博 士 論 文

BIOMIMIC APPROACH TO PASSIVE ENERGY-SAVING DESIGN OF RURAL RESIDENCES IN NORTHERN ZHEJIANG, CHINA

中国浙江省北部におけるバイオミミックアプローチを用いたパッシブ省エネ住宅設計に関する研究

北九州市立大学国際環境工学研究科

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BIOMIMIC APPROACH TO PASSIVE ENERGY-SAVING DESIGN OF RURAL RESIDENCES IN NORTHERN ZHEJIANG, CHINA

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Preface

Chinese rural construction is currently booming but faces considerable challenges in energy performance. Almost all existing studies are mainly focused on the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with function, materials and technology with the local natural climatic conditions and resources. This research presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. A theoretical framework is established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure. The prototype theory, bioscience theory and the strategy of passive energy-saving technology are applied. This approach provides a suitable concept for the analysis of the formation and composition of rural residences and propose a method to integrate passive energy-saving technologies with the other aspects during the early design stage. Northern Zhejiang is taken as an example. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort. And the aim of this research and new approach is to provide a reference model for rural construction.

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This work could not have been completed without the support, guidance, and help of many people and institutions, for providing data and insights, for which I am very grateful.

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Second, particular thanks go to Professor Zhu Wang who have taught me for his instruction and generous support during these years. Also, I would also like to thank all university colleagues, Dr. Lingting ZHANG who gives me guidance and research supports; and Ms. Yafei ZHANG, and Dr. Liyang FANG from whom I get tremendous love and encouragement as well as technical instruction; moreover, Mr. Lilei ZHOU also give me the help, cooperation, and supports of research and daily life in Japan.

Finally, I would like to express my deepest thanks to my dear husband, lovely son and parents for their loving considerations and great confidence in me that made it possible to finish this study.

Biomimic Approach To Passive Energy-Saving Design Of Rural Residences In Northern Zhejiang, China

ABSTRACT

Nowadays since the rapid process of urbanization in China, rural construction boom has also happened. Numerous investigations of rural residences have shown that the poor thermal insulation properties of building envelopes, as a function of nonstandard traditional construction materials and methods, results in substantial energy consumption. This phenomenon has greatly damaged the rural environment and feature.

In view of the national situation, some attention has been given to this issue. But almost all existing studies are mainly focused on the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with function, materials and technology with the local natural climatic conditions and resources.

This research presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. A theoretical framework is established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure. The prototype theory, bioscience theory and the strategy of passive energy-saving technology are applied. This approach provides a suitable concept for the analysis of the formation and composition of rural residences and propose a method to integrate passive energy-saving technologies with the other aspects during the early design stage.

Northern Zhejiang is taken as an example for the field investigation, and for the construction of an abstract model and menu for rural residences. The study of two important cases has been conducted to demonstrate the accuracy of the model and menu. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort. And the aim of this research and new approach is to provide a reference model for rural construction.

In Chapter 1, PREVIOUS STUDY AND PURPOSE OF THE STUDY. Firstly presents the situation of China's rural building energy consumption, then states the challenges for China's rural building energy efficiency in five aspects, finally illustrates the motivation and purpose of this research. In addition, the related studies have been reviewed.

In Chapter 2, INVESTIGATION AND ANALYSIS. In this part, firstly analysis results of Northern Zhejiang including geography, climate, local resources and economy were presented. Then the passive energy-saving technologies which are suitable in Northern Zhejiang to improve the thermal performance of buildings have been simulated test by Weather Tool. Finally the investigation results of two important villages were expounded, which indicate the existing issues of the rural houses in Northern Zhejiang.

In Chapter 3, THEORETICAL SURVEY AND NEW APPROACH. Firstly the concept and approach for rural construction was introduced. It presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. Then the prototype theory, the bioscience theory and the strategy of passive energy-saving technology were introduced separately. Finally a theoretical framework was established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure.

In Chapter 4, ESTABLISH AND ANALYSIS OF BASIC UNIT OF RURAL RESIDENCE IN NORTHERN ZHEJIANG. Firstly we built a main functional prototype according to the survey data in Chapter 2and 3. Then different functions are arranged on the plan, which can be changed into different forms according to different needs in five aspects. Meanwhile, vertical and horizontal tunnel spaces are set up in the prototype design.

In Chapter 5, ANALYSIS OF DESIGN MENU OF RURAL RESIDENCE IN NORTHERN ZHEJIANG. On the basis of the main function prototype built in Chapter 4, this section uses the principle of topology to design a "design menu" of various forms through factors such as cavity space, composite exterior walls, and topography.

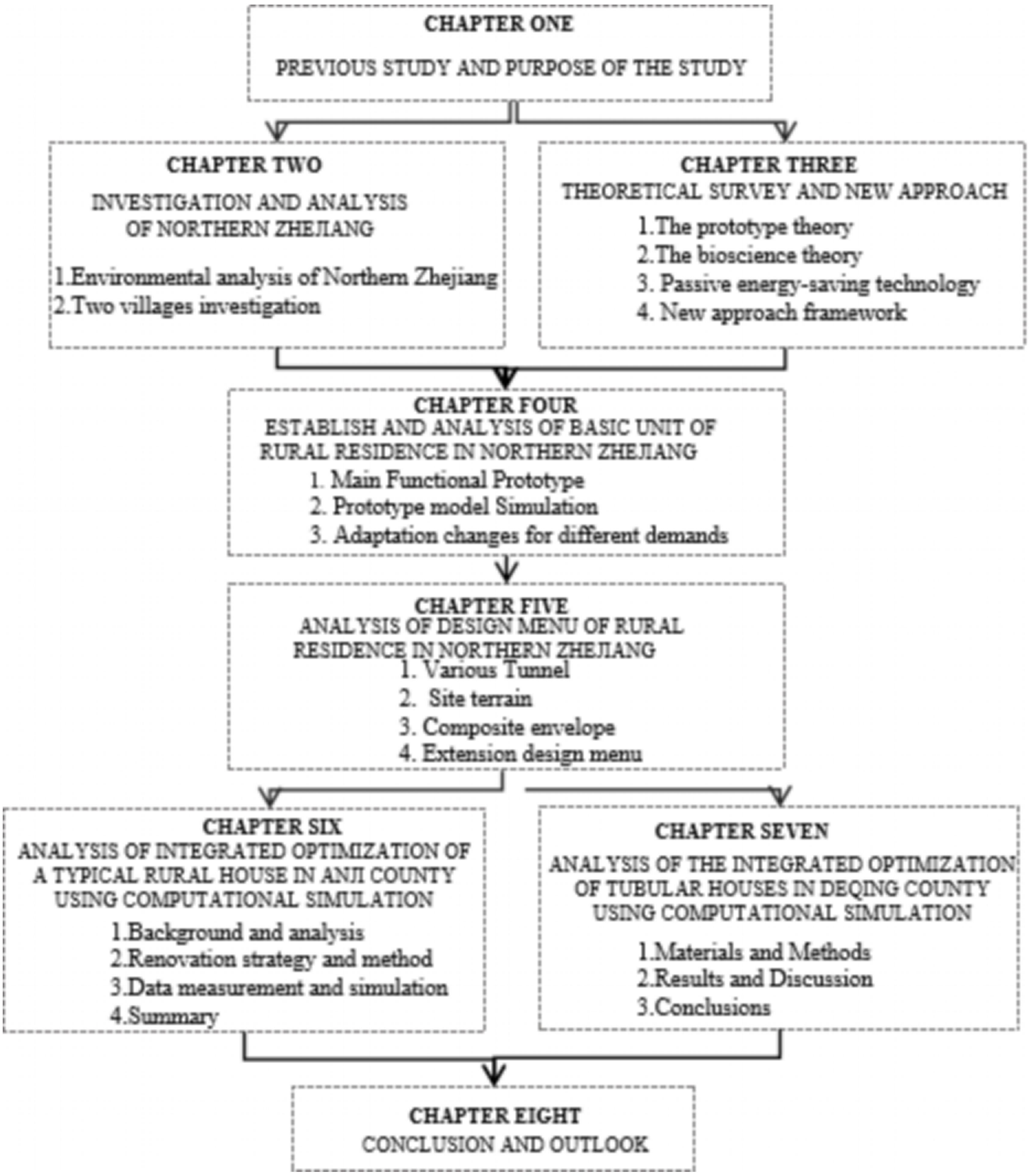
In Chapter 6, ANALYSIS OF INTEGRATED OPTIMIZATION OF A TYPICAL RURAL HOUSE IN ANJI COUNTY USING COMPUTATIONAL SIMULATION. In this part, a case study of a typical house in Anji County, Northern Zhejiang was used to demonstrate the accuracy of the model and menu. Firstly, a field measurement exercise was conducted in the building, followed by computer modeling work using open-studio software to simulate thermal performance. Then after renovation according to integrated optimization design in reality, anther field measurement exercise was conducted. Subsequently, both the two calculated values were compared for validation purposes. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort.

In Chapter 7, ANALYSIS OF THE INTEGRATED OPTIMIZATION OF TUBULAR HOUSES IN DEQING COUNTY USING COMPUTATIONAL SIMULATION. In this part, anther case study of a traditional tubular house in Deqi County, Northern Zhejiang was also expounded. Firstly, a series of experimental measurements were carried out, focusing on the characteristics of the tubular house and the current situation of the thermal comfort, to provide the basis for the study. And the field investigation about modeling parameters of tubular house and a questionnaire survey about living schedule of 121 households were conducted. Then a typical tubular house was built in Open-Studio. Several energy consumption simulations were conducted throughout the winter and summer by combining different renovations. Finally the analysis of all the result was conducted. The results also show a clear improvement in the thermal comfort.

In Chapter 8, CONCLUSION AND OUTLOOK. The conclusions of whole thesis were deduced, and the future work of optimization of rural residences in Northern Zhejiang was put forward.

王 靜 博士論文の構成

BIOMIMIC APPROACH TO PASSIVE ENERGY-SAVING DESIGN OF RURAL RESIDENCES IN NORTHERN ZHEJIANG, CHINA



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Chapter 1

PREVIOUS STUDY AND PURPOSE OF THE STUDY

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1.1 Introduction

Globally, the construction industry today consumes 40% of total energy production, generates between 30 to 40% of all solid waste, and emits 35 to 40% of total CO2 emissions. In light of the current unsatisfactory situation, a number of policies have been adopted in regions and countries all over the world. However, China is a big country with a large agricultural sector. Numerous investigations of rural residences show that the poor thermal insulation properties of the building envelopes consisting of non-standard traditional construction materials and methods result in substantial energy consumption. In addition there is an increasing trend in energy consumption year-on-year against a background of generally improving living conditions and the policy for comprehensive development of rural areas. Hence, rural residences should gradually be moving closer to becoming green buildings.

However, at present China's green buildings are all to be found in cities and towns. The renovation of rural areas tends to be a blind copy of urban living standards, whilst the construction of rural residential buildings is generally defined by the individual behaviour of farmers, who rarely consider energy-saving design principles. In addition, since the majority of researchers are concentrated in universities in urban areas, and due to the lack of appropriate technical guidance and policy support, there is a scarcity of technical guidance and standards for energy saving in China's rural areas.

In view of the national situation, there has been some attention given to this issue. But the theories tend to emphasize the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with architectural design, which is what makes "Green Buildings" become a holistic ecological technology. In the current moment, the existing research is far from attaining this goal.

The process of green building design requires the project team to constantly consider the building performance in terms of the building envelope, orientation, shading and natural ventilation together with energy efficient systems and equipment. Less resources are necessary for a major impact on these aspects if the initiatives are taken from the earliest stages of the design, and the energy saving research should be combined with the local natural climatic conditions and resources, especially in rural areas.

This research presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. A theoretical framework is established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure. The prototype theory, bioscience theory and the strategy of passive energy-saving technology are applied in this new approach and the aim of this research is to provide a reference model for rural construction.

1.2 Research Background

1.2.1 Situation of China's rural building energy consumption

Globally, the construction industry today consumes 40% of total energy production, generates between 30 to 40% of all solid waste, and emits 35 to 40% of total CO2 emissions [1, 2]. In light of the current unsatisfactory situation, a number of policies have been adopted in regions and countries all over the world. Examples of these policies are the Kyoto Protocol [3], the Energy Performance of Buildings Directive [4, 5], and the Japanese plan for a low carbon society [6], all of which have gained substantial support as a solutions for minimizing the environmental impact of buildings so as to achieve sustainable development [7].

However, China is a big country with a large agricultural sector. The rural population accounts for about 43.9% of the total population [8]. In China, the energy consumption of the construction industry accounts for about 30% of total energy production, and rural areas account for 37% [9].

Numerous investigations of rural residences show that the poor thermal insulation properties of the building envelopes consisting of non-standard traditional construction materials and methods result in substantial energy consumption [10, 11]. At present, China is in a stage of urbanization and new rural construction, and people's living levels have been greatly improved. In addition there is an increasing trend in energy consumption year-on-year against a background of generally improving living conditions and the policy for comprehensive development of rural areas.[12] With the improvement of people's living standard, the requirements for residential quarter, including lighting, heating and refrigeration, cooking, TV and washing machine are also increasing. The the total annual rural building energy consumption has increased substantially, from 364.61 million tons of standard coal equivalent (Mtce) in 1998 to 537.98 Mtce in 2007, with an annual growth of 4.4%, as shown in Fig. 1-1 [13].

While data on rural energy consumption and building energy trends are less extensive than for urban China, the data we do have point to several challenges. Energy efficiency is low, and energy consumption is high. As noted, energy use in rural houses accounted for around 65% of total building energy use in China in 2005 as showed in Fig.1-2, and even with rapid urbanization and fuel substitution, it is still expected to be a quarter of China's building energy use in 2050 [14].

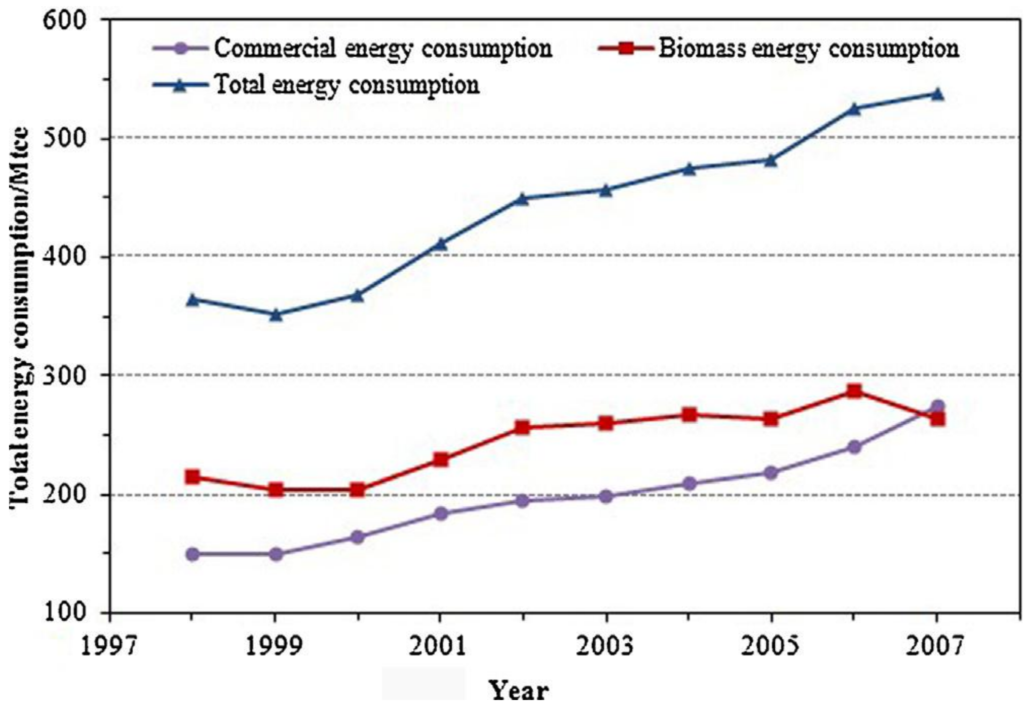

Fig.1-1 Building energy consumption in China rural areas

(Zhang, Yang, Chen, & Chen,2009).

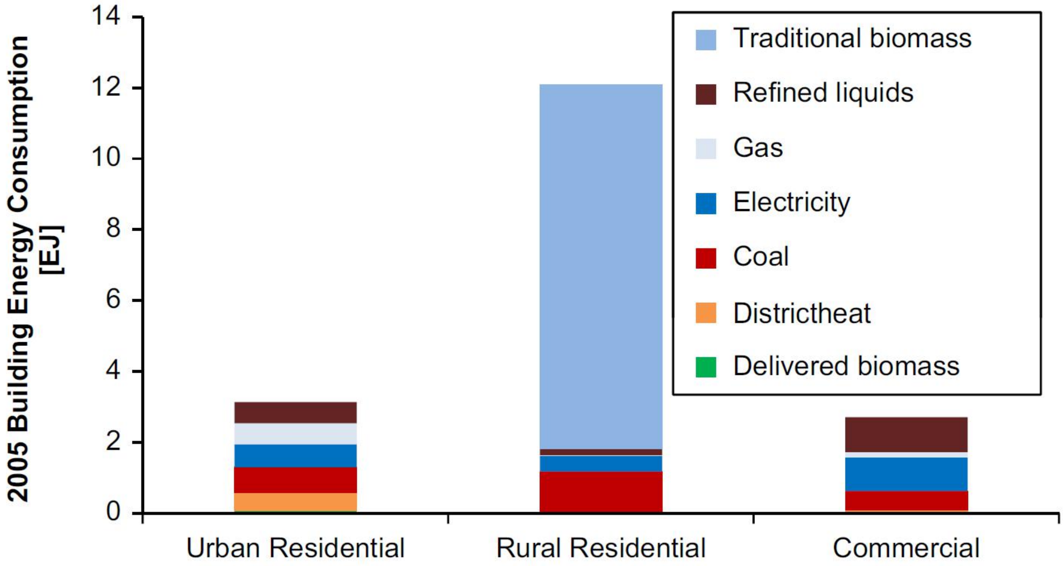

Fig.1-2. Building energy consumption in urban residential,rural residential and urban commercial buildings,2005.Source: Yu et al.(2012).[14]

1.2.2 Challenges in China's rural building energy consumption

China is a huge geographical country with widespread rural areas, which is distributed in broad region. Meanwhile, due to the multiple influence of economic level, living habits and living quality, buildings in different regions have specific characteristics. Although it has been a long time that people paid attention to rural building energy efficiency, the development of this work is still slow due to the above reasons[12].

1) Huge building areas

Since China's reform and opening up, rural building industry has entered a new upgrading period. Although rural population has reduced from 810 million to 660 million since 2000, total buildings area is still increasing rapidly to meet the requirement of per area (National Bureau of Statistics of People's Republic of China, 2008). Rural buildings area is 23.8 billion ㎡, which will bring great difficulties to building energy efficiency work. Annual new rural building area in recent years is provided in Table 1-1 (National Bureau of Statistics of People's Republic of China, 2009), where the new construction area is about 700 million-800 million ㎡ per year. With the speed up of new rural construction, new buildings area will still grow faster, so it is an opportunity to encourage people to build low carbon buildings.

Table.1-1 Annual new construction area in China rural areas

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Area(million m2)	859	839	832	813	745	751	757	658	666	692	783	844

2) Significant regional difference

The geography conditions are complicated in China, at the same time, materials distribution and weather features are also very different. So focusing on using local materials and renewable energy resources is necessary to comply with local characteristics when promoting building energy efficiency technologies and measures.[12]

According to Civil building thermal design code, building climate region can be divided into five categories: Severe cold region, Cold region, Hot-summer and cold-winter region, Hot-summer and warm-winter region and Mild region as showed in Fig. 1-3. The building indexes, such as thermal environment criterion, indoor air quality standard, energy consumption index and thermal index, will vary greatly from different climate zones, so energy efficiency standards for each region cannot be treated equally. In the process of making standards, thermal performance requirements for envelope materials must betaken into accounted. This article takes the southern part of Zhejiang as the research object, which is representative of the hot summer and cold winter climate zones.[14]

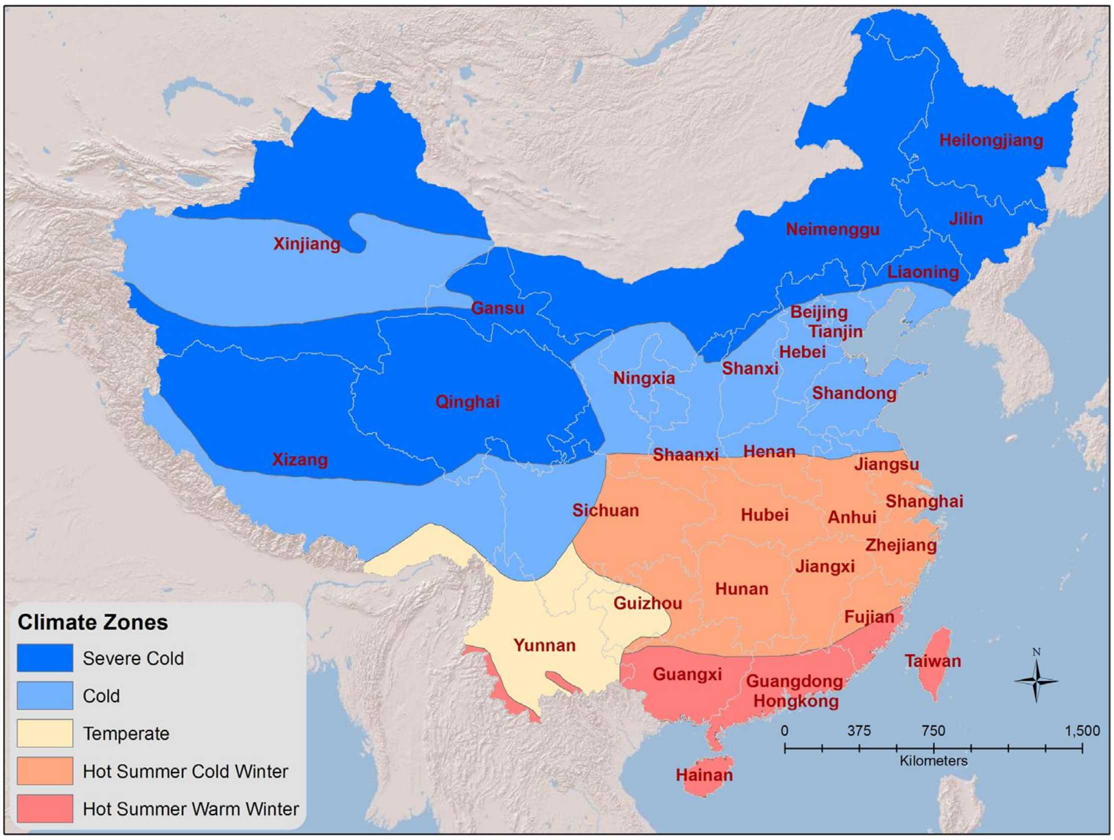

Fig. 1-3. Climate zones in China.

Source: adapted from Yu et al.(2012).[14]

3) Lack of appropriate research

However, at present China's green buildings are all to be found in cities and towns. The renovation of rural areas tends to be a blind copy of urban living standards, whilst the construction of rural residential buildings is generally defined by the individual behaviour of farmers, who rarely consider energy-saving design principles. In addition, since the majority of researchers are concentrated in universities in urban areas, and due to the lack of appropriate technical guidance and policy support, there is a scarcity of technical guidance and standards for energy saving in China's rural areas .

4) Poor heat preservation effect

Poor thermal performance of building envelope structure is the main cause of large heat dissipation. In general, external wall area accounts for about 60% of envelope area and 30% of total heat dissipation. For door and window, the main part of heat release, about 50% of total heat is dissipated. For roof and ground layer, about 15% heat is lost [15].

5) Bad energy-saving habits

Due to lack of knowledge about building energy efficiency, the energy consumption habit of rural residents' are bad. In daily life, household electrical appliances include: lighting, TV, washing machine and air conditioning, among them, lighting is the largest energy consumption appliance. China has promoted household appliances to countryside policies for many years, and now household appliances including air conditioning, refrigerator, washing machine and color TV become popular in rural areas. Fig. 1-4 shows the trend of house-hold appliances ownership [16], the electrical appliances has increased significantly, so power consumption will increase sharply. China's rural household appliance annual electricity consumption has exceeded 100 billion kWh, so the value will continues to increase if the energy habit is not good. To enhance energy-saving habit not only can reduce residents' economic burden, but also can reduce the burden of power supply in countryside.

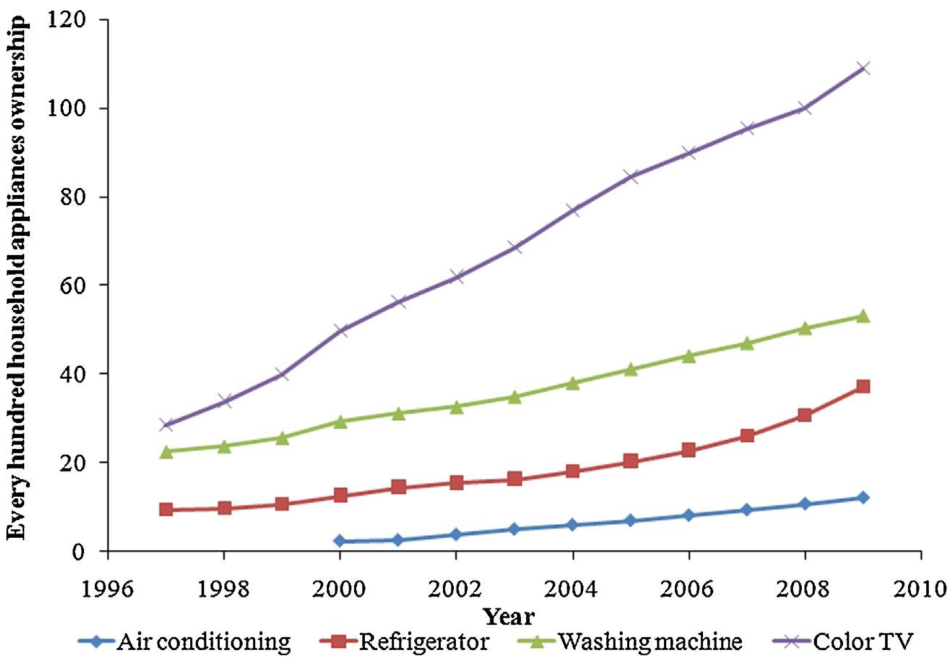

Fig.1-4 Trend of household appliances ownership in China rural areas (Jiang, 2012).

1.2.3 Building energy-saving policy

Residential energy conservation and sustainable development in rural areas are already key issues for the Chinese government [17]. Meanwhile, to promote the development of building energy efficiency, some major scientific research projects are launched in recent years. China's 12th"Five-Year plan" is focused on popularizing the concept of green development, improving technology standards for energy efficiency, and realizing the scientific transformation of urban and rural construction methods. By systematic establishing the integration of technologies and demonstration projects, the problem of energy supply in rural areas is effectively solved, so these approaches will play an important role in rural sustainable development and reducing the pressure on energy demand in China.

Therefore, based on Renewable energy law, the local governments could create laws and regulations to promote the development of building energy efficiency in the countryside. In addition, some energy-saving materials used in the new building construction are made in accordance with the laws and codes, but energy-saving performance of them are not fully utilized in rural buildings. The most effective way is to guide rural residents to construct energy-saving buildings via regulations, which should be combined with the local conditions. Design standard for energy efficiency of rural residential buildings issued in 2013 cannot comprehensively guide building energy efficiency work in rural areas. In future, building energy efficiency standards with local characteristics all should be established in construction, operation, acceptance check, evaluation, energy consumption statistics, use and maintenance[12].

At the request of MOHURD, the China Academy of Building Research, the core technical institution that drafts and supports implementation of building codes in China, developed a code for rural buildings called the Design Standard for Energy Efficiency in Rural Residential Buildings (the Design Standard). After a period of public comment, MOHURD formally adopted the Design Standard in December 2012 (MOHURD, 2011).

The Design Standard provides voluntary guidance on energy efficiency design, envelope insulation, heating, ventilation, and air-conditioning system, lighting, and renewable energy use in buildings (solar, biomass, and geothermal). Fig1-5 shows the contents of the Design Standard.

1. General Provisions
2. Terms
3. Common Requirements
4. The Architectural Layout and Energy Efficiency Design (including General Requirements, Layout Design, Building Flat and Façade Design, Passive Solar house Design)
5. Envelope Insulation (including General Requirements, Building Envelope Thermal Design, Wall, Door and Window, Roofing, Ground)
6. Heating and Ventilation Air Systems (including General Requirements, Heated Brick Bed, Heated Brick Wall and Underground Brick Bed; Natural Circulation Hot Water Heating System; Ventilation and Cooling)
7. Illumination.
8. Renewable Energy Utilization (including General Requirements, Solar Energy, Biomass Energy Utilization and Geothermal Energy Utilization)

Appendices:

A. Building Envelope Insulation, Structural Form and Insulation Material Thickness
B. Explanation of Wording in this Code
C. List of Standards Referenced
D. Explanation of Provisions

Fig.1-5 Table of contents of the Design Standard (MOHURD, 2011).[12]

By analysis of drawbacks and challenges rural building energy efficiency, it can be concluded that energy efficiency work must be supported by all aspects in China. The factors, including architectural features, geographical characteristics and economic level, should be taken into consideration.

1.3 Literature review

In view of the national situation, there has been some attention given to this issue. In 2012, the Ministry of Housing and Urban-Rural Development implemented a national standard known as the 'Design standard for energy efficiency of rural residential buildings, which provides a general introduction to the issues of rural construction [18]. In an existing study, He and Hu [19] researched a Trombe wall with ventilated blinds, the use of which improved the average indoor temperature by 5℃ in cold weather. Zwanzig [20] combined a transparent phase-change material with thermal insulation material to improve the utilization of solar radiation, and concurrently promote heat storage and release by the phase-change material. Edwin [5] analyzed the passive design strategies of houses that were entered into the Solar Decathlon Europe 2012 competition. All these studies focus on the utilization of new technologies with a high economic cost, such as thermal energy storage systems, Trombe walls, phase-change materials, etc. However rural residents cannot afford this kind of investment due to their low income levels. In rural regions, passive design with minimal input to improve the thermal properties of buildings is very significant. There is limited research into the passive design of rural buildings. Liu [21] proposed the importance of increased wall thickness to create a comfortable indoor thermal environment in a passive Yaodong dwelling, to effectively dampen the effects of external temperature changes and maintain a steady inner surface temperature. Lee [22] presented the relationship between window characteristics and building energy consumption through dynamic simulation, indicating that the optimum window characteristics vary with the climate, and proposed an optimum window type, size and orientation, providing a theoretical basis for window optimization. These studies optimized the thermal properties of buildings from a passive design perspective at low cost, yet they generally focus on a single aspect or a small group of aspects, such as external walls or windows, rather than presenting a comprehensive approach. The theories tend to emphasize the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with architectural design, which is what makes "Green Buildings" become a holistic ecological technology [23]. In the current moment, the existing research is far from attaining this goal.

The process of green building design requires the project team to constantly consider the building performance in terms of the building envelope, orientation, shading and natural ventilation together with energy efficient systems and equipment [24]. Less resources are necessary for a major impact on these aspects if the initiatives are taken from the earliest stages of the design, and the energy saving research should be combined with the local natural climatic conditions and resources, especially in rural areas [25].

1.4 Purpose of this study

In Chapter 1, PREVIOUS STUDY AND PURPOSE OF THE STUDY. Firstly presents the situation of China's rural building energy consumption, then states the challenges for China's rural building energy efficiency in five aspects, finally illustrates the motivation and purpose of this research. In addition, the related studies have been reviewed.

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In Chapter 7, CASE STUDY OF A TRADITIONAL TUBULAR HOUSE'S RENOVATION. In this part, anther case study of a traditional tubular house in Deqi County, Northern Zhejiang was also expounded. Firstly, a series of experimental measurements were carried out, focusing on the characteristics of the tubular house and the current situation of the thermal comfort, to provide the basis for the study. And the field investigation about modeling parameters of tubular house and a questionnaire survey about living schedule of 121 households were conducted. Then a typical tubular house was built in Open-Studio. Several energy consumption simulations were conducted throughout the winter and summer by combining different renovations. Finally the analysis of all the result was conducted. The results also show a clear improvement in the thermal comfort.

In Chapter 8, CONCLUSION AND OUTLOOK. The conclusions of whole thesis were deduced, and the future work of optimization of rural residences in Northern Zhejiang was put forward.

The chapter names and basic structure of the article are shown in Fig.1-6.

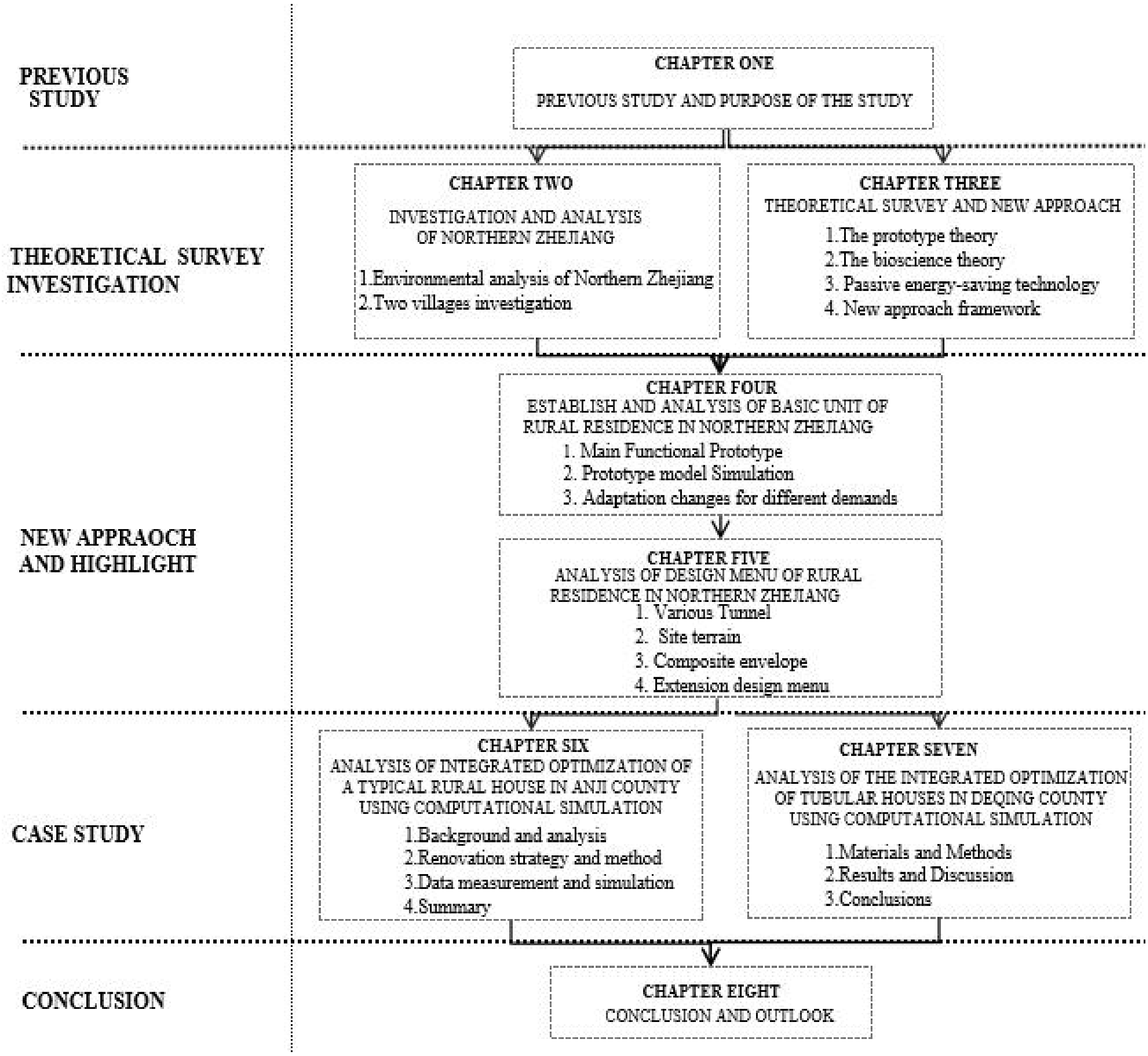

Fig.1-6. Chapter name and basic structure

Reference

1. Son, H., et al., *Implementing sustainable development in the construction industry: constructors' perspectives in the US and Korea.* 2011. **19**(5): p. 337-347.

2. Li, Y., et al., *Impact Analysis of Urban Morphology on Residential District Heat Energy Demand and Microclimate Based on Field Measurement Data.* Sustainability, 2021. **13**(4).

3. Community, U.J.R.o.E. and I.E. Law, *The United Nations Framework Convention on Climate Change.* 2006. **1**(3): p. 270-277.

4. /EU, D., *Energy Performance of Buildings Directive.* 2010.

5. Rodriguez-Ubinas, E., et al., *Passive design strategies and performance of Net Energy Plus Houses.* 2014. **83**(83): p. 10-22.

6. Lau, L.C., et al., *A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol.* 2009. **37**(11): p. 4771-4778.

7. Kibert, *Sustainable Construction: Green Building Design and Delivery (book and WileyCPE.com course bundle), 2nd Edition.*

8. Sadafi, N., et al., *Evaluating thermal effects of internal courtyard in a tropical terrace house by computational simulation.* 2011. **43**(4): p. 887-893.

9. He, B.J., et al., *Building energy efficiency in China rural areas: Situation, drawbacks, challenges, corresponding measures and policies.* 2014. **11**: p. 7-15.

10. Mohsen, M.S., B.A.J.E.C. Akash, and Management, *Some prospects of energy savings in buildings.* 2001. **42**(11): p. 1307-1315.

11. Gowreesunker, B.L., S.A.J.B. Tassou, and Environment, *Effectiveness of CFD simulation for the performance prediction of phase change building boards in the thermal environment control of indoor spaces.* 2013. **59**(JAN.): p. 612-625.

12. Evans, M., et al., *Building energy efficiency in rural China.* Energy Policy, 2014. **64**: p. 243-251.

13. Zhang, L., et al., *Rural energy in China: Pattern and policy.* Renewable Energy, 2009. **34**(12): p. 2813-2823.

14. Sha, Y.A., et al., *A long-term, integrated impact assessment of alternative building energy code scenarios in China - ScienceDirect.* 2014. **67**: p. 626-639.

15. Nan, Z., L.J.E. Jiang, and Buildings, *The Reality and Future Scenarios of Commercial Building Energy Consumption in China.* 2008. **40**(12): p. 2121-2127.

16. 清华大学, *中国建筑节能年度发展研究报告 . 20，2：2012 annual report on China building energy efficiency*. 2012: 中国建筑节能年度发展研究报告 . 2012：2012 annual report on China building energy efficiency.

17. Sun, H. and M. Leng, *Analysis on building energy performance of Tibetan traditional dwelling in cold rural area of Gannan.* Energy and Buildings, 2015. **96**: p. 251-260.

18. Wang, L.W., H.R.J.U. Bao, and R. Development, *Ministry of Housing and Urban-Rural Development: Attaching Importance to the Reconstruction of Dangerous Buildings in Rural Area and the Guidance and Support of Small Town Construction in 2013.* 2013.

19. He, W., et al., *The thermal behavior of Trombe wall system with venetian blind: An experimental and numerical study.* 2015. **104**: p. 395-404.

20. Jacobs, J., *The Death and Life of Great American Cities*. 2012: Vintage Books.

21. Zhu, X., et al., *Energy performance of a new Yaodong dwelling, in the Loess Plateau of China.* Energy and Buildings, 2014. **70**: p. 159-166.

22. A, J.W.L., et al., *Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements.* 2013. **50**(3): p. 522-531.

23. Umberto, B.J.S. Cities, and Society, *Clarifying the new interpretations of the concept of sustainable building.* 2013. **8**(1): p. 72-78.

24. Oropeza-Perez, I. and P.A.J.A.E. Ostergaard, *Potential of natural ventilation in temperate countries - A case study of Denmark.* 2014. **114**(feb.): p. 520-530.

25. Ma, C., et al., *Analysis of thermal performance and energy saving strategy of rural residence building in northwest China.* 2015.

Chapter 2

INVESTIGATION AND ANALYSIS OF NORTHERN ZHEJIANG

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2.1 Introduction

A new concept and research framework for rural residence has been proposed in Chapter 2, which needs to be confirmed its feasibility.

Over the past five years several case studies of this approach have been made by our team in northern Zhejiang, China, and this has achieved effective results. Therefore, Northern Zhejiang is taken as an example for the field investigation, and for the construction of an abstract model and menu for rural residences.

This chapter firstly makes a investigation of Northern Zhejiang, including its geography, climate, local resources and economy.

Then the passive energy-saving technologies which are suitable in Northern Zhejiang to improve the thermal performance of buildings have been simulated test by Weather Tool.

What's more, over thirty villages in Northern Zhejiang have been investigated with several case studies carried out by the research team with the assistance of financial support from National Funds. Among these, Dazhuyuan village and Cuodun village are the most important, whose investigation results have been presented in this chapter. The aim of this investigation was to find the existing issues which affects indoor living environments and energy consumption of these rural houses.

2.2 Environmental Analysis

2.2.1 Geographical Location

Since the ancient time, the northern Zhejiang Province has been an important area for Chinese economics, society and culture. In short, it has consistent ecological, environment, resources, social and cultural features, and is indeed a subject for research integrating natural terrain unit, economic and social unit and rural housing unit [1].

This research defines "Northern Zhejiang" as the plains and hills zone in Northern Zhejiang, including Hangzhou, Ningbo, Huzhou, Jiaxing and Shaoxing. It includes 347 towns, 72 townships and 8,771 villages[2]. The total land area is 44177 square kilometers and the total population is 238768 thousand[3]. (Fig2-1) Northern Zhejiang is located at the third stair in China. Compared with the southern region, Northern Zhejiang has flat and low terrain and dense rivers, fertile soil and excellent ecological environments.

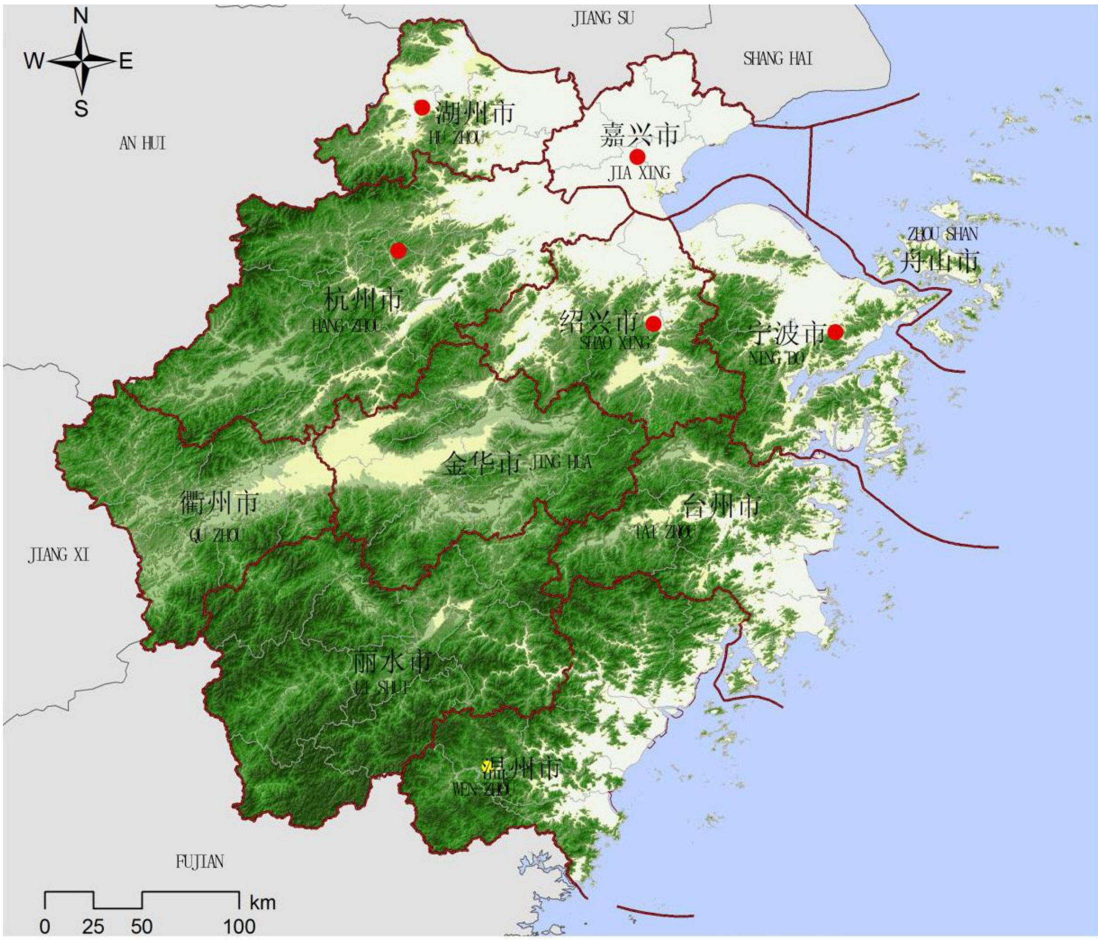


Fig. 3-1. Northern ZheJiang Topographic Map

2.2.2 Natural resources

1) hills and rivers

North Zhejiang consists mostly of hills, which accounts for about 70% of its total area. Altitudes tend to be the highest to the south and west and the highest peak of the province, the prominent mountains include Mounts Tianmu, and Mogan, which reaches altitudes of 700 to 1,500 meters (2,300 to 4,900 ft).

Valleys and plains are found along the coastline and rivers. North Zhejiang lies just south of the Yangtze Delta, and consists of plains around the cities of Hangzhou, Jiaxing, and Huzhou, where the Grand Canal of China enters from the northern border to end at Hangzhou. Major rivers is the Qiangtang Rivers. Most rivers carve out valleys in the highlands, with plenty of rapids and other features associated with such topography. Well-known lakes include the West Lake of Hangzhou.(Fig.2-2)

Fig. 2-2. Hills and rivers in Northern ZheJiang

2) Vegetation

Traditionally, the province is known as the "Land of Fish and Rice". True to its name,rice is the main crop, followed by wheat; northern Zhejiang is also a center of aquaculture in China. The main cash crops include jute and cotton, and the province also leads the provinces of China in tea production. Vegetation in north ZheJiang gives priority to mountain forests, which mainly produces the mao bamboo and tea[15]. It is known as "a land of fish and rice", it is a comprehensive productive region of agricultural products. Rice, tea, silk, oranges, bamboo products and sea products feature largely in China. (Fig.2-3)

Fig. 2-3. Bamboo and tea in Northern Zhejiang

3) Economy

Zhejiang is a relatively developed province. As of 2017, its nominal GDP was US$767 billion, about 6.26% of the country's GDP and ranked 4th among province-level administrative units. The private sector in the province has been playing an increasingly important role in boosting the regional economy since Economic Reform in 1978.(Table 2-1)

指标名称	Item	土地面积 (平方公里) Area of Land (sq. km)	年末总人口 (万人) Total Population (year – end) (10000 persons)	年平均人口 (万人) Annual Average Population (10000 persons)	生产总值 (亿元) Gross Domestic Product (100 million yuan)	第一产业 Primary Industry
杭州市	Hangzhou Municipality	16571	700.52	698.12	7802.01	255.11
宁波市	Ningbo Municipality	9816	577.71	577.06	6582.21	268.52
嘉兴市	Jiaxing Municipality	3915	344.52	343.79	2890.57	151.39
湖州市	Huzhou Municipality	5820	261.38	261.22	1664.30	122.65
绍兴市	Shaoxing Municipality	8256	440.83	440.42	3654.03	184.80

Table 2-1. GDP of North Zhejiang Province in 2012

2.2.3 Environmental characteristics analysis

Northern Zhejiang is located in hot-summer and cold-winter region and has high-quality wind energies owing to the influences of oceanic climate. It has four distinctive seasons. According to the weather data by Ecotect Weather tool （Fig.2-2,Fig.2-3）, its climate features can be summarized as follow:

1) Hot in summer and cold in winter, adequate sunlight

The annual average temperature here is 15℃-17℃. Northern Zhejiang has 30 days on average when the daily lowest temperature is lower than 0℃. And it has 5 days on average when it's higher than 30℃[4]. Its annual total ground radiation quantity is 4100-5000MJ/(m2· a), higher than the inland provinces. And its optimal orientation is 190° (south by west 10°).From June to September, local temperature exceeds the range of comfort degree of human body. And from November to December, local temperature is lower than it. Owing to heat accumulation from noon to night on a sunny day in summer, the room has a poor thermal environment making people muggy and uncomfortable; in winter, the region doesn't have heating devices, which influences the daily life in the region heavily.

2) Wet and rainy, clammy and damp-heat

This region has a lot of rivers. Owing to the evaporation of water, there is much moisture in air. In summer, Meiyu and other heavy rainfall periods lead to a high humidity in air, namely about 80%. The annual average rainfall is 1000-2000mm[5]. In summer, the wet and hot climate restrains sweating and makes people feel muggy and uncomfortable. In winter, the relative humidity is very high wetting clothes and making people feel clammy.

3) Significant monsoon, four distinctive seasons

Northern Zhejiang has significant monsoon climate. In winter it prevails northwest wind , and summer prevails southeast wind. Seal provides sufficient moisture. Summer is a season with high temperature and strong solar irradiance. Rainy seasons in spring and summer are a transition period when cyclonic activities are frequent, frontal rains are abundant and and temperature changes are huge. The wind energy should be used to strengthen the natural ventilation of building and make rooms more comfortable.

