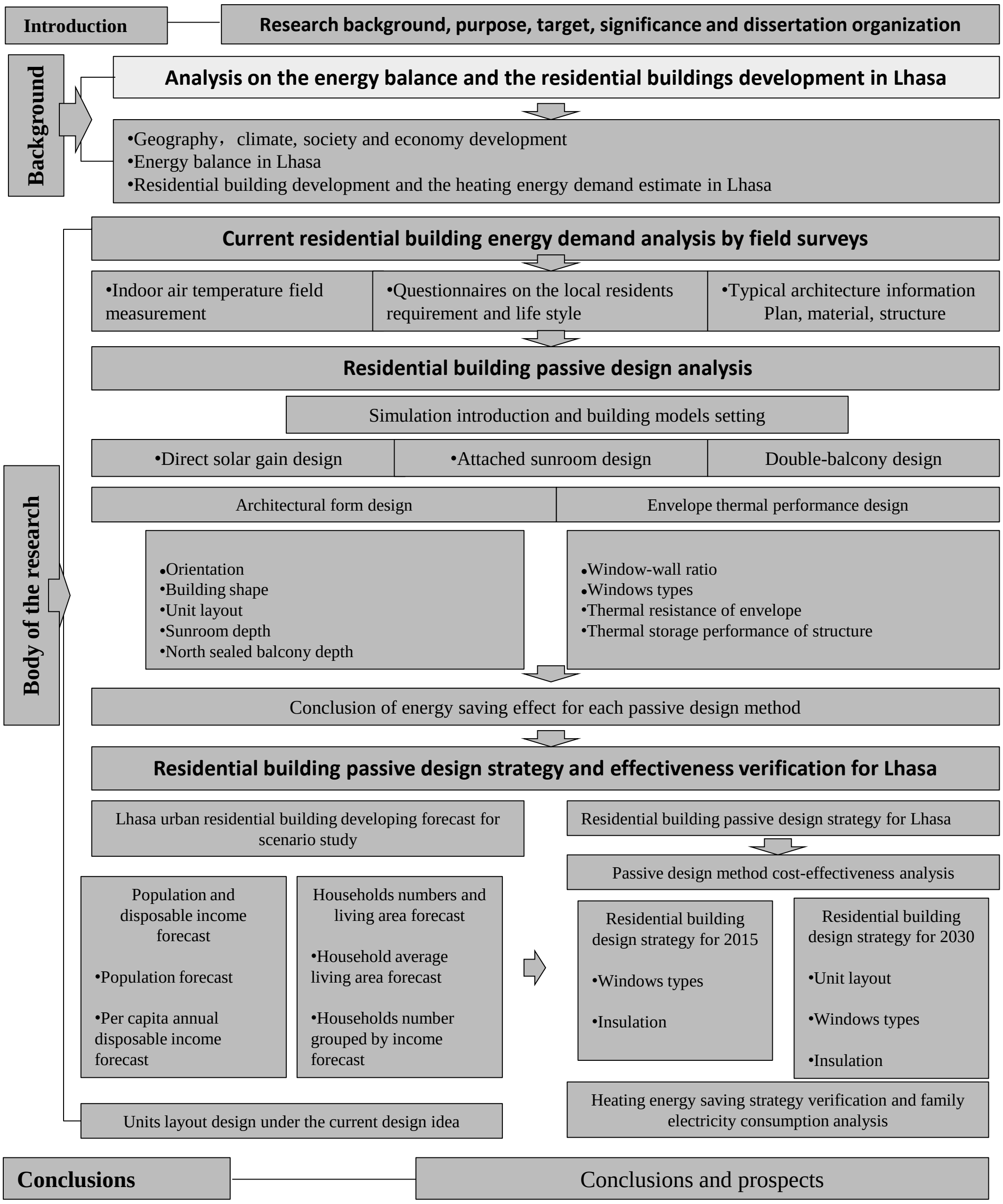

Fig.1-4 The research flow

References:

[1] Delimitation of developed countries, available at: http://zh.wikipedia.org/wiki/%E5%B7%B2%E9%96%8B%E7%99%BC%E5%9C%8B%E5%AE%B6#cite_note-0

[2] United Nations Development Program, available at: http://hdr.undp.org/en/data/map/

[3] BP Statistical Review of World Energy June 2009, available at: http://www.bp.com/multipleimagesection.do?categoryId=6840&contentId=7021557

[4] Wang Lei，Study on The Passive Solar Heating Building in Tibet， Ph.D Thesis, Southwest Jiao Tong University, 2008 (in Chinese)

[5] Jiang Yi，China Building Energy Saving Annual Bulletin 2008, Beijing: China Architecture & Building Press. (In Chinese)

[6] Buildings share of U.S. Primary Energy Consumption, U.S. Department of Energy, available at: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=1.1.3

[7] U.S. Department of Energy, Passive Solar Home Design http://energy.gov/energysaver/articles/passive-solar-home-design

[8] Wikipedia, Passive solar building design, available at: http://en.wikipedia.org/wiki/Passive_solar_building_design

[9] J.D. Balcomb, R.D. Mcfarland, Simulation Analysis of Passive Heated Buildings [C]—— the Influence of climate and Geometry on Performance, Los Alamos NM87545

[10] J.D. Balcomb ect, Evaluating of The performance of Passive Solar Heated Buildings LA-UR-83-003

[11] U.S. Department of Energy, Passive Solar Design Handbook[M], Vol.1,1980

[12] J.D. Balcomb ect, Passive Solar Design Handbook, 1980

[13] John A. Duffie Ect., Sloar Engineering of Thermal Process [C], A Wilew Interscience publication, 1980, New York.

[14] U.S. Department of Housing and Urban Development, New Energy-Conseing Passive Solar Single Family Homes [M], 1981

[15] G S Yakubu, The reality of living in passive solar homes: A user-Experience study [C], WREC, 1996 117-181

[16] Li Caowei (2005), An elementary study on policies of utilizing solar energy in houses all over the world, New Architecture. No.06. 10-12 (In Chinese)

[17] Construction Bureau of Tibet Autonomous Region, Design Standard for Energy Efficiency of Residential Buildings (DB54/0016-2007), Lhasa: Tibetan People Press; 2007 (in Chinese)

[18] Sang Guochen, Study on Construction System of Low Energy Consumption Residential Buildings in Tibet Plateau, PhD Thesis, Xi’an University of Architecture and Technology, 2009. (In Chinese)

[19] Wang Dong. Research on correct factor of envelope K factor for energy efficiency resident building in Tibet, PhD Dissertation, Chong Qing University, 2006. (In Chinese.)

[20] He Quan, Research on Architectural Culture of Tibetan Vernacular Housings, PhD Thesis, Xi’an University of Architecture and Technology, 2009. (In Chinese)

Chapter 2

2. Analysis on the energy balance and the residential buildings development in Lhasa

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In recent years along with the Chinese economic development, Lhasa's economy also made a considerable progress; the urban construction in Lhasa already gradually marched into the large-scale construction stage. At the same time, there is an obvious growth of Lhasa's energy production and consumption [1]. Large-scale use of fossil resources will accelerate the process of breaking fragile ecological environment in Lhasa [2].

As to the residential buildings in Lhasa, there is no local construction standard until 2008, the massive existing buildings in the cities followed the standard of southwest of China which is also called Sichuan province construction standard. Sichuan province is a basin, and it has the least solar energy resources in China and part of Sichuan province belongs to non-central heating area. The southwest standard is rooted in the corresponding climate characteristics. Tibet has a totally different climate condition; so the southwest standard is obviously unreasonable to be applied here.

And as a result of applying the Southwest standard, the existing residential buildings in Lhasa did not have to have insulation and other heating energy saving strategies. Accordingly, the winter indoor environment of the residential building in Lhasa was bad; the local residents used more clothes to cope with the cold. As a result, the heating energy consumption in Lhasa was very low.

On July 1, 2008, the local construction standard of Tibet Autonomous Region——*Design Standard for Energy Efficiency of Residential Buildings* [3] which is developed by Xi'an University of Architecture and Technical and some other scientific research units had been officially implemented. The winter indoor thermal environment design parameters as indoor temperature and ventilation are clearly described. This local standard focuses on the building thermal performance, the technical controlling index of building envelope performance is proposed. Also, the auxiliary heating energy consumption indicator is proposed in case some buildings cannot fully comply with the envelope thermal controlling index.

At the same time, the urban central heating system of Lhasa is under construction and it is close to completion. The main fuel of the central heating system will be natural gas and the auxiliary energy supply will be electricity [4].

It is easy to understand that the massive existing residential buildings in Lhasa do not use efficient passive design; and they will use heating system in the near future, these conditions would result in the huge environmental load. As a strategy study, this research has to consider two sceneries: 1. In the near future, the existing residential buildings should be refit for the purpose of heating energy saving; 2. In the father future, majority of the residential buildings can be newly designed towards the purpose of heating energy saving;

For the both scenarios, the residential buildings development is a key element to understand the potential heating energy consumption. And also, no matter for the new residential building design or for existing residential building refit, the local situations will be the important boundary conditions. It is necessary to explain them in detail.

As the first step of the residential building passive design strategy study, this chapter introduces the basic information and of Lhasa and analyzes the development of the residential buildings in Lhasa.

The basic information includes geography, climate, society and economy, energy condition and development of the residential buildings, in which, the geography and climate is the basic information for the passive design consideration in Chapter4, the economy condition is one necessary factor in passive design strategy study in Chapter 5. Also, the development of residential buildings and current energy condition of Lhasa city confirm again the research background in Chapter 1.

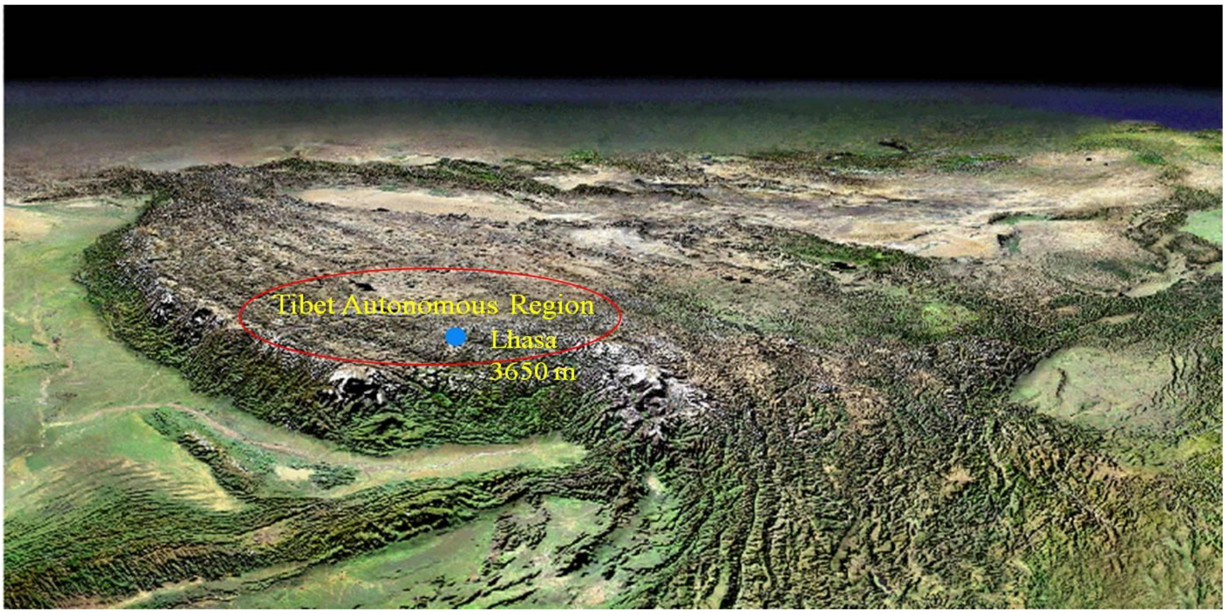
2.1 Geography and climate of Lhasa

2.1.1 Geography

Lhasa lies on the Qinghai-Tibet Plateau of the southwest border in China. Tibet is separated from South India, Nepal, Sikkim, Bhutan, Myanmar and other countries by Himalayas in the south and borders on Xinjiang province, Qinghai province, and Sichuan province in the north and east. The terrain of Tibet is tilted from northwest to southeast which is complex and diverse. It has more than 4,000 km state boundary which is the second longest province in China [5][6].

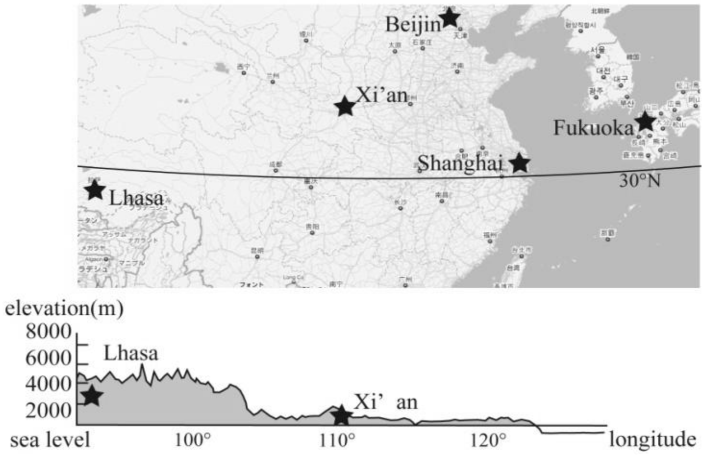
With an average elevation of 4800 m, Tibet is the highest region on the earth and has in recent decades increasingly been referred to as the “Roof of the World”. It is also called the “Third Pole of Earth”. Unique geographical environment creates unique snow-covered scenery, and it is introduced as one of the most imposing topographic features on the surface of the earth [7].

As for Lhasa city, it is located at north latitude 29 º39’, east longitude 91 º07’, which is the southeast of the Tibet Autonomous Region. The biggest width between the north and south boundary is approximately 202 km, the length along east and west boundary is approximately 277 km, the total area is 31662 Km^2. Its average elevation is 3658 m [8].



(a) Aerial view of Lhasa and Tibetan Autonomous Region

Fig.2-1(1) Topography of Lhasa [9] [10]



(b) The section plan of China along latitude 32 degree north

Fig.2-1(2) Topography of Lhasa [9] [10]

Fig.2-1 shows aerial view of Lhasa and Tibetan Autonomous Region and the section plan of China along north latitude 32 degree. According to this figure, mainland of China can be divided into three ladders by the topography. Tibet located at first ladder, which means the highest area of China. As the figure shows, at 3658m above the sea level, Lhasa is the highest provincial capital of China.

2.1.2 Climate

As a result of Tibet plateau's unusual diverse terrain, landform and Tibet's climate is complex and diverse. Generally speaking, Tibet's climate in the northwest is severe cold and in the southeast is warm moist. In general, the Tibetan climate has the characters as the following: the sunshine is abundant, the radiation is intense, the diurnal temperature range is large, the dry season and the moist season are distinct, the wind is much, the barometric pressure is low, the probability of raining at night is more than that in the day, and the oxygen content is low. Because of the abundant solar radiation, even in the cold winter, Tibet's human body thermal comfort feeling is in the comfortable zone at noontime, but at night it is too cold to endure [11].

Besides total characteristic, there are also many regional features. However, all the cities in Tibet have plateau climate features. This thesis focuses on the Lhasa; the climate of Lhasa is introduced.

(1) Low-latitude, high elevation, thin and clean air

Based on the climate zone, China can be divided into two areas, central heating area and non-central heating area. Fig. 2-2 shows climatic regions of building energy in China, the dash line drawn in the figure distinguishes between the two areas. It is easy to see from the figure that compared with other cities in the central heating areas, the latitude of Lhasa is low. This means most cities which have the same latitude with Lhasa do not have heating demand in winter.

The high elevation results in the thin and clear air in Lhasa. Fig.2-3 shows atmospheric coefficient of transparency in Lhasa, Ruisui station in Antarctica and Beijing. As the figure shows Lhasa’s atmospheric transparency coefficient approached Antarctica’s, it is one of cleanest atmospheric areas on the earth. And this is one of reason why Lhasa has so abundant solar energy.

High elevation is one of reasons why Lhasa has very few examples of high-rise buildings.

Fig.2-2 Climatic regions of building energy in China [12]

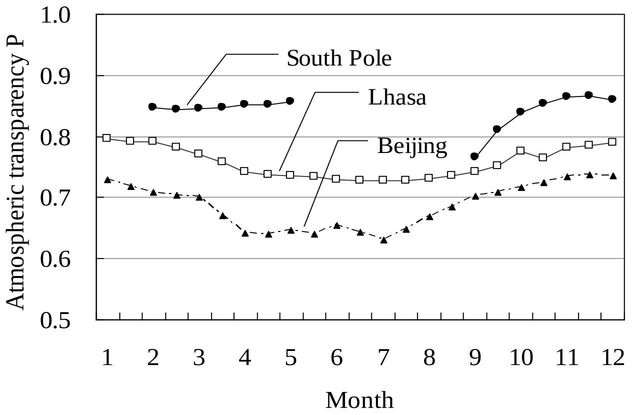


Fig.2-3 The atmospheric transparency of South Pole, Lhasa and Beijing [13]

(2) Low atmospheric pressure, low oxygen content

The air density in Lhasa is low. It is 810 g/m^3 when the temperature is 0 ℃ [14]. Fig.2-4 shows annual average atmospheric pressure of five cities. The annual average atmospheric pressure in Lhasa is 652 hPa [14], which is about 60% of Fukuoka city. In addition, it is known that the oxygen content in Lhasa is about 65% of plain area in China. It results in the vegetation monotonous in the ecological environment and the fuel wasted caused by incomplete combustion. Combined with the former introduction, the central heating system in Lhasa will consume more natural gas and emit more pollution than the plain areas do.

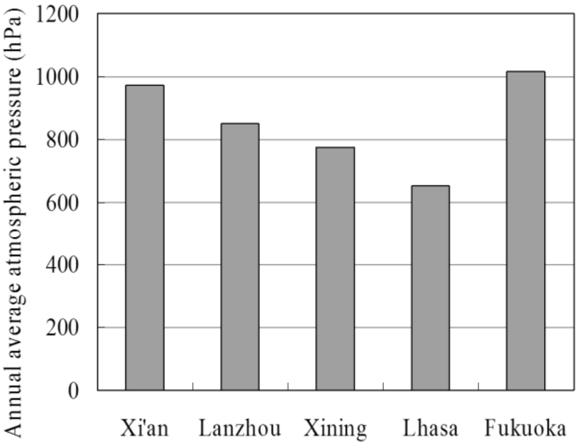


Fig.2-4 Annual average atmospheric pressure of five cities

(3) High solar exposure

Because of the high elevation and clean air, Tibet has the most abundant solar radiation among all provincial cities in China.

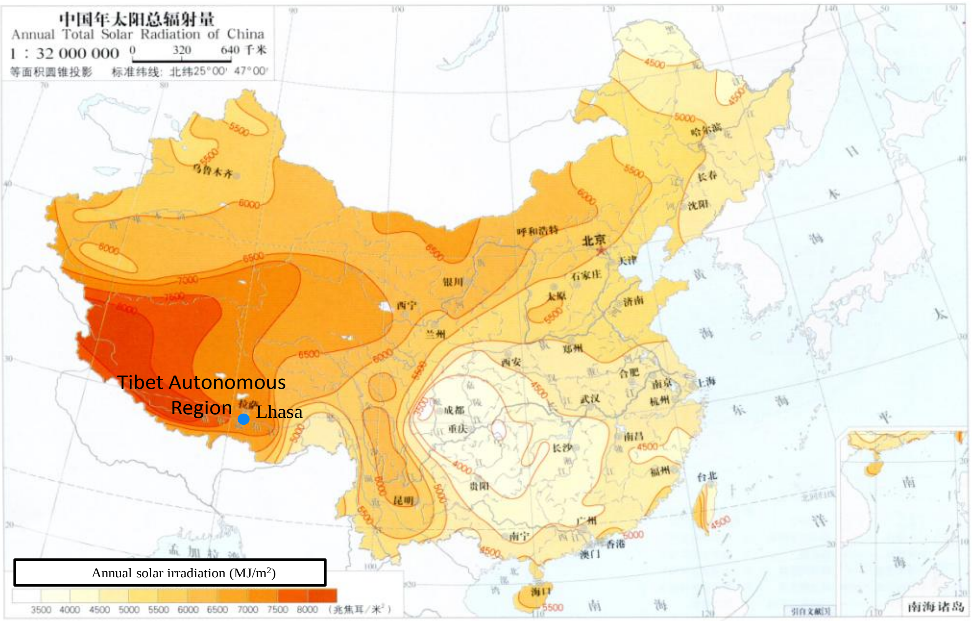


Fig.2-5 Annual gross irradiation of China [15]

Fig.2-5 shows the gross irradiation of China. Generally speaking, there is a separating line between high solar exposure area and low solar radiation area; the separating line is starting from Liaoning province in the northeast toward Yunnan province in the southwest. The west side of this line has higher exposure than the east side. And the Tibet plateau has the most abundant solar energy all over China. The southwest area of Tibet has most abundant solar radiation in the whole Tibet Autonomous Region. As the figure shows, Lhasa is the provincial capital city with most solar radiation.

Based on statistical data, Lhasa's annual average sunshine time is about 3,006 hours, and the amount of annual total solar irradiation is about 8,160 MJ/m^2 [14]. By analyzing typical year's climate data on five cities as Lhasa, Xi'an, Beijing and Fukuoka, the monthly direct solar radiation in normal direction is shown in Fig.2-6. From the figure, it is easy to see that Lhasa's monthly direct solar radiation in normal direction is the richest one among the five cities. And, it almost reaches 200 kW/m^2 in July. Even in winter, its scanty season, the value is more than 100 kW/m^2 [11]. The amount of solar radiation is much more than other cities. High solar exposure proves the passive design in Lhasa need to use the solar energy efficiently.

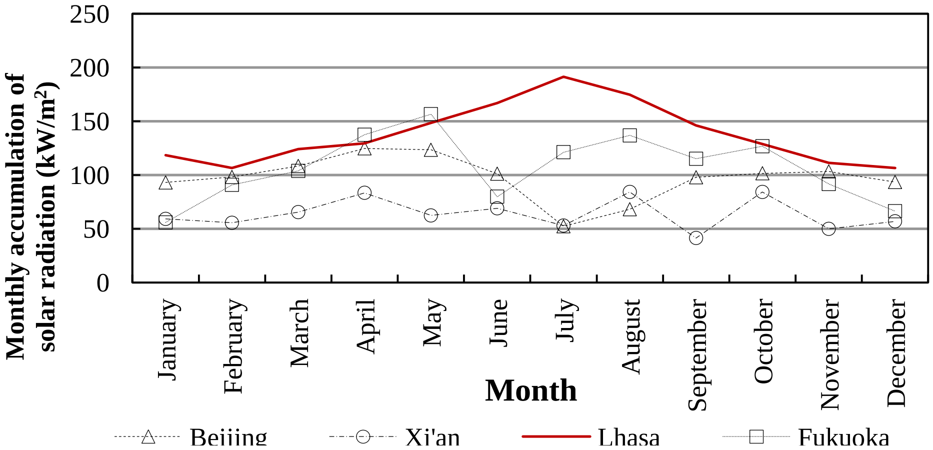


Fig.2-6 Monthly accumulation of direct solar radiance in normal direction [11]

(4) Cool summer, cold winter

It is proved that, the air temperature has linear relationship with the elevation. The average temperature will be getting lower along with the increase of the elevation. As to Lhasa, the average temperature in summer is lower than that of plain cities with the same latitude in China, this is a positive climate condition for summer cooling energy saving, however in winter season, and it is colder than other cities with the same latitude.

Fig.2-7 and Fig.2-8 respectively show the daily average temperature in the hottest month and the coldest month of Lhasa, Xi’an, Beijing and Fukuoka. Lhasa’s hottest month is June, and the temperature is 16.4 ℃ [11], and this is about 10 ℃ lower than that of the other cities. In Lhasa’s coldest month in winter, January, the monthly average temperature is -1.5 ℃ [11]; this number has no big difference with Xi’an. And as for the daily average temperature, the single day’s value is around 5-10 ℃ lower than that of Fukuoka.

According to Fig.2-7 and Fig.2-8, we can get the conclusion that the thermal comfort problem in residential buildings in Lhasa is mainly from heating demand in winter. Considered the abundant solar radiation, how to use solar radiation efficiently toward winter heating energy saving is one of the most important points during the whole research.

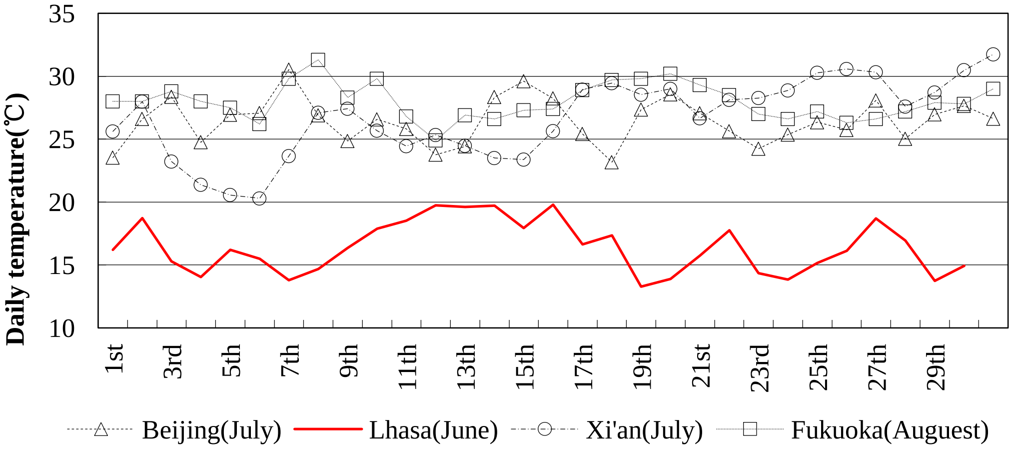


Fig.2-7 The daily average temperature in the hottest month [11]

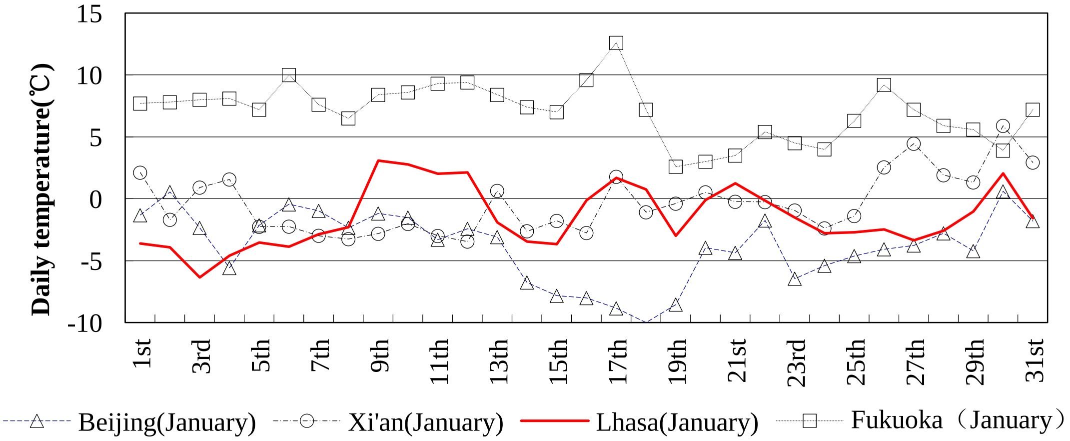


Fig.2-8 The daily average temperature in the coldest month [11]

All in all, Lhasa has the geography and climate characteristics as: low-latitude, high elevation, thin and clean air; low atmospheric pressure, low oxygen content; high solar exposure; cool summer, and cold winter. All these characteristics give the hints that passive solar design would be the first choice for meeting the winter heating demand. However, the passive design is an interdisciplinary subject; it is affected by lots of conditions, in which the economic condition has a big influence on the materials and technology choosing. It is necessary to have an understanding of the Lhasa's society and economy.

2.2 Energy balance in Lhasa

With the development of economy, there is a rapid growth of energy production and consumption. Fig.2-9 shows the growth rate of the electricity production and consumption. From the figure, we can get a conclusion by simple calculation that the average annual growth rate of Lhasa from 1994 to 2005 is 17.9 % per year; at the same time, the growth rate of whole China is 9.4 % per year. The energy consumption grows rapidly. In addition, the absolute value growth of per capita electricity consumption is from 2.2 kWh in 1960 to 704 kWh in 2008, the change rate is more than 300 times [16].

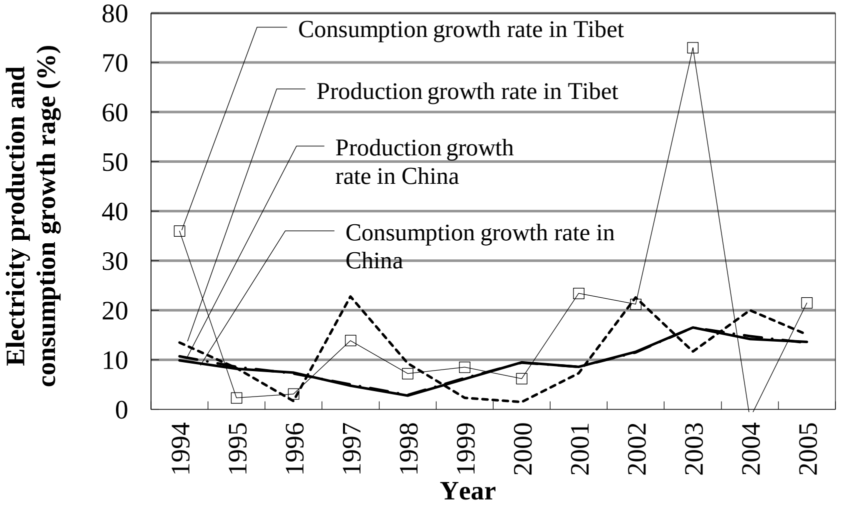


Fig.2-9 Growth rate of the electricity production and consumption in Tibet [16]

Energy condition of Lhasa is the foundation of the energy saving strategy, it is necessary to understand the energy balance in Lhasa.

2.2.1 Energy resources and the corresponding proportion in Tibet

Before 2011, the power network in Tibet did not connect with the inland power network of China; the energy demand from Lhasa is supported by the several power plants distributed in Tibet. The energy balance in Tibet needs to be analyzed.

2.2.1.1 Energy resources and in Tibet

The main energy resources of Tibet include hydraulic power, geothermal power, solar power, wind power, biomass energy and so on. Conventional energy resources as fossil oil and coal are few in Tibet. Table2-1 shows the natural resources in Tibet.

Table 2-1 Natural energy resources in Tibet [17]

Type	Evaluation	Distribution
hydraulic power	Reserves in theory: 2×109 kW Tentatively developed: 5.9×107 kW	The Yarlung Zangbo River area
geothermal power	Totally 672 hot springs The power potential:29.8×107 kWh	Yang Bajing area, Lang Jiu area
solar radiation	Most abundant in China	Tibet, especially north Tibet
wind power	Most area of Tibet belongs to abundant area	Tibet, especially north Tibet
biomass energy	Cow dung: 2.9×106 ton/year Crop straw: 2.1×106 ton/year	Rural area
fossil oil	Unclear	north Tibet area
coal	Reserves in theory: 5.48×107 ton	Chang Du area, Na Qu area and A Li area

The conventional energy sources such as coal, petroleum which can be practically developed in the near future are very few in Tibet. The hydraulic power in Tibet is very abundant. The local electric power is primarily supplied by the hydroelectric power. Table 2-2 shows the power generation in Tibet and the proportion of hydroelectric power.

Table 2-2 Power Generation in Tibet [18] **(100 million kWh)**

	2000	2004	2005	2006	2007	2008	2009
Total generation	6.61	11.51	13.34	15.15	15.17	18.46	18
Hydro power generation	5.54	10.32	12.10	13.79	13.99	14.53	15.27
Proportion of hydro power	83.8%	89.7%	90.7%	91.0%	92.2%	78.7%	84.8%

All the heat power plants in Tibet are fuel power plants. The fuel oil is completely by transferring from other localities. The expensive cost limits the use of oil boiler. Lhasa heat power plant went into operation from 1977, until 1990 this power plant had deficit of 8.2 million RMB. In the area with no hydraulic power plant or geothermal power plant, the thermal power plant can only provide 3 to 4 hours lighting electricity [19]. So, in the most of the area, the thermal power plants are the electric power backup.

Table 2-3 shows the thermal power plants in Tibet.

Table 2-3 Thermal power generation in Tibet [18] **(100 million kWh)**

	1995	2000	2004	2005	2006	2007	2008
Tibet	0.25	0.05	0.08	0.08	0.09	0.01	0.14

Except the hydro power and the thermal power, there are also some experiential new energy power plants.

(1) Geothermal power

There are two geothermal power plants, Yang Ba Jing power plant and A Li Lang Jiu power plant, in which, Yang Ba Jing power plant can produce 60.59 Million kWh/Year. From starting in 1977 to the end of 2007, this power plant already generates 2.13 billion kWh [19].

(2) Solar power

The solar power plant is mainly in Lhasa, Shan Nan, Ri Ka Ze. Until 2011, the solar power installed capacity is 9 million W [20]; Tibet is the biggest installed capacity of solar power in China. However, compared with the total social demand, this is still a very small amount.

(3) Wind power

Wind power is started from 1982 in Na Qu. The experimental wind power plant is mainly in Naqu, Shan Nan and A Li. The power generation is still few now.

(4) Coal and LPG supply

Table 2-24 shows the coal production in Tibet, as the Table shows, the coal production is not much. And as for fossil oil, according to China Energy Statistical Yearbook, there is no production in Tibet. Also, there is no natural gas in Tibet, the two gas pipes are from Xinjiang Province are under construction now. In Tibet, most of the people use LPG for family fuel. Table 2-5 shows the supply of LPG in Tibet.

Table 2-4 Coal production in Tibet [18] **(10 thousand ton)**

	1995	2000	2004	2005	2006	2007	2008
Tibet		2.13	1.64	3.35			

Table 2-5 Supply of LPG in Tibet [18]

Tibet	2000	2005	2006	2007	2008
Total Gas Supply (ton)	16680	1500	813000	814450	813348
Population with Access (10^4person)	13.8	2.8	16.0	23.5	34.4

2.2.1.2 Electricity supply in Tibet

There are four electric power networks in Tibet, which are Central Tibet Power Network, Linzhi Power Network, Changdu Power Network and Shiquanhe Power Network. The Central Tibet Network is the biggest one, and it is in charge of 73 % of the electric power zone in Tibet [21]. In the Central Tibet Network, who provides electric power to Lhasa, the 3/4 capacity is from hydrosphere, in which the main hydroelectric power station (Yamzho Yumco hydroelectric power station) accounts for one half of the total output of electrical energy.

The development of Tibet is always limited by the power problem. The power plants are under continuous construction. However, because of the unreasonable allocation of power plant construction speed and the electricity distribution ratio, a part of cities have over-supply electricity phenomenon before 2004. In 2002, the Yamzho Yumco hydroelectric power station’s power generation only achieved 60 % of its installed generation capacity, as to the Central Tibet Network, the account of whole year’s power selling is 80 % of its generation. This caused the local electric power department to encourage people using high energy consumption, low-efficiency electricity equipment blindly for the local interest [21]. The unreasonable phenomenon needs to be no longer materializing. At the same time, in winter, the dry season, there always power gap in Lhasa.

2.2.2 Current power gap in Lhasa

Along with the Qinghai-Tibet railway project's carrying out, the local economy developed rapidly, and common people's living standard improved quickly from 2005. The Tibet electrical network electricity supply capacity cannot meet the local daily need, especially in winter. As analyzed formerly, most of the electricity in Tibet is from hydropower station. Winter is a dry season, this exacerbated the shortage of electricity, and some cities in Tibet cut off the power in order to reduce the pressure caused by the tight power supply. Tibet is not self-sufficient in electricity consumption recently (Table 2-6). And in 2009, this gap even reached 32.8% of the total power generation; this is a very serious electric shortage. During the power shortage period, the outage always happened; this seriously affected the normal industry operation and the residences daily life.

Table 2-6 Power gap in Tibet [22][23] **(10^8 kWh)**

Year	2008	2009
Power gap	1.2	5.9

After the new local building energy reservation standard promulgated in 2008, most areas of Tibet has been included in the central heating area. The new buildings and the existing buildings have to add central heating systems. As introduced before, the backup energy supply for the central heating system is electricity. This exacerbates the power shortage in Lhasa.

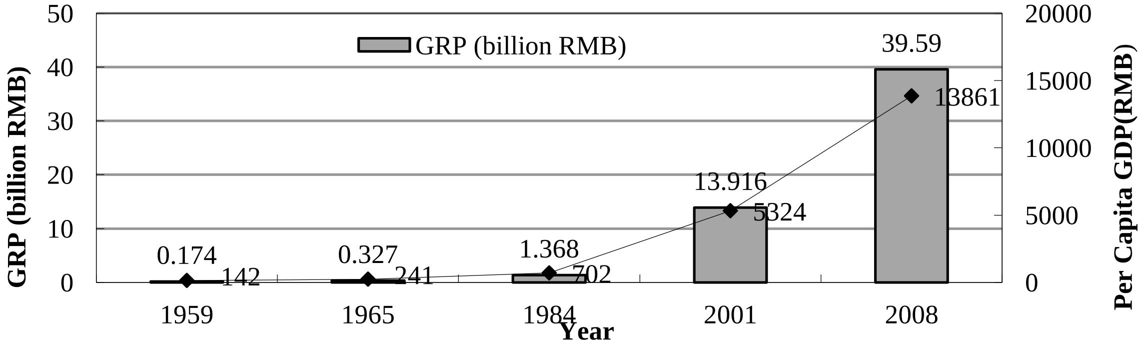
All in all, Lhasa city is a developing city which cannot get energy supply self-sufficient. Increasing of fossil fuel consumption according to development cannot be avoided. So it is very important to control the increasing speed for the future sustainable development.

2.3 Economic growth and residential buildings development

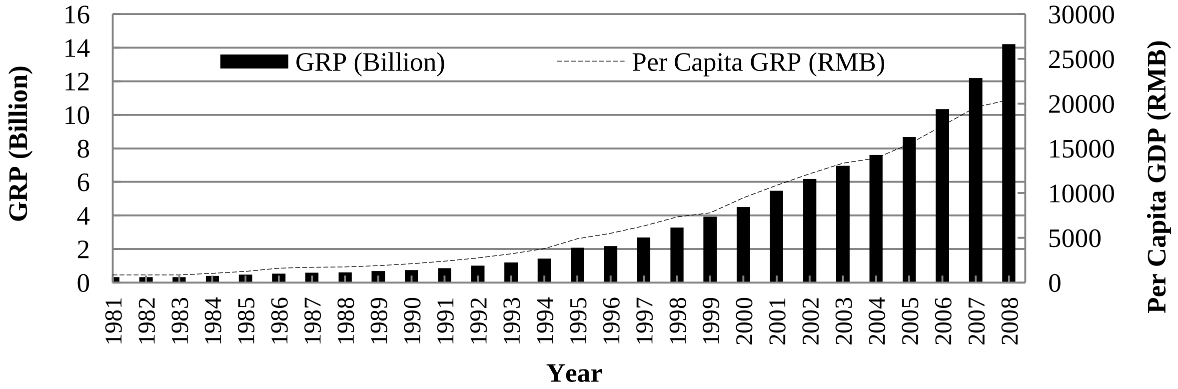
2.3.1 Society and economy

In 2008, the GRP of Tibet was 39.6 billion RMB, and the per capita GRP reached 13,861 RMB. As for Lhasa city, the GRP in 2008 is 14.2 billion RMB and this value is around 45 times of the GRP in 1981. The per capita GRP in Lhasa in 2008 is 20404.21 RMB, this is around 24 times of the value in 1981.

Fig.2-10 (a) shows the GRP and per capita GRP growth of whole Tibet from 1959 to 2008. Fig.2-9 (b) shows the GRP and per capita GRP growth of Lhasa city from 1981 to 2008. As the figure shows, after the year 2000, both Tibet and Lhasa city have a obvious GRP increasing [24].



(a) GRP and Per Capita GRP of Tibet



(b) GRP and Per Capita GRP of Lhasa

Fig.2-10 Growth of GRP and Per Capita GRP of whole Tibet and Lhasa city [24]

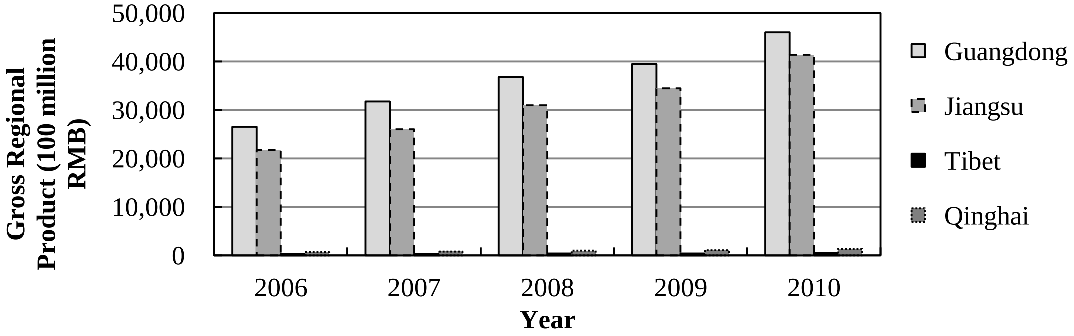


Fig. 2-11 Provincial GRP comparison [25]

Fig.2-11 shows the GRP of four providences in mainland China, including the top two provinces and the bottom two provinces. In the five years' provincial GRP (2006 to 2010), Tibet and Qinghai always stays at the bottom of the list. Guangdong province which has the highest GRP always has around 90 times GRP value of the lowest province—— Tibet. Of course, the differences was caused by complicated reasons, especially historical reasons, but still, the big differences show the different developing stages of two provinces. So for Lhasa city, it is meaningful to study the passive design strategy, not only because the initial developing stage indicates the risk of environmental load huge increasing in the future but also because of the possibility of applying the strategy in this research.

The economical development will lead to the people's income increasing. Per capita disposable income is a statistical data which can reflect the local people's living standard. Fig.2-12 shows the per capita disposable income of urban area in Lhasa, in 2010 the per capita disposable income of Lhasa urban area was 16567 RMB. It is about 10 times of the value 1684 RMB in 1990.

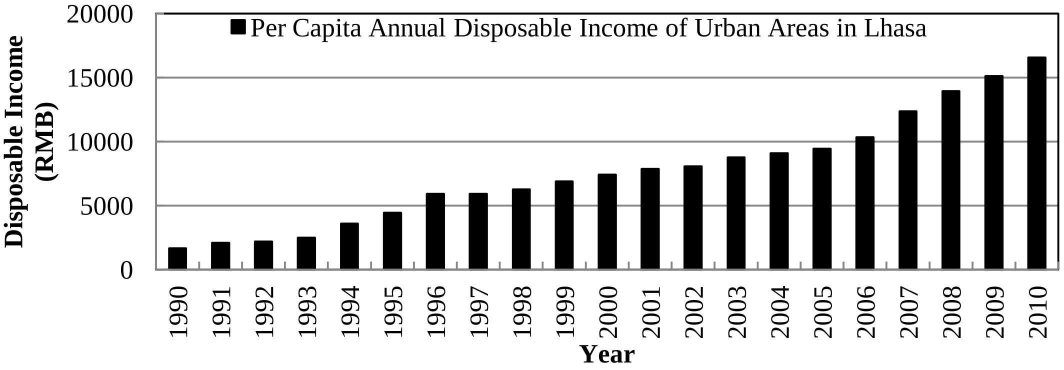


Fig.2-12 Per capita disposable income of urban area in Lhasa [26]

Fig.2-13 shows the amount of population changing of Lhasa. The increasing birthrate of the local Tibetan population and the increase of average life expectancy caused by the improvement of medical condition are the major reason for the overall population boom [27]. Moreover, since 1978, the exchange of human resources between Tibet and the inland areas has seen a steady increase in value with more and more migrant workers seeking employment and business opportunities in Lhasa.

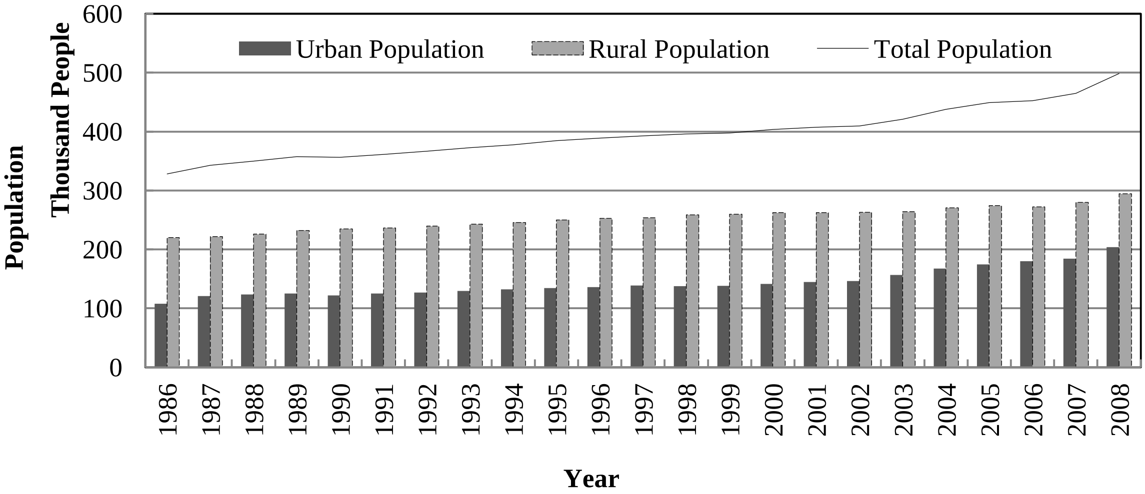


Fig.2-13 The population growth of Lhasa city [24]

The development of society and economy in Lhasa show that Lhasa already got started to fast developing. The difference between Lhasa and other big cities show that Lhasa to carry on the passive design strategy study, the economy is one important and necessary boundary condition.

