博 士 論 文

RESEARCH ON ENERGY SAVING AND ENVIRONMENTAL IMPROVEMENT
OF RURAL RESIDENTIAL BUILDINGS IN ZHEJIANG, CHINA
中国浙江省における農村住宅の省エネルギー及び環境改善に関する研究

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ABSTRACT

With the developing rural economy in China, rural energy and environmental issues have become increasingly prominent in the mainstream. On the other hand, rural households involve in traditional agriculture also engage in secondary and tertiary industries, such as handicrafts, e-business (Taobao), rural tourism and so on. In recent years, rural tourism has gradually become an important pillar industry in Zhejiang’s rural area. In this paper, rural tourism household will be taken as a research subject, and the energy consumption and indoor environment issues induced by the development of rural tourism will be studied. The objective of the thesis is to analyze energy consumption and indoor thermal environment status, develop envelope strategies for energy saving and indoor thermal environment in rural residential buildings based on field study and simulation.

Chapter one, Background and purpose. A background study was conducted to clarify the background and purpose of the study.

Chapter two, Policy and design standard for energy conservation of residential buildings. The policy and energy conservation design standards for residential buildings in the Zhejiang province (in Hot Summer and Cold Winter zone) were compared to the U.S. (in 3C zone) and Japan (in 6zone). It was found that the thermal requirements of envelopes in energy conservation standards for rural residential buildings (GB/T 50824-2013) are lower than the standards for urban residential buildings in China (JGJ 134-2010, DB 33/1015-2015), the U.S. (IECC2015) and Japan (BECS2013) in similar climate zones.

Chapter three, Theory and method of energy saving and environment improvement. With the change of an ordinary household to a rural tourism household, building energy consumption and indoor thermal environment has changed. The study was carried out in two steps: field survey and analysis, and simulation and optimization. 230 ordinary households and rural tourism households in Quzhou, Anji, and Zhoushan were studied and analyzed. Field measurements regarding the indoor thermal environment and energy consumption were carried out on 10 households. The basic information, indoor thermal environment and energy consumption of rural residential buildings were surveyed by a questionnaire, field mapping and field measuring, and were analyzed by statistical analysis and theoretical calculation analysis. Designbuilder software (based on Energyplus) was used for simulation analysis.

Chapter four, Investigation on situation of rural residential buildings. The permanent residential population, income and total floor area of rural tourism household are higher than ordinary household. Among three typical types of rural residential buildings, most rural tourism households are modern buildings, and traditional vernacular buildings built after the 1980s. Modern buildings have larger window-to-wall ratio and smaller building shape coefficient. The thermal performance of rural residential building envelops falls shorts of standard requirements, both domestic and foreign.

Chapter five, Survey on indoor thermal environment of rural residential buildings. Field measurements were carried out in the Quzhou district in summer and winter. The results show that on the coldest winter days (outdoor temperatures below 3°C), the indoor air temperature of buildings was below 8°C. On the hottest summer days (outdoor temperatures up to 36°C), most of the time, the indoor air temperature of buildings was above 30°C. The indoor thermal performance of the top floor, and south rooms with large windows were the worst performing. In addition to this, the thermal sensations of the farmers and tourists were questioned.

Chapter six, Survey on energy consumption of rural residential buildings. The results show that annual energy consumption of rural tourism households is approximately 3 to 5 times higher than that of ordinary households, especially regarding commodity energy consumption, such as electricity and LPG. In electricity consumption, the consumption of cooling energy in rural tourism 1households is higher than heating, accounting for 24% to 39%. Compared to other studies, energy consumption of rural tourism household is higher than the average of rural households in China, and is even higher than in cities.

Chapter seven, Sensitive analysis of energy saving in rural residential buildings. Strategies for energy saving were simulated, and several improving strategies about envelopes were proposed, including external walls, roofs, windows, airtightness and so on. Strategies for energy saving based on different functions, and strategies based on different regions and building forms were discussed. By improving envelopes under the ordinary household and rural tourism household models, the energy saving was obvious. For the top floor with space for storage, the energy saving caused by improving roofs is not obvious, because of the buffer effect of the air layer. Improving SHGC is more effective under the rural tourism household model. Cooling and heating energy consumption of a modern building is lower than that of a traditional building, due to a smaller shape coefficient and W-to-W ratio; the cooling and heating energy consumption in Zhoushan is lower than Quzhou, because of a cooler climate.

Chapter eight, Strategies for improving indoor thermal environment. The indoor thermal environment of rural residential buildings was simulated before and after taking measures. The south room and top floor spend more hours over the year in uncomfortable ranges, either below 8°C or above 30°C, compared to the north room. By improving envelopes, the environment of the north room is improved. Level 1 model is the most effective for top floor and south room. The roof of the Anji eco-house was renovated. Lab experiments and field measurements were carried out to improve the roof by using traditional and new materials. Then, the whole year situation was simulated and compared before and after renovation.

Chapter nine, Conclusions and future work. The results in every chapter were summarized, and discussed the insufficient work and future work.

Keywords: *rural tourism, rural residential building, energy saving, indoor thermal environment*

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Chapter 1.

Background and Purpose

1.1 Research Background

1.1.1 The Situation of Construction and Development in China Rural Areas

China is a traditional agricultural country whose rural population and rural residential buildings take a large proportion of the total population and building areas. By the end of 2014, China's rural population is about 619 million, accounting for 45.2%. The total construction area is about 56.1 billion m^2, rural residential construction area is 241 billion m^2, accounting for 43%. The new rural housing construction area is over 8 million m^2 in recent years. In addition, the rural residential building area increased from 17.7 m^2 per capita in 1995 to 38.9 m^2 per capita in 2014 (Fig.1-1). The total number of rural residential buildings is very large.

In 2005, the Chinese government officially launched a campaign named "new rural construction movement". Policies were proposed to support the rural production in order to improve the living standards in rural areas, and to narrow down the gap between urban and rural areas. According to the statistics released by China's National Bureau in 2015, per capita disposable income of rural household reached 10,489 Yuan, and per capita consumption expenditure of rural household reached 8,383 Yuan. Per Capita GDP increased from 9,215 Yuan in 2005 to 14,190 Yuan in 2015.

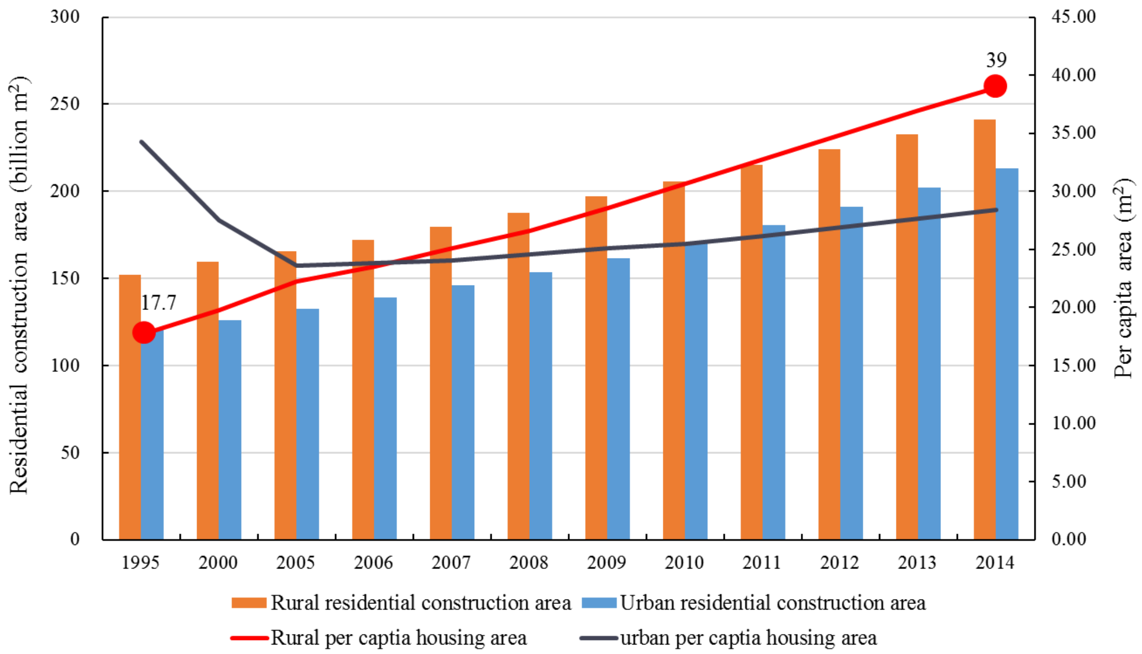

Fig.1-1Comparison of rural and urban newly built residential building areas (1995-2014) [1]

1.1.2 Rural Energy Consumption Status in China

Energy and environment have been the most talked about topic all around the world. China is an energy consuming country. China's total energy consumption keeps increasing, while energy consumption declines year by year in developed countries such as Europe and America. In 2013, terminal energy consumption in China was 1943.49Mt, which was the first in the world, accounting for 20.9% of the total global terminal energy consumption. The growth of energy consumption also goes along with the increase of CO_2 emission. By the end of 2013, China's CO_2 emission had increased to about 8977.1 Mt [2].

In the past two decades, rural areas in China have experienced rapid urbanization. Commercial energy consumption of rural household ensures sustainable growth. In 2014, the commercial energy consumption of rural household was 208 million kgce, accounting for 25% of the total building energy consumption in China. The commercial energy consumption of rural households have been consistent with the level of cities and towns, even more than that [3].

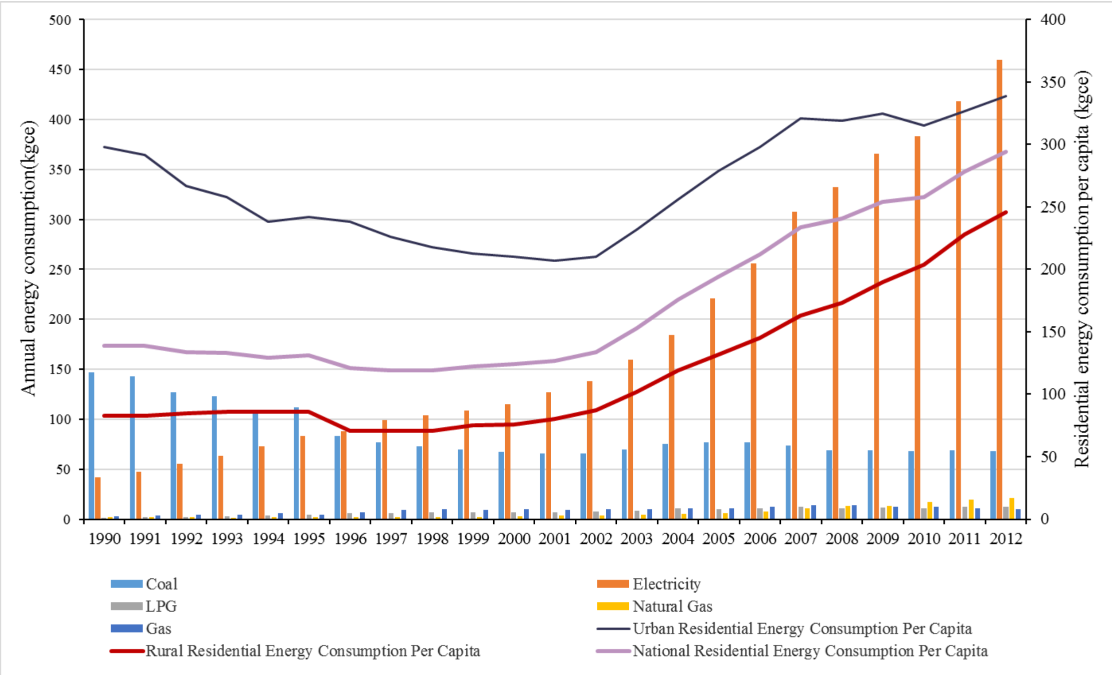

Fig.1-2Annual rural residential energy consumption (kgce,1990~2012) [1]

1.1.3 Rural Industrial Structure Adjustment in China

In order to further promote the development of the rural economy, the industrial structures in Chin's rural area was under adjustment. Some new industrial models appeared in rural areas, such as e-business, rural tourism, material processing and so on. Nowadays, the rural area, which is characterized by traditional industry, is gradually developing and moving towards the direction of multi-industry integration. With the adjustment of rural industrial structure, rural production and life style have changed sporadically, and so did the rural energy structure and energy consumption. For example, in recent years, commercial energy consumption, e.g. electricity and LPG increased rapidly. Traditional energy consumption, e.g. firewood, has decreased.(Fig.1-2) The change in rural production and life style will bring about a new challenge to rural energy consumption and environmental system in the future.

1.2 The Purpose and Significance of the Research

After the reform and opening-up in the 1980s, rural tourism began to emerge and had a rapid development in the 1990s. In the 21st century, rural tourism has entered a phase of rapid development. According to the research data [4], more than 40000 scenic spots (points) have been built in China, among which, more than half of them are in the vast rural areas. More than 500million tourists visit these rural tourism scenic areas (point) every year, and the annual tourism revenue is more than 200 billion yuan. It has become an important pillar industry for the rural economy in China.

On the other hand, there is a large number of rural residential buildings in China, but are characterized with poor indoor thermal environment and high energy consumption. The main reason is that rural building construction is determined by the farmers' individual behaviors, the poor quality of the materials used for rural building construction, primitive construction technology, and the absence of effective thermal insulation measures in rural areas. At present, energy saving technology, which is almost only adopted in urban buildings, is created to build energy efficiency standards and monitoring mechanisms. However, it is quite different from urban residential buildings in material selection, indoor thermal comfort standard and technical requirements, because of the characteristics of the rural residential buildings, the farmers' living habits, and the technical and economic conditions. With the development of rural tourism, there has been a change in rural energy consumption. If we still act according to the urban residential energy conservation standards and technical measures, not only are we going to meet the regional characteristics of rural areas, but there would be waste of resources and costs, a situation that would not be welcomed by the villagers. In such situation, the following questions should be answered:

(1) What is the current energy consumption and indoor environmental quality in Zhejiang rural buildings?

(2) What are the main problems with rural buildings, and the causes of these problems?

(3) How might we achieve sustainable strategies to improving the energy consumption and indoor thermal environment in rural buildings?

In recent years, rural tourism underwent rapid development in Zhejiang rural area. The purpose of this paper is to take Zhejiang province as an example, to study the indoor thermal environment and energy consumption in the rural residential buildings under the background of rural tourism, and then put forward the corresponding energy saving measures.

1.3 Previous Study

1.3.1 Studies on Indoor Thermal Environment in Rural Residential Buildings

1.3.1.1 Studies on Traditional Buildings

In the long-term evolution process, influenced by the local natural geographical conditions, social and economic cultures and other factors, traditional buildings are characterized by good ecological and social adaptability. However, scholars also found out that under extreme weather conditions, traditional buildings might not be able to effectively maintain indoor thermal comfort.

China has a vast territory and a unique climate condition, thereby leading to the creation of distinctive style of folk houses. Studies on the traditional residential buildings in China can be traced back to 1930s, a conducted in Tsinghua University (Building Society) on the surveying of traditional architectures [5]. After the liberation, a series of residential books have been published, forming a complete system of residential types. From the beginning of the 1990s, China's large-scale studies of the traditional environmental suitability were carried out.

Scholars studied the traditional Yaodong dwellings by using field measurement and computer modeling [6-8]. A new style of Yaodong dwelling with sunspaces was designed and built in Taoyuan village by Jiaping Liu et al. They made a further comparison between new Yaodong dwellings, old Yaodong dwellings and brick houses [9]. Fan Wang [10] simulated the indoor thermal environment of YongdingTulou building. Qindi Li et al.[11] conducted a field investigation on the indoor environmental in Tulou dwellings and compared with the ordinary rural residential buildings. Fang Wang et al.[12] and Xing Xue et al.[13]compared ganlan dwellings with ordinary residential buildings in local places, using field measurement and simulation. Some scholars discussed Wannan vernacular dwellings based on the temperature distribution in the rooms, the temperature of "cool laneway" and its cooling effect on the indoor room, and the relationship between ventilation and indoor air temperature in different opinions [14-20]. Studies of traditional Tibetan dwellings have been conducted in the Autonomous region (Lhasa)[21, 22] of the Yunnan province (Shangri-La area)[23], Qinghai-Tibet Plateau[24] and Chuanxi Plateau[25]. Surveys and comparisons were carried out between modern and traditional rural buildings [21, 22]. There are several kinds of traditional dwellings in the Tibetan Plateau, with different architectural styles and different local materials, such as Diaofang [25-27] and Single house [23]. In addition, many scholars have conducted a lot of research on other traditional dwellings, like Shoujinliao dwellings [28], Pashi houses [29], Qilou dwellings [30], seaweed houses[31] and other forms of residential buildings.

In addition, foreign scholars have also devoted their time to this field. Specific scientific studies compared the thermal environment in traditional and modern houses in Kerala (India)[32]. Results show that the traditional houses provided a more comfortable indoor environment than the modern ones. The authors have conducted the qualitative and quantitative analysis to investigate the indoor environmental condition of a vernacular residential building in the coastal region of Nagapatinam in

India. It revealed that the solar passive techniques used in these vernacular residential buildings provide comfortable thermal indoor environment irrespective of the outdoor climatic conditions[33]. Anh-Tuan Nguyen et al.[34] studied six traditional buildings in three different regions in Vietnam using in-situ survey methods and building simulations. The results of this study indicate that vernacular housing in Vietnam is creatively built to adapt to the local natural conditions. An analysis of 24 traditionally constructed dwellings with different levels of insulation and air-tightness in traditional Scottish dwellings was carried out[35]. A study was conducted on the 'prototyped dwellings' in North Cyprus, based on observation, literature review and site survey[36]. Ryozo Ooka conducted a field measurement of the indoor climate of a typical Japanese traditional folk house ("Minka") located in Hokuriku district in both summer and winter. Results shows that it was improved by the environmental control of the houses in summer, but considerably cold in winter[37]. The study by T. Tassiopoulou et al.[38] evaluated two forms of traditional dwellings in Greece, which are comfortable for use during summer and winter.

1.3.1.2 Studies on Non-traditional Buildings

From 2006 to 2007, a large scale of national surveys on indoor environmental qualities of Chinese rural housings was performed by Tsinghua University. Some field tests were carried out in a typical village in five districts[39]. The test results revealed that indoor thermal environment was poor in winter. Studies compared the thermal performances of normal rammed earth dwellings and brick houses in Qinling Mountains (cold zone)[40].

Hong Jin, Jiaping Liu and other researchers proposed that the comfortable indoor temperature in cold region was not less than 15℃, while the indoor temperature of rural residential areas in our country is 5℃~12℃. Huifen Zou et al.[41] evaluated the indoor thermal environment of the rural residence under the traditional heating mode in cold region by the Airpak software. The results show that rural residence which relies on kang and fire wall heating cannot meet the requirement of residents for comfort. Lili Zhang et al.[42] came to the conclusion that sole dependent on passive technology, such as retaining structure, sunlight, was not enough to improve the indoor thermal environment in winter, but it can improve the indoor thermal environment in summer. Feng et al.[43] and Song et al.[44] investigated the indoor thermal environment of ordinary rural buildings in hot summer and cold winter areas (like Chongqing, Hunan, South of Jiangsu). It is shown that 80% of the indoor temperature in the rural buildings is below 9℃, and the average indoor temperature is only 1℃ to 2℃ lower than the outdoor temperature in winter. In summer, the average indoor temperature is about 30℃, while the maximum temperature is close to 35℃. The indoor environment is poor, and the temperature fluctuates. A comparative analysis was performed on results from urban and rural residences in Hunan Province (in hot summer and cold winter zone).

The research on ecological rural buildings in China started from the 1970s. Since the first Chinese passive solar house was built in 1977, a large number of passive solar houses have been built in the past 35 years[45] (Fig.1-3).The earliest research on ERD can be traced back to the year 1997, the National Natural Science Foundation Project of China Green-Research on building system and the basic model of living in the Loess Plateau in China. A new style of Yaodong dwellings with several passive technologies was designed and built in Zaoyuan village of Yanan City in the Shanxi Province of China by the research group led by professor Ruoqi Zhou, Zu Wang and Jiaping Liu et al.[9, 46]. Subsequently, more scholars started paying attention to the ecological rural buildings [9, 47-50]. An experimental passive house was introduced by Zhennan Zhou [49], with additional field measurement and analysis of the house in use, exploring the possibilities of applying passive technologies with less or no heat during winter in rural areas in North China. E. L. Krüger et al.[51] evaluated the thermal performance of the wood prototype in Canoinhas, Southern Brazil. The results show that the prototype was compatible with all monitoring hours in thermal comfort and with 80% acceptability.

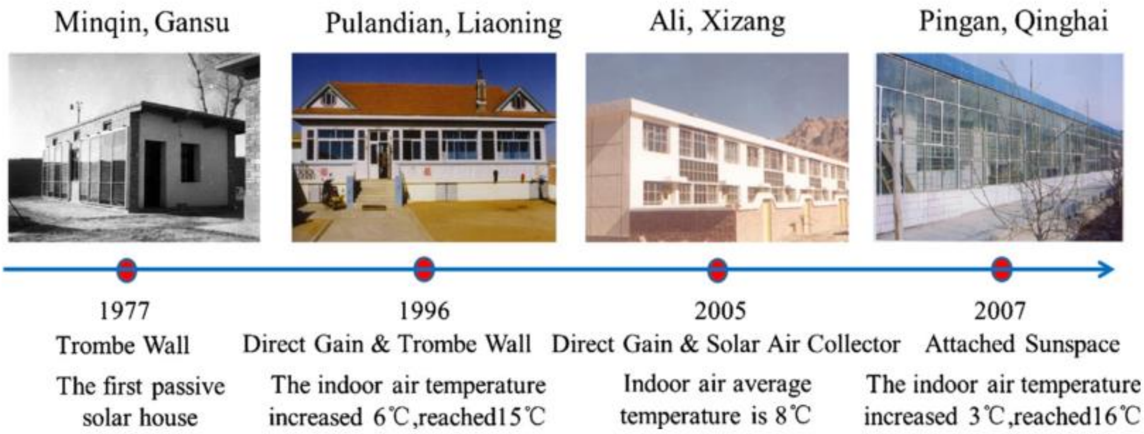

Fig.1-3 Development of passive solar house in China[45]

1.3.2 Studies on Energy Consumption in Rural Buildings

1.3.2.1 Domestic Studies

In 2007, the building energy conservation research center of Tsinghua University started publishing an annual report on China building energy efficiency which focuses on a different topic every year specifically on public buildings, northern cities and towns, rural residential buildings and buildings in towns and cities. They are the most comprehensive research reports on China's building energy efficiency. At this moment, there are two versions of rural building energy consumption report—*2012 Annual report on China Building Energy Efficiency* and *2016 Annual report on China Building Energy Efficiency*. The contents of the reports are about the basic energy consumption in China, the energy consumption status, the inference of the environment for energy use, the sustainable technology for rural building energy saving, and listed the best practice case in different area. In 2012 version, the main topics are energy saving and the indoor thermal environment [52]. However, in the 2016 version, a new topic on PM2.5 was launched [3]. A large-scale field survey on energy consumption was conducted, and the results shows that the total commercial energy consumption grew fast, the energy consumption per household is equal to the household in Cities and towns, even has the trends over it. But, in these reports, the objects didn’t include the villages, whose modes of production have changed from traditional industry to the second or third industry. Ming Shan et al. conducted a large-scale national survey of energy consumption and indoor environmental quality of rural housing in China and proposed the goal of achieving "zero coal villages" [53]. In addition, a lot of other scholars have written a lot of national field survey. Same scholars studied rural energy consumption based on statistical yearbook. Xiaohua Wang et al, analyzed the basic characteristics and development tendency of China’s rural household energy consumption in 1996.

1.3.2.2Foreign Studies

Jukka Heinonen et al[54]. analyze three of the most common types of housing’s (apartment buildings, row-/terraced houses, and detached houses) energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland, and points out the three factors which influence energy consumption: the significantly different occupation rates, the varying incentives for energy efficient behavior, and the inclusion of communal building energy. In practice case study, a case study of a Norwegian detached house is used to evaluate the sustainability of two nearly zero energy renovation strategies in Norway, by Birgit Risholt et al[55]. They pointed out that the facade renovation strategy is an energy upgrade of the facade supplemented with high renewable energy production on the site, 50–85% reduction of the heating requirement depends on the renewable energy production. Endrik Arumägi et al. analysis of energy consumption and potential energy savings based on field measurements, computer simulations and economic calculations, and renovation packages were compiled using different insulation measures, HVAC solutions and energy sources to achieve a 20%~65% reduction of primary energy.[56]

Through the analysis of studies carried out by domestic or foreign scholars, we found out that most of the researches are focused on ordinary rural households. However, the rural households whose model of production has changed from traditional industry to the second or third industry are seldom studied, such as the rural households which operate rural tourism businesses.

1.4 Relative Definition

1.4.1 Rural Tourism

1.4.1.1 Definition of Rural Tourism

At present, the definition of the concept has not been accepted. The most influential attempt to define rural tourism is that which was offered by the OECD that rural tourism can be defined as a "country experience" which encompasses a wide range of attractions and activities that take place in agricultural or non-urban areas. Its essential characteristics include wide-open spaces, low levels of tourism development, and opportunities for visitors to directly experience agricultural and/or natural environments [57]. Consequently, rural tourism in its purest form should be:

(1) Located in rural areas.

(2) Functionally built on the rural world's special features of small-scale enterprise, open space, contact with nature and the natural world, heritage, "traditional" societies and "traditional" practices.

(3) Both in terms of the rural buildings and settlements on a small scale, with traditional characteristics, and connected with local families.

1.4.1.2Global Rural Tourism Development

Rural tourism has developed all around the world in recent years. Tourism is seen as a key mechanism for revitalizing rural communities and has been supported by local and national governments across the world. Europe is considered to be the earliest and most successful area of world rural tourism[58]. EU specifically developed the EU fifth framework agreement for the development of rural tourism in Europe[59]. Regulations and policies were formulated to make rural tourism as an important means of avoiding the blind migration of the rural population to cities in New Zealand, Ireland and other countries[60]. The United States and Canada pays attention to the promotion of rural tourism, and provide rural self-help travel brochures to tourists in major rural communities. The Argentina government launched the highly anticipated rural tourism projects called "South American tribe", "The Argentina on horseback", to attract lots of tourists at home and abroad[61]. Many rural communities with unique natural resources or deep cultural heritage in South Africa improve community living standards by carrying out the rural tourism activities, such as watching wild animals and plants[62]. Japan is one of the earliest countries to carry out rural tourism. It created a combination of farm production tourisms, rich pastoral scenery and provision of unique service facilities to attract tourists in Japan. Rural tourism also reflects the national characteristics of flowers in Malaysia.

1.4.1.3 Rural Tourism Development in China

China's earliest rural tourism activities began in 1970s; most of them involve political reception activities. The real sense of rural tourism began in the 1990s and in the 21st century, rural tourism entered the rapid development phase. According to the statistics from The China National Tourism Administration, in 2015, the national rural tourism reception is more than 13.6 billion passengers, income of 440 billion Yuan, and more than 70 million farmers benefitted from rural tourism. In October 28th, 2016, the *China (YUANJIA Village) Rural Tourism Summit Forum* was held in Shanxi province. Chinese Academy of Social Sciences announced *China Rural Tourism Development Index Report* for the first time. The report predicted that rural tourism would experience rapid development in the next ten years in China and the tourists would increase to about 25 billion. The report also revealed that, on the verge of the rural tourism development, Zhejiang province ranks first.

1.4.2 Definition and Classification of Villages

1.4.2.1Definition of Villages

A village is a clustered human settlement or community[63]. Relative to city, village mainly depends on agriculture production, including agriculture, forestry, animal husbandry and fishery and services in support of these industries[3]. In recent years, with the adjustment of the industrial structure in rural areas, new forms of industries have emerged. In this study, we will mainly discuss rural tourism.

1.4.2.2Administrative Village and Natural Village

According to the *Constitution of the People's Republic of China*[64], the administrative divisions are divided into five levels: the provincial level (province, autonomous region, municipality, and special administrative region), prefectural level, county level, township level, and village level.

Administrative village is the lowest level of government administration, which is made up of one village community and several village groups or natural villages. At present, there are 27,901 administrative villages in Zhejiang province[65]. Natural village is the one that spontaneously and naturally exists within rural area, and it is not an administrative division[66].

1.4.2.3Traditional Rural Village and New Rural Community

According to the different formation of villages in Zhejiang province, they can be divided into two categories: traditional rural village, which is a naturally formed village. The other is the new rural community, which is a scientifically designed rural community.

(1) Traditional rural village

Traditional rural village refers to the residential settlement gathered by one or several clans after a long time, which usually takes the primary industry (agriculture, forestry, fishery, etc.) as the main production. The spatial layout, morphology, size and architecture are deeply influenced by natural geography, economic, customs and other factors. According to the geographical features of Zhejiang Province, the traditional rural villages can be divided into four types: hilly and mountain model, plain and river model, beach model and suburban model (Fig.1-4).

(a) Hilly and mountain model

(b)Plain and river model

(c)Beach model (d)Suburban model

Fig.1-4 Types of traditional natural village in Zhejiang Province (Source: from Google map)

(2) New rural community

The new rural community is different from the traditional natural village and the urban community. It is built using village merger, unified planning and construction. The living condition of farmers has improved and they enjoy the same public services as the urban residents. This type of new rural community saves land resources, improves land use efficiency and other resources effectively. Fig.1-5 shows the typical new rural community in Zhejiang province.

Fig.1-5 New rural community (Source: from Google map)

1.4.3 Classification of Rural Residential Buildings

Rural residential buildings are buildings erected on homestead of farmers, and the main characteristics are low-rise, detached house with courtyard. Besides the living function, rural residential buildings also include the space for agricultural production, such as agricultural machinery and storage, poultry livestock premises or other sideline production facilities. Influenced by the traditional life-style, most of rural residential buildings in Zhejiang are detached house which are distributed in different places. In 2015, the detached rural residential buildings took up 83.8% in Zhejiang province, most of them were built with brick-mixing materials, accounting for 53.8%[65].