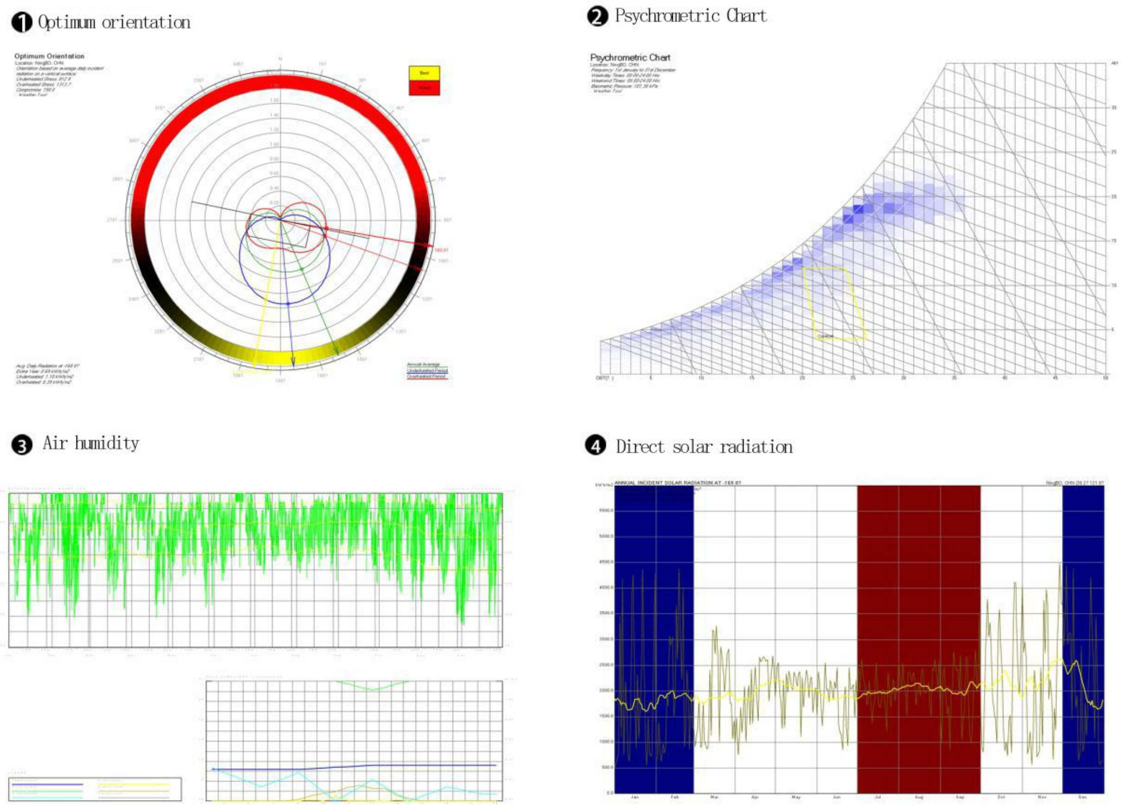


Fig. 2-2. North ZheJiang Climate data Analysis Diagram (by Weather Tool)

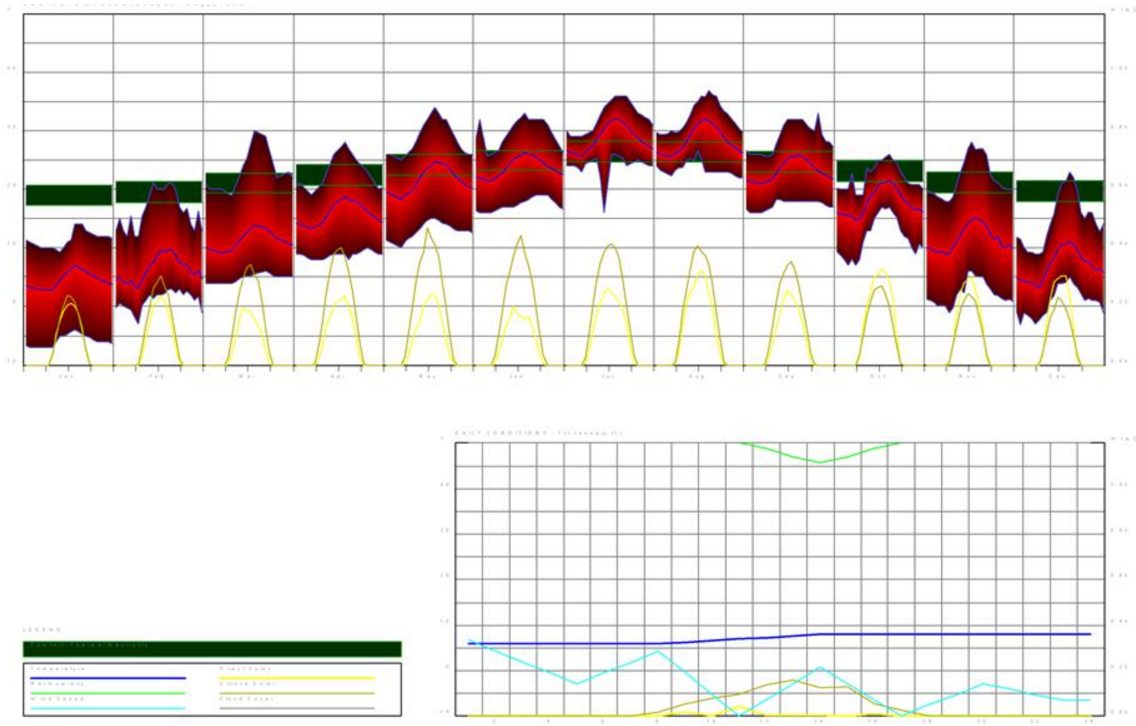


Fig. 2-3. Northern ZheJiang Temperature Analysis Diagram (by Weather Tool)

2.2.4 Technologies simulation

The application of passive energy-saving technologies can effectively improve the thermal performance of buildings. Examples are passive solar design, natural ventilation, attached sun space and composite envelopes. However, these technologies have different outcomes in different climate conditions. The following are particularly appropriate to Northern Zhejiang according to the simulation test results by Weather Tool.

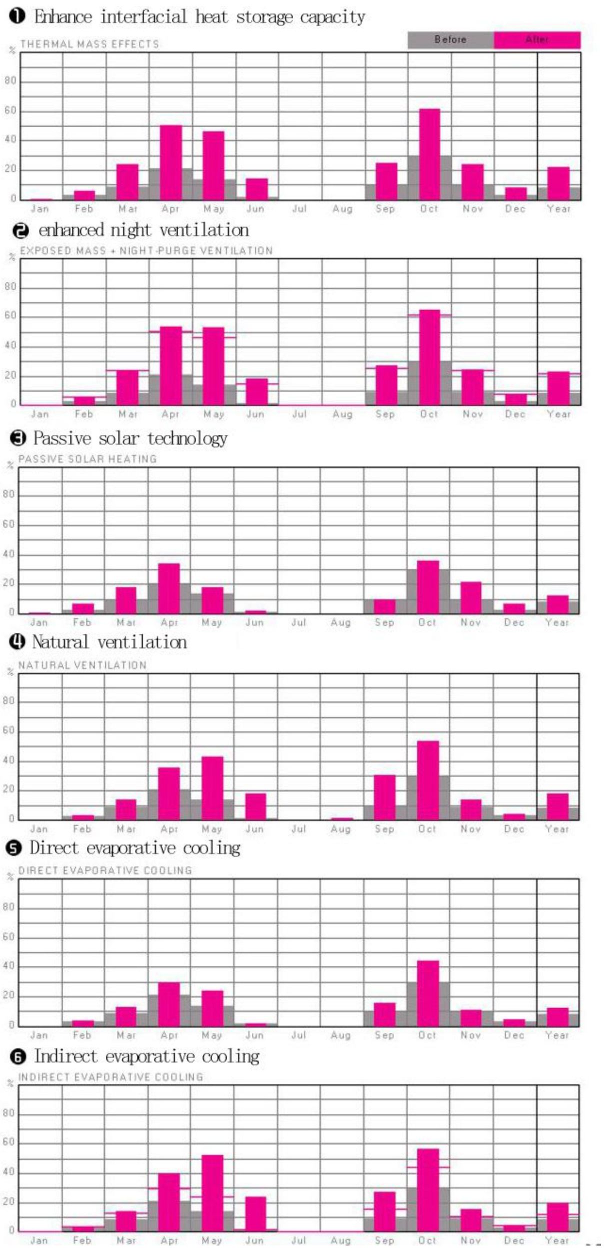


Fig. 2-4. The simulation results of the six passive energy-saving technologies used in northern ZheJiang（by Weather Tool ）

The simulation results of influence of the six passive energy-saving technologies above show that enhance envelope heat storage capacity, enhanced night ventilation, natural ventilation ,direct evaporative cooling are suitable in Northern Zhejiang to improve the thermal performance of buildings(Fig2-4).

1) Appropriate technologies for solar radiation.

Solar photovoltaic panels, solar energy heat collection and heat sinks, adjustable sun shields, shadowing, afforestation, heat collection window, and attached sunspaces are all good choices. In summer, these take advantage of sunlight for power generation, reduce direct illumination from sunlight during the day, and disperse heat through ventilation at night. In winter, these take advantage of sunlight for power generation and increase direct illumination from sunlight during the day while storing heat at night[6].

2) Appropriate technologies for wind direction and frequency.

In summer, improve natural ventilation and achieve cooling through ventilation and evaporation. In winter, control air output and humidity through ventilation and water evaporation. Vertical staircase wind pumping wells, horizontal ventilation corridors, ecological courtyards, geographic coupling cooling and ventilation and other passive energy-saving technologies are suitable choices.

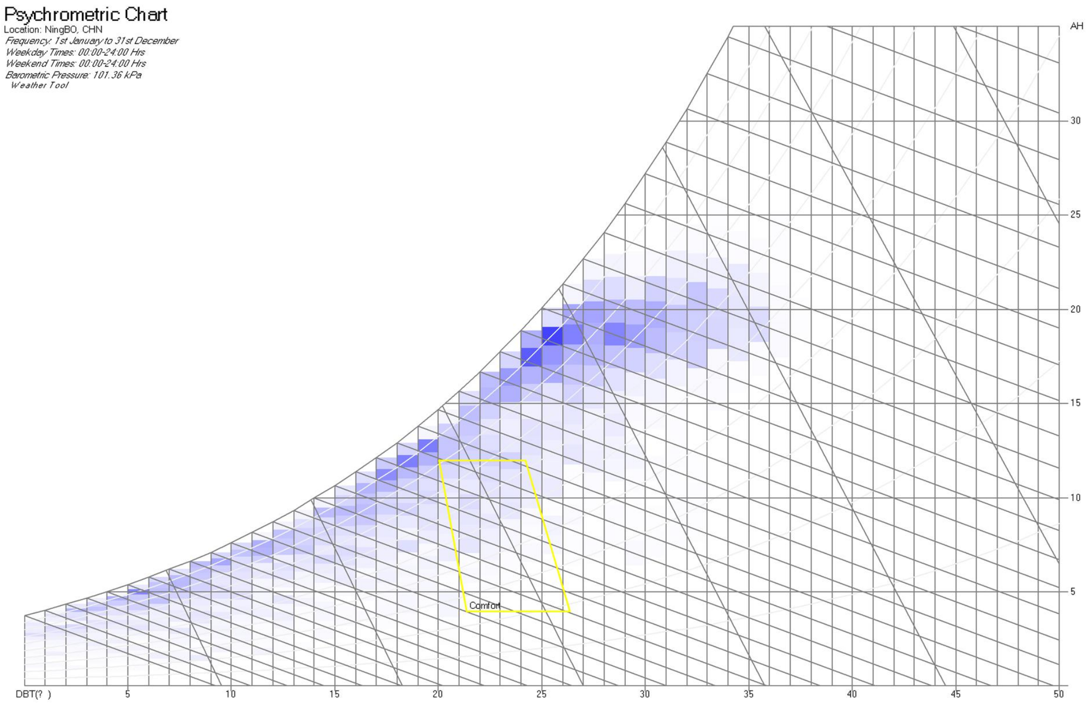
3) Appropriate technologies for humidity and rainwater.

Strengthen natural ventilation, apply mechanical ventilation, disperse moisture, collect and purify rainwater for recycling. Grass planting tiles, water seepage floors, cooling pools, rainwater collection, reclaimed water systems and other passive energy-saving technologies are available choices[7].

4) Appropriate technologies for comprehensive climate control.

The integrated design of passive energy-saving technologies is adopted. Temperature, humidity and solar radiation influence the degree of thermal comfort of the human body. The abundant wind and rainwater resources can be utilized through the application of architectural chambers, composite envelopes, utilization of renewable energy and other passive energy-saving technologies.

❶ 舒适度区域



❷ 6项节能技术对舒适度的影响分析

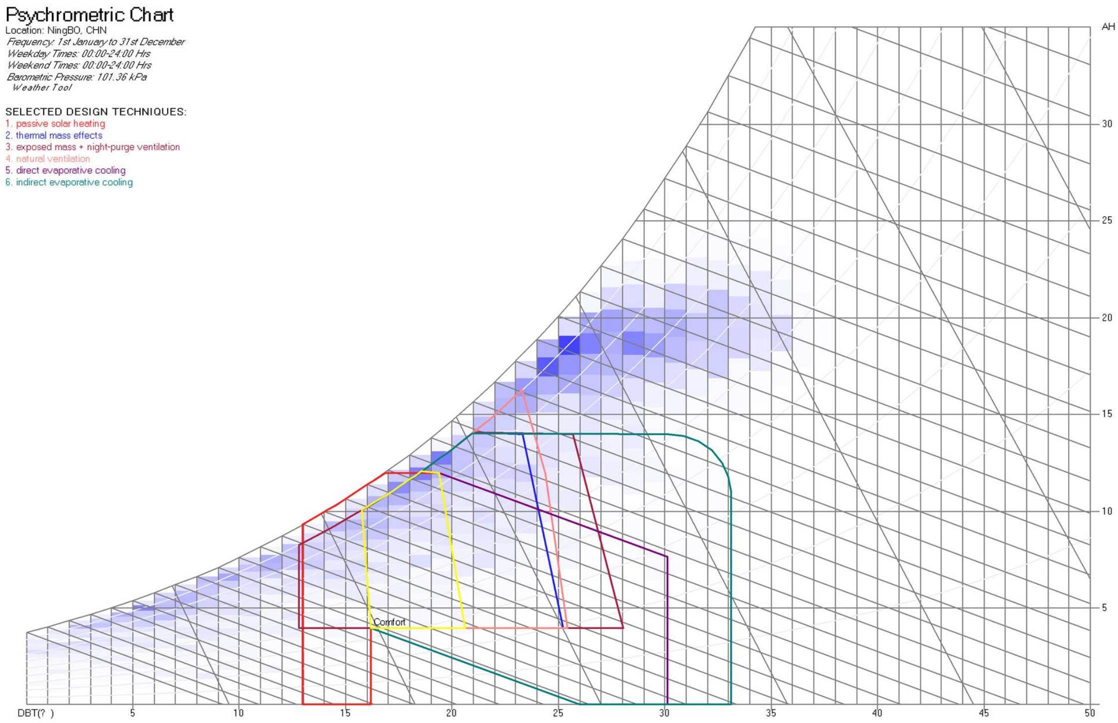


Fig. 2-5. The simulation results of the six passive energy-saving technologies used in northern ZheJiang（by Weather Tool ）

2.3 Investigation

Over thirty villages in Northern Zhejiang have been investigated with several case studies carried out by the research team with the assistance of financial support from National Funds. Among these, Dazhuyuan village and Cuodun village are the most important.

2.3.1 Dazhuyuan village

As one of the key projects of the "Beautiful Country" construction company in Zhejiang Province, China, is new housing in Dazhuyuan village comprising 62 new rural houses.[8] Before the master planning and architectural design is completed for the new village, an investigation into indoor living environments and energy expenditure in existing rural houses in the village was carried out. The aim of this investigation was to understand the existing issues affecting indoor living environments and energy consumption of these rural houses before applying appropriate technologies such as renewable energy, passive heating and cooling technologies and master planning to the vernacular architectural design to improve living quality in rural areas of China[8].

Fig. 2-6. Bird view of Dazhuyuan Village

This study was conducted between April 2016 and March 2017 in Dazhuyuan Village, Anji County, Zhejiang Province in China. The investigation was conducted in two phases. During Phase 1, interviews were conducted in 80 households. The interview included questions about: building envelope performance; heating, ventilation and air conditioning; hot water systems; lifestyle factors; indoor thermal comfort; energy consumption and previous damage to the houses. During Phase 2, the temperature and humidity of two similar houses (A and B) were monitored for a period of one-year. Table 2-1 describes the characteristics of each of these houses.

Table 2-1. Characteristics of House A and House B

House	Levels	Housing area (m2)	Completed	Family composition and age	Construction	Windows
A	3-storey + a loft	415	7years ago	husband (54), wife (51), son (24) & daughter (21)	RC frame + 300mm hollow brick	Single window
B	3-storey	390	3years ago	Husband (57), wife (54), son (28) & daughter	RC frame + 300mm hollow brick	Double-layer window

1) Basic information of housing

Among the 80 housing units assessed, 95% were found to have two or three storey, while 5% are bungalows comprising one storey. All houses were built by the occupants. Fig 2-7 presents some photographs of the houses studied and how their appearance has changed over several decades. About 81% of the houses were built more than ten years ago, and the thermal performance of these buildings tends to be poor. Brick and concrete were used as construction materials in 83% of the houses surveyed, while an exterior wall thickness of 240 mm was used in 86% of the houses. Aluminum alloy outer window frames have been used been used for the outer window frames, while the exterior windows are a single layer of ordinary glass in 90% and 94% of the houses, respectively. The internal living space of the houses ranges from 100 to 200 m2, 200 to

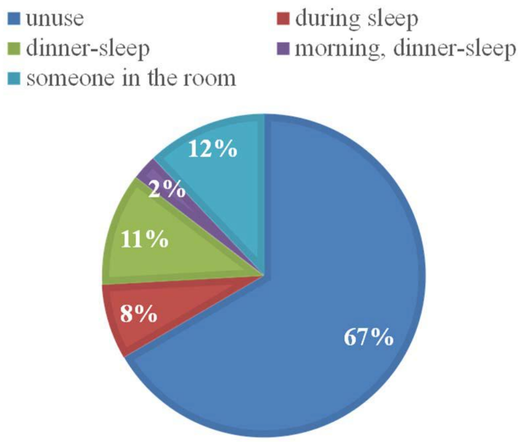
300 m2, and 300 to 400 m2 for 21%, 31%, and 29% of the houses, respectively. The overall per capita living space for these houses was 82.6 m2, which is 2.4 times the average per capita residential living area of rural China in 2010 (Annual Report on China Building Energy Efficiency, 2012) [9]. These houses are east-south orientated, or south orientated in 48% and 25% of the surveyed houses, respectively, and they have a small front yard.

Fig 2-7. Local housing construction changes in Dazhuyuan Village over three decades

2) HVAC systems and hot water supplies

Air-conditioners are installed in 92% of households, and 98% of houses use an electric fan for cooling in summer.Conversely, only 5% of these houses use rustic heating, while another 5% use electric heating in winter. Heating is used between December and early February intermittently. Fig2-8 displays the duration of use for heating in living rooms and bedrooms during the day of the houses monitored. For 67% of the time, heating was not used in the living room. For the bedroom, heating was used while residents slept, accounting for 59% of the total time. Heating is used mainly in the bedroom in winter for short duration.

Cooling equipment is used mainly from mid-June to the end of September. Fig2-9 displays graphs showing the duration of usage for cooling devices in the living room and bedroom on an average day. For 70% of the time, cooling is not used in the living room. Cooling is used while residents sleep or eat meals in the bedroom, accounting for 59% and 21% of the total time on an average day, respectively. It was also found that 5% of households used cooling equipment in the bedroom for the entire day. Heating and cooling systems and the way they are used in different rooms significantly affects indoor living environments, which may lead to discomfort or health problems.



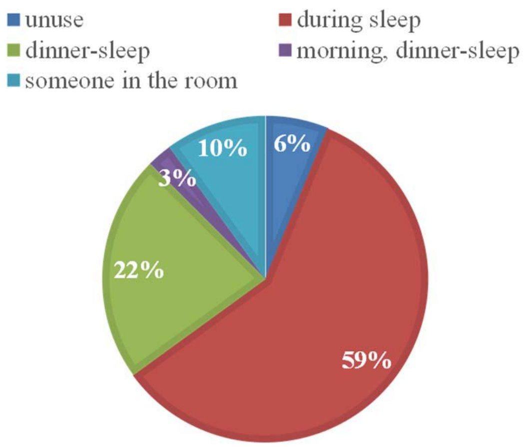
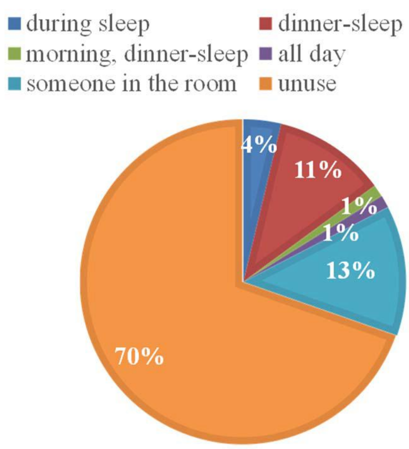


Fig. 2-8. Duration of usage of heating devices in living rooms (left) and bedrooms (right)



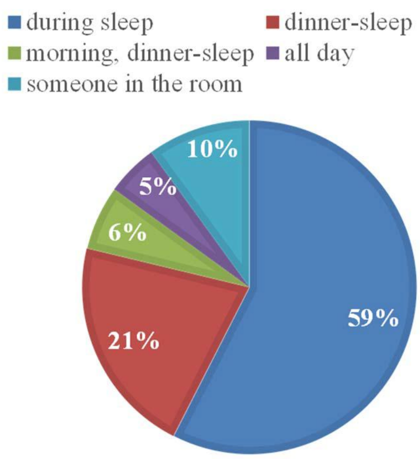


Fig. 2-9. Duration of usage for cooling equipment in living rooms (left) and bedrooms (right)

Although 80% of the houses surveyed had installed local exhaust fans in the kitchen, currently no mechanical air supply systems are used in rural houses. Solar water heaters have been installed in 93% of the houses; however, in some cases, they are not used. Straw combustion is used for a hot water supply systems and cooking in 8% of households, while 5% use an electric water heater.

3) Lifestyle factors

The family size of the households surveyed in Dazhuyuan village is usually either 3, 4 or 5 people, accounting for 34%, 21%, and 24% of total households, respectively. During weekdays, on average only 76% of the family are home, mainly the elderly, infants and young children. During weekdays either 1, 2, or 3 people are from the household, accounting for 15%, 38% and 23% of the houses surveyed, respectively. In the evening, the activities of residents are concentrated in the bedroom 98% of the time. Other habits surveyed found that 73% of residents choose to leave their windows opened all day in winter. However, this is limited to small openings. The proportion of households who leave their windows opened for the entire day increases to 81% in other seasons.

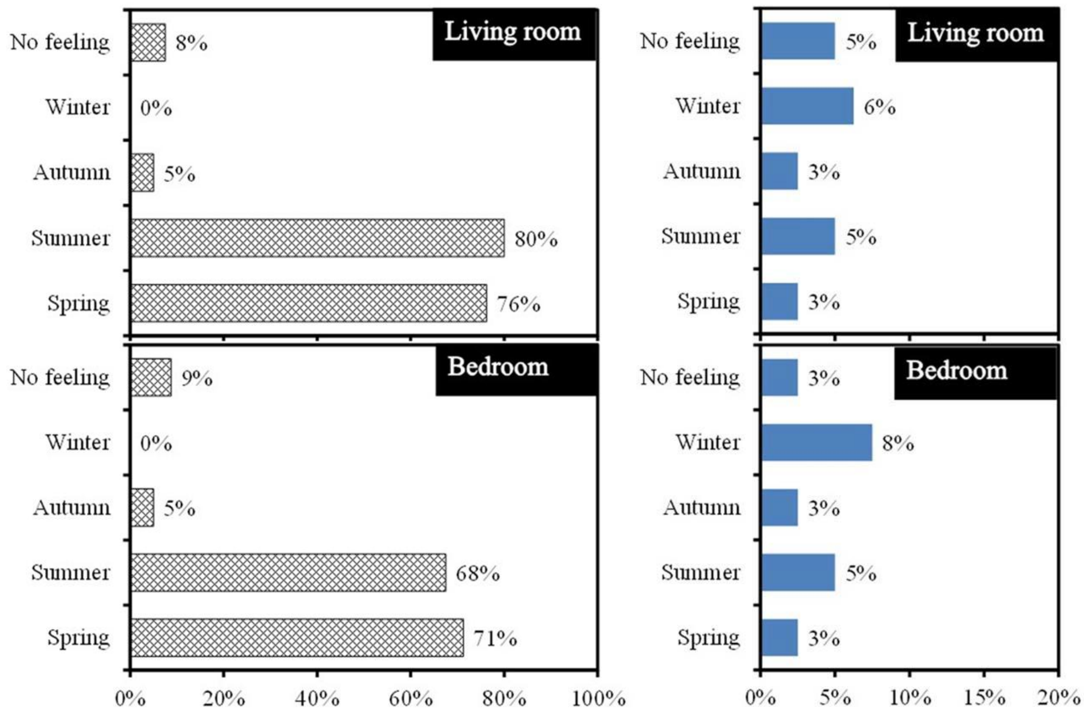


Fig. 2-10. Feelings of humidity (left) and dryness (right) in living rooms and bedrooms

Fig 2-10 shows the results of survey questions related to feeling humid (left) or dry (right) in the living rooms and bedrooms during different seasons. Most residents experience humid conditions during summer (80% in the living room and 68% in the bedroom) and spring (76% in the living room and 71% in the bedroom). The reason for the decline in experiencing humid conditions in the bedroom is attributed to the dehumidification effect of air conditioning. Residents experience dryness in each of the four seasons. However, dryness is more prevalent in the bedroom during winter[10]. This is assumed to be due to changes in the use of air-conditioning and other heating equipment.

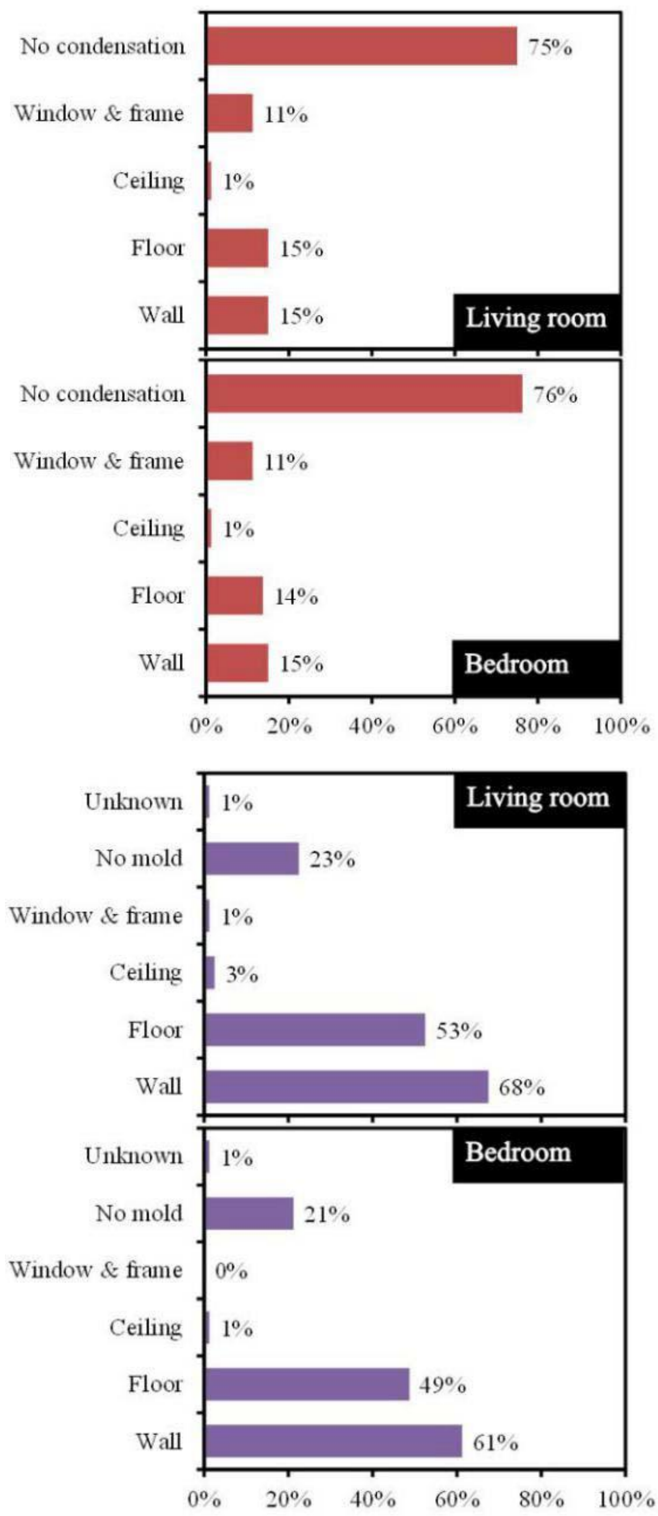


Fig2-11. Condensation and mold growth in living rooms and bedrooms

Fig2-11 shows the frequency of observation of condensation (left) and mold growth (right) occurring in different locations including living rooms and bedrooms. In these areas of the households surveyed, condensation occurs mainly on windows and window frames, floors, and walls, 11%, 15%, and 15% of the time, respectively. Mold and mildew was observed on floors in 53% of living rooms and 49% of bedrooms; and walls in 68% of living rooms and 61% of bedrooms, respectively. The prevalence of mold growth in living rooms is slightly higher than it is in bedrooms.

4) Energy usage and income

All houses in the village studied use electricity sourced from a power grid, while 96% of households use dispersed gas tanks for cooking, and a small number of villagers use straw combustion and other biomass instead of gas (4%). The average monthly electricity fee for villagers is 139 ± 57 RMB with a maximum of 350 RMB and a minimum of 25 RMB. The average monthly gas fee is 136 ± 84 RMB with a maximum of 440RMB and a minimum of 0 RMB.

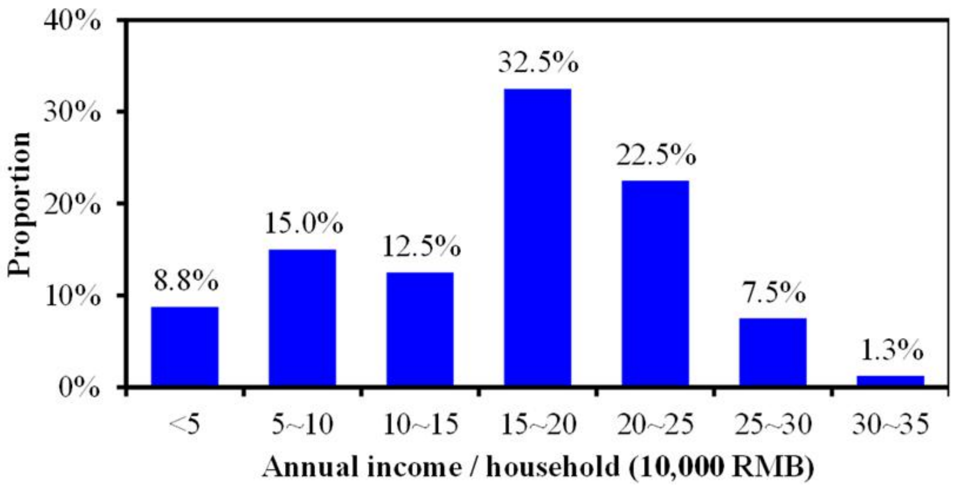


Fig. 2-12. Annual income per household in the village

Fig2-12 shows the annual income distribution per household in Dazhuyuan village. The annual income of 56% of the villagers is concentrated between 150 and 250 thousand RMB, whereas 28% of villagers are from minority families who earn between 50 and 150 thousand RMB. Families outlying these two categories comprise just over 9% of the local population. The average annual energy expenditure to income ratio is 1.65%.

5) House inspections

Fig 2-13 illustrates some of the problems experienced by rural houses observed during inspections. Some houses are not waterproof or lack insulating materials in the roof. Therefore, the thermal performance and airtightness of these rural houses is very poor. Creaks and leaks in walls, floors, and ceilings are common. Using straw for cooking can cause large amounts of dust especially on the walls of the kitchen. Significant mold growth problems on the walls and ceilings of some houses can also be observed, which corresponds with the results of the survey.

Fig. 2-13. Problems observed in rural houses during inspections

6) Annual temperature and humidity variations

Fig 2-14 and Fig 2-15 show the daily average temperature and humidity variations in House A and House B, respectively. House A and House B share similar occupant characteristics, living areas, and construction materials, but have different window types. House A has a single pane glass window, while House B has a double-glazed glass window. The average daily outdoor temperature varies between 2 and 10℃ between the middle of December to February and maintains a maximum temperature higher than 30℃ from the middle of July to August. The indoor temperature and humidity ratios varied with changing outdoor conditions, except for a bedroom on the 2nd floor during the summer in House A and the winter in House B. The indoor daily average relative humidity is comparatively high throughout the year in both houses. In each month there were days where the relative humidity was higher than 70%, which may potentially lead to mold growth.

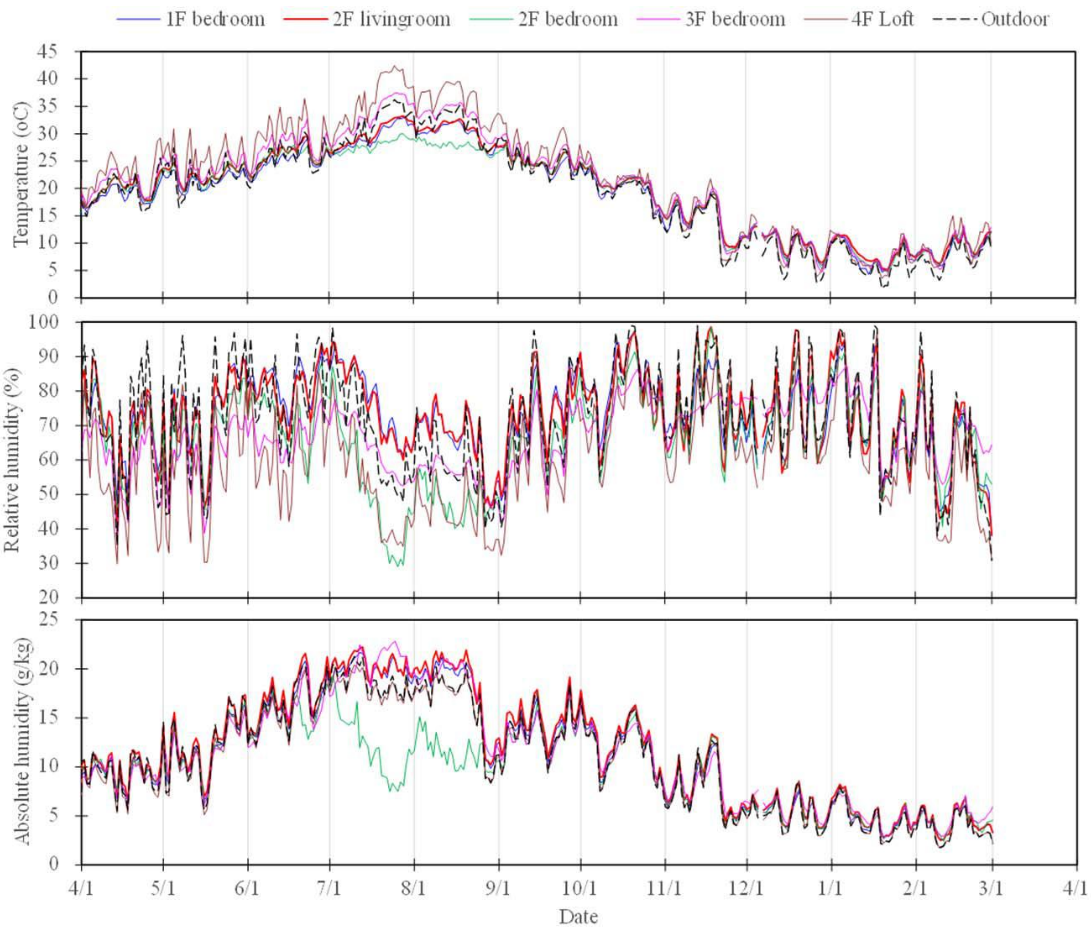


Fig. 2-14. Daily average temperature and humidity variations in House A

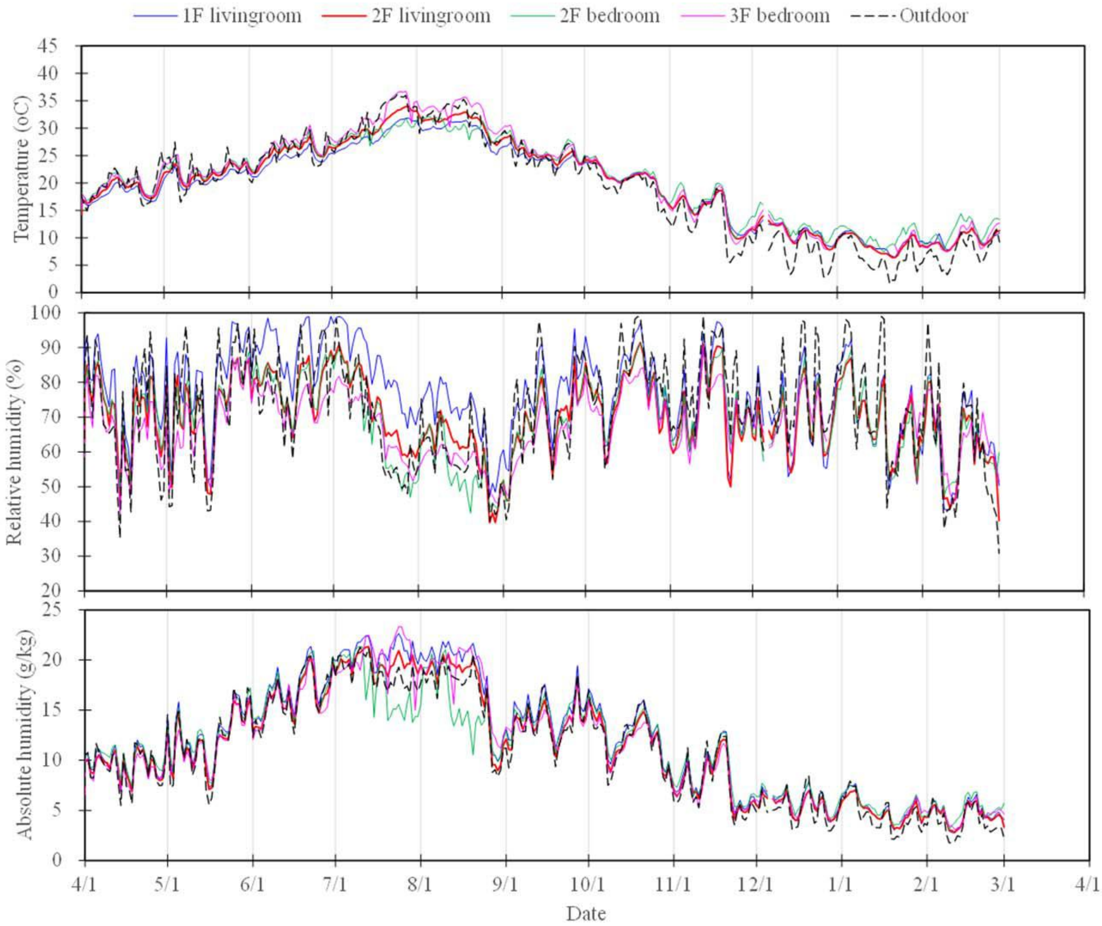


Fig. 2-15. Daily average temperature and humidity variations in House B

In House A, the only daily average temperature that was lower than 30℃ in summer was in the 2nd floor bedroom, while the 3rd floor bedroom and 4th floor loft reached over 35 ℃. The difference between the maximum and minimum daily average temperatures in the houses reached over 15℃ during summer. In winter, the indoor daily average temperature was generally 1 to 2 ℃ higher than outdoor air temperature. The humidity ratio for the 2nd floor bedroom was lower than it was for other rooms in the house, which can be attributed to the dehumidifying effect of the air-conditioner. It is assumed that air-conditioning was frequently used in the 2nd floor bedroom for cooling, whereas no heating was used in winter for House A [8].

In House B, the indoor daily temperature differences were smaller than for House A. In winter, the daily average temperature in House B was higher than the outdoor air temperature, and the minimum indoor temperature was found to be 7℃. Changes in temperature between indoor and outdoor environments has been shown to cause discomfort and health problems. While people in the case study area wear the same clothes indoors and outdoors, information and awareness of lifestyle factors that affect health in the home due to indoor and outdoor living environments needs to be disseminated. For the 2nd floor bedroom, the daily average temperature was 2℃ higher than other rooms in the house during winter and slightly lower than other rooms during summer. It can be assumed that air conditioning was sometimes used in the 2nd floor bedroom for cooling in House B to achieve a comparatively more comfortable living environment [8].

Comparing the 3rd floor bedroom and 1st floor rooms of the two houses can be used to understand conditions with no cooling or heating. The daily average temperature of the 3rd floor bedroom in House B was 2℃ lower than for House A during summer, while the temperature of the 1st floor in House B was 3℃ higher than for House A during winter. It is clear that double-layer windows achieve better indoor thermal environments during both summer and winter [11].

2.3.2 CuoDun village

The CuoDun Village is another important example with 106 households in northern ZheJiang.(Fig 2-16)

This study was conducted between July 2015 and March 2016 in CuoDun Village. The interview included questions about: building envelope performance; lifestyle factors; indoor thermal comfort and previous damage to the houses.

As Table2-2 shows , among the 106 housing units assessed, 94% were found to have two or three storey, while 6% are bungalows comprising one storey. All houses were built by the occupants. Fig2-17 presents some photographs of the houses studied. About 90% of the houses were built more than ten years ago, and the thermal performance of these buildings tends to be poor. Brick and concrete were used as construction materials in 100% of the houses surveyed, while an exterior wall thickness of 240 mm with lime was used in 90% of the houses. Aluminum alloy outer window frames have been used been used for the outer window frames, while the exterior windows are a single layer of ordinary glass in 95% and 100% of the houses, respectively.

The internal living space of the majority of the houses have a footprint of between 90 to 120m2 on a site area of 200 to 250m2. These houses are east-south orientated, or south orientated in 52% and 35% of the surveyed houses, respectively, and they have a small front and back yards.The family size of the households surveyed in Dazhuyuan village is usually 2-7 people, in which 5 people (two seniors, a couple and a child) accounting for 25% of total households.

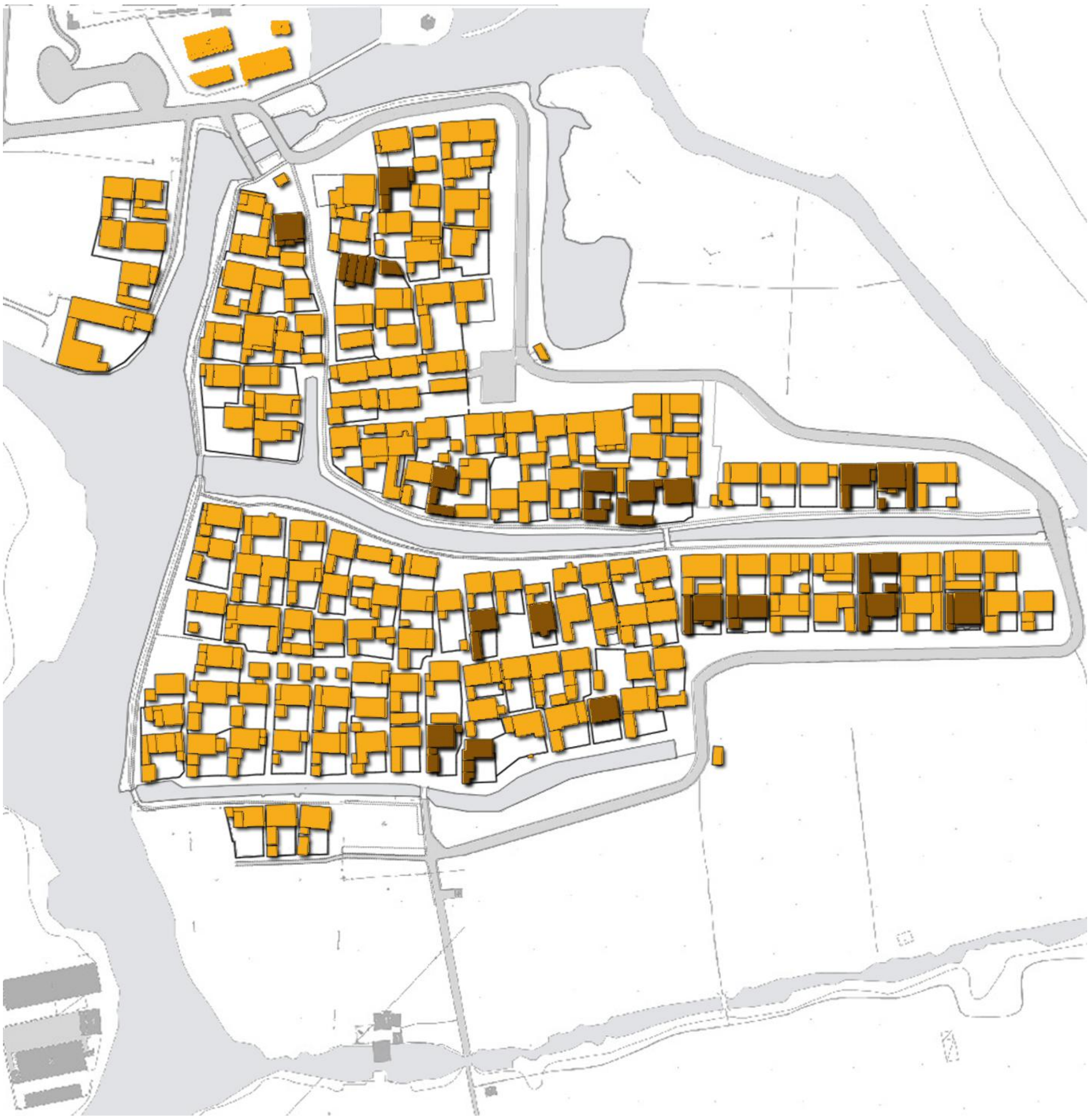


Fig. 2-16. The site plan of CuoDun Village in Northern Zhejiang

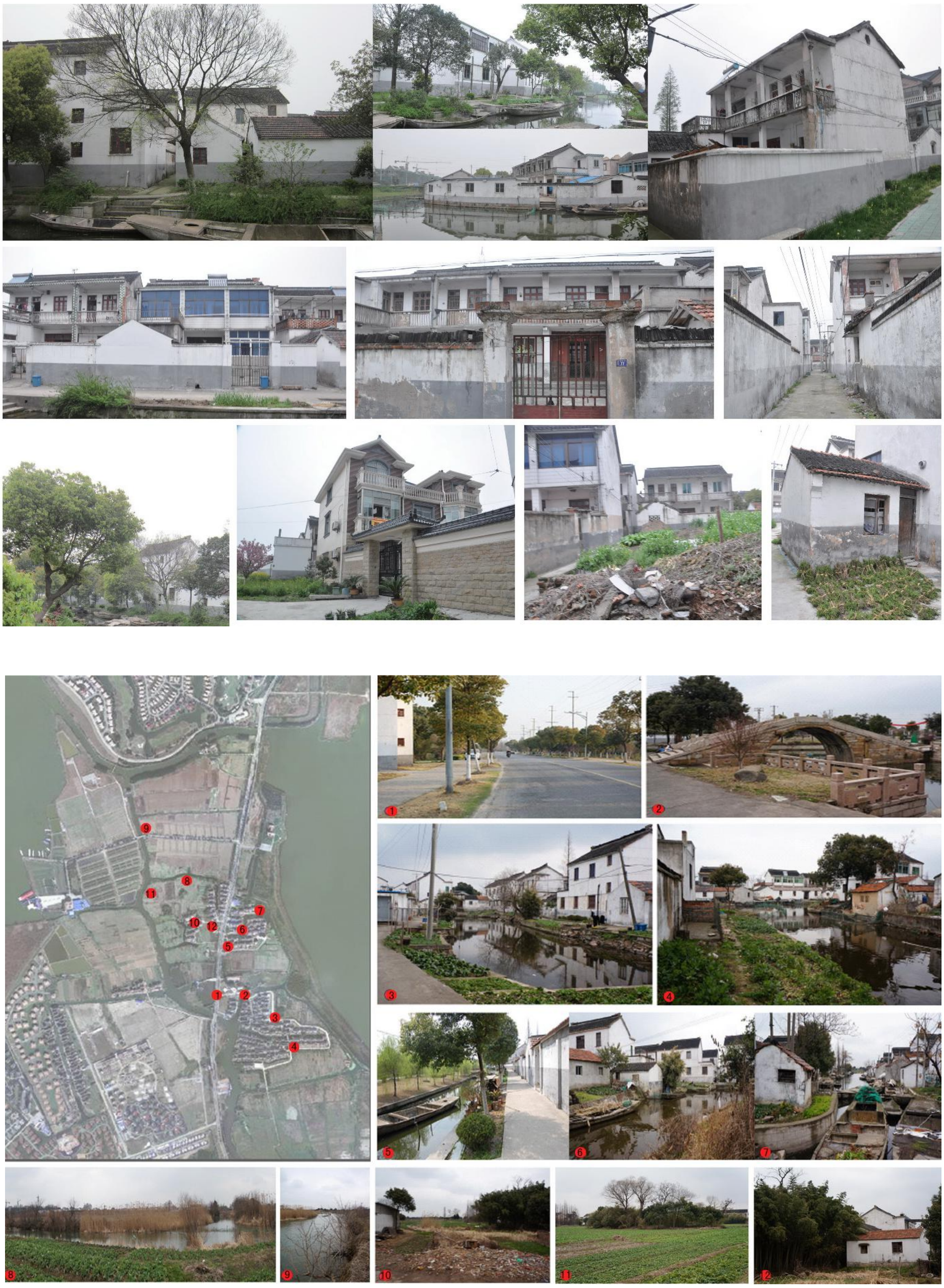


Fig. 2-17. Photos of CuoDun Village in Northern Zhejiang

Information	Building Information			Household Information	
Gate Number	Site Area/㎡	Building Foot Print/㎡	Number of floors	Number of People	Seniors + couples + children
9	255	125	2	5	2+2+1
10	192	105	3	5	2+2+1
11	172	92	1	5	2+2+1
12	190	105	2	5	2+2+1
13	164	90	2	5	2+2+1
14	240	121	1	5	2+2+1
15	293	145	2	5	2+2+1
16	190	95	2	7	2+2+2+1
17	266	105	3	5	2+2+1
18	255	103	2	5	2+2+1
19	282	115	2	7	2+2+2+1
20	277	119	2	2	0+2+0
21	205	105	2	5	2+2+1
22	320	165	2	5	2+2+1
23	392	172	2	3	0+2+1
24	260	121	1	4	1+2+1
25	454	185	2	—	—
26	300	135	2	6	2+2+2
27	214	98	2	3	0+2+1
28	259	105	2	7	4+2+1
29	173	92	2	—	—
30	180	90	2	5	2+2+1
31	470	175	3	5	2+2+1
32	203	101	2	4	1+2+1
33	281	127	2	5	2+2+1
34	236	102	1	—	—
35	478	175	2	5	2+2+1
36	356	125	2	3	0+2+1
37	218	93	2	6	2+3+1
38	288	115	2	—	—
39	294	124	2	7	2+2+2+1
40	254	98	2	3	0+2+1
41	251	102		5	2+2+1
42	236	93	3	6	2+2+2
43	260	106	2	5	2+2+1
44	346	146	2	4	1+2+1
45	128	75	1	5	2+2+1
46	117	68	1	3	0+2+1
47	235	103	2	5	2+2+1
86	307	145	2	5	2+2+1
87	286	125	3	5	2+2+1
88	266	123	2	4	2+1+1
89	280	115	2	5	2+2+1
90	264	104	2	5	2+2+1
91	269	107	2	5	2+2+1
93	288	104	2	3	0+2+1
94	234	106	2	2	0+1+1
95	253	104	2	4	1+2+1
96	255	110	2	3	0+2+1
97	323	154	2	2	
98	242	99	2	2	
99	322	135	3	4	1+2+1
100	237	95	2	2	
101	242	102	2	—	—
102	256	101	2	—	—
103	264	95	2	4	2+2+0
104	326	125	2	2	
105	327	135	2		
106	206	99	2	5	2+2+1
107	298	135	2	2	
108	268	115	2	2	
109	243	103	2	3	
110	236	103	2		
111	257	108	2	—	—
112	200	93	2		
113	279	110	2	4	1+2+1
114	294	115	2	2	

Table 2-2. Investigation date of 106 households in CuoDun Village

2.4 Summarize

As all the investigations of Northern Zhejiang show above, conclusions can be made as follow:

Northern Zhejiang consists mostly of hills and lakes and is known as "a land of fish and rice" with lots of products like bamboo, tea, fish, rice,silk,etc.