2.3.2 Residential buildings development in Lhasa

Similar with other inland cities in China, the commercial residential buildings play the main role in the urban residential buildings now. However, compared with the other provincial capital cities, the development of commercial residential buildings in Lhasa is still in the elementary stage. Before 1997, there is no commercial residential building market in Lhasa. The basic way to solve the living problem is by the fund-raising building from the state-owned units with the support from government. And the living unit can be distributed to the employer in the way of low-rent housing. After 1997 the commercial residential buildings in Lhasa start to develop [28].

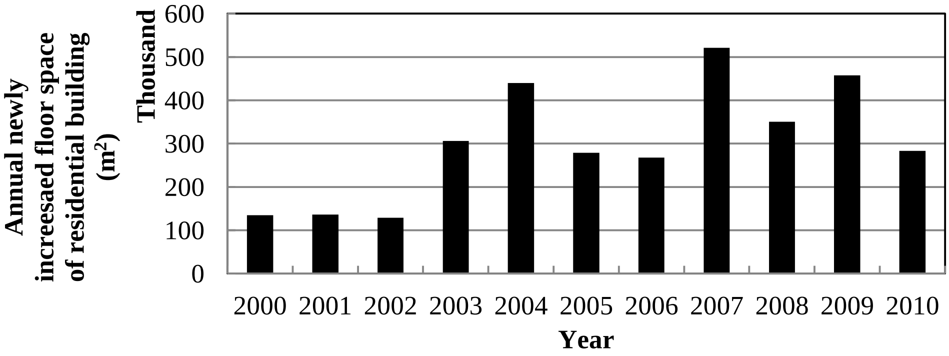


Fig.2-13 Annual newly increased floor space of residential building [26]

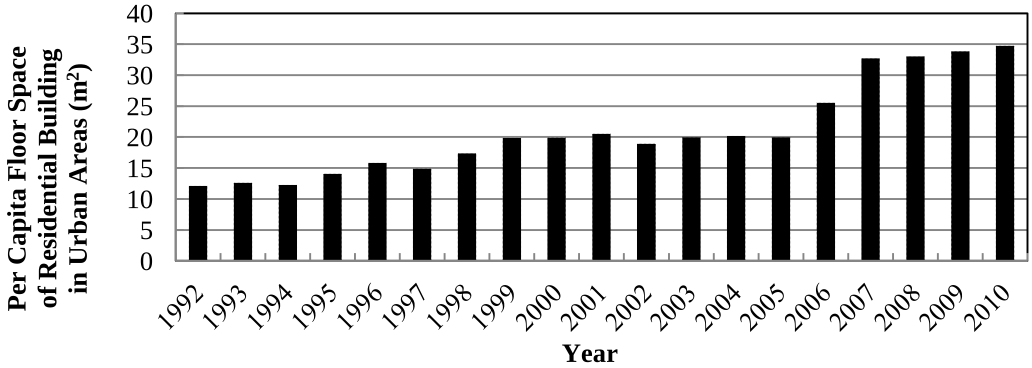


Fig.2-14 Per Capita Floor Space of Residential Building in Urban Area [26]

Fig. 2-13 shows the annual newly increased floor space of residential building under completion from 2000 to 2010 of Lhasa city; the data is from the Tibet statistical year book. It is easy to see that before 2003 the construction quantity is not much, however, after 2003 the annual newly increased construction quantity is obviously increased.

Fig. 2-14 shows the per capita floor space of residential building in urban area from 1992 to 2010 of Tibet. Because of the documents limitation, the statistical data of per capita floor space in Lhasa cannot be found. Whole Tibetan data is used to instead of Lhasa data for analysis here. The data is from the Tibet statistical year book.

It is easy to see that there are two fast increasing periods, 1998 to 2001 and 2006 to 2010. The figure shows that the living standard of Tibet residents has been enhanced obviously in the past dozens of years. At the same time, the obviously increased living space also indicates that the total area of urban residential building is hugely increased. Once all of the buildings use heating systems, the energy consumption of the whole city will hugely increased.

2.3.3 Heating energy demand estimate

As introduced before, the first local building energy reservation standard was published in 2008. However, until 2011, the existing residential building in Lhasa have not been refitted for the heating energy saving. To get the real energy demand, the field survey is the best way. However, before the central heating system operation, simulation can be one choice. Field survey and the simulation will be carried out in the Chapter3 and Chapter 4 in detail.

So, based on the condition of no historical heating energy consumption record, without simulation, the energy demand estimate in this chapter is only a trend study. The purpose of this section is to show the simple relationship with the fast construction of Lhasa city and the corresponding latent heating energy consumption. Hence, two contrastive heating energy consumption indexes are referred here.

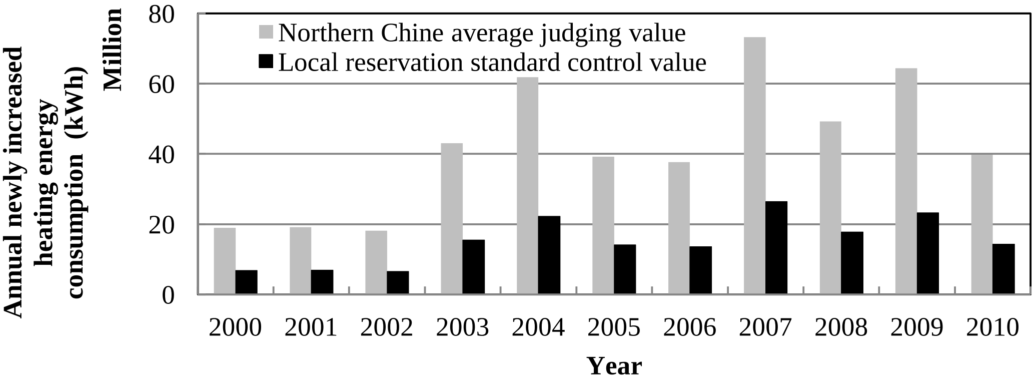
(1) Jiang Yi analyzed the average heating energy consumption in Northern China in the paper *China building energy conservation stratagems study*. According to this paper, the average heating energy consumption in the urban area of northern China is 17.3 kg standard coal per square meter in 2008 [29]. This is an average value including the building with heating energy saving design and the buildings without the energy saving design. Of course, the value is an average one, the outdoor climate and the building thermal performance are different with Lhasa. But as a contrast value, this number shows the heating energy condition of North China which can be referred as the un-controlled scenario, if applied this value into Lhasa, the heating energy consumption trend can be estimated.

(2) The first local building energy reservation standard is established by the real condition of the field social and economic development, the main purpose is to solve the energy problem when the area transit from the non-central heating area to the central heating area. The standard has the

description of passive design, especially, the envelope design. The heating energy consumption controlling indexes in the local building energy reservation standard is referred here; its value is 16 W/ m^2. It needs to be pointed that the judging value here is the maximum value allowed by the standard, if the design work has a larger value than the limitation, the building cannot be started. This maximum value does not indicate good energy saving effect. In the future, with the technology and financial condition improvement, the value can be limited in a lower level. However, as a contrastive study, 16 W/ m^2 are used to instead of the scenario under energy saving design.

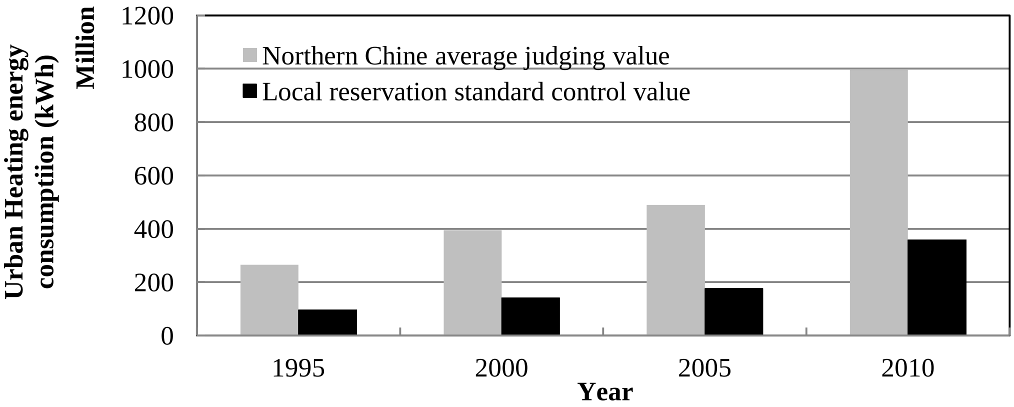
In the real situation, the heating energy consumption is affected by lots of boundary conditions, such as local climate, heating period, building design, envelope thermal performance, indoor temperature, residential building scale and so on. All these factors will be considered in the Chapter 5 for the passive design strategy study. As introduced before, this section shows the heating energy increasing trend which is one proof for the necessity of passive design strategy.

Fig.2-15 shows the heating energy consumption estimate by the two values. Fig.2-15 (a) is calculated by the two judging values multiply the annual newly increased floor space of residential builds in Lhasa. Fig.2-15 (b) is calculated by the two judging values multiply the total residential buildings area in urban area of Lhasa.



(a) Annual increased heating energy consumption

Fig.2-15(1) Heating energy demand estimates in different judging value



(b) Heating energy demand estimate

Fig.2-15(2) Heating energy demand estimates in different judging value

Fig.2-15 (a) shows the annual increased heating energy consumption, from the figure, we can see that compared with the current heating energy consumption which is almost 0 kWh, every year's heating energy consumption have a largely increasing under both judging values. And the heating energy consumption under local standard control value is much lower than that under Northern China average judging value. Fig. 2-15 (b) shows the urban heating energy demand estimate under both judging values. The urban residential building total area is calculated by the urban population multiply the per capita average living areas in Lhasa. This increase is mainly caused by the growth of urban scale and residential building area in the city.

The simple calculation shows that with the urban scale and residential building area growth, the heating energy demand value is largely increased. Compared with the power generating value in Table 2-2, the heating energy consumption by the local standard judging value in 2008 is more than 1/6 of the total power generating value of Tibet in 2008. This is the result of only Lhasa urban population which takes 18.8% of Tibet urban population uses the heating devices.

All in all, the analysis in this section proves the necessity and urgency of the residential building passive design strategy in Lhasa.

2. 4 Conclusions

This chapter mainly analyzed the climate characteristics, energy supply situation, economy and residential buildings development.

Lhasa is the highest provincial capital in China. In general, it has the following climate characteristics: sunshine is abundant, radiation is intense, the diurnal temperature range is large, and the barometric pressure is low, as is the oxygen concentration. The climate characteristics make Lhasa have a long heating demand period, but a not-so-low air temperature. The outdoor air temperature in the hottest month and the coldest month showed that it is enough to consider only heating demand in winter, because summer season is very cool.

These characteristics give the hints that to use the passive solar design will be the first choice of the winter heating demand.

Energy supply condition shows that Lhasa already faced serious power shortage, the under constructed central heating system will accelerate this unbalance energy supply condition. At the same time, the increasing of fossil fuel consumption by social developing cannot be avoided.

The economy analysis shows that Lhasa already started the rapid development procedure. The GRP difference between Lhasa and other big cities in China shows that it is useful to carry on the passive design strategy study and also the economy condition is one important boundary in making passive design strategy.

The development of the residential buildings in Lhasa shows that the passive design strategy is effective for new construction buildings because of continuously increasing of the residential buildings.

References:

[1] National Bureau of Statistics of China, China Energy Statistical Yearbook 2011, Beijing: China Statistics Press. (In Chinese)

[2] The national protection plan for ecological vulnerable areas, available at: http://www.gov.cn/gongbao/content/2009/content_1250928.htm. (In Chinese)

[3] Construction Bureau of Tibet Autonomous Region, Design Standard for Energy Efficiency of Residential Buildings (DB54/0016-2007), Lhasa: Tibetan People Press; 2007 (in Chinese)

[4] Xu Zhihui. The backbone gas network for experimental central heating zone will be completed by this year. Available at: http://www.xdrc.gov.cn/ReadNews.khtml?NewsID=3293

[5] General situation of the Tibet autonomous region, available at: http://www.lasa.ccoo.cn/gaiK/dili.asp (In Chinese)

[6] http://baike.baidu.com/view/2684.htm

[7] Wang, X., & Zheng, M. A. (1999). Tibetan specialties. Tibet: Shanghai People Press. (In Chinese.)

[8] http://baike.baidu.com/view/1153.htm

[9]http://image.baidu.com/i?tn=baiduimage&ct=201326592&lm=-1&cl=2&fr=ala1&word= %D6%D0%B9%FA%B5%D8%D0%CE

[10] http://ditu.google.cn/

[11] Zhang Qingyuan，Joe Huang, Climate data base for building design of China, Beijing: China Machine Press; 2004.(in Chinese)

[12] Liu Jiaping. A. (1996). Architecture physics. Beijing: China. Architecture & Building Press. (In Chinese.)

[13] Liu, S., & Xiong, K. (1994). Solar spectral irradiances and state of atmospheric transparency over Mizuho Station in Antarctica. Acta Scientiarum Naturalium Universitatis Pekinensis, No. 01.

[14] The climate characteristics of Tibet, available at: http://www.sccts.com/tibet/weather.htm

[15] Wind and solar energy resources center of China Meteorological Administration, available at: http://cwera.cma.gov.cn/Website/index.php?WCHID=2

[16] Wang, M., & Guo, X., et al. (2006). Research on hydropower and economic development of the Tibetan Autonomous Region. Hydro-electric power. No.12. (In Chinese.)

[17] Cai Guotian, Zhang Lei, Discussion on energy utilization situation and development in Tibet, Beijing: Energy of China, 2006, 1, pp.38~41 (in Chinese)

[18] National Bureau of Statistics of China, China Energy Statistical Yearbook 2009, Beijing: China Statistics Press. (In Chinese)

[19] Yang Haibin, (et.). Chronicle book of Tibetan electricity industry. Beijing: Minorities Press. (In Chinese)

[20]Tibet will be the biggest solar power generating capacity in China, available at: http://news.xinhuanet.com/electricity/2011-05/09/c_121394807.htm

[21] Li, W., & Da, W. (2008). Sustainable development of rural energy in Tibet-problems and countermeasures. Energy Research and Information, 24(4), 193-205. (In Chinese)

[22] http://www.chinatibetnews.com/caijing/2008-08/07/content_137857.htm

[23] http://www.lrn.cn/media/energynews/power/200911/t20091109_431161.htm

[24] Tibet Autonomous Region Bureau of Statistics, Tibet Statistical Yearbook 2008, Beijing: China Statistics Press. (In Chinese)

[25] National Bureau of Statistics of China, China Energy Statistical Yearbook 2011, Beijing: China Statistics Press. (In Chinese)

[26] Tibet Autonomous Region Bureau of Statistics, Tibet Statistical Yearbook 2011, Beijing: China Statistics Press. (In Chinese)

[27] Jiang, Y. (ed.). (2009, March 30). Report on economy and society development of Tibet. In Xinhua Net retrieved July 2009, available at: http://news.xinhuanet.com/english/2009-03/30/content_11098770_7.htm

[28] http://news.sina.com.cn/c/2007-06-06/052011965908s.shtml

[29] Jiang Yi. China building energy conservation stratagems study. Engineering Sciences. 2011, 06, pp.31~38 (In Chinese)

Chapter 3

3. Current residential building energy demand analysis by field surveys

Chapter 3. Current residential building energy demand analysis by field surveys

As introduced before, after the central heating system completion, the residential buildings in Lhasa will be heated in winter, accordingly, the urban heating energy face huge growth. By the materials from Lhasa government, the main fuel of the central heating system will be natural gas which is supposed to be imported from Xingjian Province [1]. The auxiliary energy is electricity. From the point of view for the environmental load controlling, the heating load needs to be minimized. And also, as the analysis in Chapter 2, the local electricity is mainly from the hydropower plant, in winter, Lhasa’s dry season, there is always outage in these years. So the power supply faces risk. And the import power from inland provinces consumes coal and emits CO_2; this is not a good solution. Therefore, to get the residential building energy saving strategy to minimize the heating load is necessary. Accordingly, current condition of the local residential building is the basic and important material of the research; the information includes the current indoor thermal environment, building thermal performance, unit design, demand of residents, number of home appliances and the daily schedule of the residents. The unit plan and material are the basic information for the passive design characteristics study in Chapter 4, and the family structure, daily schedule are the basic information in the strategy study in Chapter 5. To get the information is the purpose of this chapter.

The field survey is the method to get the information.

Through the twice winter surveys in 2009 and 2010, 8 different families located at different places in Lhasa were surveyed. Eight families can be classified as rural detached house, urban unit-divided apartment and townhouse. In which the unit-divided apartment is the most popular house style in Lhasa. And it is also the research target of latter chapters. The field survey included measurement and the questionnaire. Measurements had the content of indoor air temperature; the questionnaires involved the thermal environment evaluation, the clothing, future requirements of the future dwellings and the daily schedule.

3.1 Basic information of the residential buildings in Lhasa

According to the survey, high-rise buildings in Lhasa are few. Most of the residential buildings in Lhasa are multistoried buildings and low storied buildings. Almost all of the residential buildings in Lhasa face south.

In rural areas, the residential buildings usually composed by a single house and one yard; this is a similar type with the rural residential buildings in other area of northern China. As to the residential buildings in the city, there are two common styles: the unit-divided apartment and the townhouse.

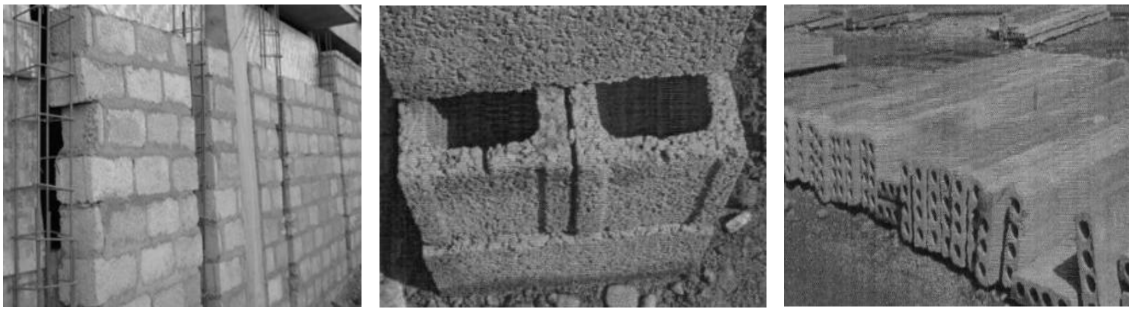
Most of the unit-divided apartments in Lhasa have four floors, three units, and every unit has one stair and two families in one floor. The townhouse here refers to the welfare projects from the local government which is named *An Ju Yuan*. The townhouse usually has two floors and one yard; the area of structure is under 200 m^2, and one separating wall is shared with the neighbor.

These two kinds residential buildings have two mainly structures；1. Brick and concrete structure; 2. Reinforced concrete frame structure.

As for the brick and concrete structure, three kinds of the local materials are used mostly, solid concrete block, shale brick and aerated concrete block, in which the solid concrete block is used mostly in the past decades, the shale brick and aerated concrete block are more popular in the recent years. For the reinforced concrete frame structure, two materials are common, hollow block and aerated concrete block.

Fig. 3-1 shows the common construction materials in Lhasa.

(a) solid concrete block (b) stone brick (c) shale brick



(d) aerated concrete block (e) hollow block (f) precast concrete plank

Fig.3-1 The common construction materials in Lhasa [2]

In the rural area, most the detached houses are one floor style. The old traditional buildings usually used wood-stone structure, as to the new ones, brick and concrete structure is more popular. For almost all the residential buildings in rural area, the envelope is made by stone brick.

No matter in rural area or the urban area, the residential buildings has one obvious characteristic—— the bigger south windows, which means the direct gain system is used. Table 3-1 shows the contrast of the traditional material and the new material.

Table 3-1 Contrast of the traditional materials and the new materials [2]

	Traditional material	New material
Roof	soil	precast concrete plank， poured concrete slab
Ring beam	No	poured concrete
Envelope	Stone brick	solid concrete block, shale brick and so on
Door and window frame	wood	Aluminum alloy, plastic-steel

As for the energy supply in residential buildings in Lhasa, it is mainly from electricity and LPG in the city; in the rural area, the cow dung and LPG are popular. In the near future, there will be two natural gas pipes from Xin Jiang Province which serves the residential buildings in Lhasa. As introduced before, the central heating system for whole city is under construction now. And, there are some single residential districts that already have the heating system.

For better understanding of the local residential buildings, the details of the field surveys are introduced in the following section.

3.2 Field surveys

3.2.1 Introduction of the surveys

Totally 8 families were surveyed in 2009 and 2010.

In 2009, 5 families were surveyed (3 rural families and 2 urban families); in 2010, 4 families were surveyed (4 urban families with one family repetitive). From Fig.3-2 to Fig. 3-8, the basic information like existing time, number of permanent residents, house area, building types, envelope materials, nationality and generations are explained.

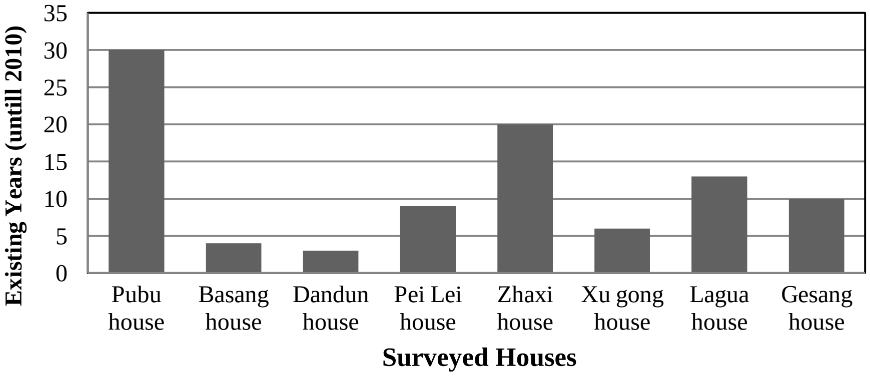
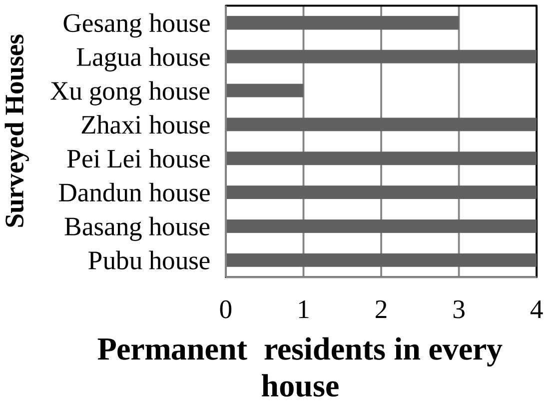


Fig.3-2 Surveyed houses completion time



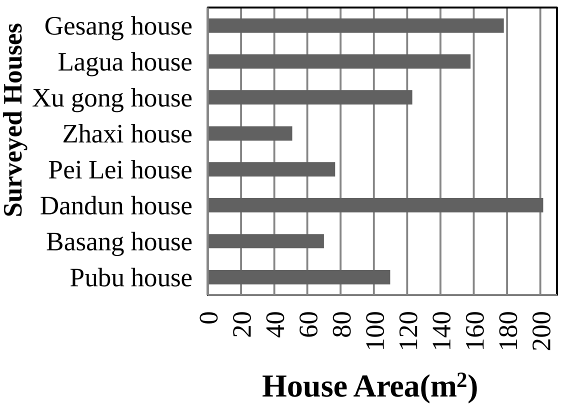
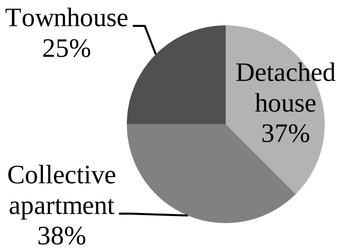


Fig.3-3 Permanent residents in surveyed houses **Fig.3-4 The area of surveyed houses**



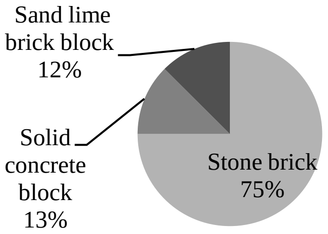
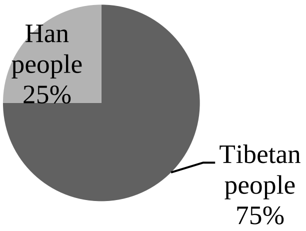


Fig.3-5 Surveyed houses' building types **Fig.3-6 Main material of surveyed houses' walls**



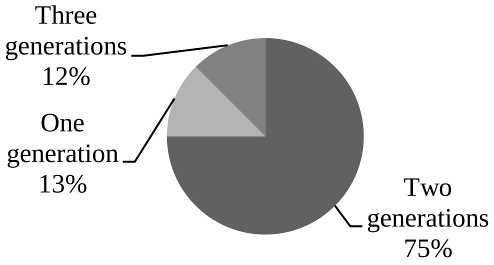


Fig.3-7 Ethnics of surveyed families **Fig.3-8 Generations in surveyed families**

Fig.3-2 shows the existing years from the completion to 2010. Fig.3-3 shows the permanent residents in every house. Fig.3-4 shows the house areas.

Most of the target buildings were built after 1995. 6 families in 8 are 4 people families. As for the floor area, generally, the detached houses and town houses families have bigger area than the apartment families, the details will be analyzed in the following section. Fig.3-5 and Fig. 3-6 show the building types and the main material, respectively. As Fig.3-5 shows, in eight families, there are three detached houses which are all in rural area; there are three collective apartments which are all in urban area; there are two townhouses, which are also in urban area. And as for the envelope, 6 in 8 buildings are stone bricks; the other two buildings, one used solid concrete block, one used sand lime brick block. And all the surveyed buildings used brick and concrete structure. Fig.3-7 shows that in these eight families, there are two Han nationality families, which are Xu Gong family and Pei Lei family, the leftover 6 families are Tibetan families. As the Fig.3-8 shows，there is one family with only one generation, which is Xu Gong; And Gesang family has three generations; the left families have two generations.

For all 8 buildings, there are no heating systems under using during the surveyed period.

3.2.2 Rural residential building survey

Three rural residential buildings are surveyed in 2009. All three rural families are located at the Caigongtang Township, Chengguan District, Lhasa City. These three detached houses all face south. The three families are all Tibetan families. All these three houses use brick and concrete structure. The external walls of these three buildings are made by the stone bricks.

The measurement items include indoor and outdoor air temperatures, and they are measured by the temperature and the humidity automatic recorders. The air temperature was taken hourly. The indoor air temperature measurement was taken in the main rooms of all three dwellings. The measured rooms are marked with the recorder number which is shown in the layout plans.

As for the questionnaire, it is about the residents’ thermal feeling and the Clothes in winter at home.

(1) Pubu house

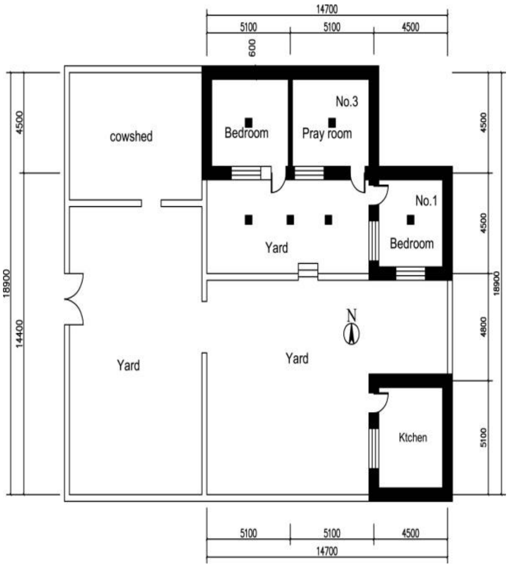
The dwelling was built up in 1980. The structure is wood and stone. This is a typical rural residential building in Lhasa. As to the envelope, all the external walls are 600 mm stone brick, no insulation was used. All the windows in the living area face south, there are no north windows. There are 4 people in this family. The householder is a 39-years old Tibetan woman.

Fig. 3-9 shows the pictures of Pubu house. As the figure shows, in the kitchen, there are two kinds of fuel, cow dung and LPG; except these two kinds fuels, this family has solar cooker.

(a) South picture (b) South windows picture

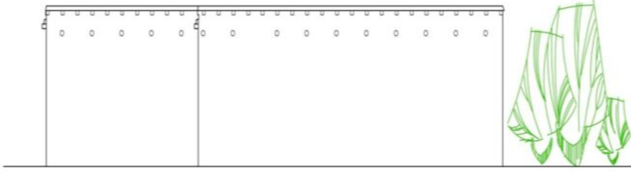
(c) Living room (Pray room) (d) Corner of the Kitchen

Fig. 3-9 Pictures of Pubu house



(a) Layout plan of Pubu house (Unit：mm)

(b) South elevation schematic diagram of Pubu house(Unit：mm)



(c) North elevation schematic diagram of Pubu house

Fig. 3-10 Layout plan and elevation of Pubu house

Fig.3-10 shows the layout plan and the elevation of this dwelling.

Fig.3-11 shows the measurement results. The measurement period was from 11 a.m., Nov. 12, 2009 to 11 a.m., Nov. 24, 2009; totally, 49 hours. The recorder number in Fig.3-11 is marked in Fig.3-10 (a). Recorder number 1 (No.1) shows the recorder in south bedroom. Recording number 3 (No.3) shows the recorder in pray room.

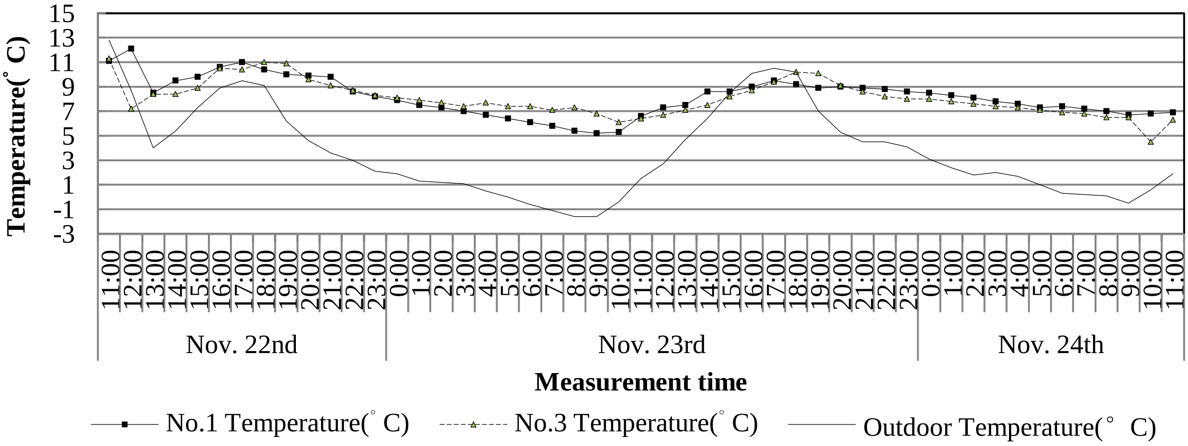


Fig.3-11 Indoor air temperature of Pubu house

As Fig.3-11 shows, the average temperature of No. 3（pray room） is 8.05℃, the minimum temperature is 4.5℃ at 10:00 in Nov.24th, and the maximum temperature is 11.3℃ at 11:00 in Nov.22nd. The average temperature of No. 1(bedroom) is 8.17℃, the minimum temperature is 5.4℃ at 8:00 in Nov.23th, and the maximum temperature is 12.1℃ at 12:00 in Nov.22nd. The average temperature of outdoor is 3.68℃ during the measurement period, the minimum temperature is -1.6℃ at 8:00 in Nov.23th, the maximum temperature is 10.5℃ at 17:00 in Nov.23th.

From the figure, it is easy to see that, during the measurement period, the indoor air temperature is lower than 18℃ which is the indoor setting temperature in winter in the first local building reservation standard [3] [4].

Fig.3-12 shows the indoor thermal environment evaluation of south pray room and south bedroom in Pubu house. In the two rooms, the residents had totally same evaluation. In the figure, from -3 to 3 means the thermal feeling of cold, cool, slightly cool, neutral, slightly warm, warm and hot, respectively.

As the figure shows, during the measurement period, in the morning, 67% votes show -1 which is slightly cool, 33% votes show 0 which is neutral; in the noon time and evening, 100% votes show 0, which is neutral.

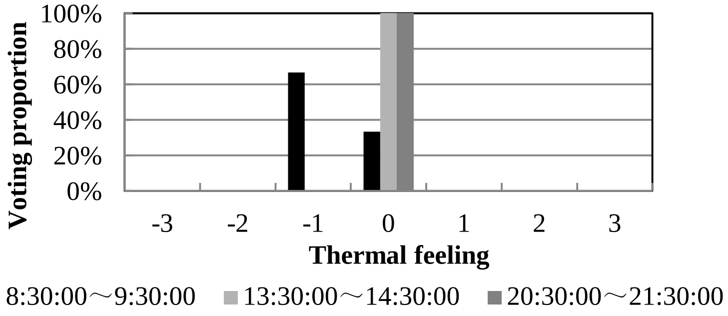


Fig.3-12 Indoor thermal environment evaluation of Pubu house

Table 3-2 shows the clothes of the voter. The 39-years old house master wears underclothes, sweater and the down jacket during the whole measurement period. The indoor cloths of this family is obviously thicker than the people who use central heating system in other places in China, which means the residents need thick clothes for cold indoor environment.

Table 3-2 Indoor clothes of the resident （Pubu house）

Pubu family	Gender	Age	Clothes
Family Member A	Female	39	underclothes+ sweater+ down jacket

Generally, the thermal environment of Pubu house during the measurement period is not good. The resident wear more clothes to cope with cold. However, the residents got used to the indoor thermal environment, with more clothes; they are almost satisfied with the thermal environment, except the midnight and morning. This situation is common in rural area.

(2) Basang house

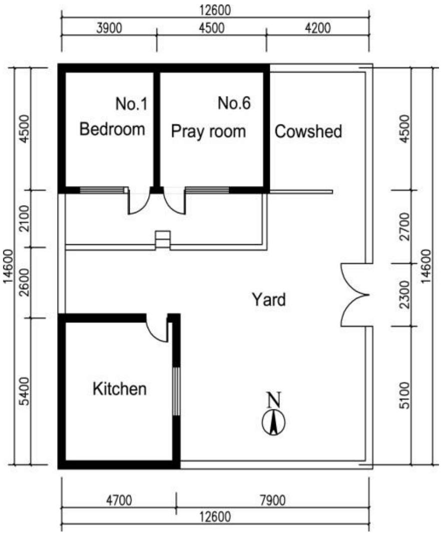
This building was completed in 2006. The structure is brick and concrete. As to the envelope, all the external walls are 300 mm stone brick, no insulation. All the windows face south. There are 4 people living in this building.

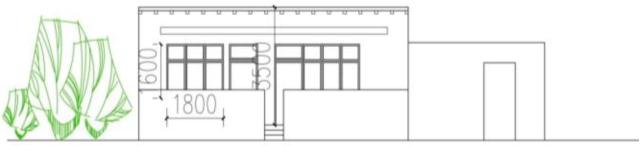
Fig. 3-13 shows the pictures of Pubu house.

(a) South picture (b) Roof picture

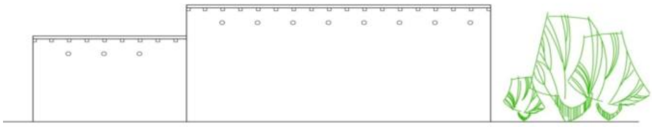
(c) Living room(Pray room) (d) Solar cooker

Fig.3-13 Pictures of Basang house





(b) South elevation schematic diagram of Basang house (Unit：mm)



(c) North elevation schematic diagram of Basang house

(a) Layout plan of Basang house (Unit：mm)

Fig.3-14 Layout plan and elevations of Basang house

Fig.3-14 shows the layout plan and the elevation of this dwelling. We can see from the figure that the south windows of this house also have the big size.

Fig.3-15 shows the measurement results. Same with Pubu house, the measurement period is from 11 a.m., Nov. 12, 2009 to 11 a.m., Nov. 24, 2009. The recorder number in Fig.3-15 is marked in the layout plan in Fig.14 (a). Recorder number 1 (No.1) shows the recorder in south bedroom. Recorder number 6 (No.6) shows the recorder in the pray room.

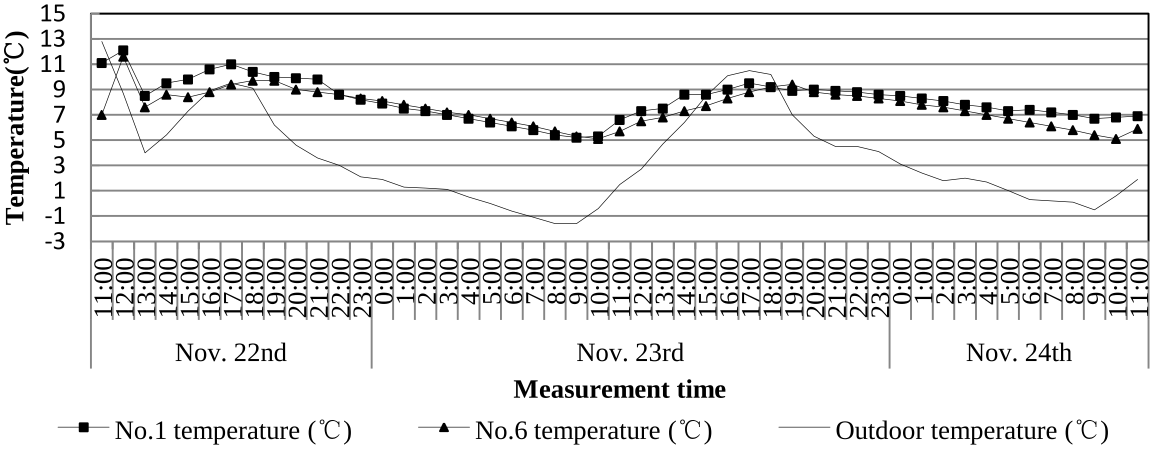


Fig.3-15 Indoor air temperature of Basang house

As Fig.3-15 shows, the average temperature of No. 1 (Bedroom) is 8.17 ℃, the minimum temperature is 5.2 ℃ at 9:00 in Nov.23th, and the maximum temperature is 12.1℃ at 12:00 in Nov.22nd. The average temperature of No. 6 (Pray room) is 7.58 ℃, the minimum temperature is 5.1 ℃ at 10:00 in Nov.23th and Nov.24th, the maximum temperature is 11.6 ℃ at 12:00 in Nov.22nd.

Fig.3-16 shows the indoor thermal environment evaluation of south bedroom in Pubu house. The voter is a 18 years-old girl. As the figure shows, during the measurement period, in the morning, 100% votes show 0, which means neural; in the noon time，25% of the votes show 0 and 75% votes show 1 which means slight warm; and in the evening, 75% votes show 0, and 25% show 1.

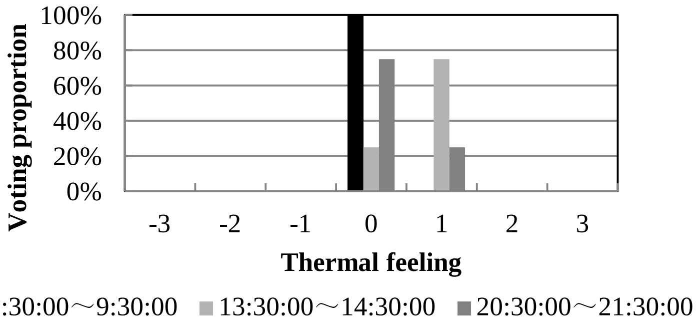


Fig.3-16 Indoor thermal environment evaluation of Basang house

Table 3-3 Indoor clothes of the residents (Basang house)

Basang family	Gender	Age	Clothes
Family Member A	Female	18	underclothes+ sweater+ down jacket

Table 3-3 shows the indoor clothes of the voter. The voter’s clothes are quite similar with Pubu house.

Generally, the thermal environment of Pubu house during the measurement period is similar with Pubu house, and the indoor air temperature has a slightly increasing, but still not well. However, as Fig.3-16 and Table 3-3 show, the resident can wear more clothes to cope with cold, and in the noon time, because of the strong solar radiation, the voter even feel slight warm.

(3) Dandun house

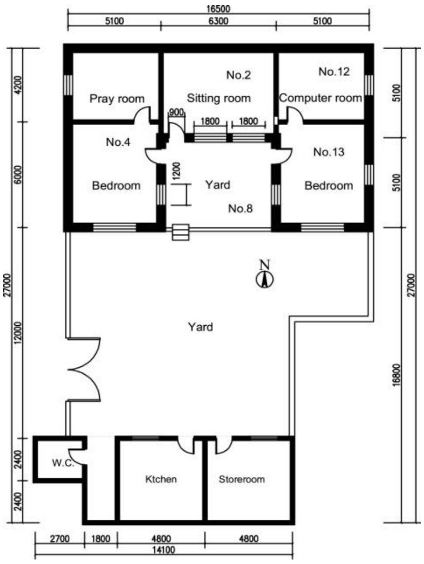
The building was completed in 2007. The structure is brick and concrete. As to the envelope, all the external walls are 500 mm stone brick, no insulation. There are 4 people living in this house.

Fig. 3-17 shows the pictures of Dandun house. Fig. 3-17 (a) is the south picture of the building; Fig.3- 17 (b) shows the south window picture; Fig.3-17 (c) shows the living room; Fig. 3-17 (d) shows the solar cooker; Fig.3-17 (e) shows the stove and cow dung. As introduced formerly, cow dung and LPG are the two main fuels in this family.

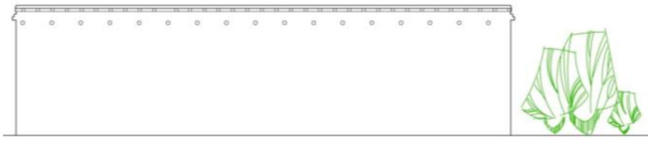
(a) South picture (b) windows picture

(c) Living room (d) Solar cooker (e) stove and cow dung

Fig. 3-17 Pictures of Dandun house



(b) South elevation schematic diagram of Dandun house (Unit：mm)



(c) North elevation schematic diagram of Dandun house

(a) Layout plan of Dandun house (Unit：mm)

Fig. 3-18 Layout plan and elevation of Dandun house

Fig.3-18 shows the layout plan and the elevation of Dandun house. Fig.3-19 shows the measurement results. The measurement period is from 11 a.m., Nov. 22, 2009 to 11 a.m., Nov. 24, 2009.

The recorder number in Fig.3-19 is marked in Fig.3-18(a). Recorder number 2 (No.2) shows the recorder in south living room; recorder number 4 and 13 show the recorders in two south bedrooms, respectively; recorder number 12 shows the recorder in north computer room.

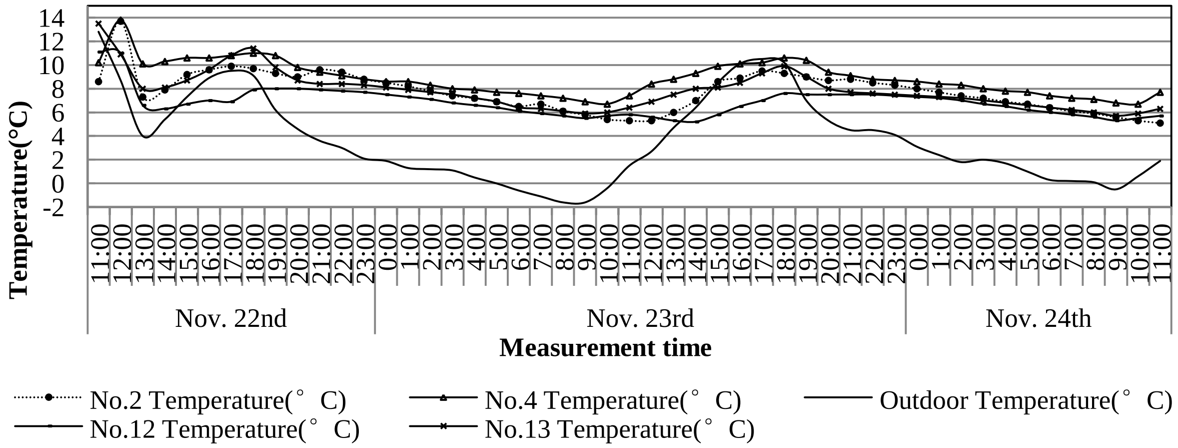


Fig.3-19 Indoor air temperature of Dandun house

As the figure shows, the average temperature of No. 4 (south bedroom) is the highest one among all the measured rooms, it is 8.84℃; the minimum temperature of this room is 6.7 ℃ at 11:00 in Nov.23, and the maximum temperature is 13.8 ℃ at 12:00 in Nov.22nd.

And, the average temperature of No.12 (Computer room, north) is the lowest one among all the measured rooms, the value is 6.8℃, the minimum temperature of this room is 5.2℃ at 14:00 in Nov.23th and Nov.24th, the maximum temperature is 11.1℃ at 11:00 in Nov.22nd.