1.4.3.1Historical and cultural building, Traditional vernacular building and Modern building

According to the building form, building materials and time, the rural residential buildings are divided into three categories: historical and cultural building, traditional vernacular building, and modern building.

(1) Historical and cultural building

It refers to the buildings built before 1949 (mostly during the Ming and Qing dynasties and the period of the republic of China), with gray bricks, gray tiles, wood. Black, white and gray are the main colors used, and they have some unique characteristics like the horse-like walls, patio, arch and woodcarving, stone carving, brick carving and so on. (Fig.1-6,a)

(2) Traditional vernacular building

Most of these are built before 2000s, with local materials such as stone, rammed earth, gray tiles, wood and so on. The room layout is simple and plain. It takes up the largest number of rural residential buildings in Zhejiang rural area at present and there are two types. The first type is shown in (Fig.1-6, b), which is mainly built before 1990s. The other one is a kind of veranda style building built after 1990s. (Fig.1-6,c)

(3) Modern building

Modern buildings are built after the 2000s, using modern building materials, such as coating, face tile, glass, concrete, stainless steel. Its advantage is that it has rich architectural form, meeting the requirements of the time, the room layout is more reasonable and practicable. (Fig.1-6,c)

(a) Historical and cultural building

(b) Traditional vernacular building

(c) Traditional vernacular building

(d)Modern building

Fig.1-6 Different types of rural residential buildings

1.4.3.2Ordinary household and rural tourism household

In traditional sense, rural residential buildings mainly refer to the dwellings where farmers live. However, with the development of rural tourism, farmers utilize their own buildings to provide food and accommodation services for tourists. In addition, the function of the buildings has changed.

(1) Ordinary household

Ordinary household refers to the rural family unit which is mainly engaged in agriculture or fishery. During slack season, some family members go to the cities or towns as migrant workers. The three buildings mentioned above fits the description and most of them are modern buildings and traditional vernacular buildings.

(2) Rural tourism household

Rural tourism household refers to the rural family unit which is not only engaged in agriculture or fishery, but also licensed to get involved in rural tourism business. During slack season, some family members engage in other jobs. Most rural households live in modern buildings and traditional vernacular buildings built after the 1980s.

In this thesis, the research objects are ordinary households and rural tourism households in traditional rural villages.

1.5 General Situation of Zhejiang Province

Zhejiang is one of the most economically developed provinces in China. It has rich tourism resources，and it is also one of the earliest provinces to carry out rural tourism. In this paper, Zhejiang province was selected as an example to study the energy and environmental issues of the rural residential buildings induced by rural tourism.

1.5.1 Geographical Location

Zhejiang province is located in the southeast of China (Fig.1-7), which is economically developed. It has a total Land area of 0.10 million square kilometers, which has a complex terrain, with mountains and hills accounting for 70.4%, plain and basin for 23.2%, rivers and lakes for 6.4%, and cultivated land area of only 2.08 million hectares. The sea area in Zhejiang is 0.26 million square kilometers and there are 3061 island areas, whose areas are larger than 500 square meters. Zhejiang is characterized with most islands in China, and Zhoushan island area of 495.4 square kilometers is China's fourth largest island. The land slopes from southwest to northeast, which can be roughly divided into six typical topography and terrains: Northern Zhejiang Plain (Hangjiahu plain), hilly area in West and East Zhejiang, plains in the middle of Zhejiang (Jinqu basin), mountain areas in the South of Zhejiang, and the southeast coastal plains and coastal islands. It contains 12 cities—— Hangzhou, Ningbo, Wenzhou, Shaoxing, Huzhou, Jiaxing, Jinhua, Quzhou and Zhoushan, Taizhou, Lishui, Yiwu. In 2014, there were 629 towns, 258 townships, 27,997 administrative villages, 12.6 million rural households, and about 32.8 million rural populations.

Fig.1-7Geographical location of Zhejiang

1.5.2 Climatic Characteristics

The climate of Zhejiang province is characterized by hot summer and cold winter. The annual average temperature is 15℃~19℃, extreme maximum temperature would be 33℃~43℃, and extreme minimum temperature would be -2.2℃~-17.4℃. In January, the average temperature is 4℃ ~8℃, while in July, average temperature is 25℃~30℃. The heating degree per day below 18℃ (HDD18) is between 1183.4℃•d~1901.6℃•d, and the cooling degree per day above 26℃(CDD26) is between 30.5℃•d~268.2℃•d. Rainfall in Zhejiang province is plentiful, and the annual average rainfall is between 980 mm ~ 2000 mm.

Table 1-1Solar energy resource of China [67]

Numbering	Classification	Annual solar radiation(MJ/m^2)
Ⅰ	Solar energy resource abundant zone	≥6700
Ⅱ	Solar energy resource relative abundant zone	5400～6700
Ⅲ	Solar energy resource ordinary zone	4200～5400
Ⅳ	Solar energy resource shortage zone	＜4200

Solar energy resources vary widely around in China (Fig.1-8). The annual average sunshine per hour is between 1710 h~ 2100h in Zhejiang province, a relative poor solar energy resources area in China. The total annual accepted solar radiation per square meter is 4190 ~ 5016MJ/m^2, which belongs to the four types of regions (Table 1-1)， equivalent to the heat of 140 ~ 170kg standard coal.

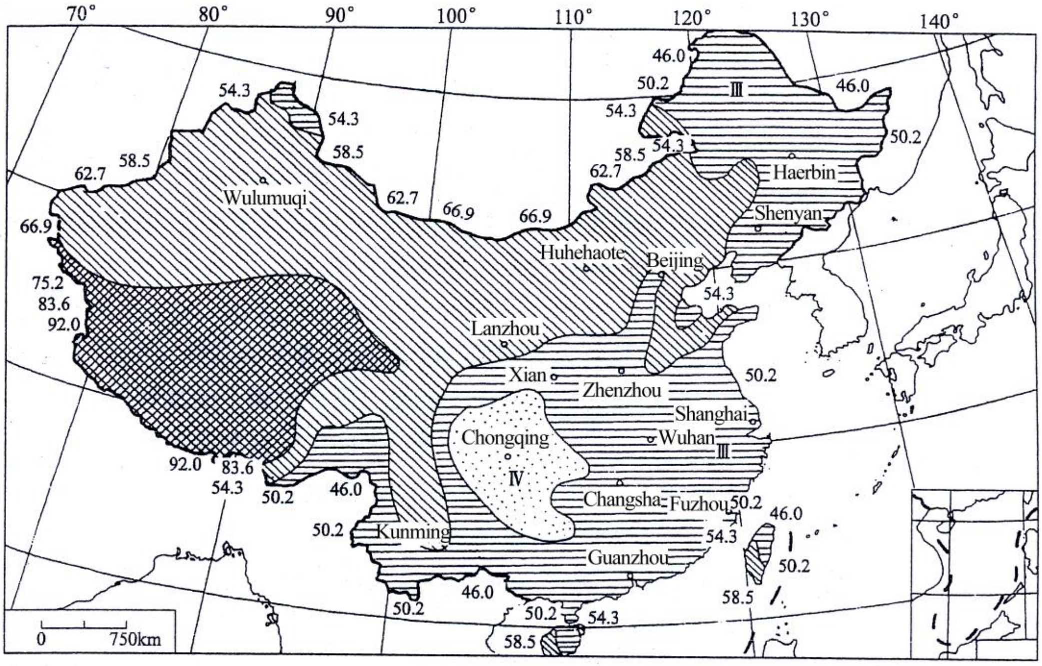

Fig.1-8 Solar energy resource distribution map of China[67]

1.5.3 Natural Resources

There are rich resources in the forest and vegetation of the Zhejiang province. Existing forest land area is about 6.68 million hectares, and the forest area is about 5.84million hectares. Forest coverage rate closes to 60.5%, ranking among China's top list. Zhejiang province also has abundant marine resources, where the sea area is about 26 square kilometers, and the mainland coastline and islands coastline are more than 6500 kilometers. There are 3061 islands, of which the island area is more than 500m2, accounting for the 40% of the total number of islands in China. In addition, tourism resources are abundant in Zhejiang. There are more than 800 significant landscapes, more than 200 water landscapes, over 100 biological landscapes, and more than 100 cultural landscapes.

1.5.4 Situation of Rural Development and Construction

Zhejiang province is one of the most developed provinces in China. As a result of the radiation and drive of the China Yangtze River Delta region, the Engel's coefficient of rural residents in Zhejiang Province dropped from 53.1 in 1995 to 37.7 in 2013, which indicates that the rural living standards reached the highest level. Coal and biomass consumption decreased, but the LPG and electricity consumption grew faster in Zhejiang rural area. (Fig. 1-9)

Zhejiang rural residents' per capita disposable income has increased from 219 Yuan in 1980 to 21125 Yuan in 2014, which amounts to 96.5 times increase. Per capita consumption expenditure increased from 192 Yuan in 1980 to 16108 Yuan in 2015, increased by 83.9 times. In 2014, rural housing area has expanded to about 2×10^9 m^2 in Zhejiang. The living environment of rural residents has greatly improved, and the per capita floor space of rural residential buildings has increased from 16.1 m^2 in 1981 to 61.3 m^2 in 2015[65].

1.5.5 Rural Tourism Development

Rural tourism has become the important pillar industry of the rural areas in Zhejiang province. The data released by the National Economic and Social Development Bulletin of Zhejiang province shows that by the end of 2015, there are 130 important historical and cultural villages, 649 general protection villages, 897 organically featured villages which accounts for 3.2% of all administrative villages, 2,389 organically featured rural tourism villages, including all kinds of heights, farms, fishing villas and so on, and 145 thousand rural tourism households which accounts for 0.4% of total rural residential households.

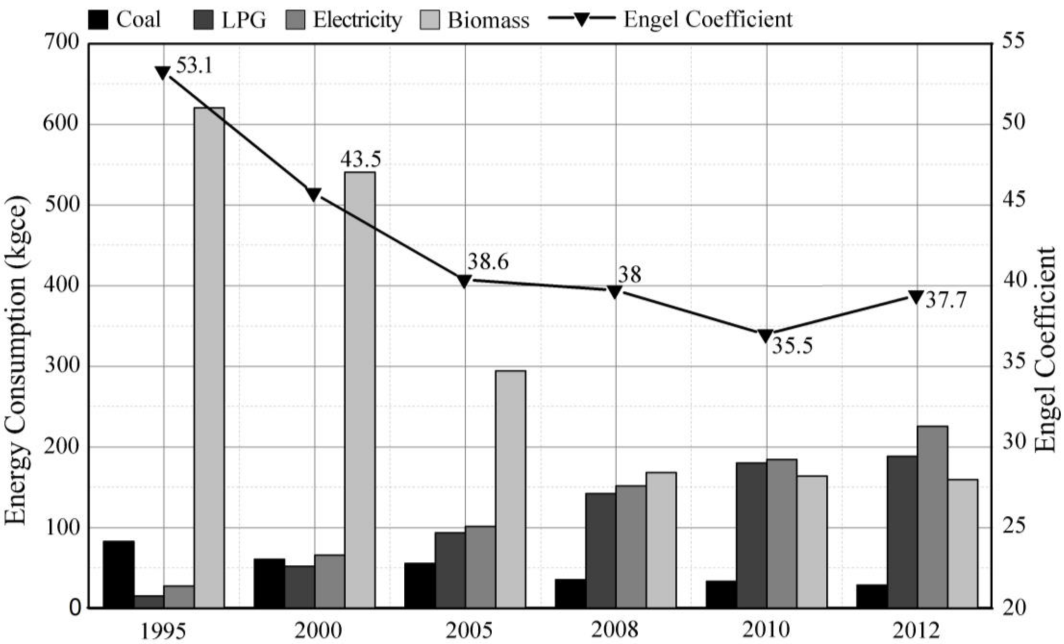

Fig. 1-9 Energy consumption and engel coefficient of Zhejiang rural area[68-70]

1.6 Research Contents

The purpose of the thesis is to study the energy saving and indoor thermal environment of rural residential buildings in Zhejiang province, on the basis of the rapidly developing rural tourism. The contents include the following and the research framework is show in Fig.1-10.

Part One: Background Study

(1) Energy consumption and indoor thermal environment of rural tourism household were altered as a result of the changes in the farmers' lifestyles; hence, new strategies should be developed to deal with this situation. However, there are few studies about rural household. The purpose of the research is to reveal the current situation of the rural household induced by the development of rural tourism and study the improving strategies for energy saving and improving indoor thermal environment. (Chapter 1)

(2) Comparison of the policies and standards of building energy conservation at home and abroad. The history and current situation, types and main contents of global policy and design standard for building energy conservation were introduced. Then, the developmental progress, climate zone, and main contents of the residential buildings were introduced and compared. (chapter 2)

Part Two: Theoretical Study

Based on the relationship between human behavior, energy consumption and indoor thermal environment, as ordinary household evolves into a rural tourism household, the energy consumption and indoor thermal environment changes. 230 ordinary households and rural tourism households in Quzhou, Anji, Zhoushan were selected as subjects. The research route, content and methods of the study were introduced. (chapter 3)

Part Three: On-site Study

(1) Investigation on situation of rural residential buildings was conducted by questionnaires and field mapping. The household information (including family composition, family income etc.), building information (including building plan, material and construction, thermal performance of envelopes) were surveyed and analyzed. (chapter 4)

(2) Survey on the indoor thermal environment of rural residential building was carried out based on the objective and subjective aspects. Field measurements of environmental parameters were conducted in the hottest period in summer and the coldest period in winter. At the same time, the thermal sensation of farmers and tourists were analyzed using questionnaires. (chapter 5)

(3) Survey on energy consumption of rural residential buildings was carried out by questionnaire and field measurement. Occupants' activity and appliances usage schedule, energy consumption and structure, influencing factors for energy consumption and comparison with other survey were analyzed. (chapter 6)

Part Four: Case Analysis

(1) Sensitive case analysis of energy saving in rural residential buildings by improving envelopes. Based on the field survey, simulations are carried out from two aspects: The first is to study single strategies of envelopes for energy saving under ordinary household model and rural tourism household model respectively. The second is to discuss and analyse energy saving by taking comprehensive strategies under different building forms and climate. (chapter 7)

(2) Strategies for improving indoor thermal environment. The current indoor thermal environment of the main living space for the whole year was simulated by taken a modern building and traditional building in Quzhou as examples. Several measures of improving envelopes were proposed and compared. Finally, a practice of roof renovation was carried out in Anji eco-house, which was renovated by using both traditional material (light clay) and new material, and the efficiency was measured and simulated before and after renovation. (chapter 8)

Part Five: Conclusion

Chapter 9 shows a summary of the study, insufficient research conducted for the study and the future study on improving energy saving and indoor thermal performance.

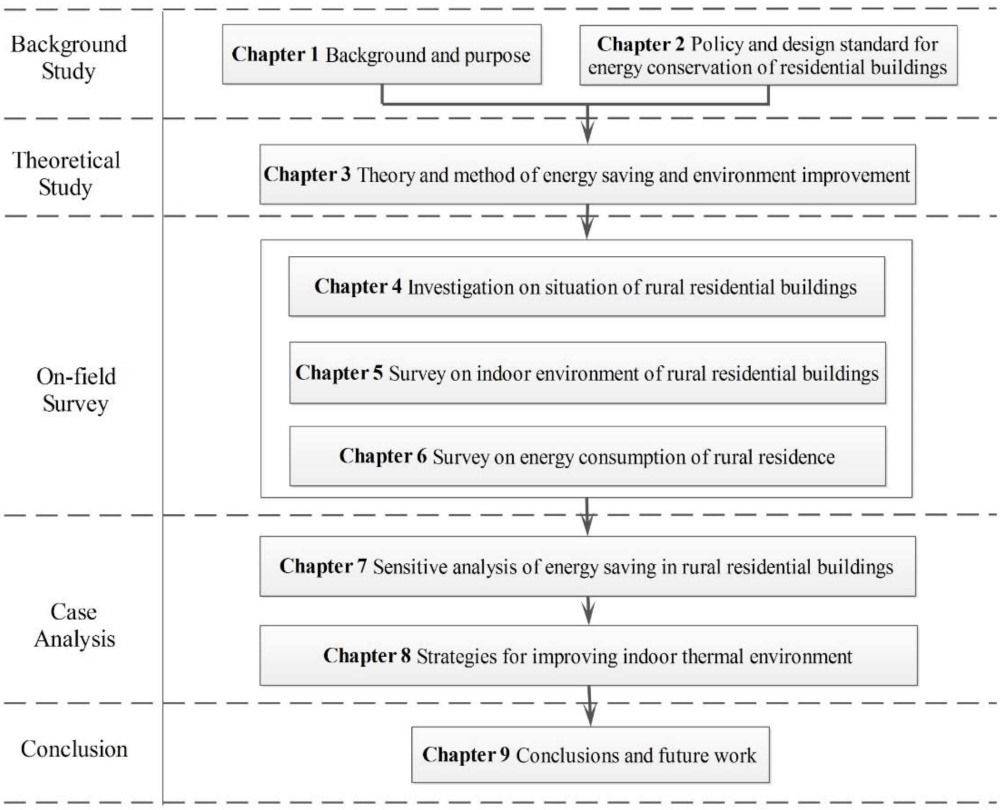

Fig.1-10 Research framework

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Chapter 2.

Policy and Design Standard for Energy Conservation of Residential Buildings

2.1 Introduction

Energy is the material basis of human survival and development, and besides, building energy efficiency has already become an important way of realizing energy saving in major countries and regions around the world. To be specific, the equation and implementation of building energy efficiency standards is an important method of achieving building energy efficiency. According to the survey data released by the United States Census Bureau (USCB) in 2009, there are 130 million sets of housing (except the mobile house), including 41,537 thousand sets of single-story residential buildings, 43,447 thousand sets of two-story residential buildings and 27,577 thousand sets of three-story residential buildings. In addition, three-story or less residential buildings account for 86.5% of the total housing. Among them, there are 82,472 thousand detached residential buildings and 7,053 thousand attached residential buildings that possess 63.4% and 5.42% of the total residential buildings respectively. Completely independent heating, air conditioner, domestic hot water and other facilities are applied in this residence. Japanese residential buildings can be classified into aggregative houses and detached houses. To be specific, the aggregative house refers to all the unit residence in general, while being called the "single family house", the detached house is the traditional independent residential building of one to three storeys in Japan. According to the statistical data released by the Ministry of Internal Affair and Communications in 2008, Japan has 32100 thousand residential buildings which cover an area of 3.4 billion square meters. Its single-detached houses and rural houses account for 85% and 6% of the total houses respectively. The building area of rural areas in China is about 27.8 billion square meters, 90% of which are residential buildings which account for about 65% of the construction area of the country and almost all of them are buildings of three storeys or less[1]. In the second place, from the point of the latitude location, China, U.S. and Japan are located in the similar latitude. Therefore, they are comparable in terms of the architectural form and climatic characteristics to a certain degree. However, the rural residential construction has always been the personal behavior of farmers in China. Therefore, the primary standard of rural residential buildings is imperfect, and their design and construction level is at a relatively low level. In recent years, along with the rural economic development of China, especially the rise of rural tourism, there is increasingly and dramatically high requirement for indoor environment and rural energy use in daily life. China also introduced a series of relevant standards. In the chapter, various building energy efficiency designs in different countries compared by analyzing the building energy conservation system and the energy conservation standard of China, US and Japan respectively.

2.2 Development Situation of Global Building Energy Efficiency Standards

2.2.1 History of Building Energy Efficiency Development

In the history of human construction, there are relevant regulations about housing construction and the responsibility of constructors on Hammurabi's law from Mesopotamia early in 1790 BC. Since then, all the countries enacted relevant construction standards to prevent disasters such as fire and earthquake. Building energy efficiency standards is a new thing. Relevant regulations on building energy efficiency are originated from cold and high-latitude areas since harsh climate conditions of these areas affect the health of users. As early as in the period of World War II, building materials with better thermal performance were used in Western European countries. They are used for constructing hollow brick walls and keeping warm with the air layer of hollow walls or constructing the double wooden floor.

Afterwards, the external thermal insulation system began to appear in Europe from the 1950s to the 1960s, and the system is initially used for making up the crack in the wall. Through practical application, they found that pasting thermal insulation materials (foam plastic board) on the exterior surface of building could efficiently cover the crack in the wall; in the meantime, the composite wall has effective heat-insulating property, which could save energy. In late 1950s, along with the improvement of living standards, Nordic countries are in urgent need of improving living conditions. They stipulated U-values, R-Values and other physical properties of building materials, thermal insulation materials and double glazing.

The first oil crisis in 1973 urged many developed countries (US, Japan, etc.) to start to attach importance to energy problems, list building energy efficiency as an important national guideline generally, and formulate building energy efficiency standards. In 1974, France took the lead in equation building energy efficiency standards and required that the energy consumption for heating of newly-built house must be 25% less than before. By the 1980s and the 1990s, most developed countries have gradually improved the building energy efficiency standard.

2.2.2 Current Situation of Building Energy Efficiency Standards

Currently, almost all the developed countries have formed perfect building energy efficiency standards and constantly enhanced the requirement for building energy efficiency. Developing countries also started to produce building energy efficiency standards gradually to improve indoor conformability and reduce rapidly rising building energy consumption of air conditioners and heating. According to the statistics concerning the situation of 80 countries and regions of the International Energy Agency (IEA), as in 2007, when 59 countries have produced "mandatory standard" and "mandatory and voluntary" energy efficiency standard. Meanwhile, 12 countries plan to produce the standard and 9 countries have failed to relevant energy efficiency standards. Fig.2-1 shows the establishment situation of residential building energy efficiency standards in the world.

Though some countries haven't produced the building energy efficiency standard, they have the energy efficiency standard or the labeling policy of building materials, construction equipment or domestic appliances. For these countries, home appliance standards and labeling can prevent excessive waste of terminal energy to some extent.

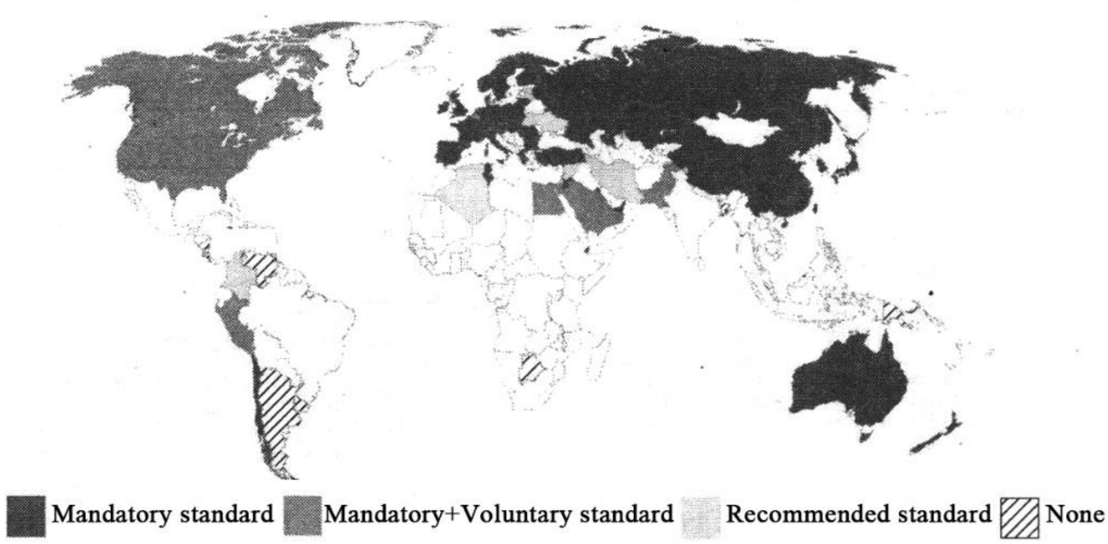

Fig.2-1 Establishment situation of residential building energy efficiency standard in the world[2]

2.2.3 Type and Main Content of the Building Energy Efficiency Standard

2.2.3.1 Main Content of the Building Energy Efficiency Standard

The building energy efficiency standard was created in the 1970s after the oil crisis. The initial building energy efficiency standard is relatively simple and it only regulates thermal performance of building envelopes. For decades, along with the development of research on computing methods, computer simulation and building energy systems, the content of the building energy efficiency standard is improved gradually. The main content of the building energy efficiency standard includes building envelopes, HVAC systems, renewable energy, building equipment, building zones and building integrated design. The specific contents are shown in Table 2-1.

Table 2-1 The main content of building energy efficiency standards

Items	Main content
Calculation conditions for indoor thermal environment	The indoor design temperature of heating and cooling rooms; the ventilation rate
Building and building envelope thermal design	Building direction, site selection, etc.; exterior walls, roofs, doors and windows, floors and other design requirements
Energy efficiency design	Ventilation, heating, cooling, air conditioning and hot water supply
Renewable energy design	Passive solar energy, passive cooling and natural ventilation and active renewable energy sources

Building equipment	Lighting, electrical equipment, building electricity
Building zones	Climate zones, building zones
Integrated design	Integration and optimization design of all kinds of energy conservation measures

2.2.3.2 Judgment Methods of Building Energy Efficiency

The methods adopted to judge whether buildings satisfy the requirement of energy efficiency in the building energy efficiency standard can be divided into two types: one is the method based on the performance requirement of each part of buildings, namely U-value based building codes; the other is the method based on overall energy consumption of buildings, namely performance based building codes. The prescriptive indicator method and the weighing and judgment method are the most commonly seen methods. Prescriptive indicator method is the earliest and simplest judgment method. Along with the improvement of the building energy efficiency level and energy efficiency standard, the more complicated and flexible weighing and judgment method came into being. Besides, there are building reference methods, energy consumption limit methods, overall energy efficiency methods, etc. The differences of various methods are shown in Table 2-2.

(1) The Prescriptive Indicator Method

The prescriptive indicator method stipulates the minimum performance limit of thermal performance of each part of buildings. When the indicator meets the regulated requirement, then the building satisfies the requirement of energy efficiency; otherwise, it fails to satisfy the requirement of energy efficiency. Besides, the mandatory provision also includes the energy efficiency standard, the building direction, the building shape coefficient and the window-wall ratio.

(2) The Weighing Judgment Method

The weighing judgment method is a performance-based design method and its core is to make dynamic analysis, comparison and judgment on energy consumption of air conditioning and heating of reference buildings and design buildings.

(3) The Reference Building Method

This method aims to make up a building that satisfies the minimum requirement of building energy efficiency (known as reference buildings which are completely consistent with design buildings in the aspect of the architectural shape, size, direction, internal space division, function of room, etc.) firstly, then calculates the energy consumption of reference buildings and design buildings, and finally makes comparison and judgment. If the energy consumption of design buildings is lower than that of reference buildings, then it satisfies the energy efficiency standard; otherwise, it fails to satisfy the energy efficiency standard. The reference building methods adopt dynamic methods to calculate energy consumption of the building's heating and air conditioners. The calculation process is significantly complicated and it should rely on the aid of computer software for simulation.

(4) The Energy Consumption Limit Method

The energy consumption limit method is adopted to calculate indoor environment that satisfies the requirement according to some parameters by building palisade structure heat loss and it is measured with the energy consumption value of unit square meter. The calculated energy consumption value must be smaller than the maximum value of regulated energy consumption.

(5) The Overall Energy Efficiency Method

The overall energy efficiency method is adopted to set the energy consumption standard of buildings by the total primary energy of buildings and the influence of environment and make the comprehensive judgment of envelope structure performance, building equipment, economic efficiency and environmental benefit of buildings and others with models that designers created by the computer. Besides, the overall energy efficiency method is able to provide designers with best scheme comparison.

Table 2-2 Characteristics of different judgment methods

Evaluation methods	Based on U-value	Based on energy performance	Need computing tools or not	Characteristics
The Prescriptive Indicator Method	√	×	×	Simple
The Weighing and Judgment Method	√	×	×	Flexible
The Reference Building Method	√	√	√	Flexible
The Energy Consumption Limit Method	×	√	√	Flexible
The Overall Energy Efficiency Method	×	√	√	Flexible; Complicated

2.3 Introduction of the U.S. Building Energy Efficiency Standard

2.3.1 Development Situation of the U.S. Building Energy Efficiency Standard

2.3.1.1 High-level Law

After the oil crisis in 1973, U.S. paid more attention to energy problems, and a series of energy policies and regulations were issued and produced:

◎1975, Energy Policy and Conservation Act of 1975

◎1976, Energy Conservation and Production Act of 1976

◎1976, Resource Conservation and Recovery Act of 1976

◎1978, National Energy Conservation Policy Act of 1978

◎1988, Federal Energy Management Improvement Act of 1988

◎1992, Energy Policy Act of 1992;2005, Energy Policy Act of 2005

◎2007, Energy Independence and Security Act of 2007(Clean Energy Act)

◎2009, American Recovery and Reinvestment Act of 2009

2.3.1.2 Basic Energy Efficiency Standard

The development of the US building energy efficiency standard has experienced a long period, which has been shown in Fig.2-2.