Northern Zhejiang is hot in summer and cold in winter and has four distinctive seasons. It has adequate sunlight, significant monsoon and lots of rainwater. In summer, Meiyu and other heavy rainfall periods lead to a high humidity in air. Therefore, Northern Zhejiang has poor internal thermal comfort in winter and summer. In addition, energy consumption is increasing year on year against a background of general improvement in living conditions and a policy of comprehensive development of rural areas. The dramatic increase in energy consumption puts huge pressure on the sustainable development of the countryside.

Appropriate strategies that combine passive cooling and heating technologies and the use of renewable energy may be proposed in the architectural design for new houses in this area. Enhancing envelope heat storage capacity, night ventilation, natural ventilation ,direct evaporative cooling are the most suitable in Northern Zhejiang to improve the thermal performance of buildings according to the simulation test results by Weather Tool.

Zhejiang is a relatively developed province. As of 2017, its nominal GDP was US$767 billion, about 6.26% of the country's GDP and ranked 4th among province-level administrative units. But the annual income of the people in rural area is still at the low stage with 150 - 250 thousand RMB, in which passive design with minimal input to improve the thermal properties of buildings is still very significant.

According to the Interviews held in Dazhuyuan Village and CuoDun Village , Zhejiang Province, although 90% of these houses are aged less than 25 years, the thermal performance of these houses was found to be low due to poor air tightness and a lack of thermal insulation of the building envelope. Brick and concrete were used as construction materials in more than 90% of the houses surveyed. Aluminum alloy outer window frames have been used been used for the outer window frames, while the exterior windows are a single layer of ordinary glass in 95% and 100% of the houses, respectively. Double-glazed windows were also shown to improve the indoor thermal environment both in winter and summer.Visible mold was observed in the living rooms, and bedrooms of over half the houses interviewed. The construction materials are simple with poor thermal performance, and the majority do not satisfy the relevant requirements of the design standard for energy efficiency of rural residential buildings. This standard was implement in 2012 by the Ministry of Housing and Urban-Rural Development and was a first step in the definition of standards for rural construction.

Air conditioning systems were installed in 90% of the houses, however, residents usually only used these systems in bedrooms in the evening. Straw combustion is used to supply energy to 8% houses for the supply of hot water and cooking.

The internal living space of the majority of the houses have a footprint of between 90 to 120m2 on a site area of 200 to 250m2. These houses are east-south orientated or south orientated , and they have a small front and back yards. The family size of the households surveyed is usually 3-6 people, in which 5 people (two seniors, a couple and a child) accounting for 25% of total households.

This investigation of the housing in the village has identified extensive lifestyle factors currently popular in rural areas, which means that improvements to the built environment have significant potential to improve the comfort and health or residents.

References

[1].ZhuWei .Study of Village Settlement Space in Northern Zhejiang Basis on Geography [D].Zhejiang University,2009：60-61.

[2].LinTao .Research on Rural Agglomeration and Settlement Space Evolution Mode of North Zhejiang.Zhejiang University,2012：1-3.

[3].LinTao .Research on Rural Agglomeration and Settlement Space Evolution Mode of North Zhejiang.Zhejiang University,2012：4-7.

[4].Zhou Gaosong.The Research on the Passive Design Strategy of Green Office Building in Hot-summer and Cold-winter Zone.Qinghua University,2013：P13.

[5].WeiQin.Theoretical and Practical Research on Human Settlements Constructive System of the Loess Plateau.Zhejiang University,2008：P85.

[6].ChenZongYan.Research on Spatial Pattern of Rural Residence in Northern Zhejiang Province. Zhejiang University,2011：P52.

[7].Xu Shuning.The Elementary Research on the Mechanism and Approach in Point of Green Settlement's Interface.Zhejiang University,2013：P14.

[8].Huibo Zhang. Investigation of indoor environment and energy consumption for rural residential houses in Northern Zhejiang Province, China.Shanghai Jiao Tong University,2017

[9]. Building energy saving research center of Tsinghua University, 2012. Annual Report on China Building Energy Efficiency, P.5.

[10]. Notice of the general office of the Ministry of Housing and Urban-Rural Development on the announcement of the list of rural construction plans and village planning demonstration lists for counties (cities) in 2016, MOHURD. 000013338/2017-00021.

[11]. Xiong, J. Lian, Z. Zhang, H. Physiological response to typical temperature step-changes in winter of China, Energy and Buildings. 138 (2017) 687-694.

[12]. Xiong, J. Lian, Z., Zhang, H., Yoshino, H. 2017 Correlation between health discomforts and temperature steps in winter of China, Building and Environment. 114 387-396.

Chapter 3

THEORETICAL SURVEY AND NEW APPROACH

CHAPTER THREE: THEORETICAL SURVEY AND NEW APPROACH

3.1 Introduction

This research applies prototype theory and bioscience theory within an overall strategy for the application of passive energy-saving technologies. This is a novel approach, particularly in the rural residential sector.

Prototype Theory is a model of graded categorization in Cognitive Science, where all members of a category have the same main prototype but present different characteristics by changing other parameters. In this research an abstract model of the RBU is built as the main prototype. Prototype Theory is also used as the expansion media to develop a menu for the RBU.

The concept of cities as a bio system is not a new idea.Thus, existing studies are mainly focused on the urban planning sector, and have neglected to examine the similarity between buildings or cities to cells or other living things from the perspective of formation and structure. Unlike other studies that have centred on entire cities, this study propose a single basic unit for rural housing as a healthy cell concept that enhances breathing, self-discipline, safety and comfort. An abstract model of this rural unit is constructed as a whole to describe how it forms, expands, and maintains balance over time.

Building energy efficiency can be approached from two aspects, namely active energy-saving design and passive energy-saving design. The former is prevalent in the later stages of building construction, in order to improve energy efficiency. The latter is required during the early stages of construction with the scope of reducing the building energy demand. Passive energy-saving design with low financial input to improve the thermal properties of buildings is particularly significant in rural regions. With the assistance of bioscience, passive energy-saving technologies can be better integrated into every part of the RBU, making it as effective as a healthy cell to deal with external factors such as air, temperature, humidity, and sunshine.

Almost all existing studies are mainly focused on the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with function, materials and technology with the local natural climatic conditions and resources. But, this approach provides a suitable concept for the analysis of the formation and composition of rural residences and propose a method to integrate passive energy-saving technologies with the other aspects during the early design stage.

3.2 Methodology

3.2.1 The Prototype Theory

Prototype Theory is a model of graded categorization in Cognitive Science, where all members of a category have the same main prototype but present different characteristics by changing other parameters. The application of Prototype Theory in architecture is not new, and early efforts can be traced back to Frank Lloyd Wright (1959), who always used "The cross plane" as a prototype in is structures, with over 1000 examples (see Fig 3-1).

During his almost 70 year career, Frank Lloyd Wright was responsible for the design of over 300 residential dwellings. As shown in Figure 3-1， When people review this body of work, a recurring theme is "the cross plan" ,which makes all the building more organic and more close to nature.

In this research an abstract model of the RBU is built as the main prototype. Prototype Theory is also used as the expansion media to develop a menu for the RBU.

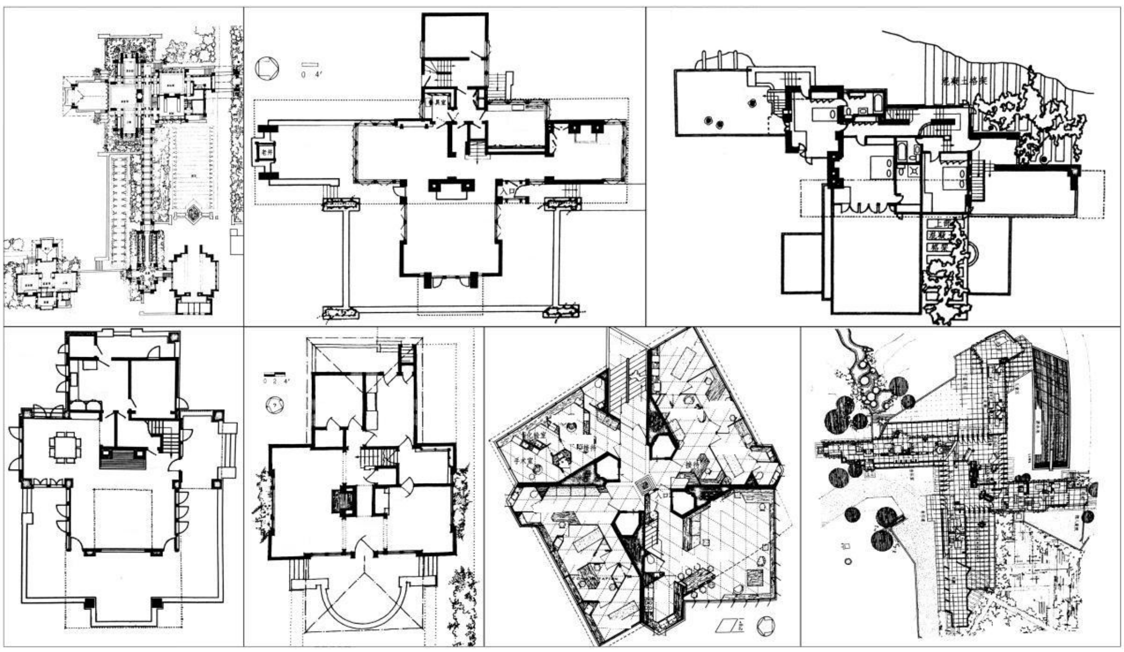


Fig. 3-1. Plans of structures by Frank Lloyd Wright

3.2.2 The Bioscience Theory

In the study of hundreds of traditional rural settlements, it is found that the forms are all very organic, resembling the structure of life systems. These buildings grow and replicate like cells without any planning, and this results in some amazing settlements (Fig 3-2). Just as living systems have a rigorous construction hierarchy from a single cell to the biosphere, rural settlements can also be viewed as composed from a single basic unit to whole systems. They are all composed of similar basic units with the same properties in terms of hierarchy, structure, function and evolution (Fig 3-4).

The concept of cities as a bio system is not a new idea[31]. Early efforts can be traced back to Perry (1929), who described the neighbourhood unit as a core cell of a residential area [30]. Saarinen (1958) was inspired by the growth of trees and proposed an organic evacuation theory to create an improved form of city with an organic order of moderate dispersion and local concentration. Jacobs (1961) also proposed the mixed community as one of the means to promote organic urban vibrancy. Several researchers correlated the concept of living organisms with urban planning, such as Wu, Chang, and Chen (2012), who regarded each cell as the centre of a local area, with the correlation of neighbouring cells as bundled elements to propose a new location management scheme with lower location management costs .

Thus, existing studies are mainly focused on the urban planning sector, and have neglected to examine the similarity between buildings or cities to cells or other living things from the perspective of formation and structure. Unlike other studies that have centred on entire cities, this study propose a single basic unit for rural housing as a healthy cell concept that enhances breathing, self-discipline, safety and comfort.

Based on this perspective, this research defines "a rural house with its yards" as the basic unit of rural residence (RBU) which is similar to a biological cell with its general internal structure. The RBU is the key component of the rural settlement system. Each RBU has a relatively clear boundary with other units, and its own independent structure [33-34]. This study proposes a basic unit for rural residence as a healthy cell concept which can breathe, regulate temperature, and reduce humidity all independently (Fig 3-3).

Fig. 3-2. From a basic unit to a rural settlement

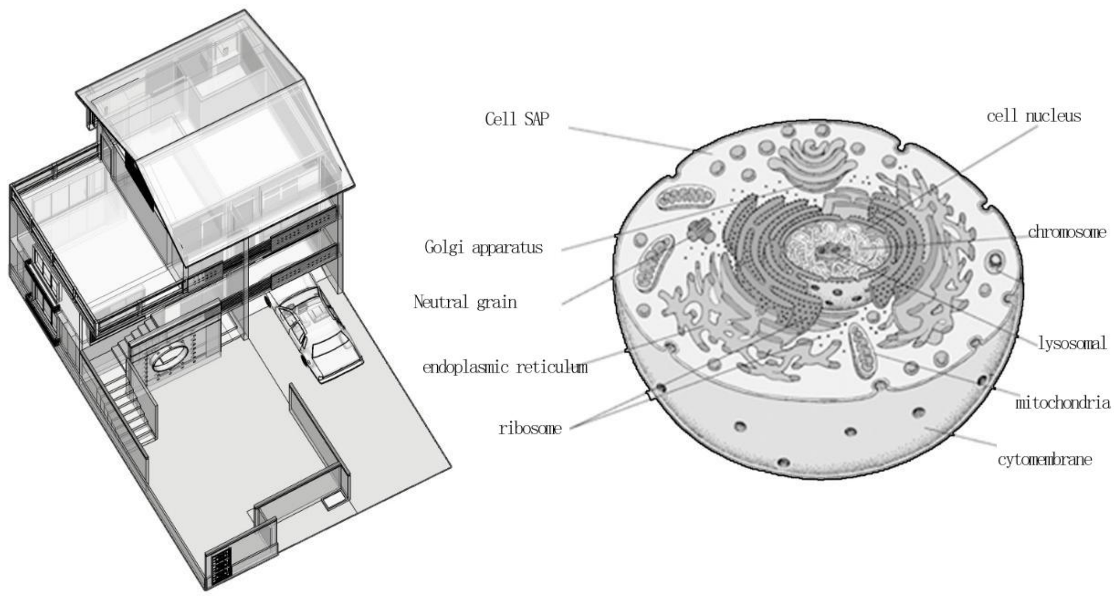


Fig. 3-3. A comparison of an RBU and a cell

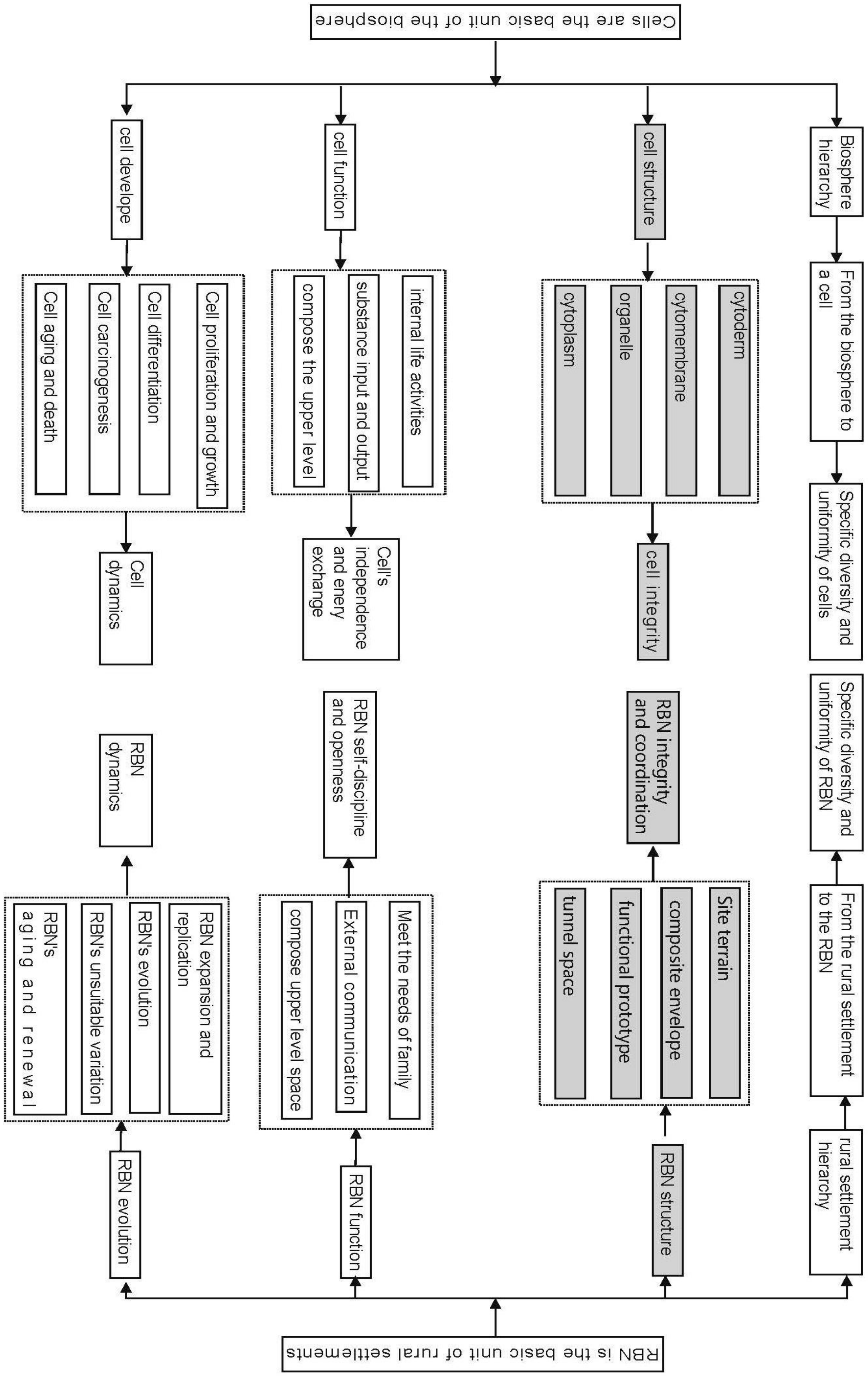


Fig. 3-4. Similar properties of cell and RBU

Although cell forms differ in thousands of ways, the internal structure remains almost identical. Cells are the basic units of the structure and function of organisms, and are composed of a nucleus, cytoplasm, membrane and a cell wall. An understanding of the composition and structure of cells, and how they gather and grow, provides the foundation for analysis of rural residences in this work (Table 3-1, Fig 3-5).

- RBU-N(nucleus)—main functional prototype

In a similar manner to the nucleus of biological cells, which produces ribosomes for the cytoplasm to conduct mRNA translation, the nucleus of the RBU (main functional prototype) produces space to meet the basic living demands of farmers, such as living room, bedroom, kitchen, bathroom, storeroom, etc.

- RBU-M（membrane）—composite envelope

The cell membrane is a thin film composed of protein molecules and lipid molecules, providing permeability and recognition, with regulatory and other properties. The composite envelope of the RBU executes exactly the same duties as the biological cell membrane, which is to isolate the internal environment from the external environment and maintain the relative independence of the internal environment. Inspired by the structure of the cell membrane, it is clear that a good envelope should not just be a wall, but should be a dynamic adjustment device for indoor and outdoor heat, light, sound, airflow, and energy activities. Therefore, composite envelopes with the same characteristics as a cell membrane are needed, such as green roofs, double skin facades, an envelope that can adjust to the sun, bamboo composite walls, permeable floors, etc.

- RBU-C（cytoplasm）—tunnel space

As the area between the nucleus and the membrane, the cytoplasm of the RBU is a tunnel space. The cell cytoplasm acts as the major site for life activities, and provides the necessary environment and basic materials for organelles. In the same way, different kinds of tunnel space in the building act as the activity sites for light, air, wind and energy. They can regulate the indoor and outdoor microclimate and improve thermal comfort with high efficiency and low consumption, such as ventilation corridors, colonnades, sun rooms, roof spaces and even courtyards.

- RBU-W（cell wall）—site terrain

The cell wall is the outermost layer of the cell, and is a transparent thin wall that supports, protects and defines the cell. The RBU's site terrain or courtyard wall executes exactly the same duty as the biological cell wall, which is to support the shape and boundary of residence and protect it.

Thus, the RBU is divided into "main functional prototype + tunnel space + composite envelope + site terrain" based on the general internal structure of a biological cell. This is very different from the traditional building segmentation approach. (Traditional architectural theories always consider the building to be composed of function room, foundation, roof, wall, structural system, equipment system, etc. Each system is also divided into several subsystems. This tends to emphasize the use of a single technology in component, thus overlooking the possibility of integrated passive energy-saving technologies to be combined with the whole design).

With the assistance of bioscience, passive energy-saving technologies can be better integrated into every part of the RBU, making it as effective as a healthy cell to deal with external factors such as air, temperature, humidity, and sunshine.

Components	**Functions**	**Examples**	**Cellular Structure**
Site terrain	limit, division	homestead boundaries or terrain	Cell wall
Main functional prototype	respective indoor basic functions	living room, bedroom, kitchen, bathroom and storeroom	Cell nucleus
Tunnel space	bearing, adjusting and flowing	tunnel space enclosed by boundary, bearing light, air, wind and activities	Cell cytoplasm
Composite envelope	protecting	roof, wall, floor, door and window	Cell membrane
The RBU - rural basic unit			**Biological cell**

Table 3-1. Divisions for the RBU

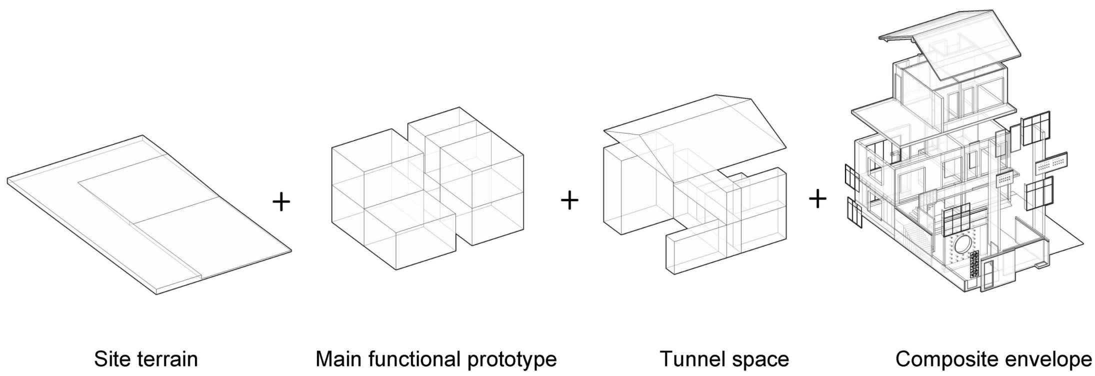


Fig. 3-5. Diagram for Basic Courtyard Units

3.2.3 Passive energy-saving technologies

Building energy efficiency can be approached from two aspects, namely active energy-saving design and passive energy-saving design. The former is prevalent in the later stages of building construction, in order to improve energy efficiency [43]. The latter is required during the early stages of construction with the scope of reducing the building energy demand [44]. Passive energy-saving design with low financial input to improve the thermal properties of buildings is particularly significant in rural regions.

The application of passive energy-saving technologies can effectively improve the thermal performance of buildings. Examples are as follow:

a. Passive solar heating technology;

b. Solar protection technology;

c. Evaporative cooling technology;

d. Cooling through natural and mechanical ventilation technology;

etc (Fig3-6,3-7,3-8,3-9,3-10,3-11)[1].

1) Passive solar heating technology

The term “passive” relates to building envelope design, whereas”active” heating relates to the use of any external energy source, other than solar thermal energy, used for building air conditioning or even solar heating [2]. Passive solar heating has been used extensively throughout history with great success [3].

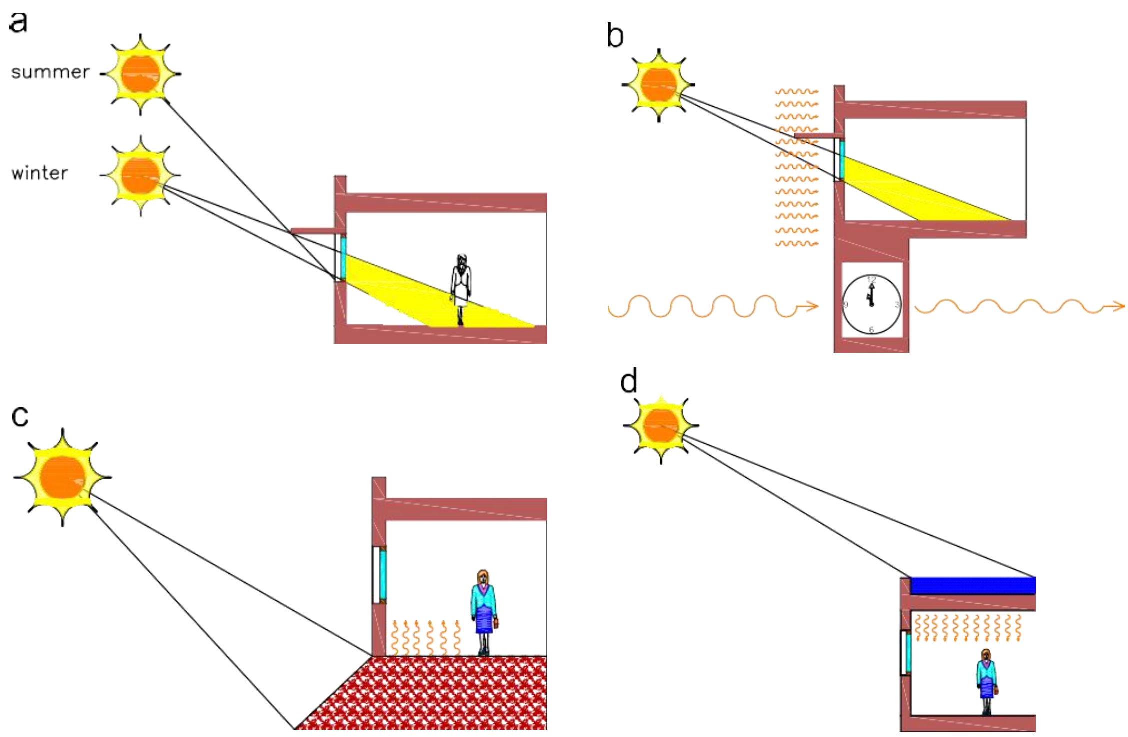


Fig. 3-6. Passive solar heating techniques (I):

(a) The awning as a passive solar heating solution; (b) representation of radiation capture through openings for a space in the passive solar heating zone. The clock indicates the possible phase difference of up to 11h for heat transmission; (c) representation of capacitive flooring for a space in the passive solar heating zone and (d) roof pond for a space in the passive solar heating zone.

Fig3-6(a) shows an example of an awning in warm areas that allows solar radiation capture during the winter season and limiting this process during the summer. Thus, the building openings can facilitate the entry of solar radiation for storage in the building flooring that can be returned with a time phase difference.

Energy storage in the walls, ceilings and floors of buildings can be enhanced by encapsulating suitable phase change materials within these surfaces to directly capture solar energy and increase human comfort by decreasing the frequency of internal air temperature shifts and maintaining a temperature nearer the desired temperature for a longer period of time [4]. (Fig3-6(b)).

Capacitive flooring (Fig3-6(c)) and roofs (Fig3-6(d)) become charged with heat energy from solar radiation and later emit this energy to their connected spaces[5-7].For roofs, the most frequent case is that of the water roof (Fig3-6(d)), which modulates the interior temperature. This solution is generally adopted in hotels in warm areas that place swimming pools on rooftops to assist with climatisation of the top story of the building, among other reasons. To a lesser degree, green roofs also help to reduce the energy demand.

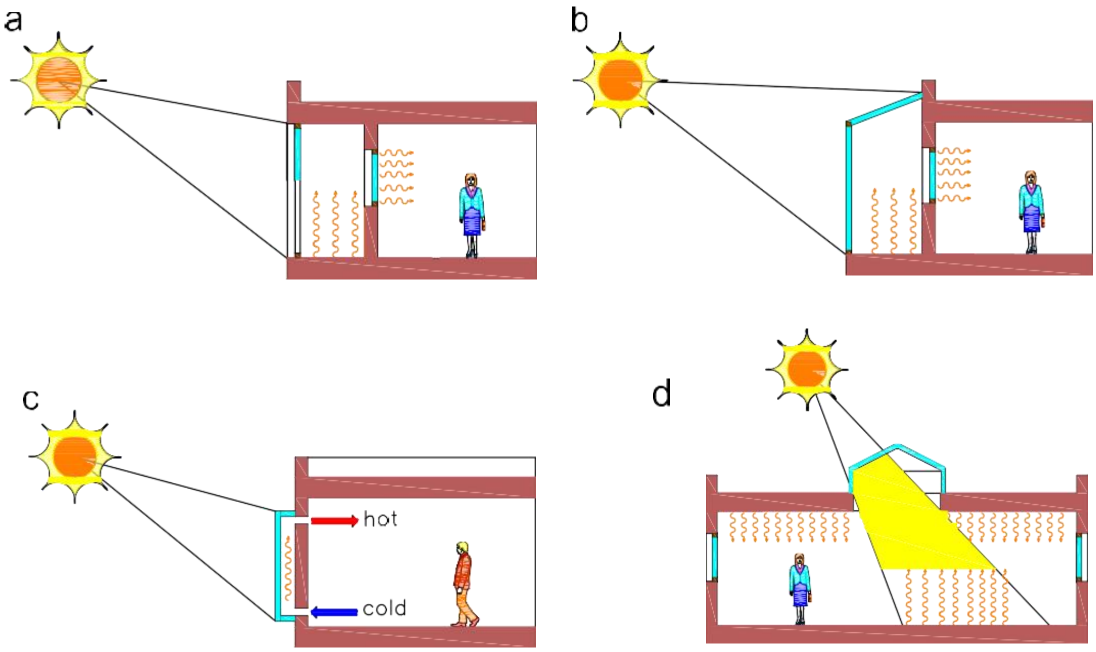


Fig. 3-7. Passive solar heating techniques (II):

(a) Representation of a glassed-in gallery for a space in the passive solar heating zone; (b) representation of an adjoined greenhouse for an area in the passive solar heating zone;(c) representation of a Trombe wall for an area in the passive solar heating zone; and (d) representation of roof openings for a space in the passive solar heating zone.

Glassed-in galleries (Fig3-7(a)) are architectural elements that capture solar radiation during cold seasons and maintain the energy by using enclosures, floors and generally capacitive materials, which later return the energy with a phase difference.

The adjoined green- house (Fig3-7(b)) is a very similar Passive energy-saving strategy that captures even more solar radiation because of its transparent top surface. In significantly colder areas, the greenhouse strategy is more appropriate than the previous strategy. Another very similar strategy is the Trombe wall (Fig3-7(c)). Roof openings are other elements that allow the entry of solar radiation to facilitate the accumulation of heat energy in capacitive materials. Examples include skylights that cover patios adjacent to living spaces (Fig3-7(d)). These living spaces are favoured by the heat provided by solar radiation, which accumulates in the patio. In warmer months, these openings must be covered to avoid excessive radiation. This strategy is very common in Southern Spain [2].

2) Solar protection technology

This area corresponds to temperature values of 20℃ or higher. In this case, Passive energy-saving technology attempt to avoid heat gains through solar radiation and avoid temperature increases to remain in the comfort zone. Protection is focused on all building openings but can also be generally applied to the building envelope. Solar protection can be implemented naturally such as the use of trees with deciduous leaves (Fig3-8(a)) or through architectural elements such as pergolas with deciduous vegetation (Fig3-8(b)), porches (Fig3-8(c)), awnings (Fig3-8(a)) and finally interior store (Fig3-8(d)) and exterior blinds (Fig3-8(d)) and exterior slats (Fig3-8(e)).

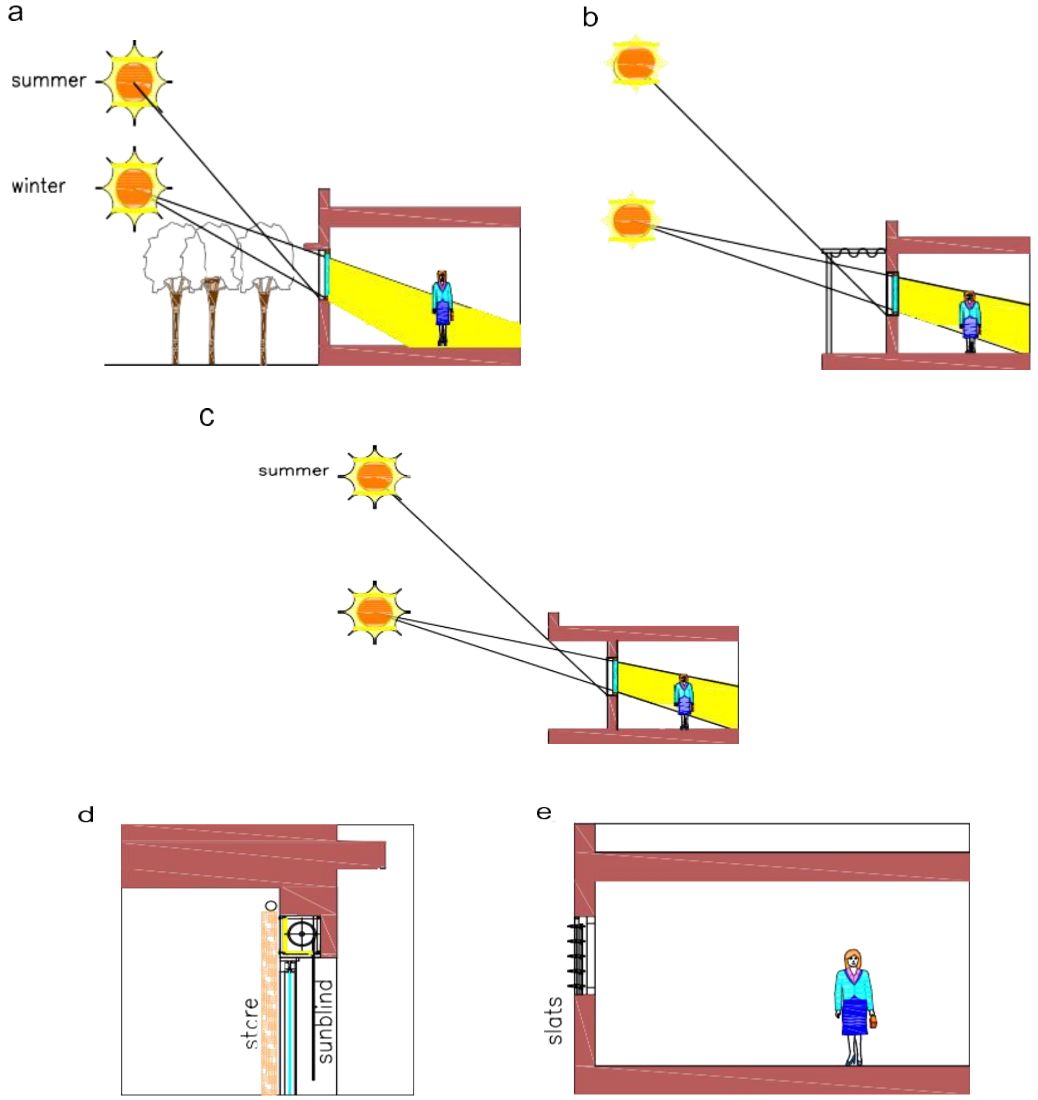


Fig. 3-8. Solar protection techniques (I)

(a) Solar protection mediated by deciduous vegetation; (b) pergola with deciduous vegetation canopy-mediated solar protection;(c) porch as a solar protection strategy(d) sunblind (outside) and store (inside); and (e) horizontal slats.

3) Evaporative cooling technology

This technology corresponds to temperatures between 20℃ and 40.5℃ and a dotted line that extends from the intersection of 25.5℃ and 75% relative humidity through the intersection at 38.5℃ and 20% relative humidity to a third intersection at 40.5℃

and 10% relative humidity. This technology is very advisable in dry and arid climates. It aims to achieve comfort by reducing the temperature through water evaporation while simultaneously increasing the relative humidity. Humidification can be achieved using exterior vegetation (Fig3-9(a)), water (ponds or fountains; Fig3-9(c)), buried pipes that are one-third-filled with water (Fig3-9(d)), patios complemented by the presence of water and vegetation that help to reduce the temperature and increase the relative humidity by conducting an evapotranspiration process (Fig3-9(b)), vegetative cover (Fig3-9(b)), the spraying of water on the roof (Fig3-9(c)), the spraying of water indoors to reduce the temperature of the overhead air (Fig3-9(d)), and the production of air circulation through convection.

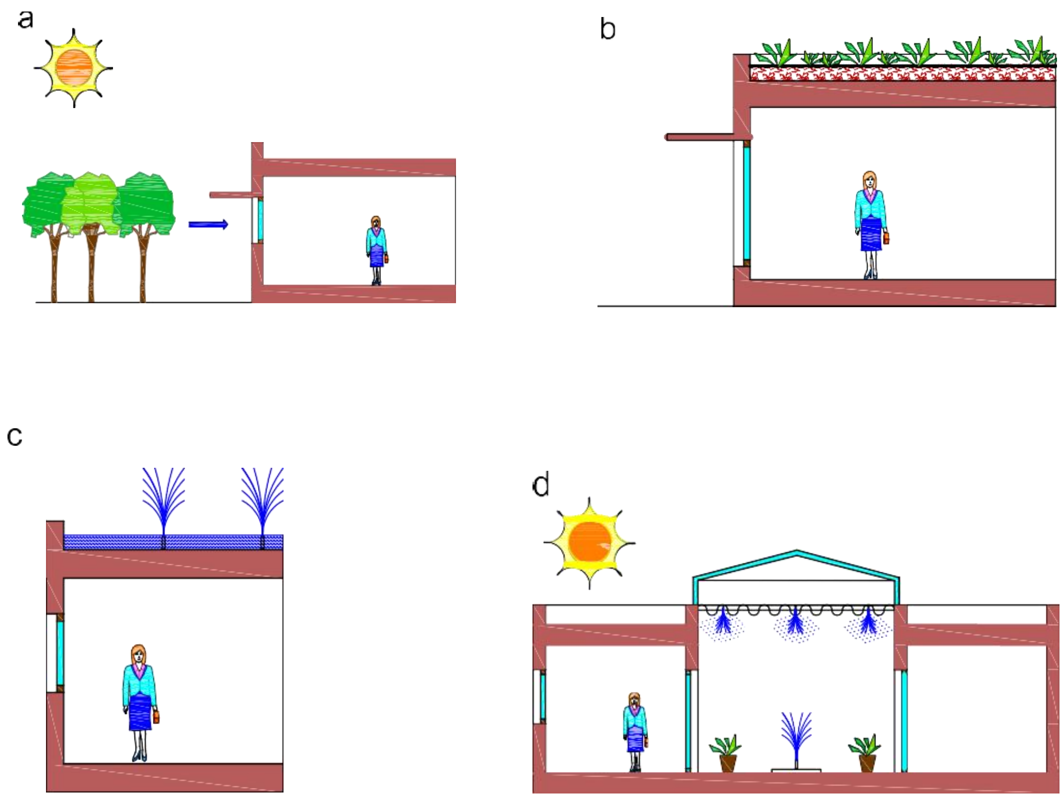


Fig. 3-9. Evaporative cooling techniques (II)

(a) Exterior vegetation for evaporative cooling; (b) roof vegetation for evaporative cooling; (b)(c) roof watering for evaporative cooling; and (d) interior watering for evaporative cooling.

4) Cooling through natural and mechanical ventilation technology

This technology is bound by temperature values between 20℃ and 31.5℃, relative humidity between 95% and 20% and a dotted line that extends from an intersection at 31.5℃ and 50% relative humidity to another intersection at 26.5℃ and 95% relative humidity. A greater thermal sensation is achieved while the indoor air is simultaneously cleaned. This can be achieved naturally using cross-ventilation from north to south facades or dominant winds (Fig3-10(a)), the chimney effect (Fig3-10(b)), a solar chamber (Fig3-10(c)), subterranean ventilation (Fig3-10(d)), wind towers (Fig3-11(e)), evaporative towers (Fig3-11(f)), vertical spaces within a building (Fig3-11(g)) or patios (Fig3-11(h)). Additionally, this effect can be achieved mechanically using fans or blowers.

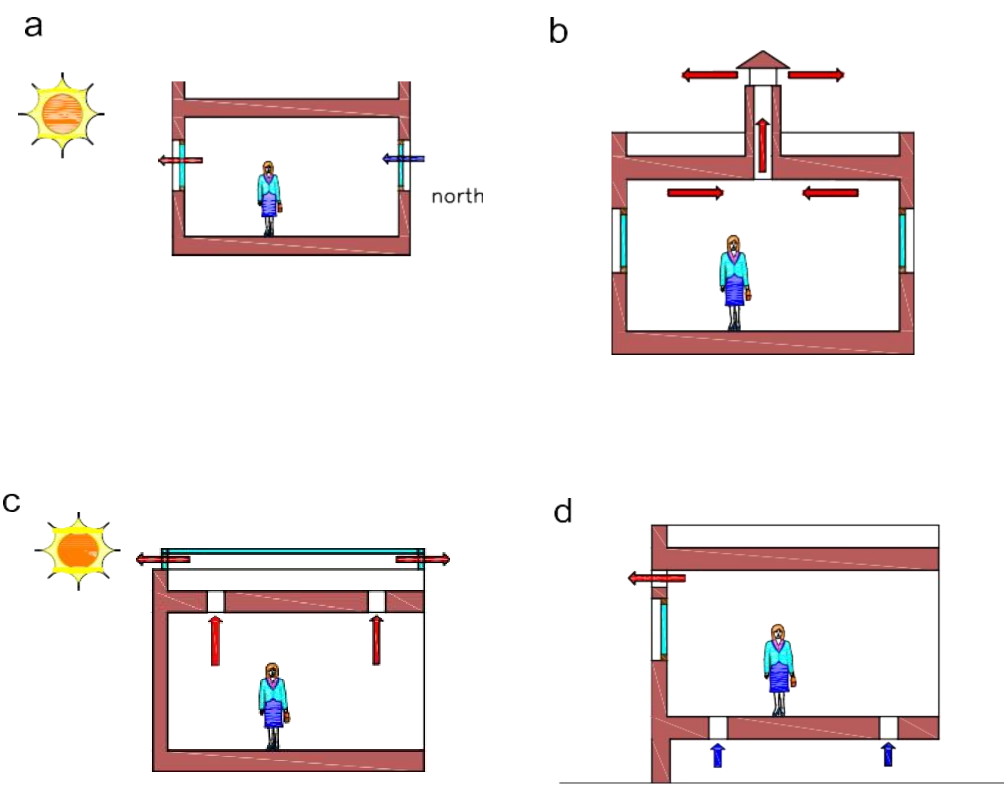


Fig.3-10. Natural and mechanical cooling ventilation techniques (I)

(a) Cross-ventilation in a north-south direction; (b) chimney effect; (c) solar chamber; (d) subterranean ventilation;

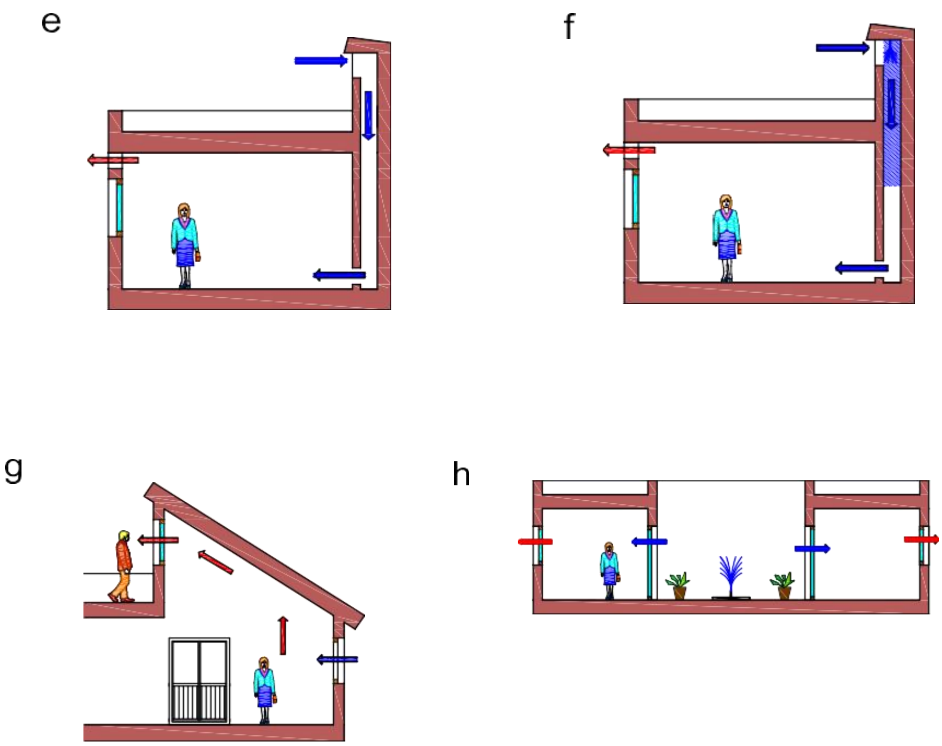


Fig.3-11. Natural and mechanical cooling ventilation techniques(II)

(e) wind tower; (f) evaporative tower; (g) vertical spaces within a building; and (h) patio as a natural ventilation-mediated cooling solution.

Passive energy-saving architecture attempts to analyse traditional architecture based on the climate and culture of a place and to study the architectural and construction solutions [8]. They have experienced a slow evolution during which it has gained social, cultural, religious, economic, technological and climatic knowledge related to particular places to yield quite singular architectural designs [9-11]. This type of architecture adapts to the climate of the place without using additional devices that consume energy and leave an ecological footprint [12-30]. Table3-2 summarizes some examples of adapting the strategies for passive energy-saving architecture in current architecture; these examples are sorted by year to show the low evolution that has taken on this topic over time[1].

These studies optimized the thermal properties of buildings from a passive design perspective at low cost, yet they generally focus on a single aspect or a small group of aspects, such as external walls or windows, rather than presenting a comprehensive approach. The theories tend to emphasize the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with architectural design, which is what makes “Green Buildings” become a holistic ecological technology . In the current moment, the existing research is far from attaining this goal.

The process of green building design requires the project team to constantly consider the building performance in terms of the building envelope, orientation, shading and natural ventilation together with energy efficient systems and equipment. Less resources are necessary for a major impact on these aspects if the initiatives are taken from the earliest stages of the design, and the energy saving research should be combined with the local natural climatic conditions and resources, especially in rural areas.

Table 3-2 Adapting the strategies of passive energy-saving architecture

Year	Country	Proposal or research aim
1981	France	For several projects in Languedoc (France) utilize site and climate to decrease heat losses and optimize direct gains
1981	Spain	This project plans to save up to 60% office building energy demand by means of passive techniques and reduce conventional energy consumption to only 10–20% of the usual consumption with active solar devices: solar thermal collectors for heating and cooling and photovoltaic panels for electricity climate, a two storey greenhouse will be presented
1983	Saudi Arabia	This paper determines the natural resources and passive energy-saving roots of the traditional settlements in an important area future direction for meaningful architecture in this region
1985	Iraq	Roofs of such souqs that exist in Iraq have both fallen and disappeared completely or been replaced by inappropriate shabby materials like corrugated iron.
1985	Italy	In order to conserve the novel concept of the souq, the study is a passive energy-saving approach to the provision or a comfortable environment both in summer and winter.They present the evolution or the passive energy-saving architecture according to a specific cultural and climatic context to propose a framework for the future orientation
1994	Iran	She focuses the research in the “wind towers” in Iran, country with a desert climate (torrid heat during the day, cold at night)
1994	Italy	Analyze the passive architecture of the different countries of Europe. They give a prospective on the practice of building solar design in the Europe
1994	countrie s Belgium	The main purposes to be pursued in the climatic conception of commercial buildings are to reduce heat loads, to allow good exploitation of natural light and ventilation in order to be able to avoid or reduce the use of air-conditioning
1996	Italy	The highlight that Knowing and utilizing natural sources of heating and cooling, the elements of microclimate, of vegetation, of natural convection of air, the heat insulation or storage properties of materials, is just as essential for a correct design as being able to use shapes and materials correctly to ensure structural stability, to withstand the effects of earthquakes, or to design spaces which are

		functional to their intended uses, in addition to being pleasant to the eye
1998	UK	It is highlighted how passive energy-saving architecture represents the use of materials and constructive elements under sustainability criteria. It represents the optimum-energy generation concept by means of the active or passive accumulation
2001	Nigeria	This paper examines and analyses the climate of Nigeria with respect to building design parameters: temperature, relative humidity, air velocity and solar radiation, with a view to providing design recommendations for the achievement of physiological comfort
2004	Spain	They made a review of passive energy-saving strategies in the Spanish popular constructions. The aim is to translate some of the passive energy-saving
2005	Mexico	A case study is presented in which a rammed earth settlement built in this industrial era by a Mexican community was proved to provide healthy, thermal comfort and social agreeability to users. The need for rehabilitating old constructions in rammed earth follows the results of this study which had focussed on the high levels of well being in indoor spaces built with local clay and traditional techniques
2006	Iraq	They analyze the old builders from this region, as shows that they putted a big effort to create passive passive energy-saving houses that corresponds the negative effects Basrah's macroclimate
2006	Italy	They classify and make a critical analysis in recent sustainable buildings for the Italian alpine region in order to verify the congruence of new typologies and new materials with the local culture and tradition
2006	Mexico	Analyze the passive energy-saving behaviour of traditional architecture for future constructions in Tecozautla (Mexico), located in a hot dry climate where an important number of traditional and historical houses still exist
2006	Egypt	They analyze the main characters of the traditional architecture in the old settlements (Balat, Al Qasr), pointing out both the typological and the technological aspects (local materials and construction processes), focussing on their environmental sustainability (presence of passive energy-saving features, integration into the landscape, minimum waste of resources)
2006	Brazil	The purpose is showing the contribution to the development of a less aggressive architecture, more attentive and integrated to the environment. It presents the architectonic solutions used to adapt his

		buildings to the hot and humid weather of the Amazonian region, by the study of two of his main works, where the use of timber was aesthetic and structurally explored and energy efficiency tools application: direct/indirect gains, thermal mass, convectional loops, sun spaces (atrium case), solar chimney, and synthesis exterior/interior
2009	Algeria	Hey make a comparative analysis between the existing traditional and typical modern housing. Modern house seems inappropriate for a desert climate. Traditional houses are most effective in answering the heat problem in summer
2009	Greece	This study investigated the luminous and thermal environments in a chosen building
2009	Cuba	which was designed and constructed, based on accumulated knowledge and past experiences to provide environmental delight to the occupants measurements and the survey, some preliminary design recommendations for residential buildings in Old Havana are provided
2009	Canada	This paper suggests that the integration of passive strategies can provide an intensive sensory and mental pleasure while optimizing both the buildings' and the occupants' performances
2010	India	They identified many house typologies in a vernacular settlement (Marikal). This study calls for a code of practice balancing modernization with the vernacular
2011	Greece	Characterize this architecture for integrating in the refurbishment of existing buildings or the design of new ones in traditional surroundings
2011	India	solar passive features related to building form and orientation, envelope design, shading, use of natural ventilation, internal space arrangements and activities of the habitants are explained for all the climatic zone of the region (North-Eastern India)
2011	Argentina	The aim is to offer a brief description of the most significant architectural types Cuyo Region (Argentina), providing examples of promotion, conservation, and re-development. Earthen architecture, when compared with other modern building methods and techniques, has outstanding qualities from a sustainable point of view
2011	Spain	This paper draws attention to the significant diversity among the typologies of rammed earth buildings constructed in Spain in recent

3.3 Framework

A framework is prepared in accordance with the above (Fig 3-12). The first step is the selection of a specific research area, followed by a thorough investigation of this area, including the geography, climate, local resources, and problems to be solved. The Prototype Theory and Bioscience Theory are the basic principles for this approach. Passive energy-saving technologies which are appropriate for this area are simulated using Weather Tool. This is followed by the construction of a specific RBU for the area consisting of " main functional prototype + tunnel space + composite envelope + site terrain" in accordance with the above analysis. The RBU is then extended to build a design menu for different requirements. Finally, this menu offers reference drawings, technical guidance and policy support for any new design and renovation in this rural area. Farmers can even choose a drawing appropriate for their requirements directly from the menu. Factories can produce prefabricated building components and modules for the rapid construction of rural residences according to this menu. The further development and application of this menu will increase the level of optimization and this will make the menu more effective. This framework is highlighted for application in rural construction in China.