Fig.3-20 shows the indoor thermal environment evaluation of south bedroom (No.4). The information of the voter is shown in Table 3. As Fig.3-20 shows, during the measurement period, in the morning, 67% voters feel slight cool, 33% voters feel neutral; in the noon time，100% of the voters feel neutral; And in the evening, half voters feel slight cool, and the other half voters feel neutral.

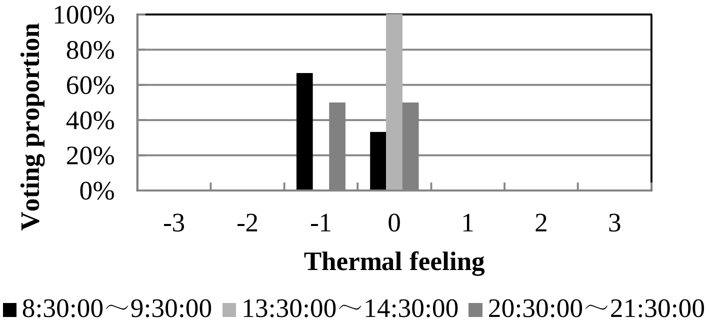


Fig.3-20 Indoor thermal environment evaluation of Dandun house

Table 3-4 Indoor clothes of the residents (Dandun house)

Basang family	Gender	Age	Clothes
Family Member A	Female	15	thermal underclothes+ sweater+ heavy jacket
Family Member B	Female	40	underclothes+ sweater+ down jacket

Table 3-4 shows the Clothes of the voter. The voter’s clothes of three houses are similar.

Generally, the thermal environment south bedroom of Dandun house during the measurement period is a little better than Pubu and Basang house, but still not well.

From the survey cases, the new completion house had relatively higher indoor air temperature. However, the indoor air temperature difference among three houses is not too big, for the south bedroom, the average temperatures of the three houses are all around 8℃，which is obviously lower than the indoor calculation temperature——18℃ in the local building energy saving standard [4]. However, the clothes and thermal feeling questionnaires showed that with thick clothes, the local residents can cope with cold. But with the local people’s living standard improving in the future, once the heating devices are used, the current buildings need to be refit for the purpose of energy saving.

3.2.3 Unit-divided apartment survey

Three apartments are introduced in this section. The apartments are all located at the center of the Lhasa City. These three buildings’ structures are all brick and concrete structure. The measurement rooms are marked with the recorder number which is shown in the layout plans. The measurement items are same with the rural buildings. Moreover, the questionnaire is about their thermal feeling and the clothes. In addition, one typical family was surveyed for the information of daily schedule.

The measurements were taken in two years, 2009 and 2010.

1. 2009 survey

Two urban families were surveyed in 2009; the measurement period is from 12:00 a.m. Nov. 25, 2009 to 16:00, Nov. 27, 2009.

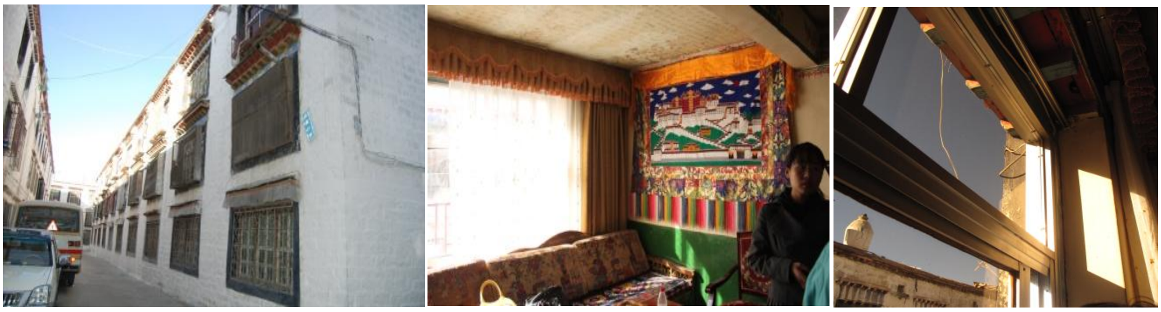
(1) Zhaxi house

The building of Zhaxi home is located at Chengguan district, Lhasa city, it was built up in 1990. All the external walls are 450 mm stone brick, no insulation, and the internal walls are 210 mm stone brick. There are 3 people living in this house. This family is Tibetan family. The area of Zhaxi house is 50.78 m^2. This apartment is rent from the local government.

Fig.3-22 shows the layout plan, external wall section plan and location diagram in the building.

Table 3-5 Basic information ot Zhaxi house

Completion time	1990
Structure	brick and concrete structure
Material of envelope	450 mm stone brick
Floor	Third floor (totally 3 floors)
Area	50.78 m^2
permanent residents	Couple and niece（3 people）

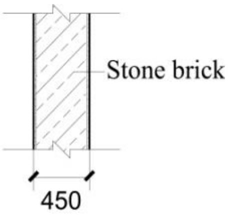


(a) North picture of the building (b) Living room picture (south) (c) South windows

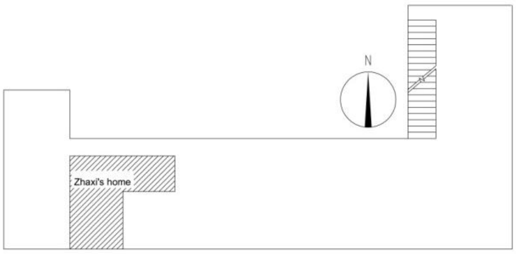
Fig.3-21(1) The pictures of Zhaxi house

(d) North picture of the building (e) North bedroom (f) Corner of the kitchen

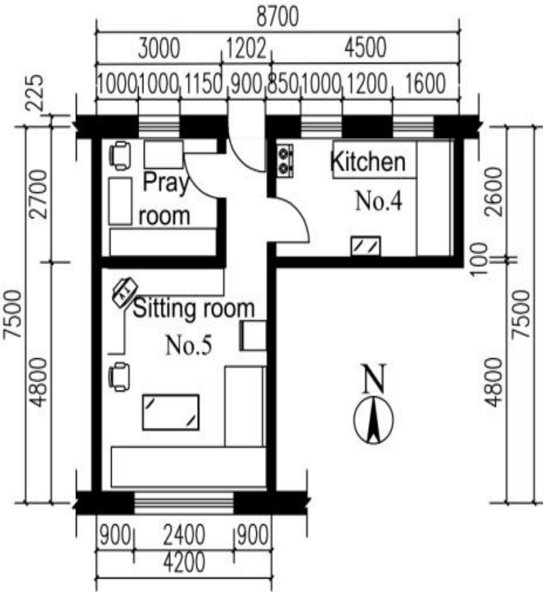
Fig.3-21(2) The pictures of Zhaxi house



(b) Section plan of the external wall
(Unit：mm)



(c)Location diagram of Zhaxi hose



(a) Layout plan of Zhaxi apartment (Unit：mm)

Fig.3-22 The layout plan, external wall section plan and location diagram of Zhaxi house

Fig.3-23 shows the measurement results. As figure shows, the average temperature of No. 5 (Living room, south) is 9.8 ℃, the minimum temperature is 7.8℃ at 10:00 in Nov.27th; the maximum temperature is 11.7 ℃ at 15:00 in Nov.27th. The average temperature of No. 4 (Kitchen, north) is 7.49 ℃, the minimum temperature is 6.1 ℃ at 13:00 in Nov.27th, and the maximum temperature is 8.6 ℃ at 1:00 in Nov.27th, south and north rooms have big temperature difference.

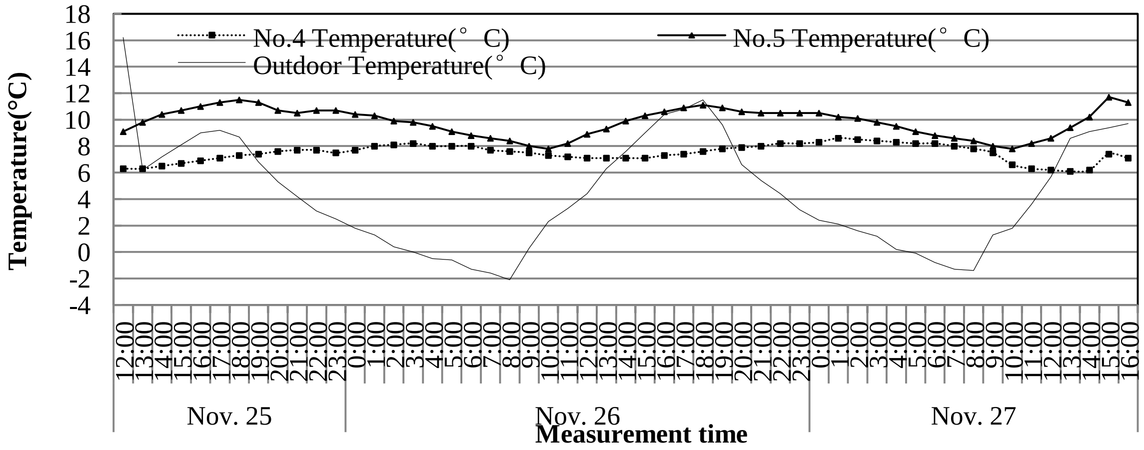
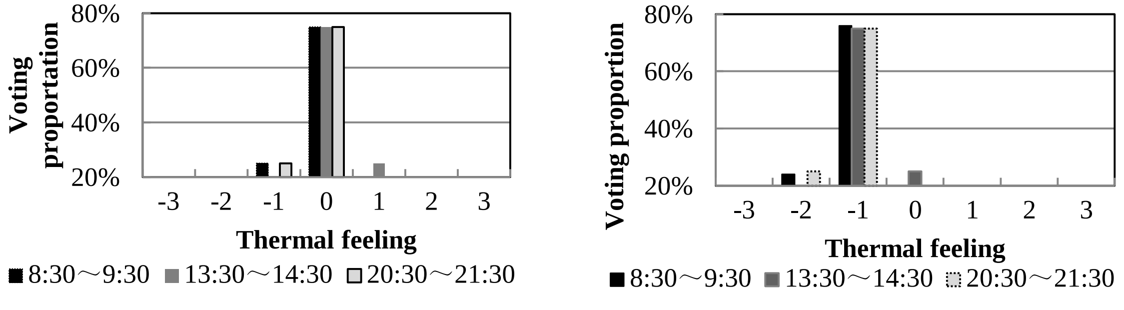


Fig.3-23 Indoor air temperature of Zhaxi house



(a). Evaluation of the Sitting room (b). Evaluation of the Kitchen

Fig.3-24 Indoor thermal environment evaluation of Zhaxi house

Fig.24 shows the indoor thermal environment evaluation. As Fig.24 shows, in this house, during the measurement period, in the morning from 8：30 to 9：30, in the sitting room, 75% occupant’s felt slightly cool and 25% felt neutral; in the kitchen, 75% occupant’s felt cold and 25% felt slightly cool. At noon from 13： 30 to 14： 30, in the sitting room, 75% occupants felt neutral and 25% felt slightly warm; in the kitchen, 25% occupants felt neutral and 75% felt slightly cool. At night from 20:30 to 21:30, in the sitting room, 25% occupants felt slightly cool and 75% felt neutral, in the kitchen, 25% occupant’s felt cold and 75% felt slightly cool.

Table 3-6 shows the indoor clothes of the voters, as the table shows, the indoor clothes of this family is similar with the rural residents. The residents in this house also need thick clothes to cope with cold.

Table 3-6 Indoor clothes of the residents (Zhaxi house)

Zhaxi family	Gender	Age	Clothes
Family Member	Male	22	Under Clothes+ sweater+ heavy jacket
Family Member	Male	45	thermal under Clothes+ sweater+ down jacket

c

Different with the former surveyed cases, the home appliances in the urban house are studied. As we know, home appliances are one important part of the urban houses energy consumption. Table 3-7 shows the home appliances of Zhaxi house.

Table 3-7. Home appliances of Zhaxi house

Kitchen appliance	Electric cooker, refrigerator;
cooking energy	liquefied petroleum gas
Heating devices	-
Shower devices	-
Lighting	3 daylight lamps
Others	TV, DVD player

Another different item in the questionnaire survey is that the residents in this family hope to use central heating system to improve the indoor thermal environment in winter.

(2) Pei Lei house

The building of Pei Lei home was finished in 2001. This family is Han nationality family. This is a typical urban residential building in Lhasa. As to the envelope, all the external walls are 240 mm solid concrete block, no insulation. Table 3-8 shows the basic information of Pei Lei house.

Table 3-8 Basic information of Pei Lei house

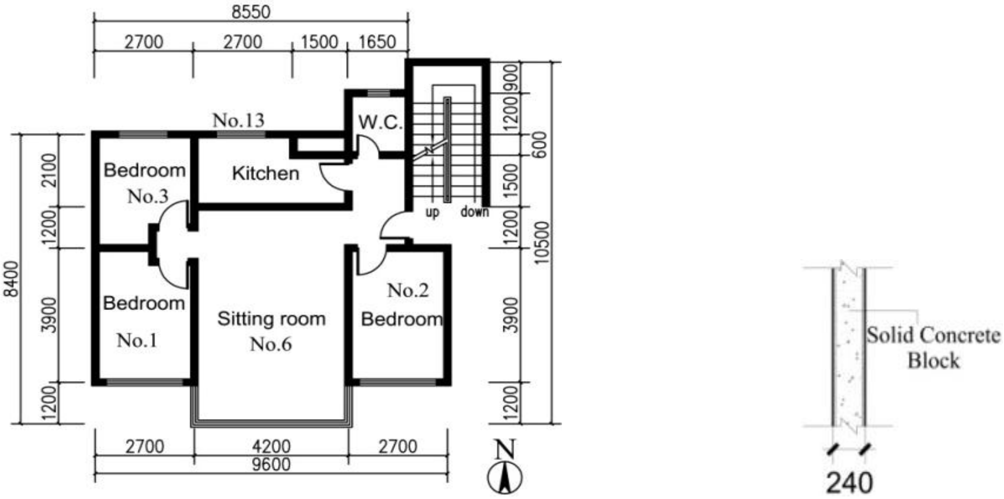
Completion time	2001
Structure	Concrete and brick structure
Material of envelope	240mm brick
Floor	Third floor (totally 4 floors)
area	76.56 m^2
permanent residents	Couple and children（4 people）

Fig. 3-25 shows the pictures of Pei Lei house.

(a) South picture of the building (b) living room picture (south)

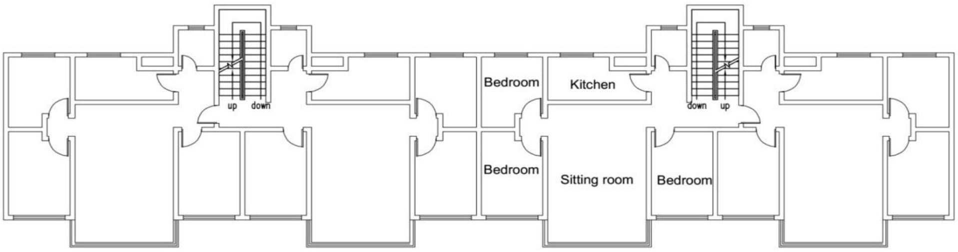
(c) North side of the building (d) LPG bottle in the kitchen (e) Solar water heater in the roof

Fig.3-25 Pictures of Pei Lei house



(a) Layout plan of the Pei Lei family (Unit：mm) (b) Section plan of the envelope (Unit：mm)

Fig.3-26(1) The layout plan, ex-wall section plan and standard floor diagram of Pei Lei house



(c) Standard floor schematic diagram of the building

Fig.3-26(2) The layout plan, ex-wall section plan and standard floor diagram of Pei Lei house

Fig.3-26 shows the layout plan, external wall section plan and location diagram of Pei Lei house. Fig.3-27 shows the measurement results of air temperature. The measurement period is same with rural houses.

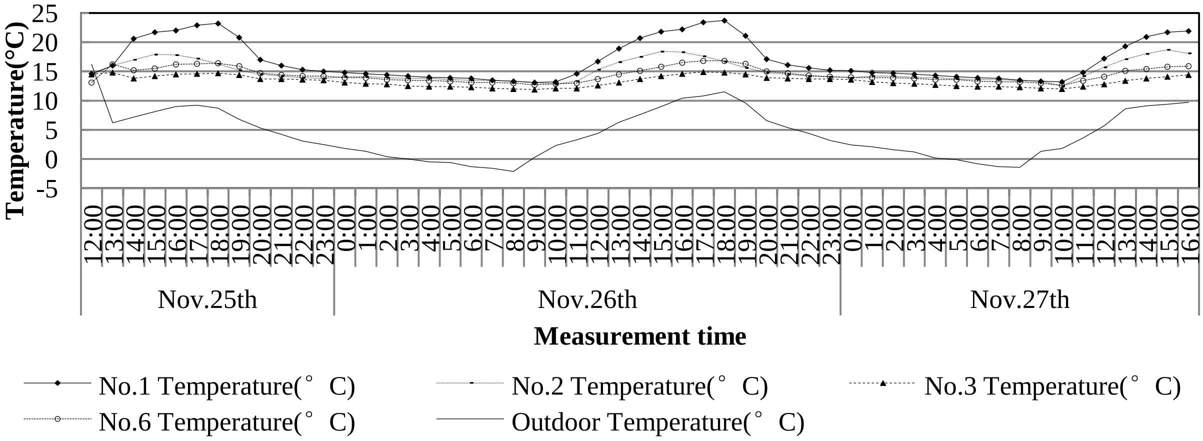
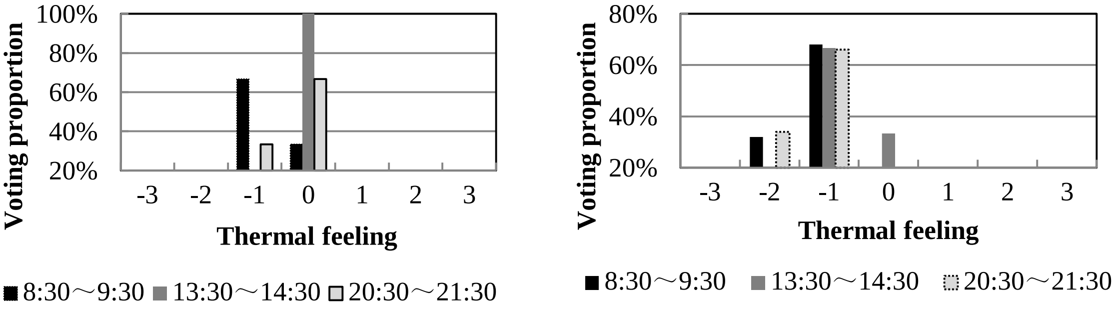


Fig.3-27 Indoor air temperature of Pei Lei house

As shown in Fig.3-27, the highest average temperature of the four measured rooms is No. 1 (south bedroom). The average temperature of No. 1 is 17.01 ℃, the minimum temperature is 13.1 ℃ at 9:00 in Nov.26th, and the maximum temperature is 23.7 ℃ at 18:00 in Nov.26th. The lowest average temperature of the four measured rooms is No. 3 (Bedroom, north). The average temperature of No. 3 is 13.34 ℃, the minimum temperature is 11.9℃ at 9:00 in Nov.26th, and the maximum temperature is 14.8 ℃ at 13:00 in Nov.25th. At the same time, the average temperature of outdoor is 4.47℃, the minimum temperature is -2.1℃ at 8:00 in Nov.26th, the maximum temperature is 16.1℃ at 12:00 on Nov.25th.



(a). Evaluation of the Sitting room (b). Evaluation of the Kitchen

Fig.3-28 Indoor thermal environment evaluation of Pei Lei house

As the thermal evaluation in Fig.3-28 shows, in this house, during the measurement period, in the morning from 8：30 to 9：30, in the sitting room, 66% occupants felt slightly cool and 34% occupants felt neutral; in the north bedroom, 33% occupant felt cold and 67% felt slightly cool.

At noon from 13：30 to 14：30, in the sitting room, 100% occupants felt neutral; in the north bedroom, 33% occupant felt neutral and 67% felt slightly cool.

At night from 20:30 to 21:30, in the sitting room, 33% occupant felt slightly cool and 67% felt neutral, in the north bedroom, 33% occupant felt cold and 67% felt slightly cool.

From the voting results, the occupants of Zhaxi house are almost satisfied with the thermal environment of sitting room, but not satisfied with the north room. By the questionnaire, the residents in this family hope to use central heating system to improve the indoor thermal environment in winter.

Table 3-9 shows the voter’s indoor clothes during the measurement period.

Table 3-9 Indoor clothes of the residents (Pei Lei house)

Pei Lei house	Gende	Age	Clothes
Family Member	Male	22	shirt+ long overcoat
Family Member	Male	45	underclothes+ coat
Family Member	Femal	33	thermal underclothes+ sweater+ long overcoat

Table 3-10 shows the home appliances of Pei Lei house, compared with the Zhaxi house, the home appliances in this family are more multiple and comprehensive. For entertainment, they use TV, DVD player and stereo equipment; and the kitten appliances are same with Zhaxi house. But this family has air conditioner for heating in winter and solar water heater for bathing. The air conditioner was installed in the sitting room, according to the interview; it was not used too much. As to the shower, generally speaking, they took bathing once a week by the solar water heater. Recently, for the young generation, they took showers three or four times a week. According to the questionnaire, the young generation of Tibetan people has a different lifestyle compared with the elder generation; the modern lifestyle is more popular among them.

With more home appliances, this family consumes more energy for daily life. The occupants hope to move to the apartment with bigger area, and also, they hope to use central heating system.

Table 3-10 Home appliances of Pei Lei house

Kitchen appliances	Electric cooker, refrigerator, micro oven;
cooking energy	liquefied petroleum gas
Heating devices	Air conditioner
Shower devices	Solar water heater
Lighting	7 daylight lamps
Others	TV, DVD player, stereo equipment

To make a comparative analysis of two urban families measured in 2009, the big differences of the indoor air temperature are obvious. The average temperatures of Zhaxi during the measurement period are listed as the following: recorder No.5 (south room), 9.82 ℃; No.4 (north room), 7.49 ℃. And, the results of Pei Lei are shown as: recorder No.1 (south room), 16.91 ℃ (south room); No.2 (south room), 15.03 ℃; No.6 (south room), 14.38 ℃ and No.3 (north room), 13.32 ℃.

Pei Lei house is a typical urban residential building style; and this is a new building. Although it does not have insulation, the designer uses big south windows and the sunroom to improve the indoor thermal environment. The measurement proves the effectiveness of the passive design idea.

Besides the thermal feeling and the home appliances questionnaire, the daily schedule is also interviewed in this family. Table 3-11 shows the weekday's daily schedule. Table 3-12 shows the weekend's daily schedule.

Table 3-11 Daily schedule of Pei Lei house in weekdays

	Householder		Wife		Daughter		Son	
	Behavior	**Room**	**Behavior**	**Room**	**Behavior**	**Room**	**Behavior**	**Room**
7:00	Sleep	Master bedroom	Sleep	Master bedroom	Wash and rinse	Rest room	Wash and rinse	Rest room
7:30	Sleep		Sleep		Breakfast	Living	Breakfast	Living room
8:00	Wash and rinse	Rest room	Wash and rinse	Rest room	Study	School	Study	School
8:30								
9:00	Work	Workplace	Shopping					
9:30								
10:00			Clean	Whole house				
10:30								
11:00			Rest	Living room				
11:30								
12:00			Cooking	Kitchen				
12:30								
13:00	Lunch	Living room	Lunch	Living room	Lunch	Living	Lunch	Living room
13:30	Lunch				Lunch	Living	Lunch	Living room
14:00	Rest	Master bedroom	Rest		Rest	Daughter bedroom	Rest	Son bedroom
14:30	Rest		Rest		Rest		Rest	
15:00	Work	Workplace	Entertain		Study		Study	
15:30								
16:00								
16:30								
17:00								
17:30								
18:00			Cooking	Kitchen				
18:30			Cooking	Kitchen				
19:00	Dinner	Living room	Dinner	Living	Dinner	Living room	Dinner	Living room
19:30	Dinner		Clean	Kitchen	Dinner		Dinner	
20:00	TV	Living room	TV	Living room	Study	Son bedroom	Study	Son bedroom
20:30								
21:00								
21:30								
22:00								
22:30	Reading	Master bedroom			Wash and rinse	Rest room	Wash and rinse	Rest room
23:00					sleep	Bedroom	sleep	Bedroom
23:30	Wash and rinse	Bedroom	Wash and rinse	Rest room				
0:00	Sleep	Master bedroom	Sleep	Master bedroom				

Table 3-12 Daily schedule of Pei Lei house in weekend

	Householder		Wife		Daughter		Son	
	Behavior	**Room**	**Behavior**	**Room**	**Behavior**	**Room**	**Behavior**	**Room**
10:00	Wash and rinse	Rest room	Wash and rinse	Rest room	Sleep	Daughter bedroom	Sleep	Son bedroom
10:30	TV	Living room	Clean	Whole house	Shower	Rest room		
11:00			Clean	Whole house	TV	Living room	Shower	Rest
11:30			Clean	Whole house			TV	Living room
12:00			Cooking	Kitchen			TV	
12:30			Cooking	Kitchen			TV	
13:00	Lunch		Lunch	Living room	Lunch		Lunch	
13:30	Lunch		Lunch		Lunch		Lunch	
14:00	TV		Shower	Rest room	TV		Reading	
14:30			Shower	Rest room	TV			
15:00			shopping		Go out		Go out	
15:30								
16:00	Go out							
16:30								
17:00								
17:30								
18:00								
18:30			Cooking	Kitchen				
19:00								
19:30	Dinner	Living room	Dinner	Living room	Dinner	Living room	Dinner	Living room
20:00								
20:30	Entertain		Clean	Kitchen	Homework	Daughter bedroom	Homework	Son bedroom
21:00			Entertain	Living room				
21:30					TV	Living room	TV	Living room
22:00								
22:30	Wash and rinse	Rest room	Wash and rinse	Rest room	Sleep	Daughter bedroom	Sleep	Son bedroom
23:00	Sleep	Master bedroom	Sleep	Master bedroom				

2. 2010 survey

Two urban families were surveyed in 2010. The measurement time of two apartments was from 12:00 am, October 25, 2010 to 18:00, October 27, 2010.

(1) Xu Gong house

The building was finished in 2004. The structure is brick and concrete structure. The measured unit is at the 3rd floor. Its area is 123.03 m^2. There is only one people living in this apartment. Table 3-13 shows the basic information of Xu Gong house; Fig.3-29 shows the pictures of this house. Fig.3-30 shows the layout plan, external wall section plan and location diagram of Xu Gong house.

It needs to be pointed out that the ex-walls of this building have different thickness. The south direction ex-wall use 240mm sand lime brick block and the other direction ex-wall use 370mm sand lime brick block. According to my study in the master thesis, the strong solar radiation can give compensation to the heat loss caused by the indoor and outdoor temperature difference. In the four directions ex-walls, the south side absorbs the most abundant solar energy in the day time, so, the compensation of solar radiation can be used to instead part of the ex-wall thermal resistance. This is also called non-balanced insulation. And Xu Gong house is one real example of the non-balanced insulation.

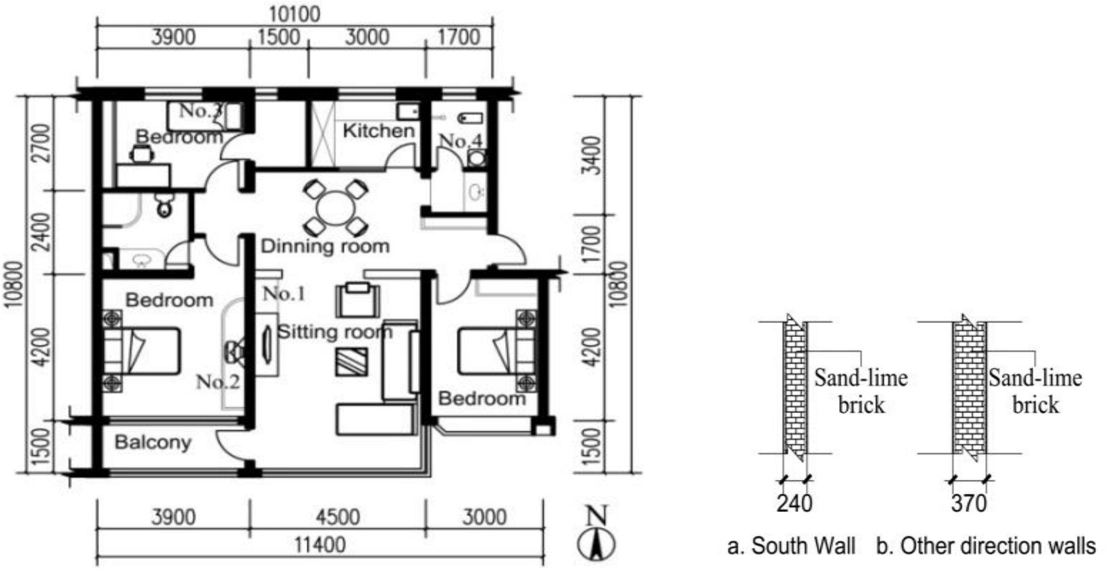
Table 3-13 Basic information of Xu Gong House

Completion time	2004
Structure	Brick and concrete structure
Material of envelope	370mm/240mm sand lime brick block
Floor	Third floor (totally 4 floors)
area	123.02 ㎡
permanent residents	One

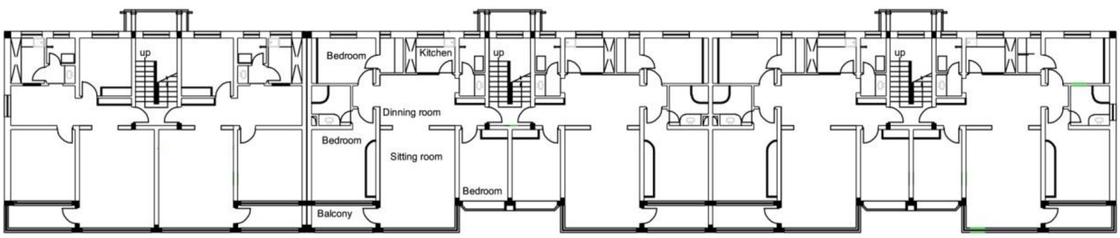
(a) South picture of the building (b) living room picture (south) (c) sunroom picture

(d) North picture of the building (e) remote of the solar water heater (f) LPG in kitchen

Fig. 3-29 Pictures of Xugong house



(a) Layout plan of the Pei Lei family (Unit：mm)　　(b) Section plan of the envelope (Unit：mm)



(c) Standard floor schematic diagram of the building

Fig.3-30(2) Layout plan, ex-wall section plan and standard floor diagram of Xu Gong house

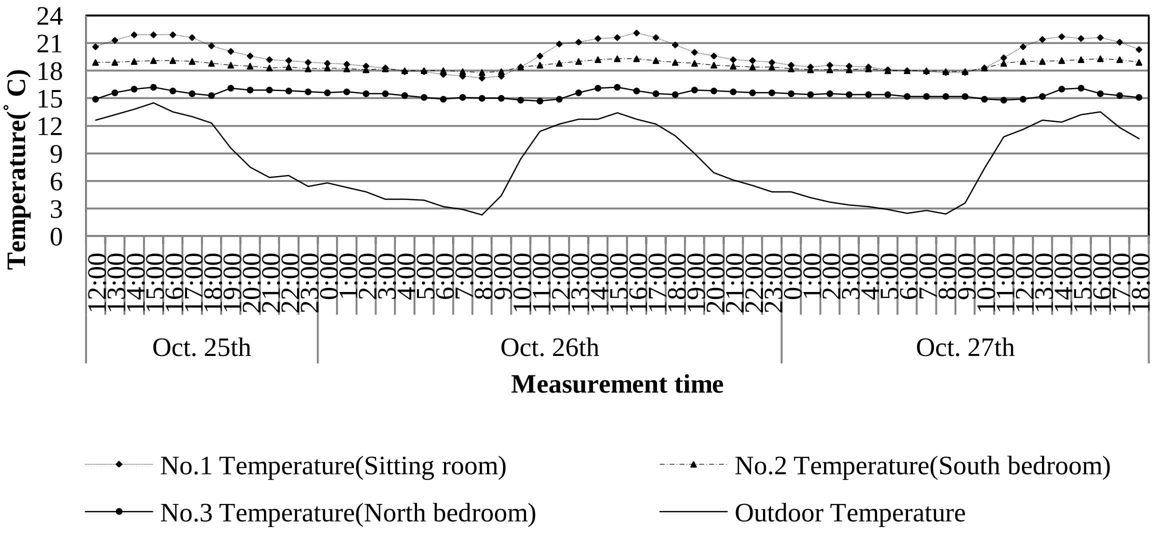
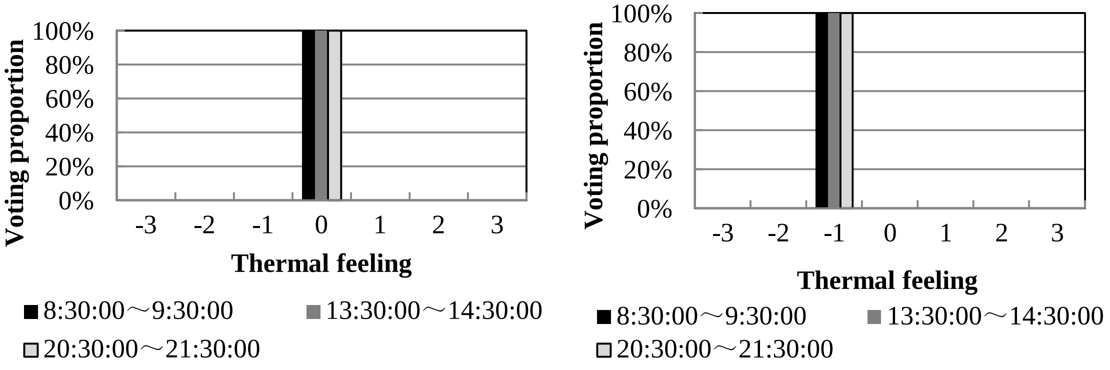


Fig.3-31 Indoor air temperature of Xu Gong house

Fig.3-31 shows the measurement results.

As shown in Fig.3-31, the highest average temperature of the four measured rooms is No.1(sitting room, south). The average temperature of No. 1 is 19.4 ℃, the minimum temperature is 16.8 ℃ at 8:00 in Nov.25th, and the maximum temperature is 22.1℃ at 16:00 in Nov.26th. The lowest average temperature of the four measured rooms is No.3 (Bedroom, north). The average temperature of No. 3 is 15.55℃, the minimum temperature is 14.7 ℃ at 11:00 in Nov.26th, and the maximum temperature is 17℃ at 16:00 in Nov.26th. At the same time, the average temperature of outdoor is 8.09℃, the minimum temperature is 2.3℃ at 8:00 in Oct.26th, and the maximum temperature is 14.5℃ at 15:00 on Oct.25th.



(a). Evaluation of the Sitting room (south)　　(b). Evaluation of the north bedroom

Fig.3-32 Indoor thermal environment evaluation of Xu Gong house

As the indoor thermal evaluation in Fig.3-32 shows, in this house, during the measurement period, for the south sitting room, the voter always felt neutral for all three times evaluation in one day; as to the north bet room, the voter always felt slight cool for all three times evaluation in one day. So, Xu Gong is satisfied with the sitting room (south). However, the north bedroom cannot satisfy him. By the questionnaire, the residents hope to use central heating system in winter.

Table 3-14 shows the voter's clothes during the measurement period. The indoor clothes of the resident in this house is thinner than the former surveyed houses.

Table 3-14 Indoor clothes of the residents (Xu Gong house)

Xu Gong	Gender	Age	Clothes
Family	Male	44	shirt+ unlined trousers

Table 3-15 shows the home appliances of Xu Gong house. Compared with the former two urban families, this family has more home appliances. For entertainment, they use TV, DVD player and stereo equipment and laptop; as to appliance in kitchen, they use induction cooker, drinking fountain, electric cooker, and refrigerator. However, this family does not have air conditioner. Solar water heater is used for bathing. According to the questionnaire, even the occupants feel satisfied with the south rooms, he still hope to use central heating system as soon as possible for better indoor thermal comfort.

Table 3-15 Home appliances of Xu Gong house

Kitchen appliance	Electric cooker, refrigerator, ventilator, induction cooker, drinking fountain;
cooking energy	liquefied petroleum gas
Heating devices	-
Shower devices	Solar water heater
Lighting	9 daylight lamps
Others	TV, DVD player, stereo equipment, computer

(2) Zhaxi house

Zhaxi house is a reparative target. The pictures of this house is shown in Fig.3-21; the basic information of this house is shown in Table 3-5; the layout plan, external wall section plan and location diagram are shown in Fig. 3-22; The home appliances are shown in Table 3-7. All these information is same, so it will not be repeated here.

Fig.3-33 shows the measured indoor air temperature results. Fig.3-34 shows the evaluation of the indoor thermal comfort.

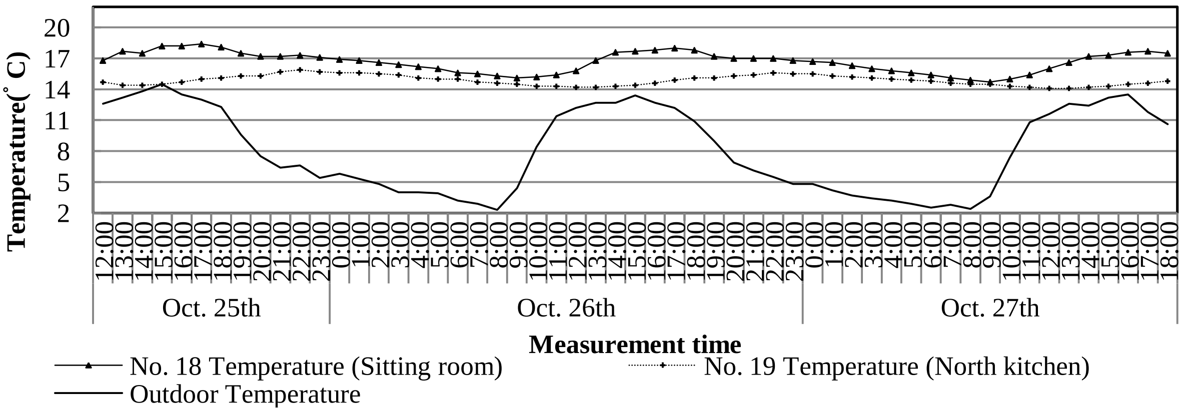
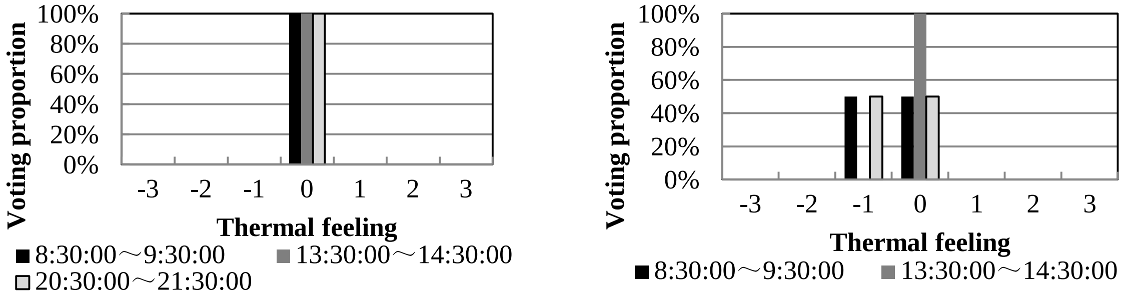


Fig. 3-33 Indoor air temperature of Zhaxi house (2010)

As Fig.3-33 shows, the indoor temperature of Zhaxi house is listed as the following: sitting room(south), 16.66°C; kitchen (north), 14.86°C; pray room(north), 14.41°C. As the same time, as shown in Fig.3-31, the average temperatures of the Xu Gong house during the measurement period are listed as: recorder No.1 (south room), 19.62°C; No.2 (south room), 18.55°C; No.3 (north room), 15.46°C. During the measurement period, the outdoor air temperature is 8.09°C in average. The indoor air temperature of Xu Gong house is higher than Zhaxi house, which means new material and the efficient passive design can improve the indoor environment efficiently.



(a). Evaluation of the Sitting room (south) (b). Evaluation of the kitchen (north)

Fig.3-34 Indoor thermal environment evaluation of Zhaxi house (2010)

As the indoor thermal evaluation in Fig.3-34, in this house, during the measurement period, for the south sitting room, the voter always felt neutral; as to the north kitchen, in the morning time from 8:30 to 9:30, half votes show slight cool, and half shows neural; at the noon time from 13:30

to 14:30, 100 % votes shows neural; and in the evening from 20:30 to 21:30, half votes show slight cool, and half shows neural.

The thermal evaluations of the both families in 2010 show better results than 2009, this is because the measurement time of 2010 is in October and in 2009, it was November. The outdoor air temperature is different. But for the two houses in 2010, they have the same climate condition; Xu Gong house had higher indoor air temperature than Zhaxi house.

Table 3-16 shows the indoor clothes during the measurement time.

Table 3-16 Indoor clothes of the residents in Zhaxi house

Zhaxi house	Gender	Age	Clothes
Family Member A	Male	22	shirt+ coat
Family Member B	Female	45	underclothes+ coat

And above all, the 2010 survey shows that along with the more scientific design, the indoor thermal environment is getting better. And for both families, the south rooms have obviously higher temperature than the north room.

3.2.4 Town house survey

In 2010, the two townhouses, Gesang house and Lagua house, were surveyed. These two families are both Tibetan families. The measurement period was from 21:00, Oct. 25 to 17:00, Oct. 27.

(1) Gesang house

Table 3-17 shows the basic information of Gesang house. Fig.3-35 shows the pictures.

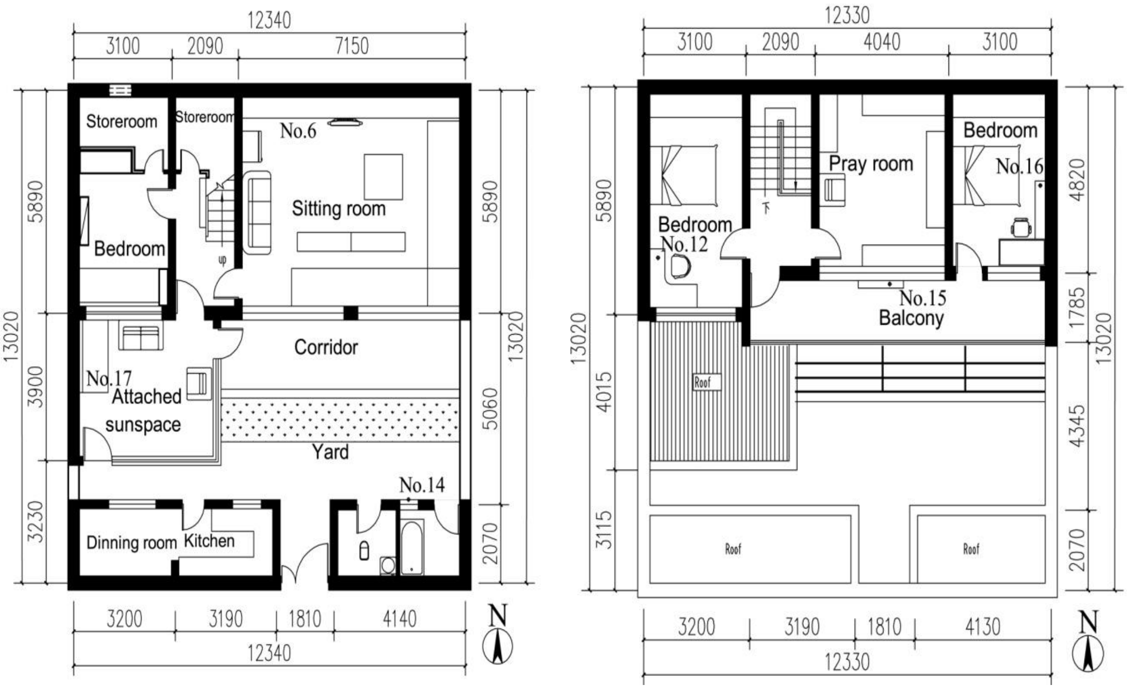
Table 3-17 Basic information of Gesang House

Completion time	2000
Structure	brick and concrete structure
Material of envelope	400mm stone bricks
Floor	Two floors
area	178 m^2
permanent residents	3

(a) sunroom in second floor (b) living room picture(south) (c) south picture of the building

(d) solar water heater (e) A Conner of kitchen (f) soar cooker

Fig. 3-35 Pictures of Gesang house



(a)First floor layout plan (Unit：mm) (b) Second floor layout plan (Unit：mm)

Fig. 3-36 Layout plan of Gesang house

Fig.3-36 shows the layout plans. Fig.3-37 shows the measurement results. The temperature recorder number in the figure is shown in the layout plan in Fig.3-36.