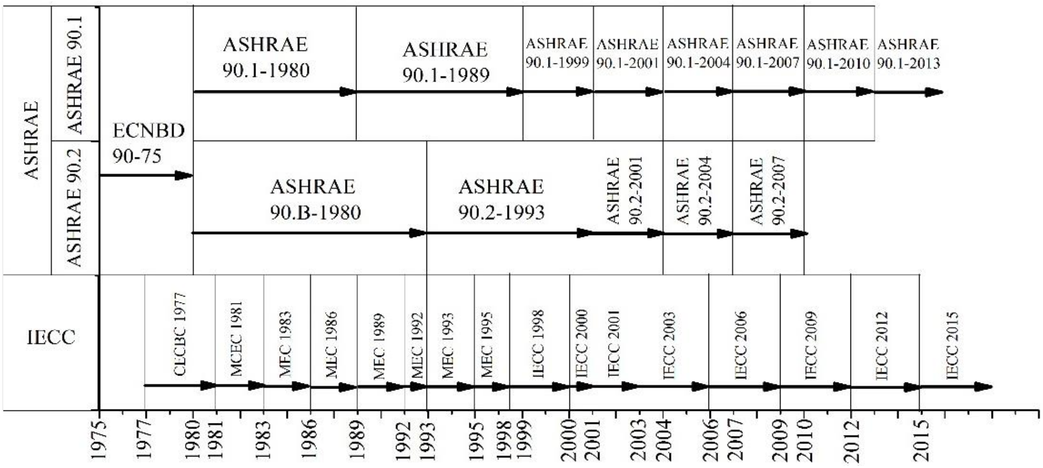

Fig.2-2 Figure of the U.S. building energy efficiency standard development process

On October 24th, 1992, *Energy Policy Act of 1992*, *EPAC1992* came into effect and the U.S. department of energy regulated to take *Model Energy Code of 1992, MEC* (predecessor of IECC) regulated by CABO as the state energy conservation standard for residential buildings of three storeys or less, and take *ASHRAE90.1-1986* regulated by ASHRAE of US as the state basic energy conservation standard of public buildings (including public buildings and houses of over three storeys). On December 19th, 2007, *Energy Independence and Security Act of 2007(Clean Energy Act)* is signed and implemented and it regulated *International Energy Consecration Code, IECC* as the residential building energy efficiency standard. ASHRAE (compiled by ICC) and IECC (jointly compiled by IESNA) are the most widely accepted building energy efficiency design standard so far after a series of institutional adjustments and revisions for decades.

In 1993, ASHRAE released the energy conservation design standard *ANSI/ASHRAE Standard 90.2-1993 Energy -Efficiency Design of Low-Rise Residential Buildings* which specially regulated bottom houses of three storeys or less. After undergoing the update of 2001 version, 2004 version and 2007 version, ASHRAE90.2 hasn't officially issued 2010 version since the revision suggestion is widely criticized. Because of the poor operability of *ASHRAE90.2*, the energy efficiency of low story residential buildings refers to IECC standard. Besides, US also has relevant energy efficiency standards for building equipment.

In 2009, ICC built SBTC (the Sustainable Building Technology Committee). In 2012, it cooperated with AIA (American Institute of Architects), ASTM International, ASHRAE, USGBC (the U.S. Green Building Council) and IES (the Illuminating Engineering Society) and released IgCC (the International Green Construction Code). The standard focuses on the sustainable development of architecture, and it is used to guide emission reduction, energy efficiency improvement and the improvement of resource use efficiency of water, land and building materials and so on within the whole building life circle, and improve indoor air quality. Therefore, compared with IECC and ASHRA, IgCC has wider scope of attention and higher energy efficiency standard[3].

2.3.1.3 U.S. Building Energy Efficiency Standard

IECC and *ASHRAE* are not mandatory standards. All the states could decide whether they adopt *IECC* and *ASHRAE* according to their government management system, economic development situation and weather difference. Therefore, the building energy efficiency standard implemented by different kinds of residential buildings has the following probabilities (Table 2-3).

Table 2-3 The use condition of the U.S. residential building energy efficiency standard [2]

Building classification	Relevant laws or standards
Public buildings of the federal government and high-rise residential buildings	Based on ASHRAE standard, energy saving rate 30%
Low-rise residential buildings of the federal government	Based on IECC standard, energy saving rate 30%
Low-rise residential buildings of the states	The residential building part in IECC standard
	According to IECC standard revised by the state
	ASHRAE90.2 standard
	The state energy efficiency standard

2.3.2 Climate Zone

At present, the standard of the US is divided into eight large climatic zones according to HDD18°C and CDD10°C and 17 small climatic zones according to humidity conditions within the large climatic zones (see Table 2-4, Fig. 2-3). The areas with hot summer and cold winter in our country are amount to 3A, 3B and 3C zone of US climate zones.

Table 2-4 U.S. climate zones [4]

Climate Zone	Characteristic	Thermal Criteria
1	Very hot-humid(1A), Dry(1B)	5000<CDD10°C
2	Hot-humid(2A), Dry(2B)	3500<CDD10°C≤5000
3A,3B	Warm-humid(3A), Dry(3B)	3500<CDD10°C≤5000 HDD18°C≤3000
3C	Warm-Marine	HDD18°C≤2000

4A,4B	Mixed-humid(4A), Dry(4B)	CDD10°C≤2500 HDD18°C≤3000
4C	Warm-Marine	2000<HDD18°C≤3000
5(A, B, C)	Cold-humid(5A), Dry(5B), Marine(5C)	3000<HDD18°C≤4000
6(A, B)	Cold-humid(6A), Dry(6B)	4000<HDD18°C≤5000
7	Very Cold	5000<HDD18°C≤7000
8	Subarctic	7000<HDD18°C

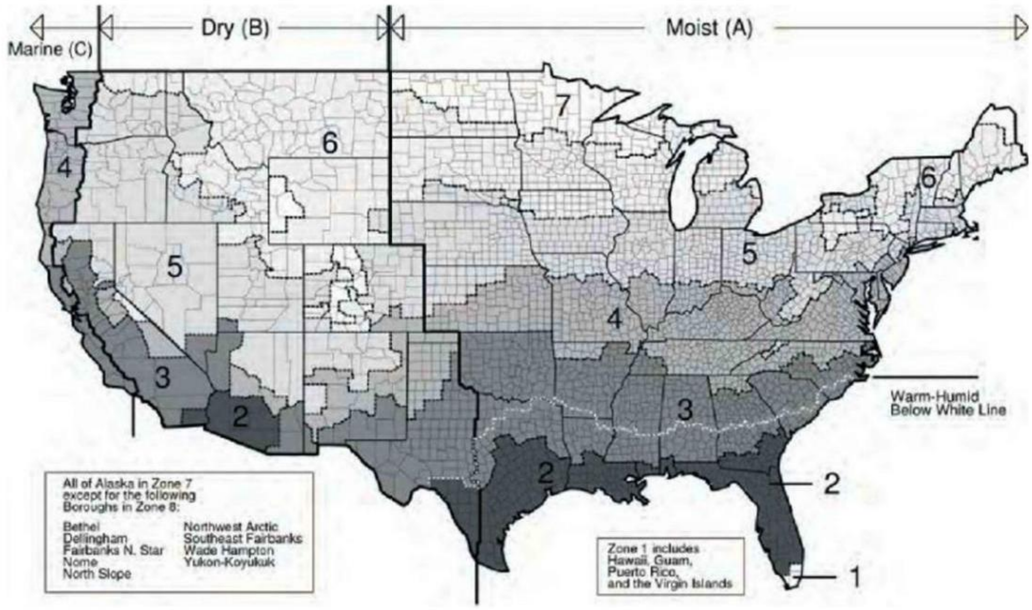

Fig. 2-3 U.S. thermal climate zone map

2.3.3 International Energy Conservation Code (IECC2015)

2.3.3.1 Development Process

The International Energy Conservation Code (IECC) is compiled and issued by ICC. The code is stemmed from the Code for Energy Conservation in New Building Construction jointly compiled by the energy conservation departments of the states in 1977. In 1981, the code was renamed as the Mode Code for Energy Conservation. In 1995, it is revised and issued by CABO, and renamed as the Model Energy Code. In 1994, after the adjustment of the organization (BOCA, ICBO and SBCCI were incorporated into ICC), ICC issued the first version of the IECC energy conservation code in 1998. Since then, it is revised every three years and at present, it has published 2000 version, 2003 version, 2006 version, 2009 version and 2012 version of *IECC* (figure). Currently, the newly published *IECC 2015* was approved and implemented in October 2015. Compared with 2006 version, it saves 50% of energy[2].

Residential buildings, townhouses and garden apartments with three storeys or less in height are covered in the IECC-Residential provision. In this code, a residential building is a detached one and two types of family dwellings, namely multiple family dwellings and single family dwellings of R-2, R-3 or R-4 built three storeys or less in height. All the other buildings, including residential buildings more than three storeys in height are regulated by the energy conservation requirements in the commercial provision.

Different from ASHRAE90 code, IECC covers all the building types equipped with heating and air conditioner equipment, and it is applicable to three storeys or less residential buildings and all the public buildings (Residential buildings, townhouses and garden apartments of three storeys or less in height are covered in the IECC-Residential provision). In this code, a residential building is a detached one and two types of family dwellings, namely multiple family dwellings and single family dwellings of R-2, R-3 or R-4 built three storeys or less in height. All the other buildings, including residential buildings more than three storeys in height are regulated by the energy conservation requirements in the commercial provision. IECC uniformly stipulated the requirement of independent residence, multiple dwelling buildings and other low-rise residential buildings, when omitting the provisions on the window area and simplified relevant requirements.

2.3.3.2 Main Evaluation Index

(1) Heat transfer coefficient (U-value)

U-value is the coefficient of heat transmission through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films. U-Factor refers to the rate of the component. The higher the value is, the larger the heat flow per unit area is. U-factor aims at the single material (single heavy wall), or abides by heat flow of the specific route's composite structure (such as frame structure wall). U_0 is used to stand for the average value of multiple heat flow routes. U_A stands for total heat loss of specific building components and the value is the product of U-factor (U_0) and the area.

(2) Thermal Resistance (R-value)

As thermal resistance, R value stands for the ability that materials resist heat to go through. Its value is reciprocal of U-factor that is only used for signifying single material or single heat flow route. For two buildings with the same architectural form, the function of rooms and air conditioner systems, the smaller the UA is, the less the heat that is lost from the building envelope of the building is, and the better the energy conservation performance is.[2]

(3) Solar Gain Heat Coefficient(SGHC)

SGHC is the ratio of the solar heat gain entering the space through the fenestration assembly to the incident solar radiation, which includes directly transmitted solar heat and absorbed solar radiation that is then reradiated, conducted or convicted into the space.

Table 2-5 Thermal requirements of building envelopes (IECC2015)[5] [$W/(m^2 K)$]

Climate zone	Fenestration	Skylight	Ceiling	Frame wall	Mass wall	Floor	Basement wall	Crawl space wall
1	2.84	4.26	0.199	0.477	1.119	0.364	2.045	2.709
2	2.27	3.69	0.170	0.477	0.937	0.364	2.045	2.709
3	1.99	3.12	0.170	0.341	0.557	0.267	0.517	0.772
4 except Marine	1.99	3.12	0.148	0.341	0.557	0.267	0.335	0.369
5 and Marine 4	1.82	3.12	0.148	0.341	0.466	0.187	0.284	0.312
6	1.82	3.12	0.148	0.256	0.341	0.187	0.284	0.312
7 and 8	1.82	3.12	0.148	0.256	0.324	0.159	0.284	0.312

2.4 Introduction to the Japanese Building Energy Conservation Standard

2.4.1 Development Situation of the Japanese Building Energy Efficient Standard

2.4.1.1 High-level Law

Along with the increase of energy consumption, the problem of global warming has been increasingly emerging. In this case, Japan has made a series of effort to reduce energy use and emission of greenhouse gases. In 1990, Japan enacted "Action Plan" to prevent global warming in the cabinet minister conference. In 1992, the United Nations Framework Convention on Climate Change was ended in the United Nations conference on environment and development. In December 1997, the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change was held in Kyoto. *The Kyoto Protocol* was approved and the standard of carbon dioxide emissions of all the countries was stipulated. In 1998, the framework was built to promote global warming counter measures.[6]

The Japanese building energy consumption (including heating and energy consumption of construction) accounts for 35%~40% of total energy consumption in the society, in which residential building energy consumption accounts for nearly 50%. Faced with huge pressure of building energy consumption, Japanese whose energy nearly depends on *Laws on Reasonable Use of Energy* (*Energy Conservation Law* for short) that regulated standard value of PAL (annual load coefficient) and CEC (air conditioning energy consumption index). The law, acting as the basic law of energy conservation policy in Japan, was revised in 1983, 1993, 1998, 2002, 2005, 2008 and 2010 respectively and serves as the framework establishment and standard of implementing residential buildings and public buildings. *Energy Conservation Law* of 2008 version expands the scope of buildings and the energy conservation program is submitted. In addition, small and medium-sized buildings over 300m^2 are required to apply energy conservation management, and at the same time, the guidance and suggestion on thermal insulation property of building materials are put forward.

2.4.1.2 The Basic Energy Efficiency Standard

Under the framework of *Energy Conservation Law*, the Japanese government introduced the energy conservation standard into residential buildings and public buildings. In 1999, it issued *the Criteria for Clients on the Rationalization of Energy Use for Buildings* (CCREUB) that is applicable to the energy conservation standard of public buildings. There are two types of standards for energy conservation of residential buildings: the first one is *the Criteria for Clients on the Rationalization of Energy Use for Houses* (CCREUH) issued by the Ministry of Economy, Trade and Industry and the Ministry of Land and Transport in 1980 and revised in 1992, 1999 and 2009 respectively; the second is *the Design and Construction Guidelines on the Rationalization of Energy Use for Houses* (DCGREUH) issued by the Ministry of Land and Transport in 1980 and revised in 1992 and 1999 separately. "CCREUH" regulates the primary energy consumption limit of residential buildings, while "DCGREUH" involves the specific requirement of retaining structure performance like exterior walls, windows and so on. In 2013, Japan incorporated three standards of residential buildings and public buildings into a standard *Building Energy Conservation 2013* that is fully implemented on April 1st, 2015.

2.4.2 Climate Zone

Japan is divided into 47 jurisdictions including the capital, Hokkaido, two prefectures and 43 provinces, similar to the administrative division level of China. Apart from Hokkaido, there are two systems under the capital, prefecture and province: one is the urban system, falling into city, town (street), chome (section) and nichome (number), and the other is the rural system, including prefecture (district), town and village. In the old standard, the region is divided into six zones, while in the new standard, it is divided into eight different areas according to HDD18 (Table 2-6).

Table 2-6 Japan climate zones

1999 Edition	2013 Edition	Thermal Criteria	Representative area
I	1	HDD18≥4500	Hokkaido
	2	3500≤HDD18<4500	
II	3	3000≤HDD18<3500	Aomori Prefecture, Iwate Prefecture, and Akita Prefecture
III	4	2500≤HDD18<3000	Miyagi Prefecture, Yamagata Prefecture, Toyama Prefecture

Ⅳ	5	2000≤HDD18<2500	other zones except Ⅰ, Ⅱ, Ⅲ, Ⅴ, Ⅵ
	6	1500≤HDD18<2000	
Ⅴ	7	500≤HDD18<1500	Miyazaki Prefecture and Kagoshima Prefecture
Ⅵ	8	HDD18<500	Okinawa Prefecture

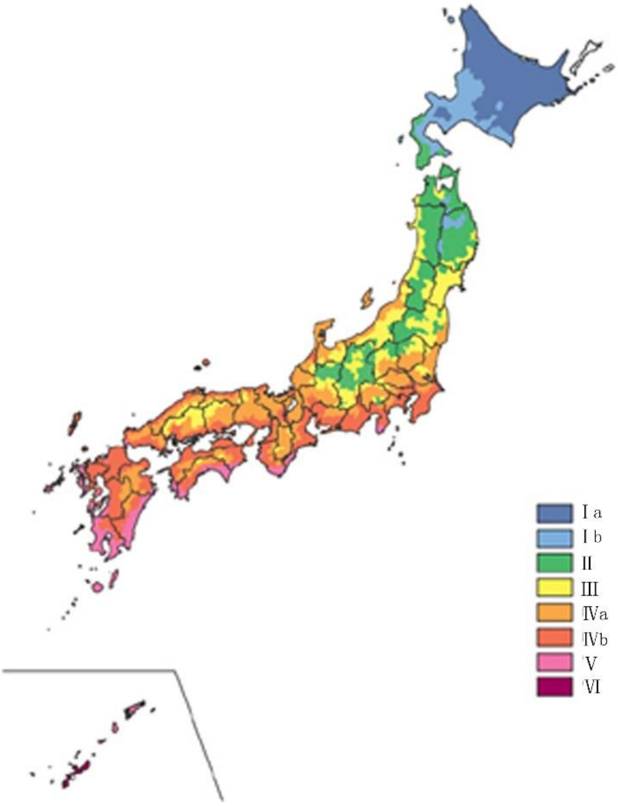

Fig.2-4 The Japanese thermal climate zone map

2.4.3 Japanese Building Energy Conservation Design Standard 2013

The Japanese building energy conservation design standard stipulated the base value of proprietors and owners of particular buildings on energy use, including residential components of residential, non-residential and composite buildings and non-residential components of non-residential buildings and composite buildings. The energy conservation standard was issued by the Ministry of Economy, Trade and Industry and the Ministry of Land and Transport, implemented since 1999, and revised several times. The standard of residential components of residential and composite buildings was abolished on October 1st, 2013 and fully implemented on April 1st, 2015.

The guidance of building design, construction and conservation guarantees the effective use of residential energy, and specific measures of realizing residential energy conservation were put forward from the aspect of residential design, construction and maintenance. To be specific, three aspects, namely the principle of preventing heat to cause loss through exterior walls and windows, the non-renewable energy consumption benchmark and maintaining security requirements are involved. The standard was enacted since 2006 and adjusted several times. The new version standard started to be implemented on October 1st, 2013.

2.4.3.1 Primary Energy Consumption

Primary energy consumption is the sum of primary energy consumption of lifting appliances and domestic appliances such as air conditioning and heating equipment, the air regenerating device, the water supply plant and elevators. In design buildings, if there is electric power generated by energy efficient equipment via using solar power generation equipment or waste heat power generation equipment, and it should be subtracted. The equation is as follows:

$$E_T = E_{AC} + E_V + E_L + E_W + E_{EV} + E_M - E_S \qquad \text{Equation (1)}$$

where, E_{AC}, E_V, E_L, E_W, E_{EV}, E_M stand for the energy consumption of cooling and heating, ventilation, lighting, water supply, elevators, household appliances. E_S stands for the energy generate from solar photo-electricity or triple generation system. In CCREUH standard, domestic appliance consumption was not considered. Primary energy consumption is the newly added evaluation method in the standard and it requires the primary energy consumption of design buildings no more than primary energy consumption of baseline buildings.

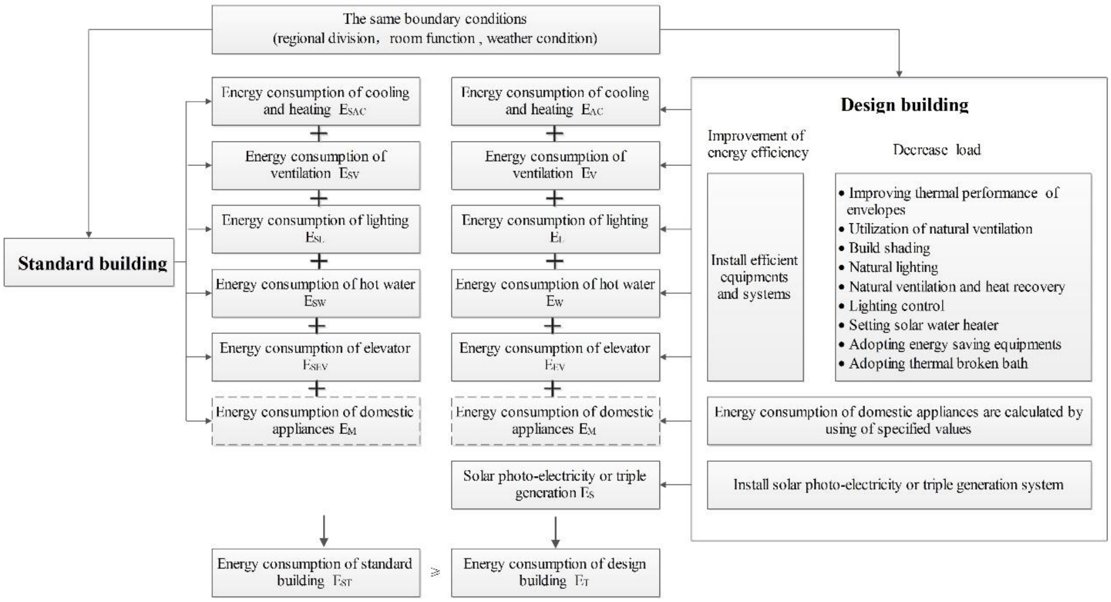

Fig. 2-5 The evaluation method

2.4.3.2 U_A and ηA

The average heat flow rate of the external building envelope (U_A) is the ratio of overall heat loss that created each unit of temperature difference Σq and the exterior area of the building ∑A. The overall heat loss created each unit of temperature difference q is sum of the lost heat of parts like roofs, courtyards, exterior walls, doors, windows and floors, etc. (as shown in the figure). The

calculation of the heat loss value doesn't include the heat loss caused by ventilation and penetration of buildings. The average solar radiation acquisition rate in the refrigeration period (η_A) is the ratio of the total solar radiation acquisition value ∑mc and the exterior area of building ∑A.
The requirement of U_A and η_A is shown in Table 2-7.

Table 2-7 Requirement of U_A and η_A

Climate zone	1	2	3	4	5	6	7	8
U_A	0.46	0.46	0.56	0.75	0.87	0.87	0.87	——
η_A	——	——	——	——	3.0	2.8	2.7	3.2

2.4.3.3 Evaluation Methods

There, different evaluation methods are regulated respectively according to various architectural forms in the standard of Japan. Japanese houses mainly involve two types: detached houses and aggregative houses. To be specific, detached houses are two layers of courtyard houses, while aggregative houses refer to multi-family cohabitation form houses. In the Japanese new judgment benchmark, these two forms are evaluated according to different indicators.

(1) For detached houses, primary energy consumption is required, and the average hot molding mica penetration flow rate U_A of external building envelopes and the average insolation acquisition rate of the air conditioning period (η_A) are smaller than the reference values.

(2) For aggregative houses, which need the primary energy consumption of all households, whole buildings and non-residential PAL values in buildings are smaller than the reference values. Similar to detached houses, multi-family households required primary energy consumption. The average hot molding mica penetration flow rate U_A of external building envelopes and the average insolation acquisition rate of the air conditioning period (η_A) are smaller than the reference values. The primary energy consumption of the whole building is not greater than the reference value. Besides, the primary energy consumption of the whole building is equal to the sum of energy consumption of all households, the energy consumption of common parts and non-residential building parts. The specific evaluation process is shown in Table 2-8 below.

Table 2-8 The evaluation methods of different houses

Types	Evaluation content
Detached houses	◎PEC ≤ Standard value ◎U_A ≤ Standard value ◎η_A ≤ Standard value
Aggregative houses	Each household: ◎PEC ≤ Standard value ◎U_A ≤ Standard value ◎η_A ≤ Standard value ＋ Whole building: ◎PEC ≤ Standard value the non-residential part ◎PAL ≤ Standard value

2.5 Introduction of Chinese Residential Building Energy Efficiency Standards

2.5.1 Development Situation of the Chinese Building Energy Efficiency Standards

2.5.1.1 High-level law

The building energy efficiency standards were firstly set by the world's major developed countries during the world's first oil crisis period in the 1970s, and underwent the process of developing from nothing. China enacted the standards relatively later in the aspect of building energy conservation, and it was not until the late 1980s that relevant laws and regulations were developed:

◎1986, The Interim Regulations on Energy Saving Management

◎1997, The Energy Conservation Law of the People's Republic of China

◎2005,The Renewable Energy Law of the People's Republic of China

◎2005, The Regulations for the Civil Building Energy Efficiency

◎2008, The Regulation of Civil Building Energy Efficiency

……

By 2010, China has issued more than 130 laws, regulations and rules related to building energy conservation, and the content involved building energy-saving technology promotion, building energy saving design, the development of new building materials, energy saving of the building material industry, wall material innovation, the application of new energy and renewable energy in building engineering, energy saving, comprehensive utilization of resources, etc.[7]

2.5.1.2 National and Local Standards

The development of China's national and local building energy efficiency standards has the features of strong administrative color and planned economy, which has adopted the idea of classified compilation. In 1986, the Ministry of Construction formally issued the first building energy efficiency design standard that is the "Energy-saving Design Standard for Civil Buildings (heating residential buildings)". In 1984, according to the requirements of the State Planning Commission (renamed as the National Development and Reform Commission in 1998), China Academy of Building Research and other relevant units complied with the "Thermal Design Code for Civil Buildings" GB50176 which was officially issued and implemented in 1993. This standard is China's first national standard of building thermal design which has regulated the thermal design of the partition and design requirements, heat preservation and heat insulation design of building envelopes, moisture proof design of envelopes and other related content. The new version in 2016 will be formally put into effect in 2017. Since then, China has experienced from the north (cold and severe cold zone) to the central (hot summer and cold winter area) and finally to the south (in hot summer and warm winter area); at that time, the first residential building was the public building; the first new building was the existing building; and the standard system of our building energy efficiency was established (Fig.2-6).

In addition, it also created the corresponding energy-efficient inspection standard, the energy-efficient transformation standard, etc. Different from the United States, approved and promulgated by the Ministry of Housing and Urban-rural Development of the People's Republic of China, the national standard (GB) and industry standards (JGJ) belong to standards enforced by the government. Local standards combined with the characteristics of climate, economic and social development on the basis of national standards lead to the improvement of specific implementation rules.

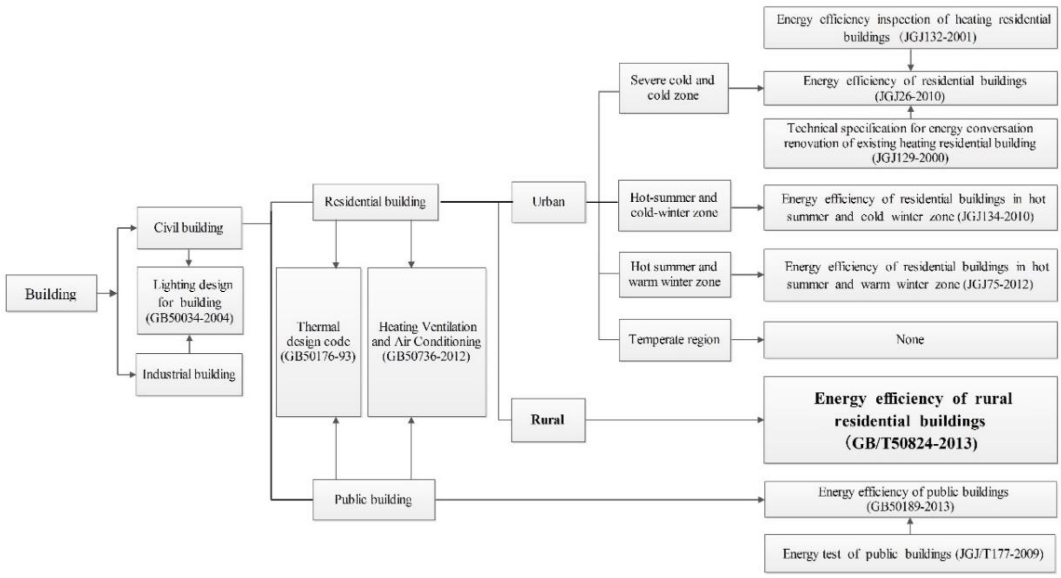

Fig.2-6 The Chinese building energy efficiency standard system

In 2010, the Ministry of Construction approved and issued the higher standard of *the Code for Green Design of Civil Buildings (JGJ/T 229-2010)*, which requires the resource saving and environment protection within the whole life cycle of buildings to be implemented. In addition, regulations on the site, architectural form, technology, equipment and materials that benefit sustainable development are made. Then, various zones also successively cause the improvement of the corresponding green building design standards and implementation guidelines.

2.5.2 Climate Zone

Climate is an important factor that affects buildings and the building energy consumption of different parts. According to the features of the climate in our country, the thermal design code for civil buildings was issued on March 17, 1993. In this code, the building climate is divided into five parts: Severe Cold Zone(SC), Cold Zone(C), Hot Summer and Cold Winter Zone(HSCW), Hot Summer and Warm Winter Zone(HSWW) and Mild Zone(M) (Fig.2-7). In each level of divisions, it has adopted HDD18 and CDD26 as secondary zoning index, and besides, each level of divisions has been subdivided (Table 2-9).

The design standard for energy efficiency of rural residential buildings was issued on December 25, 2012. In this standard, the building climate is rural areas which are divided into four parts: Severe Cold Zone, Cold Zone, Hot Summer and Cold Winter Zone, and Hot Summer and Warm Winter Zone.

In *Design Standard for Energy Efficiency of Rural Residential Buildings (GB/T 50824-2013)[1]*, the rural areas will consider the average temperature according to the most cold months and the most warm months as the climatic division index, and therefore, China's rural areas can be divided into severe cold zone, cold zone, hot summer and cold winter zone and hot summer and warm winter zone. The regional division is consistent with other relevant specifications of divisions, and the building envelope limits of parts of mild zones are executed with the reference of relevant parameters of the hot summer and cold winter zone.