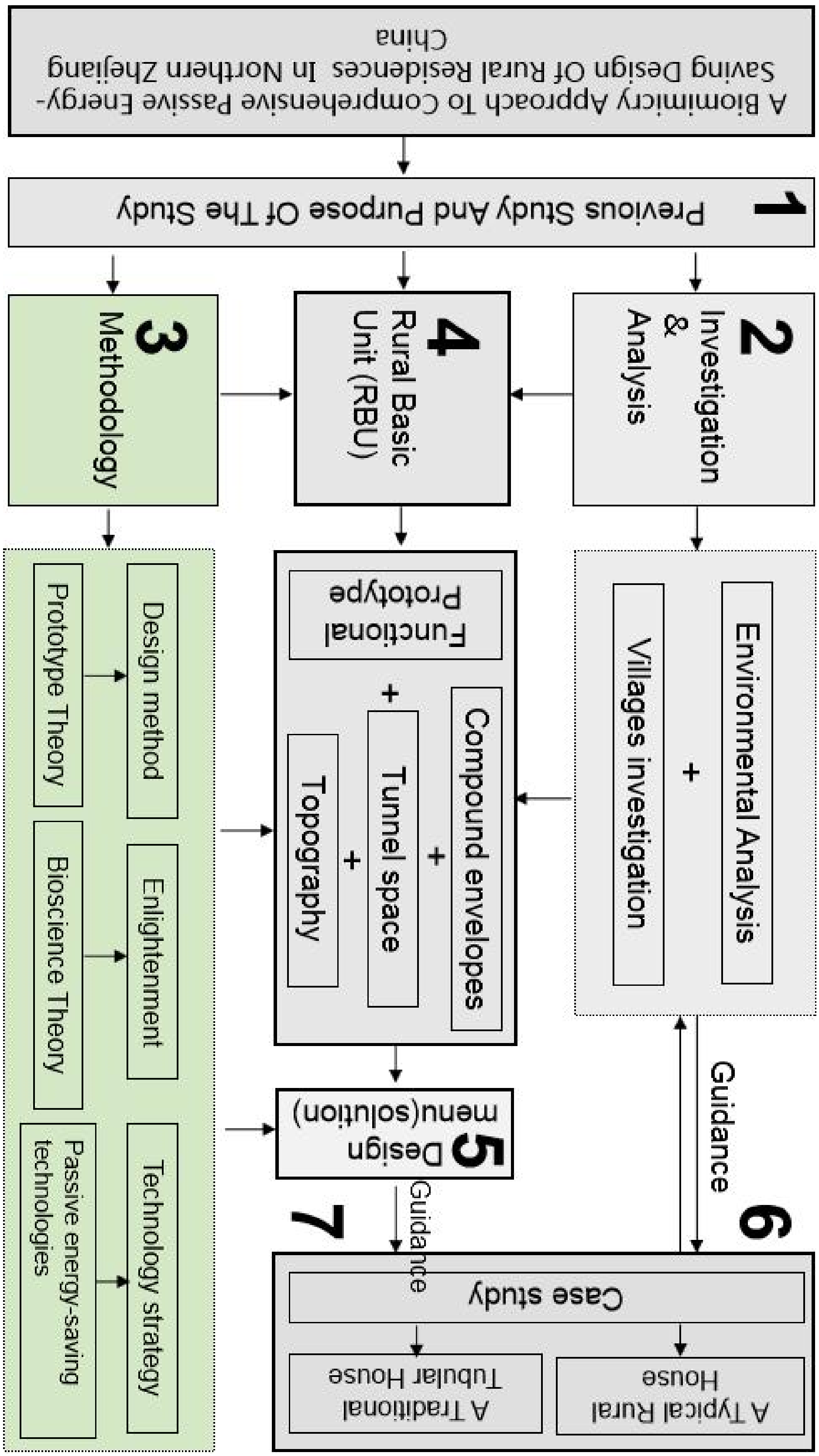


Fig. 3-12. Theories and Framework

References

[1]. Hirth L. The market value of variable renewables. Energy Economics. 2013;38:218-36.

[2]. Chan H-Y, Riffat SB, Zhu J. Review of passive solar heating and cooling technologies. Renew Sustain Energy Rev 2010;14(2):781-9.

[3]. Butti K, Perlin J. A golden thread: 2500 years of solar architecture and technology. New York: Cheshire Books; 1980.

[4]. Khudhair AM, Farid MM. A review on energy conservation in building applications with thermal storage by latent heat using phase change materials. Energy Convers Manag 2004;45(2):263 – 75.

[5]. Neila F, Bedoya C, Acha C, Olivieri F, Barbero M. The ecological roofts of third generation: an new constructive material [las cubiertas ecológicas de tercera generación: Un nuevo material constructivo]. Inf Constr 2008;60(511):15 – 24

[6]. Foglia L. Inhabiting the ground: definitional elements for a sustainable model of the ground use for residential purpose. In: PLEA 2011-architecture and sustainable development, conference proceedings of the 27th international conference on passive and low energy architecture; 2011. p. 151 – 5.

[7]. Labs K. Regional analysis of ground and above-ground climate conclusion. Undergr Space 1982;7(1):37 – 65

[8]. Pereira I, Aleixo J, Correia Guedes M. Low cost sustainable building solutions: case studies: Angola and guinea-bissau. In: PLEA 2011 - architecture and sustainable development, conference proceedings of the 27th international conference on passive and low energy architecture; 2011. p. 381-7.

[9]. Balbo R. Shape, culture and environment: a lesson of urban design from Dakhleh oasis, Egypt. In: PLEA 2006 – the 23th conference on passive and low energy architecture. Geneva, Switzerland: Universite de Geneve, vol. 2; 2006. p. 49-55.

[10]. Almusaed A, Almssad A. Bioclimatic interpretation over vernacular houses from historical city Basrah. In: PLEA 2006: 23rd international conference on passive and low energy architecture. Universite de Geneve; 2006. p. 87-91.

[11]. Indraganti M. Understanding the climate sensitive architecture of Marikal, a village in Telangana region in Andhra Pradesh, India. Build Environ 2010;45 (12):2709-22.

[12]. Butera FM. Energy and buildings in mediterranean countries: present and future. Renew Energy 1994;5(5-8):942-9

[13]. Fezzioui N, Khoukhi M, Dahou Z, Aït-Mokhtar K, Larbi S. Bioclimatic architec-

tural design of ksar de kenadza: South-west area of algeria hot and dry climate. Archit Sci Rev 2009;52(3):221-8.

[14]. Oikonomou A, Bougiatioti F. Architectural structure and environmental performance of the traditional buildings in Florina, {NW} greece. Build Environ 2011;46 (3):669-89.

[15]. Singh MK, Mahapatra S, Atreya S. Solar passive features in vernacular architecture of north-east india. Solar Energy 2011;85(9):2011-22.

[16]. Gallo C. Initiatives in the field of university education for bioclimatic architecture: world renewable energy congress–{IV} Denver, Colorado, USA, June 15-21, 1996. Renew Energy 1996;8(1-4):315-8.

[17]. Rassam SM. The thermal concept of the traditional arab market place– analysis and proposals. In: Bowen A, editor. Passive and low energy ecotechniques. Mexico City: Pergamon; 1985. p. 653-63.

[18]. Los S, Pulitzer N. Italian regional monograph. In: Bowen A, editor. Passive and low energy ecotechniques. Mexico City: Pergamon; 1985. p. 492-516

[19]. Gallo C. Bioclimatic architecture. Renew Energy 1994;5(5-8):1021-7.

[20]. Sala M, Nelli L. Bioclimatic architecture in Europe; an handbook in advanced technology. Renew Energy 1994;5(5-8):1173-7

[21]. Albatici R. Local tradition and bioclimatic architecture in the Italian alpine region. In: PLEA 2006 – 23rd international conference on passive and low energy architecture, conference proceedings; 2006. p. I107-12.

[22]. Manríquez R, Fuentes V, Guerrero L. Traditional architecture and bioclimatic

design case of study: Tecozautla, hgo. Mexico. In: PLEA 2006 – 23rd international conference on passive and low energy architecture, conference proceedings;2006. p. II899-904.

[23]. Jones DL. Architecture and the environment: bioclimatic building design. New York: Overlook Pr; 1998.

[24]. Gerber M. Towards a bioclimatic architecture; 1981. p. 669-71.

[25]. Gerber M. Bioclimatic architecture under mediterranean climate; 1983. p. 1-7.

[26]. Dobrinova A. Old bulgarian architecture an university of solar energy application. In:

Goswami D, Zhao Y, editors. Proceedings of ISES world congress 2007 (vols. I-V). Springer, Berlin, Heidelberg; 2009. p. 3054-8.

[27]. de Filippi F. Traditional architecture in the Dakhleh oasis, Egypt: space, form and building systems. PLEA Proc 2006;1:43-8.

[28]. Sakarellou-Tousi N, Lau B. The vernacular dwellings of mount Pelion in Greece.

[29]. Ajibola K.Design for comfort in Nigeria a bioclimatic approach. Renew Energy 2001;23(1):57-76.

[30]. Bosqued A, Palero S, San Juan C, Soutullo S, Enríquez R, Ferrer J, Martí J, et al. Arfrisol, bio climatic architecture and solar cooling project. In: Proceedings of PLEA2006 passive and low energy architecture, Geneva, Switzerland.

[31]. Francisco Manzano-Agugliaro. Review of bio climatic architecture strategies for achieving thermal comfort.Renewable and Sustainable Energy Reviews;2015.736-755

Chapter 4

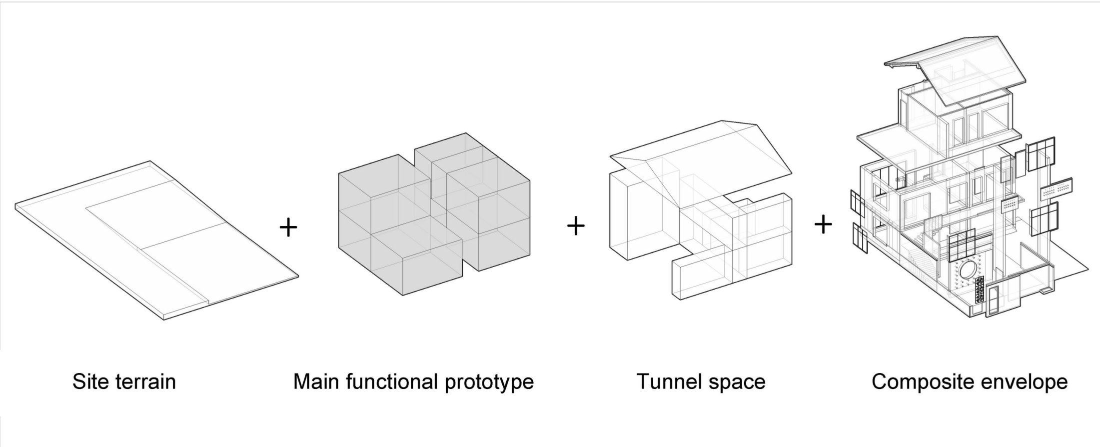
ESTABLISH AND ANALYSIS OF BASIC UNIT OF RURAL RESIDENCE IN NORTHERN ZHEJIANG

CHAPTER FOUR: ESTABLISH AND ANALYSIS OF BASIC UNIT OF RURAL RESIDENCE IN NORTHERN ZHEJIANG

4.1 Introduction

The principle of prototype emphasizes the continuity of form that maintains the essence of things. The "prototype" in the article is different from the type, but closer to the concept of the "model". It is a highly de-characterized object to ensure the high generality of its research's value. It aims to study the integrated application of traditional passive technology in rural houses.

In the previous study, based on the enlightenment of cytology, we had established a research system of "basic rural unit" of house with "basic functional prototype+ compound envelopes + tunnel space + topography". This chapter will focus on the establishment of basic functional prototype, and analyze its advantages and activity mechanisms from low-carbon perspective. Firstly we had built a main functional prototype according to the survey data in Chapter 2. Then different functions are arranged on the plan, which can be changed into different forms according to different needs in five aspects. Meanwhile, vertical and horizontal tunnel spaces are set up in the prototype design according to the greenhouse effect, chimney effect, roof effect, etc.



4.2. Main Functional Prototype

4.2.1 Basic cube Prototype

The investigations (Table 3-5) show that the majority of rural residences in Northern Zhejiang have a gross floor area of 90-120m2 and a total building area of 200-250m2. Among the 80 housing units assessed, 95% were found to have two or three storey, while 5% are bungalows comprising one storey. Thus, these rural residences generally had two storey with five residents (two adults, two seniors and a child) (Table3-5). Then, a cube of side 9.9 meters is selected as the basic model for testing the new approach, as showed in Fig.4-1. The building gross floor area is 98m2 (9.9m x 9.9m), and total building area is 180-250 m2 with 1-3 yards. The overall per capita living space for these houses was 39.2 m2, which is the same as the average per capita residential living area of rural China in 2010 (Annual Report on China Building Energy Efficiency, 2012). All of the first , second floor and roof are 3.3 meters high. This main functional prototype may not be the optimal in terms of meeting all the basic needs, since the most suitable aspect ratio for ventilation in this area is 1:1.2, but it was highly representative and variable, as showed in Fig.4-2.

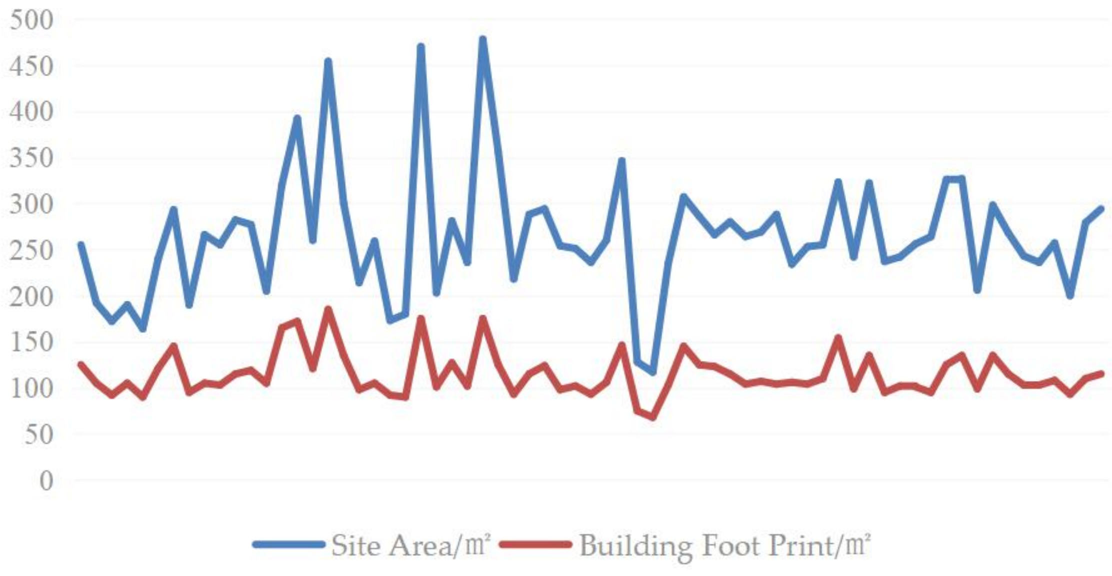


Table 4-1. Site Area and Building footprint for 106 households in CuoDun Village in North Zhejiang

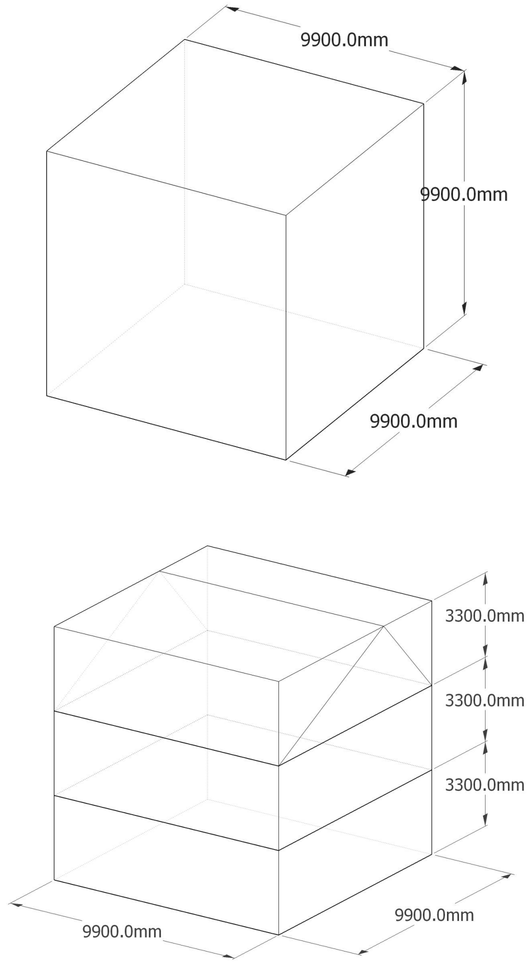


Fig. 4-1. The basic cube prototype

1) Optimum building shape coefficient:

A cube as the basic prototype model has the smallest building shape coefficient and the smallest heat loss from external walls. Commencing with a cube as the prototype, and making small changes according to different demands is the most efficient approach.

2) Suitable width and depth:

The 9.9m depth helps with ventilation and sunshine. The depth of the building will not affect the sunshine requirements below 14 meters. The relevant studies have shown that: in the case of one-way natural ventilation, the depth of space should not bigger than 6m; and in the case of two-way natural ventilation, the depth of case should smaller than 12m [Source: Lin Pingying, Research on Ecological Design Strategies for Building Cavities Adapting to Climate Change. Zhejiang University, 2008, P25]. What's more, the layout of the building should be transparent to reduce the resistance of the wind in the flow path.

3) Meet the industrial prefabrication modulus :

The industrialization of construction is a concept that was born with the Western Industrial Revolution. With the rise of the European new construction movement, building components have gradually moved towards marketization and specialization. At present, prefabricated building components, such as walls, bathrooms, kitchens have leaded the mainstream trend in the foreign construction market. In rural construction, the use of modular scales (9.9M, 3.3M) can not only provide convenience for the current construction, but also allow for the possibility of large-scale construction of prefabricated assembly foreseeable.

4) Easy to conversions:

The plane of the residence changes with the base form, sunshine conditions and so on, and a square plane provides the most convenient scenario for change (Fig 4-2).

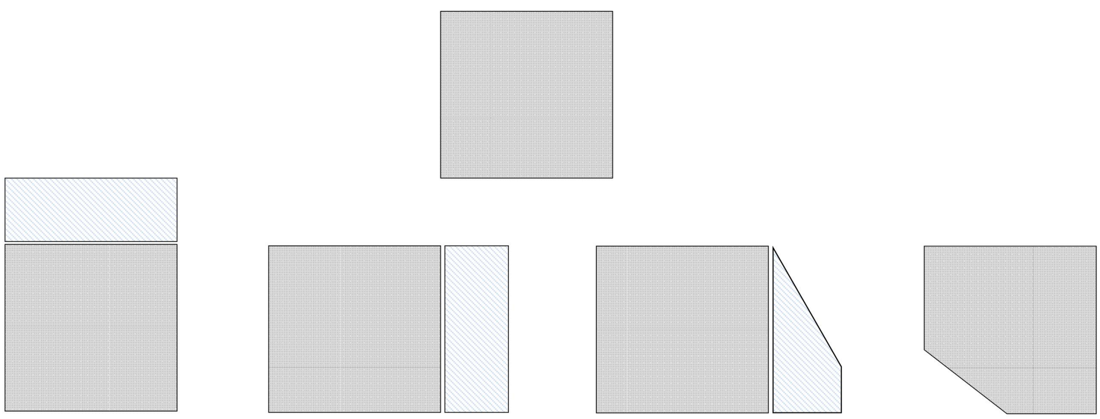


Fig.4-2. From a cube to other forms

4.2.2 Functional plan

The 9.9m are divided into 3.6m, 1.8m and 4.5m from west to east, respectively, and divided into 1.2m, 3.9m, 2.4m and 2.4m from south to north, respectively, according to building modulus and function. Different functions are arranged on the plan in a way that facilitates ventilation and lighting, according to the principles of dynamic and static separation, public and private separation, and clean and dirty separation so on. (Fig. 4-3 and Fig. 4-4)

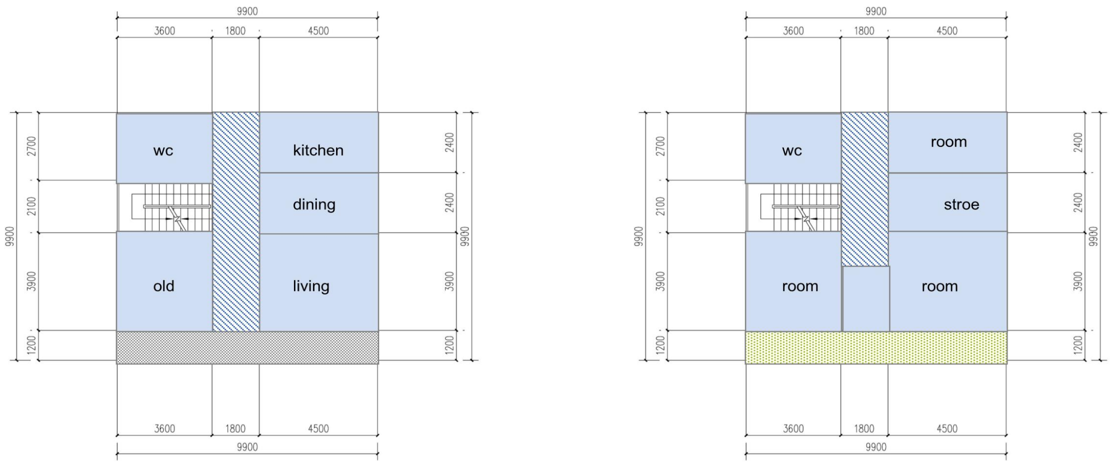


Fig. 4-3 Functional area diagram

Figure 4-4. The first and the second plan

4.3 Functional change

The plan can be changed into different forms according to different functions from the following aspects:

1) A lobby with 1.2m depth:

There is a lobby with 1.2m depth in the south of residence, presenting in the form of sun room or open corridor, according to different needs for living and storage space. In the first floor it can be designed as an integrated space for the elderly ' s room, stairwell, bathroom, kitchen or dining room; in the second floor it can be designed as bedrooms. What's more, it can also play a very important role in regulating sunlight and temperature, as showed in Fig.4-5.

Fig.4-5. First plan from basic one to other change forms

2) A corridor with 1.8m width:

The living room is the most important space for rural residence and rural life. There is a corridor with 1.8m width in the middle of the residence. And it is close to the 4.5M living room, which can provide variable division ways.

The living room, dining room and kitchen are designed in an area of 4.5M*9.9M, ranging from south to north. They can not only be separate but also combined with each other to form different types according to needs. If it is combined with the 1.8M corridor in the middle, it can bring more different forms.(Fig.4-6,4-7)

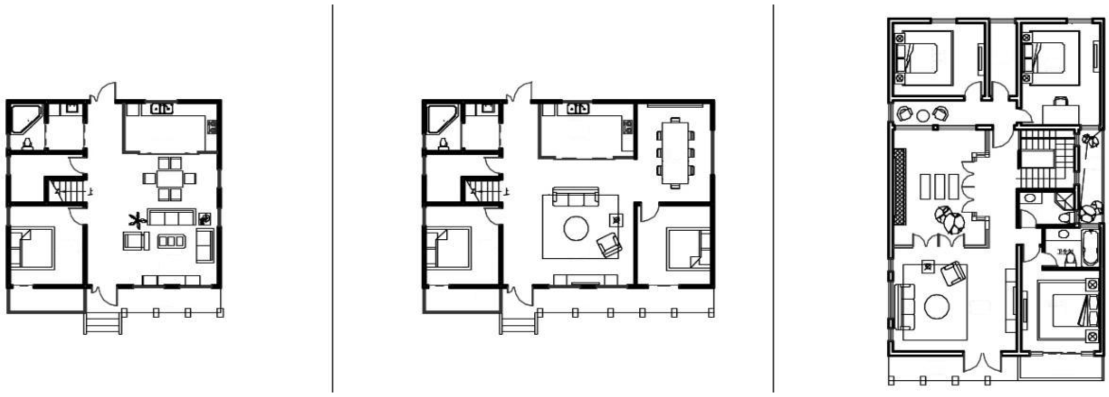


Fig.4-6. First plan developments from basic to advanced

Fig.4-7 Kitchen-dining-living room combinations for different needs

3) The bedrooms:

The bedrooms have different types for hosts, children, and the elderly according to their different habits. When considering the restricted movement of the elderly, and their urgent need for sunshine, the elderly bedrooms are arranged on the south of the first floor, besides the sun room, the south entrance, the stairs and the opened living room. The main bedroom is arranged on the south of the second floor with more area and individual characteristic spaces such as walk-in wardrobe, study room, makeup room, etc.(Fig.4-8)

4) The bathrooms:

The bathroom is arranged on the north of the house, close to the backyard and arranged on both levels. The wet and dry zones are separated to meet the living needs of modern rural life.(Fig.4-8)

5) Storage and agricultural working space:

A crop storage space is on the first level and clothing storage space is on the second level. The front and back yards and roof space act as storage and agricultural working space.(Fig.4-8)

In the traditional rural industry society, the storage and labor space in the residence has a great influence on the layout of rural residences. Thus the storage space of rural residences is also very necessary for modern rural life. A crop storage space is set on the first floor; and a clothes storage space is set on the second floor. Moreover, a spacious front yard drying space can be set in the front or rear yards, and convenient storage space for farm tools in the backyard.(Fig.4-8)

Fig.4-8 Plans of first and second floor

4.4 The tunnel space change

The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. Vertical and horizontal tunnel spaces are set up in the prototype design according to the greenhouse effect, chimney effect, roof effect, etc.(Fig 4-9).

1) Horizontal ventilation corridor

There is a 1.8M*9.9M*3.3M north-south ventilation corridor. When the doors on both sides are opened, a larger value of wind pressure ventilation can be achieved. At the same time, it can be combined with the living room, kitchen, and dining room to make lots of changes.

2) Vertical ventilation corridor

A 2.4M*3.6M*6.6M vertical ventilation corridor is set in combination with the stairs, and the air can quickly be discharged from the house due to the difference of the density. It can be designed combine with the roof. When the wind pressure is insufficient, windows can be opened on the roof, or wind tower wells can be set up to introduce air into the building from a high place, and more wind can be obtained by using a smaller air catching area.

3) Southern sunspace

There is a 1.2M*9.9M*6.6M sunspace in the south. In winter, it uses the greenhouse effect to have a positive energy-saving effect on building heating. In summer, it can be fully opened. The entrance is set in the middle, and it can make the combination of single-story sun rooms, full-height sun rooms, colonnades and other space forms. It not only meets the thermal comfort and use requirements, but also enriches the facade design and increases the diversity of prototype expansion.

4) Roof ventilation corridor

There is an air compartment of 9.9M*9.9M*3.3M on the top floor, which can be designed to form different types of roofs in combination with local architectural features, topography, and sunshine conditions. For example, traditional rural buildings adopt the form of sloping roofs, forming a triangular cavity on the top of the building, which can effectively keep warm. By controlling the slope of the north-south slope of the roof according to the direct sun angle of the area, the absorbed solar heat can be effectively controlled.

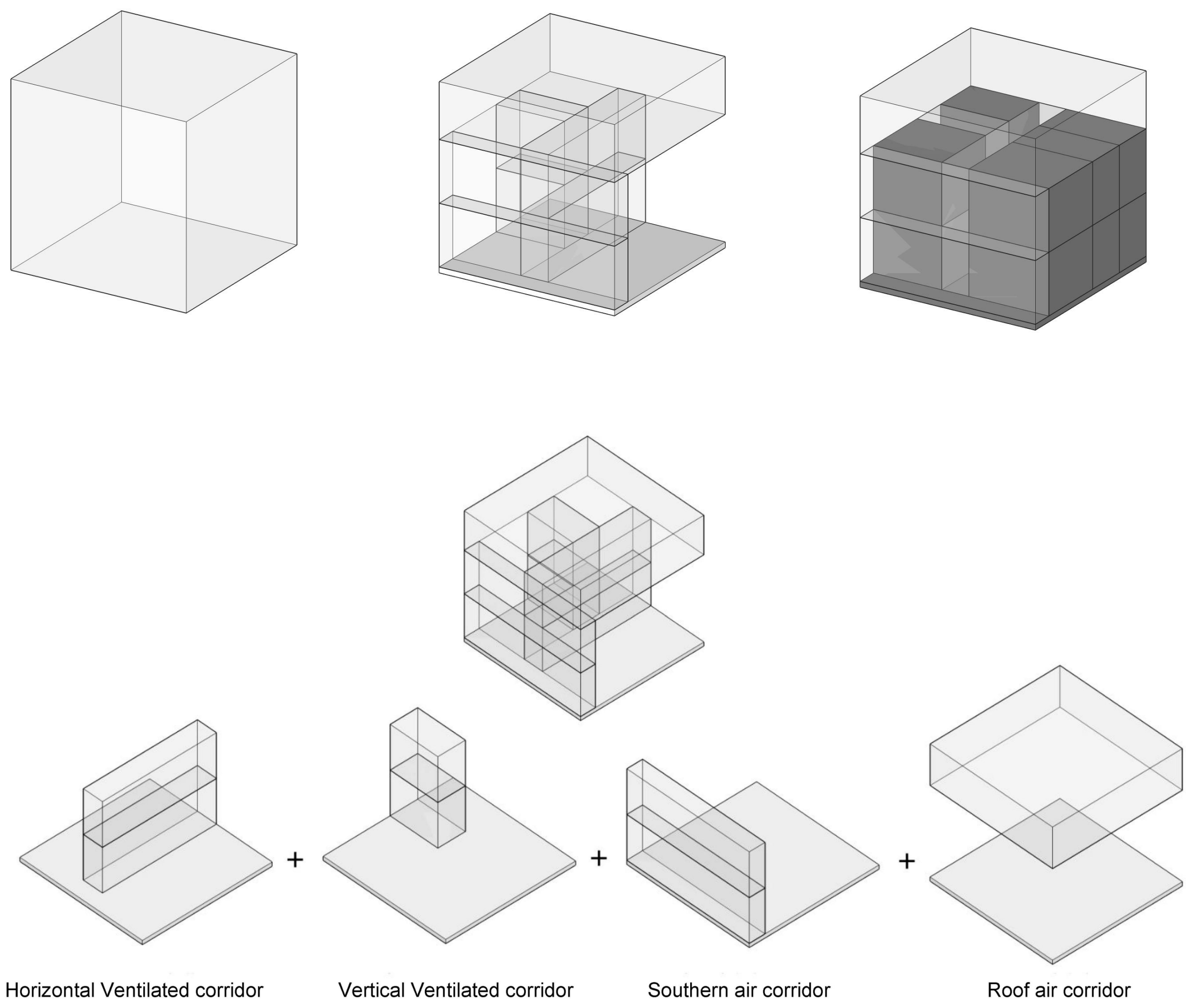


Fig.4-9. The tunnel space

4.5 Summary

The “prototype” does not refer to the analysis and extraction of the characteristics of traditional regional building patterns, but the extraction and abstraction of the inner deep structure of the residential form in northern Zhejiang based on the low-carbon orientation. The main function prototype is extracted from the internal structure of the residential forms on the low carbon orientation, which focus on climate conditions, resources, technological means, lifestyle and economic and cultural factors. This prototype has its own structure system for passive energy-saving technology. Since the "prototype" is discussed in the way of "de-characterization" model, it does not emphasize that it directly acts on the needs of rural life, but retains the maximum variability with a high degree of generality to meet different needs.

In this section firstly we had built a main functional prototype according to the survey data in Chapter 3. It was a cube with 9.9m length, which was highly representative and variable. This main functional prototype may not be the optimal in terms of meeting all the basic needs, but it has the smallest shape coefficient and provides the most convenient scenario for change. Different functions are arranged on the plan in a way that facilitates ventilation and lighting, according to the principles of dynamic and static separation, public and private separation, and clean and dirty separation so on. And The plan can be changed into different forms according to different functions in five aspects:1)A lobby with 1.2m depth; 2)A corridor with 1.8m width; 3)The bedrooms; 4)The bathrooms; 5)Storage and agricultural working space. What’s more, The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. Vertical and horizontal tunnel spaces are set up in the prototype design according to the greenhouse effect, chimney effect, roof effect, etc.

Reference

1. Renewable energy integration scenario in Kyushu, Kyuden Electrical Company. http://www.kyuden.co.jp/effort_renewable-energy_application.

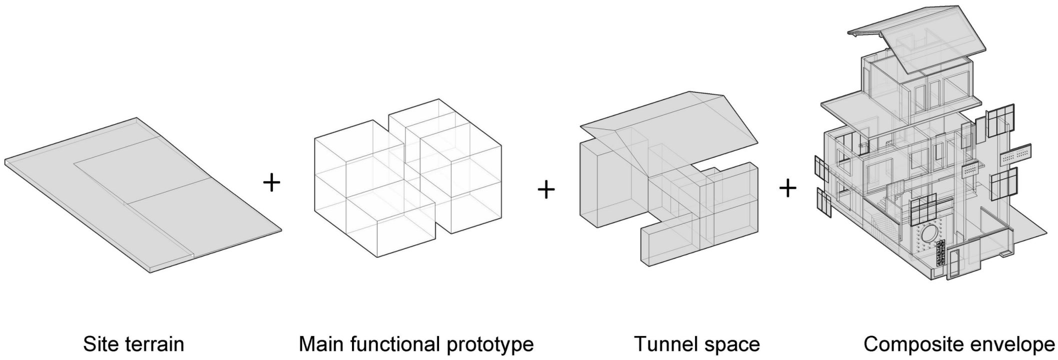
Chapter 5

ANALYSIS OF DESIGN MENU OF RURAL RESIDENCE IN NORTHERN ZHEJIANG

CHAPTER5: ANALYSIS OF DESIGN MENU OF RURAL RESIDENCE IN NORTHERN ZHEJIANG

5.1 Introduction

In modern rural areas, a single design can no longer meet people's diverse needs due to changes of people's lifestyles, economic conditions, and population structure. Therefore, on the basis of the main function prototype, this chapter uses the principle of topology to design a "design menu" of various forms through factors such as cavity space, composite exterior walls, and topography.



5.2 The tunnel space

The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. The architectural form can act as courtyards, ventilation corridors, colonnades and sunlight rooms, roof spaces, shelf spaces, etc.(Fig.5-1)

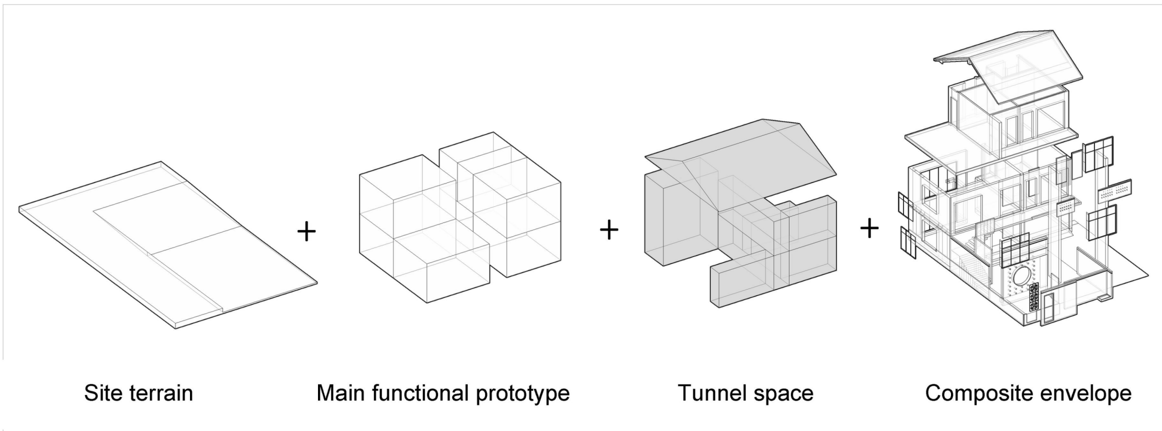


Fig.5-1 The tunnel space composition diagram

5.2.1.The courtyards

1) Front yard

Among them, the front yard is a functional courtyard of a rural house due to its good orientation, sufficient light and easy access. It can be used as a waiting space for indoor and outdoor conversion; it can carry the main outdoor activities of the family (grain drying and drying, clothes washing and drying, etc.); it can also be used as an extended space for family public life, effectively making up for the lack of indoor public space. Due to the diversity and flexibility of the front yard, it is indispensable in high-quality rural life.

2) Back yard

The backyard has become an auxiliary courtyard for rural houses due to its small scale and good privacy. It can be used as an extension of the kitchen function; it can also be used for stacking sundries, breeding poultry, setting up fermentation tanks, etc. The backyard carries the real scene of rural life.

3) Middle yard

The privacy of the middle court is the best. It is a common space form (called patio) in traditional houses. It can not only adjust the indoor and outdoor environment such as lighting and pulling wind; The functional room introduces direct light and air to improve the quality of living.

We can also make full use of the spatial form of the courtyards, according to the spatial content and characteristics of various types of them, which may present a diverse menu of residential residences with rural characteristics.(Fig.5-2)

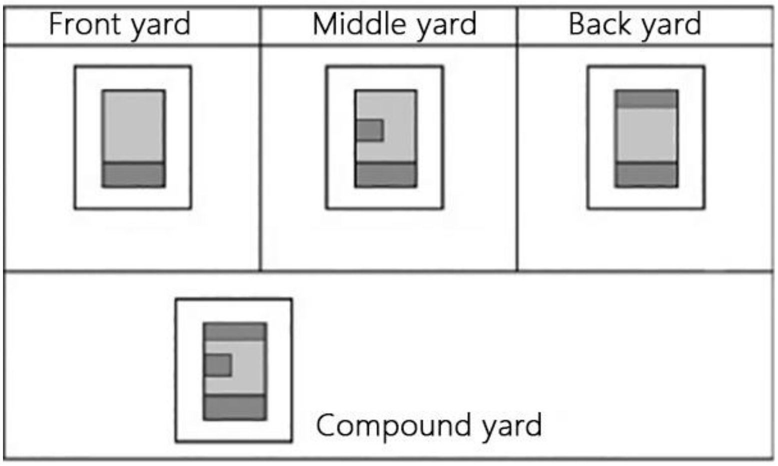


Fig.5-2 (a) Combination of different courtyards

Fig.5-2 (b) Combination of different courtyards

5.2.2.The sunspace

Most traditional residence have sloping roofs. The gray space formed by overhanging cornices and walls is an effective transition space between indoor and outdoor spaces, which plays an important role in shading, sheltering from rain, and blurring boundaries,as showed in Fig. 5-3.

There is a sunspace with 1.2m depth in the south of residence, presenting in the form of sun room or open corridor, according to different needs for living and storage space. What's more, it can also play a very important role in regulating sunlight and temperature, as showed in Fig.4-5.

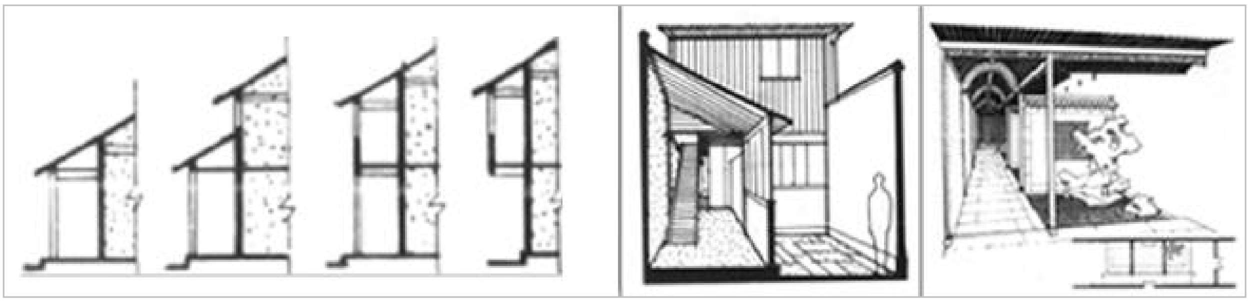


Fig.5-3 Combination of different courtyards

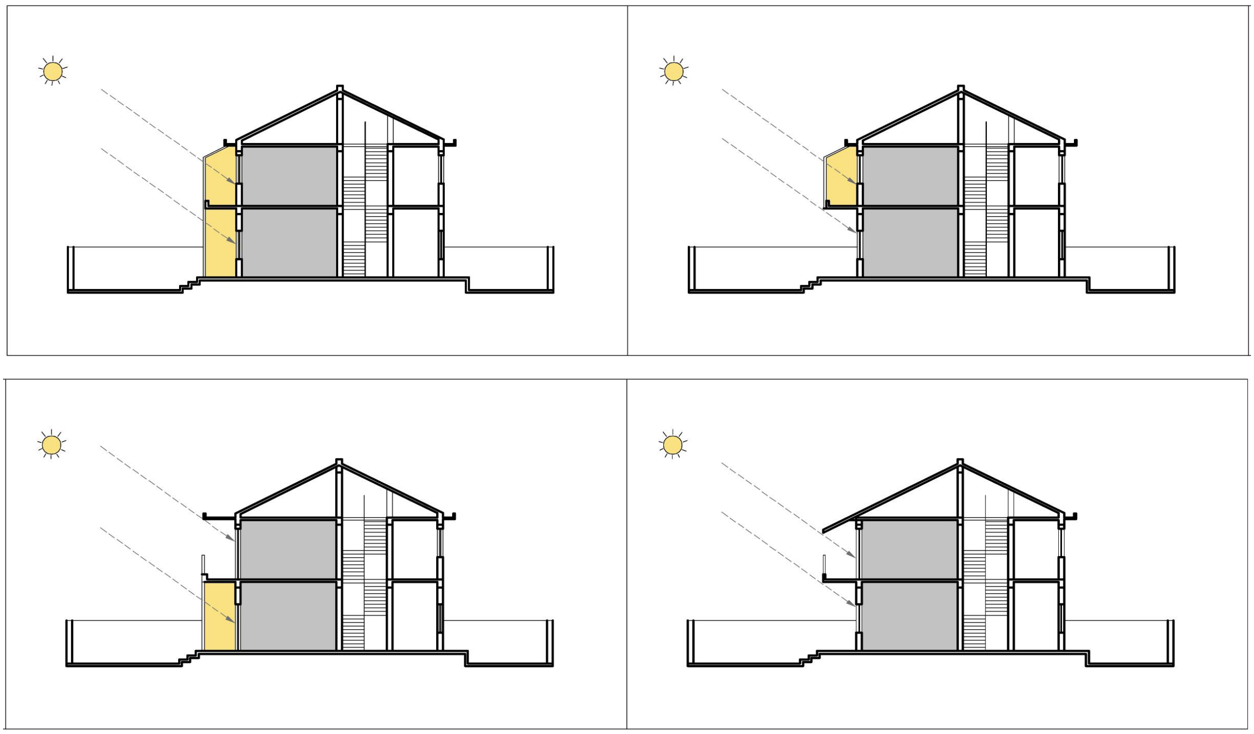


Fig.5-4 Combination of different courtyards

5.2.3.The horizontal ventilation corridor

There is a 1.8M*9.9M*3.3M north-south ventilation corridor. When the doors on both sides are opened, a larger value of wind pressure ventilation can be achieved. At the same time, it can be combined with the living room, kitchen, and dining room to make lots of changes.(Fig.5-5)

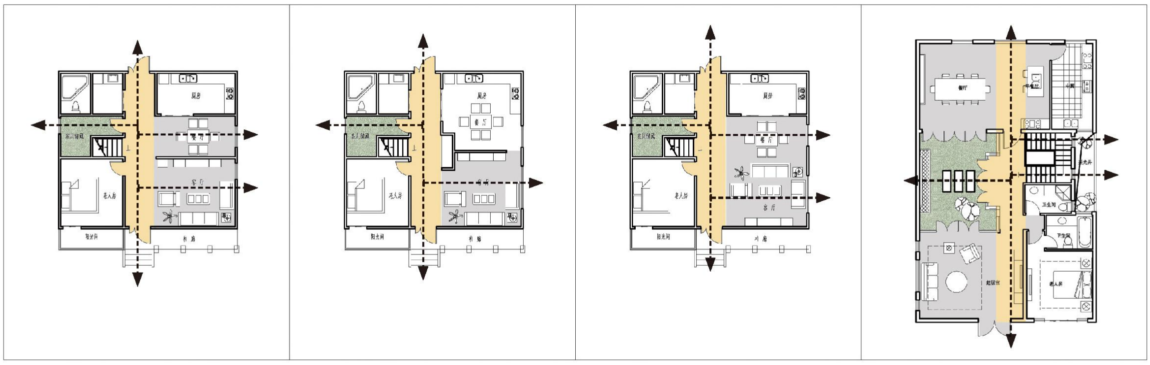


Fig.5-5 Combination of different courtyards

5.2.4.The vertical ventilation corridor

A 2.4M*3.6M*6.6M vertical ventilation corridor is set in combination with the stairs, and the air can quickly be discharged from the house due to the difference of the density. It can be designed combine with the roof. When the wind pressure is insufficient, windows can be opened on the roof, or wind tower wells can be set up to introduce air into the building from a high place, and more wind can be obtained by using a smaller air catching area.

5.2.5.The roof

There is an air compartment of 9.9M*9.9M*3.3M on the top floor, which can be designed to form different types of roofs in combination with local architectural features, topography, and sunshine conditions. For example, traditional rural buildings adopt the form of sloping roofs, forming a triangular cavity on the top of the building, which can effectively keep warm. By controlling the slope of the north-south slope of the roof according to the direct sun angle of the area, the absorbed solar heat can be effectively controlled.

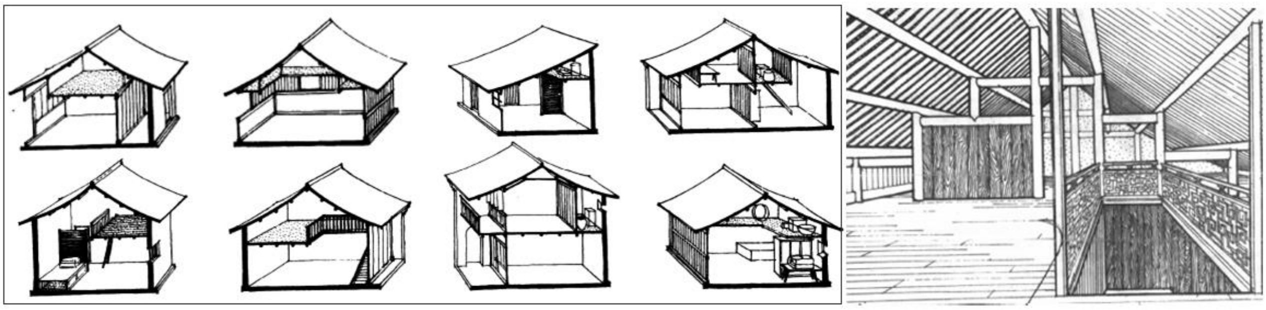


Fig.5-6 Roofs of traditional residences

Fig.5-7 Vertical draft and roof space

5.3 The topography

The construction of the building is a negative process that destroys the natural environment. Therefore, the construction of low-carbon-oriented areas should try to minimize the disturbance to the surrounding natural environment. The topography of the building is like the cell wall, which limits and divides the building space to conform to the site ' s topography, hydrology, soil, vegetation and other natural factors.(Fig. 5-8)

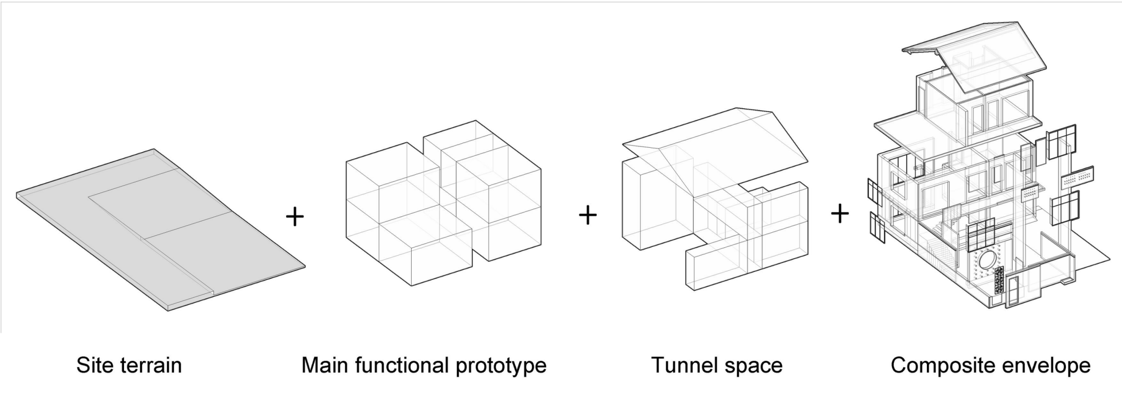


Fig.5-8. The topography composition diagram

1) The Waterfront

Most areas of northern Zhejiang are flat but densely covered with river networks. Therefore, a large number of traditional houses in northern Zhejiang are mostly built near the water. In the waterfront settlements such as Wuzhen village and Xitang village, the residences are multi-faceted by the river, as showed in Fig 5-9.

On the basis of the main function prototype, the relationship between the building and the water can be flexibly handled through design techniques such as hydrophilic platform, waterfront eaves, overhead ground floor, and waterfront cantilever,as showed in Fig 5-10.