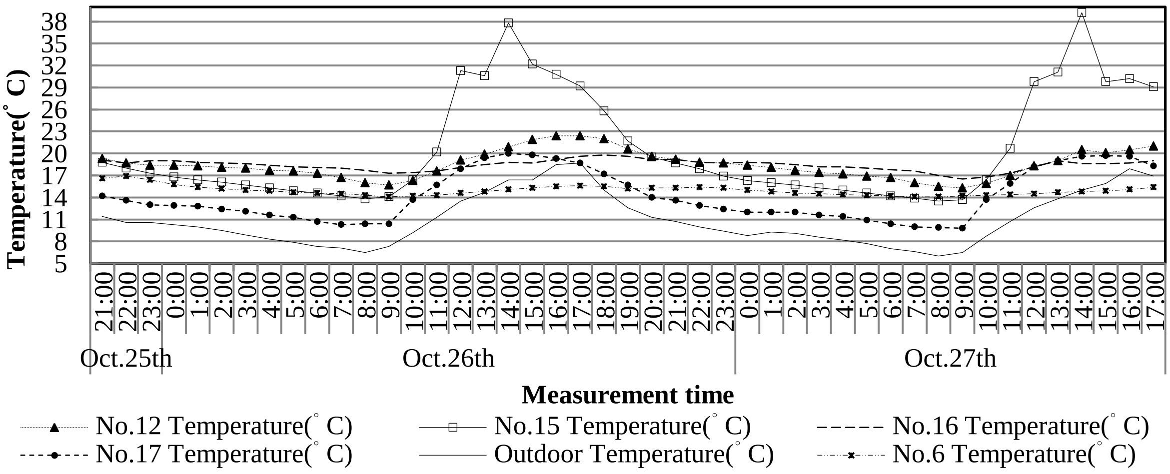


Fig.3-37 Indoor air temperature of Gesang house

As the figure shows, among the measurement rooms, No. 15 has the highest average temperature. As shown in Fig.3-36, No.15 is the sunroom in second floor. There is no shading in the south side. The average temperature of No. 15 is 20.6℃, the minimum temperature is 13.5℃ at 8:00 in Nov. 27th, and the maximum temperature is 39.2℃ at 14:00 in Oct. 26th. At the same time, the lowest average temperature during the measurement period is No.17. No. 17 is in the attached sunspace in the first floor, this space is refit by the residents themselves. As the layout plan in Fig.3-36 show, the attached sunroom has very small distance with the kitchen in the south side, which means the sunshine is shading by the kitchen. The average temperature is 14.2℃, the minimum temperature is 9.8℃ at 9:00 in Oct. 27th, and the maximum temperature is 20℃ at 14:00 of Oct. 26th. The outdoor air average temperature is 10.9℃.

The measurement results show that the air temperature in the second floor is higher than the first floor, because there is no shading in the second floor. The sunroom in second floor has the highest average temperature and the biggest indoor temperature daily range. The results prove the effect of the sunroom in Lhasa, but the overheating in summer season need to be considered.

Fig.3-38 shows indoor thermal environment evaluation of living room in Gesang house. As the figure shows, during the measurement period, in the morning from 8：30 to 9：30, in the 100% occupants felt neutral; at noon from 13：30 to 14：30, 33% occupants felt neutral and 67% felt slightly warm; at evening from 20：30 to 21：30, 33% occupants felt neutral and 67% felt slightly warm. Compared with the apartment survey, there is a big difference, the town house does not have north rooms, and main rooms in this house face south. And still, the residents in this family hope to use central heating system to improve the indoor thermal environment in winter.

Table 3-18 shows the clothes of the voters.

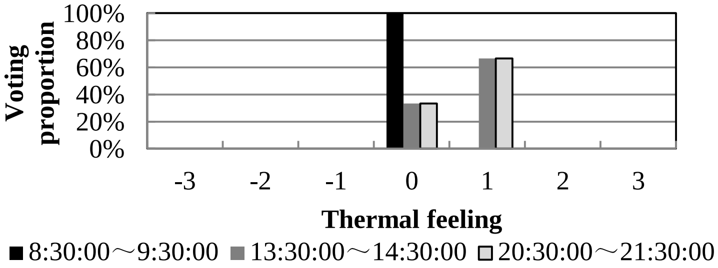


Fig.3-38 Indoor thermal environment evaluation of sitting room in Gesang house

Table 3-18 Indoor clothes of the residents (Gesang house)

Gesang family	Gender	Age	Clothes
Family Member A	Male	24	Underclothes + sweater+ coat
Family Member B	Female	55	Underclothes + sweater+ coat

Table 3-19 Home appliances of Gesang house

Kitchen appliance	Electric cooker, refrigerator, microwave oven, drinking fountain;
cooking energy	liquefied petroleum gas
Heating devices	Heat radiator
Shower devices	Solar water heater
Others	TV, DVD player, stereo equipment, computer, dust collector

Table 3-19 shows the home appliances of Gesang house. Generally, this family has good living standard. The home appliances in this family are more multifarious. For entertainment, they use two TV sets, DVD player, stereo equipment and laptop. And also, this family has heat radiator in the coldest period. Solar water heater is used for bathing. According to the questionnaire, even the occupants feel satisfied with the main rooms; the residences still hope to use central heating system for better indoor thermal comfort.

As introduced before, the attached sun space in the first floor is built by the residences. Refit of the attached sunroom is popular in the town house in Lhasa. However, with the limitation of the field space and the specific knowledge of passive design, sometimes the indoor thermal environment of the refit sun space is not good.

(2) Lagua house

Table 3-20 shows the basic information of Lagua house. The building was finished in 1997, totally 2 floors, its structure is brick and concrete structure. The external wall is 400mm stone bricks. Its area is 158.04 m^2. There are 4 people (two generations) living in this house.

Fig.3-39 shows the pictures of this house. Fig.3-39 (a) shows the refit additional sunroom in the first floor; Fig.3-39 (b) shows the inside view of the refit additional sunroom; Fig.3-39 (c) shows the living room; Fig.3-39 (d) shows the solar water heater; Fig.3-39 (e) is the shower equipment; Fig.3-39 (f) shows the cooking devices.

Table 3-20 Basic information of Lagua House

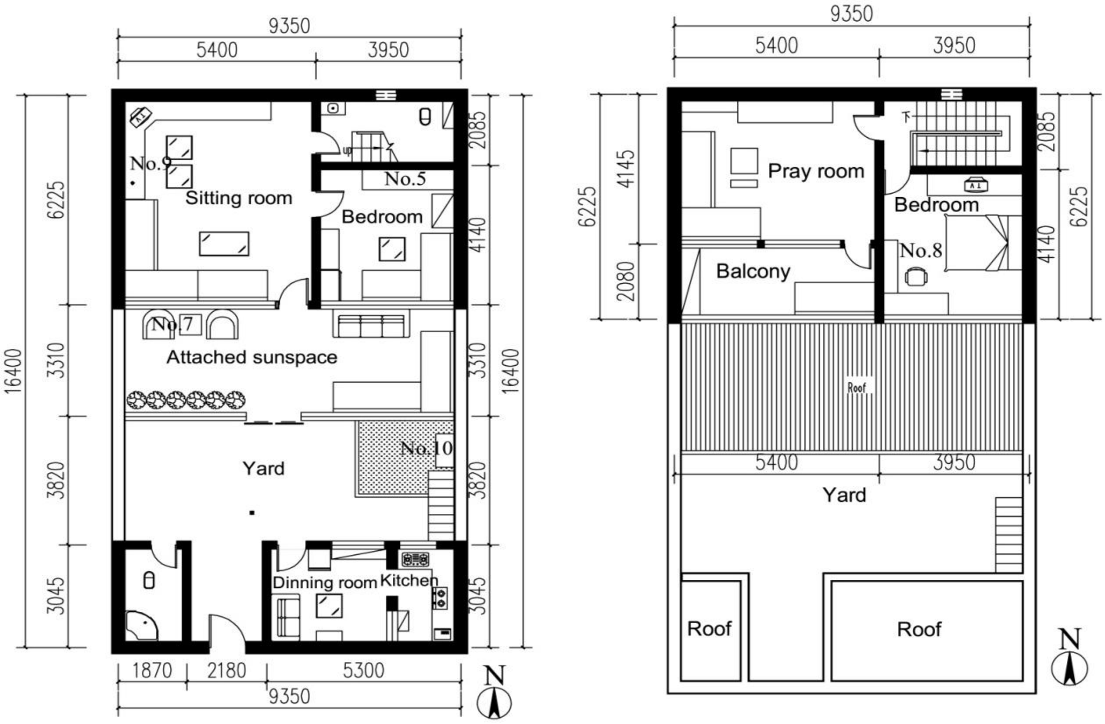
Completion time	1997
Structure	brick and concrete structure
Material of envelope	400mm stone bricks
Floor	Two floors
area	158.04 m^2
permanent residents	4

(a) Additional sunroom in first floor (b) Inside of the sunroom (c) living room

Fig. 3-39(1) Pictures of Lagua house

(d) solar water heater (e) Shower equipment (f) A corner of kitchen

Fig. 3-39(2) Pictures of Lagua house



(a)First floor layout plan (Unit：mm) (b) Second floor layout plan (Unit：mm)

Fig. 3-40 Layout drawing of Lagua house

Fig.3-40 shows the layout plan. Fig.3-41 shows the measurement results. The temperature recorder number in the figure is shown in the layout plan. Recorder No.5 was the put in the bedroom in first floor, No.7 was in the attached sunspace in the first floor, No. 8 was in the bedroom in the second floor, No. 9 was in the sitting room in the first floor.

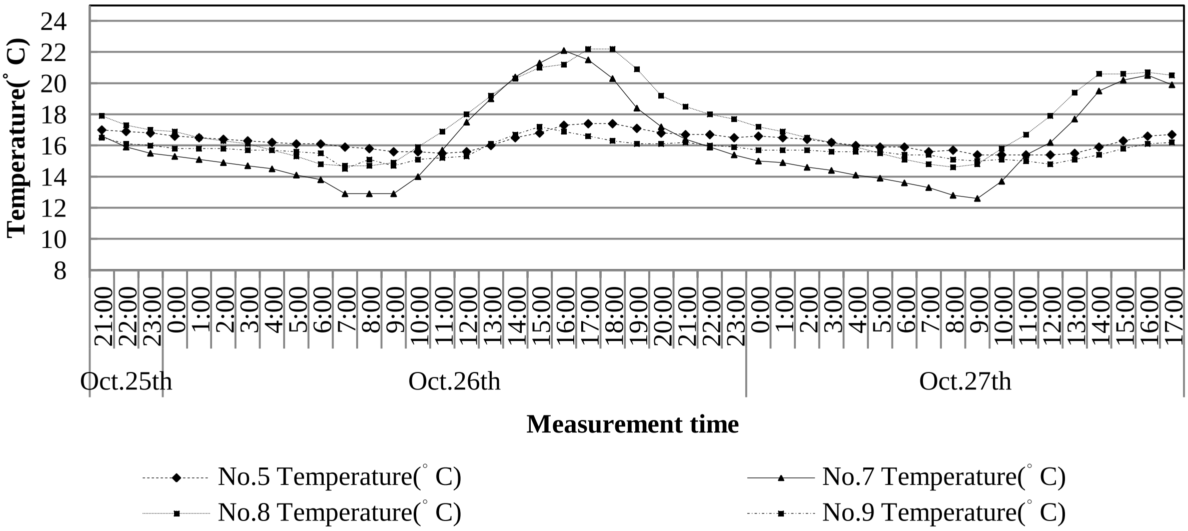


Fig.3-41 Indoor air temperature of Lagua house

As the figure shows, among the measurement rooms, No. 8 has the highest average temperature. The average temperature of No. 8 (Bedroom, second floor) is 17.6℃, the minimum temperature is 14.6℃ at 8:00 a.m. in Oct. 27th, and the maximum temperature is 22.2℃ at 17:00 in Oct. 26th. At the same time, the lowest average temperature during the measurement period is No. 9 (sitting room, first floor) is 15.75℃, the minimum temperature is 14.5 ℃ at 7:00 in Nov. 26th, and the maximum temperature is 16.9 ℃ at19:00 in Nov.25th.

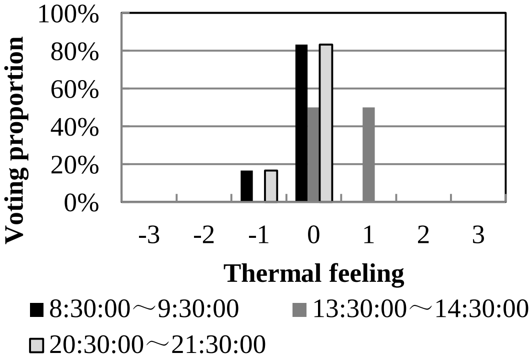


Fig.3-42 Indoor thermal environment evaluation of the living room in Lagua house

Fig. 3-42 shows indoor thermal environment evaluation of living room in Lagua house. As the figure shows, during the measurement period, in the morning from 8：30 to 9：30, 17% occupants felt slight cool and 83% occupants felt neutral; at noon time from 13：30 to 14：30, 50% occupants felt neutral and 50% felt slightly warm; at evening from 20：30 to 21：30, 17% occupants felt slight cool and 83% occupants felt neutral. Table 3-21 shows the Clothes of the voters. Table 20 shows the home appliances.

By the questionnaire, the residents in this family hope to use central heating system to improve the indoor thermal environment in winter.

Table 3-21 shows the indoor clothes of the residents in the measurement period.

Table 3-21 Indoor clothes of the residents (Lagua house)

Lagua house	Gender	Age	Clothes
Family Member A	Male	30	underclothes + shirt + coat
Family Member B	Female	55	underclothes + sweater+ Tibetan robe
Family Member C	Female	40	underclothes + sweater+ coat

Table 3-22 Home appliances of Lagua house

Kitchen appliances	electric cooker, water boiler, refrigerator, microwave oven, ventilator;
cooking energy	liquefied petroleum gas
Heating devices	electric heater
Shower devices	solar water heater
Entertainment	TV, DVD player, stereo equipment

As the home appliances in Table 3-22 shows, for entertainment, Lagua family use TV, DVD player and stereo equipment; as to appliance in kitchen, they use electric cooker, water boiler, refrigerator and microwave oven. And, this family has electric heater to cope with cold. Solar water heater is used for bathing. According to the questionnaire, the residents in this family hope to use central heating system as soon as possible for better indoor thermal comfort.

These two townhouses have the local characteristics. The solid wall use stone brick. All the rooms face south, no north room. And the first floor additional sunrooms were added by themselves. Both of the two houses’ highest temperature appears in the second floor.

3.2.5 Summary of the survey

In this section, three kinds of residential buildings in Lhasa were surveyed, detached house in rural area, unit-divided apartment and town house in urban area. In general, affected by the local climate and daily life custom, all these surveyed residential buildings have many common characteristics of passive solar design. For example, the all the living rooms were designed south direction; and the south windows have big size, the external wall is very thick; almost all of the surveyed buildings use heavy-weight material as the structure. As for the apartment in the city, the better income level families use better design houses, for example, Pei Lei house and Xu Gong house have sunroom room and more advanced materials than Zhaxi house did.

The survey shows that the indoor thermal environment of the exiting residential building still needs to be improved, even the buildings were already designed on the conception of passive design. Especially, the north rooms had poor indoor thermal environment. As introduced before, the apartment is the most common residential buildings in Lhasa, and the north rooms in apartment cannot be avoided. To improve the thermal environment of north room and reduce the thermal load is one of the key points of this research.

3.3 Conclusions

This chapter analyzed the winter indoor thermal environment and local people's requirement by field surveys. The basic information of the building and the family living condition are the foundation of the passive design characteristics study in Chapter 4 and the strategy study in Chapter 5. The followings are the results of this chapter.

(1) Affected by the local climate and culture, the existing residential buildings use some technology of passive design, more or less. The features include big south windows size, no north windows or small size north windows, heavy and thick solid wall and south direction. These are

very useful support materials for the architectural form design and structure thermal performance design in Chapter 4.

(2) In the survey, different living level family use different unit type, in current situation, the middle and high families use sunroom style. This is one proof of strategy study in Chapter 5.

(3) The characteristics shown in the current residential buildings indicates that the passive design strategy in Chapter 5 is easy to be accepted by the local government, because they have the passive design mind.

(4) The measurement results show that the current indoor air temperature is low, and it is far away from the local construction standard (18℃).

(5) Local residents desire to use heating system.

(6) The number of home appliances in the high living level house did not reach the number of developed countries as Japan. Even it was already much better than the low and middle living level house. This confirmed again that increasing of fossil fuel consumption according to the development cannot be avoided; which shows the importance of this research.

In the next chapter, the characteristics of passive design which based on the information of this chapter will be analyzed.

References:

[1] http://info.jjcn.hc360.com/2012/06/05090279142.shtml

[2] Xiaotao Li, Urban Housing of Lhasa under Multi-cultural Background, Master Thesis, Southwest Jiaotong University. 2009. (In Chinese)

[3] Liu Yang, Zhu Xinrong, Liu Yanfeng, Liu Jiaping, "Review of Design standard for energy efficiency of residential buildings in Tibet", Autonomous Region, HV&AC, Vol. 40, pp. 51-54, 2010. 9 (in Chinese)

[4] Construction Bureau of Tibet Autonomous Region, Design Standard for Energy Efficiency of Residential Buildings (DB54/0016-2007), Lhasa: Tibetan People Press; 2007 (in Chinese)

Chapter 4

4. Residential building passive design analysis

Chapter 4. Residential building passive design analysis

From the description of U.S. Department of Energy, passive design takes advantage of a building's site, climate, and materials to minimize energy use [1]. With different outdoor climate and different indoor thermal requirement, the passive design will be different. As introduced before, the summer season in Lhasa is cool, there is no cooling demand. This chapter focuses on the passive solar design for winter heating demand. This chapter will analyze the effect of each passive design by simulation.

The passive design in this chapter points to the architectural form design and the envelope thermal design.

According to the field surveys in chapter 3, the unit-divided apartment is the most popular residential building style in Lhasa. This chapter takes this style as example to study the passive design characteristics. As we know, the unit-divided apartments have many unit layouts according to the different living requirements. However, in order to make the calculation procedure not too complicated and give more clear clues for the different effect of the passive design method; this chapter uses three typical unit layouts to analyze the passive design rules in Lhasa. They are direct solar gain unit, attached sunroom unit and double-balcony unit. The analyzed models are designed based on the field survey.

The architectural form design in this chapter includes the orientation, the building shape and the unit layout of the three units. Besides, the depth of sunroom and north sealed balcony is also discussed for attached sunroom unit and double-balcony unit. The envelope thermal performance design includes the window-wall ratio design; the windows types design; the insulation layer thickness design; the thermal mass design and their combination.

The purpose of this chapter is to classify the effect of each passive design method for making passive design strategy in Chapter 5. The following items will be studied in this chapter.

1. The best passive method for each unit type;
2. Heating energy reduction effect of each method;
3. The passive design method’s relevance to the heating energy saving.

In order to give a clear understanding, Table 4-1 shows the simulating models map.

Table4-1 Simulation models’ setting for every unit

		Direct solar gain unit	**Attached sunroom unit**	**Double-balcony unit**
	Design elements	Models setting	Models setting	Models setting
Architectural form	Orientation	0 °, 15 °, 30 °, … 345° (24 models for each unit)		
	Building shape	Large depth plan; Standard; large bay plan (3 models for each unit)		
	North and south room layout	Large south rooms area to Large north rooms area (5 models for each unit)		
	Sunroom depth	/	0m, 0.6m, 1.2m, 1.8m, 2.4m； (5 models)	0.6m, 1.2m, 1.8m, 2.4m (4 models)
	North seal balcony depth	/	/	0m, 0.6m, 1.2m, 1.8m, 2.4m (5 models)
Envelope thermal performance	Window-wall ratio	0.3; 0.4; 0.5; 0.6; 0.7 (5 models for each unit)		
	Windows types	single glass; double lass; Low-e glass; (3 models for each unit)		
	Thickness of the insulation layer	0cm; 2 cm; 4 cm; 6cm (4 models of each unit)		
	Thermal mass of the structure	Light-weight; Middle-weight; Heavy-weight (3 cases for 2 scenarios, totally 6 models for each unit)		
Design factors combination	a. Window-wall ratio + b. Window type + c. Insulation	a. 0.4; 0.5; 0.6; + b. single glass; double glass; Low-e glass + c. 0cm; 2 cm; 4 cm (27 models for each unit)		

4.1 Simulation introduction and building models setting

The heating energy consumption will be calculated by the simulation software THERB [2], and the climate data was from the *Chinese Standard Climate Data Base for Buildings* [3].

Fig.4-1 is the standard floor plan of the target building, with the simulated unit located at the central area. Fig.4-2 shows the south elevation of the building. Fig.4-3 shows the three layout drawings of the simulation units. They are direct solar gain unit, sunroom unit and double sealed balcony unit. The heating rooms include rooms 1 to 7 as Fig.4-3 shows. In fact, Fig.4-1 and Fig.4-2 show the standard floor plan and south elevation of direct solar gain unit only. However，the floor plan and south elevation of sunroom unit and double sealed balcony unit are similar with direct solar gain unit, there is not necessary to repeat here.

As for the indoor temperature setting point, 18℃ is used in this chapter. This value is from *Design Standard for Energy Efficiency of Residential Buildings* [4], 18℃ is set as the indoor calculation temperature. The time step is 3600 seconds. The heating period in Lhasa is from October 30th to March 8th, 130 days in total [4]. However, in order to make the calculation not too complicated, this chapter uses only the integer months from November 1st to February 28th.

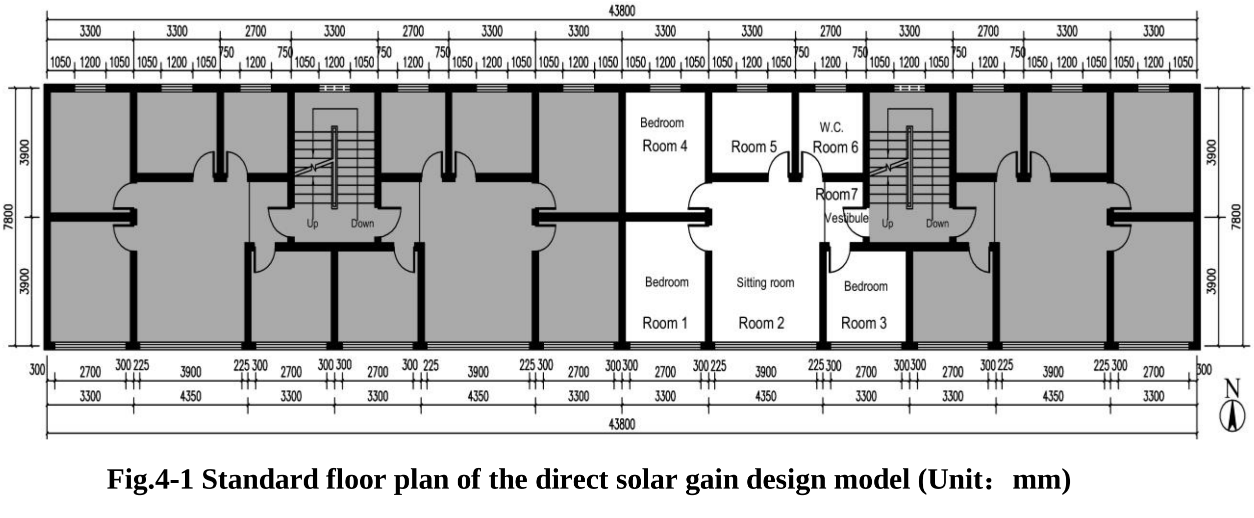


Fig.4-1 Standard floor plan of the direct solar gain design model (Unit：mm)

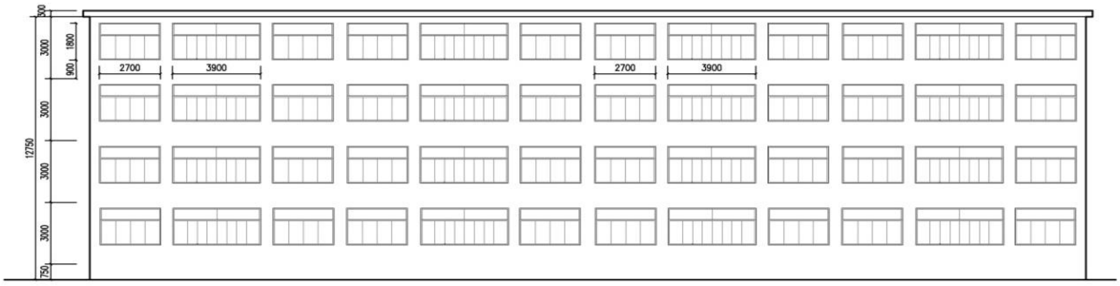
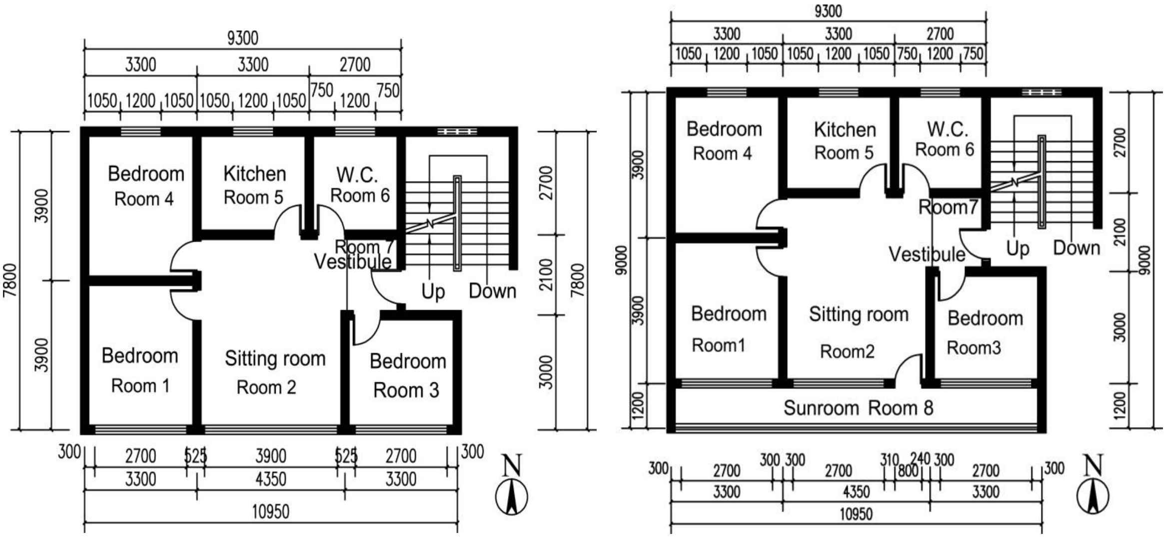
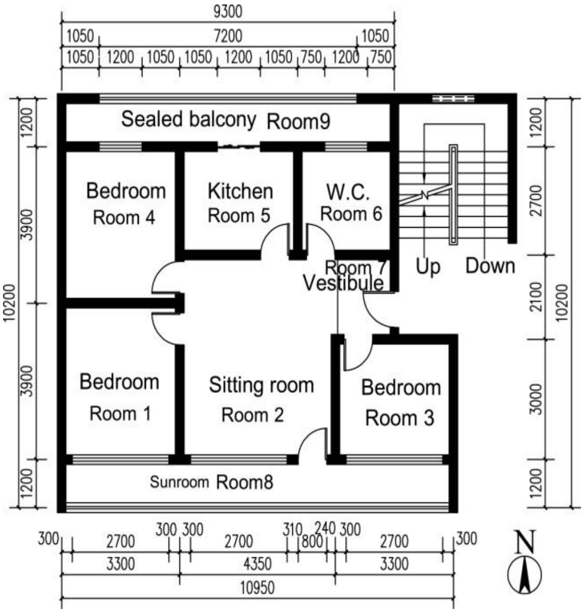


Fig.4-2 South elevation of the direct solar gain design model (Unit：mm)



(a) Direct solar gain model (Unit：mm) (b) Sunroom model (Unit：mm)



(c) Double-balcony model (Unit：mm)

Fig.4-3 Layout drawings of three unit models

Table 4-2 contains the basic information of the target building and the setting of THERB. As the table shows, the target building located at Lhasa city, there are four floors in total and the target unit located at the third floor. The area of direct solar gain unit is 77.49 m^2, the sunroom is 90.63 m^2, and the double-balcony unit is 101.79 m^2. And also, as Fig.4-3 shows， in the three units, the layout of Room 1 to Room 7 is completely same. The clear height of the building is 2.9m; the structure is brick-concrete. The surface heat exchange coefficient is from the Chinese national standard *Thermal Design Code for Civil Building* [5]. The natural ventilation of every room is 0.5 times per hour.

Moreover, in order to make the calculation not too complicated, assume that there is no heat transfer between the target unit and the adjacent rooms like the left/right neighbors or the upstairs /downstairs neighbors. Assuming the heating devices - air conditioner has COP 3, so that, the thermal load can be expressed as electricity consumption.

Table 4-2 Simulation setting

Building information	Location		Lhasa city
	Latitude, Longitude		29.39 ° , 91.07 °
	Floor/Floors		3rd/4 floors
	Area	Direct solar gain unit area	77.49 m^2
		Sunroom unit area	90.63 m^2
		Double-balcony unit area	101.79 m^2
	Clear height		2.9 m
	Structure		Brick-concrete
Calculation setting	Calculation period		Nov. 1st-Feb. 28th
	Ventilation		0.5 / hour
	Surface heat exchange coefficient	Internal	8.7W/m^{2}K
		External	23.0 W/m^{2}K

Table 4-3 shows the configuration of the basic model for the three units. Here the basic model means the architectural form analysis models in the following section. In the envelope thermal performance study, the configuration will be changed based on the study items, the detail will be explained in the case study in the following section.

Table 4-3 The configuration of the basic model of three units

External wall	Material (in to out)	Cement plaster	Lime sand brick	Cement plaster
	Thickness (m)	0.015	0.370	0.015
Internal wall	Material (in to out)	Cement plaster	Lime sand brick	Cement plaster
	Thickness(m)	0.015	0.240	0.015
Floor/ceiling	Material	Reinforced concrete		
	Thickness(m)	0.100		
Windows	Material	Single glass		
	Thickness(m)	0.006		

Before starting this chapter, it is necessary to explain why these three units are chosen to carry on the passive design study.

From the content in Chapter 3, it is easy to understand the direct solar gain unit and the attached sunroom unit are two common unit types in Lhasa. However, as to double-balcony unit, it is not common.

From the field survey, it is clear that the heating load is mainly from north rooms. In south rooms, the strong solar radiation can be considered as the compensation for the heating loss caused by the indoor and outdoor temperature difference.

To deal with the north rooms thermal load, as one design solution, a no-heating north sealed balcony can be set as a cushion space, which also can be considered as one thick insulation layer.

In Fig.4-3(c), the north sealed balcony Room 9 can be used as store space or auxiliary service room which is not heated in winter. By qualitative analysis, this unit should have a lower heating energy consumption compared with the direct solar gain unit and the sunroom unit. For a better understanding, the three units heating energy consumption is calculated in this section. The models were set as Table 4-4 shows. The construction is shown in Table 4-3.

Table 4-4 Information of three models

Insulation	Window type	window-wall ratio	North and south balcony depth
No	Single glass	0.58	0m/1.2m

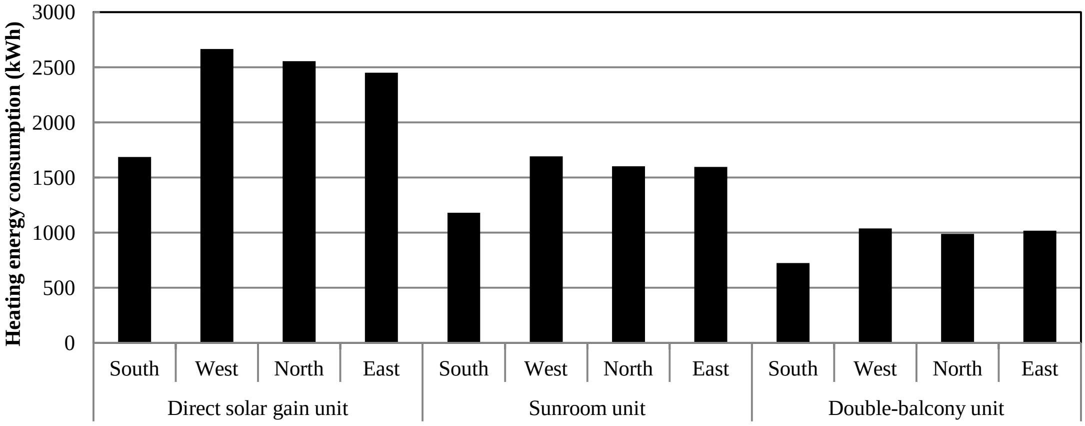


Fig.4-4 Simulation results of the three unit types

Fig.4-4 shows the calculation results. As the figure shows, the double-balcony models have the lowest heating energy consumption among all models with all four directions. Based on the results, double-balcony unit has a relative smaller energy consuming growth from south to other directions than the leftover two units.

The results prove the effect of north sealed balcony, based on this analysis, the passive design methods of these three units will be studied in detail in the following sections.

In addition, one point has to be noticed that the purpose of this chapter is to find the passive design effect for the heating energy saving in winter, therefore, the simulations in this chapter focuses on the winter energy consumption only. In principle, the good passive design for winter heating energy saving is to get enough solar radiation – enough to provide warmth during cold months. But if there is no shading design, in summer seasons, the indoor thermal environment is easy to be overheating. As we know, the solar elevation angle in summer season is higher than in the winter seasons. So, awning is one good facility to keep the extra solar radiation out in summer. By qualitative analysis, the outdoor air temperature in the hottest month in Lhasa is only around 16 ℃，with shading and natural ventilation, the cooling load can be controlled even to zero.

Besides, shading design is a flexible design process, even the mobile awning can be installed to prevent over amount of solar radiation. For the reason of time restriction, as mentioned before, winter heating energy saving is the only content of the research, and shading design is not the key research topic of this research; shading can be one of the research content in the future.

4.2 Architectural form design

As introduced before, the passive design characteristics study in this chapter includes architectural form design and the envelope thermal performance design. The architectural form design will be studied in this section. The key design factors as building orientation, unit shape, unit layout of south and north rooms and balcony depth are analyzed. The configuration is shown in Table 4-3.

4.2.1 Orientation design

From the field survey in the chapter 3, we can see that all the surveyed residential buildings face south, however, with the society and economy development; in the future, it is possible that some buildings cannot face south for the reason of land limitation, so in this section, the relationship of the building orientation and the heating energy demand is studied.

(1) Direct solar gain unit orientation design

Dire solar gain unit is one of the most popular residential building types in the existing buildings in Lhasa. Its orientation is studied here.

For the orientation study, the models are set in Table 4-5. Totally, there are 24 models, from 0 °to 345 °, every 15 °is set as a model. Building azimuth 0 °is the south direction, 90 °is the west direction, 180 °is the north direction, and 270 °is the east direction. Fig.4-5 shows the calculation results.

Table 4-5 Direct solar gain unit orientation models setting

Insulation	Windows	South Window-wall	Orientation
No	Single glass	0.58	24 models (every 15 °one model)

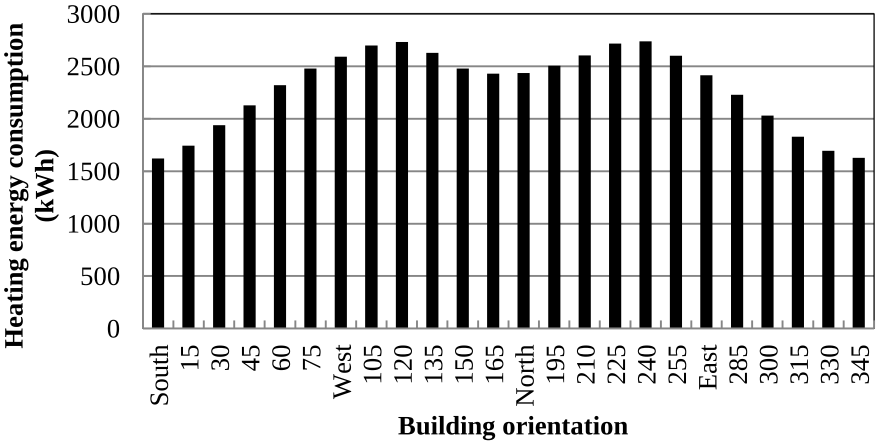


Fig.4-5 Heating energy consumption in different orientations of direct solar gain unit

From the results in Fig.4-5, it follows that, among the four common directions, the south direction has the lowest energy consumption, and the north direction has a relatively lower consumption than the west and east. This is because when the basic model in Fig.4-3 (a) turns 180 °, the original north windows face south, and this layout can be recognized as the direct solar gain design with small window-wall ratio. And as the results show, the building azimuth 120 ° and 240 ° have the top two heating energy consumption. The top energy consumption is about 1.7 times of the lowest one.

Also the results show that among the four most common orientations, the energy consumption is obviously increased when the building faces east or west. Combined the calculation results in Fig. 4-4, the unit type redesign would be one possible solution.

(2) Attached sunroom unit orientation design

Attached sunroom unit is the other popular residential building type in the existing buildings in Lhasa. The relationship of the building orientation and the heating energy demand is studied in this section.

Table 4-6 Attached sunroom unit orientation models setting

Insulation	Windows	Window-wall ratio	Sunroom depth	Orientation
No	Single glass	0.58	1.2 m	24 models

The models are set as Table 4-6 shows. Totally, there are 24 models, every 15 °a model. Fig.4-6 gives the simulation results. From the results, it follows that, among the four common directions, the south direction has the lowest energy consumption, and similar with the direct solar gain models, the north direction has a relatively lower consumption than the west and east direction.

The orientation study shows that energy consumption is obviously increased when the building faces east or west; which are the two common directions in practical building design in other cities. 120° and 240° have the top two heating energy consumption. This means the south orientation is the first choice. If other orientations have to be applied, the additional solution should be applied at the same time.

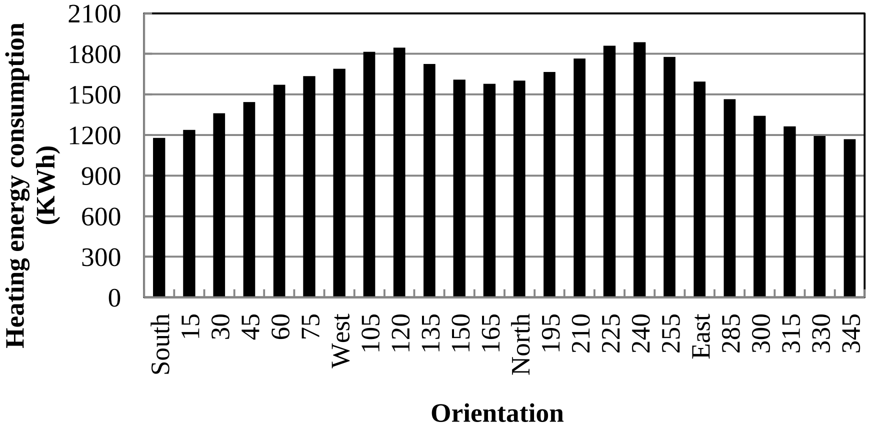


Fig.4-6 Heating consumption in different orientation of Sunroom models

(3) Double-balcony unit orientation design

Same as the previous two unit types, the building orientation is studied in this section for double-balcony unit. The models are set as Table 4-7 shows. Totally, there are 24 models. Building orientation 0 ° is the south direction, 90 ° is the west direction, 180 ° is the north direction, and 270 ° is the east direction. Fig.4-7 gives the simulation results.

Table 4-7 Orientation models information

Insulation	Windows	Window-wall ratio	Sunroom /North balcony depth	Orientation
No	Single glass	0.58	1.2 m	24 models

From the results, it follows that, among the four common directions, the south direction has the lowest energy consumption, and similar with previous two unit types, the north direction has a relatively lower consumption than the west and east direction.

Also the results show that energy consumption is obviously increased when the building faces east or west. However, compared with the previous two units, the heating energy consumption difference between maximum case and the minimum case of double-balcony unit is the smallest one.

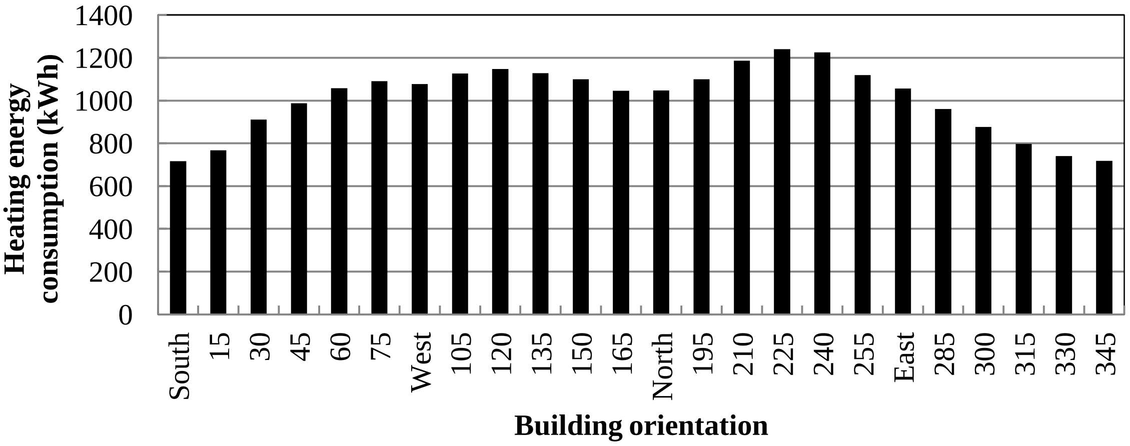


Fig.4-7 Heating consumption in different orientation of double-balcony models

4.2.2 Building shape design

The building shape here means the ratio of unit width and depth in the layout plan. In the residential building design, unit type is one of the most important design factors. In the traditional architectural design work, usually the architects consider the room function as the first class. However, as for the passive design, different combination of the width and the depth will results in the different heating energy demand. For a qualitative analysis, on one hand, the unit with large width and small dept can get more solar exposure area than the large depth small width unit; on the other hand, the large width small depth unit has more heat loss area from the north/south side ex-wall and windows. For a better understanding, three different building shape designs for every unit type are listed in this section.

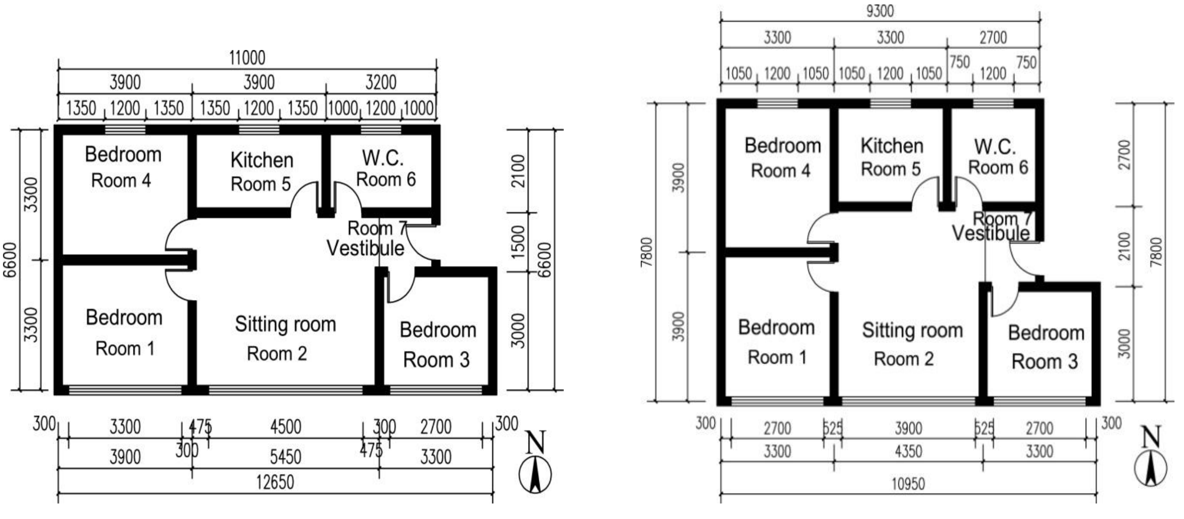
(1) Direct solar gain unit building shape design

As Fig.4-8 shows, three different building shape models will be studied here; they are large width layout; large depth layout; and standard layout. The standard here means the most common width-depth ratio in the survey. As the figure shows, the three design style units have tiny area difference, which means the heating space can be recognized as same.

Table 4-8 shows the simulation models' information. The three models have same south window-wall ratio. The windows use single glass; there is no insulation layer in all the three models.

Table 4-8 Unit shape models information for direct solar gain unit

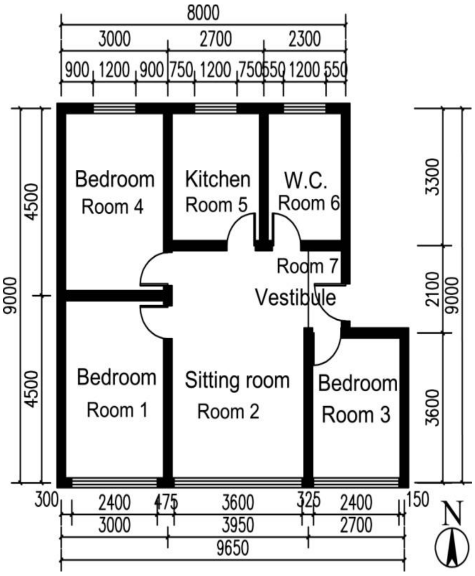
Orientation	Insulation	Windows	Window-wall ratio	Layout design
South	No	Single glass	0.58	Large width model
				Standard model
				Large depth model



(a) Large width small depth unit (77.55 m^2)

(b) Standard unit (77.49 m^2)

Fig.4-8(1) Different unit shape design for direct solar gain unit



(c) Large depth small width unit (77.94 m^2)

Fig.4-8(2) Different unit shape design for direct solar gain unit

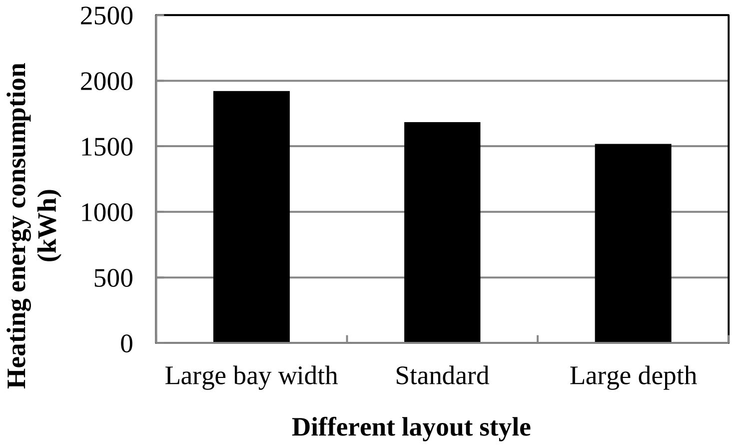


Fig.4-9 Heating consumption in different unit shape for direct solar gain unit

Fig.4-9 shows the simulation results. As the figure shows, under the condition of Table 4-8, the large depth unit has the lowest heating energy consumption. The calculation results prove that the heat gain from solar exposure area increasing in the day time is smaller than the heat loss caused by the south/north external wall area increasing. All in all, the large depth design is good for heating energy saving of direct solar gain design in Lhasa.