Table 2-9 China thermal performance design partition indexes and requirements [9]

Climate zone	Thermal index	Requirement of building insulation	Requirement of building heat insulation
SC A (1A)	6000 ≤ HDD18	Very high, must	Without considering
SC B(1B)	5000 ≤ HDD18 < 6000	High, must	Without considering
SC C(1C)	3800 ≤ HDD18 < 5000	Must be satisfied	Can be without considering
C A(2A)	2000 ≤ HDD18< 3800; CDD26 ≤ 90	Shall be satisfied	Can be without considering
C B(2B)	2000 ≤ HDD18< 3800; CDD26 > 90	Shall be satisfied	Appropriately considering both natural ventilation and shading
HSCW A (3A)	1200 ≤ HDD18 < 2000	Shall be satisfied	Shall be satisfied, and focus on natural ventilation and shading
HSCW B (3 B)	700 ≤ HDD18 < 1200	Shall be satisfied	Shall be satisfied, and emphasize natural ventilation and shading
HSWW A(4A)	500 ≤ HDD18 < 700	Appropriately be satisfied	Shall be satisfied, and emphasize natural ventilation and shading
HSWW B(4B)	HDD18 < 500	Can be without considering	Shall be satisfied, and emphasize natural ventilation and shading
M A(5A)	CDD26 < 10; 700 ≤ HDD18< 2000	Shall be satisfied	Without considering
M B(5B)	CDD26 < 10; HDD18 < 700	Appropriately be satisfied	Can be without considering

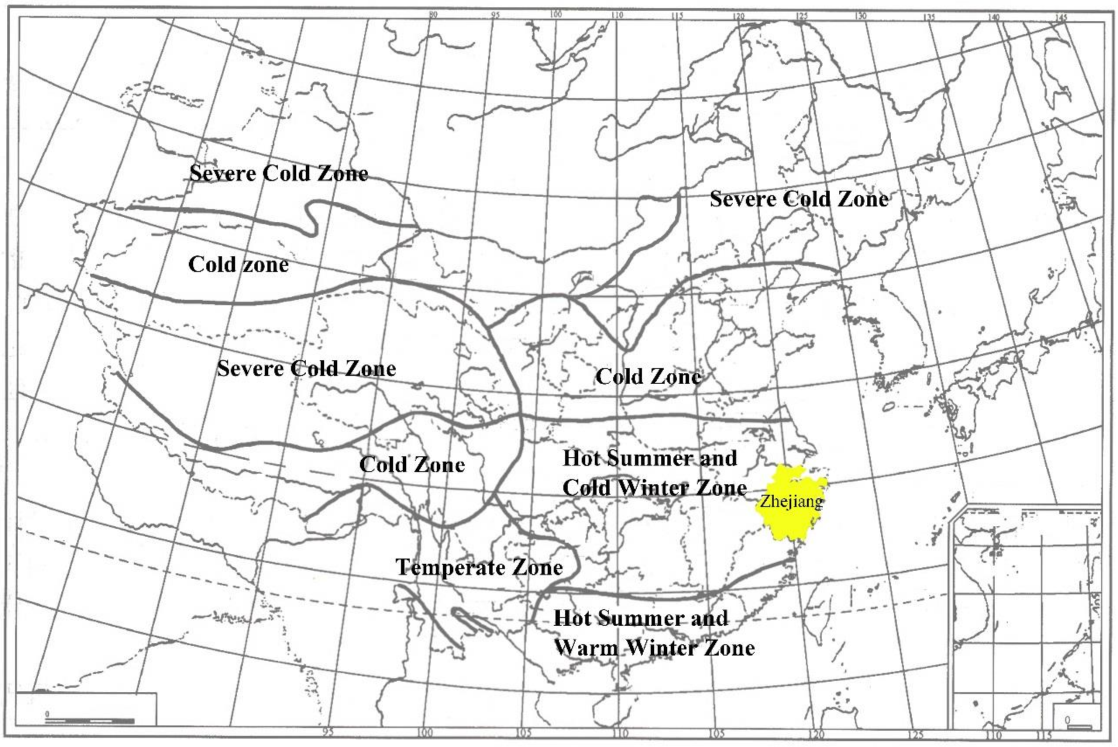

Fig.2-7 China's thermal climate zone map

2.5.3 Residential Building Standards of Different Climate Zones in China

2.5.3.1 JGJ26-2010

The area of severe cold and cold zones accounts for 70% of the total area, and the construction area possesses about 50% and there, the building energy efficiency policy was implemented firstly. Prior to the current version (JGJ26-2010) [10], there were two versions, namely JGJ26-86 and JGJ26-95 that have been abolished. The new standard on the basis of the original, thermal performance requirements of building envelopes has been improved significantly. The energy-saving target was increased to 65% (2010 Edition) from the original 30% (86 Edition) and 50% (95 Edition).

The area of severe cold zone and cold zone in China is equivalent to the area of several European countries. Therefore, the climate difference is larger. In the 2010 version of specification, it has referred to building energy efficiency standards in most countries of Europe and North America, according to different Heating Degree Days (HDD18) and Cooling Degree Days (CDD26). Besides, the severe cold zone and cold zone were divided into five climate zones (see Table 10). It has respectively set different shape coefficients and the building envelope thermal performance threshold according to the layers of buildings in the specification. When compared with the old standard, the calculation method of each part of the new standard is more accurate and specific with stronger operability. Firstly, considering the influence of solar radiation on heat transfer of building envelopes, it has adopted the modification coefficient of building envelopes and made correction to heat transfer coefficient of roofs and walls in every direction. Secondly, it has introduced the heat transfer coefficient of the heat bridge line. Considering the influence of the heat bridge on the wall and roofing in the building envelope, such as the structural thermal bridge at the wall corner, pier between two windows, bay-window, balcony, roof, floor slab, and floor, described with linear heat transfer coefficient ψ.

Table 2-10 Thermal performance requirements of building envelopes in different climate zones

Envelopes	Maximum heat transfer coefficient of different climates zones [W/(m²·K)]			
	SC	SC (B)	SC (C)	C
Exterior wall	0.25/0.40/0.50	0.30/0.45/0.55	0.35/0.50/0.60	0.45/0.60/0.70
Partition[a]	1.20	1.20	1.50	1.50
Basement exterior wall[b]	1.80/1.50/1.20	1.50/1.20/0.91	1.20/0.91/0.61	0.91/0.61/—

Note:1. "a" refers to the interior walls between heating and non-heating space. 2. "b" refers to the walls contact with soil. The thermal performance index of it is the thermal resistance, (m²·K)/W. 3. */**/*** respectively indicate the thermal performance of the wall when building storeys ≤3 storeys, 4~8 storeys and ≥9 storeys.4. This table is sorted out according to JGJ 26-2010.

2.5.3.2 JGJ 134-2010

The total area of hot summer and cold winter zones of China (Shanghai, Zhejiang, Chongqing and other places) is about 1.8 million m^2, while the resident population is up to 550 million and the gross national product (GNP) accounted for 45% of the country, which is a population-concentrated and economic-developed region. JGJ 134-2001 is the building energy efficiency standard firstly implemented in this region. The old standard copied the measures and practices of building energy efficiency of the severe cold and cold zone to some extent. After nearly 10 years of practice and Summary, the *Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and cold winter zone (JGJ 134-2010)* [11] has been done based on the old standard revision.

JGJ 134 has adopted two kinds of building energy efficiency evaluation methods: one is a prescriptive indicator method. (JGJ 134-2010) has put forward the limitation on building shape coefficients, heat transfer coefficients of building envelopes and the thermal inertia index, the heat transfer coefficients of the window, the area ratio of window to wall, and comprehensive shading coefficient, etc. The other one is a comparative judgement method, by which the influence of building shape coefficients, the area ratio of window to wall and thermal performance of building envelopes on building energy consumption are comprehensively considered. The comparative judgement method is a dynamic process, which calculated hourly building energy consumption according to the typical meteorological year (8760 hours). In addition, the calculation was significantly complicated. For the convenience of operation, the DOE-2 software was adopted in the standards developed by Lawrence Berkeley National Laboratory as a computing tool.

2.5.3.3 JGJ 75-2012

The hot summer and warm winter zone is located in the south of China, including Hainan, Guangdong, Guangxi, Fujian and Yunnan, Hong Kong, Macao and Taiwan. These zones are at the forefront of China's reform and opening up, with rapid economic development and people's constantly improving living standard. The current standard is (JGJ 75-2012) [12], while the former standard of it is (JGJ 75-2003). JGJ75 is divided into the northern and the southern district according to the average temperature in January. Building energy efficiency design of the north district mainly gave consideration to summer air conditioning and winter heating; the building energy efficiency design of the southern district should take the summer air conditioning into consideration, without considering winter heating. The same as other districts, the evaluation method of JGJ75-2012 included the prescriptive indicator method and the custom budged method. In addition, the custom budged method adopted design buildings with reference to the annual power consumption of the air conditioning heating or air conditioning heating power consumption index for comparison. The air conditioning heating power index is a simplified calculation method based on DOE-2 software fitting. The air conditioning power consumption index ECF_C and annual heating power index ECF_H calculation are as follows:

$$ECF_C = [\frac{(ECF_{C\cdot R} + ECF_{C\cdot WL} + ECF_{C\cdot WD})}{A} + C_{C\cdot N} \cdot h \cdot N + C_{C\cdot 0}] \cdot C_C \qquad \text{Equation (2)}$$

$$ECF_H = [\frac{(ECF_{H\cdot R} + ECF_{H\cdot WL} + ECF_{H\cdot WD})}{A} + C_{H\cdot N} \cdot h \cdot N + C_{H\cdot 0}] \cdot C_H \qquad \text{Equation (3)}$$

Where, A refers to the total area of buildings; N is the air circulation ratio; h is the weighted average storey height according to the building area. $ECF_{C\cdot R}$, $ECF_{C\cdot W}$, $ECF_{C\cdot WD}$, $ECF_{H\cdot R}$, $ECF_{H\cdot WL}$, $ECF_{H\cdot WD}$ are annual cooling electricity consumption index and the annual heating electricity consumption index and parameters related to roof, wall, and external doors and windows. $C_{C\cdot N}$ is the parameter related to the annual cooling electricity consumption index and air circulation ratio. 4.16. $C_{H\cdot N}$ is the parameter related to the annual heating electricity consumption index and air circulation ratio, while $C_{C\cdot 0}$, C_C and $C_{H\cdot 0}$, C_H are parameters related to the annual cooling electricity consumption index and annual heating electricity consumption index.

2.5.3.4 GB/T50824-2013

At present, China building energy efficiency design technologies are mainly concentrated in the cities, and the issued energy conservation standards are mainly aimed at the urban buildings. However, the characteristics of rural residential buildings, farmers' living habits, technical and economic conditions that determined the energy saving requirements shall be different from the requirement of urban residential buildings. Therefore, in 2013, the Ministry of Construction issued the *Design Standard for Energy Efficiency of Rural Residential Buildings(GB/T50824-2013) [1]*. This standard is further improved on the basis of the industry standard of *the Design Standard for Energy Efficiency* *of Detached Rural Housings (CECS 332:2012)[13]* promulgated by China Engineering Construction Industry Association.

According to the average temperature of the coldest months and the warmest months from different regions of China, the rural regions are divided into four thermal performance design partitions: severe cold zone, cold zone, hot summer and cold winter zone, and hot summer and warm winter zone. Buildings in rural areas regardless of the shape coefficient and the building shape in severe cold and cold zone are simple and neat, with small shape coefficients. In this case, the heat is not easy to lost; the architectural form in the hot summer and cold winter zone and hot summer and warm winter zone is plentiful, and shape coefficient is big, easy for building heat dissipation. It has put forward three forms of passive solar houses in specification: direct-gain passive solar houses heat-collecting and heat-storing passive solar houses and attached sunspaces.

In the technical code for passive solar buildings (JGJ/T 267-2012)[14] approved and implemented by the Ministry of Construction of China, our country is divided into four passive solar heating climate zones and four passive cooling climate zones.

2.5.3.5 DB 33/1015-2015

After (JGJ 134-2001) promulgated in Zhejiang province, Hangzhou firstly combined with its own circumstance issued a design standard for "Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone Detail rules" in Hangzhou (CJS03-2002). *The Design Standard for Energy Efficiency of Residential Buildings* (DB 33/1015-2003) was issued in December 2003, and besides, required new buildings shall achieve 50% of the energy efficiency design requirement. In September 2009, in urban and rural areas, "Notification on further strengthening the management of the civil building energy efficiency design technology in Zhejiang province" has been issued concerning the housing construction in Zhejiang province. Building [2009] No. 218 is for the adjustment and supplement of DB 33/1015-2003. On May 13th, 2015, "Residential building energy saving design standard of Zhejiang province"(DB 33/1015-2015) [15] has been issued, and put into effect on November 1st, 2015.

Zhejiang province belongs to the hot summer and cold winter zone, and the year-round Heating Degree Days HDD18 is between 1183.4°C·d~1901.6°C·d, while the cooling degree days CDD26 is between 30.5°C·d~268.2°C·d. Due to the complex topography, the climate difference of all zones is bigger, and the cooling and heating period is different. Zhejiang province can be divided into the north zone and the south zone. The northern district includes Hangzhou, Ningbo, Shaoxing, Jiaxing, Jinhua, Huzhou, Quzhou and Zhoushan; while the southern district includes Wenzhou, Taizhou and Lishui. The building energy efficiency design of the north district should not only consider heat protection in summer, but also heat preservation in winter; the building energy efficiency design of the southern district should focus on taking heat protection in summer, and heat preservation in winter into account. The wall heat insulation measures in Zhejiang prefer to use light color facing or building heat reflection heat insulation coating, west and east wall adopt grille member, plant sun-shading and vertical greening; wall insulation should prefer to adopt self-thermal insulation walls, or self-thermal insulation, external heat insulation, internal heat insulation and compound heat insulation and so on. It regulated heat transfer coefficient limits under bodily different form coefficients in specification. When east and west walls are sunshade structures and wall-added equivalent R value of 0.3(m^2·K)/W.

Compared with 2003 version, this version refined the requirements on partition design and energy conservation design. When the prescriptive indicator method is adopted to improve the energy efficiency design, the wall thermal performance requirements are stricter than before; when the custom budged method is adopted in energy saving design, wall thermal performance shall be broadened to avoid "short wooden division" of "Cask Effect", and increase the flexibility of design.

Table 2-11 Thermal performance requirements for walls of residential buildings [W/(m^2·K)]

Component			Prescriptive indicator method			Custom budget method	
			D≤2.5	2.5<D≤3.0	D>3.0	D≤3.0	D>3.0
Exterior wall	$\leq 0.40^{a}$	North District	1.0	1.2	1.5	1.5	1.8
		Southern District	1.2	1.5	1.8	1.8	2.0
	$>0.40^{a}$	North District	0.8	1.0	1.2	1.2	1.5
		Southern District	1.0	1.2	1.5	1.5	1.8
Separating wall and partition			2.0			——	——

Note:1. The partition refers to the partition wall in the enclosed staircase or smoke-proof staircase, antechamber or common antechamber and closed external corridor. 2. This table is sorted out according to (DB 33/1015-2015) 3. *a* refers to the shape coefficient in this table.

2.5.3.6 Discussion

It can be seen from the comparison of China's existing residential building energy efficiency design standards:

(1) The thermal performance design requirements of building envelopes in the north should be stricter than that of the southern region; local standards shall be stricter than national standards; besides, urban housing standards shall be stricter than rural residential standards.

(2) The content of all standard systems is the same basically, and the heat transfer coefficient is the most important evaluation index of building envelopes. In current standards, the calculation of different heat transfer coefficients of transparent parts is different in the north region and the south region. Severe cold and cold zones adopt the heat bridge transfer coefficient to correct the two-dimensional heat transfer of the thermal bridge positions. The south region still adopts the average heat transfer coefficient of the thermal bridge and non-thermal bridge position, but the attached

thermal resistance of the surface material of building envelopes is considered in the hot summer and warm winter zone.

(3) In addition to the prescriptive indicator method applied in the rural energy conservation standard, other standards adopted both the prescriptive indicator method and the comparative judgement method to evaluate the thermal performance of building envelopes. The specific evaluation process is shown in the figure. (Illustration: the logic calculation process chart) In addition, the calculation of comparative judgement is limited to the comparative judgement of building envelopes, and the energy efficiency of air conditioning equipment will not be involved in comparative judgement calculation.

2.6 Comparison of the Requirements Among Chinese, American and Japanese Standards

The thermal performance of building envelopes is the most important constituent part of building energy efficiency standards. In this section, with the main research area of the project and the climatic region of north Zhejiang as an example, the performance requirements of building envelopes among all current Chinese standards, among Chinese, American and Japanese standards are compared. Zhejiang province belongs to the hot summer and cold winter zone (3A zone). Besides, the annual Heating Degree Days HDD18 is between 1183.4°C·d~1901.6°C·d, while the Cooling Degree Days CDD26 is between 30.5°C·d~268.2°C·d. Climate characteristics are equivalent to 3C zone of American thermal performance design (Warm-marine, HDD18°C≤2000) and 6 zone of Japanese thermal performance design (1500≤HDD18<2000). With this zone as an example, the thermal performance requirements of building envelopes in the Chinese JGJ 134-2010, DB33/1015-2015, GB/T 50824-2013 (hot-summer and cold-winter zone), American IECC2013(3 zone) and Japanese BEES2015(6 zone) standards are compared.

2.6.1 Comparison Method

In the American IECC2015 standard, it had regulations on the ceiling, wall body, ground in the form of heat resistance (R-value), and window in the form of the heat transfer coefficient (U-value). In the comparison process, all were converted into heat transfer coefficients, and adopted the international system of units. The Japanese BECS2015 standard had regulations on main parts of building envelopes with heat transfer coefficients according to different building types. At the same time, it had regulations on heat insulation materials, the thermal bridge, etc. of building envelopes with the heat resistance. In the American IECC2015 standard, in addition to the main body part, it had regulations on heat insulation materials in the form of thermal resistance. In the comparative analysis in this section, it only made comparative analysis on the thermal performance of main parts of building envelopes.

Table 2-12 Comparison of different residential building energy saving standards in China

Standard	JGJ 26-2010	JGJ 134-2010	JGJ 75-2012	DB33/1015-2015	GB/T 50824-2013
Chief Editorial Unit	The Research Institute of Building Sciences	The Research Institute of Building Sciences	The Research Institute of Building Sciences	The Architectural Design and Research Institute of Zhejiang University, etc.	The Ministry of Housing and Urban-Rural Development
Approved by	The Ministry of Housing and Urban-Rural Development	The Ministry of Housing and Urban-Rural Development	The Ministry of Housing and Urban-Rural Development	The Department of Housing and Urban-Rural of Zhejiang Province	The Ministry of Housing and Urban-Rural Development
Standard Level	National Standard	National standard	National standard	Local standard	National standard
Forced or Not	Mandatory	Mandatory	Mandatory	Mandatory	Voluntary
Scope of Application	severe cold and cold zones; Urban residential buildings that the rural area may refer to	hot summer and cold winter zone; The urban residential building that the rural area may refer to	hot summer and warm winter zone; The urban residential building that the rural area may refer to	Zhejiang district; Urban residential buildings that the rural area may refer to	National scale; rural dispersing detached and concentrated household independent type low-rise residential (Duplexes, row)
Indoor Enactment Temperature	Winter:18°C, 0.5 ac/h	Winter:18°C,1 ac/h Summer:26°C,1 ac/h	Winter:16°C,1 ac/h Summer:26°C,1 ac/h	Winter:16°C,1 ac/h Summer:26°C,1 ac/h	severe cold and cold zone: winter:14°C,0.5 ac/h; hot-summer and cold-winter zone: winter:8°C,1 ac/h summer:30°C,5ac/h hot summer and warm winter zone: summer:30°C
Energy Efficiency Analysis Software	Two-dimensional steady-state heat transfer calculation software (PDTA)	DOE-2	DOE-2; DeST	DOE-2	——
Execution Time	2010.8.1	2010.8.1	2013.4.1	2015.11.1	2013.5.1

Table 2-13 The Comparison of residential building energy saving standards with U.S. and Japan

Standard Code	IECC2013	BECS 2015
State	America	Japan
Promulgation Agency	ICC	Territory Transport Department
Standard Level	National Standards	National Standards
Forced or Not	No	No
Scope of Application	Public and Residential Buildings	Public and Residential Buildings
Indoor Enactment Temperature	Heating:22°C; Cooling:24°C	Summer:26°C, 50%; 0.5 ac/h Winter:22°C, 50%; 0.5ac/h
Evaluation Method	Prescriptive Approach; performance Approach	Prescriptive approach; weighting method (Unsteady State)
Energy Efficiency Analysis Software	——	BEST(etc.)
Execution Time	2013.10	2015.4

2.6.2 Comparative Analysis

2.6.2.1 Evaluation Content of Building Envelopes

Firstly, the comparison of evaluation content and corresponding indexes of building envelopes of all specifications is shown below. It can be seen from comparison table above:

(1) The roof and wall classifications in the American standard and Japanese IECC2015 BEES2015 were more detailed. In IECC2015 standard, the wall was divided into framed wall, heavy wall, basement wall, climbing wall, etc. In the Japanese BEES2015 standard, depending on the type of housing (house of reinforced concrete structure, timberwork residence, framed structure housing, etc.) and different construction methods of heat break materials, the corresponding heat transfer coefficient is respectively stipulated. Comparatively speaking, the roof and wall classifications in the Chinese standard were much simpler, and set limits for the thermal inertia index and heat transfer coefficient.

(2) There were no requirements on floor and ground in three standards of China. But it respectively made regulations on overhead according to the ground in the Japanese standard.

(3) There were requirements on the heat transfer coefficient and air tightness level of door gate in the Chinese standard, but there were no such requirements in the American and Japanese standards.

(4) There were requirements on heat transfer coefficients and shading coefficients (not required in GB/T 50824-2013), the air tightness level of external windows and skylights in the Chinese standard. It regulated heat transfer coefficient of external Windows and skylights in IECC2015 standard. Besides, it regulated the hot molding mica penetration flow rate of external windows in the Japanese BEES2015, but no such requirement on skylight.

(5) The regulation on residential buildings in IECC2015 was appropriate for the residential buildings of three layers and less than three layers. The Japanese BEES2015 was suitable for the area of over 300m^2 of detached houses and conjoined houses, and also had requirements on air tightness, the opening ratio of the whole building and the residential shape. The Chinese JGJ 134-2010 and DB33/1015-2015 were suitable for the urban residence, which can also be applied to rural residential buildings; the building shape coefficient and the average area ratio of window to the wall of all directions and different layers of residential buildings were regulated in standards.

2.6.2.2 Thermal Performance Comparison of Major Parts

The thermal performance limits concerning main parts, such as roof, walls, doors and windows are compared and analyzed and we can get the following results:

(1) The thermal performance requirement of building envelopes in the American IECC2015 standard is higher than that of the Japanese and Chinese standards.

(2) Compared with the Japanese BECS2015 standard and Chinese standard, the requirements on roof, wall, and floor of the Japanese standard are higher than those of the Chinese standard. However, the window heat transfer coefficient is larger than the Chinese standard. The performance and the heat transfer coefficient of windows in the Japanese BECS2015 are related to opening ratio (the ratio of Windows area and surface area of building) and the solar radiation rate, and the performance and the heat transfer coefficient of window in the Chinese standard are related to the area ratio of window to wall, the building shape coefficient and the shading mode.

(3) Compared three domestic standards, it can be seen that the local standard in Zhejiang province on performance requirements of envelopes is higher than the performance requirement of envelopes of the hot summer and cold winter zone, and higher than the performance requirement of envelopes of the rural building as well.

Table 2-14 Comparison of thermal performance requirements in different standards [$W/(m^2 K)$]

Envelopes	IECC2015	BECS2015	JGJ 134-2010	GB/T 50824-2013	DB33/1015-2015
Ceiling/Roof	0.17	0.37(RC internal heat break);0.43(RC external heat break);0.24(others)	SC≤0.4:0.8-1.0 SC > 0.4:0.5-0.6	1.5-1.8	SC≤0.4:0.6-0.8 SC > 0.4:0.5-0.7
Exterior wall	0.34-0.77	0.75(RC internal heat break);0.86(RC external heat break);0.53(other)	SC≤0.4:1.0-1.5 SC > 0.4:0.8-1.0	0.8-1.0	SC≤0.4:1.0-1.5 SC > 0.4:0.8-1.2
Floor	0.27	0.37-0.53 (RC building);0.34-0.48(other)	1.5-2.0	——	1.0-1.5
Fenestration (Window)	1.99	6.51(detached house<0.08) 4.65(detached house 0.08-0.11) /4.07(detached house 0.11-0.13)	2.3-4.7	3.2-4.7	2.0-2.8(with movable external sunshade),1.9-2.4(without movable external sunshade)
Door			2.0-3.0	3.0	2.0-2.5
Window	0.25 (SHGC)	SHGC <0.74 or with sunshade component (detached house 0.08-0.11); SHGC <0.49 or SHGC <0.74 with sunshade component or windows with blinds (detached house 0.11-0.13)	WWR≤0.3, without consideration 0.25-0.45(summer); ≥ 0.6(winter)	——	Summer:0.25-0.45; Winter: ≥ 0.6
Skylight	3.12	——	——	——	2.8(≤roof area 4%)
Opening ratio	——	0.13(detached house);	0.45(S);0.35(E\W);0.4(N)	——	0.45(S);0.20(E\W);0.4(N)

Note:1. SC refers to building shape coefficient.

2.7 Summaries

(1) China is divided into five climate zones. Zhejiang belongs to the hot summer and cold winter zone which is similar to 3C zone in the U.S. and 6 and 7zone in Japan.

(2) The United States, Japan and other countries use a standard to cover building energy efficiency requirements of different climatic zones, while China building energy efficiency standards are produced according to different climatic conditions. The content coverage of our standard is incomplete. At present, our building energy efficiency standard includes two parts of building envelopes and HVAC systems, while building energy efficiency design of developed countries includes the content of the hot water supply system, lighting system, renewable energy system, construction and maintenance.

(4) China building energy efficiency standard is lower than that of the United States and Japan. The requirements of heat transfer coefficients of building roofs, walls, doors, windows and other enclosure structures and the efficiency of the air conditioning unit were lower than those of the European and American countries. In addition, the use of renewable energy is still at the stage of using encouragement, without mandatory requirements.

(5) Comparatively speaking, Japan's energy efficiency standard has made a fine classification for all types of buildings, and therefore, the maneuverability is strong. On the contrary, China's standard classification is more general, and the design requirements and flexibility still need to be improved constantly.

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Chapter 3.

Theory and Method of Energy Saving and Environment Improvement

3.1 Introduction

There is a close relationship among occupant's behavior, energy consumption and indoor thermal environment. (Fig. 3-1). It means that, for a building in a particular climate, the occupant activities have a significant impact on the indoor thermal environment and energy consumption. In addition, a large number of surveys and comparative studies show the different ways in which human behaviors influences energy consumption in China and developed countries.

Mike Grinshpon [2] compared the actual electricity consumption of five typical residences in cities of China and the U.S. with similar climate. Three of the residences were detached or united houses in North Carolina, America while the other two were high-rise apartments in Beijing, China. Fig. 3-2 shows the electricity consumption of the five residences in 2011, which included the electricity consumption for air conditioning, lighting, cooking, hot water and other electricity appliances, but didn't include the energy consumed for heating. It can be observed that, there is a huge difference in residential energy consumption between the two countries, which was mainly caused by the different lifestyle. Taking the use of air conditioner for example, during summer, the American residential building equipped with central air conditioner, maintained constant temperature and the windows were closed during the day. However, in Chinese residence which is equipped with split air conditioner, people would only use the air conditioner in the rooms where they were and most of the time; the windows were opened for natural ventilation.

Li et al[3]. investigated the cooling consumption of 25 households in a residential apartment in Beijing in 2006. Fig. 3-4 shows that the household air conditioner power consumption was quite different; that is, the whole floor of the average value was only 2.3kWh/ ($m^2 \cdot a$), one-sixth of the maximum value.

Professor Yoshino Hiroshi[4] of Tohoku University has conducted a survey on the Japan's household consumption in northeast and the Kanto regions. It was found out that the households have different heating energy consumption and the heating equipment operating (Fig. 3-5). Mathieu Bonte et al.[5] investigated the impact of behavioral actions of a building occupant on energy performance and thermal sensation. It can be seen that the energy consumption of different building energy modes is very different, and hence, needs different energy saving technical measures.