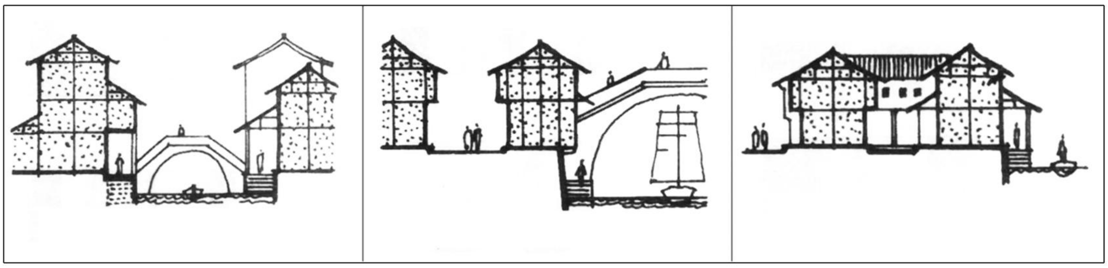


Fig.5-9. Schematic diagram of waterfront residences in Wuzhen village

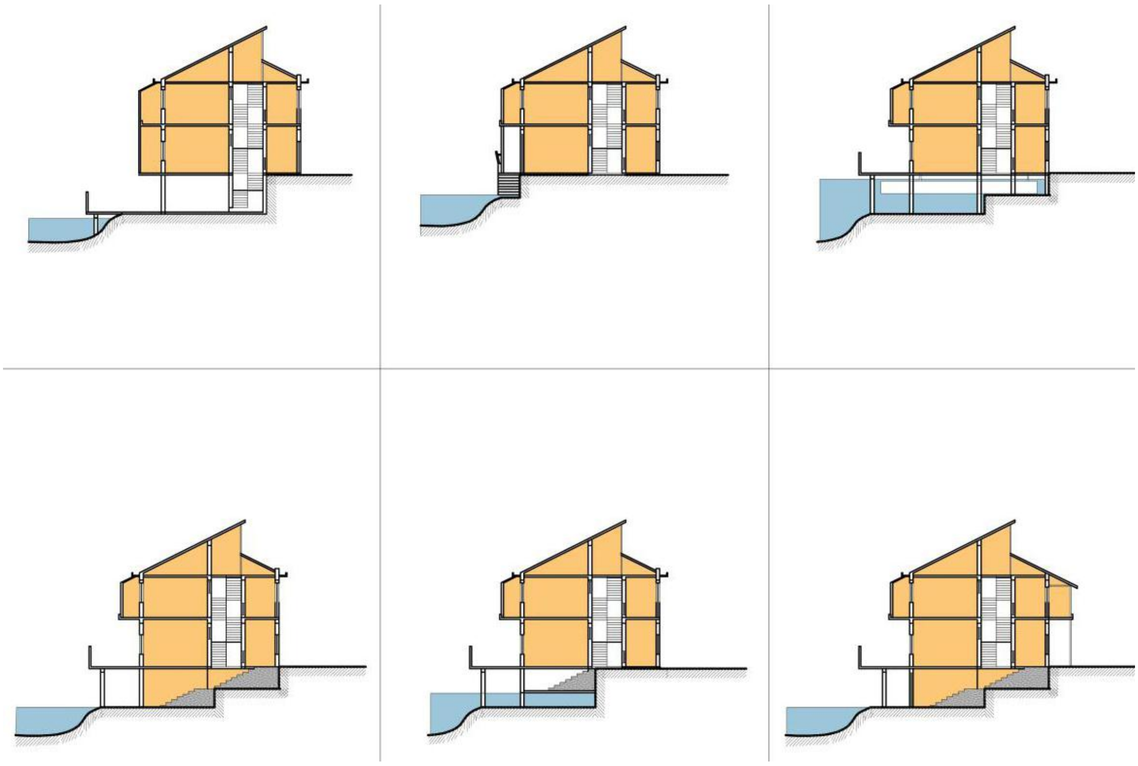


Fig.5-10. Schematic diagram of waterfront residences

2) The hills

In order to adapt to the hill topography of Tianmu Mountain and other topography in northwestern Zhejiang, and to make full use of land resources, different design techniques such as platform construction, excavation, lifting, falling, overhanging, etc, are widely used, making the residences more adaptable and flexible.

For example, using overhead techniques can not only give full play to the functions of residential auxiliary service spaces, but also effectively deal with the rainy and humid climate characteristics of northern Zhejiang, and play the role of moisture prevention, steam isolation, ventilation, and base leveling (Fig.5-11, 5-12).

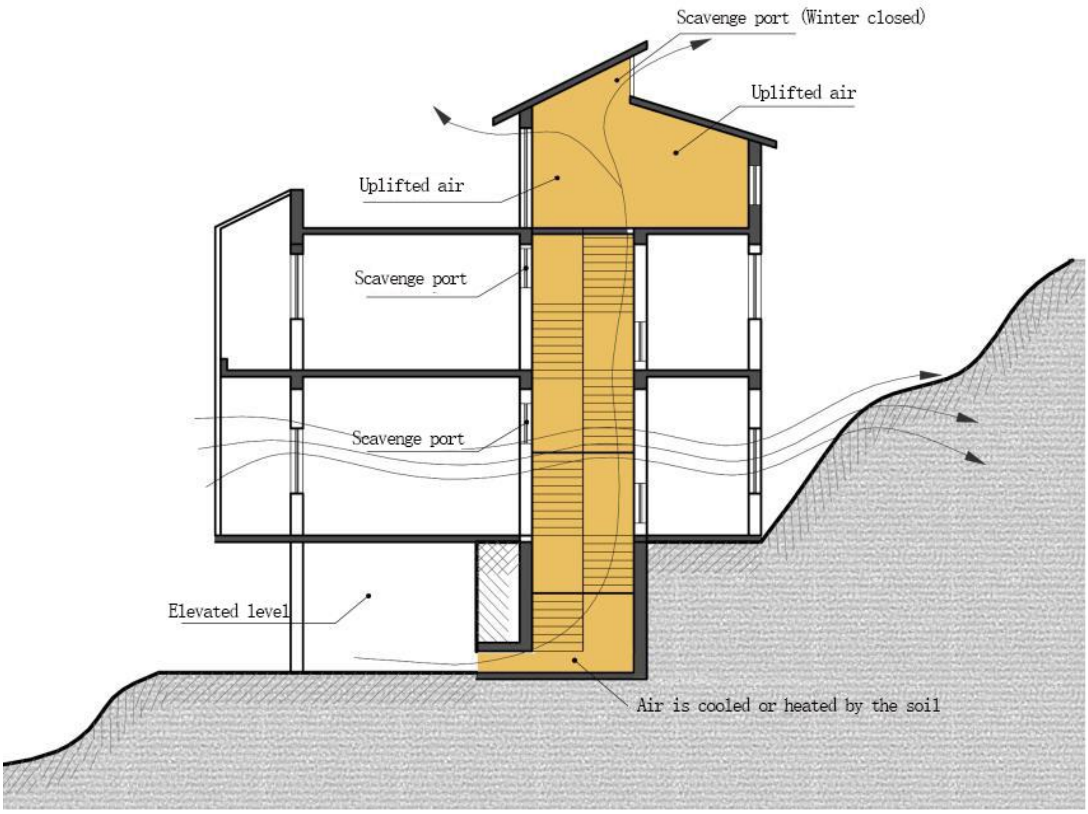


Fig.5-11. Ventilation analysis diagram

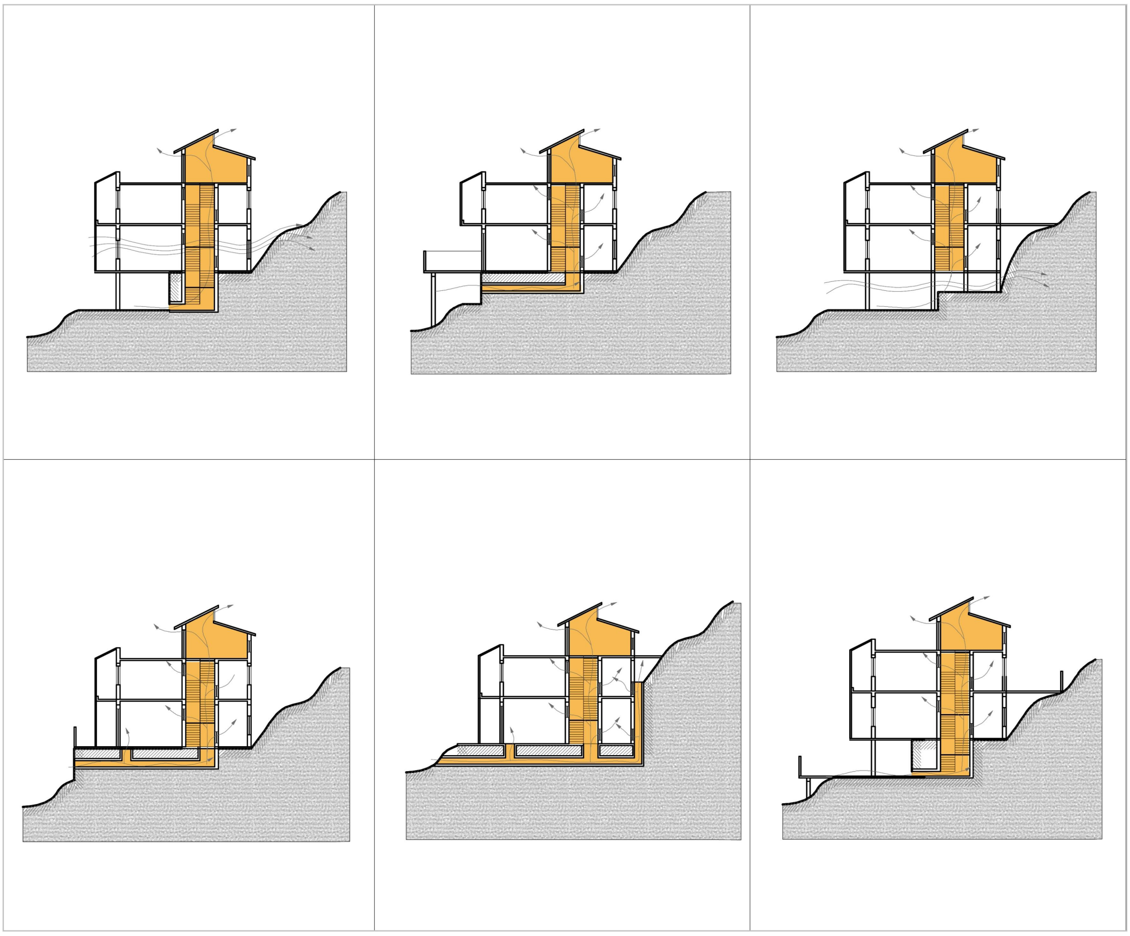


Fig.5-12. Ventilation analysis diagram

5.4 The compound envelopes

Building envelopes, including walls, roofs, floors, doors and windows, etc. In the analysis of the proportion of heat transfer and heat consumption, exterior walls account for 35%-40%, exterior windows 25%-30%, exterior doors 15%-20%, roof 10%, ground 5%, separately. [Li Ling, Li Junge, Du Gaochao. Energy-saving design of the outer protective structure of rural houses in cold areas [J]. Housing Technology, 2006: 2.] (Fig.5-13) .

A good building envelope should have the function of both energy storage and transmission. It is a shelter that can define the privacy of the space, block the wind and rain, and block the noise. Otherwise in different seasons, the demand for building envelopes will be completely opposite. Due to the diversity and variability of requirements, the building envelope can not be only composed of a single structure and material. It should be a composite envelope like the cell membrane. It is a filter and dynamic adjustment device for heat, light, sound, airflow, and energy activities between indoor and outdoor in a building.

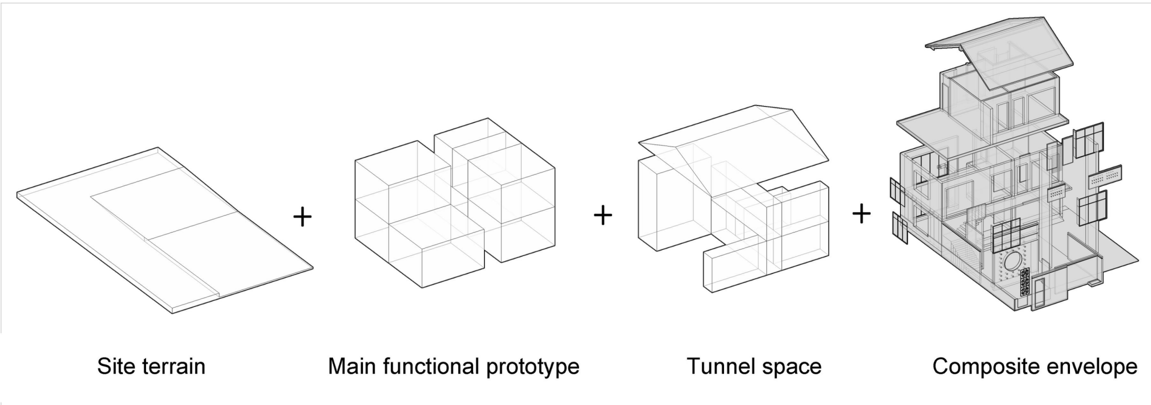


Fig.5-13. The compound envelopes composition diagram

5.4.1 The compound roof

The roof is the covering system of the house, which is a larger intermediary for heat exchange between the building and the outside world.

According to actual needs, different types of roofs such as industrial prefabricated ordinary roofs, heat collector roofs, thin-film battery roofs, daylighting roofs, planted roofs, etc. can be selected. What's more, the combination of several types of modules can simultaneously meet the comprehensive needs of heat preservation, heat collection, heat insulation, and daylighting.(Fig.5-14)

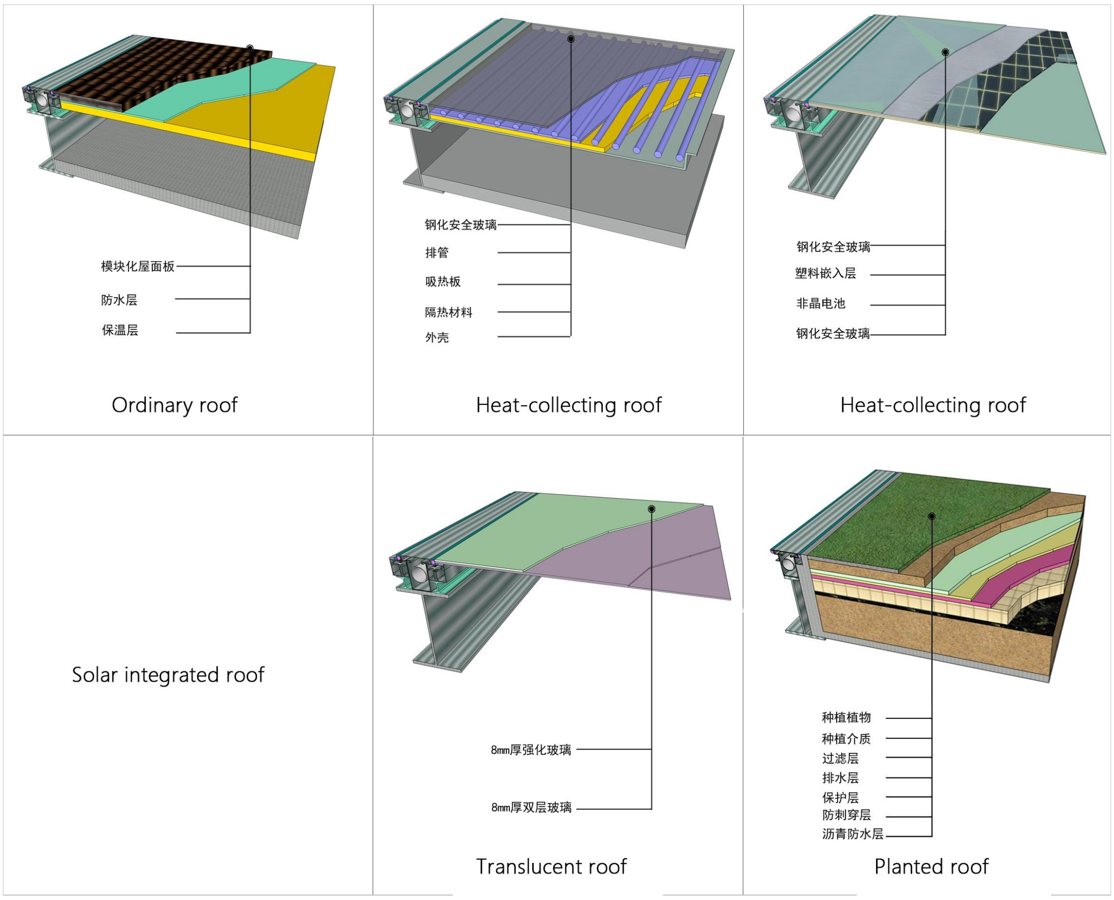


Fig.5-14. Solar integrated roof structure diagram

5.4.2 The compound walls

The wall occupies the majority of the building envelopes and consumes the largest percentage of the heat consumption. It should be designed and studied according to the characteristics of the wall in different directions.

1) The southern wall

The south is usually the largest sun exposure surface of the building. At the same time, attention should be paid to the dynamic blocking of sunlight and the collection and storage of heat. Reflectors, double-layer curtain walls, horizontal louvers, heat storage walls (tromb walls), deep overhangs, etc. can be used for integrated design.

2) The west wall

The west wall is susceptible to a lot of afternoon sun heat in summer, and sun protection measures should be strengthened. Planted roofs with dual heat insulation, vertical sunshade louvers, bamboo composite walls, adjustable reflectors, etc. can be used on the west wall.

3) The eastern and northern wall

The eastern and northern walls can be made of ordinary aerated concrete hollow blocks, double-layer hollow glass, bamboo composite walls, etc., which can meet the needs of thermal insulation.

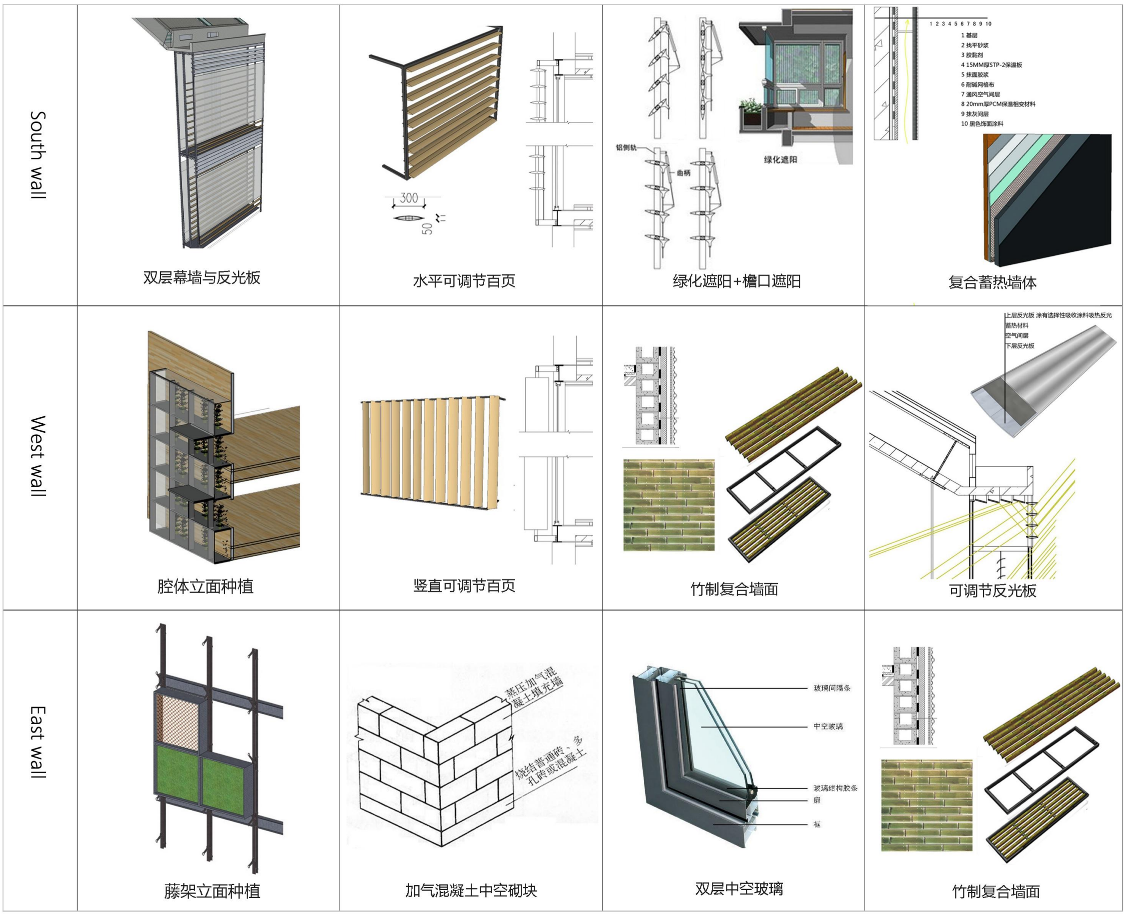


Fig.5-15. The compound walls diagram

5.4.3 The compound ground

1) Overhead floor

Overhead floor is composed of upper floor slab, lower floor slab and air space. The central cavity space can effectively block the conduction of heat insulation, guide airflow and accommodate various pipes and pipelines.(Fig.5-17)

2) Ground source heat pump

The working principle of ground source heat pump is to collect and transform the energy of cold and heat sources such as groundwater, river water or soil to improve the indoor thermal environment of the building. It is a clean renewable energy technology. If it be combined with the floor can use the solar energy accumulated in water and soil sources to adjust the indoor thermal environment effectively.(Fig.5-17)

3) Permeable ground

The permeable ground is paved with gravel, cement, additives, cement and other materials to form a pavement, which can seep rainwater into the ground quickly and collect and supplement groundwater effectively. It can solve the problem of easy accumulation of water on the pavement, and improve the safety and comfort of use.(Fig.5-17)

5.4.4 Local materials

All of the construction of these compound envelopes should be combined with local craft features and local materials in northern Zhejiang(such as bamboo, wood, bamboo board, rammed earth, rubble, etc.), which can play an important role in protecting the rural culture.(Fig.5-16)

Fig.5-16. Local materials in northern Zhejiang

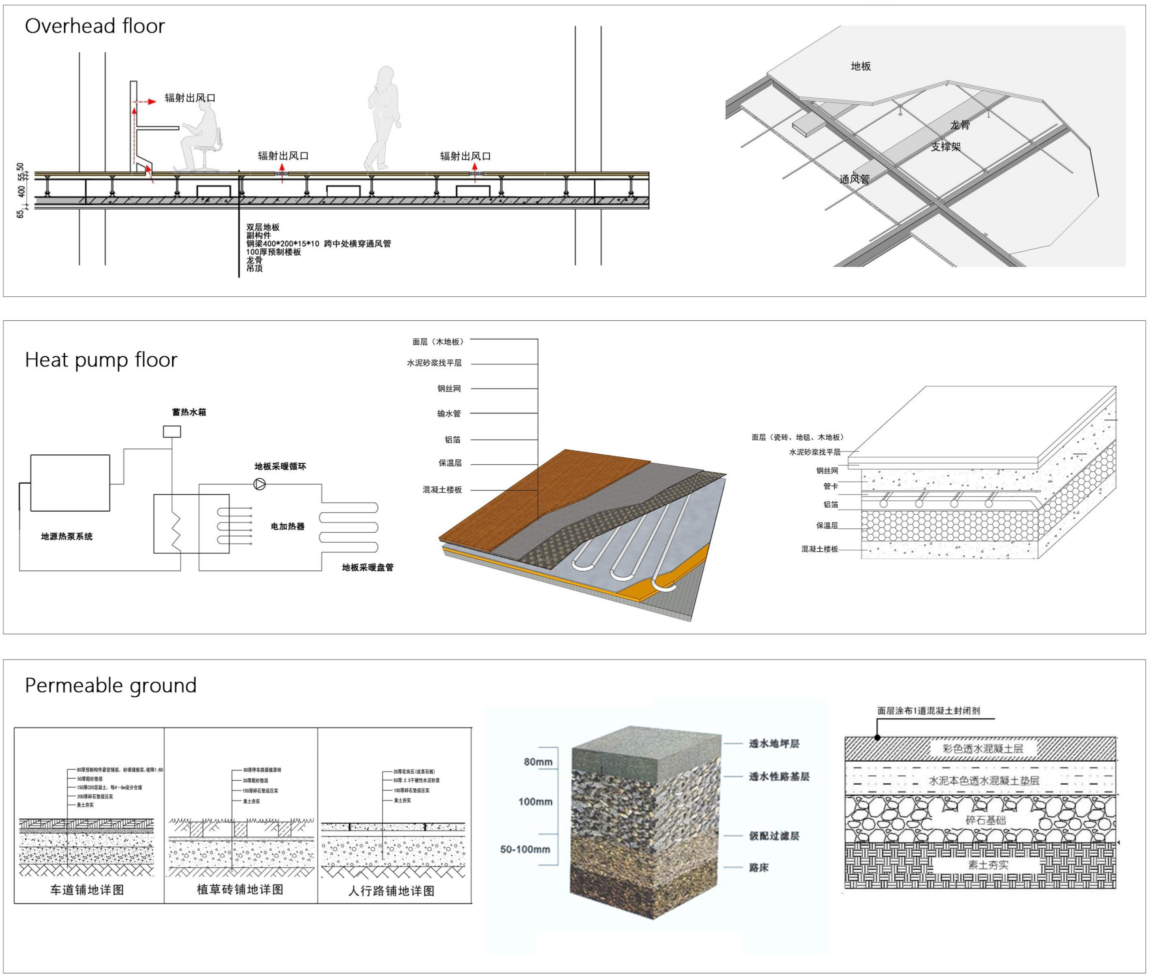


Fig.5-17. The compound ground diagram

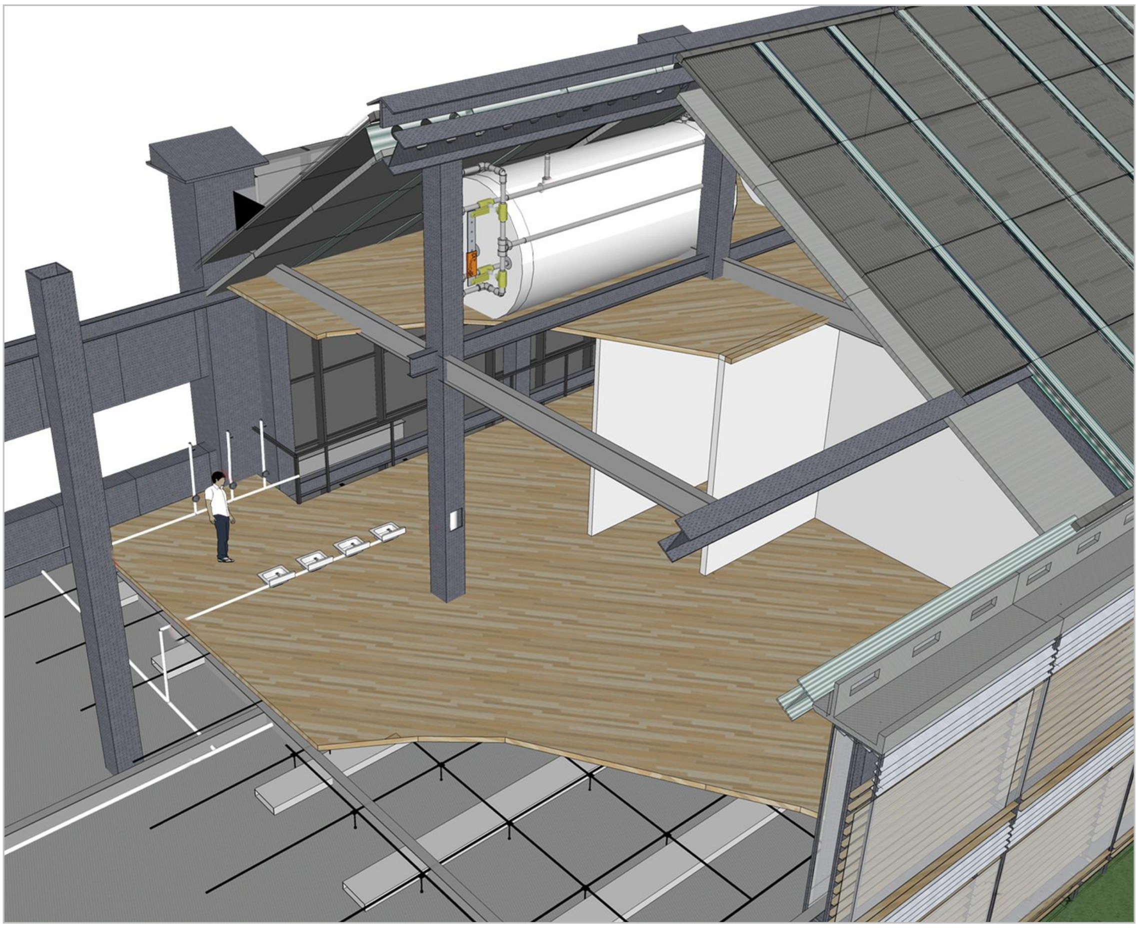


Fig.5-18. The compound envelopes diagram

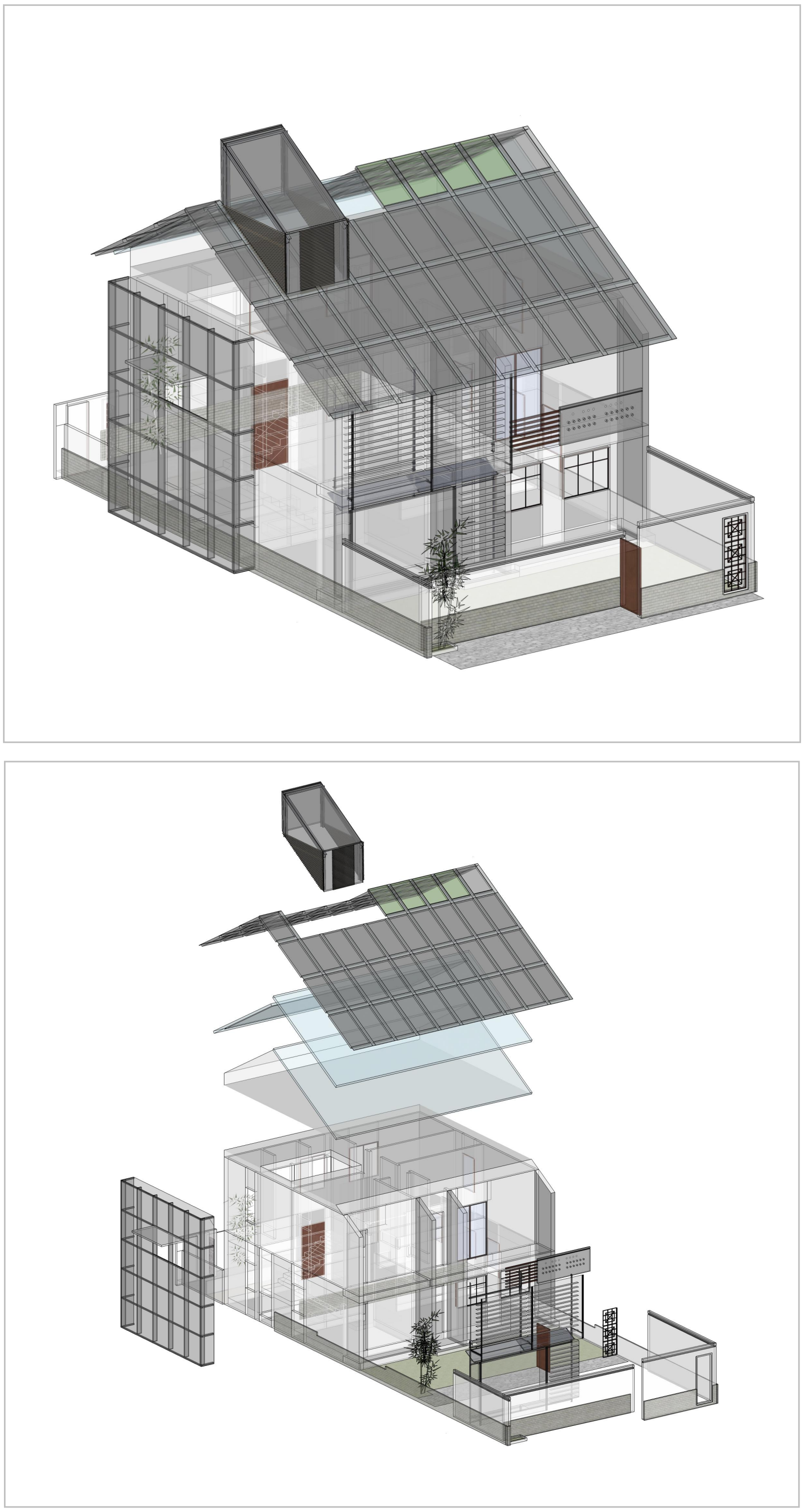


Fig.5-19. The basic unit and compound envelopes

5.5 Extension menu

The characteristics of the yard, sunshine, ventilation, corridor, roof layer, base terrain, tunnel space and composite envelope are applied to construct a menu for the RBU in northern Zhejiang Province. This menu is the basic template for designers to communicate with residents and improve the design, and therefore needs to provide good choices for the practical schemes according to various conditions of the construction.

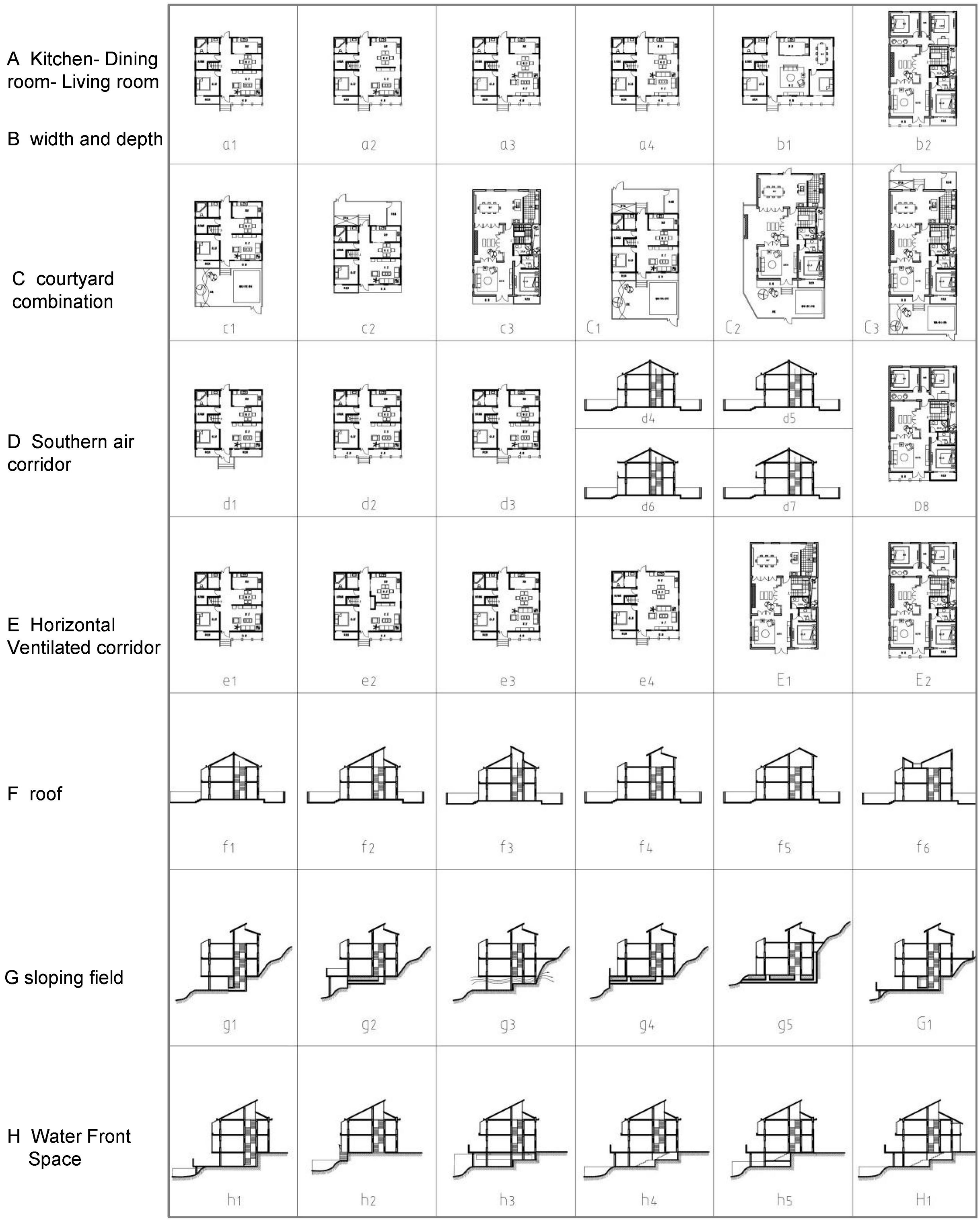


Figure 5-20. The extension design menu

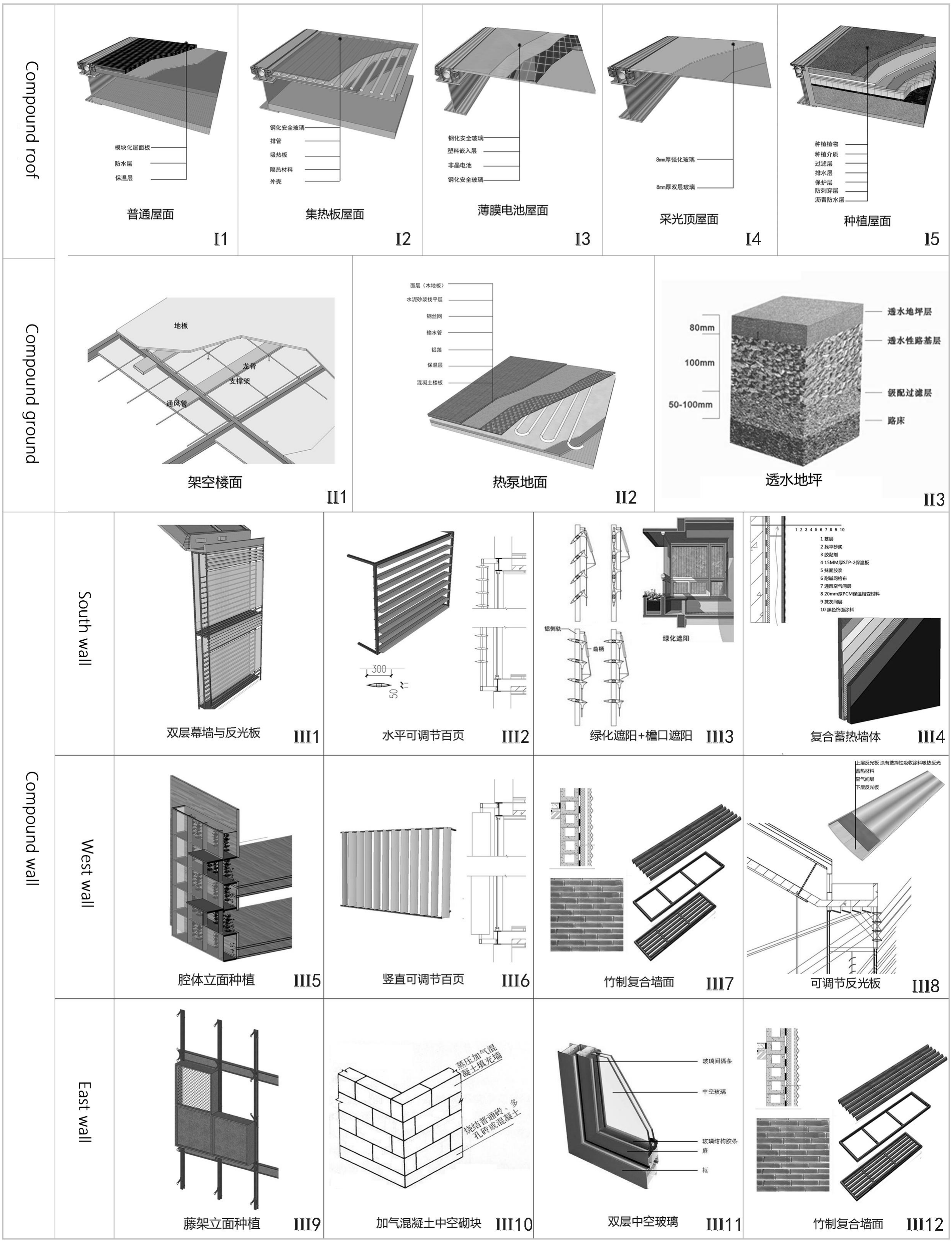


Figure 5-21. The extension design menu

5.6 Summary

In modern rural areas, a single design can no longer meet people's diverse needs due to changes of people's lifestyles, economic conditions, and population structure. Therefore, on the basis of the main function prototype, this chapter uses the principle of topology to design a "design menu" of various forms through factors such as tunnel space, composite envelopes, and topography.

The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. The architectural form can act as courtyards, ventilation corridors, colonnades and sunlight rooms, roof spaces, shelf spaces, etc.

The topography of the building is like the cell wall, which limits and divides the building space to conform to the site’s topography, hydrology, soil, vegetation and other natural factors.

A building envelope is what separates the indoor and outdoor environments of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building.

Based on the main prototype of the representative house, the research uses topology as the evolution path, and establishes the design through variable factors such as courtyards, sun rooms, ventilation corridors, stair shafts, roof interlayers, composite skins, and topographical conditions. menu. This visual design menu serves as a basic reference for the communication between designers and residents, enabling them to finally build the most suitable rural house according to the various conditions of the site.

References

1. Iwafune Y, Mori Y, Kawai T, Yagita Y. Energy-saving effect of automatic home energy report utilizing home energy management system data in Japan. Energy. 2017;125:382-92.

Chapter 6

ANALYSIS OF INTEGRATED OPTIMIZATION OF A TYPICAL RURAL HOUSE IN ANJI COUNTY USING COMPUTATIONAL SIMULATION

CHAPTER6: ANALYSIS OF INTEGRATED OPTIMIZATION OF A TYPICAL RURAL HOUSE IN ANJI COUNTY USING COMPUTATIONAL SIMULATION

6.1 Introduction

Over the past five years several case-study of this approach have been tested in northern Zhejiang by our research team, with effective results.

One important project is located in Anji County. It is an old primary school which is to be transformed into private residence. The primary school was an poor cell with incomplete structure before renovation in the view of RBU cell structure. All works been done during renovation is to make its structure more complete with nucleus, cytoplasm, membrane and cell wall of the RBU.

In this case study, the design menu is utilized to emphasize the integration of function, materials and technology with the local natural climatic conditions and resources. A field measurement exercise was conducted in the selected house, followed by computer modeling work using open-studio software to simulate thermal performance of the building. Then after renovation according to integrated optimization design in reality, anther field measurement exercise was conducted. Subsequently, both the two calculated values from field measurement before and after renovation and the simulation results were compared for validation purposes.

It is an important case study to demonstrate the accuracy of the model and menu. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort.

6.2 Background and analysis

Anji County in Zhejiang Province is in the subtropical oceanic monsoon climate region, with sufficient sunshine, abundant rainwater, hot summer and cold winter. The vegetation in the area is primarily mountain forests, which produce mao bamboo and tea [1] . A clear stream passes through the whole village to present a beautiful natural village scene of "stream, bamboo ocean, tea garden and mountain forest" [2] (Fig 6-1).

Fig. 6-1. Beautiful natural village scenes in Anji County

6.2.1 The old house

The case study is an old Primary School which is to be transformed into private residences (Fig 6-2,3,4). It is located north of the village centre, on a good site surrounded by the natural landscape. The old building is on two levels, constructed in 240mm brick walls, with roof tiles, and glass openings on the front. The dimensions are 14.4m by 9.36m by 3.9 m high. The area of one floor is 96m2 and the total area is 192m2 (Fig 6-5).

Fig. 6-2. The photos of the typical rural house

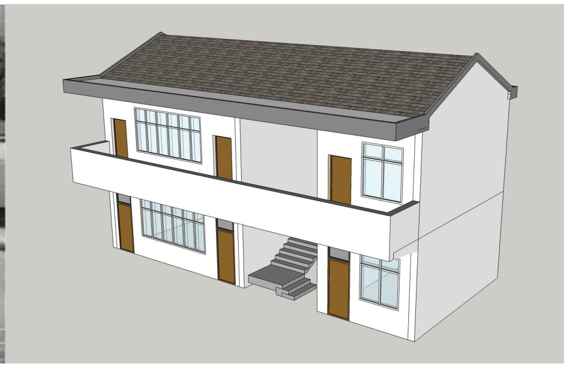


Fig. 6-3. The photos of the typical rural house

Fig. 6-4. The model of the typical rural house by sketch up

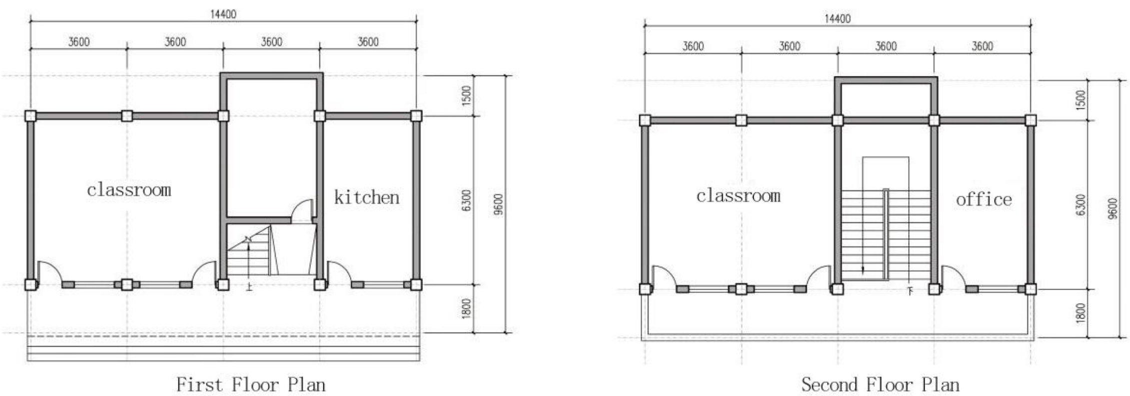
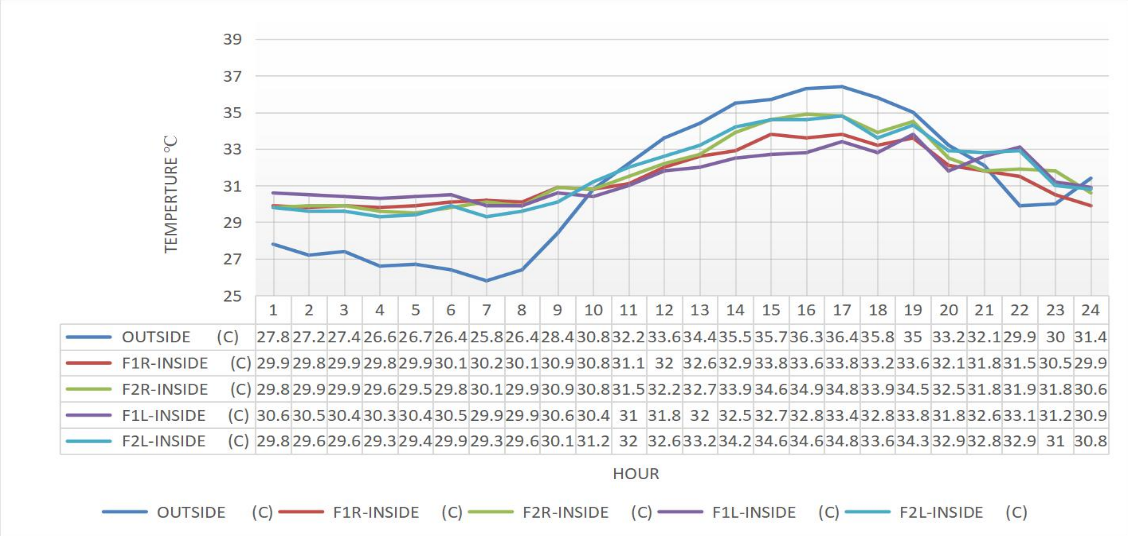


Fig. 6-5. The old first and second floor plans

6.2.2 Field measurement before renovation

Due to the limitation of climate data information the meteorological data for this area was using Hangzhou city.epw (energy-plus weather data) which is not so far from the building location with some modification based on collected information. According to the Hangzhou city .epw , 25th June has been recognized as the day with highest air temperatures in all year around. Hence, the field measurement was conducted in 25th June 2013. The data logger was placed at the central part of the house (FL1- left room,FL1- right room, FL2- left room,FL2- left room) at 1.1m above floor level. The parameters were measured at 10-min intervals and recorded continuously for 24h. At the end of the measurement period the data was exported for analysis.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OUTSIDE (C)	27.8	27.2	27.4	26.6	26.7	26.4	25.8	26.4	28.4	30.8	32.2	33.6	34.4	35.5	35.7	36.3	36.4	35.8	35	33.2	32.1	29.9	30	31.4
F1R-INSIDE (C)	29.9	29.8	29.9	29.8	29.9	30.1	30.2	30.1	30.9	30.8	31.1	32	32.6	32.9	33.8	33.6	33.8	33.2	33.6	32.1	31.8	31.5	30.5	29.9
F2R-INSIDE (C)	29.8	29.9	29.9	29.6	29.5	29.8	30.1	29.9	30.9	30.8	31.5	32.2	32.7	33.9	34.6	34.9	34.8	33.9	34.5	32.5	31.8	31.9	31.8	30.6
F1L-INSIDE (C)	30.6	30.5	30.4	30.3	30.4	30.5	29.9	29.9	30.6	30.4	31	31.8	32	32.5	32.7	32.8	33.4	32.8	33.8	31.8	32.6	33.1	31.2	30.9
F2L-INSIDE (C)	29.8	29.6	29.6	29.3	29.4	29.9	29.3	29.6	30.1	31.2	32	32.6	33.2	34.2	34.6	34.6	34.8	33.6	34.3	32.9	32.8	32.9	31	30.8

Fig. 6-6 . Recorded Temperature before renovation by field measurement on 25/6/2013

Fig.6-6 shows the climatic data recorded, the highest indoor temperature during the day was recorded as 34.9℃, the lowest indoor temperature as 29.3℃, the average indoor temperature as 31.6℃, the average outdoor temperature as 31.0℃, and the different temperature of indoor-outdoor as 0.6℃. The general rise of the temperature around noon hours shows the importance of considering noon and early afternoon hours as the times that the building will receive more heat during the day. It has also been perceived that the rooms in Floor2 was about 1 degree lower than the rooms in Floor1 in the early morning, but was about 2 degrees higher in the afternoon, which was probably caused by heat loss from the roof [3].

On the other hand, as the Fig.6-7 shows, in the hot summer, the thermal bridges in the construction were identified though photography with a thermal infrared camera.The thermal comfort conditions in the building were poor [4].