And there is one thing need to be pointed out that in the simulation, the target unit is set to locate at the center of the building as Fig.4-1 shows, there is no heat transfer from the neighboring walls.

However, if the calculation unit located at the end of the building which means that the neighboring walls in the calculation case become external walls, there will be heat loss from the new external wall. At this circumstance, the results will be different. In this condition, the good insulation layer of the new external wall is necessary. This will be considered in the future research.

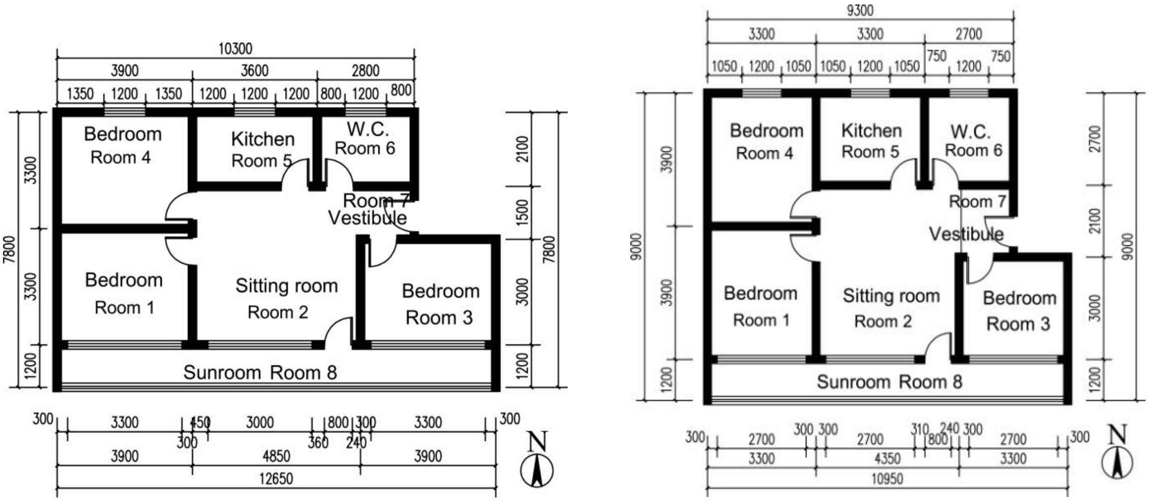
(2) Attached sunroom unit building shape design

Similar with the direct solar gain design, by qualitative analysis, the different building shape design has the different soar gain area in the south side and also the heat loss area in both south and north. So, to enlarge the width has both positive and negative effect, by qualitative analysis.

In order to make a clear understanding of the relationship between the building shape design and the heating energy demand for the sunroom unit, three unit types models are shown in Fig.4-10. As the figure shows, the three design style units have same area. Table 4-9 shows the simulation models' information.

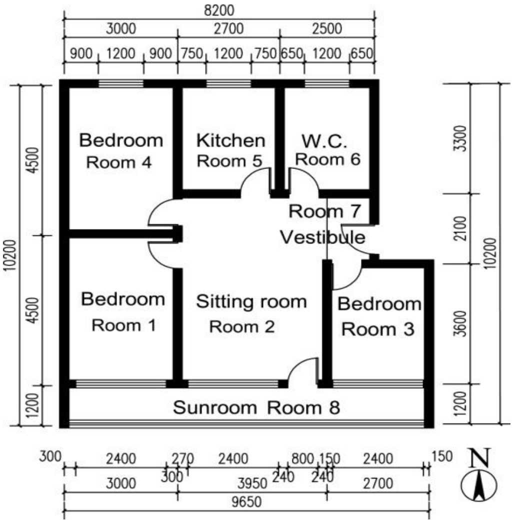
Table 4-9 Building shape models information

Insulation	Windows type	Window-wall ratio	Sunroom depth	Layout design
No	Single glass	0.58	1.2 m	Large width model Standard model Large depth model



(a) Large width and small depth layout (90.21 m^2) (b) Normal layout (90.63 m^2)

Fig.4-10(1) Different unit shape design for attached sunroom models



(c) Large depth and small width layout (90.6 m^2)

Fig.4-10(2) Different unit shape design for attached sunroom models

As the results in Fig.4-12 show, under the condition of Table 4-9, the large depth unit has the lowest heating energy consumption. But compared with the results of direct solar gain unit, the energy reduction effect is not as obvious as the former unit.

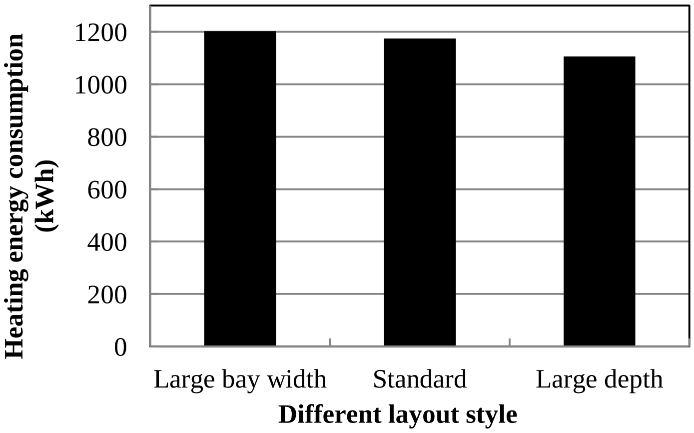


Fig.4-11 Heating consumption in different unit shape models for sunroom unit

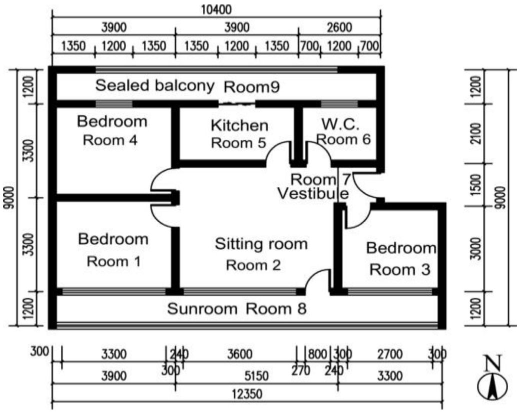
Also, the simulated units are set to be located at the center of the building as Fig.4-1 shows; the results reflect the central units only. As for the edge unit, it will have a different result because the neighboring walls became external wall.

(3) Double-balcony unit building shape design

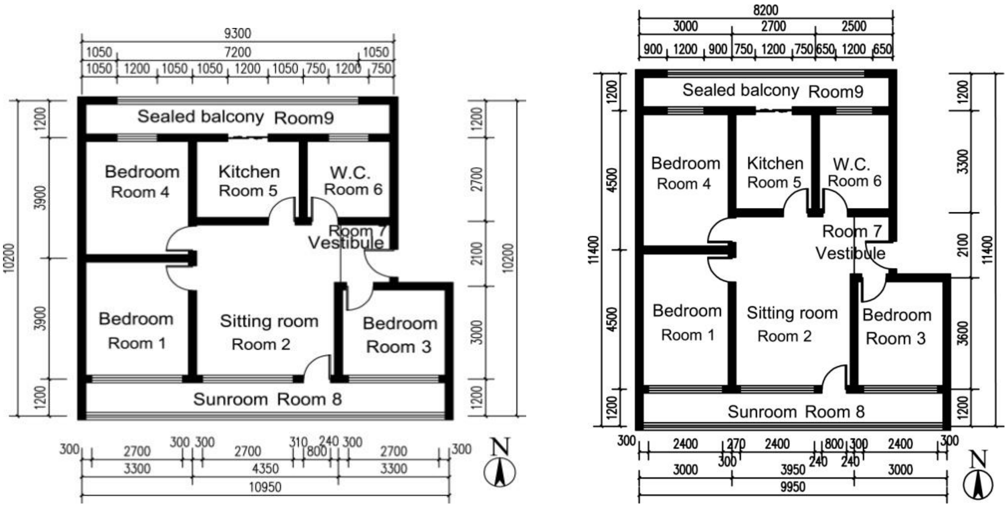
Three models with different unit types design are shown in Fig.4-12, large width small depth layout, normal layout, and large depth small width layout. The three design style units have same area; Table 4-10 shows the simulation models' information. The three models have same south window-wall ratio of 0.58. The windows use single glass; no insulation layer in all the three models.

Table 4-10 Models of double-balcony building shape design

Sunroom / North sealed balcony depth	Windows	Insulation	Windows-wall ratio	Building shape models
1.2m	Single	No	0.58	Large width Normal Large depth



(a)Large width small depth layout (101.79 m^2)



(b) Normal layout (101.79 m^2)

(c) Large depth small width layout (101.88 m^2)

Fig.4-12 Different unit shape design for double-balcony models

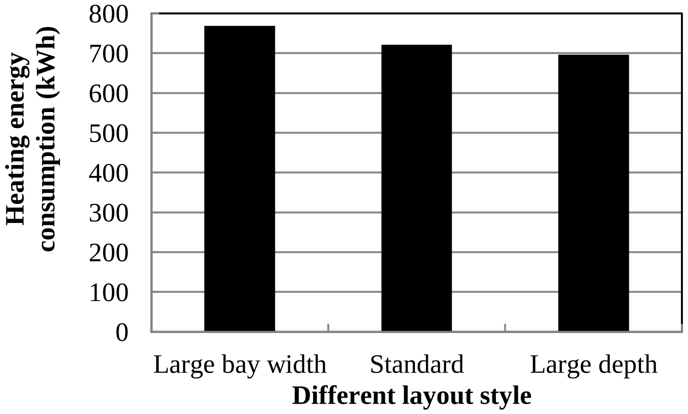


Fig.4-13 Heating consumption in different unit shape models for double-balcony unit

Fig.4-13 shows the simulation results. As the figure shows, under the condition of Table 4-10, the large depth unit has the lowest heating energy consumption. According to the results of three unit types: direct solar gain design, sunroom design and the double-balcony design, the building shape has the same tendency: the extra heat gain from solar exposure by the south external wall area increasing is lower than the heat loss caused by the south/north external walls' area increasing; the large depth unit design has better energy saving effect.

Also, the simulated unit is set to locate at the center of the building as Fig.4-1 shows; the results reflect the central units only.

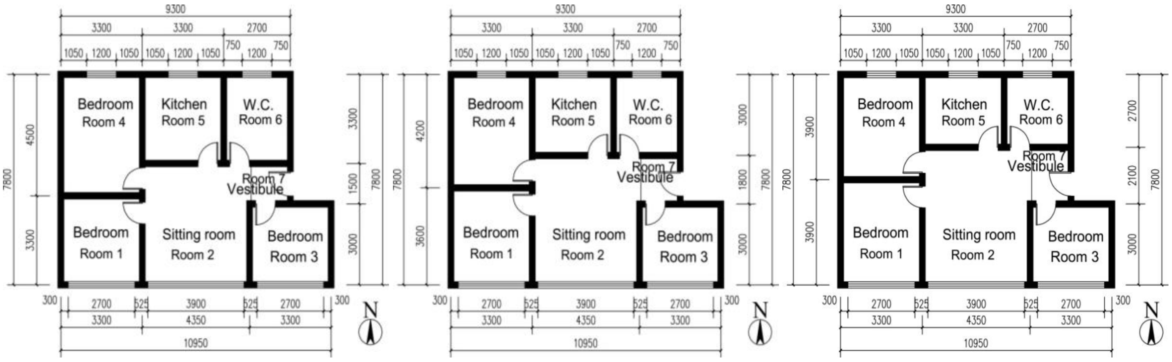
4.2.3 North and south room layout design

Generally, the unit-divided apartment in Lhasa has south side and north side rooms. Here the north and south room layout design means the area of south rooms and north rooms share different ratio by depth design. The purpose of the study in this section is to prove which room depth design has good energy saving effect, big north room depth design or big south room depth design.

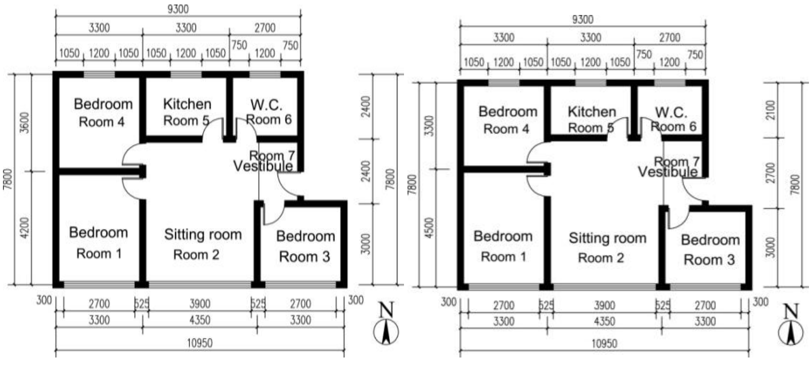
(1) Direct solar gain unit north and south room layout design

Fig.4-14 shows the 5 different rooms layout models with the same building shape, in which, layout 3 is the basic unit as Fig.4-3(a) shows. Among the five models, the partition walls between south and north rooms are located at different place, so that, from layout 1 to layout 5, the north rooms' depths are getting smaller, and south rooms' depths are getting bigger.

According to the qualitative analysis, the south rooms have solar gain during the day time, which can be considered as the compensation for heating energy consumption. However, the north rooms do not have such compensation, so the heating load of north rooms should bigger than that of the south rooms. By the simple analysis, the layout with small north room area will have the relative lower thermal load. For a better understanding, 5 models are set in this section. As Fig.4-14 shows, from model 1 to model 5, the depth of room 1(south bedroom) is changing from 3.3m to 4.5m. Table 4-11 lists the basic information of the five models.



(a) Layout 1 (b) Layout 2 (c) Layout 3



(d) Layout 4 (e) Layout 5

Fig.4-14 South and north room layout design models for direct solar gain unit (unit: mm)

Table 4-11 Unit layout models information

Orientation	Insulation	Windows	Window-wall	Unit layout models
South	No	Single glass	0.59	5 models in Fig.4-8

Fig.4-15 shows the calculation results of the north and south rooms' layout design models. The results prove that the big south room depth small north room depth design has the lower heating energy consumption. But the difference between models is very small.

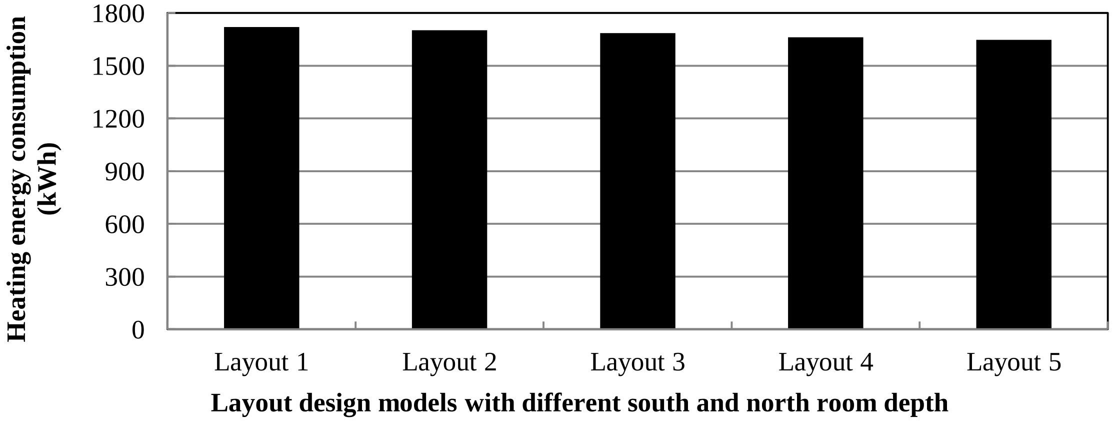


Fig.4-15 Results of the north and south room layout design models for direct solar gain unit

All in all, the room layout analysis shows that the small north room depth big south room depth unit are better building design for the energy saving. So in the real architectural work in Lhasa, the area of north rooms need to be limited for the purpose of energy saving, of course, the basic architectural function takes the first priority, after meeting the basic function, the size of the north rooms need to be controlled.

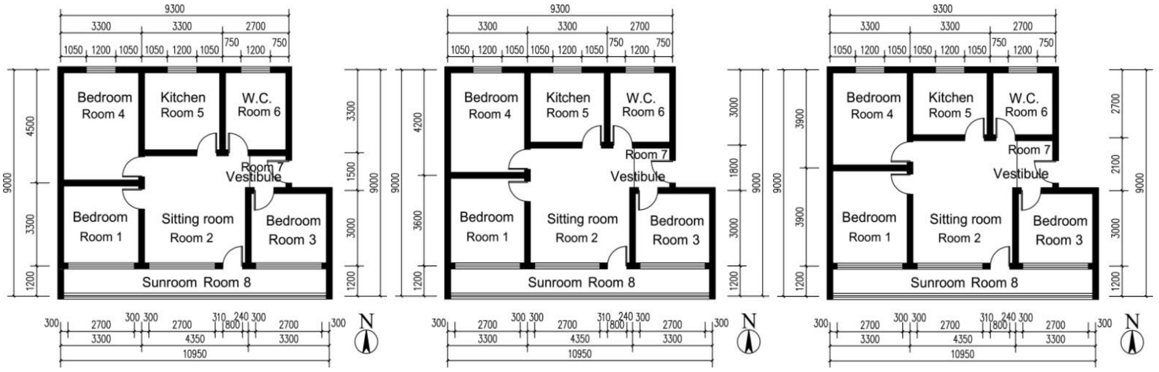
(2) Attached sunroom unit north and south room layout design

Similar with the direct soar gain unit, by simple qualitative analysis, the south rooms have solar gain during the day time; even this heat is gained through sunroom, not directly from outdoor environment. Still this is a kind of compensation by solar radiation. However, the north rooms do not have such heat gain, so the heating load of north rooms should bigger than that of the south rooms.

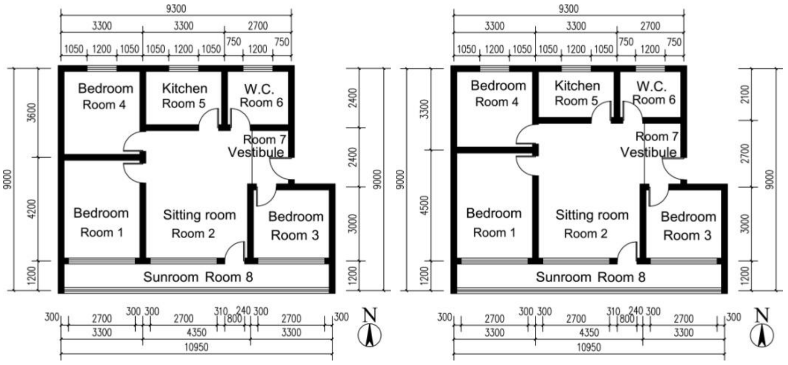
For a better understanding, Fig.4-16 shows the 5 different room layout designs with the same building shape. Among the five models, the partition walls of south and north rooms are located at different place, so that, from layout 1 to layout 5, the north rooms' depth is getting smaller, and south rooms' depth is getting bigger. Table 4-12 shows the basic setting of the simulation models. Fig. 4-18 shows the calculation results.

Table 4-12 Unit layout models information

Insulation	Windows	Window-wall ratio	Unit layout models
No	Single glass	0.58	5 models



(a) Layout 1 (b) Layout 2 (c) Layout 3



(a) Layout 4 (b) Layout 5

Fig.4-16 South and north room layout design models for sunroom unit (unit: mm)

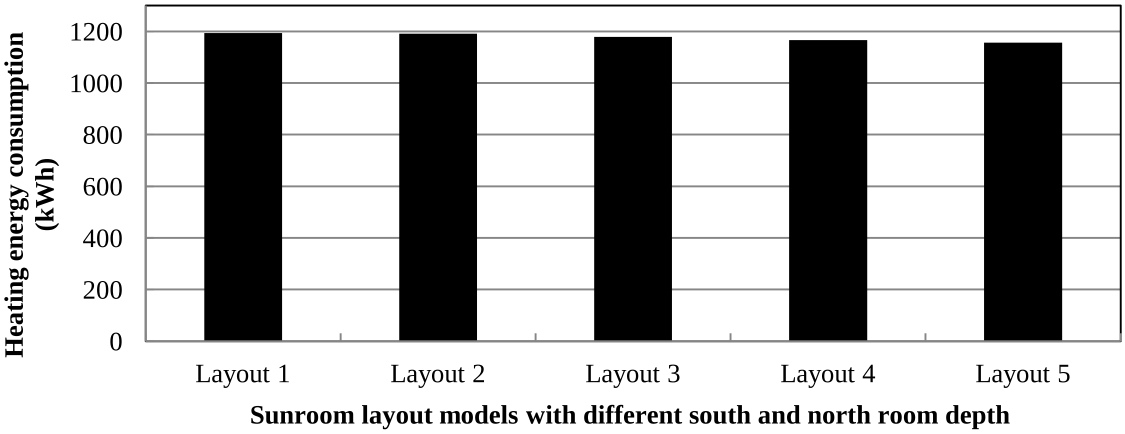


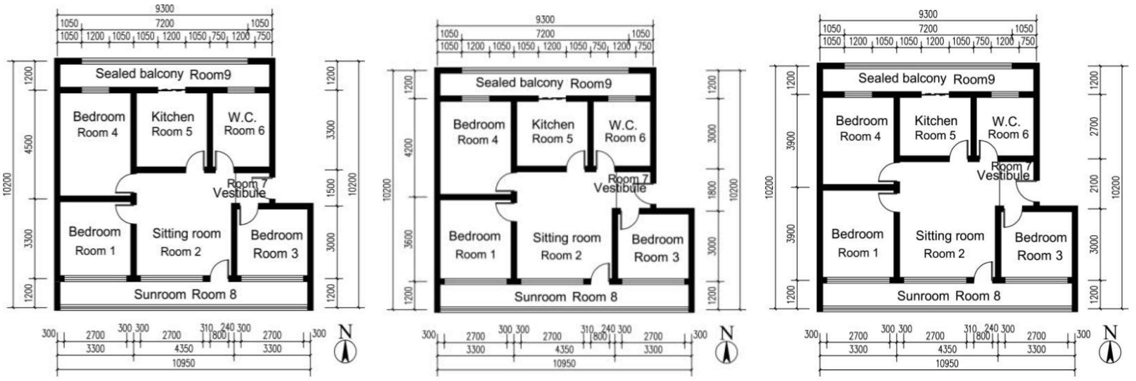
Fig.4-17 Results of the north and south room layout design models for sunroom unit

The results in Fig.4-17 prove one design rule that with the north rooms’ depth decreasing; the heating energy consumption is getting lower. But the difference shows this effect is not big. The results shows that the small north room design is a good architectural form design conception for the energy saving.

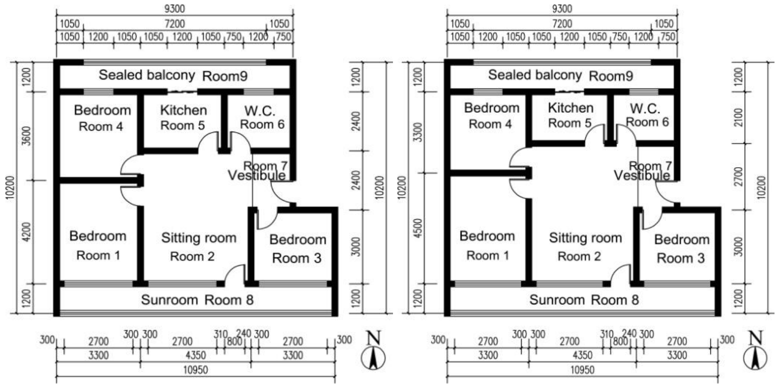
In addition, compared with the direct solar gain design, the effect of room layout in attached sunroom unit is smaller. This fact indicated that in direct solar gain unit design, the unit layout need to be paid more attention.

(3) Double balcony unit north and south room layout design

Similar with the direct solar gain models/ sunroom models, the effect of room layout is discussed in this section. Fig.4-18 shows the 5 different rooms layout design unit .Among the five models, the partition walls of south and north rooms are located at different place. So that, from layout 1 to layout 5, the north rooms’ depth is getting smaller, and south rooms’ depth is getting larger. Table 4-13 shows the basic setting of the simulation models. Fig.4-19 shows the calculation results.



(a) Layout 1 (b) Layout 2 (c) Layout 3



(d) Layout 4 (e) Layout 5

Fig.4- 18 South and north room layout design models for double-balcony unit (unit: mm)

Table 4-13 South and north room layout models' information

Insulation	Windows	Window-wall ratio	Unit layout models
No	Single glass	0.58	5 models

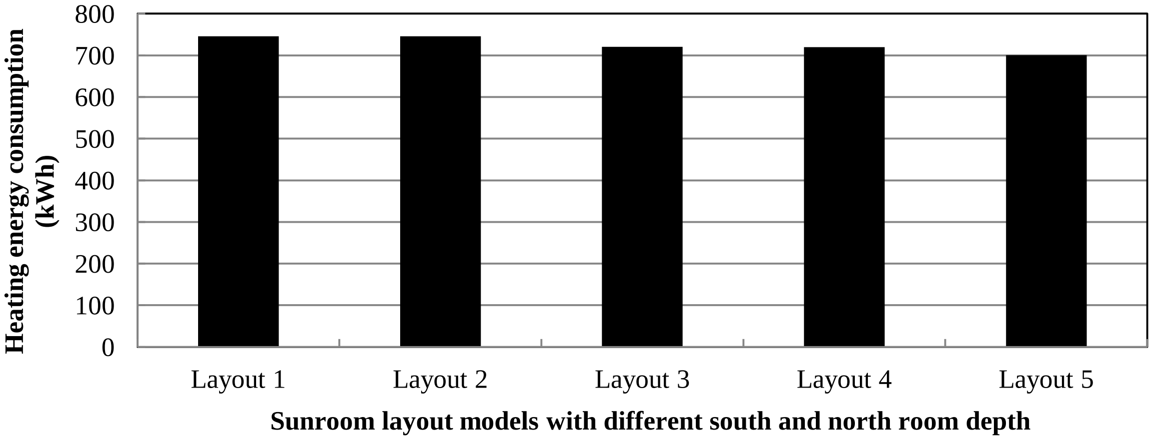


Fig.4-19 Results of the north and south room layout design models for double-balcony unit

The results in Fig.4-19 proves that the layout 5 (big south room depth small north room depth design) have the lowest heating energy consumption. But as the figure shows, the energy saving effect of the room layout design is small. In addition, among the three unit types, room layout of double-balcony unit has the lowest relevance with the energy.

4.2.4 Sunroom depth design

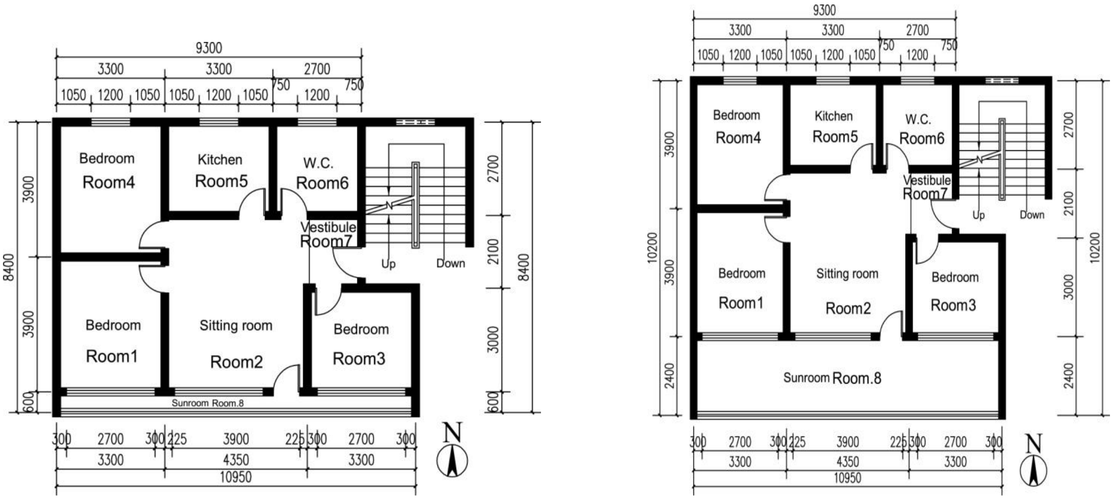
In the conception of architecture, the sunroom is also a sealed balcony, its architectural function is one connecting space between the indoor space and the outdoor environment. It also has the function of hanging and drying the laundering cloths, viewing, lighting and so on.

For the angle of passive design, sunroom is the space to collect and store solar energy. The depth of the sunroom is one important design element. It is necessary to study the relationship between the sunroom depth and the heating energy consumption.

(1) Attached sunroom unit sunroom depth design

Fig.4-20 shows the examples of different sunroom depth models. Table 4-14 shows the setting of different sunroom depth models.

As Table 4-14 shows, there are five sunroom depth models in total, 0m; 0.6m; 1.2m; 1.8m; 2.4m. Here, a sunroom depth of 0m means there is no sunroom, and the layout uses the direct solar gain model of Fig.4-3(a). Every model has a window-wall ratio 0.58 and the windows configuration is single glass. All the models here face south direction.



(a) Sunroom depth 0.6 model

(b) Sunroom depth 2.4 model

Fig.4-20 Schematic diagram of the sunroom depth models

Table 4-14 Information of sunroom depth models

Insulation	Windows-wall wall in south wall	Windows type	Sunroom depth (m)
No	0.58	Single	0; 0.6; 1.2; 1.8; 2.4

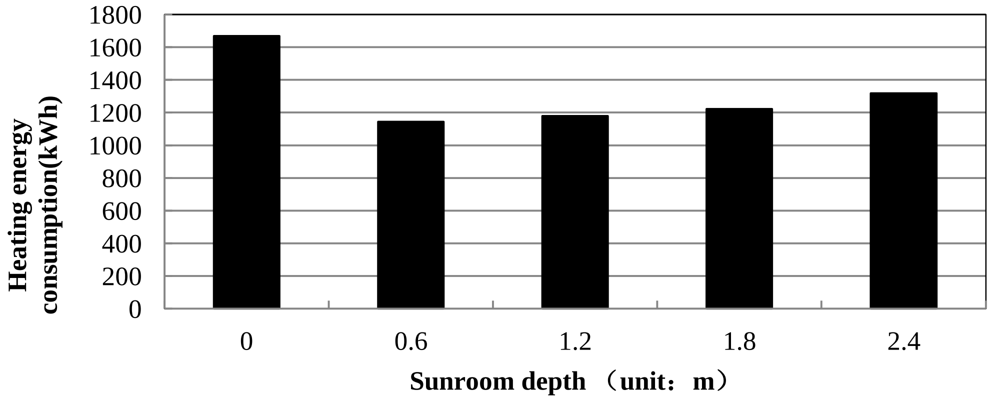


Fig.4-21 Simulation results of sunroom depth models for attached sunroom unit

Fig.4-21 shows the simulation results. Compared with the 0 m models, the sunroom models have much lower heating energy consumption. Generally, the attached sunroom is helpful for heating energy saving.

With the sunroom depth increasing, the energy consumption gets higher. Therefore the depth of the sunroom should not be designed in a large size. Moreover, the architectural function of sunroom is another boundary condition; in the case study, the sunroom depth 0.6m have a good energy saving effect, but it cannot be used as one architectural space, so a depth of 1.2m to 1.8m is suitable.

(2) Double-balcony unit sunroom depth design

As for double-balcony unit, it also has one sunroom in the south side. In this section, the relevance of the sunroom depth to the heating energy consumption is studied.

The sunroom depth study models setting of double balcony unit is similar with attached sunroom unit, so it is not necessary to show the layout here again. Totally, there are four sunroom depth models, 0.6m; 1.2m; 1.8m; 2.4m. Every model has a window-wall ratio 0.58 and the windows configuration is single glass. All the models face south.

Table 4-15 Models of sunroom depth

Sunroom depth	Windows type	Insulation layer	Windows-wall ratio in south side
0.6m; 1.2m; 1.8m; 2.4m	Single glass	No	0.58

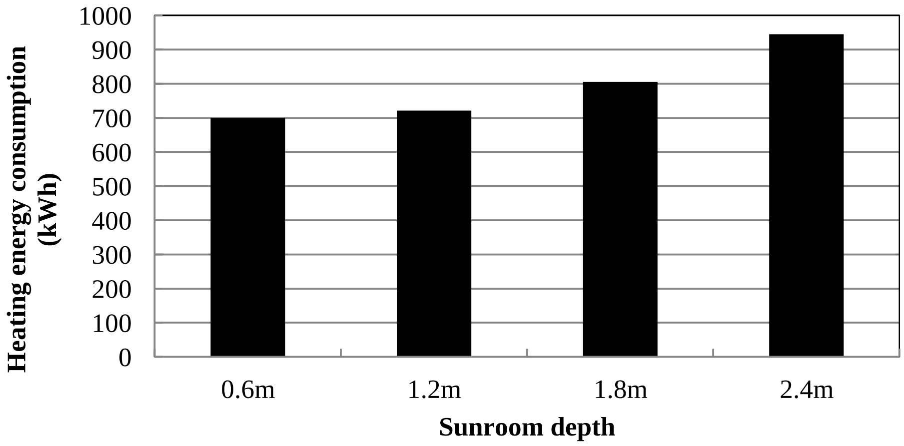


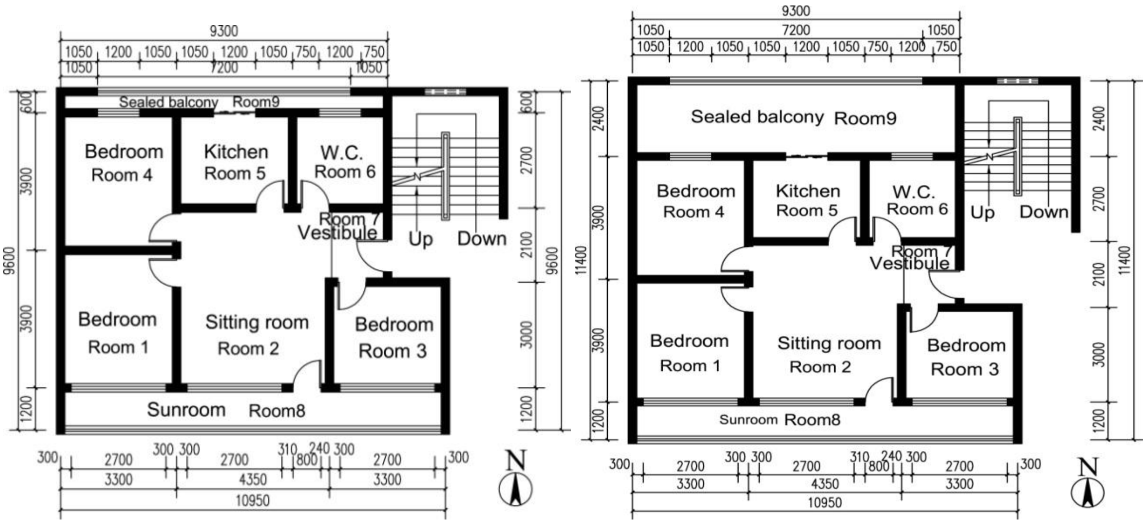
Fig. 4-22 Simulation results of the sunroom depth models for double-balcony unit

Fig.4-24 shows the simulation results. It is easy to see that the energy consumption gets higher with the sunroom depth increasing. Therefore, the depth of the sunroom should not be designed in a large size, combined with its architectural function; a depth of 1.2m to 1.8m is suitable.

4.2.5 North sealed balcony depth design

North sealed balcony here only points to the double-balcony unit. Firstly, we can make a simple qualitative analysis. As to the cushion space (north balcony), with the increasing of its depth, the heating insulating effect should get better, so that, the heating energy consumption should get smaller. To make a better understanding, the relationship between north sealed balcony depth and the heating energy consumption of the building is studied in this section.

Fig.4-23 shows the examples of different north balcony depth models. In the figure, the target models were created by keeping the layout of the rooms 1 to 7 in unchanged and changing the depth of the north balcony. As Table 4-16 shows, there are five north balcony depth models in total: 0m, 0.6m, 1.2m, 1.8m, and 2.4m. Every model has a same window-wall ratio 0.58 and the windows use single glass.



(a) North sealed balcony depth 0.6 (b) North sealed balcony depth 2.4

Fig.4-23 Schematic diagram of the north sealed balcony depth models (Unit: mm)

Table 4-16 Models of north sealed balcony depth analysis

North sealed balcony depth	Sunroom depth	Windows	Insulation	Windows-wall ratio in south side
0m; 0.6m; 1.2m; 1.8m; 2.4m	1.2m	Single	No	0.58

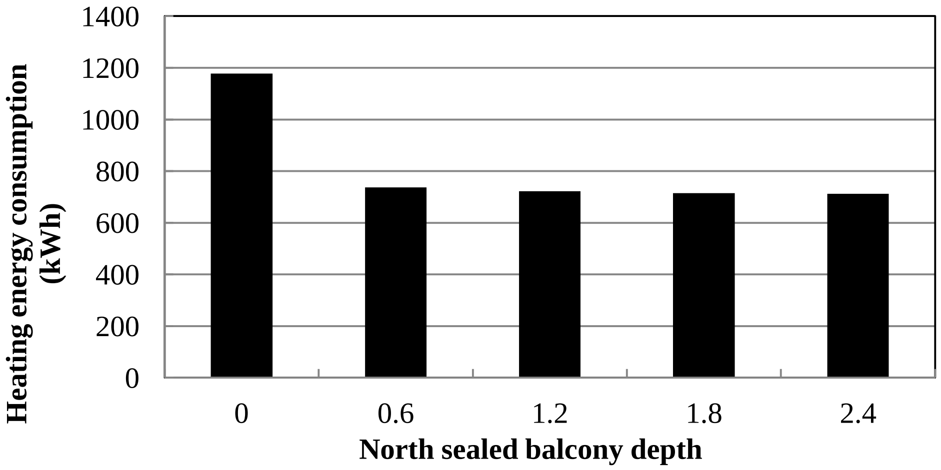


Fig.4-24 Simulation results of the north balcony depth design models

Fig.4-24 shows the simulation results. In general, the north sealed balcony is helpful for heating energy saving because from the 0m case, the energy has a great reduction. With the north balcony depth increasing, the energy consumption gets decreasing. But as the figure shows, the difference between cases is small, except the first one. So, in the building design process, the north sealed balcony is necessary, however its depth do not have too much effect on heating energy saving.

4.3 Envelope thermal performance design

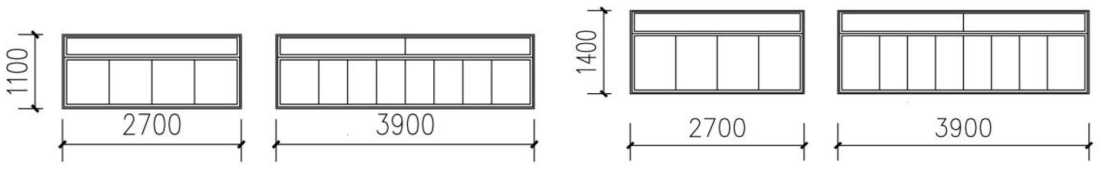
The thermal performance of envelope is very important to the building passive design. In this section, the envelope thermal performance design factors are studied for all three units. The design factors include window-wall ratio, windows type, external wall insulation and structure thermal mass design. In the following sections, these design elements will be studied one by one.

4.3.1 Window-wall ratio design

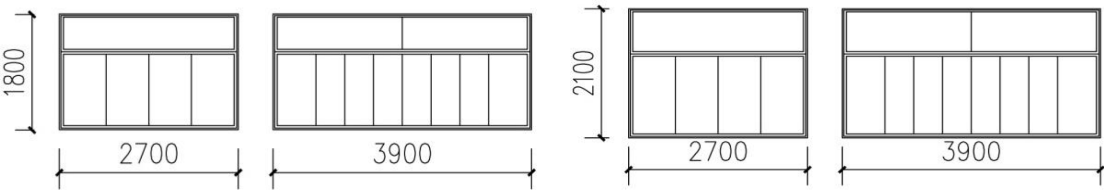
Window-wall ratio is a key design element for the solar access especially in the high solar exposure area like Lhasa. The design characteristics of window-wall ratio for three unit types will be studied in this section.

(1)Direct solar gain unit window-wall ratio design

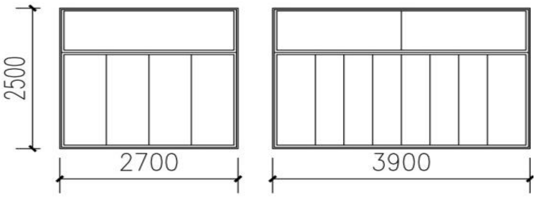
Table 4-17 shows five different window-wall ratio simulation models for direct solar gain unit. As the transparent part, glazing has hardly any thermal storage performance; a big window-wall ratio will affect the indoor thermal steady. In field survey, the extremely big window-wall ratio was rare. Common cases of existing residential buildings have the window-wall ratio form 0.4 to 0.6. For a better understanding, this section use extended cases from 0.3 to 0.7. Fig.4-25 shows the modes of different south windows size. From Modle1 to Model 5, the window-wall ratio is from 0.3 to 0.7, respectively.



(a) Window-wall ratio 0.3 Model (b) Window-wall ratio 0.4 Model



(a) Window-wall ratio 0.5 Model (b) Window-wall ratio 0.6 Mode



(e) Window-wall ratio 0.7 Model

Fig.4-25 Window-wall ratio models (Unit: mm)

Table 4-17 Window-wall ratio models information

Insulation	Window type	Orientation	Window-wall ratio
No	single glass	South	0.3; 0.4; 0.5; 0.6; 0.7

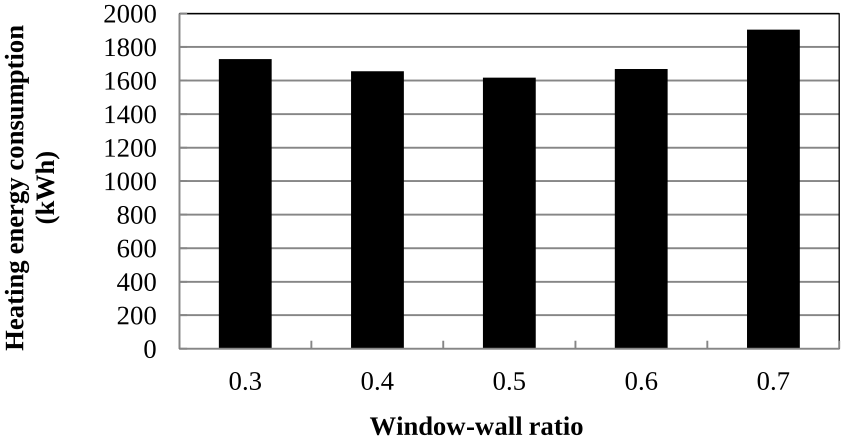


Fig.4-26 Simulation results of window-wall ratio models for direct solar gain unit

Fig. 4-26 shows the calculation results. From the results, it follows that, the windows-wall ratio 0.5 in south wall has the lowest heating energy consumption among all the window-wall models under the condition in Table 4-17.

In Lhasa，south windows are not only the heat loss structure but also the heat gain structure. From the ratio 0.3 to ratio 0.5, the solar heat gain by the windows area increasing makes the energy consumption goes down. However, the single glass window has poor thermal resistance performance, as the results shows, when the south window-wall ratio is beyond 0.5, even though more solar energy from the windows is gained, the heat loss caused by the poor thermal resistance windows also increases. From the figure, when the window-wall ratio is beyond 0.5, the heat loss through windows is higher than the solar heat gain from the windows. So the heating energy consumption increases when this ratio is beyond 0.5.

It is easy to get the conclusion that the transparent part of the envelope is one of the key control elements for the passive design in Lhasa. The single glass windows have a poor thermal resistance performance, so single glass models have the balance point at window-wall ratio 0.5; if better thermal resistance windows cannot be applied; the south window-wall ratio should not to be maximized.

(2) Attached sunroom unit window-wall ratio design

In attached sunroom unit design, window-wall ratio is also a key factor which affects the indoor thermal environment and the heating energy demand. Table 4-18 shows the basic setting of the window-wall ratio models. As the table shows, there are 5 models.