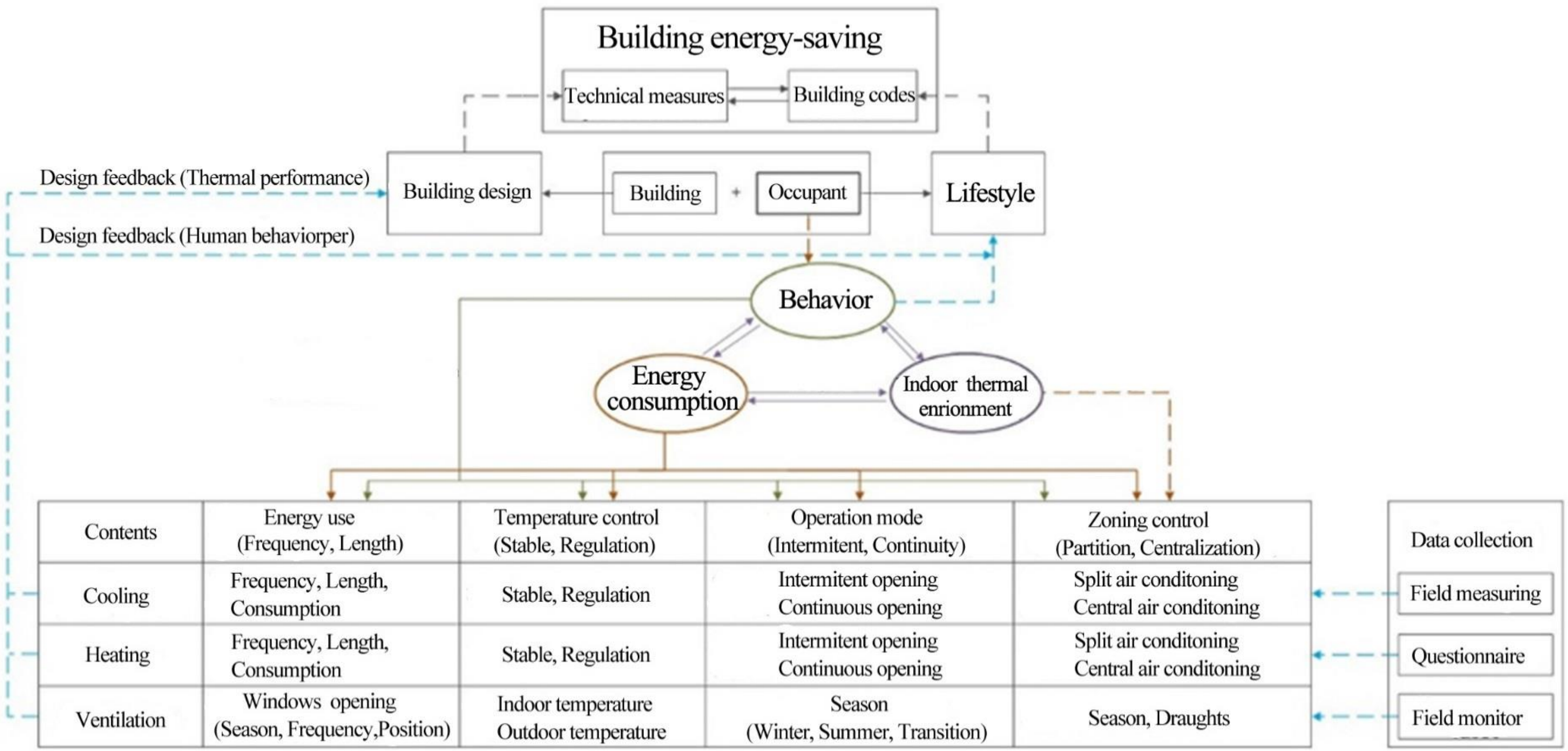
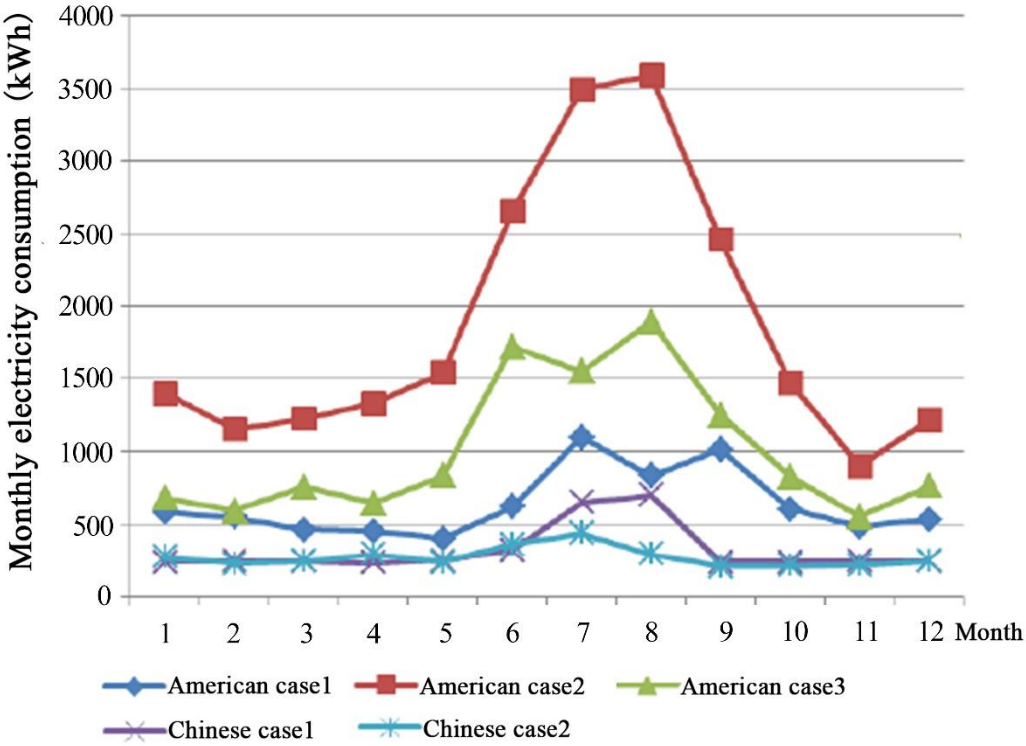
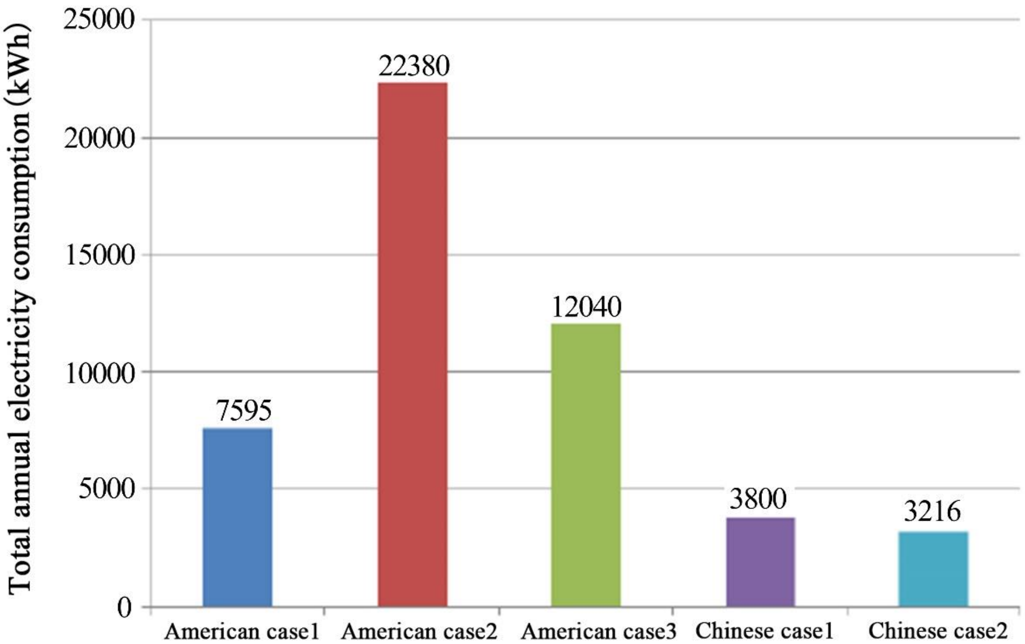


Fig. 3-1 Relationship between behavior, energy consumption and indoor thermal environment[1]

(Source: Modified from *A study on occupant's behavior and thermal environmental energy efficiency of dwellings*)



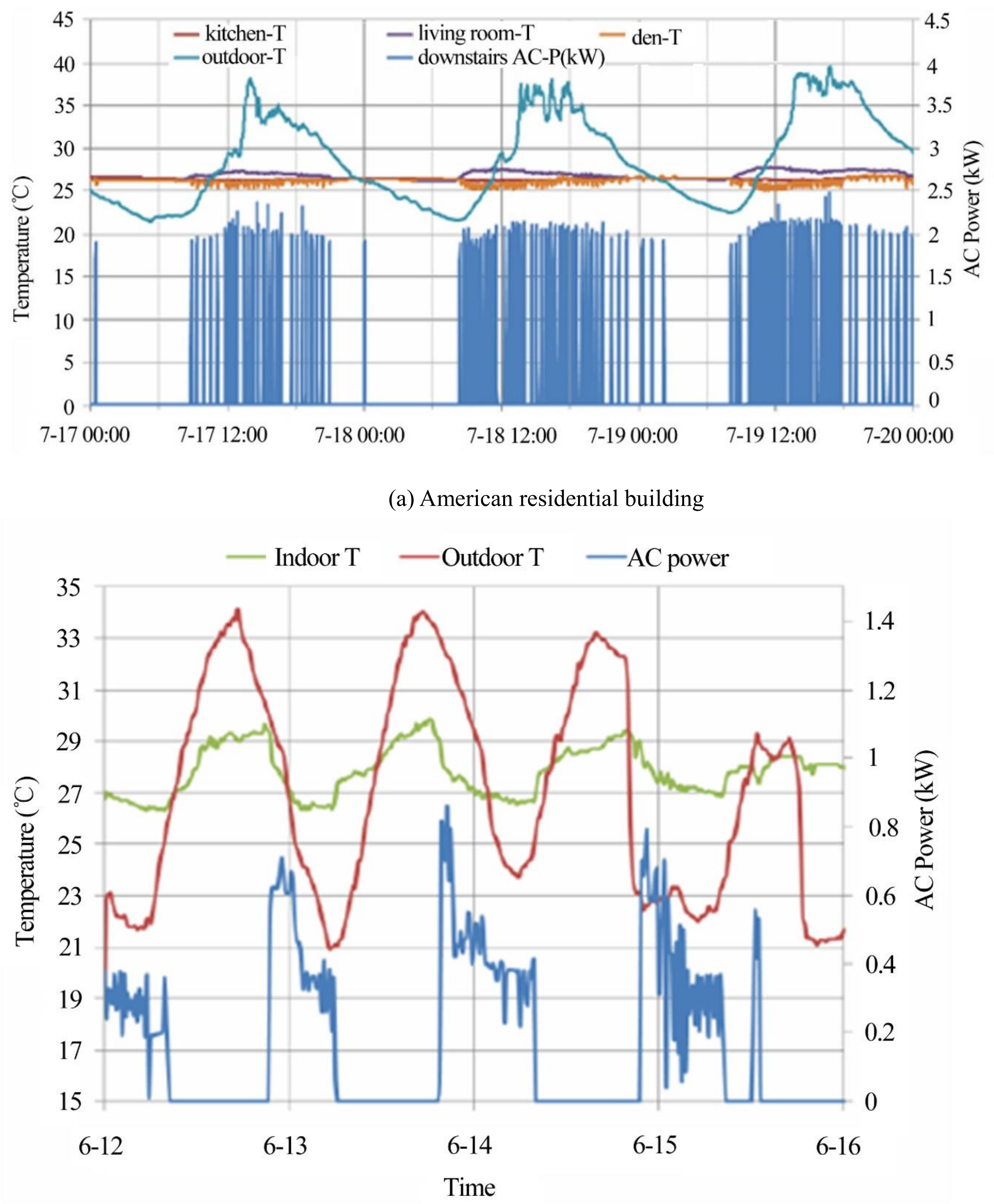
(a) Monthly electricity consumption



(b) Total annual electricity consumption

Fig. 3-2 The comparison of electricity consumption between American and Chinese residences [2]

(Source: *A Comparison of Residential Energy Consumption Between the United States and China*)



(a) American residential building

(b) Chinese residential building

Fig. 3-3 Situation of the indoor temperature and air conditioner operation [2]

(Source: *A Comparison of Residential Energy Consumption Between the United States and China*)

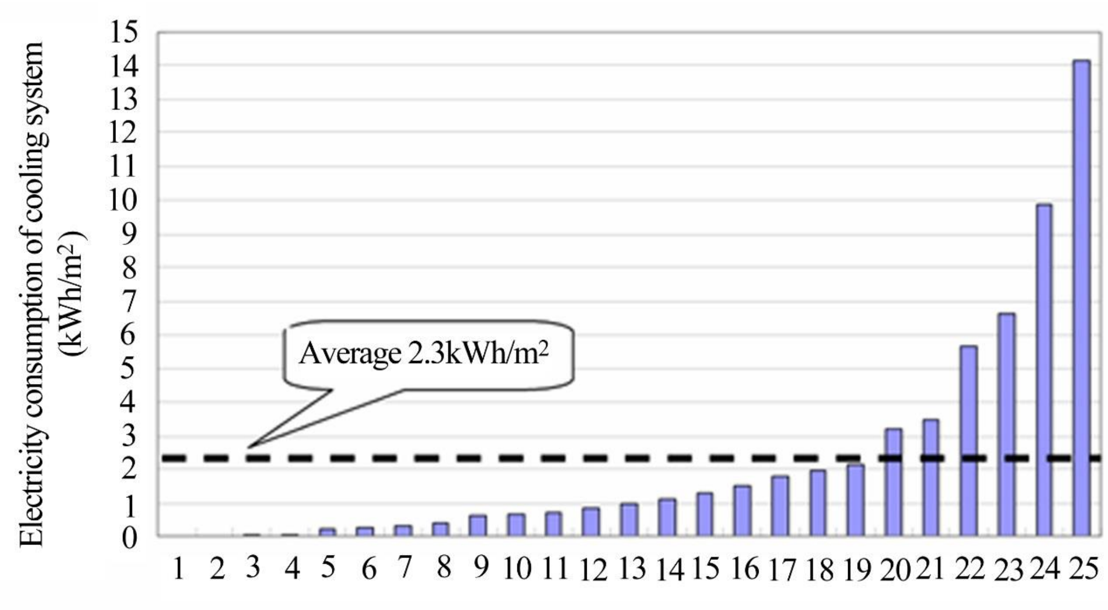
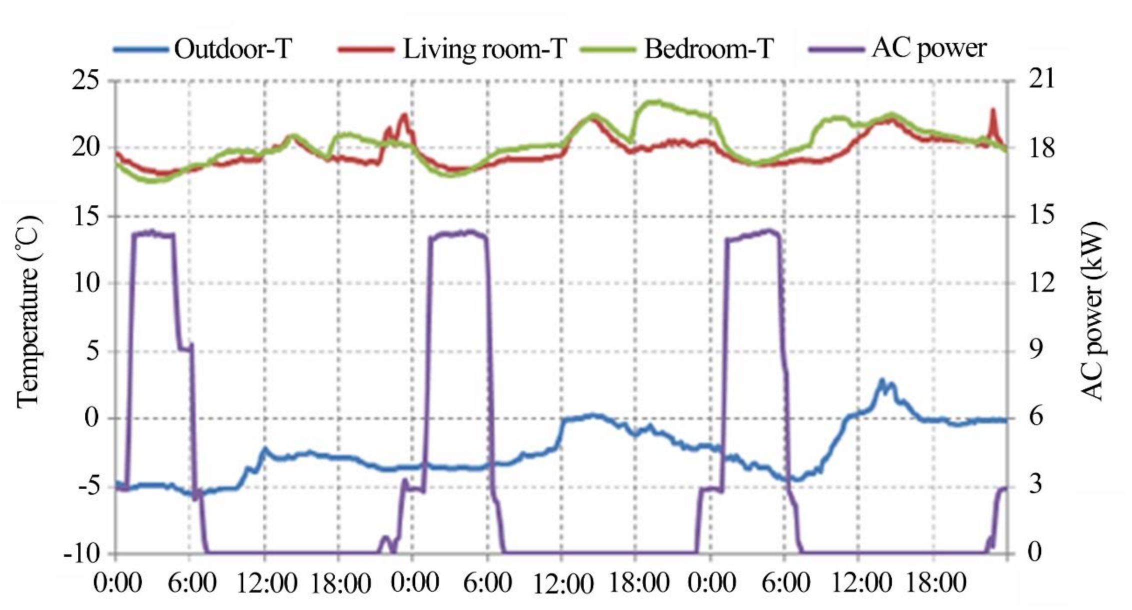
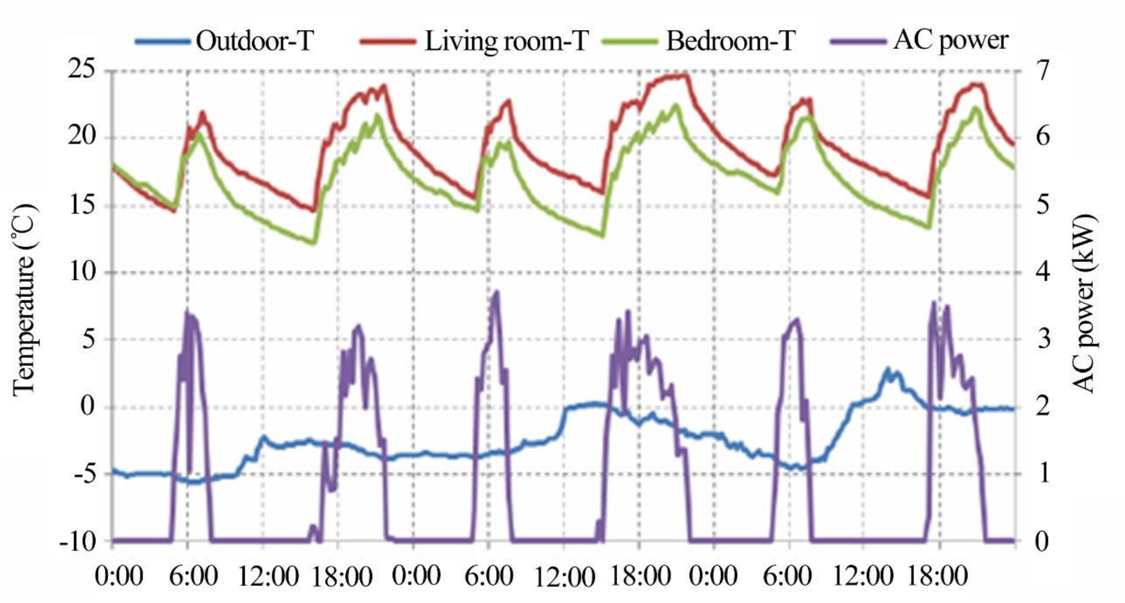


Fig. 3-4Air conditioning electricity consumption per unit floor area [6]

(Source: Simulation Research on Occupant Energy-related Behaviors in Beijing)



(a) Continuous heating family



(b)Intermittent heating family

Fig. 3-5Different heating energy consumption and indoor environmental differences [4]

In addition, the occupants' living lifestyle has a great influence on the indoor thermal environment. Song et al.[7] measured the thermal environment of rural residence in Chongqing in winter, and found out that the farmers' living habits influenced the indoor thermal environment, especially the door usage mode. Liu et al.[1] carried out an analysis on the influence of window opening by residents and air conditioning on the indoor temperature of the residences in Shenzhen.

In a word, the indoor thermal environment and the residential energy consumption are impacted by the occupant' behavior. In recent years, rural tourism has developed speedily in Zhejiang Province. With the change in traditional agricultural production to service industry, the farmers' lifestyle has change. However, the influence of energy consumption has never been studied. In view of the current situation, special attention must be paid to this issue.

3.2 Research Content and Research Route

3.2.1 Research Area

In order to answer these questions, different rural areas operating rural tourism were selected for this study. Four aspects should be taken into account:1) climate condition,2) geographical position,3) economic development situation,4) rural tourism development situation. Finally, three areas were chosen for this study: Quzhou, Anji, and Zhoushan. (Fig.3- 6) The typical summer day temperature of the three regions are shown in Fig.3- 7.

Fig.3- 6 Research areas (Quzhou, Anji, Zhoushan)

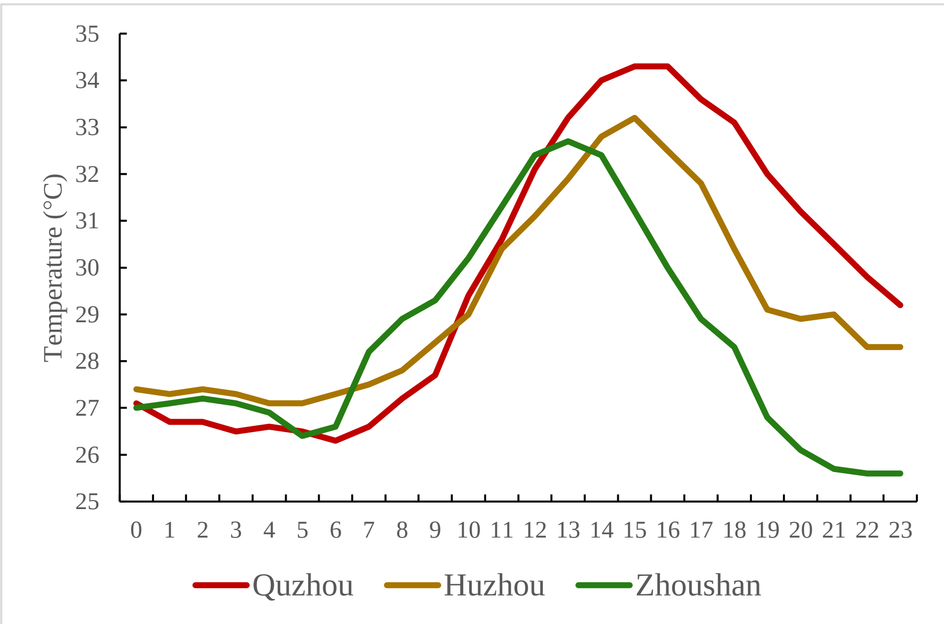


Fig.3- 7 Typical summer day temperature (Quzhou, Anji, Zhoushan)

(1) Qu zhou

Qu zhou (118°01′ ~ 119°20′E, 28°14′ ~ 29°30′N)lies in the west inland area of Zhejiang province, the western end of Jinqu basin.Quzhou belongs to subtropical monsoon climate. Quzhou has a total population of 845,852 and an area of 2,354 km^2. The annual average temperature ranges from 16°C ~ 17°C, while extreme maximum temperature is 41.8°C and extreme minimum temperature is -11.4°C. Its average annual rainfall is between 1500mm ~ 2300mm. It is characterized by short spring and autumn, long summer and winter. Quzhou is far away from the big cities and belongs to the underdeveloped inland region of Zhejiang province. In 2015, the per capita disposable income of rural residents is 16,215Yuan [8], which ranked the 58th out of the total 68 counties. However, it has rich tourism resources, and there are more than 150 scenic spots, such as Jianglang Mountain, Lanke Mountain, Longyougrottoes, Longmen Mountain and so on.

It's reported in the 2015 Statistics Bulletin of the National Economic and Social Development of Quzhou that there was a total of 1969 rural tourism households and the number of employees exceeded 22.8 thousand. The rural tourism households had more than 22.1 million tourists, and the operating income amounted to 1.09 billion Yuan, with an increase of 31.7% and 34.6% respectively [9].

(2) Anji

Anji (119°14′~119°53′E, 30°23′~30°53′N) is located in Huzhou city, which leans on Tianmu Mountain and close to Hangzhou and Shanghai. It is a rapid developed open area of the Yangtze River Delta Economic Zone, which has several famous scenic spots such as Kowloon Gorge, Tianchi, Tianhuanping. Anji has a total population of 464,112 and an area of 1,886 km^2. In 2015, the per capita disposable income of rural residents is 23,556 Yuan[8], the 31th out of the total 68 countries of Zhejiang. It belongs to subtropical oceanic monsoon climate, the annual average temperature is about 16.6°C, extreme maximum temperature is 38.7°C and extreme minimum temperature is -8.5°C. Its average annual rainfall is about 1400mm. Anji is named the first ecological country in China, with a vegetation coverage rate of 75%.

(3) Zhoushan

Zhoushan (121°30′ ~ 123°25′E, 29°32′ ~ 31°04′N) is located in Zhoushan islands of Zhejiang province, which is the gateway to the Yangtze River and Yangtze River Delta, and it is also one of the Free Trade Area of China. It belongs to the northern subtropical monsoon marine climate, warm in winter and cool in summer. The annual average temperature is about 16°C. The hottest month is August, with the average temperature between 25.8°C ~ 28.0°C. The coldest month is January, with the average temperature between 5.2°C ~ 5.9°C. Its average annual rainfall is about 927 ~ 1620mm. The average annual solar radiation is 4126×10^6~4598×10^6KJ/ m^2, and the average annual sunlight is 1941 ~ 2257hours. Shengsi is one of the country of Zhoshan, made up of more than 400 islands. It is a unique island scenic spot in terms of national level in China. It has a population of 77,500 and an area of 97 km^2. In 2015, the per capita disposable income of rural residents is 25,060Yuan [8], which is 20th out of the total 68 countries of Zhejiang. Ultimately, the rural tourism has developed very well.

In order to collect the basic data, field surveys were carried out years ago in these three areas. The surveys comprise of two parts. The first part was carried out in 2014, during the international workshop between the University of Kitakyushu and several Chinese universities in Hangzhou, including Zhejiang University, Zhejiang University of Technology, Zhejiang A&F University and so on. About 60 students took part in the survey on Anji Ligeng village. The second part was carried out in 2016 winter and summer in Quzhou and Zhoushan. The survey was supported by local planning department in order to survey the thermal performance of the rural buildings in local place and the energy consumption between the ordinary rural household and the rural tourism household.

3.2.2 Research Route and Content

The study was carried out step by step. First step: Field survey and analysis. Second step: Simulation and practice. (Fig. 3-8)

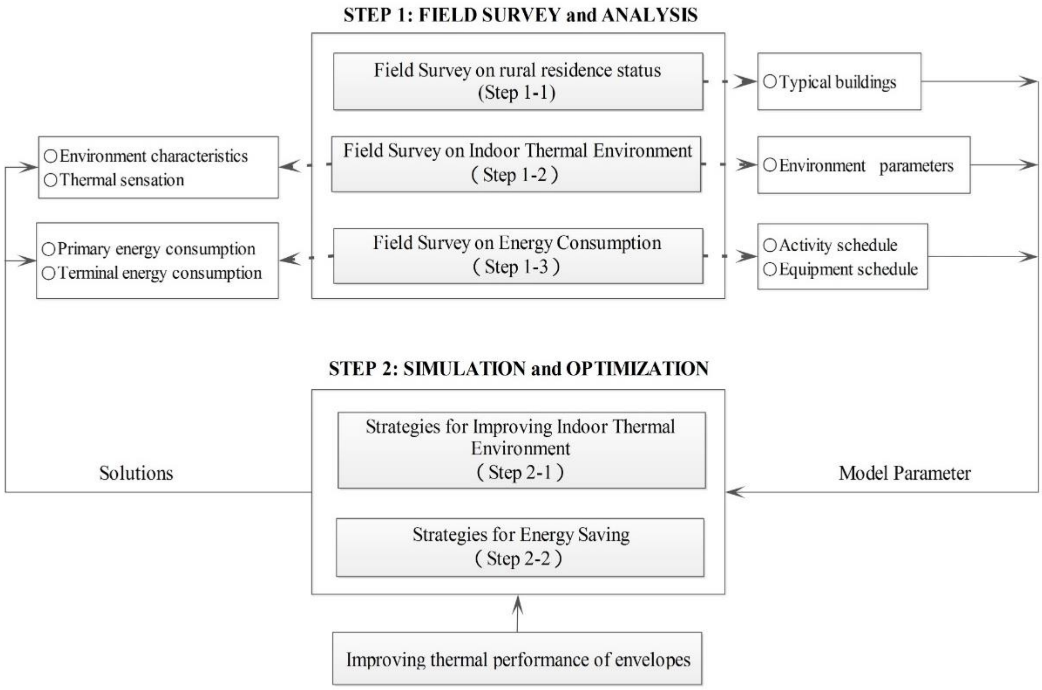


Fig. 3-8 Research route

Step one consists of three aspects: (1) Step one-one: survey on rural residential status: including household information, building information, and building mapping. (2) step one-two: survey on energy consumption: including energy use, household appliance and human behavior. (3) step one-two: survey on indoor thermal environment: including environmental parameter measurement and thermal sensation. The surveys were carried out using questionnaire, field mapping and fielding measuring. The specific contents of each item are shown in Table 3-1. To ensure that the surveyed information was valid, the survey team went out with the village leaders for explanation and translation because lots of the peasants were illiterate. It took 40 ~ 60 min to conclude one survey questionnaire. At the same time, the rural building had a concise detail. For the field measurement, several typical buildings were selected, and measured in 48 hours. The basic data collected through surveys were analyzed according to the calculation method of section 3.2~3.4, and the results would be the parameters for the second step.

Moreover, the second step includes strategies for improving indoor thermal environment and improving envelopes through simulation and practice. The building was selected and simulated by using Design builder software according to section 3.5. For practice, the roof of a rammed earth rural building was renovated using traditional and new materials and the effect of indoor thermal environment was compared before and after renovation by field measurement and simulation.

Table 3-1Survey contents

Items		Main Content	Method
Rural residence status	Household Information	family member, age, cultural status, income, career, etc.	Questionnaire
	Building Information	Period of construction, building orientation, building area, building material and construction, etc.	Questionnaire
	Building Mapping	Building plane, windows and doors size	Field mapping
Indoor thermal environment	Environmental parameter	Temperature, humidity, indoor wind velocity, solar radiation, PMV	Field measuring
	Thermal sensation	Rural residents and tourists' thermal sensation, clothes etc.	Field measuring Questionnaire
Energy Consumption	Energy use	Electricity consumption, usage of LPG, firewood and solar energy etc.	Field measuring Questionnaire
	Household Appliance	Number of household appliances, model, power etc.	Questionnaire
	Human Behavior	Rural residents and tourists' activity, appliances using frequency and time table etc.	Questionnaire

3.3 Thermal Performance Analysis Method for Building Materials and Envelopes

There are four methods for analyzing thermal performance of building materials and envelopes: theoretical calculation, simulation analysis, field measurement and laboratory experiment. In this study, theoretical calculation, field measurement and laboratory experiment were adopted. There are various building materials used in construction of the rural buildings, hence, it's impossible to take field measurement during the surveys. Therefore, theoretical calculation is adopted, the calculation method is listed below and all the physical parameters were adopted according to *Thermal design code for civil building* [10]. For the renovation of the Anji rammed earth building, both field measurement and laboratory experiment were adopted.

3.3.1Theoretical Calculation Method

3.3.1.1 Thermal Resistance and Heat Transfer Coefficient

(1) Thermal resistance of multi-layer homogeneous material

Envelopes made up of multi-layer homogeneous materials (including enclosed air layers), such as brick walls with inner and outer mortar covers, perpendicular to the direction of heat flow may be regarded as multi-layered homogeneous material layers. The thermal resistance of the envelopes can be calculated with formula shown below:

$$R_0 = R_i + \sum R + \sum R_{ag} + R_e \qquad \text{Equation (1)}$$

Where, R_0 standards for total thermal resistance, (m^2·K)/W.

R_i standards for internal surface heat transfer resistance, set as 0.11(m^2·K)/W.

R_e standards for external surface heat transfer resistance, set as0.04(m^2·K)/W.

R_{ag} standards for air layer thermal resistance, (m^2·K)/W.

Among them, $R = \frac{d}{\lambda}$

d standards for material layer thickness, m.

λ standards for thermal conductivity, W/(m·K).