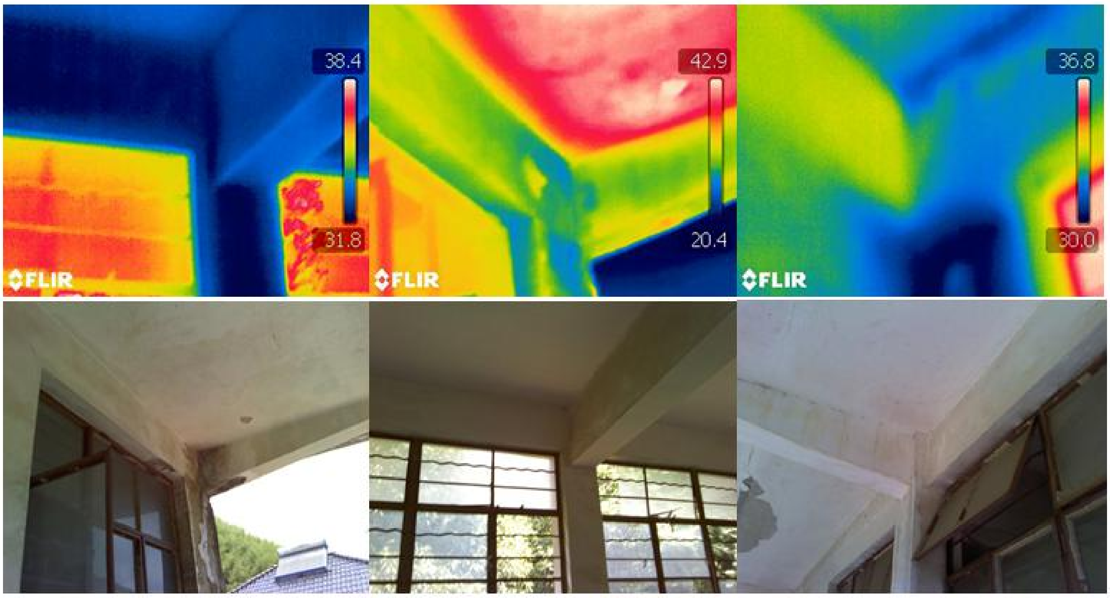


Fig. 6-7. The old thermal bridge images

6.2.3 Problems to be solved

The following problems needed to be resolved by the new design. This old building is a poor cell with an incomplete structure:

- The RBU-N(nucleus−−main functional prototype) need to be transformed into a residence since the economic style of this village has changed.The house transformed from primary school building so that the main structure were preserved due to lowering construction cost.
- The RBU-M (membrane—composite envelope) is too simple. It is covered by brick wall, roof tile, and glass opening in front, which makes the indoor thermal comfort is relatively poor.
- The RBU-C （cytoplasm－－tunnel space) is not suitable for its forms and dimensions.For example, the old 3.4m width of the stairs, 3.9m height and the open corridors are not suitable for the dimensional requirements of dwellings.
- The RBU-W (cell wall—site terrain) is not made optimum use of. The spatial form of the house is too simple.

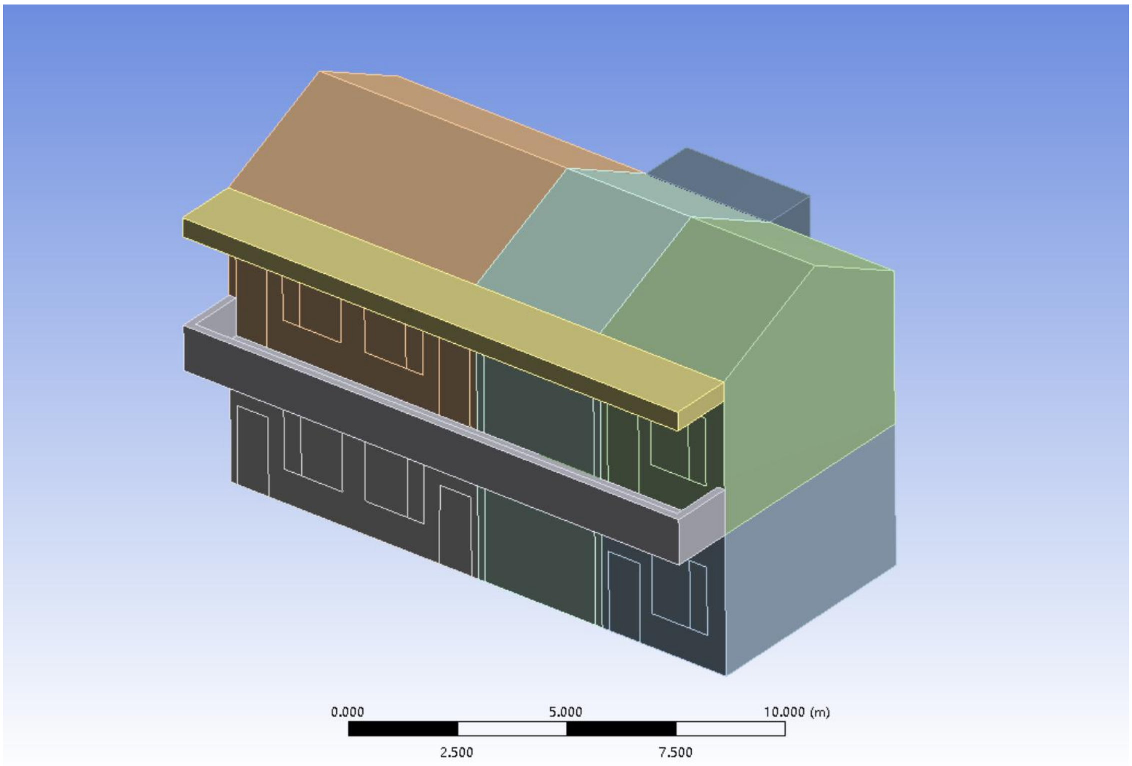


Fig. 6-8. The model before renovation

6.3 Renovation strategy and method

6.3.1 Renovation of the RBU-N (nucleus—main functional prototype)

The old first floor is changed into bedrooms. The second floor is changed into three bedrooms. The rectangular plane on the first floor is expanded to an "L" shape in accordance with the demand for study, kitchen, dining, storage, and parking space. (Fig 6-9,6-10).

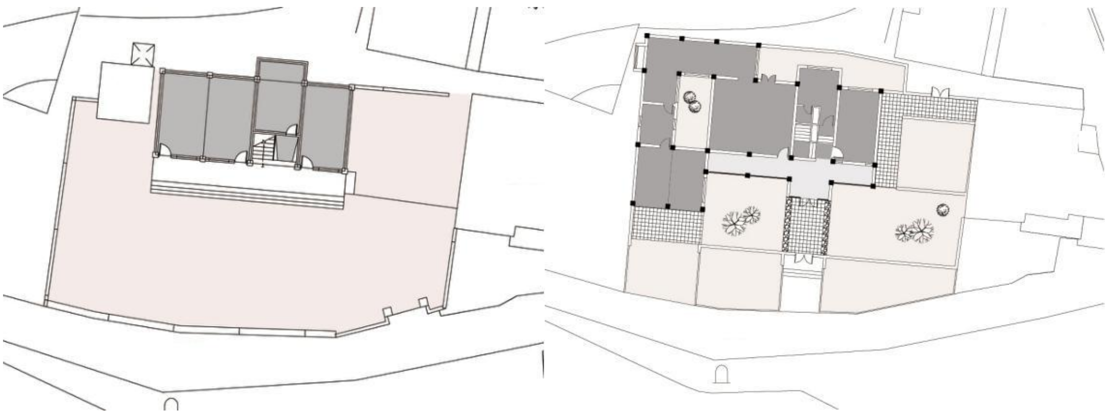


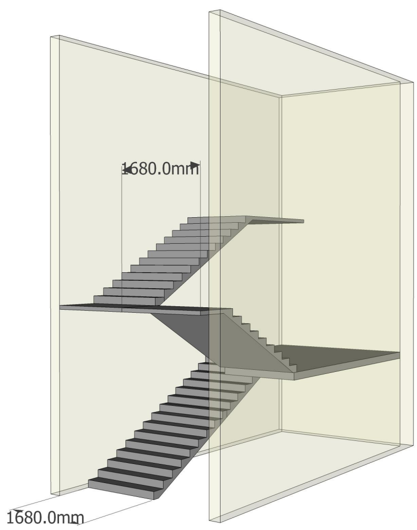
Fig. 6-9. Comparison of the old and the new plans

Fig. 6-10. The new first and second floor plans

6.3.2 Renovation of the RBU-C（cytoplasm—tunnel space)

1) The ventilation tunnel

The staircase is transformed into a ventilation tunnel. 900mm is taken from the 3400mm staircase shaft to construct a wind tunnel from local rubble. The chimney effect is used to promote indoor ventilation. The tunnel is connected to the fireplace in the left and right rooms on the lower floor. In summer, the tunnel on the roof absorbs solar radiation and rises in temperature. The air in the lower section of the wind tunnel maintains a lower temperature, and hence the cold air pressure at the low level is greater than that of the air above. The air rises and air from the rooms on both sides is drawn into the wind tunnel to supplement the rising air, driving the air flow. (Fig 6-11).



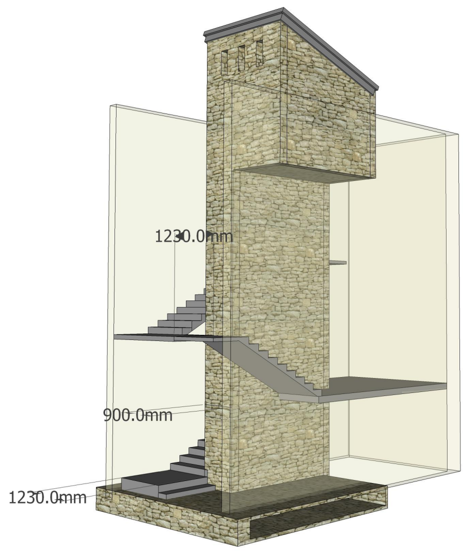


Fig. 6-11. A comparison of the old and the new staircase

The ventilation before and after renovation is simulated by Ansys 19.0. The ansys meshing finite element analysis grid is used to control the generation based on regular tetrahedron in the proximity and curvature mode. The minimum mesh size of the proximity and curvature is controlled to 0.005m. (Before the renovation, the number of nodes is 526,413; After the renovation, the number of nodes is 933065.)

The k-e model is act as the turbulence model. The outdoor environmental parameters : In the winter, the north wind is 3.3m/s, and in the summer, the southwest wind is 2.9m/s(GB50736-2012). The convergence condition is set as each parameter falls below 0.0001.(Fig 6-10,6-11)

The results show that in winter when the windows and doors of sunlight room are closed, the wind tunnel has a air pulling effect, which can effectively achieve indoor fresh air replacement. In summer, when the doors and windows of the classroom are all open, and the wind tunnel has a wind pressure and air extraction function. With the assistance of the sunlight heating at the top , the building ventilation can be effectively improved.(Fig 6-12, 13, 14, 15, 16, 17, 18, 19).

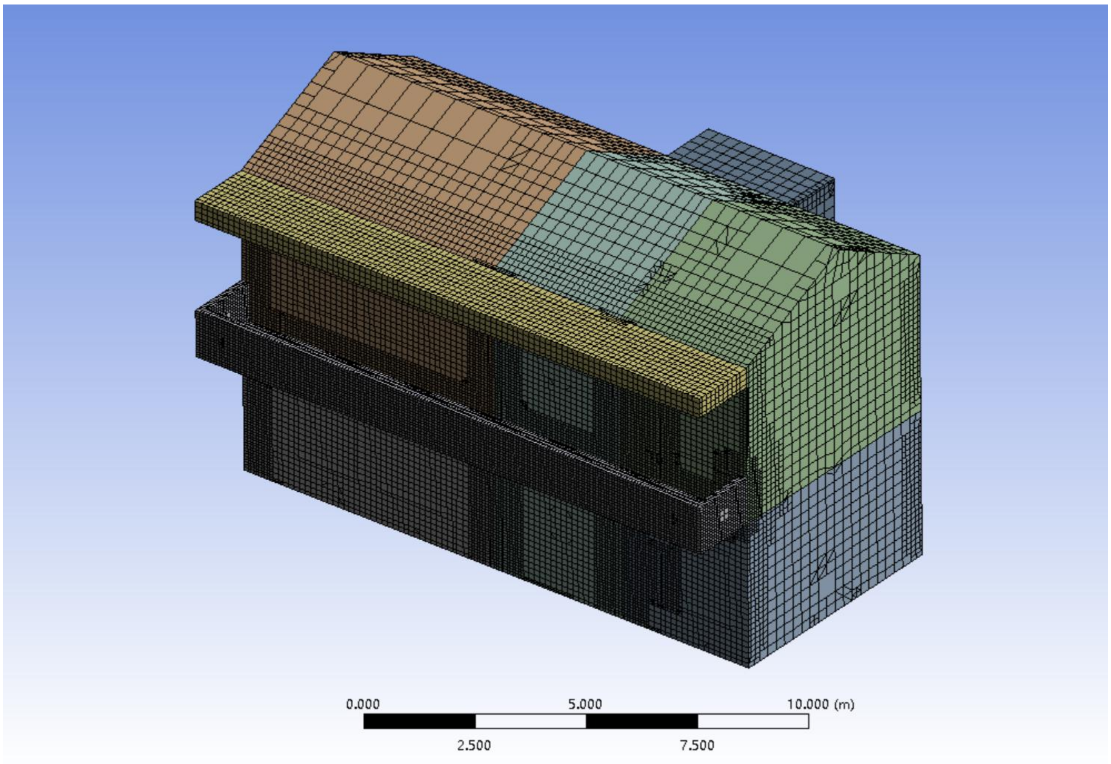


Fig. 6-12. Model before renovation

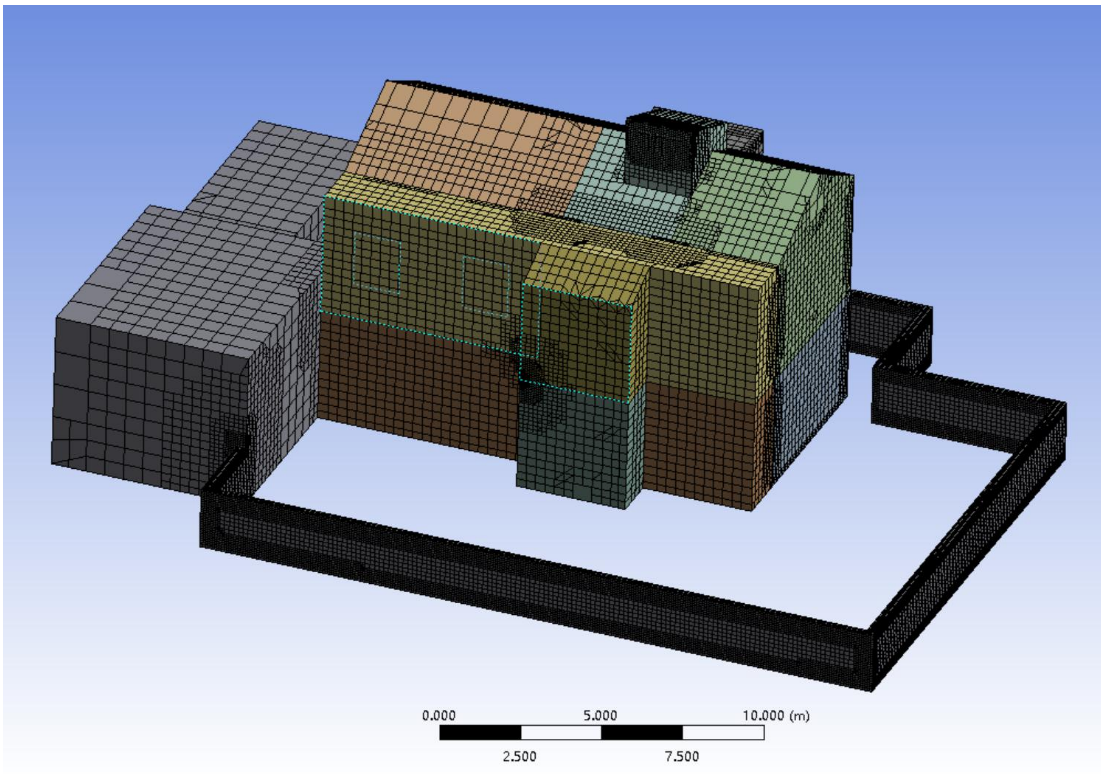


Fig. 6-13. Model after renovation

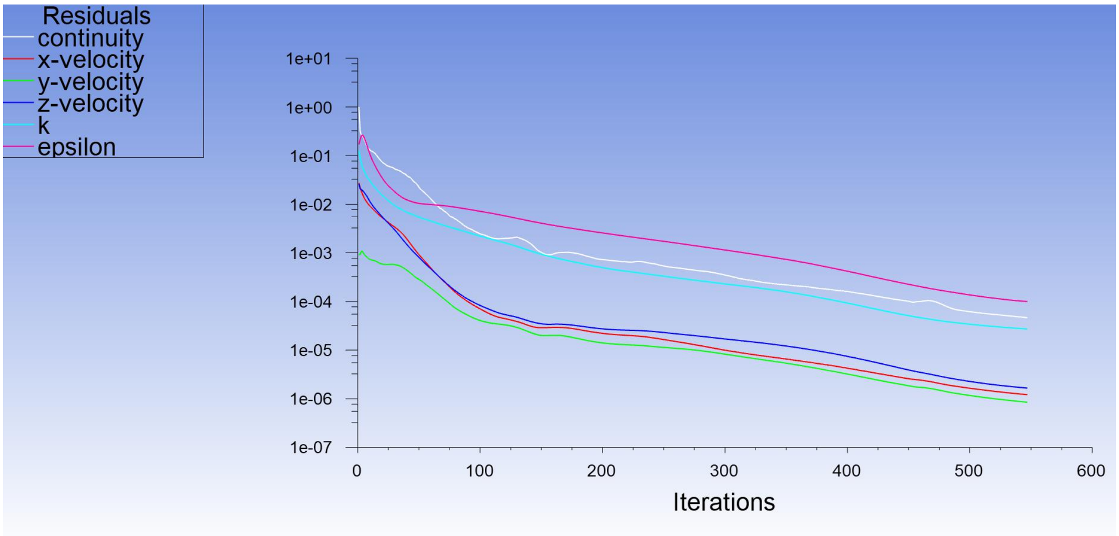


Fig. 6-14. Ventilation in winter before renovation

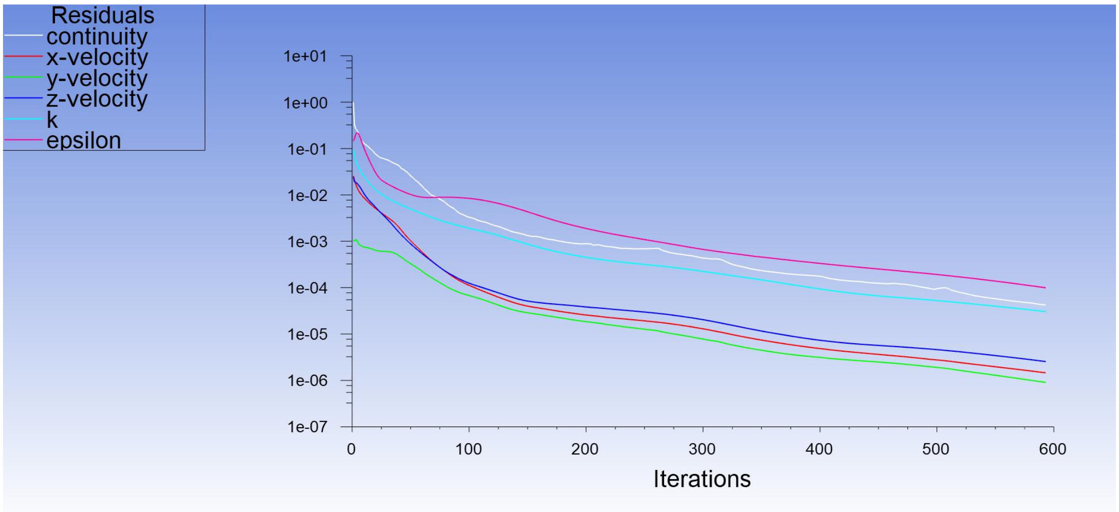


Fig. 6-15. Ventilation in winter after renovation

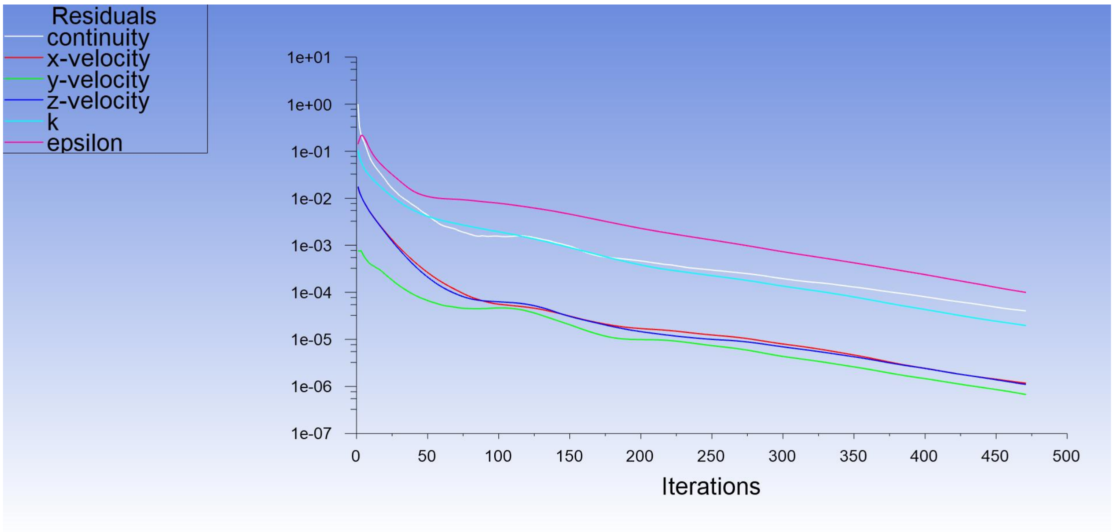


Fig. 6-16. Ventilation in summer before renovation

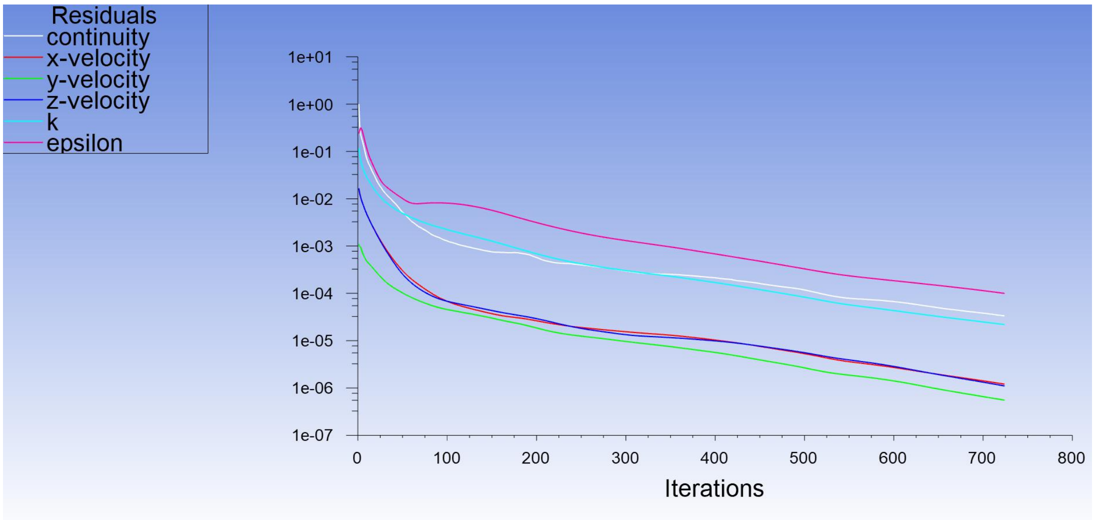


Fig. 6-17. Ventilation in summer after renovation

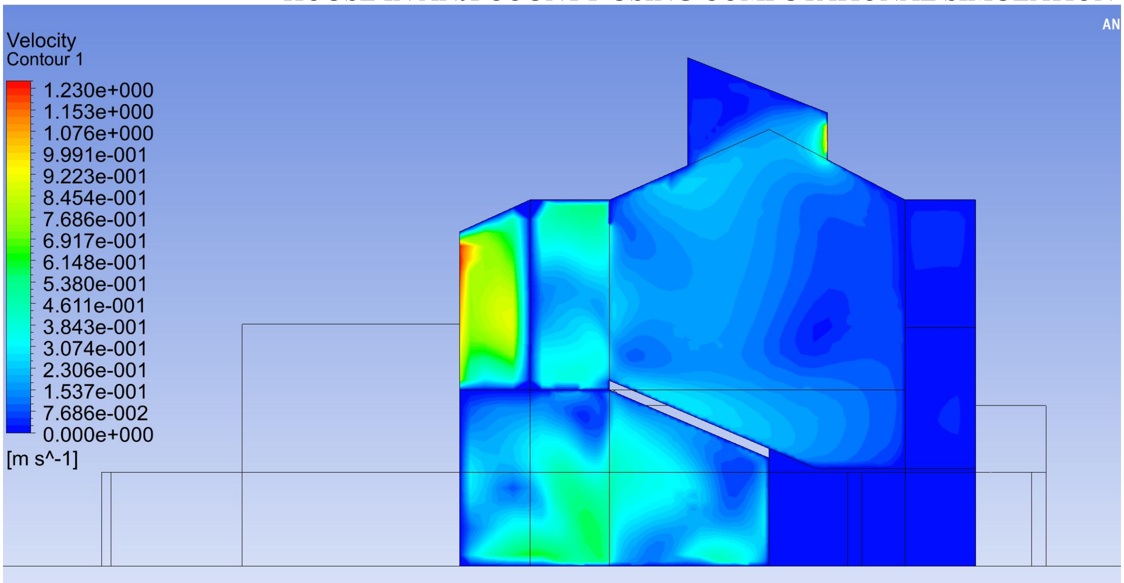


Fig. 6-18. Ventilation in summer after renovation

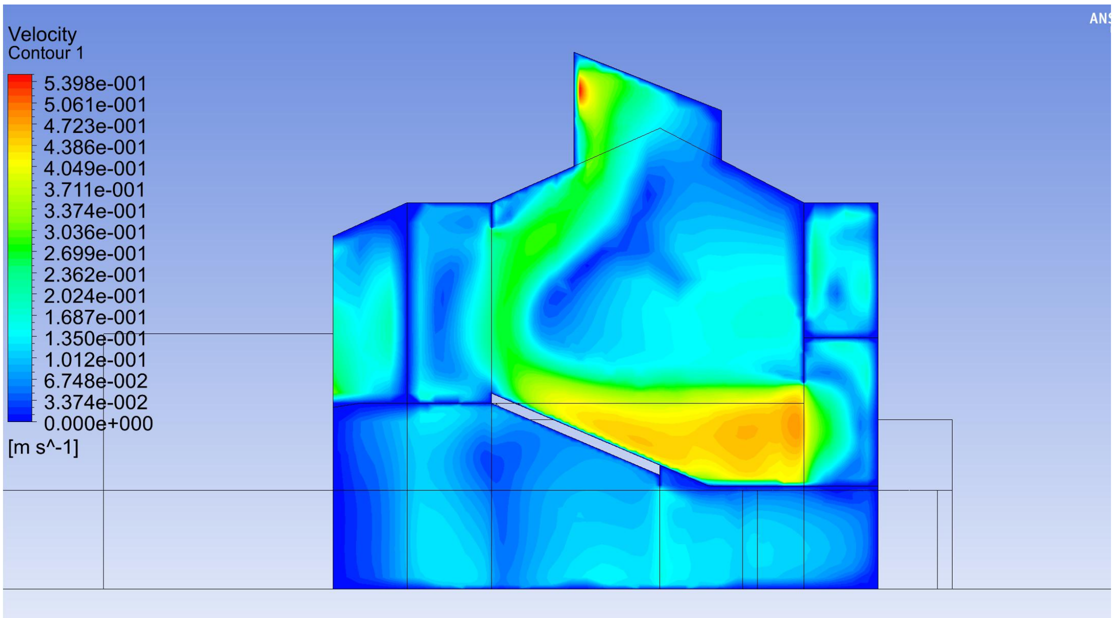


Fig. 6-19. Ventilation in winter after renovation

2) The open corridor is transformed into a sunspace room

The extended corridor is used as an insulating layer by using double glazing in the "sunspace room". The bamboo is increased to adjust the bean curd blade and create a transitional space with adjustable temperature, light and privacy. This can be combined with dark Trombe wall to release solar thermal energy into the internal room at night.(Fig 6-20)

Fig.6-20. The sunlight room as constructed

6.3.3 Renovation of the RBU-M（membrane—composite envelope）

1) Composite envelopes with bamboo

Bamboo is the most abundant local resource in Anji. Bamboo grows and has excellent tenacity, intensity, and strong plasticity. This local inexpensive material is well suited to the architecture.

It is frequently raining in Anji, and this causes the side wall to peel off deteriorate, reducing the walls heat-insulating properties. The bamboo composite envelope is used for the east-west wall, with an air layer between the wall and bricks. This improves the heat-insulating property of the external building envelope, and allows the colour of the bamboo components to be changed and replaced regularly.

Bamboos adjustable external sunshade for different times of day and year. In summer, this can be used to reduce radiant heat, so as to moderate the indoor temperature and reduce cooling energy consumption. In winter, the solar energy can be used to warm the indoor space during the day. At night, the air layer between shutters and windows can be used to prevent thermal losses.

To analyze the effects of materials on the thermal performance of zones, the materials of the walls were changed. The bamboo compound envelope was used for the east and west walls, with an air gap between the bamboo and bricks. Instead of common materials with U-value of 1.95W/m2 K (240mm brick with 20mm plaster on both sides), materials with lower U-value of 0.75W/m2 K were chosen (240mm brick with 75mm air gap and 50mm bamboo outside).(Fig. 6-21)

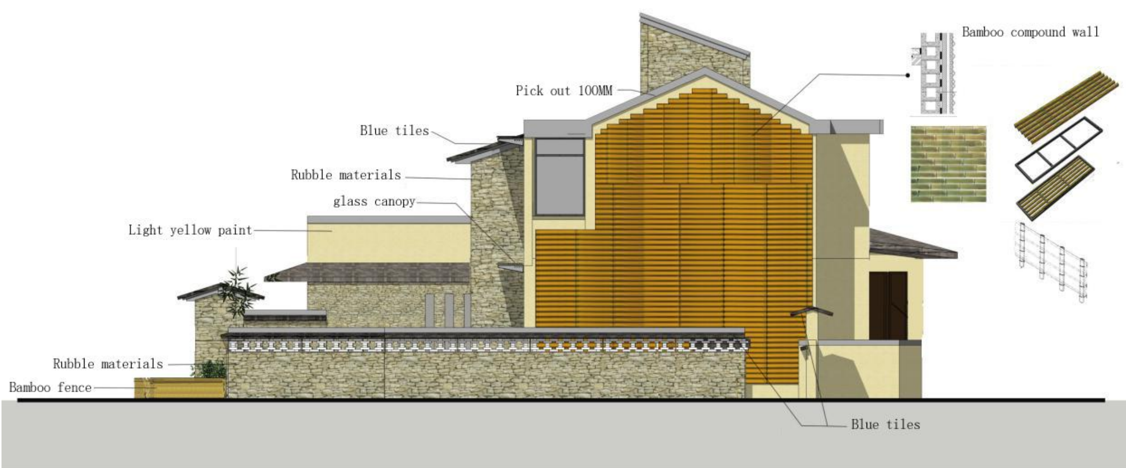


Fig. 6-21. Bamboo compound wall drawing

2) Rubble material

The design uses local rubble which is an abundant resource with mature process technologies for foundation, composite envelope and wind tunnel.(Fig 6-22)

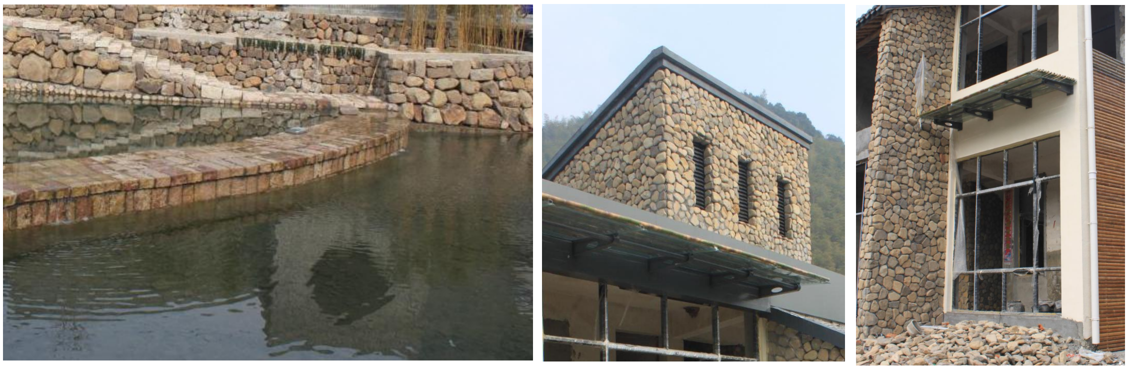


Fig. 6-22. Local rubble used in construction

3) Solar heat collection roof

Solar heat collection roof can enable solar energy for hot water demands. Moreover, a backwater system can eliminate the wastage of cold water. (Fig 6-23)

Fig. 6-23. The renovation drawing

6.3.4 Renovation of the RBU-W（cell wall—site terrain)

1) The courtyards

The new plan has internal, external and grey space types with front, middle and back yards, enhancing spatial mobility and enrichment, auxiliary use, ventilation, and micro-climate regulation.(Fig. 6-24)

Fig. 6-24. The new master plan after renovation

- Permeability ground

The road in the yard is paved with traditional stone with high water permeability. This is a typical local building style to solve the problem of water pooling in roads and public areas.(Fig6-25)

- Courtyard plants

Lots of broad leaved plants (e.g. loquat and banana) are planted in the courtyard, which has an area of 275m2, loquat and banana), so as to increase plant transpiration, reduce ground temperature, and provide shadow. (Fig6-25).

Fig. 6-25. Integrated technologies in renovation

6.4 Simulation

6.4.1 Open-studio software

In the next step, in order to investigate the thermal condition of the case study house, a model was built using open-studio software. open-studio is a complete building design and environmental analysis tool that covers the broad range of simulation and analysis functions. This software seemed more suitable to comply with the objectives of the current study since it is a highly visual building simulation tool with a wide range of performance analysis functions covering thermal, energy, lighting, shading and resource use. Similarly, many researchers have used this software to evaluate the required design configurations in their studies. In this study, open-studio was utilized to generate temperatures in four indoor spaces in a residential building model.

6.4.2 Modeling dates

The weather data file for open-studio is from Energy Plus web page(Hangzhou city .epw) and the building materials are either chosen from open-studio library or created from user library. The property values for these materials are calculated from open-studio material property. Table 1 and 2 display the zone and material properties of the simulated residential building model.

Zone properties	Description
Zone number	4
Zone name	F1-Right,F1-Left,F2-Right,F2-Left,
The type of active or passive system used	Natural ventilation
Comfort lower band	18℃
Comfort upper band	26℃
The occupants' metabolic rate	Sedentary activity: 70W (5 persons)

The occupants' clo value (thermal insulation of clothing)	1.0

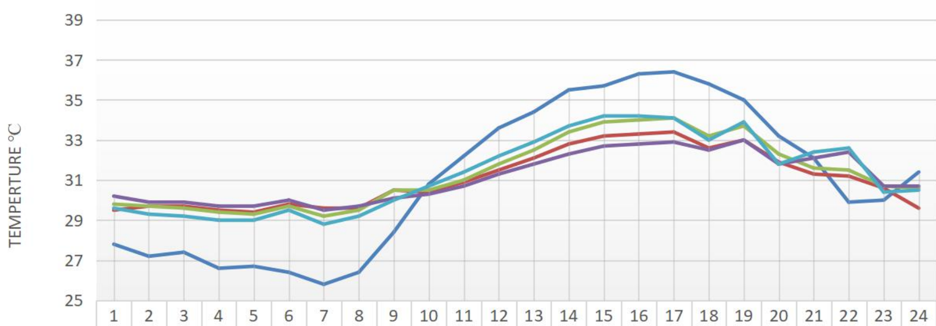
Table 6-1. Zone properties of the simulated residential building model

Element	Description	U value (W/m2 K)
Roof	Concrete roof tiles with insulation	0.896
Ceiling	Suspended concrete ceiling intermediate floor	1.45
Floor	100mm thick concrete floor with 1500 soil	0.88
External wall	240mm brick wall with 20mm thick cement plaster on both sides	2.62
Door	40mm thick soild core pine timber door (external door)	2.3
Window	Single glazing 6mm thick	5.44

Table 6-2. Material descriptions of the simulated residential building model

6.4.3 Simulation result before renovation

Using the weather data of the same day with field measurement (Hangzhou city .epw 25/6/2013), open-studio simulation showed the temperature as Fig.6 displayed, the highest indoor temperature of 4 zones was 34.2 ℃, lowest indoor temperature was 29.0 ℃and the average indoor temperature was 31.19 ℃.



HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OUTSIDE (C)	27.8	27.2	27.4	26.6	26.7	26.4	25.8	26.4	28.4	30.8	32.2	33.6	34.4	35.5	35.7	36.3	36.4	35.8	35	33.2	32.1	29.9	30	31.4
F1R-INSIDE (C)	29.5	29.7	29.7	29.5	29.4	29.8	29.6	29.6	30.5	30.4	30.9	31.5	32.1	32.8	33.2	33.3	33.4	32.6	33	31.9	31.3	31.2	30.6	29.6
F2R-INSIDE (C)	29.8	29.7	29.6	29.4	29.3	29.7	29.2	29.5	30.5	30.5	31	31.8	32.5	33.4	33.9	34	34.1	33.2	33.7	32.3	31.6	31.5	30.7	30.6
F1L-INSIDE (C)	30.2	29.9	29.9	29.7	29.7	30	29.5	29.7	30.1	30.3	30.7	31.3	31.8	32.3	32.7	32.8	32.9	32.5	33	31.8	32.1	32.4	30.7	30.7
F2L-INSIDE (C)	29.6	29.3	29.2	29	29	29.5	28.8	29.2	30	30.7	31.4	32.2	32.9	33.7	34.2	34.2	34.1	33	33.9	31.8	32.4	32.6	30.4	30.5

Fig.6-26 . Simulation Temperature before renovation on 25/6/2013 by open-studio

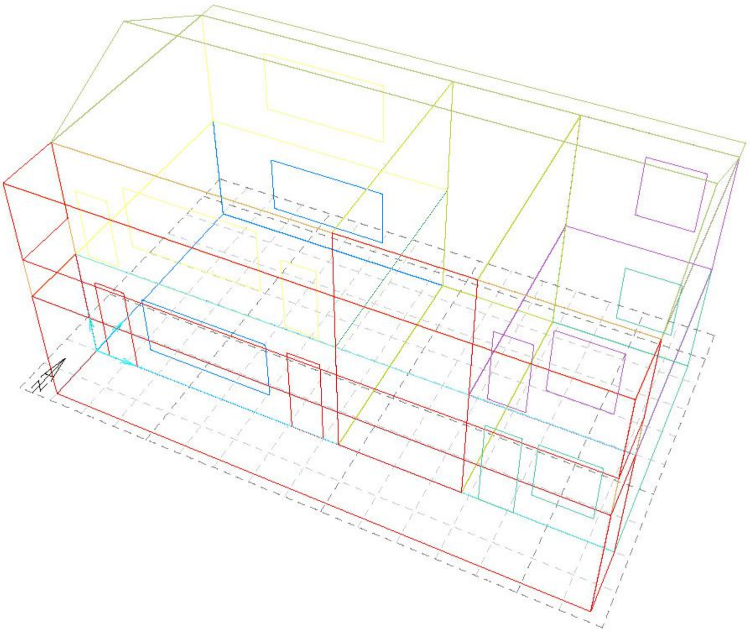


Fig. 6-27. The model before renovation by open-studio

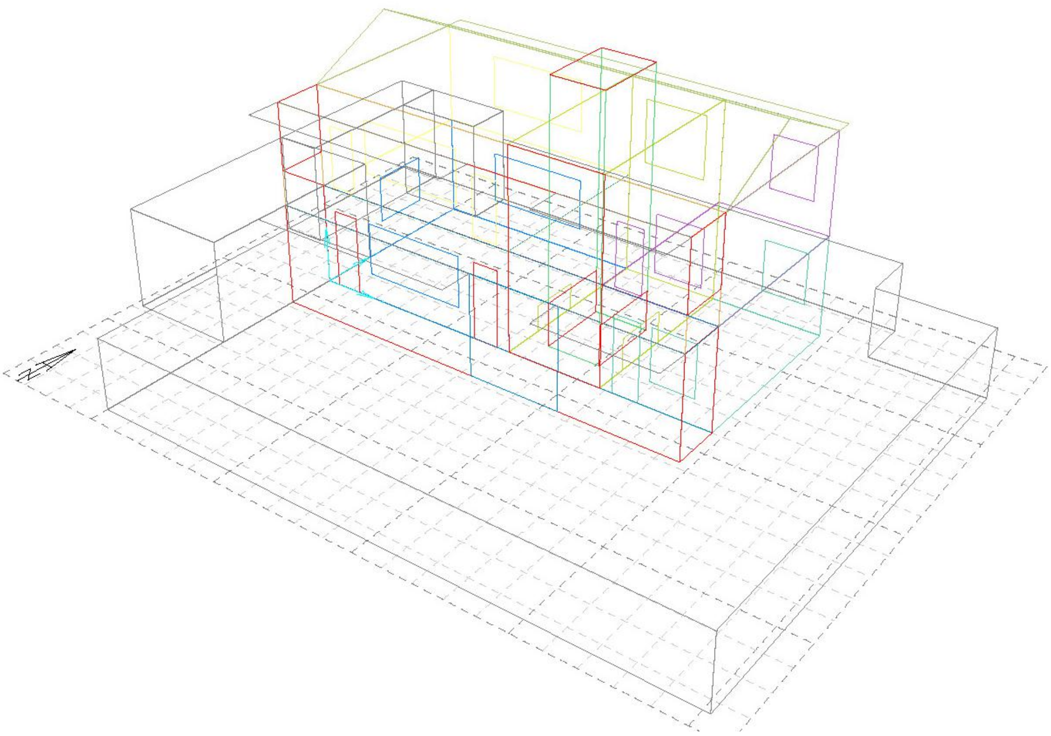


Fig. 6-27. The model after renovation by open-studio

6.4.4 Temperature variation between field measurement and simulation

For validation of the results from simulation, a comparison between the temperature variations of field measurement and open-studio temperature simulation from the same date has been conducted. As Fig.6-28 displays, each zones shows very close performance in temperature between field measurement one and simulation one. Taking the Floor1-right room zone for example, the highest indoor temperature during that day was recorded as 33.8℃and the lowest indoor temperature as 29.8 ℃, while open-studio simulation showed the highest indoor temperature as 33.4 ℃ and also lowest indoor temperature as 29.4 ℃. It has also been perceived that the average temperature delta between simulation and field measurement was 0.4℃.

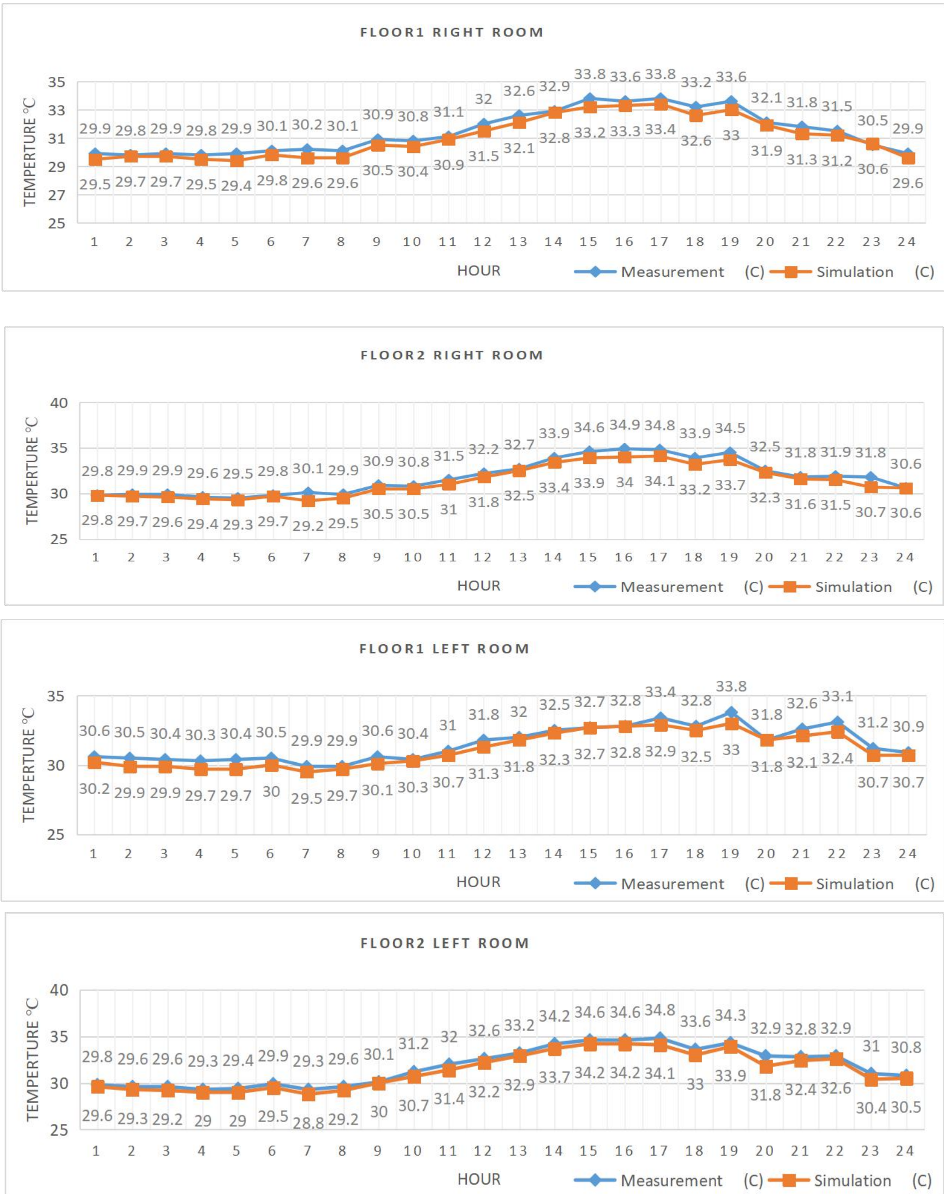


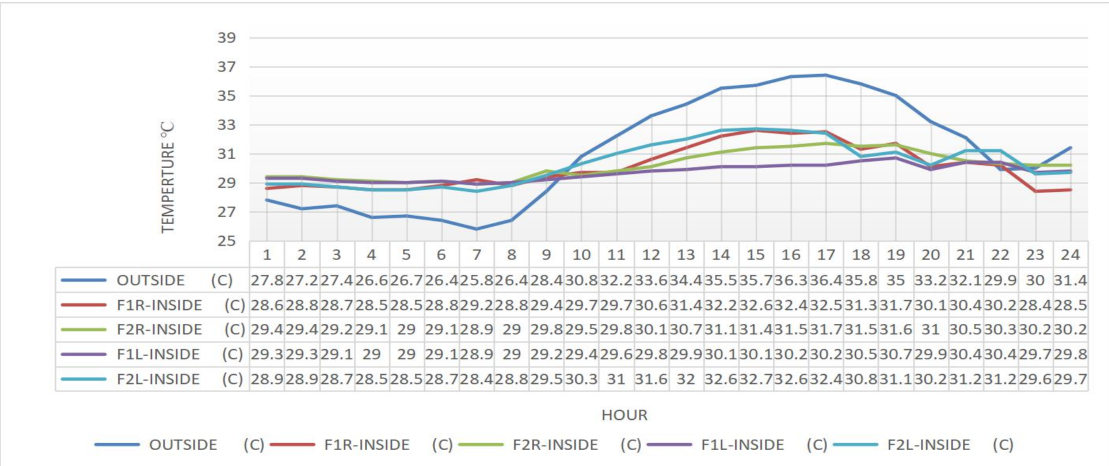
Fig. 6-28. Temperature variation between field measurement and simulation

6.4.5 Temperature variation before and after renovation

The thermal performance of this house had been simulated after using integrated passive energy-saving technologies. Fig.12 shows the temperature results, the highest indoor temperature during the day was 32.7℃, the lowest indoor temperature was 28.4 ℃, and the average indoor temperature was 30.05℃. In comparison with the old one (the highest indoor temperature was 34.2 ℃ ,lowest indoor temperature was 29.0 ℃ , the average was 31.19 ℃), the average indoor temperature dropped from 31.19℃ to 30.05℃, which was a great improvement in thermal comfort. What's more, the indoor temperature have become more stable in the whole day after renovation according to the result showed in Fig.6-29.

Fig.6-30 displays the comparison between temperature variations of each zones for before and after renovation. The temperature has decreased by average 1.14℃ (0.4℃-3.4℃) all the time after using integrated passive energy-saving technologies in the hottest day of a year, which also results in a clear improvement in the thermal comfort.