Table 4-18 Information of window-wall ratio models

Insulation	Direction	Windows type	Sunroom depth	Window-wall ratio
No	South	single glass	1.2m	0.3; 0.4; 0.5; 0.6; 0.7;

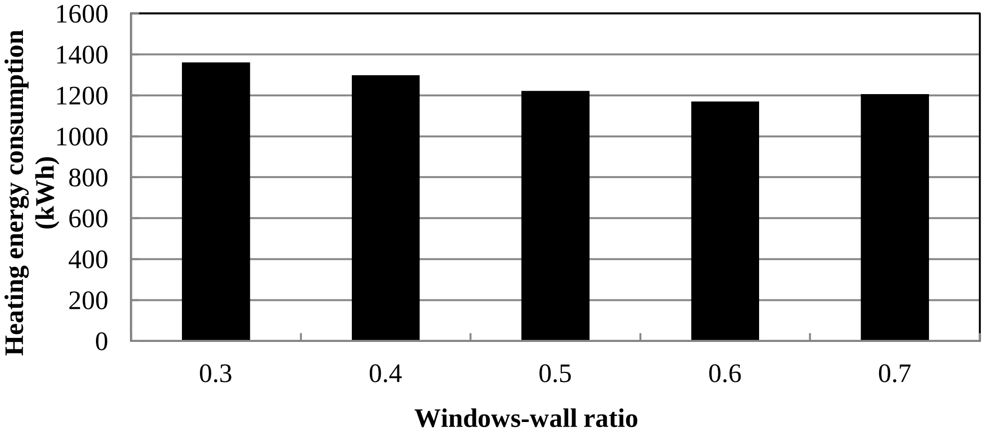


Fig.4-27 Simulation results of window-wall ratio models for attached sunroom unit

Fig.4-27 shows the calculation results. From the results it follows that, under the condition of Table 4-18; the windows-wall ratio 0.6 in south wall has the lowest heating energy consumption among all the window-wall models. The heating energy consumption trend is similar with the direct solar gain unit, but the balance point is different. This is because of the buffering effect of the sunroom. The sunroom in the simulation case can be recognized as the direct solar gain model adds one insulation layer. The south rooms of sunroom unit get solar radiation through the sunroom. However, in direct solar gain unit; the solar radiation affects south rooms directly. So the balance point between solar heat gain through windows and the heat loss through the windows is changed. The direct solar gain unit has higher relevance with the window-wall ratio.

(3) Double-balcony unit window-wall ratio design

Same with the previous two unit types, window-wall ratio are key thermal design factors for building energy saving of double-balcony unit. Table 4-19 shows the basic setting of the models for the window-wall ratio design. There are 5 window-wall ratios setting from 0.3 to 0.7.

Table 4-19 Models of windows type and window-wall ratio for double-balcony unit

Insulation	Direction	Windows	Sunroom/north balcony depth	Window-wall ratio
No	South	single glass	1.2m	0.3; 0.4; 0.5; 0.6; 0.7;

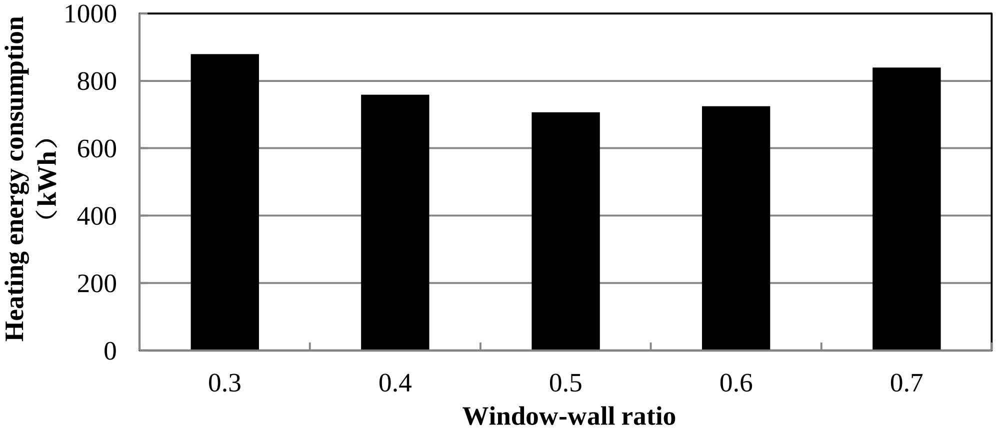


Fig. 4-28 Simulation results of window-wall ratio models for double-balcony unit

Fig.4-28 shows the calculation results. From the results, it follows that, under the condition of Table 4-19; the single glass windows models have the balance window-wall ratio for heating energy saving at 0.5.

All in all, the window-wall ratio is a complex design factor. The unit type affects the balance point for energy saving. This is a completed design element which needs overall consideration.

4.3.2 Windows types design

As mentioned before, the single glass windows have poor thermal resistance, so, to enlarge the windows size has two effects, solar energy gain and the indoor heat loss. Based on the analysis, the better thermal performance windows need to be discussed.

(1) Direct solar gain unit windows types design

This section studies the interaction effect between south window-wall ratio and the window thermal performance. Three kinds of windows types were introduced in the cases study. Table 4-20 shows these three window types—— single glass windows, double glass windows and low-e glass windows. As the table shows, the single glass has 6mm thickness; double glass has double glazing and 10mm air layer in the middle; low-e glass windows here means the double glass window which has one more low-e layer on the indoor side glass. All the models have the same basic setting as follows, no insulation, south direction. Fig.4-29 shows the calculation results.

Table 4-20 Window configuration (Unit: mm)

Windows type	Configuration (in to out)
Single glass	Glass: 6
Double glass	①.Glass: 6；②.Air:10；③.Glass: 6
Low-e	①.Glass: 6；②.Low-e layer；③.Air:10；④.Glass: 6

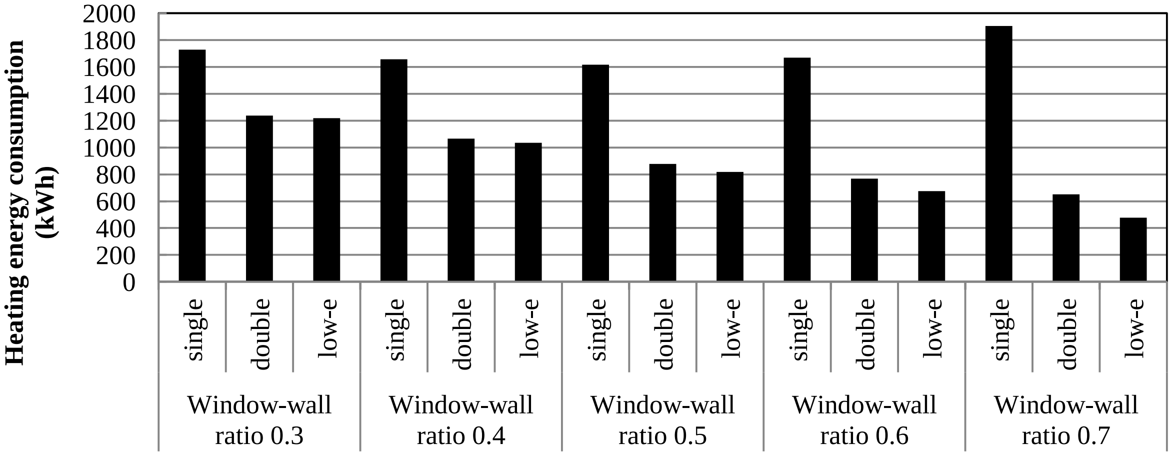


Fig.4-29 Results of window types models for direct solar gain unit

From Fig.4-29, we can see that there is a great energy reduction by applying double glass windows and low-e windows in every window-wall ratio group. And it is clear that, along with the window-wall ration increases, in double glass and low-e windows group, the heating energy consumption has a gradual decrease. We can conclude that for these two window types, a bigger south window-wall ratio results in a better heating energy saving effect. And at last, as mentioned before, single glass windows have a balance value at window-wall ratio 0.5.

(2) Attached sunroom unit windows types design

In this section, three kinds of the windows type are analyzed for attached sunroom unit. The configuration of these three kinds of windows is already shown in Table 4-20. Table 4-21 shows the models setting information. Fig.4-30 shows the calculation results.

Table 4-21 Information of window types models for sunroom unit

Insulation	Direction	Windows type	Sunroom depth	Window-wall ratio
No	South	Single glass; Double glass; Low-e glass	1.2m	0.3; 0.4; 0.5; 0.6; 0.7;

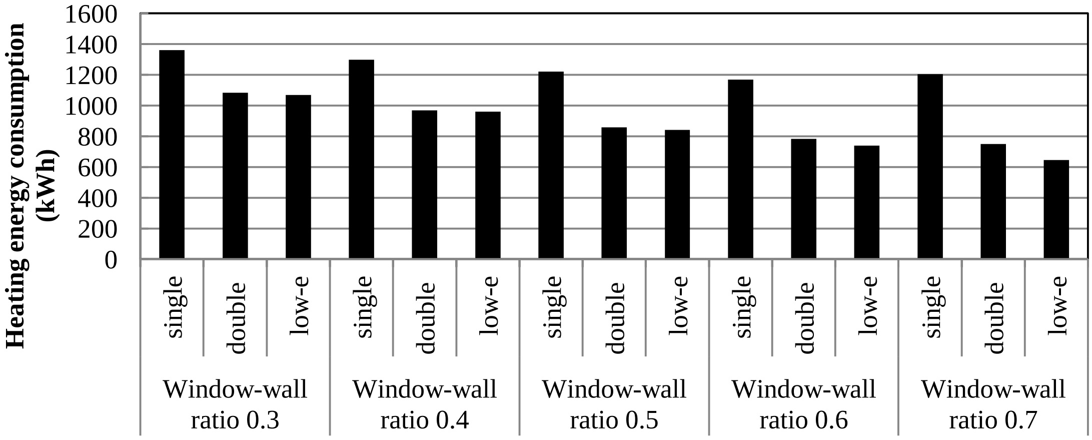


Fig.4-30 Results of window types models for attached sunroom unit

From Fig.4-30, we can see, single glass windows have the highest heating energy consumption for every window-wall ratio; this is because of its poor thermal performance. From the figure, it is not difficult to see that changing the single glass window to double glass/ low-e windows has a good effect for energy saving. And in every window-wall ratio group, the low-e models have always the lowest energy consumption. However, the energy saving effect of changing the double glass to low-e windows does not have an equivalent result as changing single glass did. In addition, the energy reduction by windows types in sunroom unit is lower than that of direct solar gain unit.

(3) Double-balcony unit windows types design

Same with the previous two unit types, windows types is studied for double-balcony unit. Table 4-22 shows the basic setting of the models for the windows types design combined with the window-wall ratio. In every window-wall ratio group, three windows type are considered.

Table 4-22 Models of windows type and window-wall ratio for double-balcony unit

Window-wall ratio	Sunroom/ north balcony depth	Insulation layer	Windows type
0.3; 0.4; 0.5; 0.6; 0.7	1.2m	No	Single glass; Double glass; Low-e

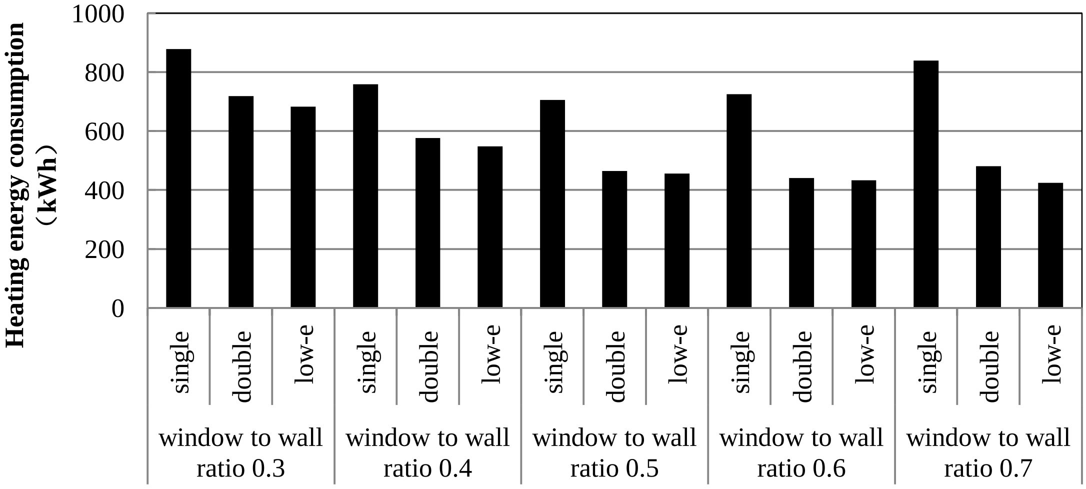


Fig. 4-31 Results of window types models for double-balcony unit

Fig.4-31 shows the calculation results. From the results, it follows that, in every window-wall ratio group, the single glass always results in the highest heating energy consumption. At the same time, energy reduction form single glass to double/ low-e windows is big; and changing the double glass windows to low-e windows does not have a equivalent effect.

All in all, the windows types study in this section proves that changing the single glass to better thermal performance windows types has a good energy reduction effect for all three unit types.

4.3.3 External wall thermal resistance design

There is no doubt that to add the insulation layer is a basic way to control the heat loss from the external walls. This section will study the effect of the resistance to the heating energy consumption in Lhasa.

(1) Direct solar gain unit external wall thermal resistance design

In this section, 4 different insulation layer thickness models are discussed. Table 4-23 shows the configuration of the external walls. Table 4-24 shows the insulation models setting. As this table shows four models are set here.

Table 4-23 Configurations of the external walls for thermal resistance study

Ex-wall (in to out)	Cement plaster	Lime sand brick	EPS layer	Cement plaster
Thickness	0.015m	0.37 m	6 Models	0.015 m

Table 4-24 Ex-wall thermal resistance models setting

Models	EPS layer (cm)	Ex-wall thermal resistance [(m^2 K)/W]
1	0	0.37
2	2	0.84
3	4	1.32
4	6	1.80

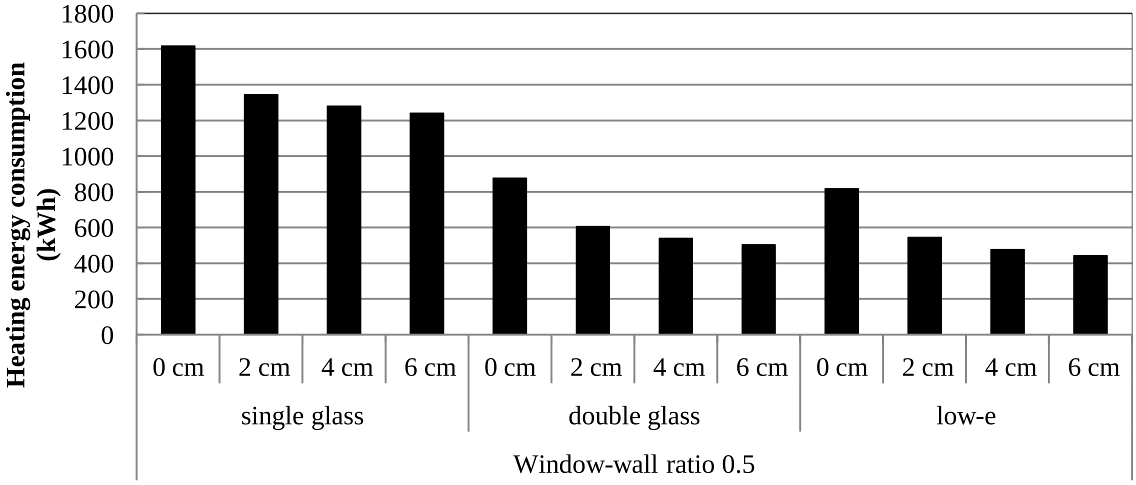


Fig.4-32 Simulation results of thermal resistance models for direct solar gain unit

Fig.4-32 shows the calculation results. From figure, it is clear that for all windows type group, with the thickness of the insulation layer increasing, the heating energy consumption decreases. As for the heating energy consumption reduction effect, 0cm to 2cm has the best effect. As a conclusion, thermal resistance does well in the energy saving effect; but the thickness does not have big effect.

As for the difference among the three windows types, the single glass group has obviously higher energy consumption than the double glass windows and low-e windows group. And the low-e group has lowest energy consumption. As for the energy reduction effect, to add the insulation layer does not have as good energy reduction effect as to change windows types did.

(2) Attached sunroom unit external wall thermal resistance design

In this section, the interaction of windows types and the external wall thermal resistance is studied for attached sunroom unit. Table 4-25 shows the information of thermal resistance of the external wall and the windows type. The configuration of the external walls is same with the models in direct solar gain unit. Fig.4-33 shows the calculation results.

Table 4-25 Information of external wall thermal resistance models

Insulation layer (EPS layer)	Windows type	Sunroom depth (m)	Window-wall ratio
0cm; 2cm; 4cm; 6cm	Single; Double; Low-e	1.2	0.5

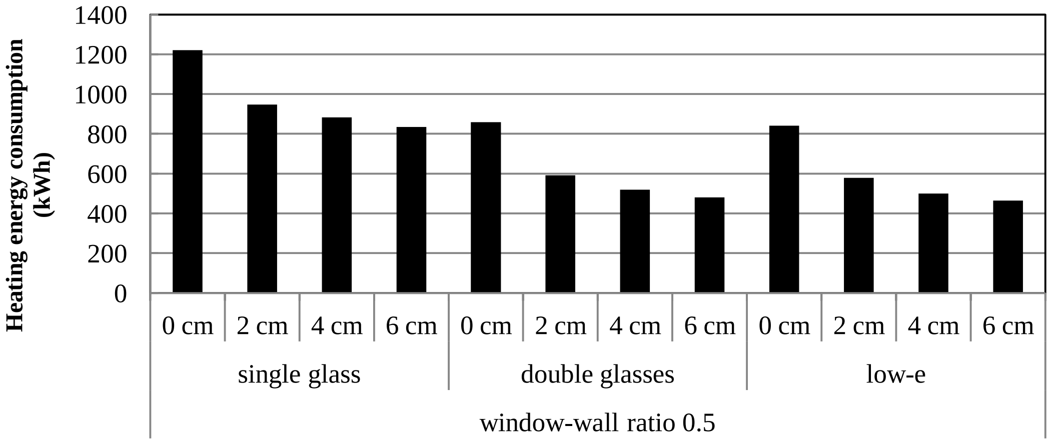


Fig.4-33 Simulation results of the thermal resistance models from attached sunroom unit

From Fig.4-33, it is clear that for all three windows types' models, with the thickness of the insulation layer increasing, the heating energy consumption decreases. As for the reduction effect, the effect from 0 cm to 2 cm is the best one. As a result, in Lhasa, the insulation layer is necessary for sunroom unit, however, the thickness does not contribute too much for the energy reduction.

From the point of view of heating energy saving effect, the first step of the energy saving work in Lhasa for the sunroom unit design is to change the single glass windows to double glass windows/ low-e windows and then the insulation layer should be applied, because the windows types have a better effect.

(3) Double-balcony unit external wall thermal resistance design

Table 4-26 shows the target models' information of thermal resistance and the windows types. The configuration of the external walls is same with the models in direct solar gain. So it is not necessary to repeat here. Fig.4-34 shows the calculation results.

Table 4-26 Models of thermal resistance

Insulation layer (EPS layer)	Windows type	Sunroom/north balcony depth (m)	Window-wall ratio
0cm; 2cm; 4cm; 6cm	Single; Double; Low-e	1.2	0.4

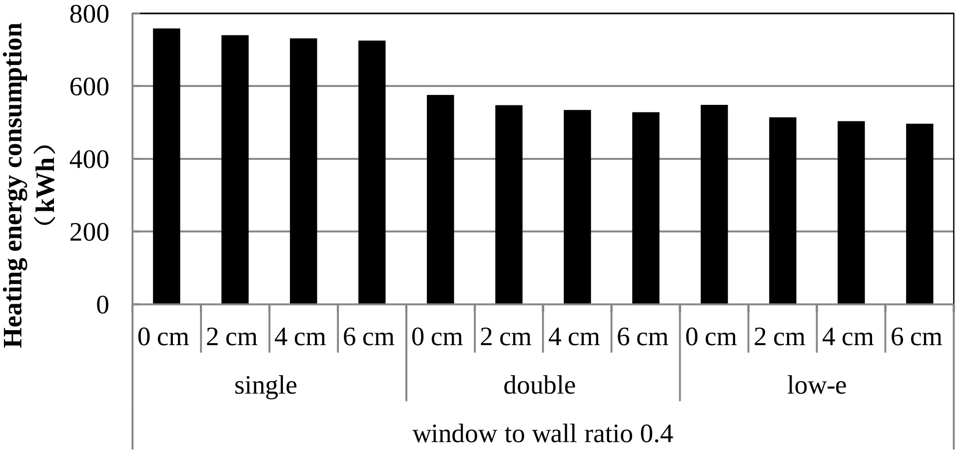


Fig.4-34 Simulation results of the external wall insulation models for double-balcony unit

From Fig.4-34, it is clear to see, for all the single glass, double glass and low-e models, with the thickness of the insulation layer increasing, the heating energy consumption decreases. Therefore, better thermal resistance of the external wall works well on heating energy saving, however, as the figure shows, the effect is not so obvious for double-balcony unit.

All in all, three unit types have the same characteristics. The insulation layer is helpful to the heating energy consumption; however, the effect of the thickness increasing is not as big as from 0cm to 2cm. Also, compared with the effect of windows types, the effect of the insulation is lower.

4.3.4 Thermal storage performance design

Thermal storage performance of the structure relates with the indoor thermal steady. The solid structure of the build has the delayed action and the attenuation to the outdoor air temperature fluctuation. In the area with high solar exposure, the solar radiation in normal direction has the compensation effect for heat loss caused by the indoor and outdoor temperature difference. In this case, the solar radiation can be recognized as the equivalent temperature, it is obvious that the daytime and the night time have the big difference of this equivalent temperature fluctuation. This phenomenon enlarges the indoor temperature fluctuation caused by the daily range of the outdoor air temperature fluctuation. The physical explanation is shown in my paper *Analysis on Non-Balance Insulat*ion in Lhasa [6].

As a normal understanding, without good thermal storage performance, the indoor temperature will also have a big fluctuation which will affect the thermal feeling. So the structure's thermal storage performance is important. In this section, the thermal storage performance will be studied.

(1) Thermal storage performance design for direct solar gain unit

Three models are set in this section. Table 4-27 shows the models setting. The light-weight structure uses aerated concrete; the middle-weight structure uses hollow clay brick; the heavy-weight structure uses reinforced concrete. The entire models have window-wall ratio 0.5, the direction is south, and the window uses single glass.

In this section two scenarios are studied. In scenario one, the external walls and the internal walls use the material in the Table 4-27; in scenario two, besides the external walls and the internal walls, the floor/ ceiling applies the same materials. This section takes the indoor air temperature in January as the example to study the effect of thermal mass for non-heating condition.

Table 4-27 The external walls configuration of thermal storage models

	Light-weight	Middle-weight	Heavy-weight
Main structure material	aerated	hollow clay brick	reinforced concrete
Thickness (m)	0.0786	0.24	0.30
Conduction[W/(m K)]	0.19	0.58	1.74
Specific heat[kJ/(kg·K)]	1050	1050	920
Density(kg/m^3)	500	1400	2500
Thermal resistance [(m^2 K)/W]	0.41	0.41	0.41 (with 0.01m EPS)

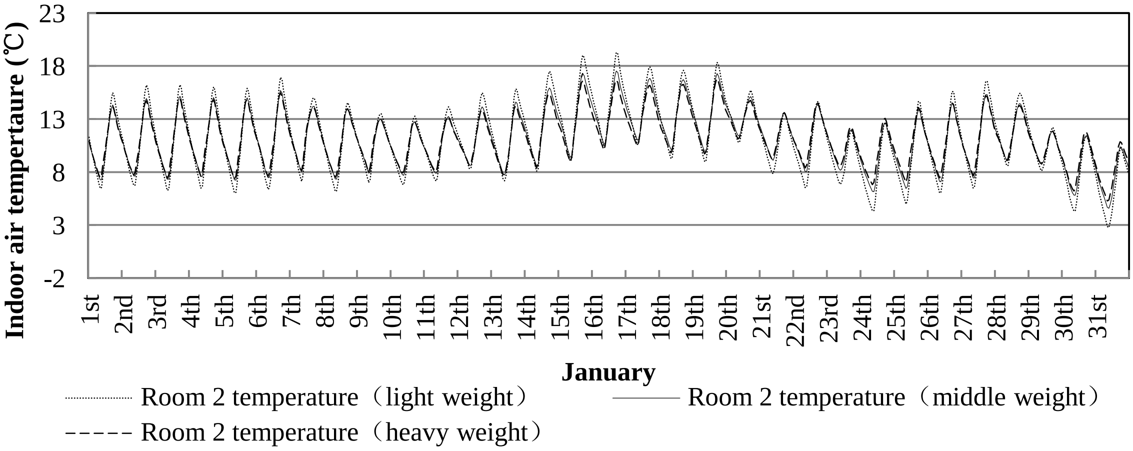


Fig.4-35 Indoor air temperature fluctuation of thermal storage models (scenario one)

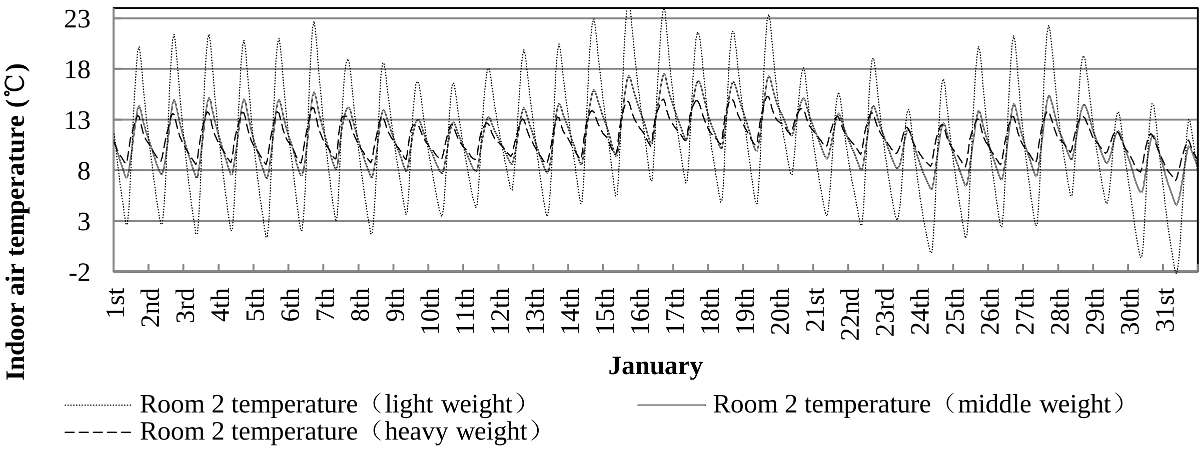


Fig.4-36 Indoor air temperature fluctuation of thermal storage models (scenario two)

Fig.4-35 shows the indoor air temperature of Room 2 (living room in Fig.4-3) in January. As introduced before, the models in this scenario apply the external wall and the internal wall with the materials listed in Table 4-27. The monthly average values of daily range of three models——light weight, middle weight, and heavy weight, are 8.09℃, 6.31℃, 6.08℃, respectively. The light weight model has the biggest temperature fluctuation and the heavy weight model have the smallest temperature fluctuation.

Fig.4-36 shows the results of the thermal storage models applied the external wall, the internal wall and the floor/ceiling with the material listed in Table 4-21. The monthly average values of daily range of three models are 16.19℃, 6.31℃, 4.20℃, respectively.

Obviously, the floor/ceiling is important to the indoor thermal steady. For better indoor thermal steady, the heavy weight material is necessary to be applied.

For a heating energy reduction study, the heating energy consumption of each model is necessary to be studied. The configuration is shown in Table 4-27. Fig. 4-37 shows the heating energy consumption results.

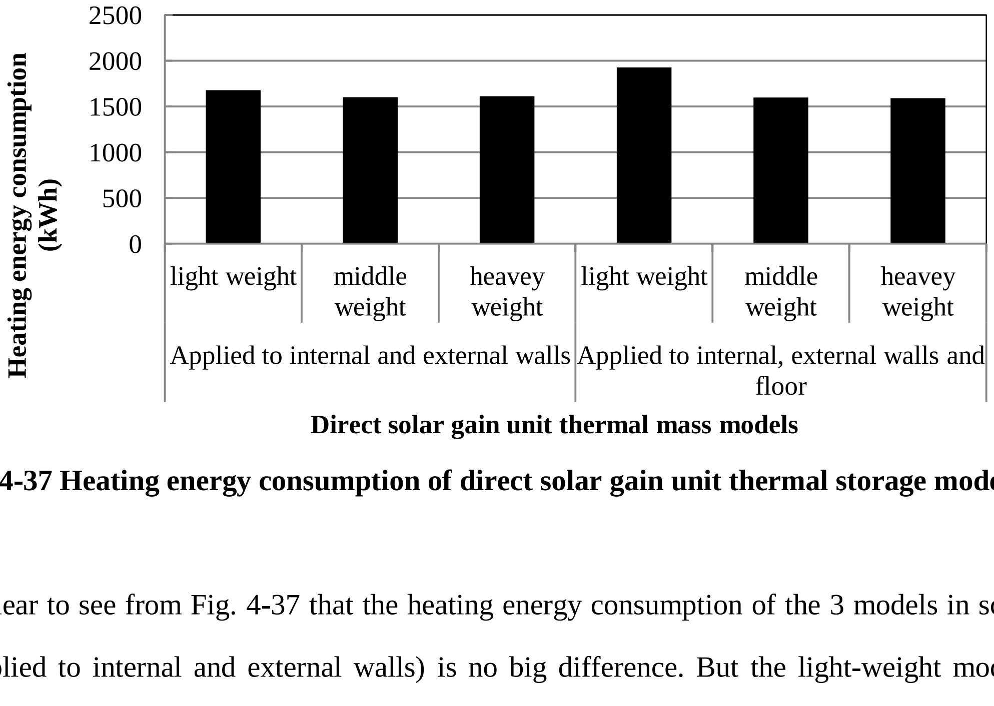


Fig.4-37 Heating energy consumption of direct solar gain unit thermal storage models

It is clear to see from Fig. 4-37 that the heating energy consumption of the 3 models in scenario one (applied to internal and external walls) is no big difference. But the light-weight model has relatively higher energy consumption. As to the scenario two (applied to walls and floors), the same trend is shown, but the heating energy consumption of light-weight model is obviously higher. It is easy to understand. Light weight model has the bigger temperature fluctuation. At the peak point, heating load of the light-weight model is higher than the other two models. So, from the angle of heating energy saving, the light-weight materials should not be applied.

(2) Thermal storage performance design for attached sunroom unit

In this section the thermal storage performance for the structure of the sunroom models are analyzed. The models are set as Table 4-28. In this simulation, the structure, the models setting, and the external wall configuration are set same with direct solar gain unit.

Table 4-28 Thermal mass models

Orientation	Windows type	Sunroom depth (m)	Window-wall ratio
South	Single	1.2	0.5

Same with the direct solar gain unit study, in this section, two scenarios are studied. First, the external walls and the internal walls use the material in the Table 4-27; second, the external walls, the internal walls and the floor/ ceiling use the material in Table 4-27.

Fig.4-38 and Fig.4-39 show the calculation results of indoor air temperature for the both scenarios (no air conditioner system).

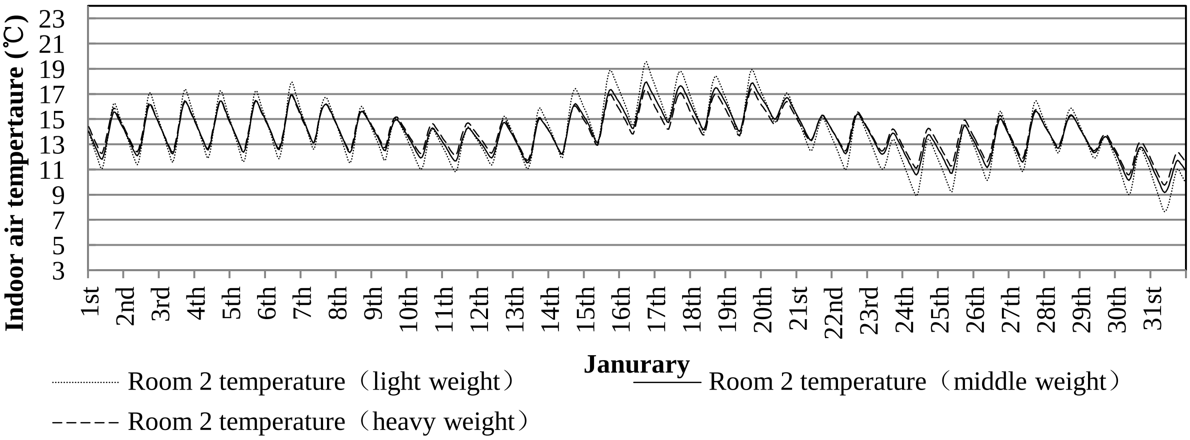


Fig.4-38 Indoor air temperature fluctuation of thermal storage models (scenario one)

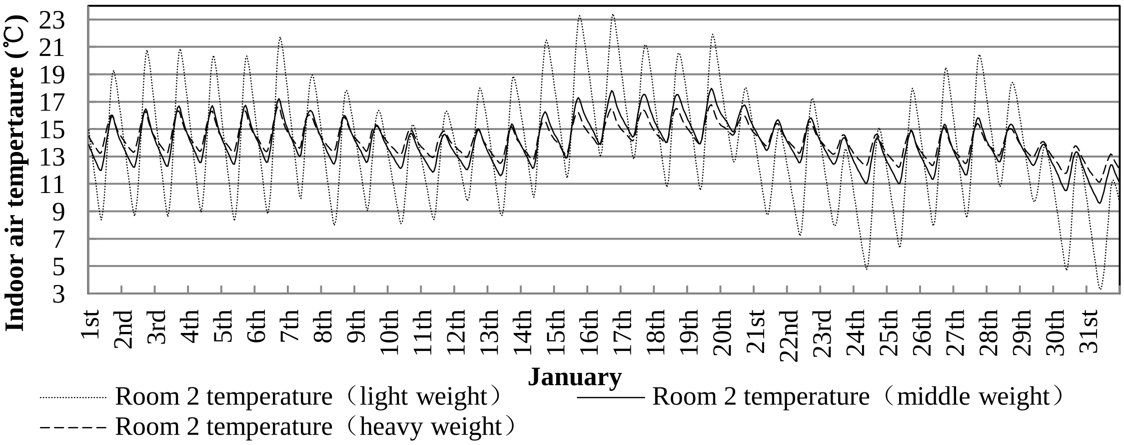


Fig.4-39 Indoor air temperature fluctuation of thermal storage models (scenario two)

Fig.4-38 shows the calculation results of the scenario one which applied the external walls and the internal walls with the light weight, middle weight, and heavy weight material. In January, the monthly average values of daily range of light weight, middle weight, and heavy weight are 4..44℃, 3.22℃, 3.14, respectively. The light weight model has the biggest temperature fluctuation and the heavy weight model have the smallest one.

Fig.4-39 shows the results of scenario two. In January, the monthly average values of daily range of light weight, middle weight, and heavy weight are 9.61℃, 3.39℃, 2.41℃, respectively.

From the results differences, it is obviously to see that the floor/ceiling is important to the indoor thermal steady. And light material is not good for the thermal steady.

Same with the direct solar gain unit, heating energy consumption of the models is simulated.

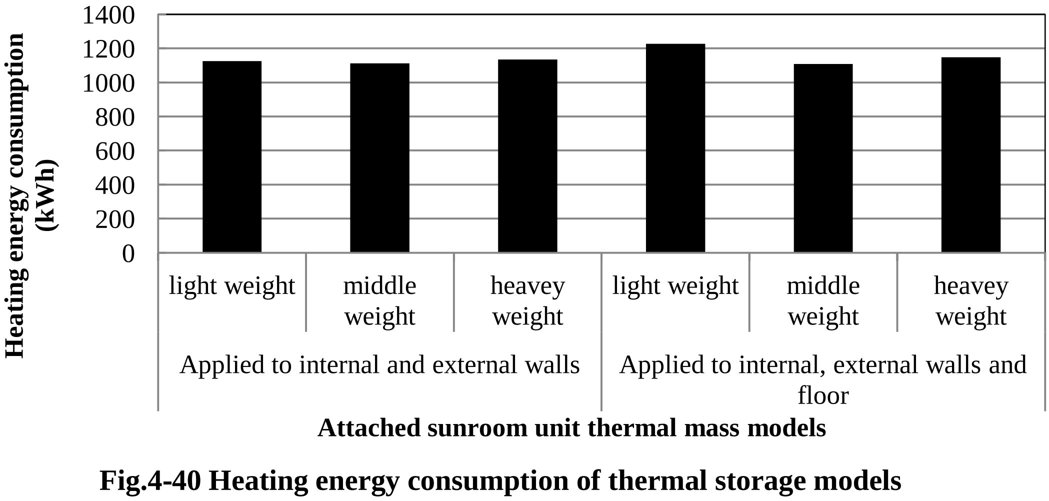


Fig.4-40 Heating energy consumption of thermal storage models

The case setting is shown in Table 4-28. Fig. 4-40 shows the heating energy consumption results of the 6 models. It is clear to see from Fig. 4-37 that with the same condition, the heating energy consumption of the 3 models in scenario one (applied to internal and external walls) have no big difference, these results have same trend with the direct solar gain unit. As to the scenario two (applied to all walls and floors), the light weight material case has the highest heating energy consumption, this is because the thermal load at the peak point of light weight material is bigger than the other two cases. And from the figure, we can see that the heating energy consumption of heavy-weight model has slightly higher energy consumption than the middle-weight model, this is because the heavy structure has bigger thermal capacity, compared with the middle-weight model, and it stores more energy before heating the indoor air temperature.

All in all, from the angle of heating energy saving, the light-weight materials structure should not be applied.

(3) Thermal storage performance design for double-balcony unit

The thermal storage performance of the double-balcony models are analyzed in this section. There are 3 models for the thermal storage performance study. The light-weight structure uses aerated concrete; the middle-weight structure uses hollow clay brick; the heavy-weight structure uses reinforced concrete.

Table 4-29 Thermal mass models

Orientation	Windows type	Sunroom/north balcony depth (m)	Window-wall ratio
South	Single	1.2	0.5

Same with the thermal mass study of direct solar gain unit/ sunroom unit, in this section, two scenarios are studied. First, the ex-external wall and the internal walls use different thermal mass materials; second, the ex-external wall, the internal walls and the floor/ ceiling use different thermal mass materials.

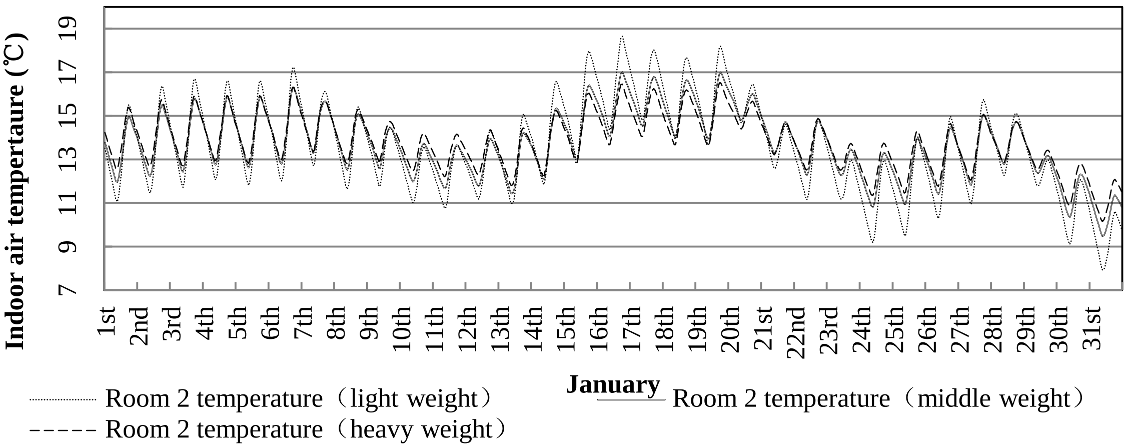


Fig.4-41 Simulation results of thermal storage models (scenario one)

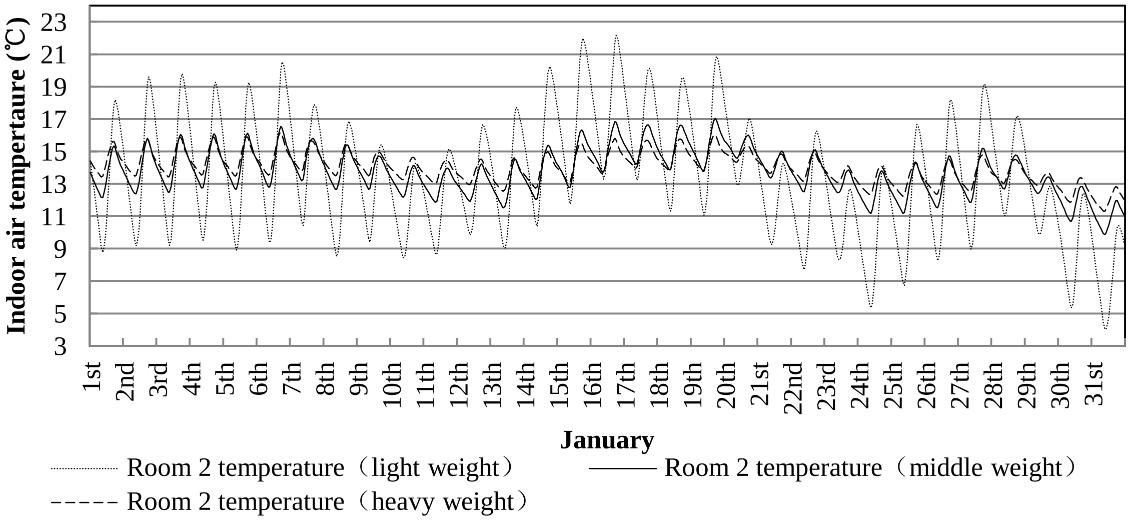


Fig.4-42 Simulation results of thermal storage models (scenario two)

Fig.4-41 shows the calculation results of the thermal storage models which apply the external walls and the internal walls. The monthly average values of daily range for three models ——light weight model, middle weight model, and heavy weight model are 3.74℃, 2.55℃, 2.42℃, respectively. The light weight model has the biggest temperature fluctuation and the heavy weight model have the smallest temperature fluctuation.

Fig.4-42 shows the results of the thermal storage models applied the external wall, the internal wall and the floor/ceiling. The monthly average values of daily range of light weight, middle weight, and heavy weight are 8.14℃, 2.68℃, 1.87℃, respectively.

Same with the previous two unit types, the heating energy consumption of the models is simulated. The simulating models setting are shown in Table 4-29. The calculation results are shown in Fig.4-43.

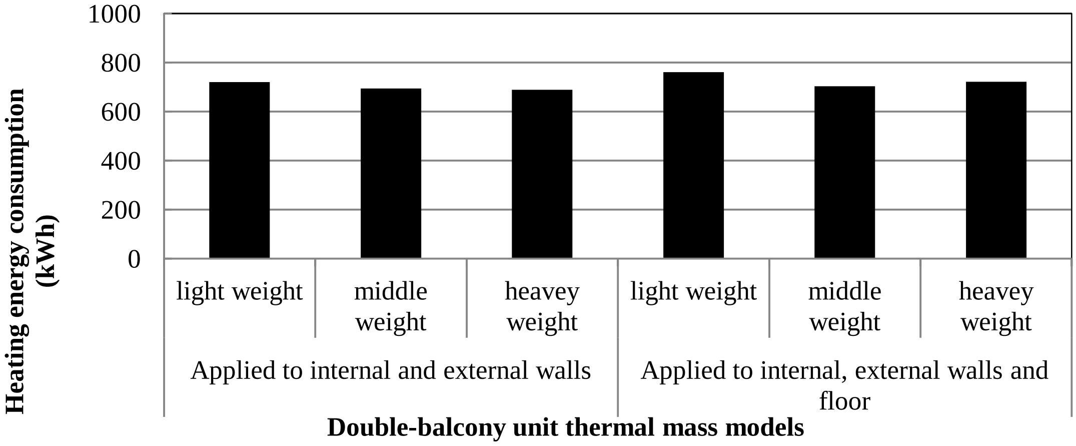


Fig.4-43 Heating energy consumption of double-balcony unit thermal storage models

From Fig. 4-43 we can see that with the same condition the heating energy consumption of the 3 models in scenario one (applied to internal and external walls) is no big difference, and the light-weight model has tiny higher energy consumption. As to the scenario two (applied to all walls and floors), the light weight material case has the highest heating energy consumption, The reason here is same with the previous two study units.

And from the figure, we can see that the heating energy consumption of heavy-weight model has slightly higher energy consumption than the middle-weight model, this is because the heavy structure has bigger thermal capacity, compared with the middle-weight model, and it stores more energy before heating the indoor air temperature.

For all the three unit types, direct solar gain unit, sunroom unit and double-balcony unit, in Lhasa city, the floor/ceiling is important to the indoor thermal steady. Among these three unit types, under the same condition, the direct solar gain unit has the biggest temperature fluctuation; the double-balcony unit has the smallest temperature fluctuation. The sealed balcony is a good design for the indoor thermal steady.

All in all, the light-weight materials should not be applied; middle weight and heavy weight materials should be applied. As the field survey in Chapter 3 shows, most of the local contraction materials for brick-concrete are heavy materials, the fillers walls of frame structure need to be paid attention.