(2) Thermal resistance of Composite structure

Envelopes which consist of more than two kinds of materials, such as various forms of hollow wall, are non-homogenous in the direction perpendicular to the heat flow, and there is no unidirectional heat transfer in the interior. When calculating the thermal resistance, it is divided into several sections along the interface of different materials in the composite material layer parallel to the heat flow direction. The average wall thermal resistance is calculated as follows:

$$R_0 = \frac{F_0}{\frac{F_1}{R_{0.1}} + \frac{F_2}{R_{0.2}} + \cdots + \frac{F_n}{R_{0.n}}} + (R_i + R_e)$$ Equation (2)

Where, R_0 standards for total thermal resistance, (m^2·K)/W.

F_0 stands for the total heat transfer area perpendicular to the heat flow direction, m^2.

F_1、F_2…… F_n stands for each heat transfer area divided in parallel to the heat flow direction, m^2.

$R_{0.1}$、$R_{0.2}$…… $R_{0.n}$ stands for the total heat transfer resistance of each heat transfer part, (m^2·K)/W.

R_i stands for internal surface heat transfer resistance, set as 0.11(m^2·K)/W.

R_e stands for external surface heat transfer resistance, set as0.04(m^2·K)/W.

(3) Heat transfer coefficient

Heat transfer coefficient is calculated as the following equation:

$$K = 1/R_0$$ Equation (3)

3.3.1.2 Thermal inertia index (D)

The thermal coefficient represents the material's ability to store and release heat, and the thermal inertia represents the envelopes' ability to resist temperature action. The thermal inertia index of envelop is related to the thermal resistance and coefficient of heat accumulation for each layer. The higher the thermal resistance and the larger the thermal storage coefficient, then the thermal inertia index gets higher. The larger the thermal inertia index of the building envelope components, the lower the internal surface temperature, hence, in hot summer, the interior of the envelope will not be scorching.

(1) Multi-layer homogeneous material wall

The thermal inertia index of multi-layer homogeneous material envelopes is the sum of the thermal inertia indexes of each layer material. Because the air layer's coefficient of heat accumulation is very small, the thermal inertia index can be ignored.

The envelopes' thermal inertia index calculated by the following formula:

$$D = \sum D = R_1 S_1 + R_2 S_2 + R_3 S_3 + \cdots + R_n S_n$$ Equation (4)

Where, D represents thermal inertia index, dimensionless.

$R_1, R_2 \cdots R_n$ represent thermal resistance of each layers, (m²·K)/W.

$S_1, S_2 \cdots S_n$ represent the coefficient of heat accumulation of each layers, (m²·K)/W.

(2) Composite envelope

When the middle layer of the envelope consists of more than two types of materials, the average thermal resistance and the average coefficient of heat accumulation should be calculated. The thermal inertia index can be calculated using the following formula:

$$D = \overline{R} \cdot \overline{S} \qquad \text{Equation (5)}$$

among them, $\overline{R} = \dfrac{d}{\overline{\lambda}}$; $\overline{S} = \dfrac{S_1F_1 + S_2F_2 + \cdots + S_nF_n}{F_1 + F_2 + \cdots + F_n}$

Where, $\lambda_1, \lambda_2 \cdots \lambda_3$ represent the thermal conductivity of each layer, W/(m·K).

$F_1, F_2 \cdots F_3$ represent heat transfer area divided by parallel to the heat flow of each layer, m^2,

$S_1, S_2 \cdots S_3$ represent the heat transfer coefficient of each layer, W/(m^2·K).

3.3.2 Field Measurement of Envelopes' Thermal Performance

3.3.2.1 Measurement Method for Thermal Data

The field measurement for the rammed earth rural building in Anji was carried out in winter, and it is seen as one-dimensional-steady-state heat transfer, because the outdoor temperature changes is relatively small, and the heat often transfers from indoor to the outdoor. The heat flux equation of the envelope can be calculated using the principle formula:

$$q = \lambda \frac{\theta_1 - \theta_2}{d} \qquad \text{Equation (6)}$$

Where, q stands for heat flux per unit area, W/m^2.

λ stands for thermal conductivity of the envelope, W/(m·K).

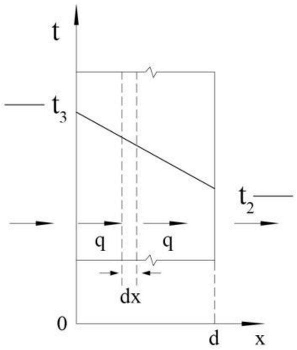
d stands for thickness of the envelope, m.

θ_1, θ_2 stands for the temperature of higher surface and lower surface respectively, K.

Based on one-dimensional-steady-state heat transfer principle, we measured the heat transfer coefficient and thermal resistance of envelopes by measuring the inner and outer surface temperature, heat flux per unit area, indoor and outdoor temperature.

3.3.2.2 Measurement Instruments

On the field measurement, the JTRG-II building thermal temperature and heat flux circuit automatic detector was used to measure the indoor/outdoor temperature, building surface temperature and heat flux (Fig.3-9,b). It adopts copper constantan thermocouple to measure the temperature, with an accuracy of ±0.5°C, a resolution of 0.1°C which ranges from -50°C ~150°C. The heat flux is measured using the heat flow meter (110×55×4mm) which has an accuracy of ±5%, resolution of 0.1W/m^2 and which ranges from -0~1000 W/m^2[11].



(a) One-dimensional-steady-state heat transfer principle (b) Measuring instrument

Fig.3-9 Field measurement principle and measuring instrument

3.3.3 Measurement Method for Thermal Conductivity of Materials

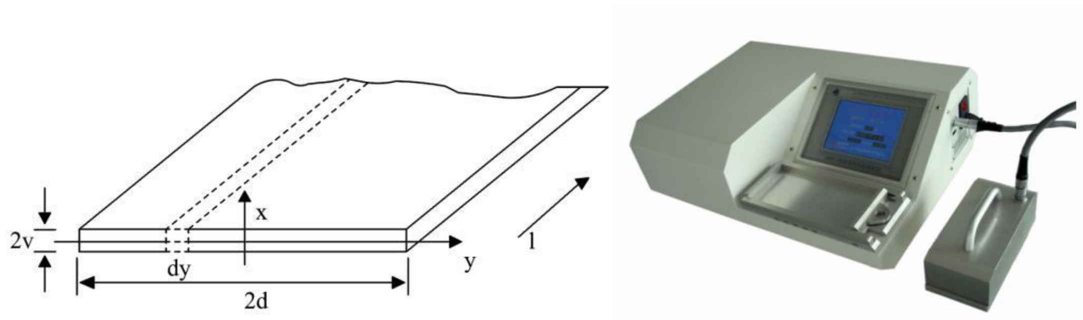
In the renovation practice of Anji rammed earth building, the light clay was mixed with bamboo powder and clay. This is in line with the literature written on the thermal conductivity of this kind material. On the other hand, we wanted to obtain the optimum mixed ratio through experiment. Therefore, an experiment was carried out using JTKD-I quick thermal conductivity meter, which was produced by Beijing Century Jian Tong Environment Technology Co Ltd.

There are two transient methods of determining thermal conductivity of building materials: *Transient hot-strip method(THS)*and *Transient plane heat source method(TPS)[12]*.Compared with steady state method, the transient method can calculate the thermal conductivity in a short period of time. TPS method is however superior than the THS[13]. The measuring instrument (Fig.3-10,b), we used in the study, is based on *THS* method, which was proposed by Gustafsson[14] et al. in 1970s and has been widely used in measuring the thermal conductivity of liquid, loose material, non-metal solid materials. It is a non-steady-state method which works with the principle of placing a long thin metal belt on a relatively large medium. The metal belt has the same temperature with the medium at the initial time, as the time t=0 begins, the metal belt gets heated through a continuous current, and the heat produced by metal belt would be transferred to the surrounding medium (Fig.3-10,a). The hypothesis belt and the tested material are infinite, and there is non-contact resistance between the material and belt. Then we can get the thermal conductivity of the medium according to the temperature distribution of the belt and the surrounding medium.

$$\lambda = \frac{q_L}{4\pi}[\frac{dT_m(t)}{d(\ln t)}]^{-1} \qquad \text{Equation (7)}$$

Where, q_L stands for the heating power per unit length of the hot-trip, W/m.

$\frac{dT_m(t)}{d(\ln t)}$ stands for the slop of $T_m(t)$ to $\ln t$.



(a) Principle of THS method (b) Measuring instrument

Fig.3-10Principle of THS method and the measuring instrument

3.4Indoor Thermal Environment Evaluation and Measurement Methods

3.4.1Thermal Comfort Evaluation Index

Thermal comfort is defined by ASHRAE Standard 55-92[15] as *the condition of mind that expresses satisfaction with the thermal environment.* There are two kinds of approaches existing in the contemporary thermal comfort research: heat balance models based on laboratory studies and adaptive models based on field studies [16]. Human thermal comfort is the evaluation standard for indoor thermal environment quality, which is based on the human body psychological and physiological perceptions of the indoor physical environment. Since the early 1920s, scholars at home and abroad have studied the related factors and evaluation models of the indoor thermal comfort by experiments and field tests [17]. Temperature is the most convenient and most widely used indicator. In addition, there are some other evaluation methods such as PMV-PPD, the thermal neutral temperature, uncomfortable index, and enthalpy wet figure.

3.4.1.1PMV-PPD, ePMV

(1) PMV-PPD

In 1967, the Danish professor Fanger P.O. published the famous human body thermal comfort equation on the basis of the experimental data from Kansas State university[17]. In 1970, according to the thermal sensation vote collected by 1396 trained people in the United States and Denmark, Fanger made a regression analysis on the basis of the human body heat balance equation, and found out that the quantitative relationship between the Predicted Mean Vote(PMV) and the Predicted Percentage do not agree (PPD)[18]. This evaluation method is considered to be the most comprehensive evaluation index in the world, which consists of six factors—air temperature, radiation temperature, air velocity, air humidity, human metabolic rate and clothing thermal resistance, and has been adopted by ISO7730[19]. The PMV is given by the equations below[19]:

$$PMV = (0.303e^{(-0.036M)} + 0.028)\times\{(M-W) - 3.05\times10^{-3}\times[5733 - 6.99\times(M-W) - P_a]$$
$$-0.42\times[(M-W) - 58.15] - 1.7\times10^{-5}\times M\times(5867 - P_a) - 0.0014\times M\times(34 - t_a)$$
$$-3.96\times10^{-8}\times f_{cl}\times[(t_{cl}+273)^4 - (\overline{t_r}+273)^4] - f_{cl}\times h_c\times(t_{cl} - t_a)\}$$

Equation (8)

Where,

$$t_{cl} = 35.7 - 0.028\times(M-W) - I_{cl}\times\{3.96\times10^{-8}\times f_{cl}\times[(t_{cl}+273)^4 - (\bar{t}+273)^4] + f_{cl}\times h_c\times(t_{cl}-t_a)\}$$

Equation (9)

$$h_c=\begin{cases}2.38\times|t_{cl}\text{-}t_a|^{0.25} & \text{for } 2.38\times|t_{cl}\text{-}t_a|^{0.25}>12.1\times\sqrt{v_{ar}}\\ 12.1\times\sqrt{v_{ar}} & \text{for } 2.38\times|t_{cl}\text{-}t_a|^{0.25}<12.1\times\sqrt{v_{ar}}\end{cases}$$ Equation (10)

$$f_{cl}=\begin{cases}1.00+1.290I_{cl} & \text{for } I_{cl}\leq 0.078\ \text{m}^2\cdot\text{K/W}\\ 1.05+0.645I_{cl} & \text{for } I_{cl}>0.078\ \text{m}^2\cdot\text{K/W}\end{cases}$$ Equation (11)

Where,

M is the metabolic rate, W/m^2

W is the effective mechanical power, W/m^2

I_{cl} is the clothing insulation, (m^2·K)/W

f_{cl} is the clothing surface area factor

$t_a$is the air temperature, °C

$\overline{t_r}$ is the mean radiant temperature, °C

$v_{ar}$is the relative air velocity, m/s

P_a is the water vapour partial pressure, Pa

$h_c$is the convective heat transfer coefficient, W / (m^2·K)

$t_{cl}$is the clothing surface temperature, °C

The PMV index predicts the mean value of the thermal votes of a large group of people exposed to the same environment, and divided into 7-point thermal sensation scale, based on the heat balance of the human body (Table 3-2). However, individual votes are scattered around this mean value and it is important to predict the number of people likely to feel uncomfortably warm or cold. The PPD is an index that establishes a quantitative prediction of the percentage of the thermally dissatisfied people who feel too cold or too warm, and this can be calculated by the equation shown below[19]:

$$PPD = 100 - 95\times e^{(-0.03353\times PMV^4 - 0.2179\times PMV^2)}$$ Equation (12)

Table 3-2 Seven-point thermal sensation scale

thermal sensation	Cold	Cool	Slightly cold	Neutral	Slightly warm	Warm	Hot
PMV	-3	-2	-1	0	1	2	3
PPD (%)	100	75	25	5	25	75	100

The acceptable thermal environment parameters recommended by ISO7730 are -0.5 < PMV < 0.5, PPD < 10%. An environment is considered as very comfortable when PMV varies between -0.5 and +0.5. It is considered as comfortable between -1.0 and +1.0. However, the PMV index is deprived for steady-state condition, and should be used only for values of PMV between -2 and 2, and when the six main parameters are within the following intervals:

M=46 W/m^2 ~ 232W/m^2(0.8 met~4 met); I_{cl}=0 (m^2·K)/W ~ 0.310 (m^2·K)/W (0 clo~2 *clo*);

t_a=10 °C ~ 30 °C,$\overline{t_r}$=10 °C ~ 40 °C, υ_{ar}=0 m/s ~ 1 m/s, P_a=0 Pa ~ 2700 Pa

When PMV≥2 or PMV≤-2, there will be a large deviation and particularly in the hot parts, when there is no considerable sweat evaporation cooling system, there will be an obvious distortion.

(2) ePMV

Through several studies, more scholars have discovered that PMV- PPD index does not apply to all countries and regions and this is based on study of the youth in European and American countries[20]. In 2002, Fanger put forward the extended PMV(ePMV) model in *Indoor Air* meeting through the field survey of non-air-conditioned buildings in warm climates[21]. According to the characteristics of the climate in different countries, the PMV value should be multiplied by the correction coefficient 0.5 ~ 1.0. For China, Fanger pointed out that the coefficient was 0.7.

Table 3-3 Expectancy factors for non-air-conditioned buildings in warm climates[21]

Expectation	Classification of non-air-conditioned buildings		Expectancy factor,e
	Location	Warm periods	
High	In regions where air-conditioned buildings are common	Occurrs briefly during the summer season	0.9~1.0
Moderate	In regions with some air-conditioned buildings	Summer season	0.7~0.9
Low	In regions with few air-conditioned buildings	All seasons	0.5~0.7

3.4.1.2 APMV

The adoptive comfort theory was first proposed in the 1970s, based on the findings of surveys of thermal comfort conducted in the field [22, 23]. The fundamental assumption of the adaptive approach is expressed by the adaptive principle: *if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort[23]*. In field studies, people flexibly adapted to ensure thermal comfort through various approaches, such as putting on/taking off clothing, switching on/off a fan or heating and taking in hot/cold drinks. Chinese scholars Yao Runming, Li Baizhan, Liu Jing et al[16, 24], through more than 20,000 questionnaires and mathematical statistics analysis, proposed the adaptive mean thermal sensation (APMV). In China, this indicator is classified as evaluation index of the artificial indoor thermal comfort for indoor environment, which has been adopted by *the evaluation standard of civil building indoor thermal environment (GBT 50785-2012)[25]*.The human thermal sensation system is synonymous to "Black box" (Fig.3-11), and the steady-state heat-balance model(PMV) can be described as follows:

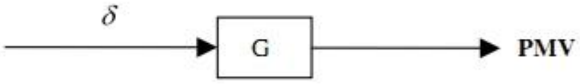


Fig.3-11 Thermal comfort static model diagram

$$PMV=G\times\delta \qquad \text{Equation (13)}$$

According to the adaptive model, humans can achieve thermal comfort through adaptations (Fig.3-12), so aPMV can be obtained via the following equation:

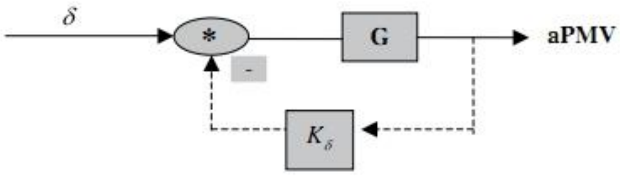


Fig.3-12 Thermal comfort adaptive model diagram

$$aPMV = G\times\delta - aPMV\times K_{\delta}\times G \qquad \text{Equation (14)}$$

Assuming λ = K_δ/(δ)，Equation (14) can be written as:

$$aPMV = \frac{PMV}{1+\lambda\times PMV} \qquad \text{Equation (15)}$$

Where, λ stands for adaptive coefficient.

In order to find out the value of the adaptive coefficient λ, field investigations were carried out in typical climate zones of typical cities in China for the natural ventilated buildings, such as residential buildings, shops, hotels, office buildings, educational buildings and so on. Through the analysis, the adaptive coefficient λ for diverse buildings in different climate zones which are characterized by cold and hot environments is indicated in Table 3-4. For natural ventilated environments, it is divided into three categories as shown in Table 3-5.

Table 3-4 Adaptive coefficient λ[25]

Climate zone		Residential building, shop, hotel, and office buildings	Education building
Very cold and cold zones	PMV≥0	0.24	0.21
	PMV < 0	-0.50	-0.29
HSCW, HSWW, TZ	PMV≥0	0.21	0.17
	PMV < 0	-0.49	-0.28

Note: HSCW means hot summer and cold Winter zone, HSWW means hot summer and warm zone, TZ means temperate zone.

Table 3-5 Assessment category for indoor thermal environments in free-running buildings[25]

Category	Evaluation index(aPMV)	Evaluation of thermal and humid environment
I	-0.5≤aPMV≤0.5	90% satisfaction among people
II	-1≤aPMV<-0.5 or 0.5< aPMV≤1	75% satisfaction among people
III	aPMV<-1 or aPMV>1	less than 75% satisfaction among people (Unacceptable)

3.4.1.3 Other Indexes

Besides PMV-PPD, ePMV and APMV mentioned above, there are other indexes in different countries which are applied according to the thermal characteristic. The other indexes are introduced below, and the comparison is listed in Table 3-6.

(1) Effective Temperature, New Effective Temperature and Standard Effective Temperature

Effective Temperature (ET) was first proposed by American scholar Houghton and Yaglon in 1923 to 1925[17]. Based on this, the American scholar Gagge and his colleges improved and proposed the New Effective Temperature(NET) in 1971[26] and Standard Effective Temperature (SET) in 1986[27]. According to the physiological conditions of human body, SET takes into account three factors: physics, physiology and psychology, which is particularly suitable in evaluating the thermal environment in cases of high temperature and high humidity.

(2) Catarrhal cooling capacity, equivalent temperature and subjective temperature

British climate is characterized by the cold winter, normal temperature and humidity in summer. The main focus of the indoor thermal environment is space heating. The main indexes include catarrhal cooling capacity, equivalent temperature and subjective temperature etc.

Table 3-6 Indoor thermal environment evaluation index

Index	Proposer	Main index	Applicable conditions
ET	Houghton,Yaglon (America 1923)	Temperature, humidity	Artificial environment
NET	Gagge, Stolwijk,Nishi ect. (America, 1971)	Temperature, humidity, Standard clothing, fixed sitting posture	Wearing standard clothing, in sitting posture, low wind speed
SET	Gagge, Stolwijk, Nishi ect. (America， 1971)	Temperature, humidity, Different activities, clothing thermal resistance	In the temperature range without shivering
Catarrhal cooling capacity	Hill (Britain, 1914)	Average radiation temperature, air temperature, air velocity	Heating environment (Wind speed is not fast, and the wind direction is not important)
PMV-PPD	Fanger (Denmark,1972)	Average radiation temperature, air temperature, air velocity, air humidity, human metabolic rate, clothing thermal resistance	Steady state, artificial environment
ePMV	Fanger (Denmark, 2002)	Average radiation temperature, air temperature, air velocity, air humidity, human metabolic rate, clothing thermal resistance, expectancy factors	non-artificial environment
APMV	Runming Yao, Baizhan Li etc. (China, 2009)	Average radiation temperature, air temperature, air velocity, air humidity, human metabolic rate, clothing thermal resistance, adaptive coefficient	non-artificial environment

PMV/ePMV/aPMV are all based on a large survey of people, who live in cities or towns. At present, there is no special indoor thermal environment evaluation index for rural residence. Therefore, in this study, ePMV is mainly adopted to evaluate the indoor thermal envionment of rural residential buidlings in summer and PMV for winter.

3.4.2 Measurement of Basic Parameters

3.4.2.1 Measuring Instruments

According to Fanger' balance therory, human thermal sensation is mainly related to the thermal balance of his or her body as a whole. This balance is influenced by physical activity and clothing, as well as the envrionment parameters: air temperature, mean radiant temperature, air velocity and air humidity[19]. At the same time, the indoor environmnt is also influenced by outdoor environmental factors. Outdoor environmental parameters include solar radiation, wind speed, air temperature, relative humidity. In this study, all the parameters were measured by the instruments shown in Fig. 3-13. The monitored data and technical specifications of measuring instruments were list in Table 3-7, which all met the ISO7726 [28] and GBT 50785-2012 requirements. The indoor air quality and thermal comfort tester (JT-IAQ-50) were adopted to evaluate the indoor thermal envrionment. The solar radiation was recodered by solar radiation recorder (JTR05).The auto-loggers (TES-1361C and TR-7WF) were used to simultaneously monitor the indoor and outdoor air temperature and relative humidity.

Table 3-7 Monitored data and technical specifications of measuring instruments

Instrument name	Monitored parameters	Measurement range	Accuracy	Record time
Indoor air quality and thermal comfort tester (JT-IAQ-50)	Air temperature	-20°C ~85°C	±0.5°C	once a minute
	Relative humidity	0~100%	±1.5%	
	Wind speed	0.05~5m/s	0.03m/s+2%	
	Black ball temperature	-5°C ~125°C	±0.5°C	
Solar radiation recorder (JTR05)	Total solar radiation	0 ~ 2000W/m^2	0.3μm ~ 3.2μm	once a minute
	Air temperature	-20°C ~85°C	±0.5°C	
thermometer (TES-1361C)	Air temperature	-20°C ~60°C	±0.8°C	once a minute
	Relative humidity	10%~95%	±3%	
thermometer (TR-72nWF)	Air temperature	-10°C ~60°C	±0.3°C (-20°C ~ 80°C)	once a minute
	Relative humidity	10%~95%	±5%	

(a)JT-IQA-50 (b) JTR05 (c) TR-7WF (d)TES-1361C

Fig. 3-13 Measuring instruments

3.4.2.2 Instrument Parameters Setting and Measuring Method

(1) Instrument parameters setting

According to international standard ISO7730, PMV-PPD metabolic rates, clothing thermal resistance are related to different activities, e.g. clothing for different seasons. Combined with the actual survey, the metabolic rate and clothing insulation were set as follows.

1) Metabolic rate

Metabolic rate is related to different activities. The occupants' activity levels (metabolic heat production) were set according to ISO 7730.

Table 3-8 Metabolic rates for various activities [19]

Activity	Metabolic Rate	
	W/m^2	met
Reclining	46	0.8
Seated, relaxed	58	1.0
Sedentary activity (office, dwelling, school, laboratory)	70	1.2
Standing, light activity (Shopping, laboratory, light industry)	93	1.8
Standing, medium activity (Shop assistance, domestic work, machine work)	116	2.0
Walking	110 to 200	1.9 to 3.4

Occupants mainly sit, talk, and watch TV while in the sitting room and the human metabolic rate was set as 1.0 met (58.15W/m^2). Occupants mainly lie and recline in the bedroom and the human metabolic rate was set as 0.8 met (46.52W/m^2).

2) Clothing

The clothing insulation (I_{cl}) can be estimated according to the data presented in the table ISO7730[19]. During winter, rural residents wear thin clothes (such as underwear with long sleeves and leggings, thermos-jacket and trousers, parka with heave quilting, socks, shoes, cap, gloves) in the room against cold. The clothing insulation (I_{cl}) equals to 2.55clo, about 0.395($m^2 \cdot K$)/W in the living room, and 2.0 clo in the bedroom. During summer, both rural residents and tourists wear short sleeved shirt, light trousers, and short skirts etc. The clothing insulation (I_{cl}) is set as 0.5clo, about 0.08($m^2 \cdot K$)/W.

(2) Measuring method

The thermal comfort monitoring process was carried out during summer and winter. All measurements points were set at 1.5m above the ground level. The outdoor data loggers were shaded using appropriate devices during the whole measurement. The measuring points were set in the main activity spaces, such as living rooms, bedrooms. During winter, the test time was fixed before and after the Great cold day (December 20), which is the coldest day of the whole year. During summer, the test time was set during the hotest days. All data were automatically recorded every minute for at least three days.

As the objective feelings of the tourists have a great impact on the indoor environment and building energy consumption, hence, thermal sensation questionnaires about the rural residents and tourists were carried out too.

3.5Analysis and Method of Energy Consumption Structure for Rural Residence

The primary energy consumption of the rural residence in Zhejiang rural area include commercial energy (electricity, LPG, coal et al.), biomass energy (firewood, stalk et al.) and new energy (solar energy et al.). According to the end use, the terminal energy consumed in rural residence could be divided into cooking & boiling of water, heating, cooling, lighting, and electrical appliance. The relationship between the primary energy consumption, the terminal energy consumption and the appliances is shown in Fig. 3-14.Firewood, stalk, coal, LPG and solar energy mainly consumed during cooking & boiling water. In the rural areas, the farmers put charcoal in the brazier produced while cooking with firewood. In the study, this part is not included in the heating process. However, electricity is the most complex, because heating, cooking & boiling, cooling, lighting and electric appliance all consume electricity. Based on the survey, the primary energy consumption was calculated based on the questionnaires.

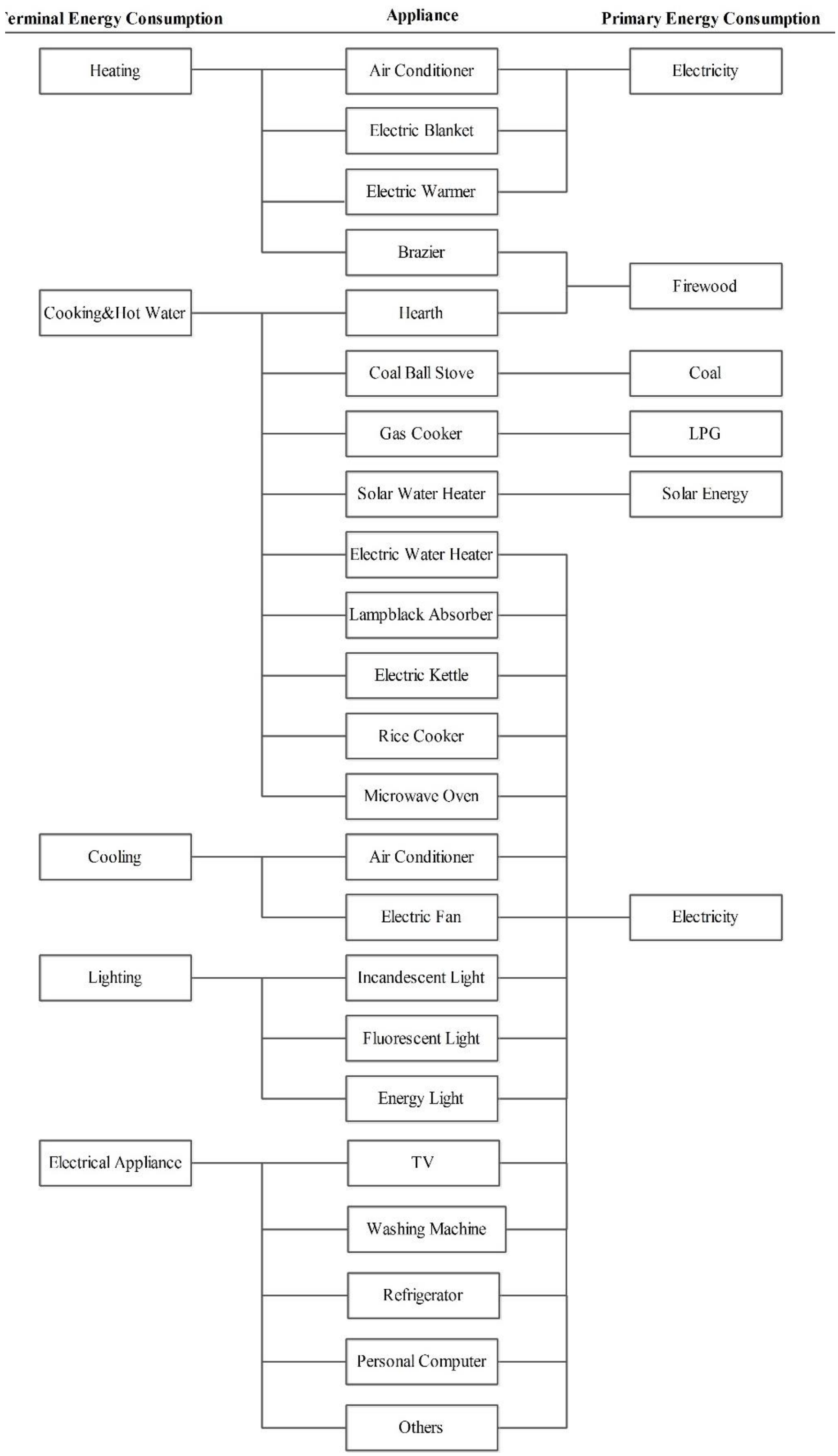


Fig. 3-14 Relationship between terminal energy consumption, appliances and energy resource

3.5.1Calculation Method for Energy Resource

The consumption of LPG, coal, stalk and firewood were calculated according to the questionnaire. The electricity consumption was provided by local power supply bureau. All energy consumption was converted from physical unit into coal equivalent. The average annual consumption of each type of energy per capita can be calculated using the following equation:

$$E_{N,avg} = \frac{1}{n}\sum_{i=1}^{n}\beta_i E_{N,i} \qquad \text{Equation (16)}$$

Where, N stands for the energy type, n stands for the number of people in surveyed households, $E_{N,i}$ stands for the annual consumption of the *N*th-type-energy of *i*th surveyed household, β_i stands for the corresponding conversion coefficient to average low calorific value given in Table 3-9.