It has also been perceived that while the temperature has decreased around the critical noon hours (13–18 pm), little increase in temperature was perceived in the morning and afternoon hours. This is despite the fact that the temperature was still around the acceptable range (28.0–29℃), and as people often open windows at this time, which might cause the actual temperature be much lower than simulation one.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OUTSIDE (C)	27.8	27.2	27.4	26.6	26.7	26.4	25.8	26.4	28.4	30.8	32.2	33.6	34.4	35.5	35.7	36.3	36.4	35.8	35	33.2	32.1	29.9	30	31.4
F1R-INSIDE (C)	28.6	28.8	28.7	28.5	28.5	28.8	29.2	28.8	29.4	29.7	29.7	30.6	31.4	32.2	32.6	32.4	32.5	31.3	31.7	30.1	30.4	30.2	28.4	28.5
F2R-INSIDE (C)	29.4	29.4	29.2	29.1	29	29.1	28.9	29	29.8	29.5	29.8	30.1	30.7	31.1	31.4	31.5	31.7	31.5	31.6	31	30.5	30.3	30.2	30.2
F1L-INSIDE (C)	29.3	29.3	29.1	29	29	29.1	28.9	29	29.2	29.4	29.6	29.8	29.9	30.1	30.1	30.2	30.2	30.5	30.7	29.9	30.4	30.4	29.7	29.8
F2L-INSIDE (C)	28.9	28.9	28.7	28.5	28.5	28.7	28.4	28.8	29.5	30.3	31	31.6	32	32.6	32.7	32.6	32.4	30.8	31.1	30.2	31.2	31.2	29.6	29.7

Fig.6-29 . Simulation Temperature after renovation in summer by open-studio

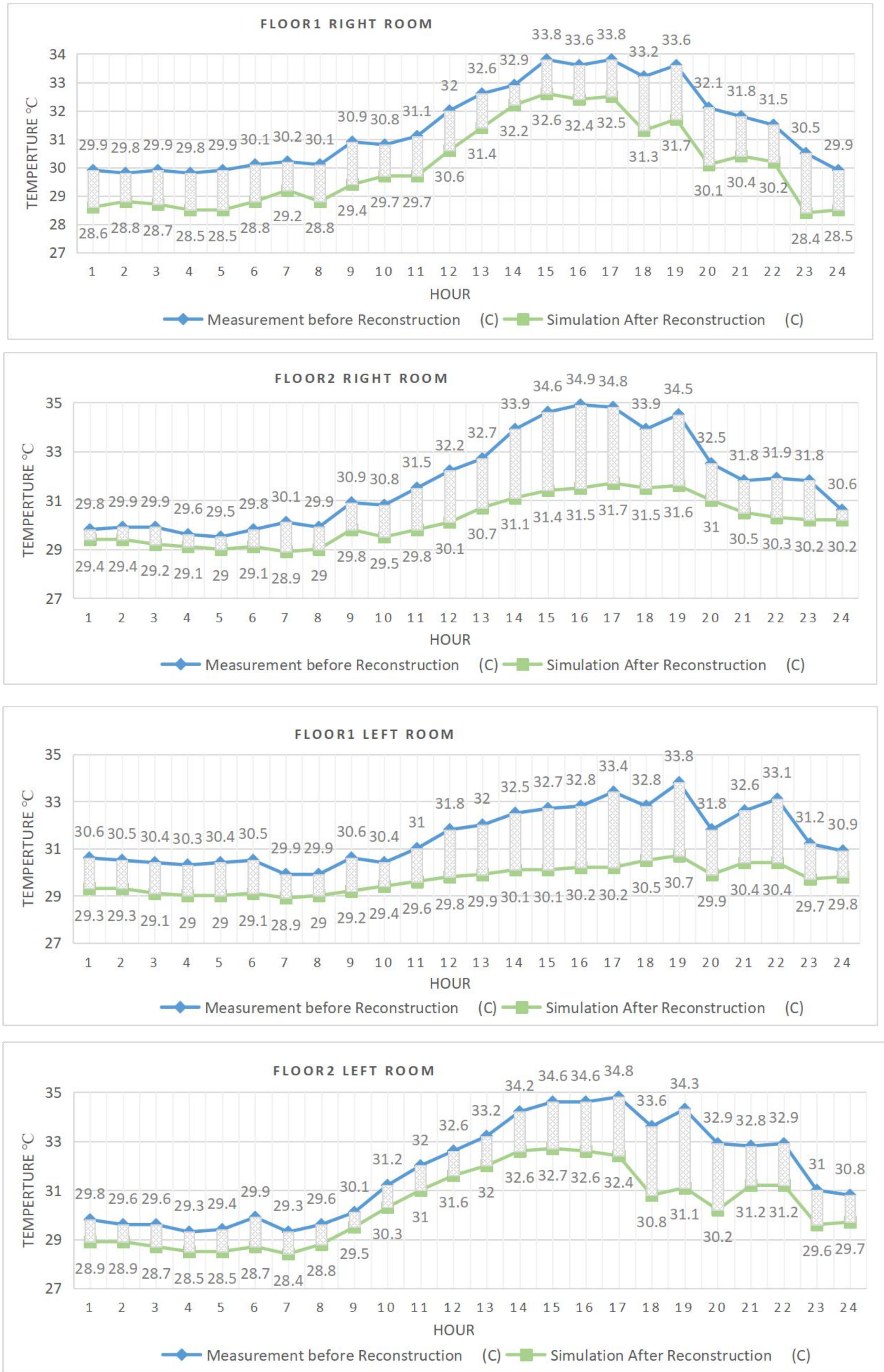
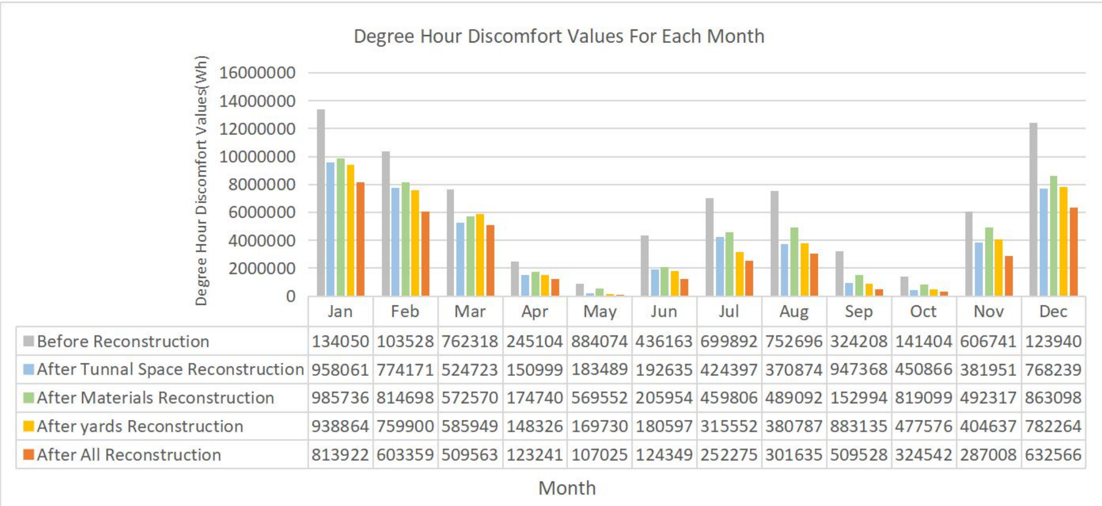


Fig.6-30.Temperature variations for before and after renovation in summer

6.4.6 Comparison of Degree Hour Discomfort Values

In order to evaluate thermal performance of integrated optimization of rural residences during the whole year, and to make the analysis more precise and accurate, a comparison between degree hour discomfort values of each situation was conducted.

This method uses the upper and lower comfort band temperatures set for each zone. If the internal zone temperature is above the upper value (26℃) or below the lower value （18℃）, it is deemed uncomfortable. The amount of time the internal temperature of the zone spends outside the specified comfort conditions is calculated for each month or year, resulting in a graph similar to that shown below.(Fig6-31,32)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Before Reconstruction	134050	103528	762318	245104	884074	436163	699892	752696	324208	141404	606741	123940
After Tunnal Space Reconstruction	958061	774171	524723	150999	183489	192635	424397	370874	947368	450866	381951	768239
After Materials Reconstruction	985736	814698	572570	174740	569552	205954	459806	489092	152994	819099	492317	863098
After yards Reconstruction	938864	759900	585949	148326	169730	180597	315552	380787	883135	477576	404637	782264
After All Reconstruction	813922	603359	509563	123241	107025	124349	252275	301635	509528	324542	287008	632566

Fig.6-31 . Degree hour discomfort values of each situation for each month

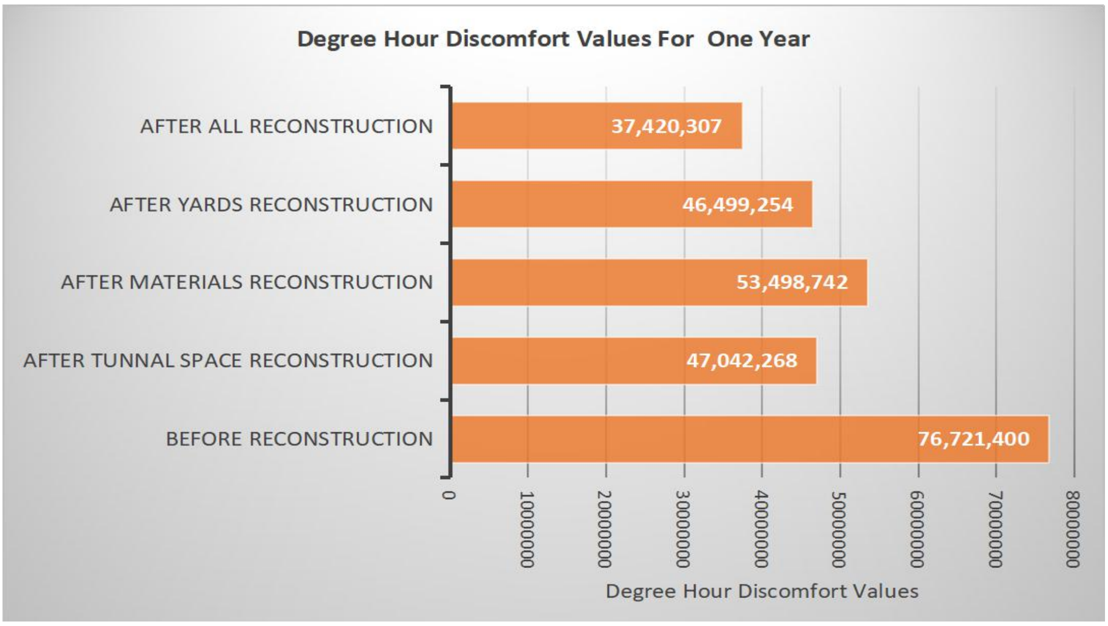


Fig.6-32 . Degree hour discomfort values of each situation for each year

According to the results, all three methods had reduced degree hour discomfort values effectively. Among them, after courtyards renovation discomfort values was reduced by 39.4% , followed by tunnal space renovation as 38.7%, and material renovation as 30.3%.

After tunnal space renovation, in summer, the window of the sunshine room is opened and the vertical ventilation tunnel will effectively reduce the indoor temperature, in winter, the vertical ventilation tunnel is closed and the sunshine room will effectively raise the indoor temperature. In summer, the wind tunnel on the roof absorbs solar radiation and rises in temperature. The air in the lower section of the wind tunnel maintains a lower temperature, and hence the cold air pressure at the low level is greater than that of the air above. The air rises and air from the rooms on both sides is drawn into the wind tunnel to supplement the rising air, driving the air flow, which will help in temperature reduction.In winter, sunshine room helps capture solar radiation and maintain the energy by using generally capacitive materials, which later return the energy with a phase difference. This can also be combined with dark Trombe wall to release solar thermal energy into the internal room at night.

After changing the materials of east and west walls, results have revealed changes in temperature variations. It is clear that the type and thickness of the new wall material has increased the effects of thermal mass. After introducing the bamboo compound envelope, the overall UA (U-value×surface area) has decreased because of the air gap and bamboo, which will also cause the temperature decrease. This improves the heat-insulating property of the external building envelope, and also allows the colour of the bamboo components to be changed and replaced regularly.

After all renovation discomfort values was reduced by 51.3% , which resulted in a clear improvement in the thermal comfort as the temperature result showed before.

6.4.7 Field measurement after renovation

This house had been renovated completely according to integrated optimization design and put into use in 2017 (Fig.6-33, 34). Field measurement after renovation was also conducted during one of the hottest day in June 2017. This was a sunny day, with a maximum outdoor temperature of 42℃ and an average temperature of 31.18℃. The indoor temperature was between 28.6-31.2℃, and the average was 29.09℃. It was even 1℃ lower than the results of simulation after renovation(when the outdoor average temperature was 31.0℃, the indoor average temperature was 30.05℃), which was probably caused by the bamboos adjustable external sunshade, the rubble materials used in composite envelope and wind tunnel and plants in the yards that was not included in the simulation.

Fig.6-33. Photo after renovation

Fig.6-34. Photo after renovation

6.5 Summary

A simple case study in Anji County Northern Zhejiang is used to demonstrate the accuracy of the model and menu. This is a renovation of an existing rural building, similar to the repair of an incomplete cell. The old poor cell with an incomplete structure has been remedied in the RBU-N(nucleus--main functional prototype), the RBU-M (membrane—composite envelope), the RBU-C (cytoplasm—tunnel space) and the RBU-W (cell wall--site terrain). During renovation the RBU design menu in Northern Zhejiang is using for full integration with the local climate, natural resources and technologies.

A field measurement exercise was conducted in the selected house both before and after renovation, followed by computer modeling work using open-studio software to simulate thermal performance of the building. Subsequently, both the two calculated values from field measurement and the simulation results were compared.

The simulation results showed that after renovation the highest indoor temperature dropped from 34.2℃ to 32.7℃, the lowest indoor temperature dropped from 29.0℃to 28.4℃,the average indoor temperature dropped from 31.19℃to 30.05℃, and the indoor temperature became more stable in the whole day, which was also verified by the field measurement after renovation. On the other hand, after courtyards renovation degree hour discomfort values was reduced by 39.4% , followed by tunnal space renovation as 38.7%, and material renovation as 30.3%.

It is perceivable that, in summer the window of the sunshine room was opened and the vertical ventilation tunnel, the bamboo composite wall and the courtyard effectively decreased the indoor temperature, in winter the vertical ventilation tunnel was closed and the sunshine room and the bamboo composite wall effectively increased the indoor temperature.

Since only local materials were used in the renovation, the cost of the optimized residence was not much higher than that of a traditional residence. It was still within the limits of the local economic ability, while the indoor thermal environment was improved, and annual heating costs were lowered, which was particularly significant in rural regions. Thus, this research provides a reference for rural construction, which has strategic importance to improve quality of rural life, reduce energy consumption, improve environment quality and promote economic development.

This research is still in its early stages, further studies on the effects of the sun shading system, the rubble materials, plants in the yards, and more accurate studies on the effects of the thickness and type of wall, simulation of ventilation flow are all recommended.

References

[1]. Xu Shuning.The Elementary Research on the Mechanism and Approach in Point of Green Settlement's Interface.Zhejiang University,2013：P14.

[2]. Wang Youwei.The Research on Shading of Traditional Houses in the South Area of Yangtze River.TianJi University,2012.

[3]. Klaus Daniels:Low-Tech Light-Tech Hight-Tech [M]. Basel Boston Berlin：Birkhäuser

[4]. Chen, X.; Yang, H.; Lu, L. A comprehensive review on passive design approaches in green building rating tools. Renew. Sustain. Energy Rev. 2015, 50, 1425–1436.

Chapter 7

ANALYSIS OF THE INTEGRATED OPTIMIZATION OF TUBULAR HOUSES IN DEQING COUNTY USING COMPUTATIONAL SIMULATION

CHAPTER7: ANALYSIS OF THE INTEGRATED OPTIMIZATION OF TUBULAR HOUSES IN DEQING COUNTY USING COMPUTATIONAL SIMULATION

7.1 Introduction

Globally, the construction industry today consumes 40% of the total energy production, generates between 30% and 40% of all solid waste, and emits 35–40% of total CO2 emissions [1,2]. As the current situation is not satisfactory, a number of policies have been adopted worldwide. Examples include the Kyoto Protocol [3], Buildings Directive Energy Performance [4,5], and the Japanese low-carbon society plan [6], all of which have worked successfully as solutions for minimizing the environmental influence of buildings in order to make them sustainable [7].

However, China is a large country with a large agricultural sector, and the rural population accounts for 43.9% of the total population [8]. In China, the energy consumption of the construction industry accounts for 30% of the total energy production, with rural areas accounting for 37% of that value [9,10]. Numerous investigations of rural residences have shown that the poor thermal insulation properties of building envelopes, as a function of nonstandard traditional construction materials and methods, results in substantial energy consumption [11–14]. In addition, there is an increasing trend in annual energy consumption due to the generally improving living conditions in rural areas.

In view of the national situation, some attention has been given to this issue. In 2012, the “design standard for energy efficiency of rural residential buildings” was implemented by the Ministry of Housing and Urban–Rural Development, which provided a general national standard to address the issues of rural construction [23]. In an existing study, Hu and He researched a Trombe wall with Venetian blinds, which could increase the average indoor temperature by 5 °C during winter [24]. Zwanzig researched a transparent phase-change material to improve the utilization of solar radiation and promote heat storage and release ability [30,31]. Nayak had analyzed the state of solar cell devices based on performance and device stability in both organic and inorganic photovoltaics (PVs) [42]. Meysam had optimized the solar cell device integration of ultra-thin poly films via a single-step all-dry process [43]. All of these studies focused on the use of a single technology with a high economic cost. However, rural residents cannot afford this kind of investment because of their low income levels. In rural regions, integrated passive energy-saving technologies in combination with minimal input are most appropriate for improving the thermal performance of residences. The processes involved in this approach require a constant consideration of the building performance, including the building envelope, orientation, shading, and natural ventilation, together with the use of energy-efficient systems [25]. Currently, existing research is far from achieving this goal.

In addition, thermal performance research should be combined with local natural climatic conditions and regional architectural forms, especially in rural areas [26–29]. Chinese researchers have been paying close attention to existing rural residential dwellings, such as Yaodong dwellings located in the arid region of China [15] and Tibetan traditional dwellings located in the cold rural area of Gannan [16]. The tubular house is a typical form of traditional residential building that has a long history, as shown in Fig. 7-1. It is abundant in southern China, where the summer is hot and humid, in regions such as Guangdong, Guangxi, Taiwan, and Zhejiang, and it is even widely found in India, analogously called a “tube house”. Tubular houses, which are named for their narrow and long forms, are a good example of a regional building adapted to the local climate. The arrangement, involving a spatial structure connected by internal patios and long corridors, provides a characteristic regional architectural form for research. Since almost all the tubular houses are built in the form of townhouses, the shape factor can be decreased, and the heat loss from the external surfaces can be reduced. Furthermore, two yards enable a reduction in the heating load by introducing sunlight and a reduction in the cooling load by providing ventilation. Thus, it has a positive effect on the energy conservation. If the tubular house can be inherited as a component in the process of urbanization, it will aid in energy conservation and natural ecosystem protection in southern China.

In the past decade, extensive work has been carried out to reveal the thermal mechanisms of tubular houses. A team from the South China Institute of Technology [17] studied the basic principles of insulation and ventilation of tubular houses in Guangzhou. Lin [18] studied the relationship between ventilation, wind pressure, and thermal compression in tubular houses. Gao [19] proposed that increasing the height of the yard could increase the ventilation effect of tubular houses. Ling [20] studied the relationship between the yard area and the energy consumption of tubular houses in Fujian. The famous Indian architect Correa [21] indicated that tubular houses should improve the wind effect of the atrium in the yard to promote indoor ventilation. However, considering the research methodology and technique strategy, numerous researchers have focused on the impact of architectural forms and ventilation. Unfortunately, the energy consumption of tubular houses has not been investigated in previous research, and there remains a lack of experimental validation and quantitative analysis.

Our group from Zhejiang University has studied tubular houses in northern Zhejiang

Province for more than 10 years [22]. Active heating or cooling systems are generally in high demand for buildings in the northern Zhejiang Province due to the "hot in summer and cool in winter" climate of the region. Previous field measurements showed that there was much room for improvement with regard to thermal conditions in such dwellings, with both winter and summer cases requiring particular attention. Analyses of energy consumption and energy-saving potential based on field measurements and computer simulations for dwellings have been widely applied worldwide [16]. In this study, numerical simulations of the annual energy consumption were conducted using the tubular house model in Open-Studio. Different energy efficiency measures were evaluated in terms of the decrease in the annual energy consumption. Subsequently, the results show that various levels of reduction in energy consumption (varying from 1.6% to 30.5%) were achieved by combining different renovations. Furthermore, the relationship between energy consumption and insulation material thickness was established using a highly fitting logarithmic curve. To facilitate the understanding of the research method framework, it is presented in Fig.7-2.

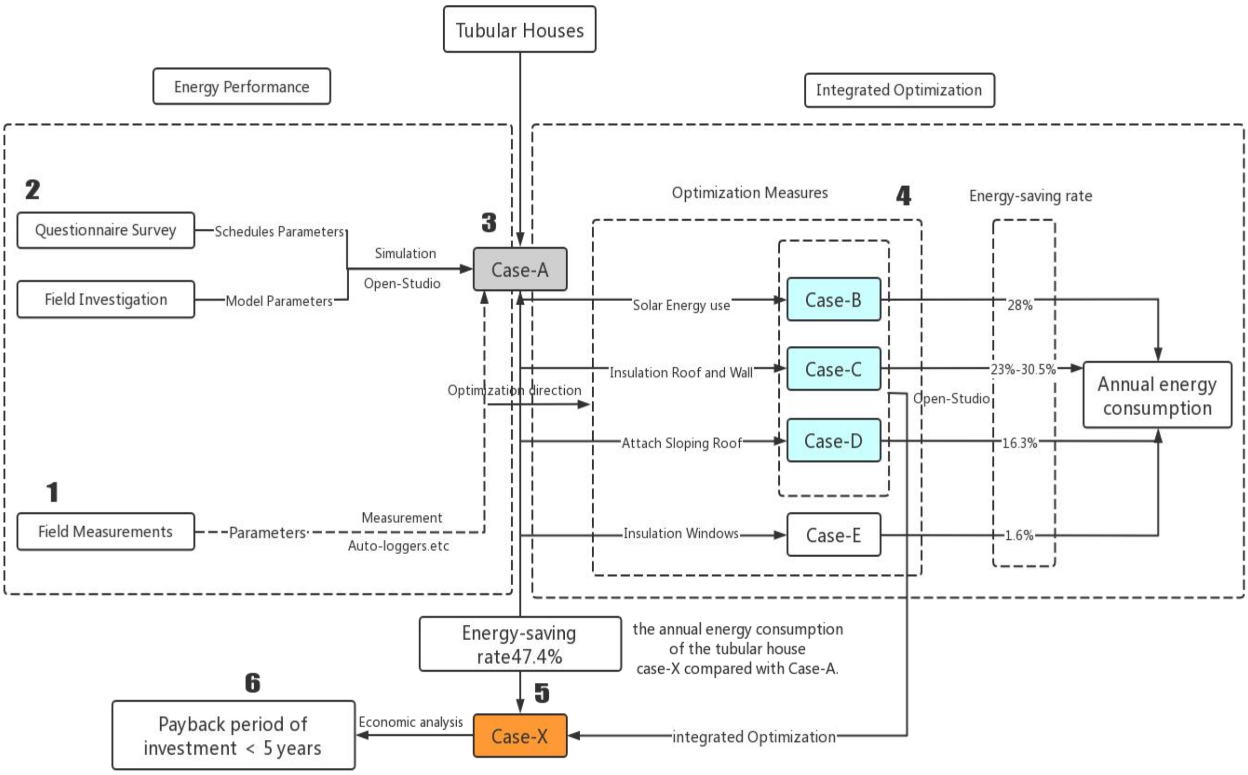


Fig. 7-2. Research methods framework.

Step 1. Field Measurement: A series of experimental measurements were carried out, focusing on the characteristics of the tubular house and the current situation of the thermal comfort, to provide the basis for the study.

Step 2. Investigation: The field investigation about modeling parameters of tubular house and a questionnaire survey about living schedule of 121 households were conducted.

Step 3. Models Built: A typical tubular house was built in Open-Studio as CASE-A according to the parameters in steps 1 and 2.

Step 4. Simulation: Several energy consumption simulations were conducted throughout the winter and summer by combining different renovations to solve the problems found in steps 1 and 2.

Step 5. Analysis: Analyze all the simulation results, taking CASE-X as the integrated optimization measure, with an energy-saving rate of 47.4%.

Step 6. Economic analysis: Take economic analysis of CASE-X with a total renovation cost of CNY 41,143.1, and the payback period of investment within five years.

7.2 Materials and Methods

7.2.1 Research Object

The protection of traditional dwellings has received increasing attention. Energy consumption and indoor comfort are very important factors for their sustainable development [42]. The tubular houses located in Zhang Luwan village in northern Zhejiang Province were chosen as the study buildings. The village has a long history. Furthermore, considering that almost all the tubular houses are built in the form of townhouses rather than separate single houses, the research object of this study was a typical two-story tubular house located in the middle of a group of townhouses as Case-A, shown in Fig. 7-s 1b, 3, and 4a. It faces south, with 3.6 m from east to west and 28 m from north to south, with proportions of 1:7.77, presenting a long and narrow form so as to meet the construction demands of high density at lower layers. Moreover, it can also be divided into three parts by internal yards: the front as the living room, the middle as the dining room, and the back as the kitchen on the first floor, while the second floor features three bedrooms. The height of both the floors is 3 m. The total building area is 154.08 m2. Fig. 7-3 shows a model diagram of a tubular house. This house was fit for a “hot in summer and cold in winter” climate, where active heating or cooling systems are generally in high demand, and it belongs to the highly focused residence group under a public social structure.

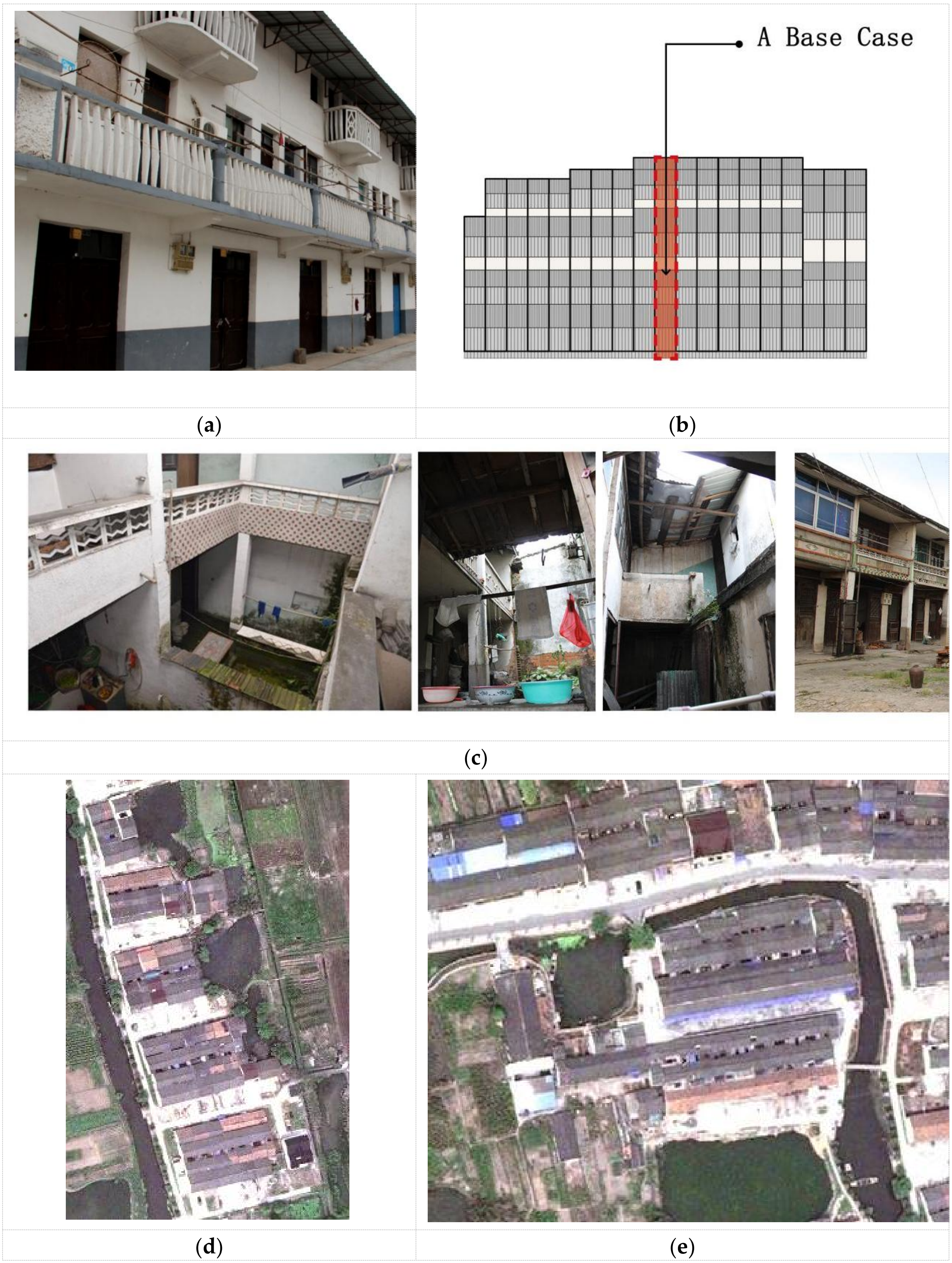
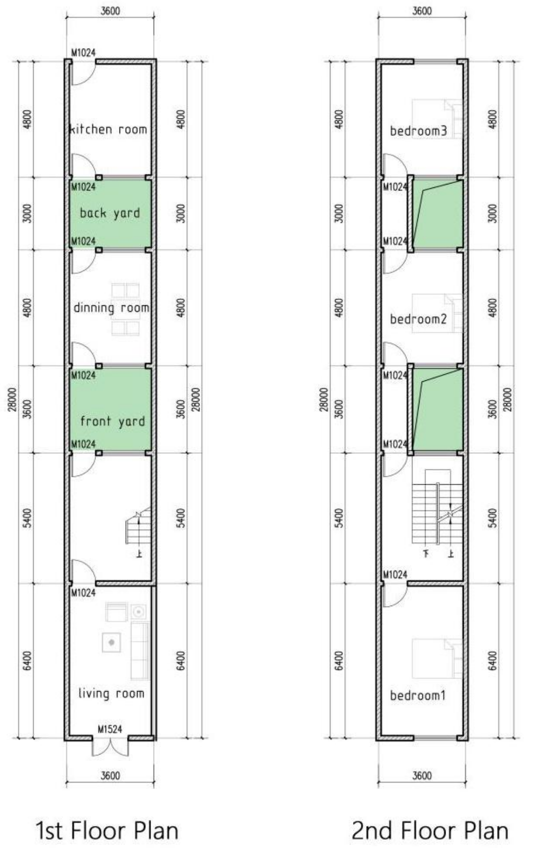
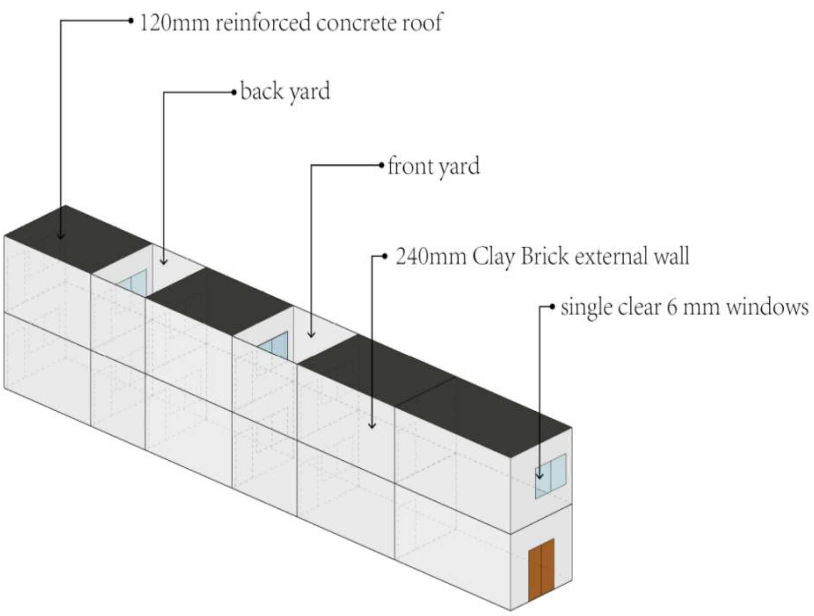


Fig. 7-1. (a,c) Appearance of the traditional tubular houses; (b) a base case in a group arrangement of tubular houses; (d,e) Google map of the tubular houses (2021).



(**a**)



(**b**)

Fig. 7-3. (a) Layout of a tubular house in CAD 2020, and (b) 3D model of a tubular house in Sketchup 2019.

7.2.2. Field Measurements

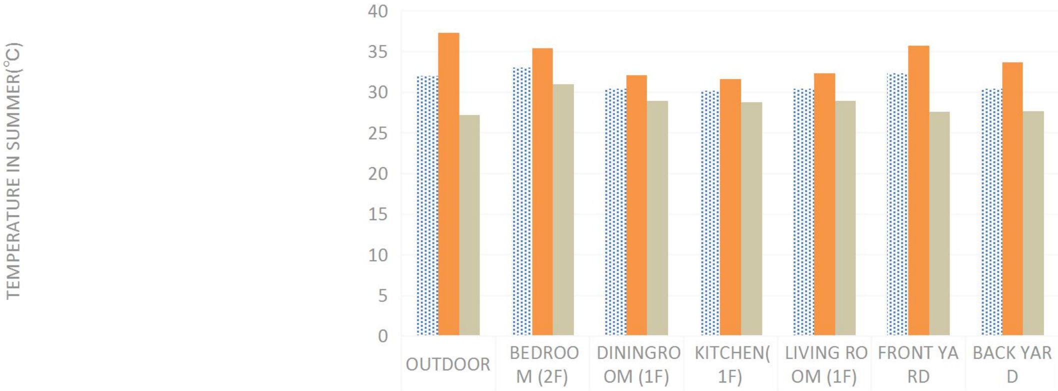
It is important to note that the thermal environment of a traditional tubular house is not always optimal. There is much room for improvement in terms of the thermal conditions in such dwellings, with both winter and summer cases requiring particular attention. The thermal properties of the building envelopes are the main reason for the poor thermal environment. A traditional tubular house is always covered by poor envelopes such as a 120 mm reinforced concrete roof, a 240 mm clay brick external wall, and single clear 6 mm windows, according to the field survey.

A series of experimental measurements were carried out, focusing on the characteristics of the tubular house and local climate in 2019 during winter and summer. Auto-loggers were used to simultaneously monitor the indoor and outdoor air temperatures and relative humidity. These instruments were placed at a height of 1.5 m in the middle of eight zones. There were no active systems in operation when the measurement was conducted. All the field measurements were carried out without active system used, focusing on the characteristics of the tubular house and the current situation of the thermal comfort to provide the basis for the study.

A general summary of the measurements revealed that traditional tubular houses have particular structural and thermal characteristics.

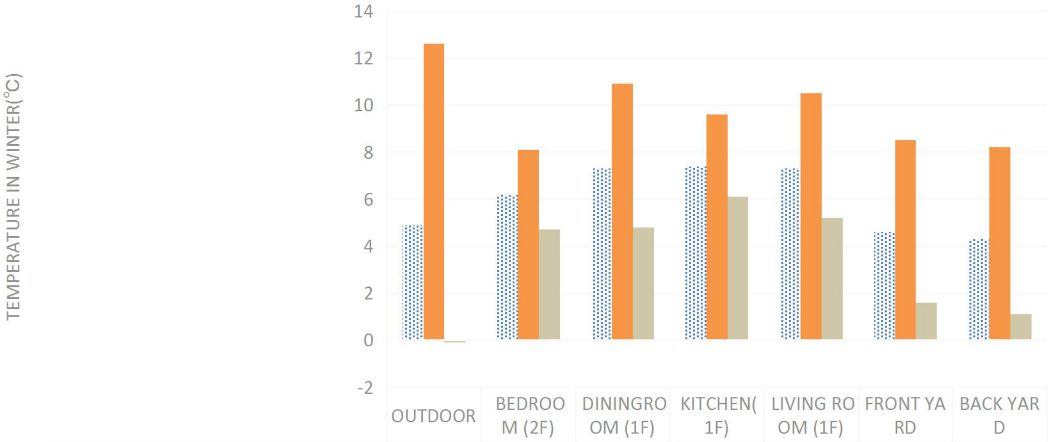
The results in Fig. 7-5 show that the arrangement and spatial structure played important roles in making the indoor temperature lower than the outdoor temperature in summer; however, the temperature in some zones was still too high. In winter, the indoor temperature was higher than the outdoor temperature, reflecting the advantages of a tubular house. However, the average indoor temperature was approximately 4–7 °C; thus, inhabitants would feel cold without a heating method.

In summer, the indoor and courtyard temperatures of the tubular house increased with height. The temperature difference between indoors and outdoors on the second floor was 1.9 °C, while that on the first floor was 5–5.8 °C. In winter, the situation was the opposite. The analysis suggested that in summer, the higher indoor temperature of the second floor was due to insufficient heat insulation by the roof material. In winter, for the zones of the first floor, the heat loss was low because there was no direct heat transfer in the outdoor environment. The temperature of the front yard was slightly lower than that of the back yard because of the higher ratio of width to height of the yard and more sunlight in the former (the width of the front yard is 3600 mm and the back yard is 3000 mm, while they share the same height of 6000 mm). Furthermore, the indoor relative humidity in summer reached 70%. It can be clearly seen that there is much room for improvement in terms of the thermal conditions in such dwellings, with both winter and summer cases requiring particular attention. Thus, a search for feasible improvements is required.



	OUTDOOR	BEDROOM (2F)	DININGROOM (1F)	KITCHEN(1F)	LIVING ROOM (1F)	FRONT YARD	BACK YARD
Average temperature in summer(°C)	32	33	30.4	30.2	30.4	32.3	30.4
The highest temperature in summer(°C)	37.3	35.4	32.1	31.6	32.3	35.7	33.7
The lowest temperature in summer(°C)	27.2	31	28.9	28.8	28.9	27.6	27.7

(a)



	OUTDOOR	BEDROOM (2F)	DININGROOM (1F)	KITCHEN(1F)	LIVING ROOM (1F)	FRONT YARD	BACK YARD
Average temperature in winter(°C)	4.9	6.2	7.3	7.4	7.3	4.6	4.3
The highest temperature in winter(°C)	12.6	8.1	10.9	9.6	10.5	8.5	8.2
The lowest temperature in winter(°C)	-0.1	4.7	4.8	6.1	5.2	1.6	1.1

(b)

Fig. 7-5. (a) Field measurement results of indoor and outdoor temperature in summer, and (b) field measurement results of indoor and outdoor temperature in winter.

7.2.3. Computer Simulation

1) Open-Studio

The current study addressed this problem via simulation using the energy simulation program Open-Studio as the main analysis tool. Open-Studio is a cross-platform collection of software tools to support whole-building energy modeling using Energy-Plus and advanced daylight analysis using Radiance. Open-Studio includes graphical interfaces and a software development kit (SDK). Open-Studio features the same algorithms and data as Energy-Plus, which is a complete building design and environmental analysis tool that covers a broad range of simulation and analysis functions, covering thermal properties, energy, lighting, shading, and resources. As described by many researchers [30,32–34] who used this software to evaluate the required design configurations in their studies, it was chosen as the most suitable for the objectives of the current study because it is a highly visual building simulation tool. Using simulation methods through the works of EnergyPlus and Open-Studio for energy conservation purposes shows high applicability in many studies [35–40]. Models of the tubular house were built for comparative analysis, and energy consumption simulations were conducted throughout the winter and summer.

2) Simulation Parameters

The weather data file for Open-Studio was obtained from the EnergyPlus web page (Hangzhou city.epw), and the building materials were either chosen from the Energy-Plus library or created from the user library. Tables 1 and 2 display the zone and material properties of the tubular house model, respectively.

Table 1. Material descriptions of the tubular house model.

Component	Layers	Thickness (mm)	Thermal Conductivity (W/(m·K))	Density (kg/m3)	Specific Heat (J/kg·K)	Heat Transfer Coefficient (W/(m2·K))
CASE-A roof	Reinforced concrete	120	1.74	2500	920	
CASE-A external wall	240 clay brick	240	0.81	1800	1050	
CASE-A internal wall	120 clay brick	120	0.81	1800	1050	
CASE-A floor	Reinforced concrete	100	1.74	2500	920	
CASE-A windows	Single clear 6 mm	6				6.4
CASE-C insulation roof	XPS	10–100	0.03	27		
CASE-C insulation wall	XPS	10–100	0.03	27		
CASE-E double single-glazed windows						3.0

Table 2. Zone properties of the tubular house model.

Zone Properties	Description
Zone number	6
The type of active or passive system used	Electric heating coil system (in winter) Natural ventilation (in summer, when 12 °C < T outdoor < T inside) DX cooling coil system (in summer)
Comfort lower band	18 °C
Comfort upper band	26 °C
Occupants' metabolic rate	Sedentary activity: 70 W (6 persons)

3) Simulation Case Design: Winter Heating Case/Summer Mixed Cooling Case

Because the active system used for both cooling during summer and heating during winter for the internal spaces is AC in southern China, the electricity from the power grid was chosen as the energy supply pattern in the simulation throughout the year. The setting parameters in the simulation need to be adjusted considering the air-conditioned conditions and occupancy schedules for various rooms.

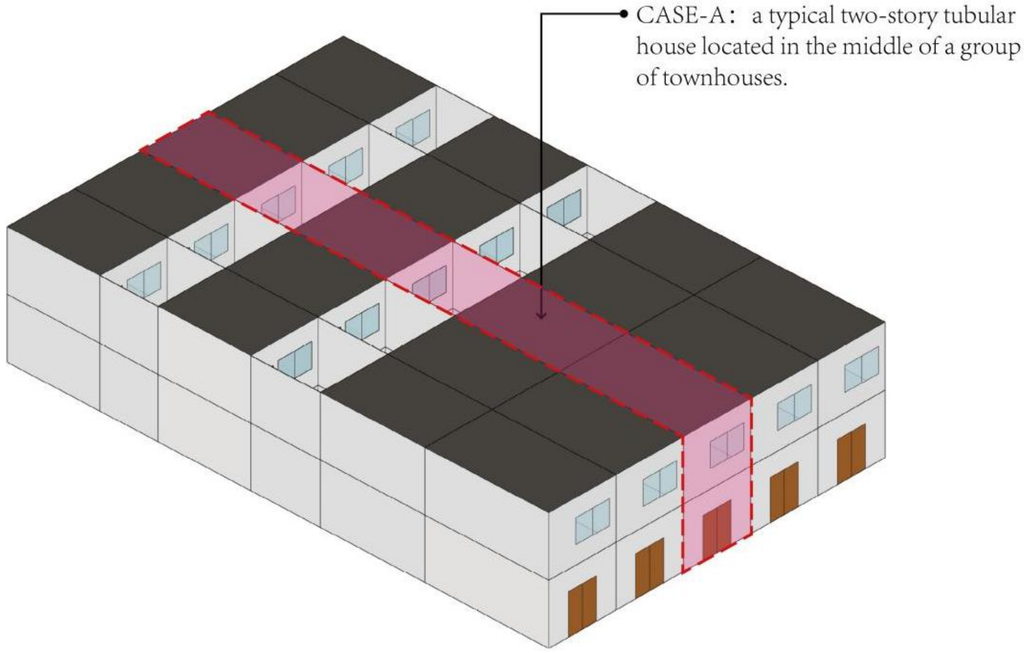
In this study, the energy performance of five buildings (CASE-A/CASE-B/CASE-C/CASE-D/CASE-E) was investigated as a function of two operational cases. In the winter heating case, the building was airtight, and air exchange between the inside and outside occurred solely via infiltration. The inside air temperature was controlled using a heating system (18 °C in this study). In the summer mixed cooling case, the buildings were operated in a mixed mode of active cooling and natural ventilation. More specifically, if the outside air temperature was lower than the inside temperature and higher than the natural ventilation set-point temperature (12 °C in this study), then natural ventilation was introduced to chill the indoor air. If the cooling capacity of the natural ventilation is insufficient, the active cooling system operates to maintain the indoor air set-point temperature (26 °C in this study).

The energy consumed by the system was in the form of electricity, and the COP of the cooling system was 1.67. The internal gains (including lighting and equipment) were designed to be 4 and 5 W/m2. All interior spaces were heated or cooled, except for the yards.

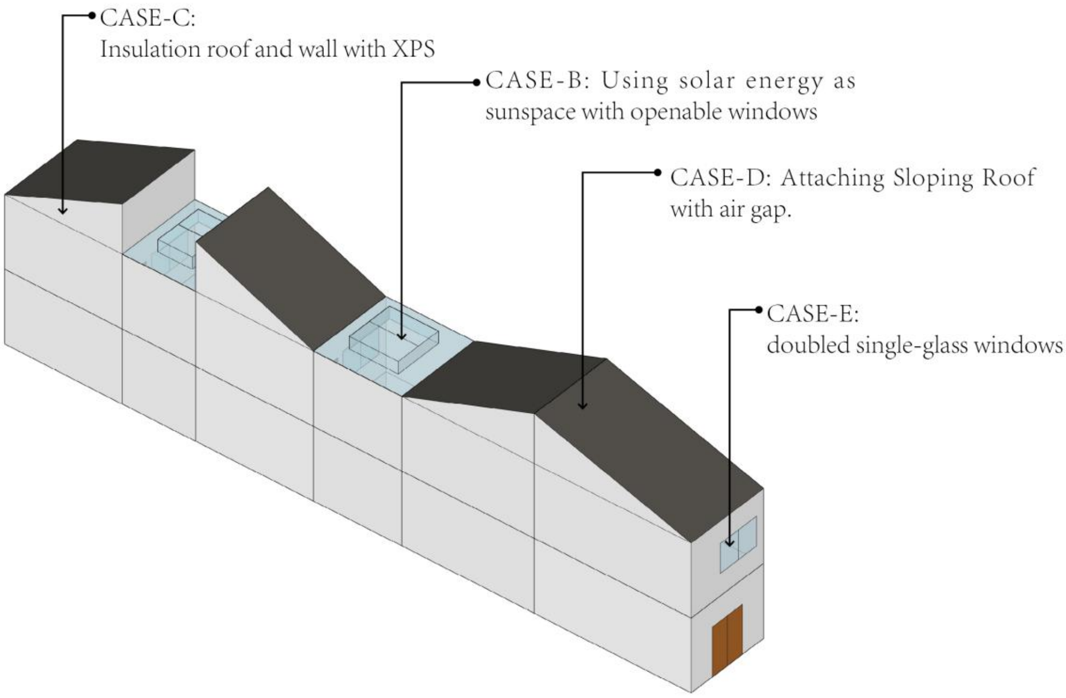
According to a questionnaire survey of 121 households, there were six members in most families. Considering daily life and sleep habits, indoor occupancy reaches its maximum during mealtimes, at 7:00–8:00 a.m., 1:00–2:00 p.m., and 5:00–6:00 p.m. Outside of these times, an average low occupancy of two persons is typical. The sensible heat was quantified at 70 W for each person with light activity.

4) Energy Saving Using Different Measures

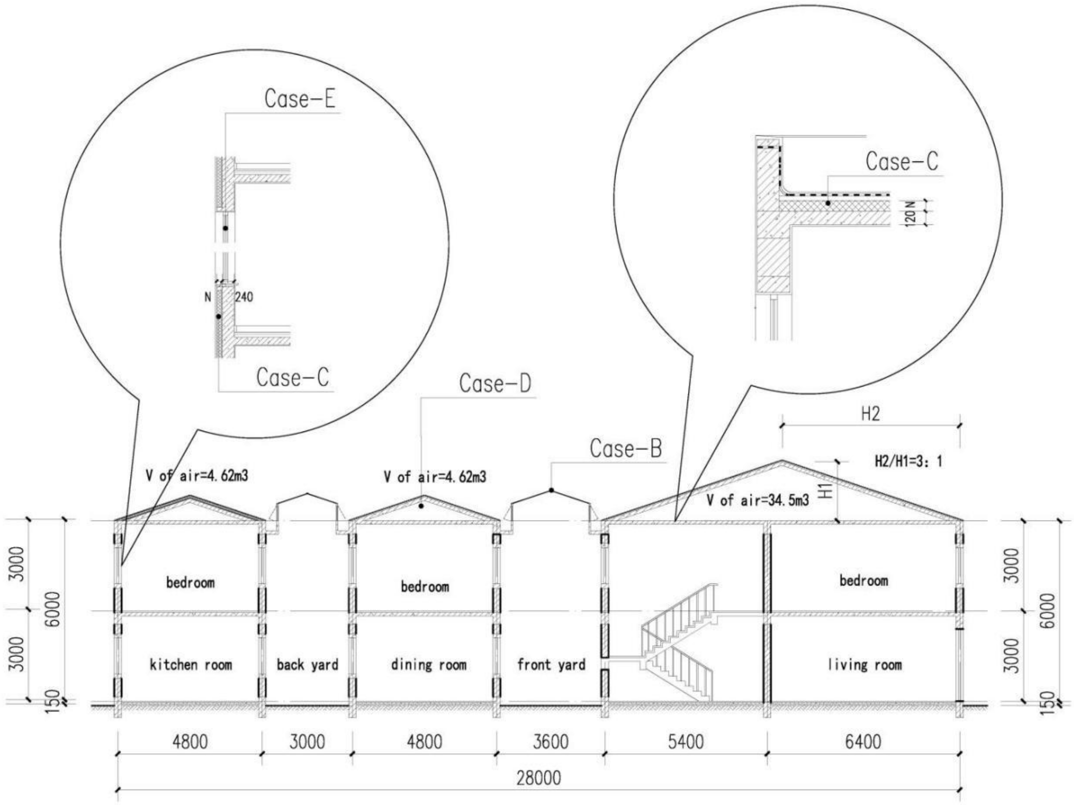
Optimizing rural residences with low economic inputs to minimize energy consumption is vital. Considering that the thermal properties of the building envelopes are the main reason for the poor thermal environment, energy efficiency measures could be introduced to address these aspects, such as decreasing the shape factor (CASE-A), using solar energy with a sunroom (CASE-B), introducing a thermal insulation layer into the external wall and roof (CASE-C), attaching a sloping roof with an air gap (CASE-D), and installing double single-glazed windows (CASE-E), as shown in Fig. 7-4.


CASE-A：a typical two-story tubular house located in the middle of a group of townhouses.

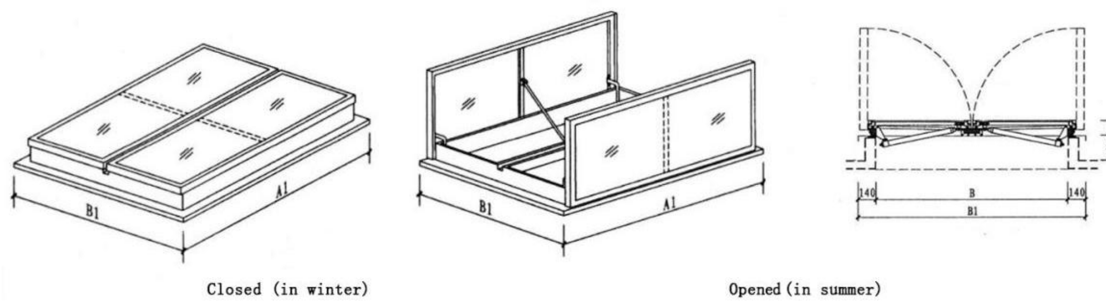
(**a**)


CASE-C:
Insulation roof and wall with XPS
CASE-B: Using solar energy as sunspace with openable windows
CASE-D: Attaching Sloping Roof with air gap.
CASE-E:
doubled single-glass windows

(**b**)



(c)



(d)

Fig. 7-4. (a) The Image of CASE-A, (b) image of new tubular houses with different energy efficiency measures in Sketchup 2019, (c) image of new tubular houses with different energy efficiency measures in Cad2021, and (d) image of the sun-space windows.