4.4 Key design factors combination

In the former sections, every single unit design element and the envelope thermal design element are analyzed. For a better understanding of the effect of the passive design factors, the key design factors interaction and combination are necessary to be studied.

As for architectural form design, it is a very flexible conception; it is affected by many other boundary conditions as architectural function, site, art design and so on. It is difficult to give a certain definition for the best unit shape or the south/north room's depth layout, so in the beginning of this chapter, it is clear that the architectural form study is the design trend study. It is not suitable to consider the architectural form in the combination study. So only the envelope thermal design elements are considered in here.

The combination of the thermal resistance, window types and window-wall ratio is analyzed in this section.

4.4.1 Direct solar gain unit key design factors combination

Table 4-30 and Table 4-31 show the information on the simulation models. The window-wall ratios are 0.4, 0.5 and 0.6. The bigger window-wall ratio is not selected here, because the glass has hardly thermal storage performance, bigger window-wall ratio will result in the big indoor temperature fluctuation. In addition, the bigger window-wall ratio requires larger window height, and this is not good for the shading design in summer. So the common window-wall of 0.4, 0.5 and 0.6 are studied. As to the insulation layer thickness, the 0cm, 2cm and 4 cm are selected.

Table 4-30 Configurations of the external walls for design factors combination study

Windows type	Window-wall ratio	Insulation layer thickness
Single glass	0.4	0cm
Double glass	0.5	2cm
Low-e glass	0.6	4cm

Table 4-31 Insulation thickness and the corresponding thermal resistance

EPS layer (m)	Ex-wall thermal resistance [(m^2 K)/W]
0	0.37
0.02	0.84
0.04	1.32

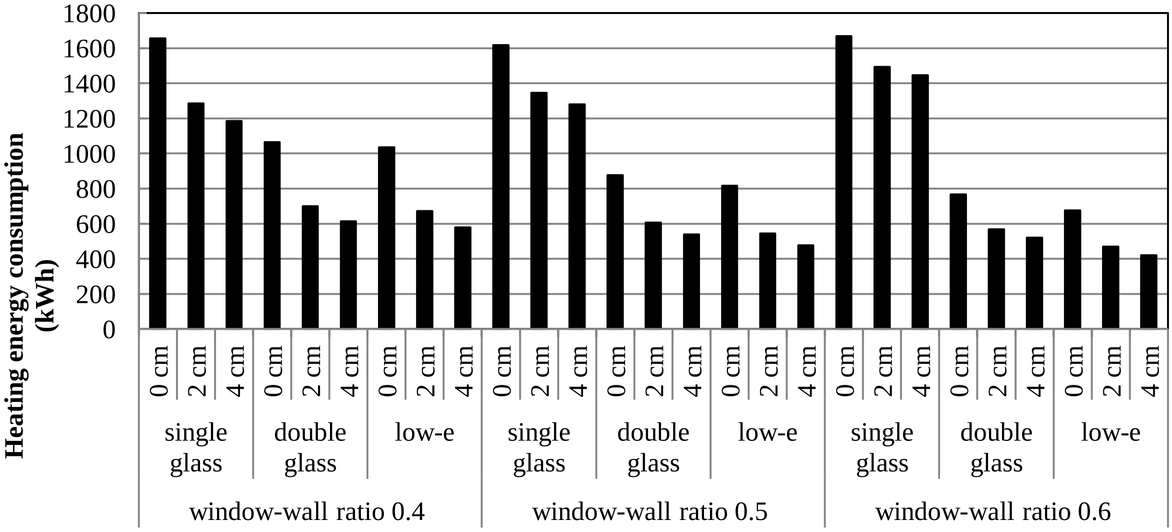


Fig.4-44 Calculation of direct solar gain design factors combination

Fig.4-44 shows the simulation results, it is clear that for all windows types and window-wall ratio groups, with the insulation layer thickness increasing, the models have lower energy consumption. In double glass windows and low-e windows group, bigger window-wall ratio results in the lower heating energy consumption, however, in the single glass windows group, there is no such rule. This indicates that the thermal performance of the windows has to be improved together with the solid wall's thermal performance improvement, or else, the bigger window-wall ratio is meaningless.

In every window-wall ratio group, the energy consumption difference between single glass windows and double glass/ low-e windows is big, but between double glass widows and low-e windows, the difference is not equivalent big. So the first step in the building energy saving design in Lhasa would be to replace the single glass windows with better thermal performance windows from the effect of the heating energy saving.

4.4.2 Attached sunroom unit key design factors combination

Same reason with direct solar gain unit, the envelope thermal performance design factors are analyzed in this section. The design factors include window-wall ratio, window types and external wall thermal resistance. The models are set in Table 4-32. Window-wall ratio use 0.4, 0.5 and 0.6. Insulation uses 0 cm, 2 cm, 4 cm, which are the common value in the real design.

Table 4-32 Models of sunroom design factors combination study

Sunroom depth	Windows type	Window-wall ratio	Ex-wall Insulation layer
1.2m	Single; Double; Low-e	0.4; 0.5; 0.6	0 cm EPS，2 cm EPS 4 cm EPS

Fig.4-45 shows the calculation results. As this figure shows, better thermal resistance results in lower energy consumption. Especially, the heating energy reduction effect between the models with and without insulation layer is the most obvious one. Similar to direct solar gain unit, double glass and low-e glass have obviously lower heating energy consumption than the single glass does. With window-wall ratio increasing from 0.4 to 0.6, for all windows types group, the heating energy consumption decreases.

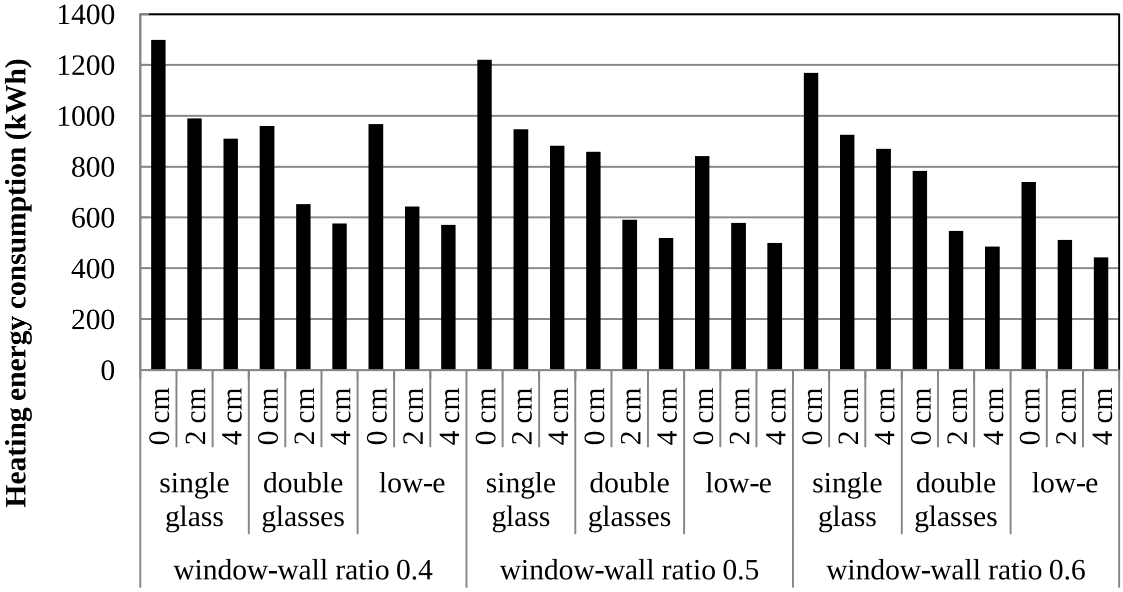


Fig.4-45 Simulation results of sunroom design elements combination

According to the simulation results, for attached sunroom design in Lhasa, the single glass windows should not be used. The effect of changing windows type is bigger than enlarging the window-wall ratio and adding insulation layer.

4.4.3 Double-balcony unit key design factors combination

In the combination study of double-balcony unit, the items as window-wall ratio, window types and external wall thermal resistance are analyzed. The models are shown in Table 4-33.

Table 4-33 Models of double-balcony design factors combination

Sunroom depth	North balcony depth	Windows type	Window-wall ratio	Ex-wall Insulation layer
1.2m	1.2m	Single; Double; Low-e	0.4; 0.5; 0.6	0 cm EPS，2 cm EPS 4 cm EPS

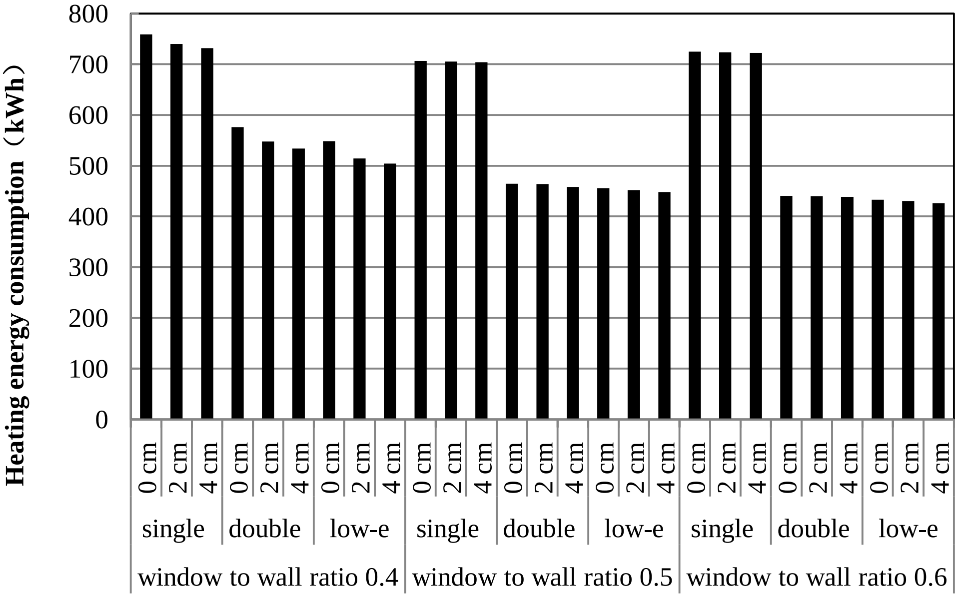


Fig.4-46 Simulation results of double-balcony design factors combination

Fig.4-46 shows the calculation results. As the figure shows, the better thermal resistance of external walls gave the lower heating energy consumption. However, for the window-wall ratio 0.5 and window-wall 0.6, the effectiveness of enlarging EPS layer thickness became weak. And, for all three window-wall group, double glass and low-e glass have obviously lower energy consumption than the single glass models.

4.5 Summary of all case studies

In the previous sections, the passive design factors of architectural form design and the envelop thermal performance design and their combination are studied. Totally, 323 simulation cases are studied in this chapter.

In order to make a clear clue to get passive design characteristics and the best effect in every studied design items, it is necessary to make a simulation results table. Table 4-32 shows the best case setting in every simulation item (based on the window-wall ratio 0.6).

Table 4-34 Simulation results of the cases study in Chapter 4

		Direct solar gain unit			**Attached sunroom unit**			**Double-balcony unit**		
		Best case		Value 2 (kWh)	Best case		Value 2 (kWh)	Best case		Value 2 (kWh)
		Case setting	Value 1 (kWh)		Case setting	Value 1 (kWh)		Case setting	Value 1 (kWh)	
Architectural form	Orientation	South	1684.5	979.6	South	1178.3	512.1	South	724.3	312.4
	Building shape	Large depth	1518.8	403	Large depth	1106.1	95.8	Large depth	696.4	72.1
	Room layout	Large south room area	1646.8	72.6	Large south room area	1156.6	37.1	Large south room area	700.5	45.7
	Sunroom depth	/	/	/	0.6 m	1144.2	174.2	0.6 m	699.3	245.3
	North seal balcony depth	/	/	/	/	/	/	2.4 m	711.8	25.3
Envelope thermal performance	Window-wall ratio	0.5	1617.1	287.6	0.6	1169.4	192.2	0.5	706.2	132.5
	Windows types	Low-e	675.1	993.1	Low-e	738.9	430.5	Low-e	432.6	292.7
	Thickness of the insulation layer	6 cm	1446.6	221.6	6 cm	869.9	299.5	6 cm	719.9	4.9
	Thermal mass	Heavy weight	1599	78	Heavy weight	1111	14	Heavy weight	688	31
Design factors combination	a. W-w ratio + b. Window type + c. Insulation	a. 0.6 + b. Low-e + c. 4 cm	420.1	1248.1	a. 0.6 + b. Low-e + c. 4 cm	442.7	856	a. 0.6 + b. Low-e + c. 4 cm	422.02	336.58

In Table 4-34, the column with light gray shows the setting of best models in each design factor. And “Value 1” shows the heating energy consumption of the best case. “Value 2” shows the difference between best case and the worst case in heating energy consumption, which also can be considered as the effect of the corresponding design factor.

This table shows the summary of each design factor, which has been explained one by one in detail in the previous sections. So, the details of the explanations are omitted here.

4.6 Conclusions

In this chapter, the passive design of unit-divided apartment in Lhasa has been studied. For the three unit types, direct solar gain unit, sunroom unit and the double sealed balconies unit, the basic architectural form design elements and the envelope thermal performance design elements were analyzed.

For architectural form design， several results are shown as following:

1. Orientation has strong influence to energy consumption. For example of direct solar gain unit, under the condition shown in 4.2.1, the top energy consumption case is 1.7 times of the lowest one (south).

2. Only direct solar gain unit has big relevance with the building shape design. Sunroom unit and double-balcony unit do not have big relevance with it.

3. For all three units, the north and south room layout design affects heating energy consumption, but the relevance is not big.

4. Sunroom and north balcony can reduce much energy. As shown in 4.1, 27% heating energy can be reduced by sunroom and 56% energy can be reduced by the combination of sunroom and north balcony. The depth of the sunroom and north sealed balcony affects heating energy, but the relevance is not big.

For envelope thermal performance design， several results are shown as following:

1. Windows types have the strongest influence to heating energy. Double glass windows also have good effect although the low-e is the best type (58% energy reduction for direct solar gain unit).

2. Insulation reduces more than 17% heating energy (direct solar gain unit); the thickness of the insulation does not have strong influence.

3. Window-wall ratio affects heating energy consumption, but the influence is not high.

For the design factors combination study, the best value of window-wall ratio changes by the windows type and unit type. This is a completed design factor, the design needs over all consideration.

References:

[1] U.S. Department of Energy, Passive Solar Home Design

http://energy.gov/energysaver/articles/passive-solar-home-design

[2] Ozaki A, Watanabe T, Takase S, Simulation Software of the Hydrothermal Environment of Buildings Based on Detailed Thermodynamic Models, eSim 2004 of the Canadian Conference on Building Energy Simulation. pp.45-54.

[3] Zhang Qingyuan，Joe Huang, Climate data base for building design of China, Beijing: China Machine Press; 2004.(in Chinese)

[4] Construction Bureau of Tibet Autonomous Region, Design Standard for Energy Efficiency of Residential Buildings (DB54/0016-2007), Lhasa: Tibetan People Press; 2007 (in Chinese)

[5] Ministry of Housing of the People's Republic of China, Thermal design code for civil building (GB50176-93), Beijing: China Planning Press; 1993 (in Chinese)

[6] En Li, Jiaping Liu. Analysis on Non-Balance Insulation in Lhasa. Advanced Materials Research (Volumes 243 - 249), 2011, pp 6990-6996.

Chapter 5

5. Residential building passive design strategy analysis and effectiveness verification for Lhasa

Chapter 5. Residential building passive design strategy analysis and effectiveness verification for Lhasa

This research aims to give one solution for Lhasa’s sustainable development in the future. The solid content in this chapter is to control the heating energy consumption in winter in the urban area in the future by passive design strategy. In general, the urban scale residential building heating energy consumption is affected by urban heating area, climate and indoor thermal comfort standard, heating period and building performance. In which, the heating area is affected by the population and economy growth; these two items will be analyzed by forecast study in the following sections. As to climate, indoor thermal comfort standard and heating period, they are defined in the local standard. The strategy study in this chapter is mainly about the building performance, which includes building architectural form and thermal performance.

For the passive design strategy study, this chapter will analyze the combination of passive design effect and the corresponding additional cost. The effect of every passive design method is already studied in Chapter 4; this chapter will use the results. And as shown in Chapter 2, Lhasa’s economy is developing rapidly; however, the current status is much lower than any other provincial cities in China. So, in the strategy study, the cost has to be considered.

Based on this background, this chapter will take prediction of 2015 and 2030 as contrast examples to study the urban residential building heating energy consumption difference between the active building design idea (BAU case) and the design idea based on passive design strategy. The heating energy consumption difference shows the effectiveness of the strategy. As a scenario study, , the unit-divided apartments are used to represent the real residential buildings conditions in Lhasa. And the heating energy will be calculated by simulation.

All in all, the passive design strategy for the sustainable development of Lhasa will be the main content of this chapter. The purposes of this chapter are shown as following items:

1. To draw up the passive design strategy acceding to Lhasa's future economic growth.
2. To show the process of the making passive design strategy.
3. To grasp the effect of strategy in Lhasa based on the future forecast.

5.1 Urban residential building developing forecast for scenario study

The heating energy consumption of single unit is already discussed in Chapter 4. In this chapter, the research target is changed to urban energy consumption, so the city development forecast is the basic information for the study. The first step of the urban residential building heating energy consumption controlling is to forecast the urban population, per capita income and per household living area, these items will be discussed in the following sections. Fig.5-1 shows the research flow.

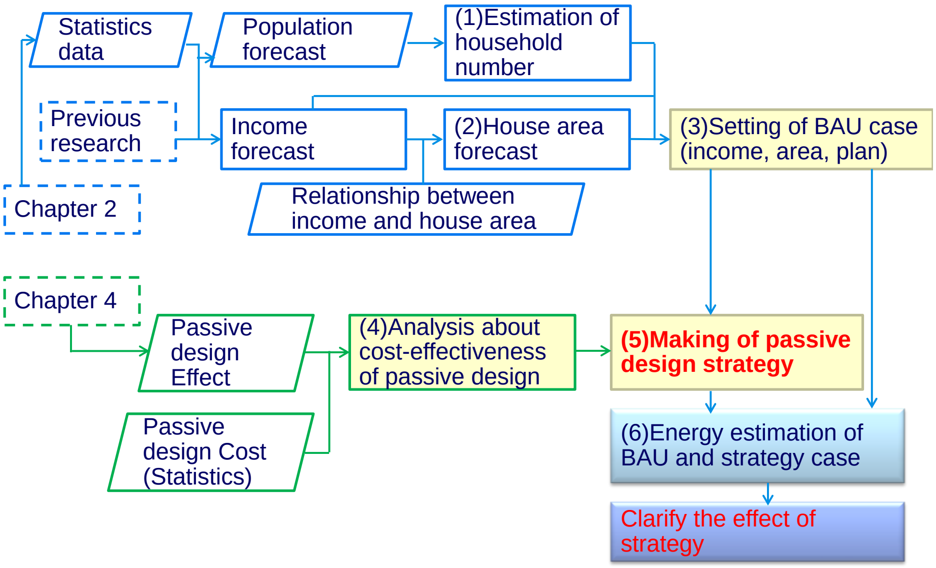


Fig.5-1 Research flow of Chapter 5

5.1.1 Population and disposable income forecast

(1) Population forecast

Population forecast belongs to the research field of demography. This paper uses the results from the report *Regional Population Projections for China* [1], the forecast results of population in Tibet for 2015 and 2030 are shown in Table 5-1.

Table 5-1 Population forecast of Tibet [1] (10 thousand persons)

Year	2015	2030
Population	341	398.7

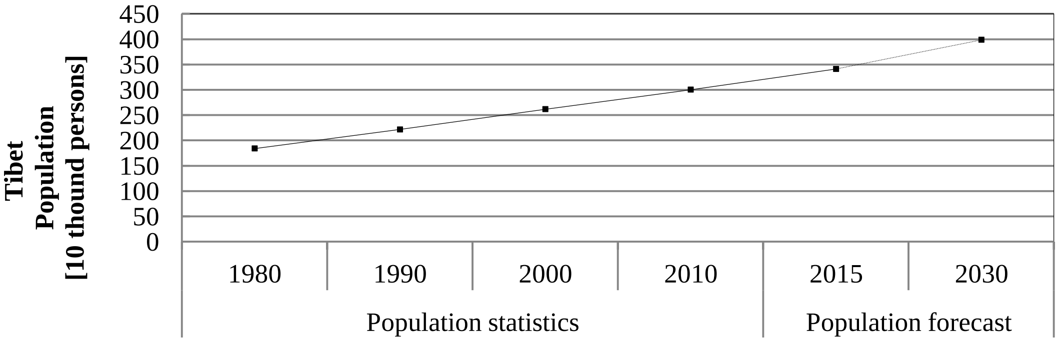


Fig.5-2 Tibetan population forecast [1] [2]

Fig.5-2 shows the Tibetan population increasing from the 1980 to 2010 by the population statistics from *Tibet Statistical Yearbook* [2] and the population forecast result of document [1].

However, from document [1] we can only get the provincial population forecast result, there is no more circumstantial data as city population in the document [1]. However, this thesis focuses on Lhasa city, so it is necessary to get forecast result of Lhasa population from the Tibetan population.

Table 5-2 is the population statistics of Lhasa and Tibet. According to the table, the population ratio of Lhasa to Tibet is growing. As the table shows, the population of Lhasa in 2010 is 559423, the population of Tibet is 3002166, and Lhasa population takes 18.6% of completely Tibetan population.

Table 5-2 Population statistics of Lhasa and Tibet [2] ~ [5] (10 thousand persons)

Year	1980	1990	2000	2010
Lhasa Population	28.85	35.65	47.44	55.94
Tibet Population	183.99	221.47	259.83	300.21
Ratio	15.7%	16.1%	18.3%	18.6%

Assume the same share can be applied in 2015 and 2030; we can get the population forecast of Lhasa from the Tibet. The results are shown in Table 5-3.

Table 5-3 Population forecast of Lhasa [1] (10 thousand persons)

Year	2015	2030
Tibet Population in Total	341	398.7
Ratio	18.6%	18.6%
Lhasa Population in Total	63.426	74.158

In addition, in document [1], the urban share of whole Tibet is forecasted; in 2015, the urban share is 29.39%; in 2030, it is 40.35%. Assume that Lhasa city has the same urban share with whole Tibet; the urban population of Lhasa can be calculated. Fig.5-3 shows the results.

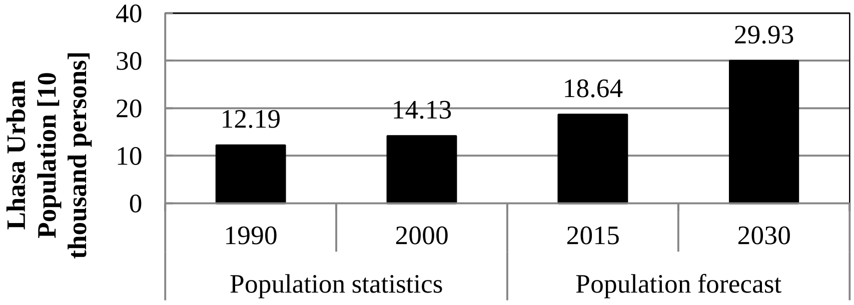


Fig.5-3 Lhasa Urban population forecast

(2) Per capita annual disposable income forecast

In capita income study, least squares curve fitting is the common method to get the trend line of income development. The paper, *Changing Trends of Income Gap between Urban and Rural*

Residents in Tibet and Analysis of Social Impact [6], uses statistical data of urban per capita disposable income and least squares curve fitting to get the income forecast for Lhasa in 2020. This section uses the same method to get the forecast for 2015 and 2030 [2] [6]. Fig.5-4 shows the curve fitting of disposable income of urban households in Lhasa.

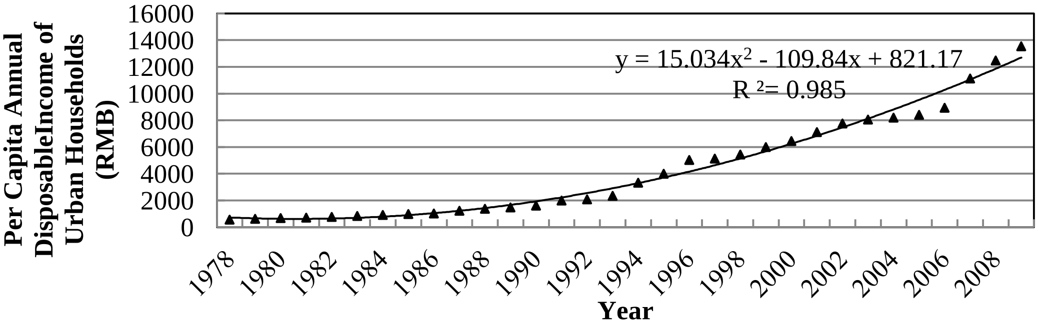


Fig.5-4 Per Capita Annual Disposable Income of Urban Households in Lhasa [2] [6]

After calculation, the results are listed as following: in 2015, the per capita annual disposable income of unban households in Lhasa is 17,828 RMB/capita; in 2030, it is 35,786 RMB/capita.

5.1.2 Households number and living area forecast

(1) Per household average living area forecast

According to the research document [7], the statistical data of per capita living area of China is obviously related with per capita disposable income. Fig. 5-5 shows this relationship of China.

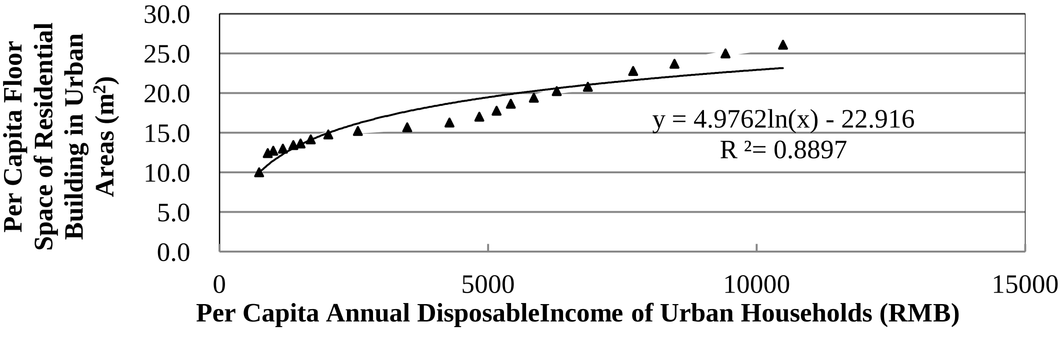


Fig.5-5 Per capita disposable income and per capita floor space of urban households in China

Applying the same method to Lhasa, with the relationship between income and the living area, the per capita living area of Lhasa can be calculated by the income from the last section. However, no matter *Lhasa Statistical Yearbook* or *Tibet Statistical Yearbook*, the Per Capita Floor Space of Residential Building in Urban area of Lhasa city is not available. So in this section, the per capita floor area of Tibet is used.

Fig.5-6 shows the statistical data of per capita floor space of residential building and per capita disposable income from *Tibet Statistical Yearbook*. Moreover, Fig.5-7 shows the related formula of curve fitting.

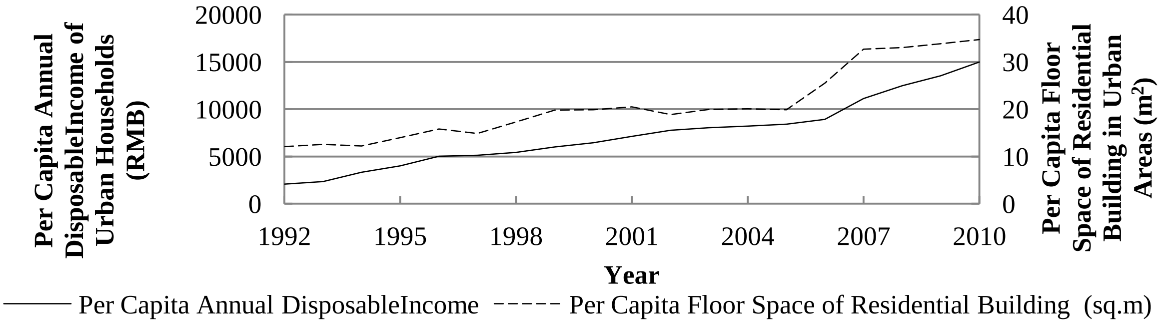


Fig.5-6 Statistics of Tibet urban per capita disposable income and per capita living area [2]

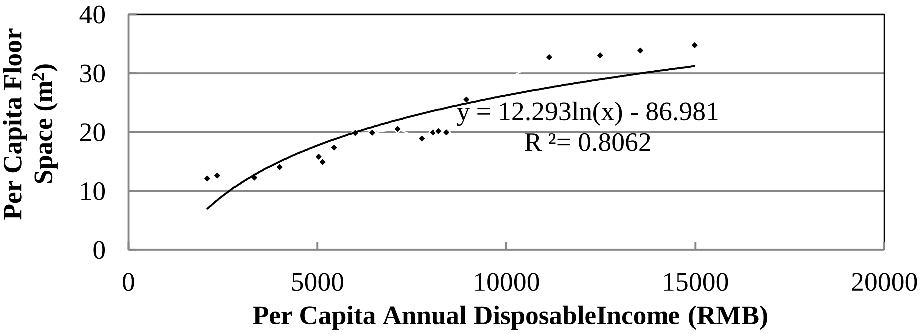


Fig.5-7 Curve fitting of relationship between disposable income and living area

With the curve fitting formula in Fig.5-7, and the urban disposable income forecast results in 5.1.1, the per capita floor space of residential building can be calculated; the results are shown in Table 5-4.

Table 5-4 Per capita floor space forecast of urban households in Lhasa

Year	2015	2030
Per capita disposable income forecast result (RMB)	17,828	35,786
Per capita floor space forecast result (m^2)	33.4	41.9

(2) Households number grouped by income forecast

According to the 2010 National Population Statistical Bulletin [5], in Lhasa, the average urban household was 3.19 people in 2010.

Assuming the same average value can be applied in 2015 and 2030, with the population in Fig.5-3 divided by 3.19; the urban household number can be calculated. Then, combining the 3.19 people per household with the per capita living area from Table 5-4; the average household living area can be calculated. Table 5-5 shows the results.

Table 5-5 Urban household number and average living area forecast

Year	Household number	Average living area (m^2)
2015	58,424	106.55
2030	93,816	133.66

According to the *Tibet Statistical Yearbook* [2] and the *China Statistical Yearbook* [8], the groups of low, middle, high-income families were separated by the ratio of 20%, 60% and 20%, respectively. Assuming the same ratio can be applied in 2015 and 2030, and combining the household number in Table 5-5, the urban household number grouped by income is shown in Table 5-6.

Table 5-6 Urban households number grouped by income level

Income level		Low	Middle	High	Total
Ratio		20%	60%	20%	100%
Household number	2015	11685	35054	11685	58424
	2030	18763	56290	18763	93816

As for the per household living area of every income level household in Lhasa, it is necessary to separate the living area of each income group from the average living area of total Lhasa population.

From document [9], in Lhasa, the local government has been carrying out the Low-rent House Project from 2008 to guarantee a minimum standard in living conditions for low-income families. In 2010, the area of per low-rent apartment was 80 m^2 for four people family. This value is around 80% of the average urban household living area in 2015 as shown in Table 5-5; therefore, it is reasonable to assume in 2015, middle-income households which occupy 60% of the total households have an average living area in Table 5-5, low-income households which occupy 20% of the total households have 80% of the average area, and in order to meet the average area, the leftover 20% of households, high-income households, is set to have 120% of the average area. Apply the same method to 2030; the living areas of different income level families for both 2015 and 2030 are shown in Table 5-7. As a result, the corresponding income can be calculated by the formula shown in Fig.5-7.

Table 5-7 Urban average living area forecast grouped by the income

Income level		Low	Middle	High	Average
2015	Living area (m^2)	85.2	106.5	127.8	106.5
	Income forecast (RMB/ Capita)	10,047	17,828	31,981	17,828
2030	Living area (m^2)	106.9	133.6	160.4	133.6
	Income forecast (RMB/ Capita)	17,893	35,786	72,400	35,786

After the forecast procedure, the information of Lhasa urban households and living area is shown as following description.

In 2015, low-income household number is 11685 and per household average living area of this group is 85.2 m^2; as to the middle-income household, the household number is 35054 and the average living area of this group is 106.5 m^2; as to the high-income household, the household number is 11685 and the average living area of this group is 127.8 m^2. In 2030, low-income household number is 18763 and per household average living area of this group is 106.9 m^2; as to the middle-income household, the household number is 56290 and the average living area of this group is 133.6 m^2; as to the high-income household, the household number is 18763 and the average living area of this group is 160.4 m^2.

5.1.3 Unit layout design under the current design idea

The heating energy consumption based on the current design idea is the foundation data to verify the effectiveness of the passive design strategy. So the first step is to design residential buildings under the current design idea.

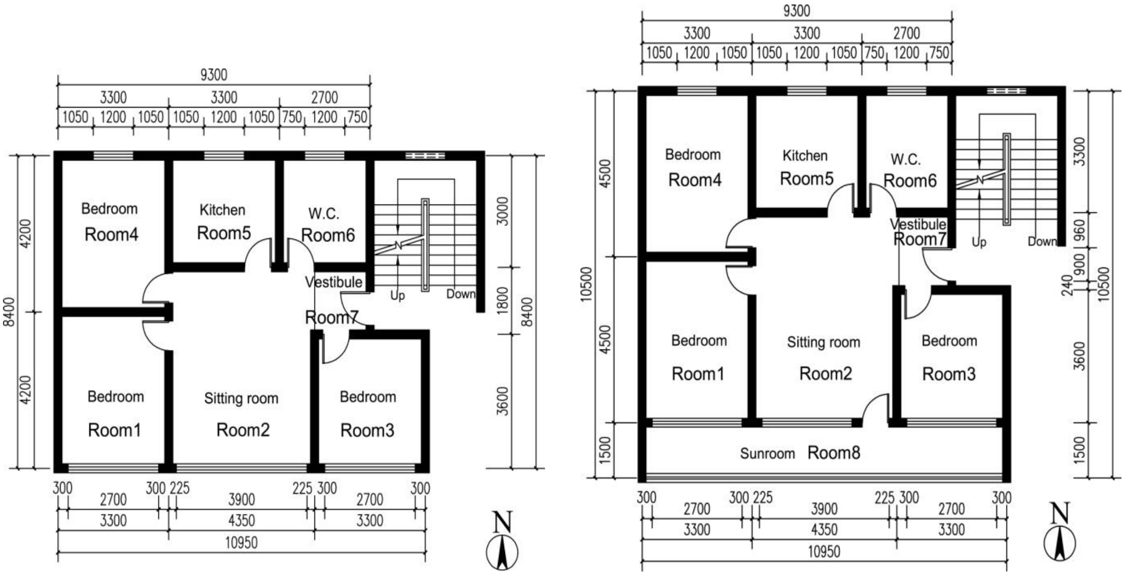
In fact, in the real situation, there are many unit types for apartments in Lhasa. However, in different unit type design, the basic function and the layout type are similar. This section is a scenario study; after classifying the existing apartment design characteristics, and apply it to the design procedure, the unit types in Fig.5-8 are used to be instead of a projection of the real situation of the residential buildings in 2015 and 2030. The design idea is based on the field surveys and the interview with the local architects, which is already shown in Chapter 3. As the figure shows, there are two unit types, direct solar gain style and the sunroom style.

As Table 5-7 shows, middle-income families in 2015 have a living area of 106.5 m^2 which is similar as low-income family’s 106.9 m^2 in 2030. For the sake of simplifying the calculation, Fig.5-8 (b) Plan B (106.6 m^2) represents the both scenarios. For the same reason, Fig.5-8 (c) Plan C (129.28 m^2) shows high-income families in 2015 (127.8 m^2) and the living situation of middle-income families in 2030 (133.6 m^2).

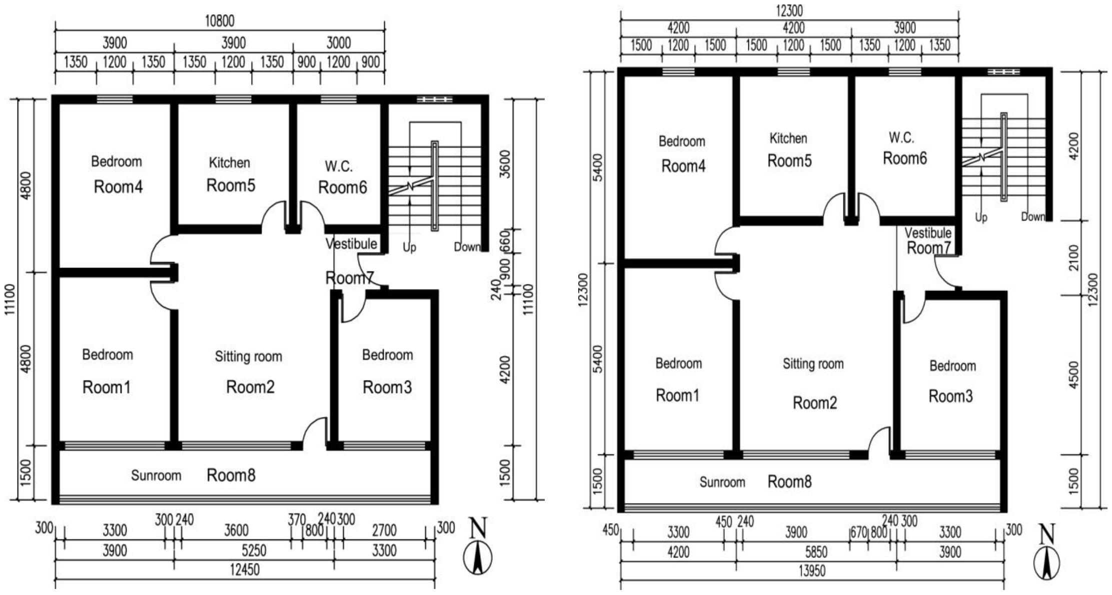
Table 5-8 shows the basic unit layout information for the scenario study.

Table 5-8 Typical unit design for the scenario study

Income level		Low	Middle	High
2015	Unit Plan	Plan A	Plan B	Plan C
	Area (m^2)	84.06	106.6	129.28
2030	Unit Plan	Plan B	Plan C	Plan D
	Area (m^2)	106.6	129.28	161.19



(a) Plan A (84.06 m^2) (b) Plan B (106.6 m^2)



(c) Plan C (129.28 m^2) (d) Plan D (161.19 m^2)

Fig.5-8 Layout drawing (Unit：mm)

5.2 Residential building passive design strategy for Lhasa

In this section, the residential building passive design strategy is studied. In Chapter 4, the building design factors including unit architected design and the envelope thermal performance design are already discussed. However, in Chapter 4, the analysis focuses on the design factors only; the economy condition is not considered..

So, in this chapter, the passive design strategy is considered by the combination of passive design effect and the corresponding extra cost.

5.2.1 Passive design strategy analysis

As Fig.5-8 shows, Plan A, Plan B, Plan C show the residential building plan in 2015, among the three plans, both direct solar gain unit design and the sunroom unit design are used; in 2030, Plan B, Plan C, Plan D are used to show the residential building plan in 2030, the three plans are all sunroom units, no direct solar gain unit. So, the passive design strategy in this section is to redesign or refit the direct solar gain unit and the sunroom unit with the appropriate passive design method.

From the angle of using passive designed architectural form, the good unit form design will reduce the energy consumption. But it is only suitable for the newly constructed buildings. For the newly constructed buildings, to use good unit plan will not have additional cost compared with the current design idea plan, this is a good choice.

As to the existing buildings, only energy saving retrofit is suitable. In this case, the windows type and the insulation are easy to be used. As to the window-wall ratio, according to the result of Chapter 4, it do not have the higher relevance to the energy compared with the windows type, moreover, changing the window-wall ratio is a big project in the brick-concrete structure. So, for the energy saving retrofit, windows type and insulation are two considered items.

Based on this analysis, three passive design methods will be considered to make the passive design strategy. They are unit plan design, windows types design and the insulation layer design.

As analysis before, the extra cost is the other important boundary condition to make the strategy. Table 5-9 shows the prices of different windows types [10]. As for the price of insulation, according to the website of manufacturers, its price is 300 RMB/m^3 [11].

Table 5-9 The price of windows in different configuration [10]

Window type	Single glass	Double glass	Low-e
configuration	Glass: 6 mm	Glass: 6 mm Air:9 mm Glass: 6 mm	Glass: 6 mm Low-e layer Air:9 mm Glass: 6 mm
Price	47RMB/m^2	120RMB/m^2	280RMB/m^2

Table 5-10 shows the effect of passive design and the corresponding cost. The effect is based on the results in Chapter 4 (windows-wall ratio 0.6). The cost here means the additional cost to use the corresponding passive design method, and it shows the materials cost only.

The purpose of this table is to find the best cost performance; this is based on the consideration of the economic burden in Lhasa. The item with the best cost performance can be applied to all the households. At the same time, the items with good energy reduction also need to be applied.

Table 5-10 Cost-effectiveness analysis of passive design method

Passive design method		Base plan							
		Direct solar gain				Sunroom			
		Heating Energy [kWh]	Energy Reduction [kWh]	Cost [RMB]	Benefit/Cost [kWh/RMB]	Heating Energy [kWh]	Energy Reduction [kWh]	Cost [RMB]	Benefit/Cost [kWh/RMB]
No method		1668				1169			
Add Sunroom or north balcony	Single glass	1169	499	926	0.54	725	444	304	1.46
Windows types	Single to Double	768	900	1,912	0.47	784	385	1,912	0.20
	Single to Low-e	675	993	6,102	0.16	739	430	6,102	0.07
Insulation layer	0 to 2cm	1492	176	207	0.85	926	243	207	1.17
	0 to 4cm	1447	221	415	0.53	870	299	415	0.72

From the table, it is clear that the installation of 2 cm insulation layer has the best cost performance for direct solar gain unit and the second cost performance for sunroom unit. It should be used as one of the passive design strategy for all households.

As for the energy reduction effect, double glass windows and low-e glass windows have very good effect (Energy reduction columns). Double glass has higher cost performance than low-e. So, it should be applied.

North balcony has a very good cost performance to sunroom unit, so it should be applied.

For high income family, if they are not sensitive with the price, the low-e windows should be installed for its good effect.

5.2.2 Residential building passive design strategy for 2015

2015 is not far in the future. It is reasonable to assume that the new residential buildings will not be much in 2015. The implementation of retrofitting for existing residential buildings will be the way of thinking for passive design strategy in 2015. So the main way for energy saving design will be an improvement of the thermal performance of the envelope by renovation. The unit type will be kept as same as Fig.5-8 (a), Fig.5-8 (b) and Fig.5-8 (c); as analyzed in the previous section; the window types and the insulation are considered.

(1) Window types

The most common windows type in Lhasa now is single glass windows. However, according to the results of former section, for both the direct solar gain design and the sunroom design, both double glass and low-e windows have good energy saving effect. And double glass windows have higher cost performance.

Considering the local economic condition, double glass will be suitable at the first stage for most of households. In addition, as to the high-income households, as we can assume that they are not sensitive to the price, the low-e windows will be used.

(2) Insulation

According to the field survey, the insulation layer is rare in the local residential buildings. As shown in previous section, 2 cm insulation has the best cost performance. So, 2 cm EPS layer is used.

Based on the foregoing analysis, the design strategy of 2015 is listed in Table 5-11.

Table 5-11 Design strategy for 2015

Building information without strategy	Income level	Low	Middle	High
	Passive design	Direct solar gain	Sunroom	Sunroom
	Unit layout	Plan A	Plan B	Plan C
	Insulation	No insulation		
	Window type	Single	Single	double
Passive design strategy for 2015	Passive design	Direct solar gain	Sunroom	Sunroom
	Unit layout	Plan A	Plan B	Plan C
	Insulation	2cm EPS	2cm EPS	2cm EPS
	Window type	Double	Double	Low-e

5.2.3 Residential building passive design strategy for 2030

Considering the fast urban construction examples in other cities of China, as we can assume that in 2030, practically all apartments of high-income households and middle-income households, which will make up 80% of the total residential buildings in 2030, will be newly designed apartments. This means new unit layouts can be applied for the purpose of energy saving.

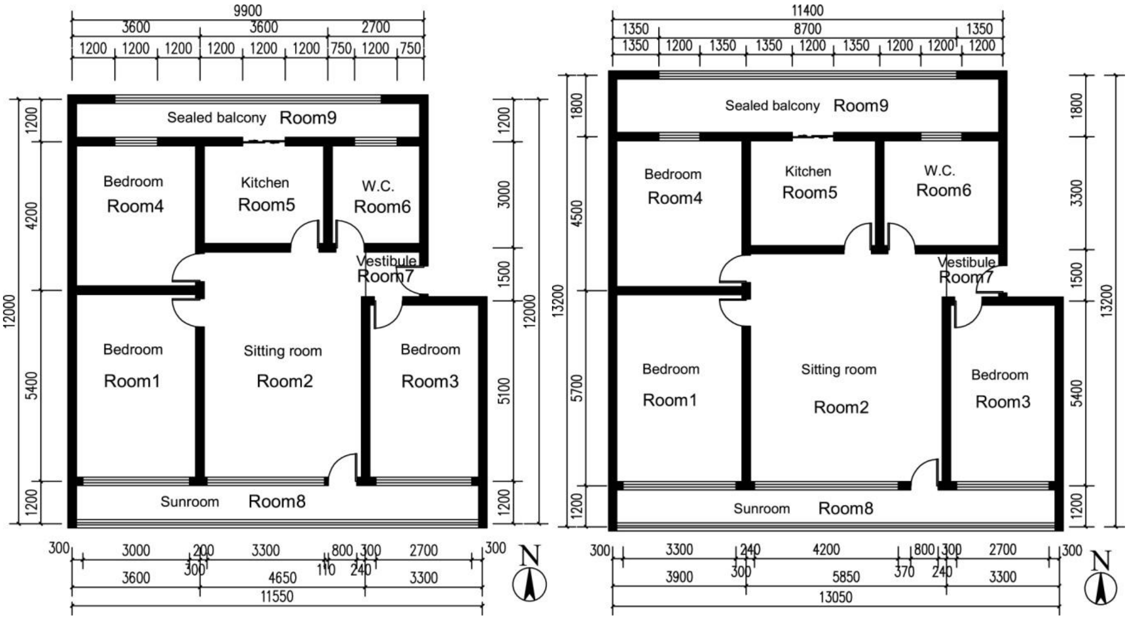
On the other hand, low-income families will still live in already existing apartments, which means the strategy for this group would be to refit the envelope. As former analysis, compared with 2015, the per capita disposable income of 2030 is around twice as high, so residents can afford better materials.