Table 3-9Conversion factors from physical unit to coal equivalent [29]

Energy type	Average low calorific value
Electricity	3600 KJ/KWh
LPG	50179 KJ/kg
Firewood	16726 KJ/kg
Stalk	12545 KJ/kg

For ordinary household, the hot water is supplied using solar energy and electric water heater. The average annual consumption of solar energy per capita was calculated using the following equation:

$$E_{SE,avg} = \frac{1}{n}(c \times m \times \Delta t) \times r \qquad \text{Equation (17)}$$

Where, *c* stands for specific heat capacity of water, it is 4.2×10^3 J/(kg·°C). *m* stands for mass of water. *Δt* stands for the change of the temperature. *r* stands for utilization rate, %. Energy consumption from solar energy during bathing was difficult to survey, we supposed the flow rate was 0.04 L/s, 15 minutes each time, and people took their baths 3 times a week. Thus, it amounted to 36L hot water per capita every time.

For rural tourism households, hot water is supplied through the assembly system of solar energy and air source heat pump. We supposed the solar energy is fully utilized. The average annual consumption of solar energy per capita can be calculated using the following equation:

$$E_{SE,avg} = \frac{1}{n}(Q \times N \times S \times \beta) \qquad \text{Equation (18)}$$

Where, *Q* is solar radiation, MJ/(m^2·y); *N* is average ownership of solar water heater per household; S is collecting area of solar water heater, m^2; β is the heat collection efficiency, %.

Therefore, from the above equations, we calculated the total average annual energy consumption per with the following equation:

$$E_{hh,avg} = E_{electricty,avg} + E_{LPG,avg} + E_{firewood,avg} + E_{stalk,avg} + E_{SE,avg\ firewood} \quad \text{Equation (19)}$$

3.5.2 Calculation Method for Terminal Energy Consumption

Terminal energy consumption is classified into five parts: heating, cooling, and lighting, cooking and boiling of water, electric appliances. Firewood, LPG and solar energy were used for cooking and boiling water. Electricity covers all the five parts, and this was the most complex part to figure out in the distribution. In this study, household energy consumption breakdown based on usage was calculated using the following equations:

$$E_{cooling} = E_{e\text{-}cooling} = \sum_i (n_i p_i t_i d_i)_{cooling} \quad \text{Equation (20)}$$

$$E_{heating} = E_{e\text{-}heating} = \sum_i (n_i p_i t_i d_i)_{heating} \quad \text{Equation (21)}$$

$$E_{lighting} = E_{e\text{-}lighting} = \sum_i (n_i p_i t_i d_i)_{lighting} \quad \text{Equation (22)}$$

$$E_{appliances} = E_{e\text{-}appliances} = \sum_i (n_i p_i t_i d_i)_{appliances} \quad \text{Equation (23)}$$

$$E_{cooking\&hotwater} = E_{LPG} + E_{firewood} + E_{SN} + E_{e\text{-}cooking\&hotwater} = E_{LPG} + E_{firewood} + E_{SN} + \sum_i (n_i p_i t_i d_i)_{cooking\&hotwater}$$

Equation (24)

Where, $E_{cooling}$, $E_{heating}$, $E_{lighting}$, $E_{appliances}$, $E_{cooking\&hot\ water}$ stand for energy consumption of cooling, heating, lighting, electric appliances, cooking & boiling of water respectively. $E_{e\text{-}heating}$, $E_{e\text{-}cooling}$, $E_{e\text{-}lighting}$, $E_{e\text{-}appliances}$, $E_{e\text{-}cooking\&hot\ water}$ stand for electricity consumption for heating, cooling, lighting, electric appliances, cooking & boiling water, respectively. E_{LPG}, $E_{firewood}$, E_{SN} stand for annual consumption of LPG, firewood and solar energy. n_i and p_i stand for the number of equipment and its power, respectively. t_i and d_i stand for the average hour of each equipment used in a day and the average days in which the equipment is used in a year.

3.5.3 Correlation Analysis

There are three methods for calculating linear correlation coefficient: Pearson's correlation coefficient(*r*), Spearman ranking correlation coefficient(*r*) and Kendall correlation coefficient (*τ*). The Pearson's correlation coefficient (*r*) is the simplest and wildly used measure of strength for linear dependence between two variables with a value between −1 and +1 (inclusive). It can be calculated using the following equation:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})}}$$

Equation (25)

Where, n represent the sample size.x_i, y_i represent sample measuring values.

(1) If 0<|r|<1, it means there is a correlation between X and Y. If r>0, it means X is positively correlate with Y. On the contrast, if r<0, X is negatively correlate with Y.

(2) If r=0, there is no linear correlation between X and Y. However, there may be a nonlinear relationship between the two variables.

(3) If |r|=1, a perfect positive correlation existed between X and Y.

In this study, correlation analysis of parameters was carried out by SPSS19.0. All the data was checked before any comparison was made to ensure it is normally distributed. Variables that do not meet this condition of normality with a value larger than 1 for skewness (a measure of asymmetry) and kurtosis (a measure of 'peakedness') were transformed before being assessed in SPSS.

3.6 Simulation Method of Indoor Thermal Environment and Energy Consumption

3.6.1 Simulation Software

At present, the domestic and foreign research on indoor thermal environment is in three ways: experimental research, micro climate laboratory based on field measurement of conditions (including questionnaire survey and field survey) and numerical simulation analysis by software. The researches on energy consumption are carried out by actual measurement, theoretical calculation or simulation.

In this study, both the indoor thermal environment and energy consumption were simulated and analyzed under different strategies. In recent years, numerical simulation has become an effective method to predict building environment and energy consumption, which saves time and resources. It also gives predictions for numerous different cases and can simulate extremely complicated circumstances which people rarely examine by experimental methods. Development of Software simulation is divided into several stages:

(1) First generation (1960~1970): The cooling and heating load was calculated according to HVAC manual, which was based on static calculation method.

(2) Second generation (1970~1980): With the development of computer, simulation software was released. The thermal environment and energy consumption was simulated using software, such as DOE-2, BLAST, which were based on the reflection coefficient method.

(3) The third generation (1980~1990): The thermal environment of buildings and energy consumption were simulated based on thermal balance algorithm, which began to have users interface, such as eQuest, Ecotect. With the exception of time and space which were independent, other variables were mutually coupled between the other variables.

(4) The fourth generation (1990~2000): The user interface was further improved and optimized, and these were also based on heat balance algorithm. The models can reflect the real physical environment, and have a more compatible and interactive database.

Over 50 years, with the rapid development of computer simulation technology and the importance of energy and environment in many countries, simulation softwares are widely used for studies on energy saving and environmental improvement, such as Doe-2、EnergyPlus、eQUEST、Ecotect、DeST、TRN-SYS and so on. Energy Plus is an open source building energy simulation software and is recognized as the most widely used building energy simulation software in the world, which is developed by Department of Energy (DOE) and Lawrence Berkeley National Laboratory (LBNL). Energy plus is based on the simulation software of BLAST and DOE-2, which can be used for dynamic simulation of cooling, heating, lighting, ventilation and energy consumption. Energyplus calculates the thermal loads of a building using the heat balance method. This method takes into account all heat balances on the outdoor and indoor surfaces and transient heat conduction throughout the building. The simulation results from Energyplus have been validated in numerous analytical, comparative, and empirical tests [30].

In this study, research was carried out based on field measurements, and simulated by using *Designbuilder* software. This software is a graphical user interface software of *Energy plus(version 8.4)*, and allows the modeling of a multi-zone building, HVAC-systems, internal and solar loads, outdoor climate, etc. and provides simultaneous dynamic simulation for heat transfer and air flows.

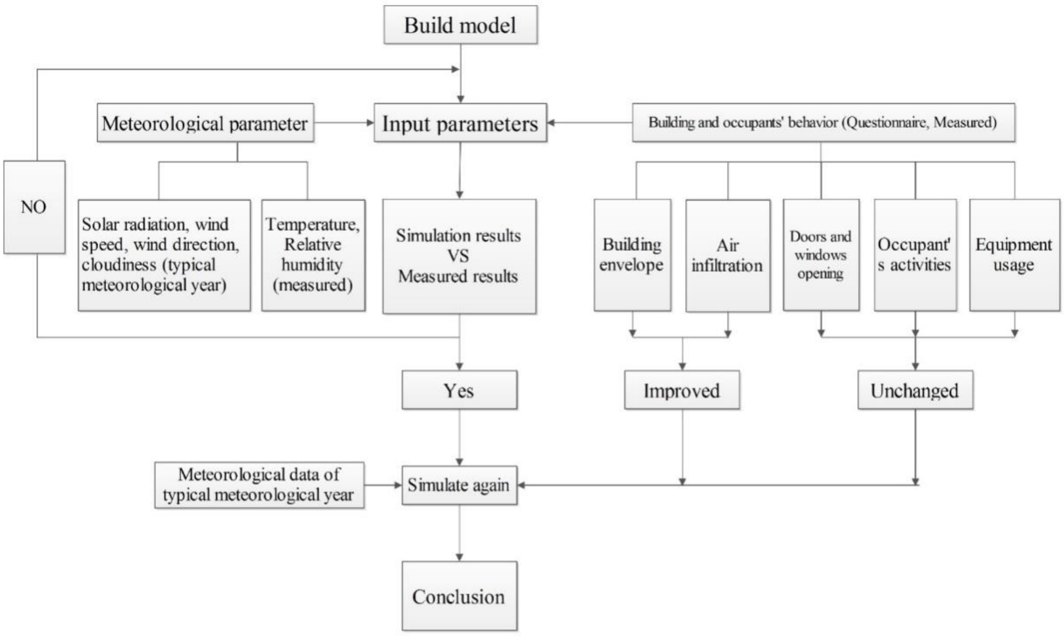


Fig.3-15 Simulation process

3.6.2Simulation Method

At present, building simulation models consider occupants in simplistic ways. Yet, many studies tend to show that it leads to large discrepancies between simulated and measured energy demands. In this study, the simulation of energy consumption and indoor thermal environment were based on the actual occupants' behavior. Firstly, typical buildings were selected and their models were built.

Secondly, the models were calibrated and corrected. The building information, occupants' behavior and part of the weather information obtained from the field survey were input and simulated. If the simulated data was in accordance with the field-measured data, the model could be used for the further simulation, conversely if it needs calibration. Then, the meteorological data of typical meteorological year and new strategies were input for further simulation. The results of 8760 hours were obtained and analyzed. The simulation process is shown below (Fig.3-15)

3.6.3 Parameters Setting

3.6.3.1 Location and Climate of the Site

On the simulation process of model calibration, the outdoor meteorological data such as air temperature, relative humidity, solar radiation, were collected through field measurement. For the wind speed, wind direction, and cloudiness, which have not been collected because of lack of instruments, the data from *Energy plus* software were adopted, according to the similar meteorological conditions. On further simulation process, due to the fact that the data provided by the local meteorological bureau was incomplete, all the meteorological data used in this study were gathered from *Energy plus* software, which was based on monitoring data over several years from meteorological stations.

In addition, there were three areas selected in this study, Quzhou, Anji, and Zhoushan. However, there was no meteorological data for Anji in *Energy plus* software, the data of Hangzhou, which was close to Anji, was applied for simulation.

3.6.3.2 Basic Situation of Buildings

(1) Basic information of buildings

The models were built according to the axle wire of the exterior walls. The detailed description of the construction adopted in *Energy Plus* software was based on the real situation. The U-value and D-value ware calculated according to section 3.2 in this Chapter, the thermal parameters of materials came from the China thermal design code for civil buildings (GB 50176)[10].

(2) Building air tightness and infiltration

Because there is no building air tightness regulations in China, and field measurement on residential buildings, according to the *Design Standard for Design standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[31]* regulating the air permeability graduation should be higher than graduation 4, thus the value of graduation 4 was adopted in this simulation, hence, the corresponding building air tightness was respectively set as 0.68ac/h. The infiltration was obtained through examination and correction and finally, the infiltration was 1ac/h.

Through this investigation, it was discovered that occupants always kept the building ventilated by opening windows or doors during summer, enhancing natural ventilation. While during winter, they seldom open windows or just open the windows to allow the entry of fresh air when the residential room is occupied, thus there's no certain air exchange rate value. According to the

Standard [31], the air exchange rate should be 1.0 ac/h in winter and 5.0 ac/hin summer. When the air condition is on operation, this value was set as the zone ventilation value with the same schedule of air-conditioner's operation schedule.

3.6.3.3 People

(1) People and activity

The number of people and the people's activity schedule were set according to the field survey.

(2) Metabolism

The occupants' activity plays a role in heat exchange with thermal indoor environment mainly through heat convection and heat radiation, and the thermal comfort reflect on people through thermal sensation which depends on the heat balance of the human body, the metabolic heat production and the heat loss. The schedule for people's activity was set according to the existing condition and the average at-home ratio and the metabolism was set according to Table 3-8.

3.6.3.4 Equipment

(1) HVAC

In modern rural residential buildings, air conditioners are often used especially in Zhejiang rural areas. However, in some traditional rural residential buildings, air conditioners are not in use. Field survey results show that, young people tend to use air conditioner, but older people seldom. The heating/ cooling set point was 16 °C and 26 °C in winter and summer respectively, which was the indoor design temperature in winter and summer according to *Design Standard for Energy Efficiency of Residential buildings in Zhejiang Province (DB33/1015-2015) [32]*. For the free-running rural residential buildings, the indoor temperature was set as 8 °C and 30 °C in winter and summer respectively according to *Design standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[31]*.The operation schedule was set according to the field survey and adjusted according to the final electricity consumption breakdown.

(2) Electric equipment

The rural household appliances such as television, refrigerator, washing machine, cooking equipment as well as other electricity-consumed equipment, also known as "plug loads", was similar to the urban residential buildings. According to investigation and the calibration of energy breakdown, the electric appliances gains are simply set as the total design level. According to *(DB 33/1015-2015) [32],*the average heat gain was 4.3W/m^2.

(3) Lights

The lighting power density was set as 7 W/m^2 according to *Design standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[31]*. The illumination in every room was set as seen in the table below.

Table 3-10 The lighting power density of rural residential household[31]

Room	Lighting power density (W/m^2)	Value of intensity of illumination(lx)
Living room	7	100
Bedroom		75
Dining room		150
Kitchen		100
Toilet		100

3.6.4Model Validation and Correction

Energy plus software has been widely used for simulation and proved the reliability of simulation results[30, 33]. After the model definition and simulation parameters input, the simulation results of indoor thermal environment should be verified by comparing with the field-measurement results. If the simulated data was in the accordance with the field-measured data (the difference less than 10%), the model can be used for the further simulation, conversely it needs calibration which can be achieved by changing the air tightness of the building.

3.7 Summaries

This chapter mainly focuses on the research route and analysis methods of the thesis. With the rapid development of rural tourism in Zhejiang province, the farmers' lifestyle has changed greatly, and this has also impacted the energy consumption. Then, what is the current situation of these rural households? What are the main problems? How can it be improved? The thesis answers these questions thoroughly. In the thesis, the study focuses on the rural residential buildings in Quzhou, Anji and Zhoushan as examples and it was carried out in two steps: first step is the field survey and analysis. Second step is simulation and practice. Then, analysis methods were introduced.

(1) For the evaluation method for thermal performance of materials and envelopes, theoretical calculation method was adopted to evaluate the thermal performance of all kinds of envelopes surveyed in Chapter 4. In Chapter 8, there was a roof renovation of a rammed earth building in Anji. Field measurements were applied before and after renovation in winter, and this was based on "one dimensional steady state heat transfer principle". The light clay used for renovation, was selected based on the "transient hot-strip method".

(2) In Chapter 5, ePMV was used to evaluate the thermal sensation of free-running rural residential buildings in summer, and PMV was used for stable environment in winter. Then, the measuring instruments and the measuring method were demonstrated.

(3) In Chapter 6, the primary energy consumption was calculated according to the field survey and the data provided by local government. The terminal energy consumption was calculated according to the number of appliances and time.

(4) In Chapter 7 and Chapter 8, *Design builder* software based on *Energy plus* was adopted. Then, the simulation method, parameters setting and the method of model validation and correction were introduced.

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Chapter 4.

Investigation on Situation of Rural Residential Buildings

4.1 Introduction

An important characteristic of rural tourism is that "visitors directly experience [the] agricultural and/or natural environment", and "connect with local families" [1]. Therefore, rural residential buildings are the most important conduits for rural tourism. There are three types of rural residential buildings in the Zhejiang province according to the differences in geographical climate, social economy, history, culture and lifestyle mentioned in Chapter 1, section 1.4: historical and cultural buildings, traditional vernacular buildings, and modern buildings. Most rural tourism households are modern buildings and traditional vernacular buildings. The basic status of rural families and the characteristics of rural residential buildings were investigated via interviews, questionnaires and field mapping. The purposes of the study in this section were to (1) search and discover the different situations of ordinary households and rural tourism households, (2) investigate the characteristics of typical rural residential buildings, (3) collect and analyze the building materials, constructions and thermal performance of envelopes.

4.2 Data Source and Survey Contents

4.2.1 Data Source

From 2014 to 2016, we interviewed and surveyed 6 townships, 12 traditional rural villages and 230 rural households in Quzhou, Anji and Zhoushan. Divided up, we surveyed 120 ordinary households and 20 rural tourism households in Quzhou, 45 ordinary households and 5 rural tourism households in Anji, and 20 ordinary households and 20 rural tourism households in Zhoushan. These stretched across 8 ordinary villages, 2 villages in the primary stage of rural tourism, and 2 villages in the developed stage of rural tourism. We looked at 12 historical and cultural buildings, 142 traditional vernacular buildings, and 76 modern buildings. The information can be found in Table 4-1.

4.2.2 Survey Contents

The research contents include the following aspects:

(1) Basic information of rural households

The basic information of rural households was obtained by questionnaires, including the number of family, the permanent residential population, main source of income, household income of the past three years, the number of guestrooms, gender, career, age, etc.

(2) Basic information of rural residential buildings

The basic information of the buildings includes ten aspects, such as the courtyard type, building style and features, construction quality, build time, usage of buildings, building structure, roof and attic style, number of stories and so on. This information was obtained through questionnaires too. In addition, the whole building was mapped and photographed, and the function and status of each room recorded in detail.

(3) Building material and construction of envelopes

The details of building structure, material and construction of envelopes were recorded by interviewers, including roofs and attic, walls, floors, ground, doors, windows and so on. The size and position of the windows and doors were also mapped. In addition, all the building details were photographed.

Table 4-1 Characteristic of surveyed areas and households

Location	Name	Household type	Building type
Quzhou	Wengyuan village	Ordinary household:18 Rural tourism household:0	Historical and cultural building:1; Traditional vernacular building:17; Modern building:0
	Shibian village	Ordinary household:18 Rural tourism household:0	Historical and cultural building:0; Traditional vernacular building:13; Modern building:5
	Gengtou village	Ordinary household:13 Rural tourism household:0	Historical and cultural building:3; Traditional vernacular building:4; Modern building:6
	Handu village	Ordinary household:12 Rural tourism household:0	Historical and cultural building:1; Traditional vernacular building:4; Modern building:7
	Liujia village	Ordinary household:12 Rural tourism household:0	Historical and cultural building:4; Traditional vernacular building:8; Modern building:0
	Poshi village	Ordinary household:11 Rural tourism household:0	Historical and cultural building:0; Traditional vernacular building:4; Modern building:7
	Yushan village	Ordinary household:20 Rural tourism household:0	Historical and cultural building:0; Traditional vernacular building:15; Modern building:5
	Yangkeng village	Ordinary household:20 Rural tourism household:0	Historical and cultural building:3; Traditional vernacular building:11; Modern building:6
	Xiachen village	Ordinary household:2 Rural tourism household:14	Historical and cultural building:0; Traditional vernacular building:1; Modern building:15

Anji	Ligeng village	Ordinary household:45 Rural tourism household:5*	Historical and cultural building:0; Traditional vernacular building:35; Modern building:15
Zhoushan	Donghaiyucun village	Ordinary household:20 Rural tourism household:20	Historical and cultural building:0; Traditional vernacular building:30; Modern building:10
Totally		230	Historical and cultural building:12; Traditional vernacular building:142; Modern building:76

Note: 1. The villages in the developed stage of rural tourism mean that the households operating rural tourism account for more than 5% of the total number of households in the village.

2. * one rural tourism household in Jianshan village in Anji.

4.3 Features of Households

4.3.1 Family Population

Our field survey shows that for ordinary households, the average total family population(TFP) is about 4 to 5 people per household. Most frequent size is 5 people per household, consisting of two older couples, two young couples, and a child, accounting for 25.5% of the households surveyed. The next most widespread demographic is four persons to one household, accounting for 23.5%.

A large amount of the labor force goes out for work in ordinary villages, and only goes home on holidays or the Spring Festival. The migrant workers take up a high proportion of the total population in a family. The permanent residential population of ordinary households is about two people per household, accounting for 50.3% of the house surveyed. Most of them are older couples. Among the permanent residential population, the population over 50 years old accounts for 73%, the population over 60 years old reaching 48%. According to international standards, a region where the people more than 60 years old account for 10% is an aging society. It is clear that rural area in Zhejiang has significant characteristics of aging.

Fig. 4-1 shows that the permanent residential population(PRP) of rural tourism households is higher than ordinary households. For rural tourism household, the average total family population is about 4 to 5 persons per household, which is similar to ordinary household. The permanent residential population of ordinary household is about 2, the most common is 2 old couples. For rural tourism households, the permanent residential population is about 3 to 4, which is obviously higher than ordinary households. Taking Donghaiyucun (in Zhoushan) as an example, the proportion of migrant workers account for 26.7%. A lot of young people go back home for rural tourism business. Rural tourism offers a possible solution to some of the problems associated with lost economic opportunities and population decline[2].

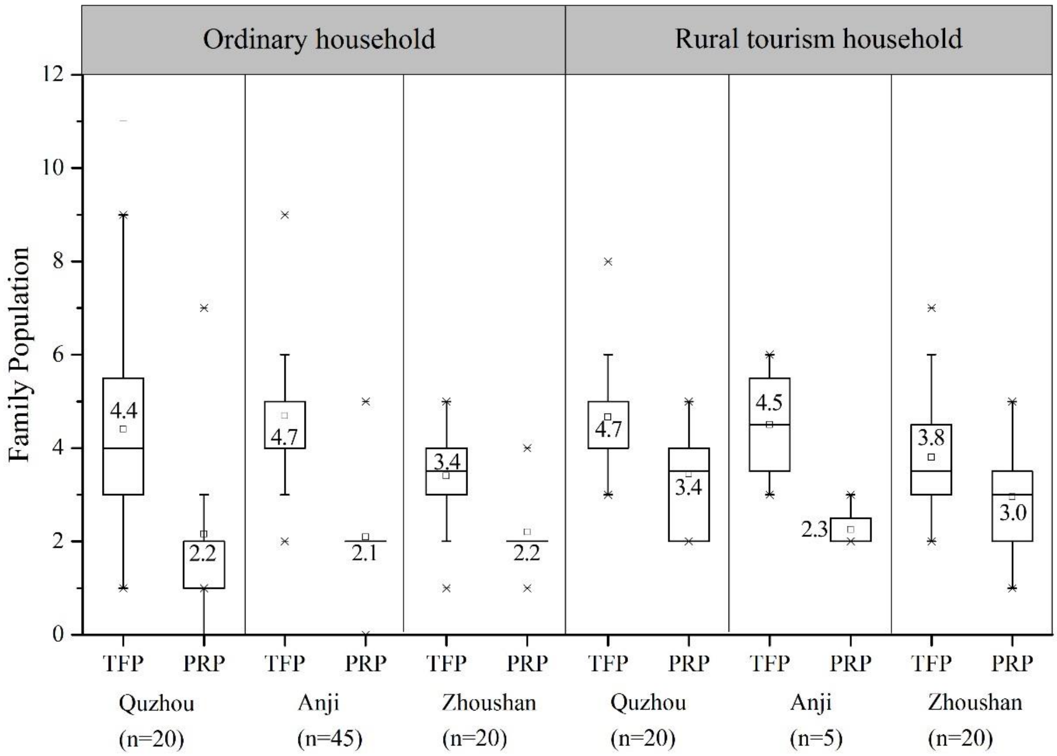


Fig. 4-1 Comparison of total family population (TFP) and permanent residential population (PRP)

4.3.2 Main Source of Family Income

Fig. 4-2 shows the histogram of income sources in the surveyed area. For ordinary households, migrant laborers working outside the home is the main source of family income, the primary industry is reduced, the income source is diversified. The primary industry is not the only occupation, accounting for 22.8% of the total family income sources. However, Ligeng village which is located in Anji and closer to the big cities, the primary industry accounts for 65% of total family income sources, mainly the production and processing of traditional primary industry, such as high mountain tea, Chinese chestnut, bamboo and bamboo products. The main income source is from young laborers working in big cities, accounting for 54.1%. In addition, farmers work nearby, during non-busy-farming season, accounting for 32.4%.

In rural tourism households, rural tourism business has replaced the primary industry, becoming the main income source. Rural tourism households in Xiacheng village (Quzhou) and Donghaiyucun (Zhoushan) village have seen their primary industry disappear gradually. Rural tourism has become the main income source, accounting for more than 85%. Taking Donghaiyucun village for an example, nearly every household engages in rural tourism. Among the households surveyed, only 5% of households still engage in traditional fishing, and even they also operate rural tourism.

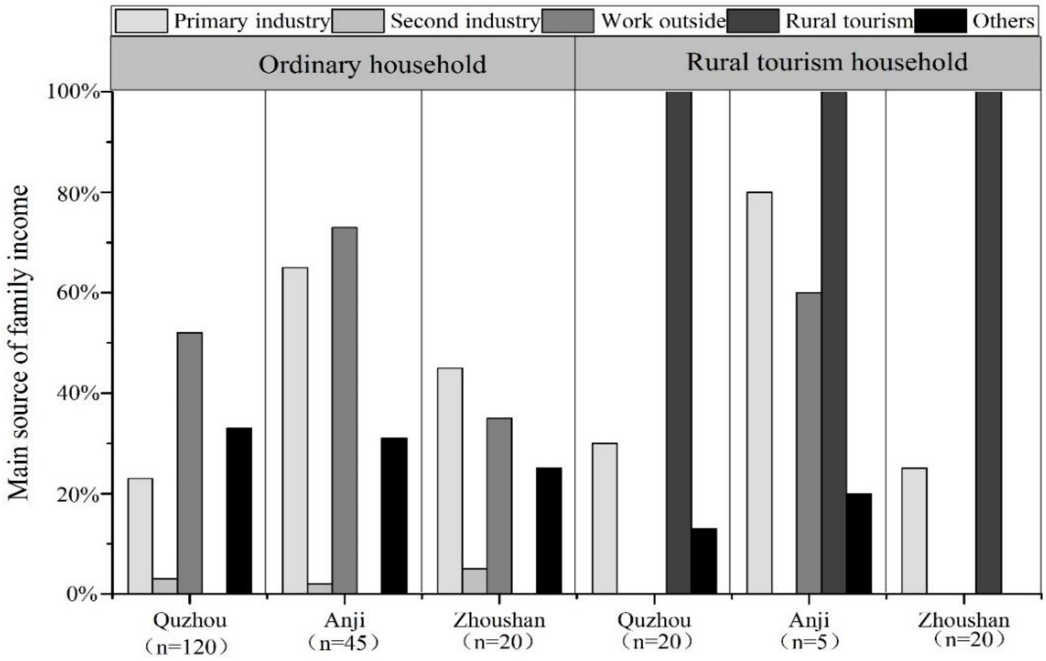


Fig. 4-2 Main source of family income

4.3.3 Household Income

Fig. 4-3 shows the proportion of low-income family of ordinary households is higher than in rural tourism households. In Quzhou, the annual household income of ordinary households below 50,000Yuan account for 61%; for rural tourism households, accounting for 14%. In Anji, the annual household income of ordinary households below 50,000Yuan account for 9%; there is no rural tourism households below 50,000Yuan in surveyed households. In Zhoushan, the annual household income of ordinary households below 50,000Yuan account for 15%, for rural tourism households, accounting for 20%.

On the other hand, the family income of households in economically developed areas is higher. The annual income of ordinary households in Quzhou is between 100,000 to 150,000Yuan accounting for 7%, above 200,000Yuan accounting for 8%. In Anji, the annual household income of ordinary households between 100,000 to 150,000Yuan accounting for 2%, between 100,000 to 150,000Yuan accounting for 2%. In Zhoushan, the annual household income of ordinary households between 100,000 to 150,000Yuan accounting for 35%, between 100,000 to 150,000 Yuan accounting for 10%, above 200,000Yuan accounting for 10%.

The annual household income of rural tourism households in Quzhou between 100,000 to 150,000Yuan accounting for 35%, there is no family income higher than 150,000Yuan among the surveyed households. In Anji, the annual household income between 100,000 to 150,000Yuan accounting for 40%, between 150,000 to 200,000Yuan accounting for 20%. In Zhoushan, the annual household income of ordinary households between 100,000 to 150,000Yuan accounting for 35%, between 100,000 to 150,000Yuan accounting for 20%, above 200,000Yuan accounting for 20%.