7.3. Results and Discussion

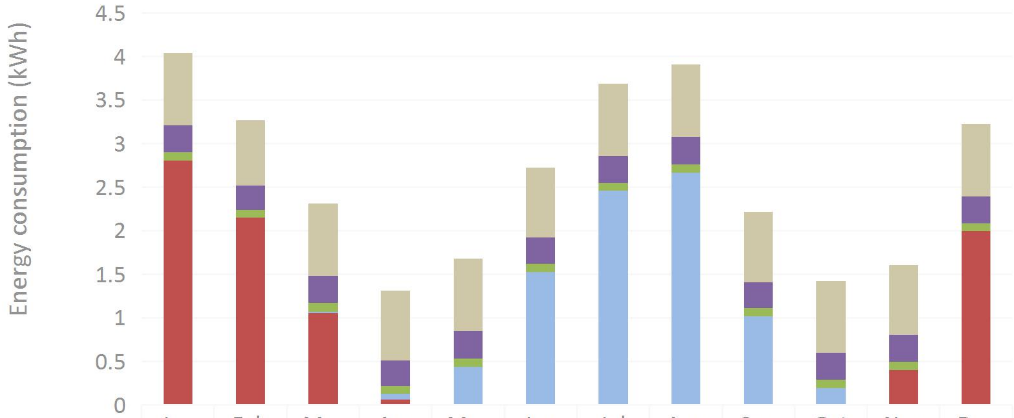
7.3.1. Simulation Results of CASE-A

Most tubular houses are built in the form of townhouses rather than separate single houses. Hence, the shape factor can be decreased, and the heat loss from the external surfaces can be reduced.

CASE-A is a typical two-story tubular house located in the middle of a group of townhouses with an area of 154.08 m2, while the modified building area was 115.20 m2. According to the CASE-A analysis in Open-Studio, the annual energy consumption of the tubular house was 21,603 kWh in total, and 187.53 kWh/m2 in the building area. The heat load was 55.05 W/m2, while the cooling load was 54.04 kWh/m2.

As shown in Fig. 7-s 6–8, it is evident that both the cooling and heating loads accounted for approximately 27% of the total energy consumption. The energy-saving renovation of the tubular house should focus on both winter and summer, especially in July (average outdoor temperature of 27.6 °C), August (average outdoor temperature of 28.2 °C), January (average outdoor temperature of 5.2 °C), and February (average outdoor temperature of 6.6 °C). On the other hand, April and October represent the most comfortable seasons, with average outdoor temperatures of 16.2 °C and 19.2 °C, respectively, and the energy consumption during these seasons is almost zero.

Fig. 7-9 shows the peak loads for each space. This suggests that both the cooling and heating peak loads of the second floor are much higher than those of the first floor because of insufficient roof insulation. Furthermore, the peak loads of the rooms beside the courtyard are lower than those of the other rooms, suggesting that the courtyard enables a reduction in the heating load by introducing sunlight and a reduction in the cooling load by providing ventilation. Thus, it has a positive effect on the energy conservation.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fans	829.86	749.55	829.86	803.09	829.86	803.09	829.86	829.86	803.09	829.86	803.09	829.86
Interior Equipment	308.93	280.27	314.94	292.56	314.94	303.38	304.12	314.94	298.57	308.93	303.38	304.12
Interior Lighting	95.65	87.52	98.61	90.91	98.61	94.91	94.61	98.61	93.87	95.65	94.91	94.61
Cooling	0.51	0.41	19.6	70.12	437.52	1524.1	2457.6	2666.5	1018.5	182.83	2.88	0.66
Heating	2805.8	2153.5	1052.7	60.25	0.28	0.09	0.1	0.03	0.22	9.54	402.24	1993.8

Fig. 7-6. Energy consumption of various equipment of CASE-A.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Outdoor Air Dry Bulb (C)	5.2	6.6	10.8	16.3	21.2	24.9	27.6	28.2	24.1	19.2	12.7	6.5
Cooling Load (kWh)	0.51	0.41	19.6	70.12	437.52	1524.11	2457.64	2666.56	1018.53	182.83	2.88	0.66
Heating Load (kWh)	2805.86	2153.51	1052.75	60.25	0.28	0.09	0.1	0.03	0.22	9.54	402.24	1993.83

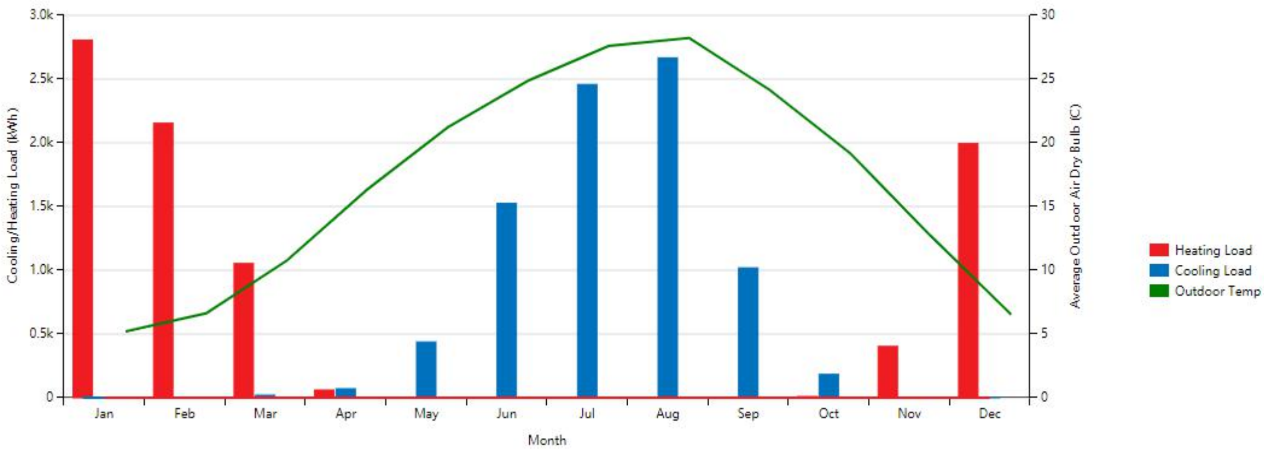


Fig. 7-7. Monthly cooling load and heating load (kWh), as well as the monthly average outdoor temperature (°C).

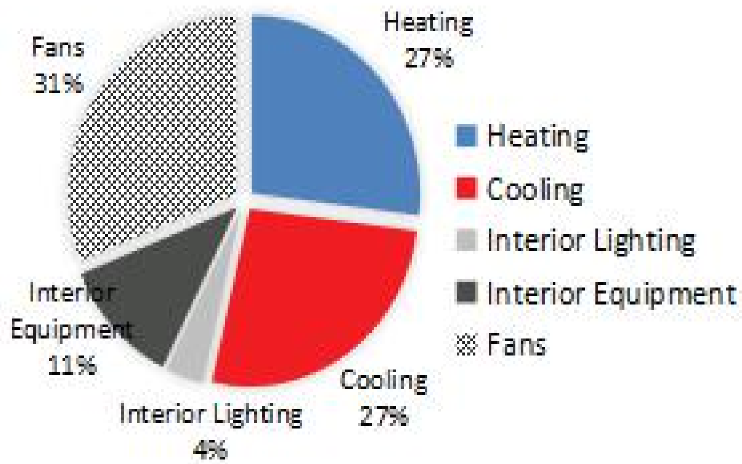


Fig. 7-8. Energy consumption of various equipment.

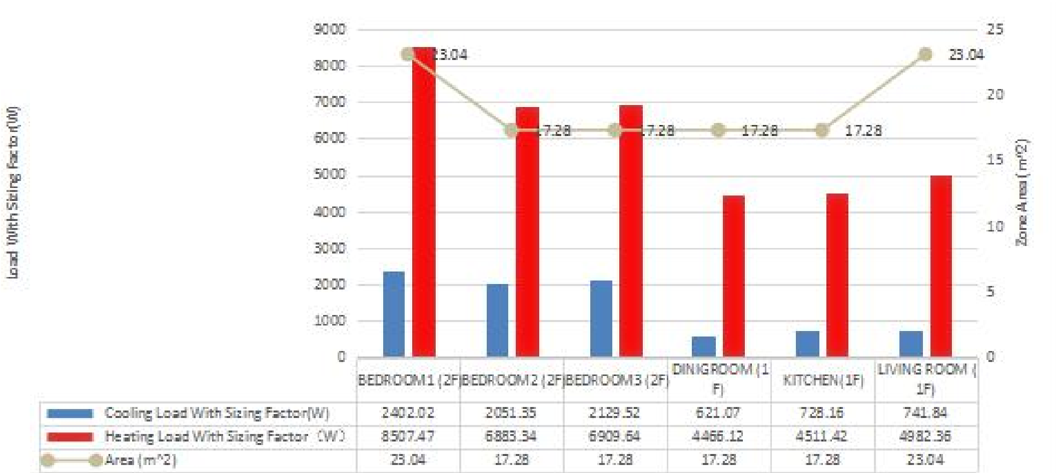


Fig. 7-9. Cooling peak load and heating peak load of each zone, along with the sizing factor (W).

7.3.2. Simulation Results of using Solar Energy and Sunroom

CASE-B: Two yards were transformed into sunrooms with openable windows added to the roof. These windows were closed in winter for indoor heat storage and opened in summer to increase ventilation, thereby reducing energy consumption.

As shown in Fig. 7-10 and 11, in CASE-B, the annual consumption decreased from 187.85 to 134.98 kWh/m2, with an energy-saving rate of 28%, providing the most effective energy-saving measures.

The original tubular houses feature a narrow patio to extract wind and accelerate indoor air circulation. After the renovation, as shown in Fig. 7-12, in summer, the high windows were opened, and the glass roof was heated by solar radiation, which enhanced the effect of wind extraction and discharged the indoor heat. In winter, the windows were closed to form a greenhouse effect, which helped to maintain indoor heat. In this way, tubular houses can have a better energy-saving effect and become more economical.

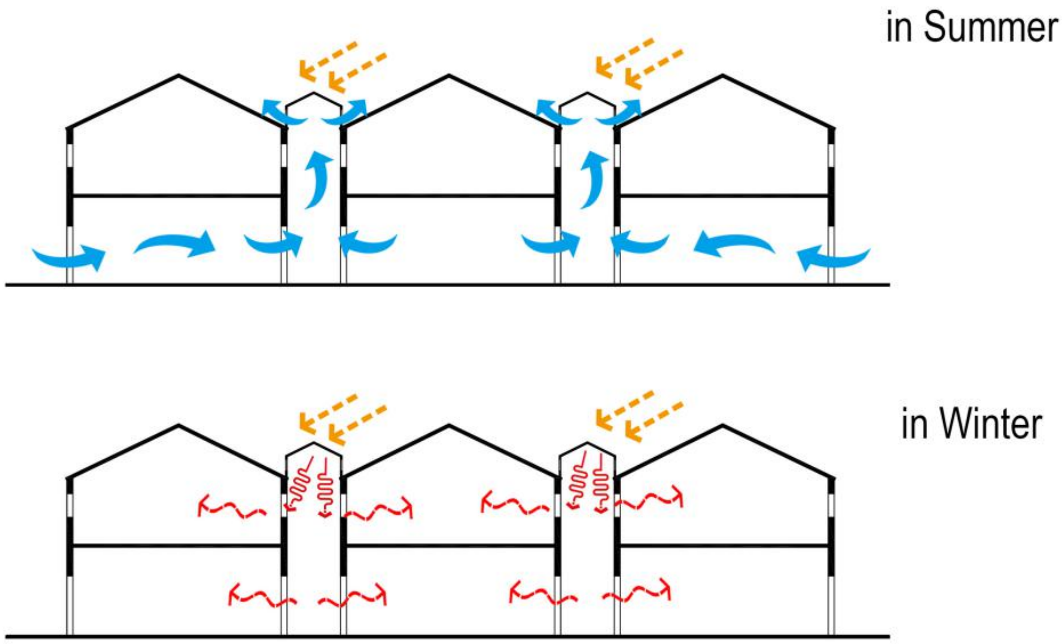


Fig. 7-12. Working diagram of using solar energy and a sunroom in summer and winter.

7.3.3. Simulation Results of insulation Roof and Wall

CASE-C: Thermal insulation in external walls and roofs has become a widespread energy-saving measure for village buildings in China. Extruded polystyrene and expansion polystyrene boards, commonly known as XPS and EPS boards, are generally used as insulation materials. An extruded polystyrene board was selected as the insulation material for the simulation because of its superior adhesive properties. Insulation materials (XPS) with different thickness (10–100 mm) were added to the roof (CASE-C roof) or walls (CASE-C wall) to assess their effect on annual energy consumption.

As shown in Fig. 7-13, thickening the insulation materials of the roof from 0 to 100 mm led to a decrease in winter energy requirements to 144.95 kWh/m2, with an energy-saving rate of 23%. Accordingly, thickening the insulation materials of the walls from 0 to 100 mm could also decrease the winter energy requirement to 130.58 kWh/m2, for an energy-saving rate of 30.5%. It is evident that the insulation material of the walls was more effective because the exterior wall area was larger than that of the roof. More importantly, the energy-saving rate decreased slowly when the thickness of the insulation materials was increased beyond 30 mm, according to the trend shown in Fig. 7-13. Considering the economic factors, it is recommended to choose 30 mm XPS, which was found to be the most efficient.

By simulating the impact of different XPS thicknesses on the energy consumption of tubular houses, a curve regression simulation was performed on the data. The relationship between energy consumption and XPS material thickness was established using a highly fitting logarithmic curve. The specific energy consumption (EIR) and thickness of the roof insulation material XPS (N) were fitted to the following logarithmic function: $EIR = 177.469 - 7.317 \times \ln(N)$, where N = 10, 20, 30, …, 90, 100 (see Equation (1)), with a fitting index $R2 = 0.969$ and a Pearson correlation coefficient $p < 0.0001$, much lower than the limit of 0.01, indicating a high degree of fitness, as shown in Fig. 7-14. The specific energy consumption (EIW) and thickness of the wall insulation material XPS (N) were fitted to the following logarithmic function: $EIW = 194.114 - 14.173 \times \ln(N)$, where N = 10, 20, 30, …, 90, 100 (see Equation (2)), with a fitting index $R2 = 0.986$ and a Pearson correlation coefficient $p < 0.0001$, much lower than the limit of 0.01, indicating a high degree of fitness, as shown in Fig. 7-15. A highly fitting logarithmic curve may rigorously guide the choice of insulation material thickness in the energy-saving renovation of other tubular houses.

7.3.4. Simulation Results of attaching Sloping Roof with Air Gap

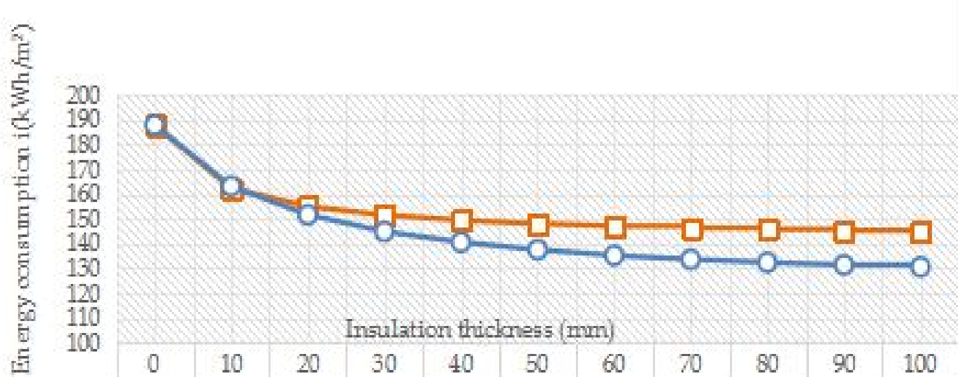
CASE-D: The traditional tubular house has a flat roof without any insulation measures. CASE-D involved adding a sloping roof with an air gap to the top of the house, thereby not only adapting to the architectural features of this area, but also contributing to roof insulation (see Fig. 7-4).

As shown in Fig. 7-10, in CASE-D, the annual energy requirement decreased from 187.85 to 157.36 kWh/m2, with an energy-saving rate of 16.3%, thus exhibiting a significant result.

7.3.5. Simulation Results of insulation Windows

CASE-E: The insulating level of windows in traditional tubular houses is also relatively poor. All single clear windows with an aluminum window frame commonly used in traditional tubular houses were replaced with double single-glazed windows.

As shown in Fig. 7-10, in CASE-E, the annual energy requirement decreased from 187.85 to 184.88 kWh/m2, with an energy-saving rate of only 1.6%, thus providing little reduction in energy consumption. This is because the external window area of tubular houses is quite small, and simple double-glazing would not have much of an effect.



	0	10	20	30	40	50	60	70	80	90	100
EIR(kWh/m2)	187.85	162.27	155.01	151.47	149.42	148.05	147.06	146.35	145.78	145.32	144.95
EIW(kWh/m2)	187.85	163.1	151.6	144.87	140.53	137.48	135.19	133.62	132.4	131.37	130.58

Fig. 7-13. Energy consumption for insulation materials (XPS) of different thickness (kWh/m2).

$$EIR = 177.469 - 7.317 \times \ln(N),\ N = 10, 20, 30, \ldots, 90, 100;\ R2 = 0.969, \quad (1)$$

where EIR is the energy consumption in the case of the insulation roof (kWh/m2) and N is the insulation thickness of XPS.

$p < 0.05$, ** $p < 0.01$.

Parameter Estimates of EIR and N

	Unstandardized Coefficients		Standardized Coefficients	t	p
	B	Standard Error	Beta		
Constant	177.469	1.798	-	98.679	0.000 **
ln(N)	−7.317	0.464	−0.984	−15.77	0.000 **

$$EIW = 194.114 - 14.173 \times \ln(N),\ N = 10, 20, 30, \ldots, 90, 100;\ R2 = 0.986, \quad (2)$$

where EIR is the energy consumption in the case of the insulation wall (kWh/m2) and N is the insulation thickness of XPS.

p < 0.05, ** p < 0.01.

Parameter Estimates of EIW and N

	Unstandardized Coefficients		Standardized Coefficients	t	p
	B	Standard Error	Beta		
Constant	194.114	2.152	-	90.21	0.000 **
In(N)	−14.173	0.555	−0.994	−25.528	0.000 **

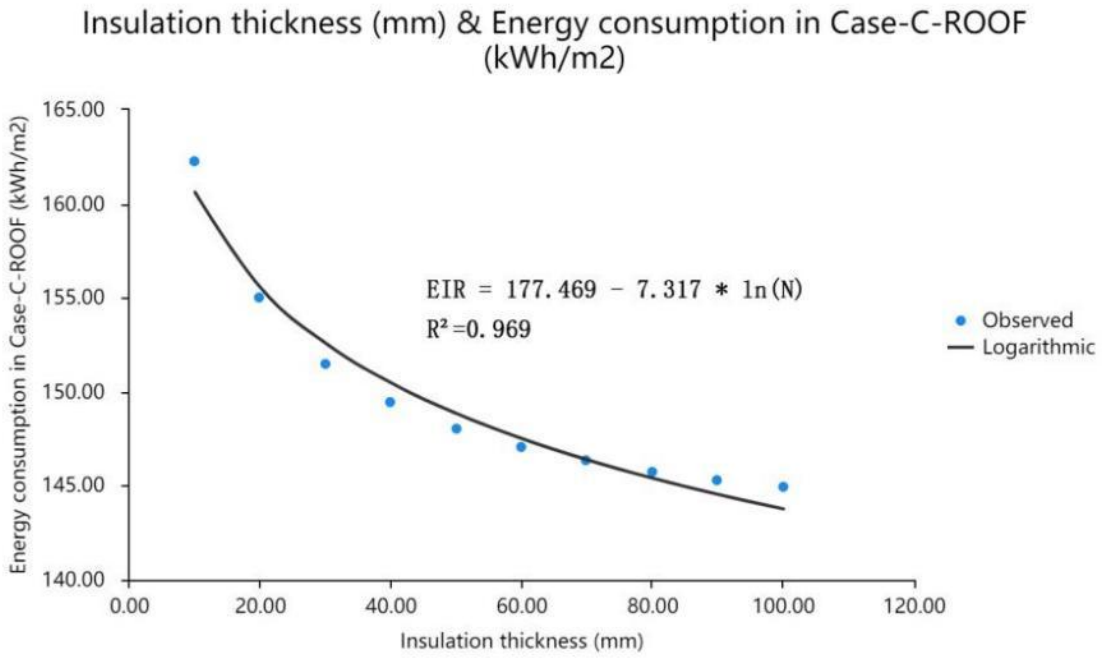


Fig. 7-14. Logarithmic curve of EIR and N.

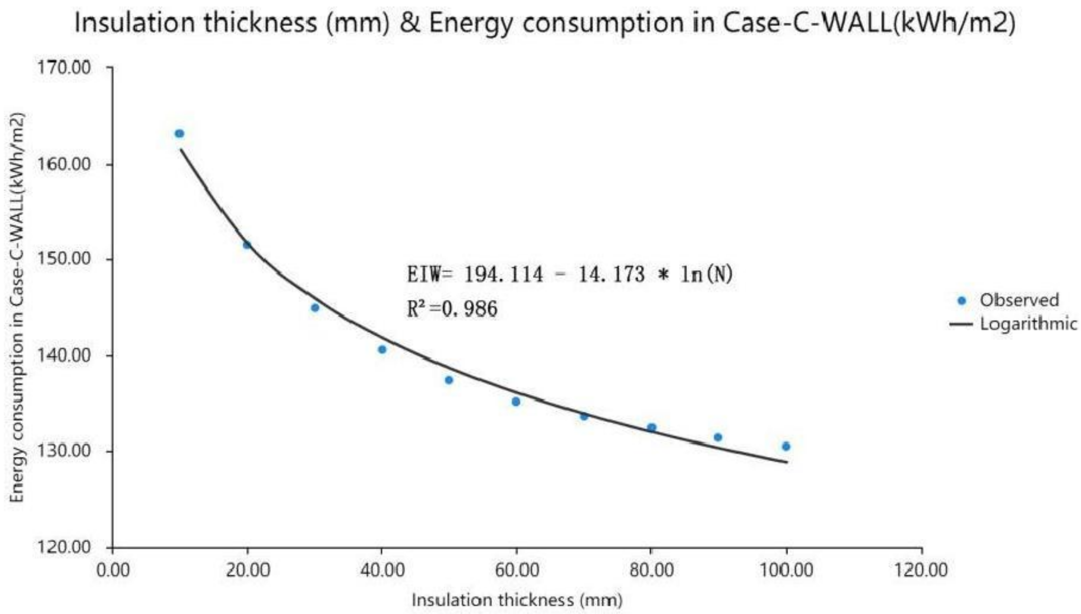
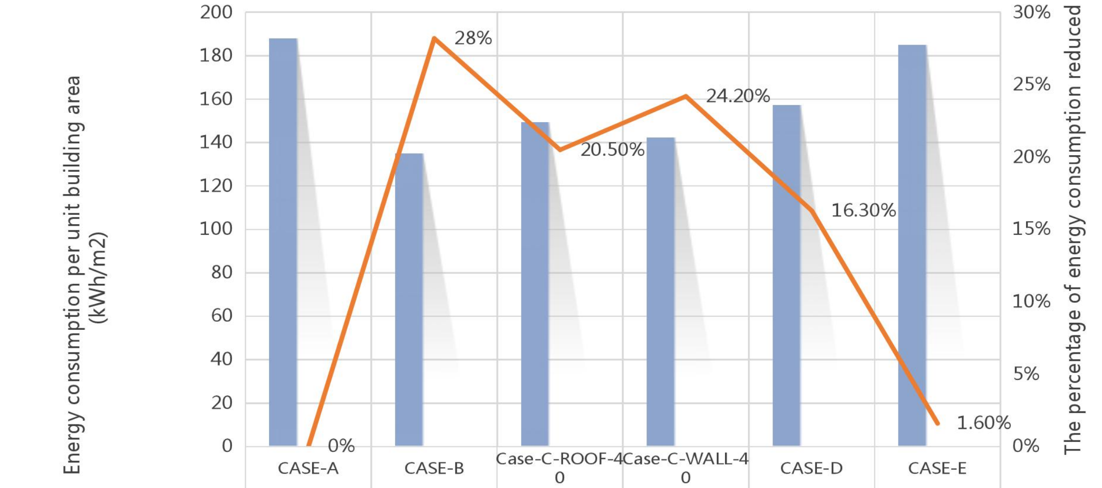
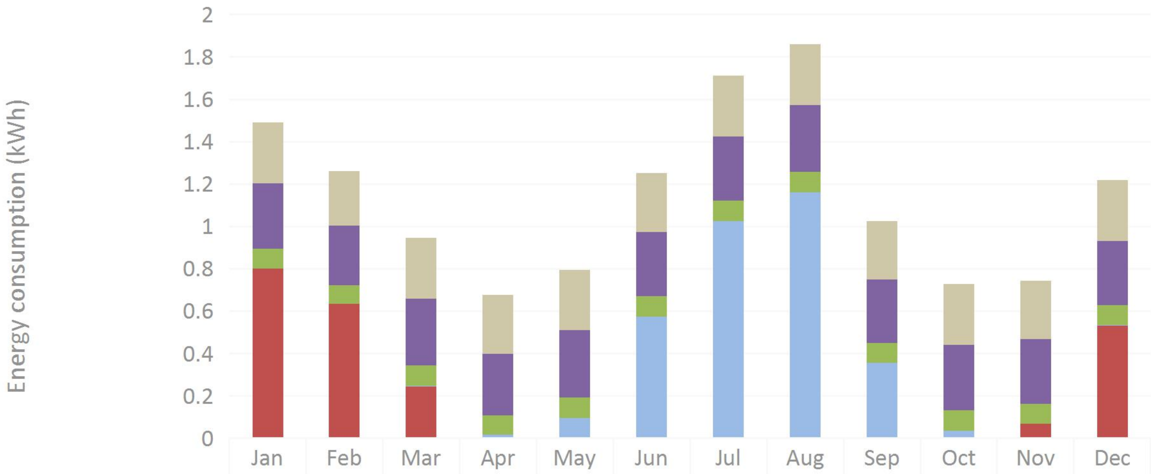


Fig. 7-15. Logarithmic curve of EIW and N.



	CASE-A	CASE-B	Case-C-ROOF-40	Case-C-WALL-40	CASE-D	CASE-E
Energy consumption	187.85	134.98	149.42	142.4	157.36	184.88
Energy consumption reduced	0%	28%	20.50%	24.20%	16.30%	1.60%

Fig. 7-10. Energy-saving rates of different measures. CASE-A: a traditional tubular house built in the form of townhouses; CASE-B: solar energy use with sunroom; CASE-C-ROOF-40: insulation roof with 40 mm XPS; CASE-C-WALL-40: insulation wall with 40 mm XPS; CASE-D: sloping roof with air gap; CASE-E: double single-glazed windows.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fans	286.65	258.91	286.65	277.41	286.65	277.41	286.65	286.65	277.41	286.65	277.41	286.65
Interior Equipment	308.93	280.27	314.94	292.56	314.94	303.38	304.12	314.94	298.57	308.93	303.38	304.12
Interior Lighting	95.65	87.52	98.61	90.91	98.61	94.91	94.61	98.61	93.87	95.65	94.91	94.61
Cooling	0.18	0.24	1.22	10.19	95.87	575.53	1026.0	1160.6	356.53	37.15	0.47	0.28
Heating	800.48	635.68	245.98	7.05	0.3	0.1	0.14	0.07	0.2	0.32	69.25	533.79

Fig. 7-11. Energy consumption of various equipment of the CASE-X.

7.3.6. Simulation Results of integrated Optimization

Based on all the simulation results above, considering the economic factors, the best integrated optimization measures for tubular houses in northern Zhejiang should be conducted as follows: CASE-B + CASE-C (30 mm) + CASE-D = CASE-X. The optimal measures were determined by all the simulation results of CASE-B to E. As shown in Fig. 7-10, CASE-B, CASE-C, and CASE-D all provided significant results in terms of energy consumption, while CASE-E provided little reduction, with an energy-saving rate of only 1.6%. According to the CASE-X analysis in Open-Studio, the annual energy consumption of the tubular house was 13,719 kWh in total, and 86.83 kWh/m2 in the building area, with an energy-saving rate of 47.4% compared with CASE-A. The heat load was 14.52 kWh/m2, while the cooling load was 20.66 kWh/m2, and the heat load was more optimized than the cooling load.

According to the National Bureau of Statistics of China, the consumption of 1 kWh of electrical power requires the burning of 0.404 kg of standard coal, which results in CO_2 emissions of 0.872 kg. The CO_2 emissions corresponding to CASE-A and CASE-X were 18,838.21 kg (21,603 kWh) and 11,962.9 kg (13,719 kWh), respectively, with a total difference of 6875 kg.

7.3.7. Economic Analysis of Renovation

Economic efficiency is an important factor restricting building renovations. Among insulation materials [30], the expansion of polystyrene board (EPS) and extruded polystyrene board (XPS) insulation are widely used. The XPS boards were chosen as exterior wall insulation and priced at 80 CNY/m2. Subjected to geographical and technological limitations, existing solar rooms mainly use aluminum–plastic materials with an average price of 120 CNY/m2.

According to the simulation results, the annual accumulated heat load of the building was 7884 kW h before rebuilding. Converting the saved heat load of renovation measures into electricity priced at CNY 1.1, the total energy-saving benefit is CNY 8672.4.

As shown in Table 3, the sunroom costs CNY 4752, accounting for only 11.5% of the total cost of energy-saving renovation, with the most effective energy-saving rate of 28%. Attaching a sloping roof accounted for 46.6% of the total cost, with the most effective energy-saving rate of 16.3%. The total renovation cost is CNY 41,143.1, and the payback period of investment is within 5 years (4.75).

Table 3. Energy-saving renovation costs.

Component	Energy-Saving Materials	Price (CNY/m2)	Area (m2)	Labor Cost (CNY/per)	Total Cost (CNY)
Insulation roof	30-XPS	80	77.04	80	12326.4
Insulation wall	30-XPS	80	30.56	80	4889.6
Sunroom	Aluminum frame window	120	23.76	80	4752
Sloping roof	Reinforced concrete	150	83.376	80	19,175.1
Total cost					41,143.1

7.4. Conclusions

Tubular houses, named for their narrow and long forms, are common in southern China. They are a good example of a regional building that is adapted to the local climate. According to the results of field measurements, the thermal environment of traditional tubular houses is not always optimal, whereby both the cooling and heating loads account for approximately 27% of the total energy consumption. Thus, energy-saving renovations of tubular houses should focus on both winter and summer, especially in the months of July, August, January, and February. On the other hand, April and October are the most comfortable seasons, with average outdoor temperatures of 16.2 °C and 19.2 °C; as such, the energy consumption during these seasons is almost zero.

In the CASE-B to E simulation, different energy efficiency measures were evaluated in terms of their effects on annual energy consumption. The results show that various levels of reduction in energy consumption (varying from 1.6% to 30.5%) were achieved by combining different renovations. Among them, using solar energy with a sunroom was found to be the most effective approach, with an energy-saving rate of 28%, followed by the approach of attaching insulation to the walls and roof, with an energy-saving rate ranging from 13.2% to 30.5%. Furthermore, it was found that the energy-saving rate decreased slowly when the thickness of insulation materials was increased beyond 30 mm, according to the trend of the logarithmic curve. Thus, considering the economic factors, it is recommended to choose 30 mm XPS, which was found to be the most efficient. Additionally, attaching a sloping roof with an air gap to the top of the house was also successful, with an energy-saving rate of 16.3%; however, double single-glazed windows provided little reduction in energy consumption, with an energy-saving rate of only 1.6%, owing to the small external window area of tubular houses.

The relationship between energy consumption and XPS material thickness was also established using a highly fitting logarithmic curve. The specific energy consumption (EIR) and thickness of the roof insulation material XPS (N) were fitted to the following logarithmic function: $EIR = 177.469 - 7.317 \times \ln(N)$, with a fitting index R2 = 0.969 and a Pearson correlation coefficient $p < 0.0001$. The specific energy consumption (EIW) and thickness of the wall insulation material XPS (N) were fitted to the following logarithmic function: $EIW = 194.114 - 14.173 \times \ln(N)$, with a fitting index R2 = 0.986 and a Pearson correlation coefficient $p < 0.0001$. This conclusion can effectively guide the choice of insulation material thickness in the energy-saving renovation of tubular houses.

The best integrated optimization measures for tubular houses in northern Zhejiang should be conducted as follows: CASE-B + CASE-C (30 mm) + CASE-D = CASE-X ,with an energy-saving rate of 47.4% compared with CASE-A. The total renovation cost is CNY 41,143.1, and the payback period of investment is within 5 years (4.75).

This study showed that the application of environmental adaptations to tubular houses, along with improved thermal insulation, can drastically reduce energy consumption. If this is inherited as a component in the process of urbanization, it will aid in energy conservation and natural ecosystem protection in Northern Zhejiang.

References

[1]. Berardi, U. Clarifying the new interpretations of the concept of sustainable building. Sustain. Cities Soc. 2013, 8, 72–78.

[2]. Son, H.; Kim, C.; Chong, W.K.; Chou, J.S. Implementing sustainable development in the construction industry: Constructors' perspectives in the us and korea. Sustain. Dev. 2011, 19, 337–347.

[3]. The United Nations Framework Convention on Climate Change. 2008. Available online: http://unfccc.int/essential_background/kyoto_protocol/items/1678.php (accessed on 22 March 2016).

[4]. Energy Performance of Buildings Directive 2002/91/EC(EPBD); European Commission: Brussels, Belgium; Luxembourg, 2002.

[5]. Rodriguez-Ubinas, E.; Montero, C.; Porteros, M.; Vega, S.; Navarro, I.; Castillo-Cagigal, M. Passive design strategies and performance of Net Energy Plus Houses. Energy Build. 2014, 83, 10.

[6]. Lau, L.C.; Tan, K.T.; Lee, K.T.; Mohamed, A.R. A comparative study on the energy policies in Japan and Malaysia in fulfilling their nations' obligations towards the Kyoto Protocol. Energy Policy. 2009, 37, 4771–4778.

[7]. Kibert, C.J. Green Building Design and Delivery. Sustain. Constr. 2012, 4, 53

[8]. Sadafi, N.; Salleh, E.; Haw, L.C.; Jaafar, Z. Evaluating thermal effects of internal courtyard in a tropical terrace house by computational simulation. Energy Build. 2011, 43, 887–893.

[9]. Zou, Y.; Song, B.; Liu, J. An interpretation of the national standards for energy efficiency design of rural residential buildings. Heat. Vent. Air Cond. 2013, 43, 77–81.

[10].He, B.J. Building energy efficiency in China rural areas: Situation, drawbacks, challenges, corresponding measures and policies. Sustain. Cities Soc. 2014, 11, 7–15.

[11].Building Energy Conservation Research Center TU, Chinese Residential Energy Annual Development Report in 2013; China Architecture and Building Press: Beijing, China, 2013. (In Chinese)

[12].Building Energy Conservation Research Center TU, China Building Energy Efficiency Annual Development Report in 2012; China Architecture and Building Press: Beijing, China, 2012. (In Chinese)

[13].Mohsen, M.; Akasha, B. Some prospects of energy savings in buildings. Energy Convers. Manag. 2001, 42, 1307–1315.

[14].Gowreesunker, B.L.; Tassou, S.A. Effectiveness of CFD simulation for the performance prediction of phase change building boards in the thermal environment control of indoor spaces. Build. Environ. 2013, 59, 612–625.

[15].Zhu, X.R.; Liu, J.P.; Yang, L. Energy performance of a new Yaodong dwelling in the Loess Plateau of China. Energy Build. 2014, 70, 159–166.

[16].Sun, H.; Leng, M. Analysis on building energy performance of Tibetan traditional dwelling in cold rural area of Gannan. Energy Build. 2015, 96, 251–260.

[17].Jin, Z.S. Energy saving treatment of Guangzhou old residential. South China Inst. Technol. 1965, 4,.48–49.

[18].Lin, H.K. Study on Guangzhou Tubular House Model Space Adapting to Hot and humid Climate. South China Univ. Technol. 2012, 25, 105-106.

[19].Gao, N. Numerical Simulation of Natural Ventilation of Traditional Residential Buildings in Lingnan Area. Build. Energy Environ. 2015, 34, 76–79.

[20].Lin, S.D. Preliminary study on spatial design of tubular houses in Zhangzhou. Chin. Foreign Build. 2013, 8, 75–77.

[21].Wang, X.L. Study on the regional sexuality of living space. Hebei Univ. Technol. 2008, 3, 45-48.

[22].Deng, X.R. Influence of structure of tubular houses on ventilation in Northern Zhejiang Province. Zhejiang Univ. 2020, 11.

[23].Lee, J.W.; Jung, H.J.; Park, J.Y.; Lee, J.B.; Yoon, Y. Optimization of building window system in Asian regions by analyzing solar heat gain and day-lighting elements. Renew. Energy 2013, 50, 522–531.

[24].Berardi, U. Clarifying the new interpretations of the concept of sustainable building. Sustain. Cities Soc. 2013, 8, 72–78.

[25].Oropeza-Perez, I.; Østergaard, P.A. Potential of natural ventilation in temperate countries—A case study of Denmark. Appl. Energy 2014, 114, 520–530.

[26].Maestre, I.R.; Cubillas, P. Influence of selected solar positions for shading device calculations in building energy performance simulations. Energy Build. 2015, 101,

144–152.

[27].Badescu, V.; Laaser, N.; Crutescu, R. Warm season cooling requirements for passive buildings in Southeastern Europe (Romania). Energy 2010, 35, 3284–3300.

[28].Badescu, V.; Laaser, N.; Crutescu, R.; Crutescu, M.; Dobrovicescu, A.; Tsatsaronis, G. Modeling, validation and time-dependent simulation of the first large passive building in Romania. Renew. Energy 2011, 36, 142–157.

[29].Ma, C.; Liu, Y.; Wang, D. Analysis of thermal performance and energy saving strategy of rural residential buildings in Northwest China. J. Xi'an Univ. Arch. Technol. 2015, 47, 427–432.

[30].Sadafi, N.; Salleh, E.; Haw, L.C.; Jaafar, Z. Evaluating thermal effects of internal courtyard in a tropical terrace house by computational simulation. Energy Build. 2011, 43, 887–893.

[31].Jacobs, J. The Death and Life of Great American Cities; Random House: New York, NY, USA, 2016.

[32].Al-Sallal, K.A. Testing glare in universal space design studios in Al-Ain. UAE desert climate and proposed improvements. Renew. Energy 2007, 32, 1033–1044.

[33].Krüger, E.L.; Dorigo, A.L. Daylighting analysis in a public school in Curitiba, Brazil. Renew. Energy 2008, 33, 1695–1702.

[34].Kharrufa, S.N.; Adil, Y. Roof pond cooling of buildings in hot arid climates. Build. Environ. 2008, 43, 82–89.

[35].Yi, H.; Braham, W.W. Uncertainty characterization of building energy analysis (BEmA). Build. Environ. 2015, 92, 538–558.

[36].Mastrucci, A.; Rao, N.D. Decent housing in the developing world: Reducing lifecycle energy requirements. Energy Build. 2017, 152, 629–642.

[37].Bui, D.K.; Nguyen, T.N.; Ghazlan, A. Enhancing building energy efficiency by adaptive façade: A computational optimization approach. Appl. Energy 2020, 265, 114797.

[38].Shan, X.; Luo, N.; Sun, K.; Hong, Y. Coupling CFD and building energy modelling to optimize the operation of a large open office space for occupant comfort. Sustain. Cities Soc. 2020, 60, 102257.

[39]. EnergyPlus TM Version 9.1.0 Documentation—Engineering Reference. U.S. Department of Energy. 2019. Available online: https://www.energyplus.net/ (accessed on 18 Apr 2019).

[40]. EnergyPlus, U.S. Department of Energy's (DOE) Building Technologies Office (BTO). Available online: https://energyplus.net/ (accessed on 18 Apr 2019).

[41]. Chi, F.A. An investigation of the impact of Building Azimuth on energy consumption in sizhai traditional dwellings. Energy 2019, 180, 594–614.

[42]. Nayak, P.K.; Mahesh, S.; Snaith, H.J.; Cahen, D. Photovoltaic solar cell technologies: Analysing the state of the art. Nat. Rev. Mater. 2019, 4, 269–285.

[43]. Heydari Gharahcheshmeh, M.; Tavakoli, M.M.; Gleason, E.F.; Robinson, M.T.; Kong, J.; Gleason, K.K. Tuning, optimization, and perovskite solar cell device integration of ultrathin poly(3,4-ethylene dioxythiophene) films via a single-step all-dry process. Sci. Adv. 2019, 5, eaay0414.

Chapter 8

CONCLUSION AND PROSPECT

CHAPTER EIGHT: CONCLUSION AND PROSPECT

8.1 Conclusion

China is a big country with a large agricultural construction. Numerous investigations of rural residences show that the poor thermal insulation properties of the building envelopes consisting of non-standard traditional construction materials and methods result in substantial energy consumption. In addition there is an increasing trend in energy consumption year-on-year against a background of generally improving living conditions and the policy for comprehensive development of rural areas. Hence, rural residences should gradually be moving closer to becoming green buildings.

However, at present China's green buildings are all to be found in cities and towns. The renovation of rural areas tends to be a blind copy of urban living standards, whilst the construction of rural residential buildings is generally defined by the individual behaviour of farmers, who rarely consider energy-saving design principles. In addition, since the majority of researchers are concentrated in universities in urban areas, and due to the lack of appropriate technical guidance and policy support, there is a scarcity of technical guidance and standards for energy saving in China's rural areas.

The main works and results can be summarized as follows:

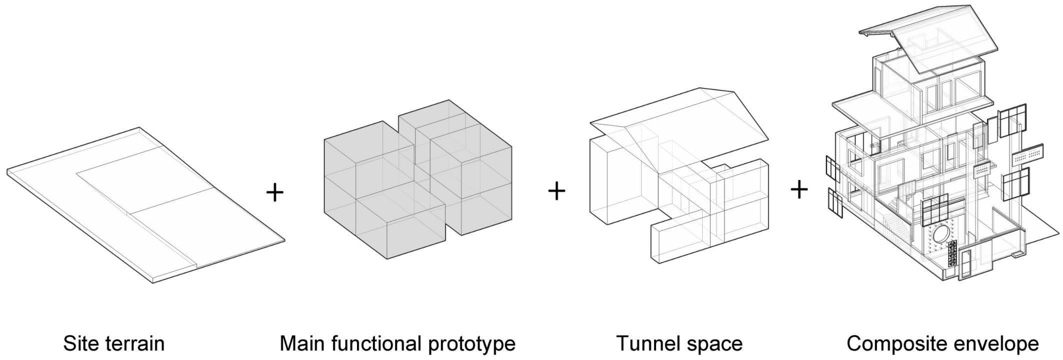
In Chapter 1, PREVIOUS STUDY AND PURPOSE OF THE STUDY. Firstly presents the situation of China's rural building energy consumption, then states the challenges for China's rural building energy efficiency in five aspects, finally illustrates the motivation and purpose of this research. In addition, the related studies have been reviewed. In view of the national situation, there has been some attention given to this issue. But the theories tend to emphasize the use of a single technology, while ignoring the use of integrated passive energy-saving technologies in combination with architectural design, which is what makes "Green Buildings" become a holistic ecological technology. In the current moment, the existing research is far from attaining this goal. The process of green building design requires the project team to constantly consider the building performance in terms of the building envelope, orientation, shading and natural ventilation together with energy efficient systems and equipment. Less resources are necessary for a major impact on these aspects if the initiatives are taken from the earliest stages of the design, and the energy saving research should be combined with the local natural climatic conditions and resources, especially in rural areas.

In Chapter 2, INVESTIGATION AND ANALYSIS. In this part, firstly analysis results of Northern Zhejiang including geography, climate, local resources and economy were presented. Then the passive energy-saving technologies which are suitable in Northern Zhejiang to improve the thermal performance of buildings have been simulated test by Weather Tool. Finally the investigation results of two important villages were expounded, which indicate the existing issues of the rural houses in Northern Zhejiang.

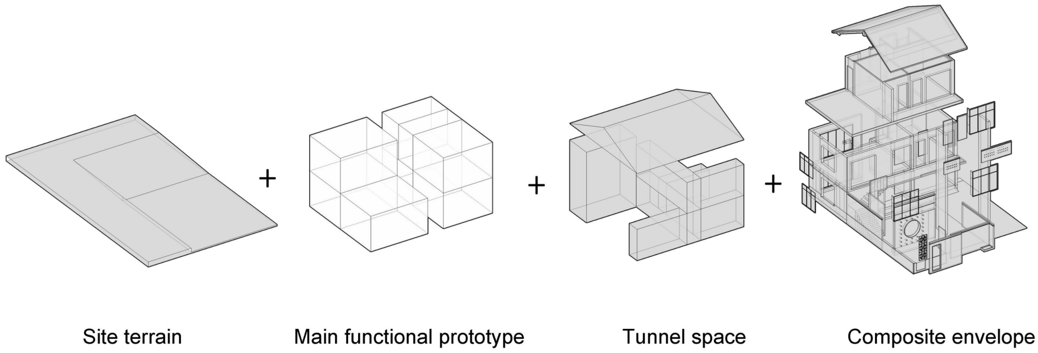
In Chapter 3, THEORETICAL SURVEY AND NEW APPROACH. Firstly the concept and approach for rural construction was introduced. It presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. Then the prototype theory, the bioscience theory and the strategy of passive energy-saving technology were introduced separately. Finally a theoretical framework was established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure. This approach provides a suitable concept for the analysis of the formation and composition of rural residences and propose a method to integrate passive energy-saving technologies with the other aspects during the early design stage.

According to the Interviews held in Dazhuyuan Village and CuoDun Village , Zhejiang Province, although 90% of these houses are aged less than 25 years, the thermal performance of these houses was found to be low due to poor air tightness and a lack of thermal insulation of the building envelope. Brick and concrete were used as construction materials in more than 90% of the houses surveyed. Aluminum alloy outer window frames have been used been used for the outer window frames, while the exterior windows are a single layer of ordinary glass in 95% and 100% of the houses, respectively. Double-glazed windows were also shown to improve the indoor thermal environment both in winter and summer.Visible mold was observed in the living rooms, and bedrooms of over half the houses interviewed. The construction materials are simple with poor thermal performance, and the majority do not satisfy the relevant requirements of the design standard for energy efficiency of rural residential buildings. This standard was implement in 2012 by the Ministry of Housing and Urban-Rural Development and was a first step in the definition of standards for rural construction. The internal living space of the majority of the houses have a footprint of between 90 to 120m2 on a site area of 200 to 250m2. These houses are east-south orientated or south orientated , and they have a small front and back yards. The family size of the households surveyed is usually 3-6 people, in which 5 people (two seniors, a couple and a child) accounting for 25% of total households. Air conditioning systems were installed in 90% of the houses, however, residents usually only used these systems in bedrooms in the evening. Straw combustion is used to supply energy to 8% houses for the supply of hot water and cooking. This investigation of the housing in the village has identified extensive lifestyle factors currently popular in rural areas, which means that improvements to the built environment have significant potential to improve the comfort and health or residents.

In Chapter 4, THE BASIC UNIT OF RURAL RESIDENCE. In this section firstly we had built a main functional prototype according to the survey data in Chapter 3. It was a cube with 9.9m length, which was highly representative and variable. This main functional prototype may not be the optimal in terms of meeting all the basic needs, but it has the smallest shape coefficient and provides the most convenient scenario for change. Different functions are arranged on the plan in a way that facilitates ventilation and lighting, according to the principles of dynamic and static separation, public and private separation, and clean and dirty separation so on. And The plan can be changed into different forms according to different functions in five aspects:1)A lobby with 1.2m depth; 2)A corridor with 1.8m width; 3)The bedrooms; 4)The bathrooms; 5)Storage and agricultural working space. What ' s more, The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. Vertical and horizontal tunnel spaces are set up in the prototype design according to the greenhouse effect, chimney effect, roof effect, etc.



In Chapter 5, DESIGN MENU OF RURAL RESIDENCE. This research uses topology as the evolution path, and establishes the design through variable factors such as courtyards, sun rooms, ventilation corridors, stair shafts, roof interlayers, composite skins, and topographical conditions. This visual design menu serves as a basic reference for the communication between designers and residents, enabling them to finally build the most suitable rural house according to the various conditions of the site. The tunnel space of the building is a dynamic adjustment system, as an energy container for wind, space, and sunlight, which can automatically exchange material and energy with the outdoors like cells. The architectural form can act as courtyards, ventilation corridors, colonnades and sunlight rooms, roof spaces, shelf spaces, etc. The topography of the building is like the cell wall, which limits and divides the building space to conform to the site's topography, hydrology, soil, vegetation and other natural factors. A building envelope is what separates the indoor and outdoor environments of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building.



In Chapter 6, CASE STUDY OF A TYPICAL RURAL HOUSE'S RENOVATION. In this part, a case study of a typical house in Anji County, Northern Zhejiang was used to demonstrate the accuracy of the model and menu. Firstly, a field measurement exercise was conducted in the building, followed by computer modeling work using open-studio software to simulate thermal performance. Then after renovation according to integrated optimization design in reality, anther field measurement exercise was conducted. Subsequently, both the two calculated values were compared for validation purposes. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort. It is an important case study to demonstrate the accuracy of the model and menu. The results show that renovation based on this menu and new approach results in a clear improvement in the thermal comfort.

In Chapter 7, CASE STUDY OF A TRADITIONAL TUBULAR HOUSE'S RENOVATION. In this part, anther case study of a traditional tubular house in Deqi County, Northern Zhejiang was also expounded. Firstly, a series of experimental measurements were carried out, focusing on the characteristics of the tubular house and the current situation of the thermal comfort, to provide the basis for the study. And the field investigation about modeling parameters of tubular house and a questionnaire survey about living schedule of 121 households were conducted. Then a typical tubular house was built in Open-Studio. Several energy consumption simulations were conducted throughout the winter and summer by combining different renovations. Finally the analysis of all the result was conducted. Different energy efficiency measures were evaluated in terms of the decrease in the annual energy consumption. Subsequently, the results show that various levels of reduction in energy consumption (varying from 1.6% to 30.5%) were achieved by combining different renovations. Furthermore, the relationship between energy consumption and insulation material thickness was established using a highly fitting logarithmic curve.The results also show a clear improvement in the thermal comfort. This study showed that the application of environmental adaptations to tubular houses, along with improved thermal insulation, can drastically reduce energy consumption. If this is inherited as a component in the process of urbanization, it will aid in energy conservation and natural ecosystem protection in southern China.

In Chapter 8, CONCLUSION AND OUTLOOK. The conclusions of whole thesis were deduced, and the future work of optimization of rural residences in Northern Zhejiang was put forward.

To summary, this article This research presents a new and comprehensive approach, which defines "a rural house with its yards" as the basic unit of rural residence (RBU) and constructs an appropriate model for this unit passive energy-saving technologies according to the requirements of rural life. A theoretical framework is established to analyse the formation of the basic unit and considers the RBU as similar to a biological cell with its general internal structure. The prototype theory, bioscience theory and the strategy of passive energy-saving technology are applied in this new approach and the aim of this research is to provide a reference model for rural construction.

8.2 Prospect

This research is still in its early stages, further studies on different energy efficiency measures in terms of their effects on annual energy consumption and more accurate studies on the effects of the thickness and type of wall, simulation of ventilation flow are all recommended. The process of green building design requires the project team to constantly consider the building performance in terms of the building envelope, orientation, shading and natural ventilation together with energy efficient systems and equipment. Less resources are necessary for a major impact on these aspects if the initiatives are taken from the earliest stages of the design, and the energy saving research should be combined with the local natural climatic conditions and resources, especially in rural areas. If this is inherited as a component in the process of urbanization, it will aid in energy conservation and natural ecosystem protection in Northern Zhejiang.