Based on these analyses, the building energy saving strategy is listed as following:

(1) Unit layout

As shown in Table 5-10 Cost-effectiveness analysis of passive design methods, in the architectural form design, to add north sealed balcony have the best cost performance. So for the newly constructed buildings, the double-balcony is chosen.

Fig.5-9 shows the new unit design.



(a) Plan E (129.28 m^2) (b) Plan F (161.19 m^2)

Fig.5-9 Layout drawings of new unit design for 2030 (Unit：mm)

Based on the double-balcony unit design factors study in Chapter 4, both of the sunroom depth and the north sealed balcony depth related with the heating energy consumption in winter. Therefore, as the Fig.5-9 shows, the sunroom depth of Plan E and Plan F is 1.2m which belongs to the balance depth zone for the energy saving and the sunroom functions. For the same reason, the north sealed balcony of Plan E uses 1.2m and Plan F uses 1.8m.

As for the unit shape, both of the two units are designed as large depth and small bay width.

In the north and south room depth design, both of the two units use the large south room depth and small north room depth design. For Plan E, the depth of south Room 1 is 5.4 m, at the same time, this value of north Room 4 is 4.2 m; for Plan F, the depth of south Room1 is 5.7 m and the depth of north Room 4 is 4.5 m.

However, the unit design is a flexible conception, the units design here are two examples which follows the suggested unit design principle in Chapter 4. Architectural design is a process to find the solution among many boundary contradictions, in the real design work, the unit design should comply with the energy saving design conception in Chapter 4, but the details like the room size should depend on real circumstances.

(2) Window types

For the double-balcony unit, it is proven in Chapter 4 that among the three window types, low-e windows lead to the lowest energy consumption. Nevertheless, in most occasions, the energy consumption difference between double glass windows and the low-e windows are not big. Consequentially, for high-income families, it is reasonable to use low-e windows because this group is set not be sensitive to the price. However, for the middle and low-income families, double glass windows are suitable, based on the consideration of the cost and the energy saving effect.

(3) Insulation

As shown in the double-balcony models study in chapter 4, better insulation results in lower heating energy consumption. For both high and middle-income families, small quantities of EPS layer can be applied. As for the low income family, as analyzed before, the strategy will be renovating. Considered the income increasing form 2015, the insulation should not same as middle income family in 2015. So, the 4 cm insulation is used here. Based on the foregoing analysis, the design strategy of 2030 is listed in Table 5-12.

Table 5-12 Design strategy for 2030

Building information without strategy	Income level	Low	Middle	High
	Passive design	Sunroom	Sunroom	Sunroom
	Unit layout	Plan B	Plan C	Plan D
	Insulation	No insulation		
	Window type	double	double	double
Passive design strategy for 2030	Passive design	Sunroom	Double-balcony	
	Unit layout	Plan B	Plan E	Plan F
	Insulation	4cm EPS	2cm EPS	2cm EPS
	Window type	Double	Double	Low-e

5.3 Passive design strategy verification and family electricity consumption analysis

5.3.1 Simulation introduction and models setting

The family energy consumption in Lhasa can be divided into two parts: winter heating and the home appliances energy consumption. Same as in Chapter 4, THERB is used in this section for heating energy consumption. The software SCHEDULE Ver.2.0 can be used to calculate the home appliances energy consumptions. Their daily schedule is from the survey shown in Chapter 3. SCHEDULE is a simulation software program for automatically generating the schedule of living in a house, which is developed by the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.

Fig.5-10 shows the simulation flow.

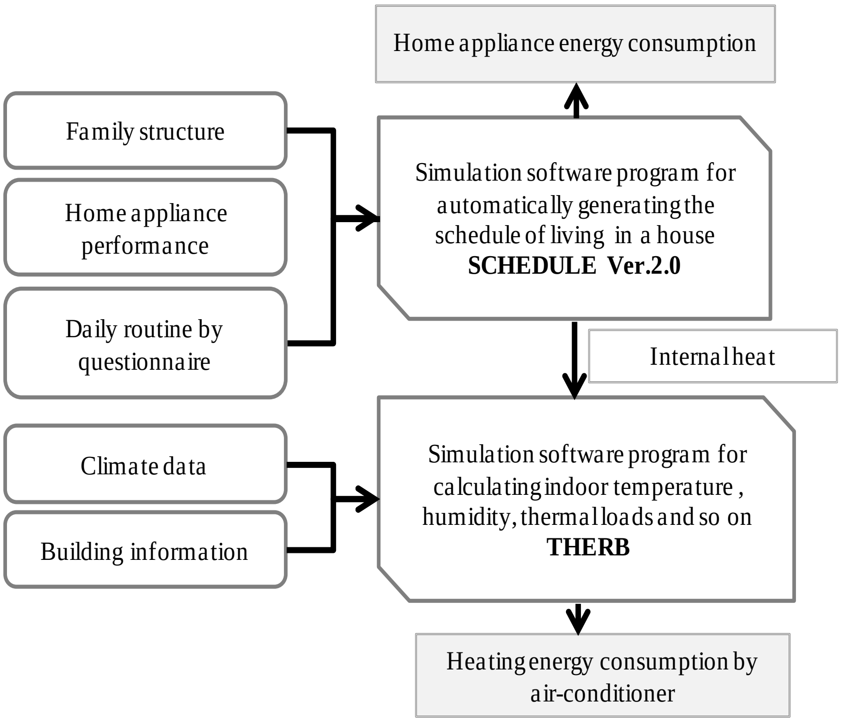


Fig.5-10 Simulation flow

Field survey showed that the local people use LPG and electricity for cooking, however, for the sake of complexity reduction, as we can assume that local people use only electrical cooking devices.

The simulation setting is shown in Table 5-13. The configuration of the structure is shown in Table 5-14. Moreover, in order to make the calculation not too complicated, assume that there is no heat transfer between the target unit and the adjacent rooms. Assuming the air conditioner has COP 3, so that, the thermal load can be expressed as electricity consumption.

Table 5-13 Simulation setting

Building information	Location		Lhasa city
	Latitude, Longitude		29.39 ° ， 91.07 °
	Floor/Floors		3rd/4 floors
	Position in the building		Middle
	Clear height		2.9 m
	Structure		Brick-concrete
Calculation setting	Calculation period		Nov. 1st-Feb. 28th
	Ventilation		0.5 / hour
	Surface heat exchange coefficient	Internal	8.7 W/m^{2}K
		External	23.0 W/m^{2}K

Table 5-14 The configuration of the models

External wall (in to out)	Material	Cement plaster	Lime sand brick	EPS	Cement
	Thickness	0.015 m	0.370 m	Set in models	0.015 m
Internal wall (in to out)	Material	Cement plaster	Lime sand brick	Cement plaster	
	Thickness	0.015m	0.240 m	0.015 m	
Floor/ceiling	Material	Reinforced concrete			
	Thickness	0.100 m			
Windows	Type	Single	Double	Low-e	
	Material	glass	glass + air + glass	glass + air + low-e layer+	
	Thickness	6 mm	6 mm+10mm+6	6 mm+10mm+6 mm	

As Table 5-15 shows, there are 12 simulation cases in total. All the models have the south window-wall ratio of 0.59.

Table 5-15 Building performance of simulating models

Simulation scenario		2015			2030		
Household income		Low	Middle	High	Low	Middle	High
No strategy cases	Cases	N-Low-15	N-Mid-15	N-Hig-15	N-Low-30	N-Mid-30	N-Hig-30
	Unit plan	Plan A	Plan B	Plan C	Plan B	Plan C	Plan D
	Passive design	Direct solar gain	Sunroom		Sunroom		
	Ex-wall configuration	15mm Cement plasters+ 370mm lime sand bricks + 15mm Cement plasters					
	Windows types	Single		Double	Double		
With strategy cases	Cases	S-Low-15	S-Mid-15	S-Hig-15	S-Low-30	S-Mid-30	S-Hig-30
	Unit plan	Plan A	Plan B	Plan C	Plan B	Plan E	Plan F
	Passive design	Direct solar gain	Sunroom		Sunroom	Double-balcony	
	Ex-wall structure	15mm Cement plasters+ 370mm lime sand bricks+ EPS layer+ 15mm Cement plasters					
	Thickness of EPS	20mm	20mm	20mm	40mm	20mm	20mm
	Windows type	Double		Low-e	Double		Low-e

a. Introduction of models without energy saving strategy

(1) Case N-Low-15 is the basic model based on the current design idea, which is shown in Fig.5-8 (a); its area is 84.06 m^2. The building performance is based on the most ordinary family in Lhasa, which can be classified into the low-income level. The building faces south. There is no insulation layer in the building. All windows use single glass.

Table 5-16 Home Appliances in simulating models

	POWER (W)		TYPE				
	Popular	Efficient	Case N-Low-15 Case S-Low-15	Case N-Mid-15 Case N-Low-30	Case S-Mid-15 Case S-Low-30	Case N-Hig-15 Case N-Mid-30 Case N-Hig-30	Case S-Hig-15 Case Plan S-Mid-30, Case S-Hig-30
Refrigerator	60	35	Popular	Popular	Efficient	Popular	Efficient
Boiling pot	66	30	-	Popular	Efficient	Popular	Efficient
Microwave oven	200	170	Popular	Popular	Efficient	Popular	Efficient
Bidet	35	20	-	-	-	Popular	Efficient
Washer	126	80	Popular	Popular	Efficient	Popular	Efficient
Cooker	225	150	-	Popular	Efficient	Popular	Efficient
Hair drier	450	450	-	-	-	Popular	Efficient
Ventilator	20	20	-	Popular	Efficient	Popular	Efficient
Desk lamp	30	10	Popular	Popular	Efficient	Popular	Efficient
Vacuum cleaner	200	200	-	Popular	Efficient	Popular	Efficient
Flat iron	500	500	-	-	-	Popular	Efficient
TV	120	50	Popular	Popular	Efficient	Popular	Efficient
Audio device	100	50	Popular	Popular	Efficient	Popular	Efficient
Computer	300	50	-	-	-	Popular	Efficient

For Case N-Low-15, there are not many home appliances. As Table 5-16 shows, the appliances only meet the basic convenience demands for daily life. This is the model of a low consumption living style. This scenario is designed for low-income families who use heating devices in 2015.

(2) Case N-Mid-15 is the sunroom model shown in Fig.5-8 (b); its area is 106.6m^2. This case represents the house condition of a middle-income family in 2015. The building performance and the home appliances are based on the most widely spread residential buildings in Lhasa that can be classified into the middle-income level. The building faces south. There is no insulation layer in the building. All windows use single glass.

Compared with Case N-Low-15, this model is middle income family, so the model has more appliances. This case shows the scenario that middle-income family uses heating devices in 2015.

(3) Case N-Hig-15 is the sunroom model; as Fig.5-8(c) shows, its area is 129.28m^2. This is a high-income family's home in 2015. There is no insulation layer in the building. From the field survey, only rare luxurious house use double glass windows. This household is set as high income level; so, all windows are set to use double glass.

Compared with the former two cases, this family has more appliances. This case is set to simulate a high-energy consumption family in 2015.

(4) Case N-Low-30 shows the housing conditions of low-income families in 2030. It shares the same unit plan and structure with Case N-Mid-15, but the single glass windows are changed to double glazing windows. This setting is based on the assumption that by 2030, there might be basic building energy saving requirement by the local government, so double glass windows are applied.

This case shows that with the society developing, a low-income family in 2030 reaches the living standard of a middle-income family in 2015.

(5) The repeated model Case N-Mid-30 shows a middle-income family's home in 2030. This case shows that the middle-income family in 2030 has the same living style with the high income family in 2015. The building performance and home appliances are identical with that of the high-income family's home in 2015.

(6) Case N-Hig-15 presents a high-income family's unit in 2030; as shown in Fig.5-8 (d), its area is 161.19 m^2. Compared with the case of high income family in 2015, the living area of this family is much bigger. Based on the assumption that by 2030, the basic building energy saving measures is required by the local government, so double glass windows are applied.

The home appliances are identical with the high-income family in 2015. This case is set to simulate a high-energy consumption family in 2030.

b. Introduction of models with energy saving design strategy

In aforementioned section, different strategies for an energy saving design have been analyzed.

This section refers to the strategies for 2015 and 2030. For the models with strategy, Table 5- 15 shows the building performance, Table 5-16 shows the home appliances.

In these two tables, Case S-Low-15, Case S-Mid-15 and Case S-Hig-15 show the low, middle, high-income households in 2015 with energy saving strategy, respectively. Case S-Low-30, Case S-Mid-30 and Case S-Hig-30 show the low, middle, high-income households in 2030, respectively.

5.3.2 Simulation results analysis

This section shows the heating energy consumption in winter and the family energy consumption includes the heating energy consumption and appliances electricity consumption over a whole year. The heating energy consumption results are shown in Fig.5-11; the whole year's family electricity consumption is shown in Fig.5-12.

There is one important thing need to be pointed out that the results in Fig.5-11 and Fig.5-12 only represents the models whose position is in the middle of the building. As for the edge units in one building which means the units have the external walls face east or west, the results will be getting bigger.

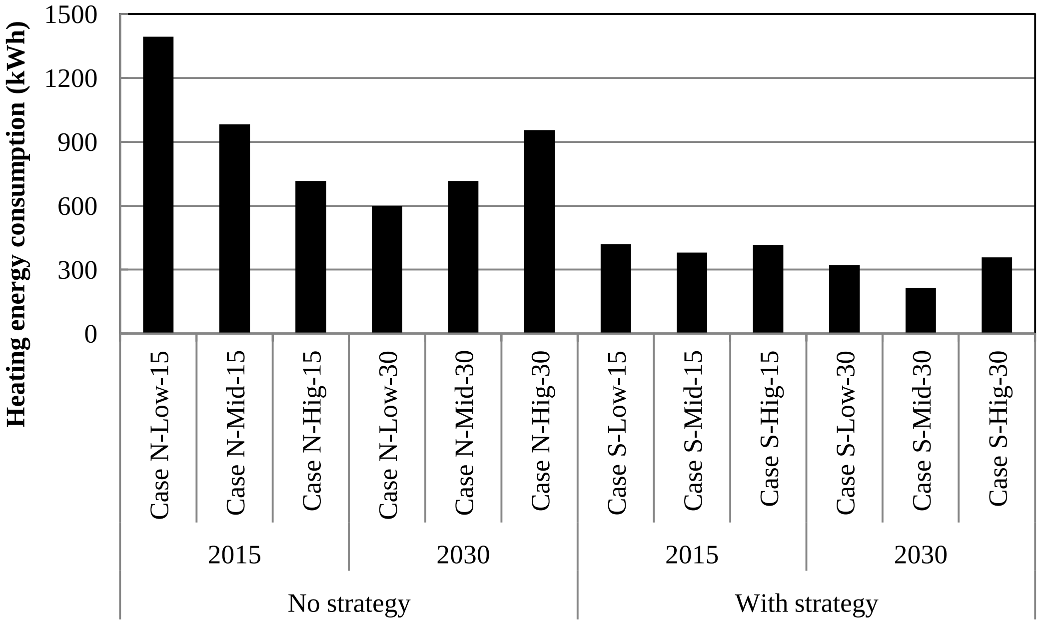


Fig.5-11 Heating energy consumption comparison

As Fig.5-11 shows, with a proper passive design strategy, the heating energy consumption can be controlled. By 2015, a low-income family’s heating energy consumption would decreases by 69.9%; a middle-income family decreases by 61.3%; and a high-income family decreases by 41.9%. In 2030, a low-income family’s heating energy consumption would go down 46.4%; a middle-income family goes down 70.0%; and a high-income family goes down 62.5%.

The whole year’s total electricity consumption is shown in Fig.5-12.

From Fig.5-12, it is clear that the home appliances are the other key factor of family electricity consumption. However, by applying a passive design strategy and efficient home appliances, the family electricity consumption also decrease significantly. By 2015, a low-income family’s electricity consumption would decrease by 33.8%; a middle-income family decreases by 42.1%; and a high-income family decreases by 40.5%. In 2030, a low-income family’s heating energy consumption would go down by 36.2%; a middle-income family goes down by 45.4%; and a high-income family goes down by 45.1%.

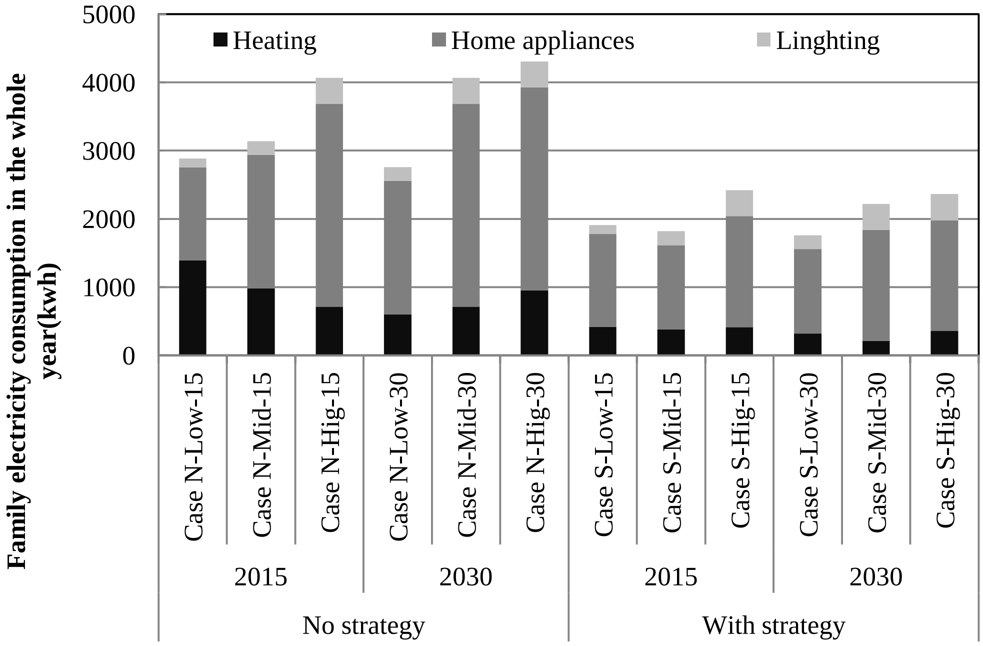


Fig.5-12 The electricity consumption comparison

As the former setting, the urban scale residential building's energy consumption can be calculated by accumulating individual family energy consumption.

The individual heating energy consumption in Fig.5-11 and the individual family electricity consumption in Fig.5-12 multiply by the corresponding household number in Table 5-6, respectively; the urban scale heating energy consumption and residential building electricity consumption can be calculated, respectively. Fig.5-13 shows the results.

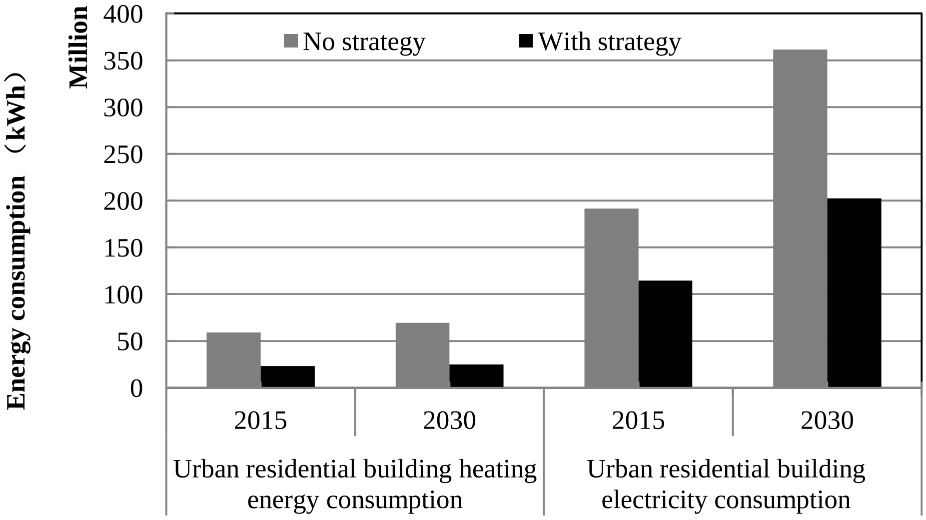


Fig.5-13 Energy consumption comparison between two scenarios

As Fig.5-13 shows, it is clear that the strategy scenario largely reduces energy consumption compared with the scenario with no strategy.

The heating energy consumption is lower by 60.9% in 2015 and 64.3% in 2030, respectively; and the total residential building electricity consumption is lower by 40.2% in 2015 and 44.0% in 2030, respectively.

This research mainly focuses on the heating energy consumption control, it is clear to see, the heating energy consumption is well controlled from 2015 to 2030 in Fig.5-14. For the scenario of no passive design strategy, form 2015 to 2030, with the population increasing and the living standard improving, the heating energy consumption increases 17.6%; however, with the energy saving strategy, the number is 7.6%.

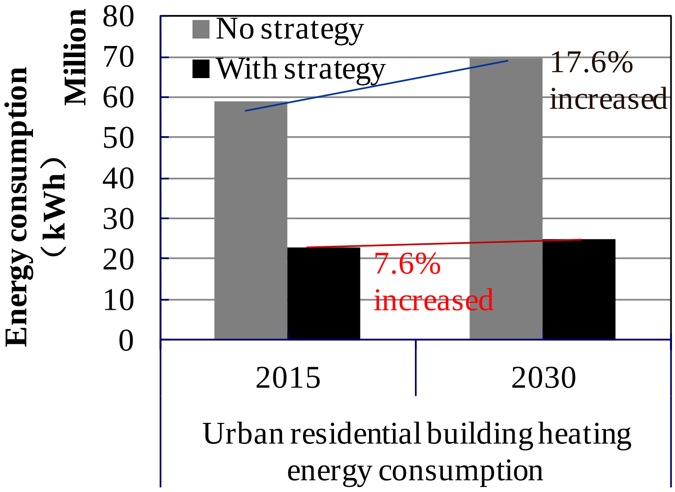


Fig.5-14 Heating energy increasing rate from 2015 to 2030

5.4 Conclusions

This chapter studied the passive design strategy for Lhasa by the combination of passive design methods effect and the corresponding extra cost. By applying the strategy to 2015 and 2030, its effectiveness is verified.

The following points are the conclusions of this chapter.

1. Lhasa’s population in 2030 will grow up 1.6 times of the value in 2015, and per capita income will grow up to 2 times.

2. With the society development, the per capita living area in 2030 will be 1.2 times of the one in 2015.

3. By the combination of the passive design effect and the cost, adding 2 cm insulation layer has the best cost performance, though the effect is not big. Low-e windows and double glass windows have good energy saving effect. And for sunroom unit, the north balcony has very good effect and cost performance.

4. Following methods are recommended as passive design strategy according to the economic situation: 2cm insulation layer (EPS), double glass, north balcony, low-e windows.

5. By the strategy, the heating energy consumption is lower by 60.9% in 2015 and 64.3% in 2030. And the heating energy increasing proportion from 2015 to 2030 is reduced from 17.6% to 7.6% by the strategy.

6. The process of making the passive design strategy is shown in this chapter.

References:

[1] Toth F, Cao G, Hizsnyik E, Regional population projections for China, IIASA Interim Report IR-03-042, International Institute for Applied Systems Analysis, Laxenburg, Austria, 2008.

[2] Tibet Autonomous Region Bureau of Statistics, Tibet Statistical Yearbook1990-2010, Beijing: China Statistics Press. (In Chinese)

[3] Bureau of Statistics of Lhasa, Lhasa Statistical Yearbook 2008, Beijing: China Statistics Press. (In Chinese)

[4] Tibet Autonomous Region Bureau of Statistics, “Lhasa city statistical data from 2000 National Population Statistical Bulletin” available at: http://www.stats.gov.cn/tjgb/rkpcgb/dfrkpcgb/t20020331_15404.htm. (In Chinese)

[5] Tibet Autonomous Region Bureau of Statistics, “Lhasa city statistical data from 2010 National Population Statistical Bulletin” available at: http://www.tjcn.org/plus/view.php?aid=22694. (In Chinese)

[6] Wang Lijuan, “Changing Trends of Income Gap between Urban and Rural Residents in Tibet and Analysis of Social Impact”, Economic Research Guide, Vol. 146, pp.143-146, 2011.36. (In Chinese)

[7] China Real Estate Chamber of Commerce, “The developing trend of urban residential buildings in China for the next 20 years”, available at: http://news.dichan.sina.com.cn/bj/2011/01/25/269535.html. (In Chinese)

[8] National Bureau of Statistics of China, China Statistical Yearbook1985-2010, Beijing: China Statistics Press. (In Chinese)

[9]Yang Zhenglin, “Construction of Low-rent houses in Lhasa”, available at:http://news.china.com.cn/rollnews/2010-07/04/content_3019042.htm (In Chinese)

[10] http://www.ganghuabolibj.cn/listinfo.aspx?ID=95&cateID=39

[11] http://detail.china.alibaba.com/offer/677521058.html (In Chinese)

Chapter 6

6. Conclusions and prospect

Chapter 6. Conclusions and prospects

6.1 Conclusions

This research aimed to find one of the solutions for the target developing city to control the environmental load by passive design strategy. This research takes Lhasa as the example to study the passive design strategy. Lhasa's climate condition shows the passive design is a good choice to meet the heating demand in winter. The current energy balance proves Lhasa already faced serious power shortage. The field survey proves local residents have heating requirement. With the building information from the field survey, the passive design characteristics in Lhasa are studied by simulation, the effects of every passive design methods were classified. By the combination of the every passive design method's effect and the corresponding additional cost, the passive design strategy was drawn up. And then, its effectiveness was verified in the future scenario study by simulation. The results showed, Lhasa city can get a sustainable development with few heating energy increasing by the proper passive design strategy.

At the same time, the whole procedure of making this strategy is shown in the thesis.

The conclusions of every chapter are show as the following:

Chapter 1 shows the research background and purpose of the whole research. It is a meaningful and urgent topic to carry on the passive design strategy study in the developing cities. The purpose of this research is to draw up the passive design strategy for Lhasa, and show the procedure of the making this strategy.

Chapter 2 shows the necessary information of Lhasa. In this chapter, the climate, energy condition, economic situation and development of the residential buildings are grasped by the documents investigation. The climate condition shows it is a good choice to use abundant solar energy to save heating energy. The power supply condition shows Lhasa already faced seriously electricity shortage. The development of the residential buildings and the economic growth show that the fossil fuel consumption growth in the future cannot be avoided.

All these information prove the necessity and the priority of passive design.

Chapter 3 shows the field survey. The purpose of the field survey is to grasp the building information such as the plan, material, structure and envelope thermal performance for the simulation setting in Chapter 4. And the information of family structure, daily schedule, and home appliances supports the simulation setting in Chapter 5 for the home appliances energy consumption study.

The field survey proved that the passive design strategy can be easily applied, because the existing buildings had the conception of passive design.

Field survey proves that local residents have heating demand.

Chapter 4 shows the passive design characteristics study. The effect of every passive design factors are classified for making the passive design strategy in Chapter 5.

By the three unit heating energy consumption comparison, it is clear that more than 27% energy consumption can be reduced by add sunroom, and 56% energy can be reduced by the combination of sunroom and north balcony.

Among all envelope thermal performance design factors, the windows type has the strongest influence to energy.

Adding insulation also has good energy saving effect (17% reduction for direct solar gain unit). The thickness does not have big influence.

Chapter 5 shows the passive design strategy for Lhasa city by the combined consideration of both passive design effect and the corresponding extra cost. Through the scenario study, effectiveness of the strategy is verified by simulation. At the same time, the whole process of making the strategy is shown.

By the forecast study, the population of Lhasa in 2030 is 1.6 times of the one in 2015, and per capita income will grow up to 2 times.

Following methods are recommended as passive design strategy according to the cost-effectiveness analysis: 2cm insulation layer (EPS), double glass, north balcony, low-e windows.

By applying the strategy proposed in the thesis, 64% heating energy can be reduced in 2030. This result proves that the passive design strategy is useful for the local government.

Following the same research procedure, the way of passive design strategy study can be applied to other developing cities.

6.2 Prospects

In the future research, the other developing cities which also face urgent energy and environment problems can be chosen as research object. The same research flow can be applied.

As to this research, the unit-divided apartment which is the most widely spread in Lhasa is chosen as the concrete analyzing target. However, in the urban area, townhouse is the other common residential building. It has the different architectural design characteristics. As the supplement of this research, it can be one research target in the future.

In Chapter 5, the higher efficient home appliances are used as one potential solution to the family electricity consumption growth. In the further future, the local people might have much higher living standard than now, which means the massive home appliances might consume much higher electricity, at that time, only choosing efficient appliances may not enough. The new technologies as PV systems and fuel cell systems may provide another solutions to appliances energy consumption.

The discussed items can be concluded as following:

(1) Other developing city’s passive design strategy study;

(2) Town house passive design strategy;

(3) The combination of passive design and the new energy sources as PV system and fuel cell system to control the whole family energy consumption.

Field Questionnaire survey I

Questionnaire of the thermal environment in winter

(English version)

①Date: 2010-11-__ ②weather: ( )sunshine( )cloudy( )overcast( )snowy；

1. Basic information

Name: Sex：

Age： Address:

①There are ______（number of people）in this house. ②In daytime or nighttime, there are more people staying in the house? ( ) Daytime ( ) Nighttime

2. Building information

① ____floor（total ____floors） ② This building was built in____(year)

③ The structure is: ( ) masonry structure ( ) reinforced concrete structure （ ） Others

3．Thermal feeling questionnaire

Please fill the blank three times one day, thank you!

	morning （8：30～9：30）		**noon** （13：30～14：30）		**night** （20：30～21：30）	
Orientation	( )east ( )west ( )south)north ( )other________					
Windows and doors	Door ( ) opened ( )half-open ( )closed	Window ( ) opened ( )half-open ( )closed	Door ( ) opened ( )half-open ( )closed	Window ( ) opened ( )half-open ( )closed	Door ( ) opened ( )half-open ( )closed	Window ( ) opened ( )half-open ( )closed
curtain	( ) opened ( )half-open ( )closed		( ) opened ( )half-open ( )closed		( ) opened ( )half-open ( )closed	

Appendix

<table>
<tr>
<td rowspan="2">Heading devices
Please make a circle before one or more numbers
1.Air-conditioner
2.Electric room heater
3.Centrol heating system
4.Stove
5.Others ________</td>
<td>Is it running or not now?
( ) Yes
( ) No</td>
<td>Is it running or not now?
( ) Yes
( ) No</td>
<td>Is it running or not now?
( ) Yes
( ) No</td>
</tr>
<tr>
<td>If more than one devices are running now, please write:
(e.g. 1+2=Air-conditioner+ Electric room heater)</td>
<td>If more than one devices are running now, please write:
(e.g. 1+2=Air-conditioner+ Electric room heater)</td>
<td>If more than one devices are running now, please write:
(e.g. 1+2=Air-conditioner+ Electric room heater)</td>
</tr>
<tr>
<td rowspan="2">If there is no heating devices</td>
<td colspan="3">this is because:
( ) 1 It is not too cold in winter, I do not need it.
( ) 2.The control heating system is under construction now.
( ) 3.It cost too much. 4.Others____________________</td>
</tr>
<tr>
<td colspan="3">Do you have the experience of using the room with heating devices? If so, how do you think about it?
( ) 1 I like heating room more, if possible, I will use it
( ) There is not so much difference, I do not care.</td>
</tr>
<tr>
<td rowspan="2">Your thermal feeling now
(e.g.”-1” means you feel a little bit cold.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">-3 very cold ； -2 cold, but I can endure; -1 a little bit cold;
0 comfortable; +1 a little bit hot; +2 hot
+3 very hot</td>
</tr>
<tr>
<td>Do you feel comfortable now？</td>
<td>( )Yes
( )No</td>
<td>( )Yes
( )No</td>
<td>( )Yes
( )No</td>
</tr>
<tr>
<td rowspan="2">Your dress now
(coat)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td colspan="3">1.Long underwear 2.Thermal underwear 3. Sweater
4. Cotton-patted clothes 5. Jacket 6. Overcoats.
7. Feature dress 8.Tibetan robe</td>
</tr>
</table>

Your dress now (trousers)			
	1 :long underwear; 2.thermal underwear 3. long woolen underwear 4 :sports trousers or jeans 5 :cotton-padded trousers		
Surface temperature (Please use the infrared radiation thermometer and fill in the blank .)	roof：__________℃	roof：__________℃	roof：__________℃
	ground：__________℃	ground：__________℃	ground：__________℃
	South wall：__________℃	South wall：__________℃	South wall：__________℃
	North wall：__________℃	North wall：__________℃	North wall：__________℃
	East wall：__________℃	East wall：__________℃	East wall：__________℃
	West wall：__________℃	West wall：__________℃	West wall：__________℃

Which season is your favorite season with the best thermal feeling? ( )Spring ( )Summer ( )Autumn( )Winter	What usually do you wear in each season?			
	Spring	Summer	Autumn	Winter

Thank you very much! The questionnaire is finished here. Following will be finished by us.

Number of the temperature recorders	
Materials of the construction	roof: ground: walls: windows: doors:
Please draw the plan of the building.	Please draw the plans with size in the attached papers (All the sizes are needed here, the information of the record (location and No.) is also needed in the plan)

冬季室内热环境问卷调查表

(Chinese version)

①日期:2010 年 10 月_______日；　　②天气:(　　)晴(　　)多云(　　)阴(　　)雪；

一．基本信息

姓名:　　　　　　　　　　性别：

年龄：　　　　　　　　　　地址:

① 房间共______人使用。②房间什么时间使用人数多？(　　)白天(　　)晚上.

二．房屋情况

① ____层（共____层）　②房子建造时间为：________年

③房子结构：(　　)砖混 (　　)钢筋混凝土（　　）其他_________

三．热感觉调查表（请填写黑色粗框里的内容，在括号中打勾，就像：（ √ ），或者填空）。

请完成下面的热感觉调查表，谢谢您的帮助!

热感觉调查表

一天的早上、中午、晚上各填写一次，谢谢！

	早上 （8：30～9：30）		**中午** （13：30～14：30）		**晚上** （20：30～21：30）	
房间朝向	(　　)东　(　　)西　(　　)南　(　　)北 其他_____________					
门窗开启情况	门 (　　)全开 (　　)全关 (　　)半开	窗 (　　)全开 (　　)全关 (　　)半开	门 (　　)全开 (　　)全关 (　　)半开	窗 (　　)全开 (　　)全关 (　　)半开	门 (　　)全开 (　　)全关 (　　)半开	窗 (　　)全开 (　　)全关 (　　)半开
窗帘是否开启	(　　)全开 (　　)半开 (　　)全关		(　　)全开 (　　)半开 (　　)全关		(　　)全开 (　　)半开 (　　)全关	

<table>
<tr><td colspan="2" rowspan="2">取暖方式
（可多选）
(　　)1.空调
(　　)2.电暖器
(　　)3.集中供暖
(　　)4.火炉
5.其他__________</td><td>现在是否开启：
(　　) 未开
(　　) 开启</td><td>现在是否开启：
(　　) 未开
(　　) 开启</td><td>现在是否开启：
(　　) 未开
(　　) 开启</td></tr>
<tr><td>若同时开启不止一种采暖方式，请写出（比如空调采暖+电暖器，请填写 1+2）：</td><td>若同时开启不止一种采暖方式，请写出（比如空调采暖+电暖器，请填写 1+2）：</td><td>若同时开启不止一种采暖方式，请写出（比如空调采暖+电暖器，请填写 1+2）：</td></tr>
<tr><td colspan="2" rowspan="2">如果没有采暖</td><td colspan="3">是因为：
(　　)1.不是太冷　　(　　)2.暖气还没有通过来
(　　)3.采暖花销太大　　4.其他__________</td></tr>
<tr><td colspan="3">您是否曾经有过使用采暖房间（供暖设备为集中供暖，或者空调等）的经历？
(　　)1.有　　(　　)2.没有
如果有的话，您认为采暖或者不采暖的差别大吗？
(　　)1.差别很大，有条件一定要采暖 (　　)2.差别不大，有没有都行</td></tr>
<tr><td colspan="2" rowspan="2">现在的热感觉
（请按照提示的方法填写您现在的热感觉，比如：填写“−1”，表示您现在感觉稍微有点冷）</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">−3 非常冷；　−2 比较冷；　−1 有点冷；　0 不冷不热，正好；
+1 稍微有点热；　+2 热；　+3 很热</td></tr>
<tr><td colspan="2">对现在的室内温度，您感觉舒服吗？</td><td>(　　)1.不太舒服
(　　)2.舒服</td><td>(　　)1.不太舒服
(　　)2.舒服</td><td>(　　)1.不太舒服
(　　)2.舒服</td></tr>
<tr><td rowspan="2">您现在的衣着</td><td rowspan="2">上衣</td><td></td><td></td><td></td></tr>
<tr><td colspan="3"><i>注释：1. 普通内衣，2. 保暖内衣，3. 毛衣，4. 棉衣 5. 西服休闲服等普通外套，6. 大衣，7. 羽绒服，8. 藏袍 9. 其他______________</i></td></tr>
</table>

<table>
<tr><td rowspan="2"></td><td rowspan="2">裤子</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td colspan="12">*注释：1. 普通秋裤，2. 保暖秋裤，3. 毛裤，4. 牛仔裤或休闲裤，5. 棉裤*</td></tr>
<tr><td colspan="2" rowspan="6">房间现在各面表面温度
（请使用红外线测温仪，测温后，填写此项。）</td><td colspan="4">天花板：__________℃</td><td colspan="4">天花板：__________℃</td><td colspan="4">天花板：__________℃</td></tr>
<tr><td colspan="4">地面：__________℃</td><td colspan="4">地面：__________℃</td><td colspan="4">地面：__________℃</td></tr>
<tr><td colspan="4">南墙：__________℃</td><td colspan="4">南墙：__________℃</td><td colspan="4">南墙：__________℃</td></tr>
<tr><td colspan="4">北墙：__________℃</td><td colspan="4">北墙：__________℃</td><td colspan="4">北墙：__________℃</td></tr>
<tr><td colspan="4">东墙：__________℃</td><td colspan="4">东墙：__________℃</td><td colspan="4">东墙：__________℃</td></tr>
<tr><td colspan="4">西墙：__________℃</td><td colspan="4">西墙：__________℃</td><td colspan="4">西墙：__________℃</td></tr>
<tr><td colspan="2" rowspan="2">从冷热感觉来讲，您认为哪个季节是最舒适的季节？
(　　)春 (　　)夏
(　　)秋(　　)冬</td><td colspan="12">您各个季节的衣着是怎么样的？</td></tr>
<tr><td colspan="3">春</td><td colspan="3">夏</td><td colspan="3">秋</td><td colspan="3">冬</td></tr>
<tr><td colspan="14">**调查问卷到此结束，下面由调研人员填写**</td></tr>
<tr><td colspan="2">温度记编号</td><td colspan="12"></td></tr>
<tr><td colspan="2">测量房间围护结构的6个内表面材料</td><td colspan="12">天花板：　　地面：
南墙：　　北墙：
东墙：　　西墙：</td></tr>
<tr><td colspan="2">测量户型平面图</td><td colspan="12">简图及尺寸绘制在下一页
（图中需要标注外墙和屋顶的厚度，如有保温层请尽量注明材料和厚度，测量仪器的位置和编号也请在图中标明。）</td></tr>
</table>

Field Questionnaire survey II

Questionnaire for the home energy consumption

（English version）

How many people in your family? (permanent residents)	
What kinds of cooking devices in your home?	( )Electronic Cooking Devices ( ) Solar Cooker ( ) Liquefied Petroleum Gas ( )Natural Gas ( )Stove(fuel_________) ( )others____________
What is the water heater in your home?	( )Solar Water Heater ( ) Electrical Water Heater ( ) LPG Water Heater ( )Natural Gas Water Heater ( )Cooking devices ( ) others_________________

1.If you use the LPG (natural gas or stove) for cooking and heating water, how about the cost of fuels per month? Please fill in the following blank. The unit price of natural gas(LPG) is______RMB/bottle（RMB/m^3） and if you use stove, the cost is______RMB/month_

Month	Jan.	Feb.	March	Apr..	May	Jun	July	Aug.	Sep.	Oct.	Nov.	Dec.
Cost(RMB)												

How do you deal with the hot feeling in summer?	( )Nothing, I do not feel hot at all ( )Open the windows for the ventilation ( ) Air-conditioner ( )others_____________________
	If you use the air conditioner, how much do you pay for the electricity bill per month in summer season?______ RMB/month

How do you deal with the cold feeling in winter?	(　　) Nothing, I do not feel cold　　(　　) Close the windows and doors (　　)Central heating system　　(　　) Electric heater (　　)Stove　　(　　)other________________
	If you use the air-conditioner or the electric heater to be the heating device, how does it cost you for the whole winter?__________RMB
	If you use the stove as the heating device, the fuel is (　　) Coal (　　) cow dung(　　)other_______ And the cost is________RMB for the whole winter.
	If you use the control heating system, the cost is_____RMB for the whole winter. And the indoor temperature is______℃
Which of the following is the most convenient for you without considering the cost now?	
Cooking devices	(　　)Electronic Cooking Devices　　(　　) Solar Cooker (　　) Liquefied Petroleum Gas　　(　　)Natural Gas (　　)Stove(fuel_________)　　(　　)others____________
Water heater	(　　)Solar Water Heater　　(　　) Electrical Water Heater (　　) LPG Water Heater　　(　　)Natural Gas Water Heater (　　)Cooking devices　　(　　) others_________________
For the hot feeling in summer, you will deal with it by_____	(　　)Open the window for the ventilation (　　) Air-conditioner (　　) Others__________
For the cold feeling in winter, you will deal with it by_____	(　　)Solar Water Heater　　(　　) Electrical Water Heater (　　) LPG Water Heater　　(　　)Natural Gas Water Heater (　　)Cooking devices　　(　　) others_________________

家庭能耗问卷调查表

请在完成下面的家庭能耗调查表，谢谢您的帮助!

您家的**常住**人口构成是怎么样的？	共________人
您家里一般使用什么做饭？	( )电饭锅，电炉，电磁炉 ( )太阳灶 ( )天然气 ( )煤气罐灶 ( )火炉，燃料是________ ( )其他______________
您家现在使用什么样的热水器？	( )太阳能热水器 ( )电热水器 ( ) 天然气 ( )煤气热水器 ( )不用专门热水器，用灶台热水 ( )其他_________________

如果您用天然气、煤气罐或者火炉做饭和烧热水，每月大约要花多少燃料费？请填写下表。

天然气或者液化气的单价为______元/罐（元/立方米），火炉用_____作为燃料，单价______

1 月	2 月	3 月	4 月	5 月	6 月	7 月	8 月	9 月	10 月	11 月	12 月
___元	____元	___元	___元	___元	___元	___元	___元	___元	___元	___元	____元

您家里夏季一般使用什么样的方法应对天气炎热？	( )夏天不热，什么也不使用 ( )打开窗户通风降温 ( )空调降温 ( )其他________________ 如果使用空调的话，一般夏天平均每月电费有多少？ ______________元。
您家里冬季一般怎样采暖？	( )不觉得冷，什么也不使用 ( ) 紧闭门窗即可 ( ) 通有暖气 ( ) 电暖器 ( ) 火炉 ( )其他_____________________ 如果使用电暖器或者空调取暖的话，一般一个冬天电费有多少？ ______________元。 电价为__________元/度

	如果使用火炉的话，燃料是？(　　)煤，(　　)牛粪，其他________ 一般一个冬天费用有多少？__________元。
	如果使用集中供暖(暖气)的话，一般一个冬天采暖费要交多少？ _______________元。效果如何？室内温度能达到_________度。
如果有条件可以改善现在的经济和能源供给状况，您会选择哪种更为便利的生活方式？	
您认为用什么方式做饭更加方便？	(　　　)电饭锅，电炉　(　　)太阳灶 (　　　)天然气 (　　　)煤气罐　　　(　　)其他_____________________
您认为用什么方式烧热水更加方便？	(　　　)太阳能热水器　(　　　)电热水器 (　　　)天然气热水器　(　　　)其他
您认为哪种降温方式更适合您？	(　　　)打开窗户通风降温 (　　　)空调降温 (　　　)其他__________
您认为哪种采暖方式更适合您？	(　　)集中供暖 (　　)空调、电暖器 (　　)火炉 (　　)其他___________

请您提供近几个月的电费单据，这对我们正在进行的家庭能耗削减研究非常重要，谢谢！