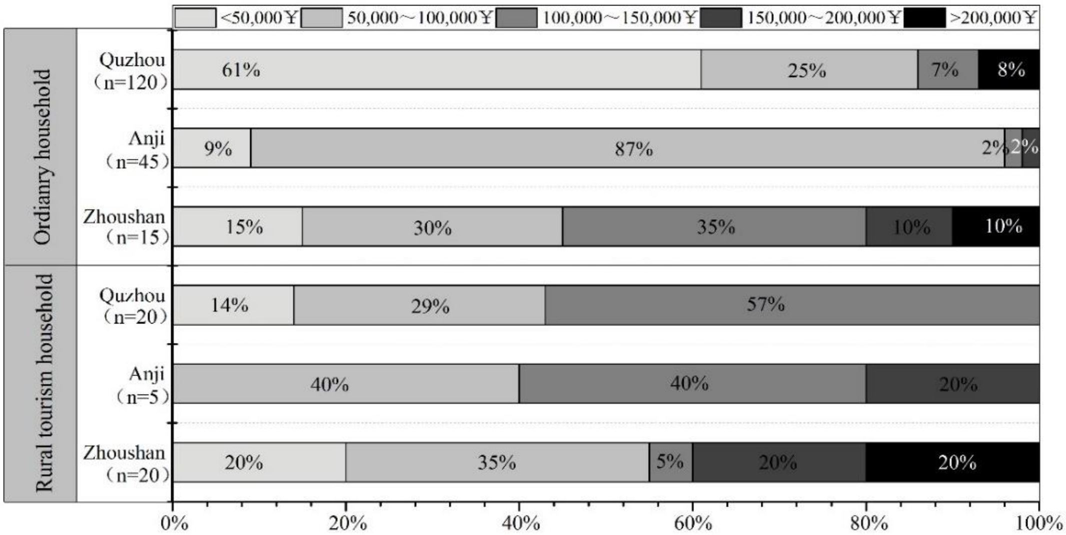


Fig. 4-3 Family income level

4.4 Features of Rural Residential Buildings

4.4.1 Built Time, Building Style, Building Story

4.4.1.1 Historical and Cultural Building

The historical and cultural buildings surveyed were built before liberation (1949), and most of them were built in the late Qing dynasty and the period of the republic of China. Unfortunately, due to many fierce wars, the impact of state policies and lack of repairs, a lot of historical and cultural buildings have been destroyed or can no longer be used. There were 12 historical and cultural buildings surveyed among the whole researched objects, accounting for 5.8%. In surveyed villages, the historical and cultural buildings in Liujia village(Quzhou) that are far away from cities are well preserved. However, there are no historical and cultural buildings in relatively developed villages such as Donghaiyucun village(Zhoushan), Xiacheng village(Quzhou) and Ligeng village(Anji).

Chinese traditional buildings use "Jian" (the space surrounded by four pillars) as the basic unit. Usually there are more than three "Jian" in historical and cultural buildings. The one in the middle is a hall usually called "Tangwu" in China, which is used for sacrifice, dinner, reception and entertainment. Tangwu, a semi open space, is surrounded by "Xianfang" (bedrooms) which are the core of the whole house. The courtyard in front of the hall is a typical feature of historical and cultural buildings. There is at least one courtyard, according to the size and plan of the building. The wings on both sides include the bedrooms, kitchen and other rooms. The depth and width of the building is between ten meters and fifteen meters respectively, and the depth is larger than the width. The buildings have one or two stories. The first floor is the main activity space, and the height is about 2.9 m to 3.2 m. The second floor is attic, and the height from floor to the ridge of roof is about 2.4 m which is always used for keeping clutter now. The typical building plans are shown as Fig. 4-4, the typical profile is shown as Fig. 4-8.

(a)Typical first floor (b) Typical top floor

Fig. 4-4 Typical building plans (Historical and cultural building)

4.4.1.2 Traditional Vernacular Building

At present, traditional vernacular buildings are the most widespread in Zhejiang rural areas. There were 142 traditional vernacular buildings surveyed, accounting for 61.7% of the total. Traditional vernacular buildings still use "Jian" as the basic unit. Traditional vernacular buildings can be divided into two types: the buildings built before the 1980s, and the buildings built in the 1980s and 1990s.

(1) Traditional vernacular buildings built before the 1980s

Before reform and opening up in 1980s, due to the underdevelopment of the rural economy, fired clay bricks were expensive. In order to save on the cost of construction, farmers built their houses by using local materials which were easy to get, such as clay and stone. This kind of building evolved from historical and cultural structures, so that it used some of their characteristics, but the spatial form is more concise and compact compared with historical and cultural buildings. Courtyards disappeared gradually, and evolved into outside platforms. The semi-open space (hall or living room) evolved into a relatively closed space. In this stage, the traditional vernacular building was only one story tall too, about 2.6-3m. The attic is not as high as the historical and cultural building: the height of exterior wall is about 1.8m, and the height from the floor to the ridge of roof is about 3m. The first floor is the main living space, including the hall (living room), bedrooms, kitchen, etc. There's no window in the hall, but in the other adjacent rooms there are some windows toward the north and south which are about 1 meter wide and 1.2 meters high. Because it is humid in South China, the attic is mainly used to store hay and foodstuff. But now it is almost idle, thanks to the decline of agriculture. North-south symmetrical windows in the attic help for ventilation, even if the window size is as small as 0.8 meters high. Traditional vernacular building plane is relatively simple. The number of "Jian" is always more than three, some are more than ten. According to the position of aisle, there are several types: no aisle, aisle in the front, middle or back. The typical plans are shown in Fig. 4-5, the typical profile is show in Fig. 4-8.

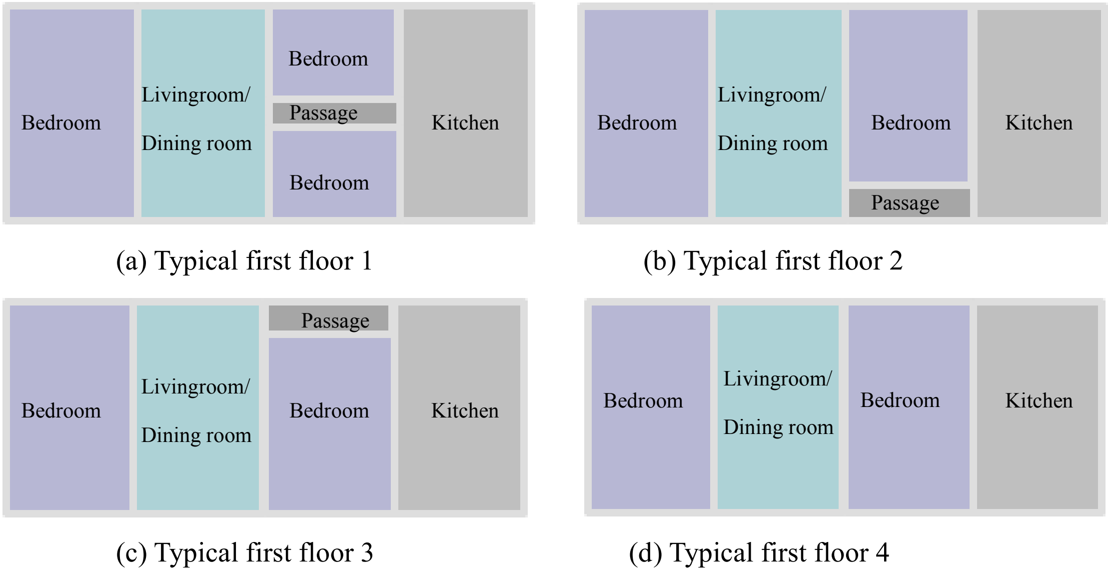


Fig. 4-5 Typical building plans of traditional vernacular building (before 1980s)

(2) Traditional vernacular buildings built in 1980s to 1990s

The traditional vernacular buildings built in 1980s to 1990s are the most widespread buildings in Zhejiang today. Since the 1980s, with the increase of the production of fired clay bricks, the price has been reduced gradually. It is time-consuming to build buildings with earth and stone, which has made red solid bricks a more popular alternative. In addition, modern materials appeared in the countryside gradually, such as steel and concrete. As a result, the architectural form is also changed. Similar to the buildings built before 1980s, the interior facilities are not perfect, and do not have sanitary facilities. Vehicles are stored in the veranda, which has more space and is easily affected by the weather. The building plans still keep the traditional "Jian" as unit, and the hall (living room) is still the center of the whole building. The common plan has several types, including "line" type, "L" type, "bracket" type and so on. Among them, "—" type is the most common. More floors are included, usually two or three stories, with two stories being more common. The first floor is higher than others for the sake of sacrificial activities in the hall, with a height of 3.2m ~ 3.9m. In addition, there’s a kitchen, a bedroom for older family members and production houses on the first floor. The attic on the second floor has evolved into a living space, the height from floor to roof about 3.0m ~ 3.5m. Besides the pitched roof, there are also flat roofs. The houses often include a corridor, which is used for airing clothes and for passage. The typical plans are shown as Fig. 4-6, the typical profile is shown as Fig. 4-8.

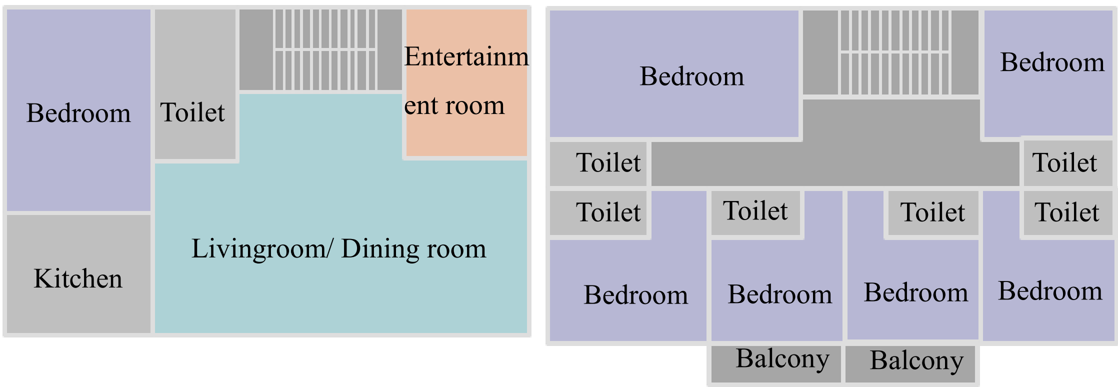
(b) Typical first floor (c) Typical second floor

Fig. 4-6 Typical building plans of traditional vernacular building(1980s~1990s)

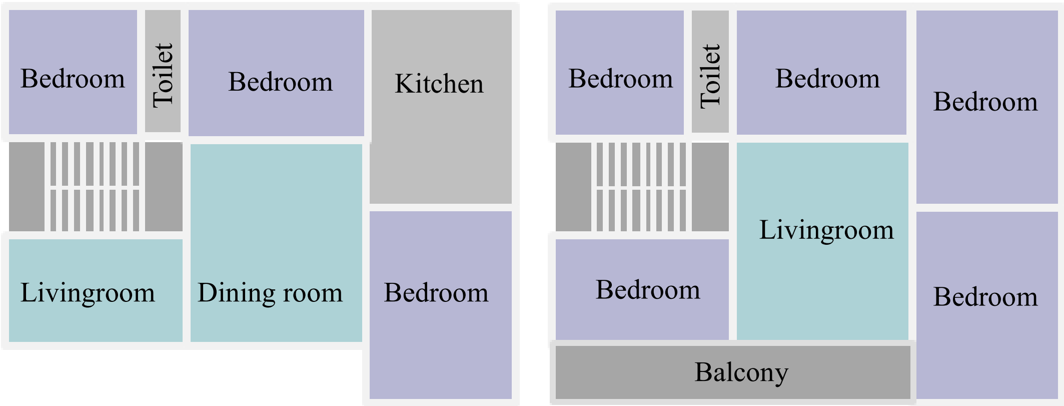
4.4.1.3 Modern Building

After the 2000s, with the further development of the rural economy, urban buildings have had a great influence on rural buildings. Migrant workers and rural construction teams have brought new building designs to the villages, so rural residential buildings are more diverse, functional and complete to meet the needs of modern life.

Modern rural residential buildings present the trend to multi-layer, but due to the control of the government planning, the rural residence are usually 2 ~ 4 stories. The height of the first and second floor is about 3.0 ~ 3.5 m; the third floor is 2.9 m; the height of the ridge is about 2.8 m. The first floor is mainly the public space, including dining-room, living room, kitchen, garage and bedroom for the older. On the second floor, there are bedrooms, study room, guestroom and living room. The typical plans are shown in Fig. 4-7. Taking the influence of typhoon into consideration, the buildings in Zhoushan (such as Donghaiyucun village) on the island are significantly much lower than those in the mountain area, and each floor is about 3 m.

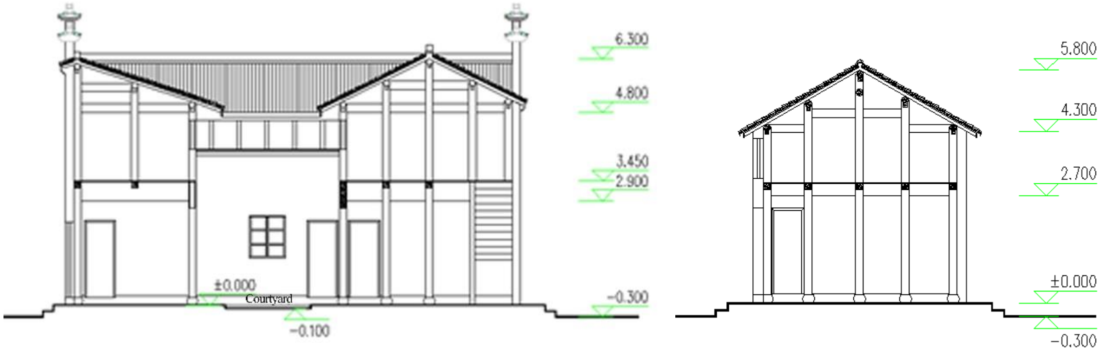


(a)Typical first floor 1 (b) Typical second floor 1



(e)Typical first floor 2 (f) Typical second floor 2

Fig. 4-7 Typical building plans of modern building



(a) Historical and cultural building (b) Traditional vernacular building(before 1980s)

(c) Traditional vernacular building (after 1980s) (d) Modern building

Fig. 4-8 Typical profile of historical and cultural building

4.4.2 Floor Area, Total Building Area

The analysis of building area is based on the village planning layouts provided by local planning departments and mapped with field measurement. The building floor area and total construction area in different regions are shown in Fig. 4-9. There is no obvious difference between ordinary households and rural tourism households on building floor areas, which is about 100.3m^2 to 153.5m^2 on average.

Table. 4-1 Relevant provisions of rural residential buildings in Zhejiang rural areas

Quzhou	2 ~ 4 stories, eaves height is up to 12m; For 1~3 family members in one household: Homestead area is 68~90 m^2, the major is 90 m^2; For more than 3 family members in one household: Homestead area is 90~110 m^2， the major is 105 m^2;
Zhoushan	No more than 3 stories; For no more than 2 family members in one household: Homestead area is 80~100 m^2; For 3 ~ 4 family members in one household: Homestead area is 100~120 m^2; For more than 5 family members in one household: Homestead area is 125~140 m^2.
Anji	No more than 3 stories; The height of 1st floor is no more than 3.6m; the height of 2nd floor is no more than 3.2m; The height of 3rd floor is no more than 3m. The height from the outside ground in the main entrance to the eave or the top of parapet is less than 10m. For no more than 4 family members in one household: Homestead area is 100~130 m^2; For more than 5 family members in one household: Homestead area is 110~150 m^2.

However, the average building area of rural tourism household ranges from 263.9m^2 to 498.3m^2, which is obviously larger than an ordinary household, from 207.7m^2 to 498.3m^2. To a certain extent, it's associated with homestead inheritances from the past generation. In general, the villages which have more historical and cultural buildings or traditional cultural buildings preserved tend to have smaller building areas. For example, there are more than 80% of traditional rural households in Liujia and Yangkeng, with an average total building area of 176.6 m^2 and 161.2 m^2 respectively. On the contrary, the larger proportion of modern buildings in the villages, the larger total building area is, such as Xiachen village which is a rural tourism village,with the average area of 486.3 m^2. Relatively speaking, the household operating rural tourism has a larger building area. For example, the average building area in Donghaiyucun village is about 265.3 m^2, and 486.3 m^2 in Xiachen village. On the whole, the rural residential buildings in Zhejiang present the trend of multi-story and larger building area. In response to this phenomenon, in different regions, the government and planning department have made relevant provisions on building stories, story height, and homestead area. (Table 4-1)

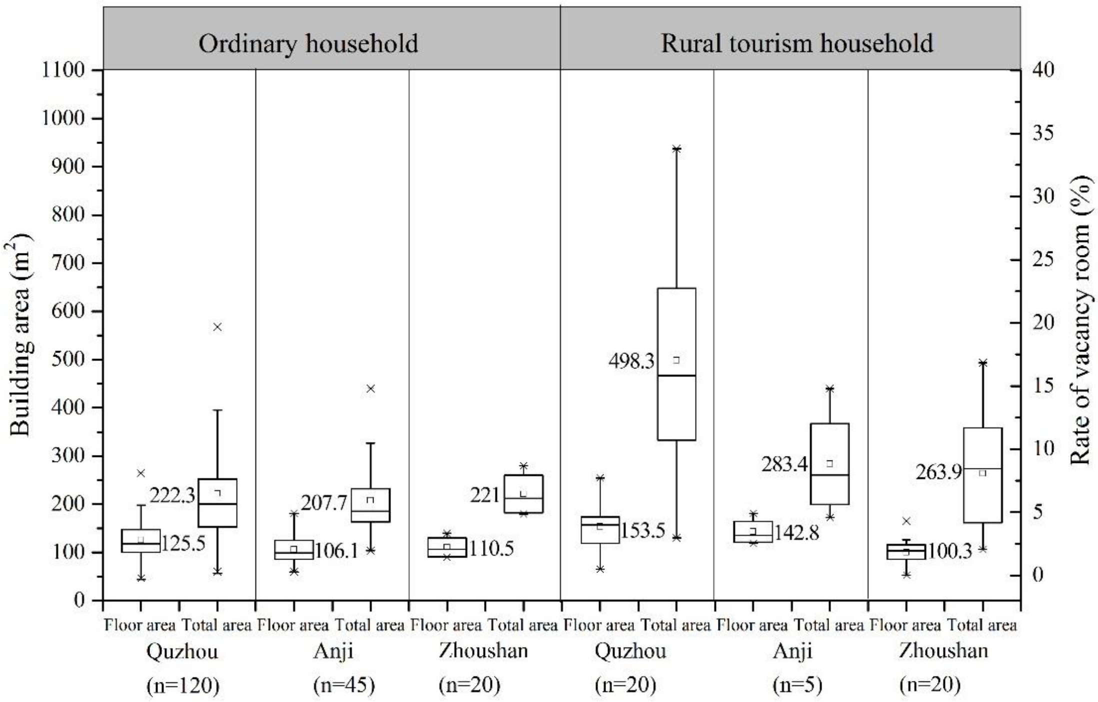


Fig. 4-9 Building area

4.4.3 Window to Wall Ratio, Shape Coefficient of Building

4.4.3.1 Window to Wall Ratio (WWR)

Window-to-wall ratio (WWR) refers to the ratio of the transparent part of the window and balcony door on the outside wall toward the same direction in the building to the total area of the outside walls in the same direction Wall (including the area of the transparent part of the window and balcony doors on the wall)[3]. The formula is shown as follows:

$$WWR = \frac{Win_0}{Wall_0} \quad \text{Equation (1)}$$

Where, WWR is the window to wall ratio, dimensionless; Win_0 is the area of windows and the transparent part of doors, m^2; $Wall_0$ is the area of exterior wall, including the area of Win_0, m^2.

In the analysis process, there are three assumptions:

1) All the buildings surveyed are in a north-south orientation. Because the building layout in the traditional natural villages is formed spontaneously based on the terrain or roads, without unified planning and design, the building orientation is different.

2) In the field survey, some windows were broken or glassless, especially in the idle space. In order to study the overall characteristics of buildings, it is assumed that the windows are complete.

3) In the historical and cultural buildings, the walls and windows toward the courtyard are classified into the area that toward the same direction according to their orientation.

The following results can be obtained from Fig. 4-10 :

(1) Historical and cultural buildings are relatively closed, and the WWR is small. In the east, west and north orientation, the average WWR is small at 0.03. The WWR is larger in south, where it is about 0.07.

(2) For traditional vernacular buildings built in 1980s to 1990s, the WWR of north and south is similar to each other, the average WWR being 0.16 and 0.15 respectively. In contrast, the average WWR of east and west is smaller, which is 0.05 and 0.03 respectively.

(3) Historical and cultural buildings and traditional vernacular buildings tend to be symmetrical along a middle axis with the courtyard and central room. However, the forms of modern buildings are various, and window forms are more diverse. In order to get better lighting, the WWR is larger than traditional buildings, especially in the west. The average WWR of east and west is 0.05 and 0.08 respectively. The average WWR of south and north is larger, which is 0.12 and 0.14 respectively.

4.4.3.2 Shape Coefficient of Building

Shape coefficient of building refers to the ratio of the building surface F_0 in contact with the outdoor atmosphere to the building's volume surrounded by the outdoor atmosphere V_0. The formula is shown as follows:

$$S = \frac{F_0}{V_0} \qquad \text{Equation (2)}$$

In general, as shown in Fig. 4-10, the shape coefficient of buildings built in different periods have the following features:

(1) Historical and cultural buildings have compact forms and rectangular plans and they are generally simple with little variations. In addition, at least one courtyard is included in the plan, which makes the shape coefficient of building larger than other buildings. The shape coefficient is between 0.53 and 0.86, the average shape coefficient is 0.72.

(2) With the disappearance of the courtyard in traditional vernacular buildings, they are more compact. The shape coefficient of building decreases, which is between 0.54 and 0.82, and the average is 0.69.

(3) Due to the abundance of modern building forms, the shape coefficients of the buildings are quite different with a range from 0.4~0.9. However, in general, modern buildings are more compact and have more reasonably functional layouts, so the shape coefficient is smaller, with an average of 0.65.

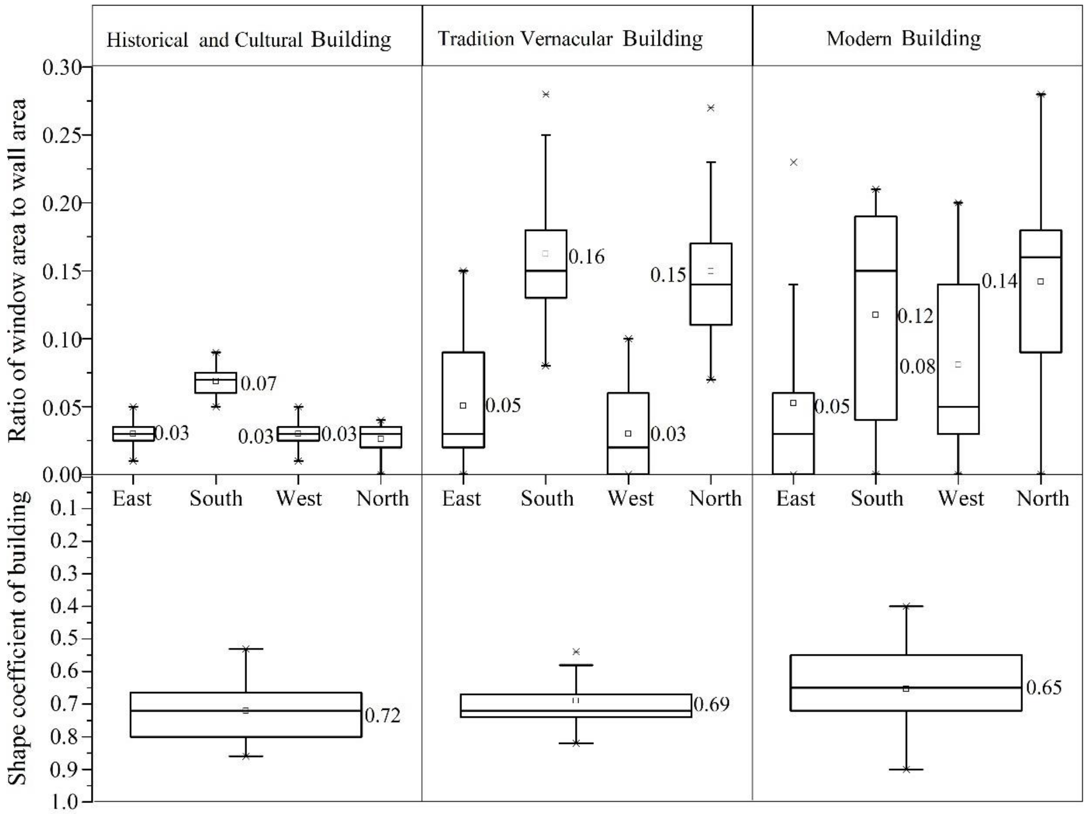


Fig. 4-10 WWR and building shape coefficient of buildings in different period

4.5 Building Constructions and Thermal Performance of Envelopes

4.5.1 Building Envelope

4.5.1.1 Roof and Attic

(1) Roof materials and forms

From ancient times to nowadays, there have been over 760 kinds of tiles used all over the world[4]. Gray tile is one of the traditional roof materials in China, and is very common in Zhejiang's rural area. It's widely used in the roofs of traditional buildings built before 1980s. Each tile is about 200~250mm long, and 150~200mm wide. Gray tiles are directly placed on the purlins. In order to prevent leakage, each row of tiles overlaps the one below, and the overlapping area is more than 50%. However, due to the small volume and light quality of the tile without mortar to bond them together, it's easy to have a slip or leakage. The gray tile roof is shown on Fig. 4-11(a).

After the 1980s, gray tiles were gradually replaced by red clay tiles, which were imported from abroad. They are a kind of flat tile, larger than gray tiles with a size of 360×220mm ~ 400×240mm.

Different from gray tiles, they connect with each other by tile claws and water chutes inside and outside, so that the effective use area of tiles is greatly improved, and the roof weight reduced (Fig. 4-11,b).

In order to protect the limited land resources, the Chinese government began to limit the production of clay products in the 1990s, including clay tiles. After 2000, all sorts of color cement tiles (or named color tile) came up and gradually became the main roofing materials in Zhejiang's rural areas, which are made of cement, sand and all kind of adding pigments (Fig. 4-11,c). Besides tile claws, cement tiles have fixed holes to ensure a strong connection with tile battens.

(a) Gray tile roof (b) Red clay tile roof (c) Cement tile roof

Fig. 4-11 Roof materials in Zhejiang rural areas

(a) Attic without decoration (b) Attic with tile roof (c) Attic with concrete roof

Fig. 4-12 Several attic forms in modern buildings

(2) Attic forms

The Zhejiang province has a lot of rain, so pitched roofs are commonly used in rural residential buildings for the sake of waterproofing. Attics are the space found directly below the pitched roof of a house[5], where is mainly used for storage, such as hay, foodstuff, farm tools in traditional rural residential buildings built before 1980s. Because attics fill the space between the ceiling of the top floor of a building and the slanted roof, they are known for being awkwardly shaped spaces with exposed rafters and difficult-to-reach corners[5]. For traditional buildings, the height of exterior wall is about 1.5~1.7 m, the height of ridge is about 2.5 m or so. Since 1980s, the attic space becomes larger, where is used to be the main living space besides storage. The height of eave is about 2.7~3 m, and the height of ridge is more than 4m(Fig. 4-12a). In order to avoid the leakage of rain and dust falling, farmers make bamboo sticks into bamboo mats as ceilings, which covered with the mixture of lime, clay, plant fiber and so on. This traditional ceiling has a good function of insect-resistant and moisture-proof. In modern rural residential buildings, attics are usually decorated. In addition, the attics are also set between pitched roofs and the horizontal concrete floor slabs (Fig. 4-12b, c).

4.5.1.2 Walls

There are nearly 30 types of walls due to different materials and constructions in Zhejiang rural areas in different period, such as brick walls, rammed earth walls, stone walls, wood walls in traditional buildings. And there are also some kinds of new wall materials adopted in modern buildings. The 12 types listed in the figure are the most common as shown in Fig. 4-16.

(1) Gray brick wall, wood wall

Gray brick is a kind of traditional wall material in China, which is made of clay. In the fired process, the bricks cool down by water, which makes the iron ions in the clay incomplete oxidize. Fe_3O_4 is generated and the bricks appear blue. There are several sizes, the common sizes in Zhejiang are 240mm×80mm×40mm, 290mm×140mm×90mm, 240mm×60mm×10mm. The load bearing exterior walls of the historical and cultural building can be made of gray bricks, which are all rowlock walls. The masonry method of different rowlock wall is different in different regions (Fig. 4-15). In general, the void of the rowlock wall will be filled with crushed bricks, stones and clay.

(2) Rammed earth wall, stone wall

Before the reform and opening up, because of the restriction of economic condition in rural areas, farmers made use of local materials (such as rammed earth, stone, etc.) to build house. Through the survey on existing traditional vernacular buildings, there are two types of massive walls, and they are composed of either clay or granite stone. In the rural area of Quzhou and Anji, clay is employed as the main wall materials. In Zhoushan islands, rural residential buildings are made of granite stones, which is abundant in local place. The thickness of rammed earth wall is about 350 ~ 370 mm. Stone wall is made by the regular stone or irregular freestone with the thickness of about 400 ~ 500 mm. For rammed earth walls, stones are also partly employed in the foundation. The two kinds of walls have good thermal inertia and thermal stability.

Rammed earth is a technique for building walls, foundations, and floors using natural raw materials such as earth, chalk, lime or gravel[6]. It is an ancient building method that can be found on every continent (Fig. 4-13). In China, there are still a large number of famous rammed earth buildings, such as Tulou dwelling in Fuzhou. Rammed earth can be regarded as a kind of natural concrete. Building a rammed-earth wall involves compressing a damp mixture of earth that has suitable proportions of sand, gravel and clay into an externally supported frame, which is usually made of wood or plywood.

Fig. 4-13 Rammed earth buildings distribution in the world[7]

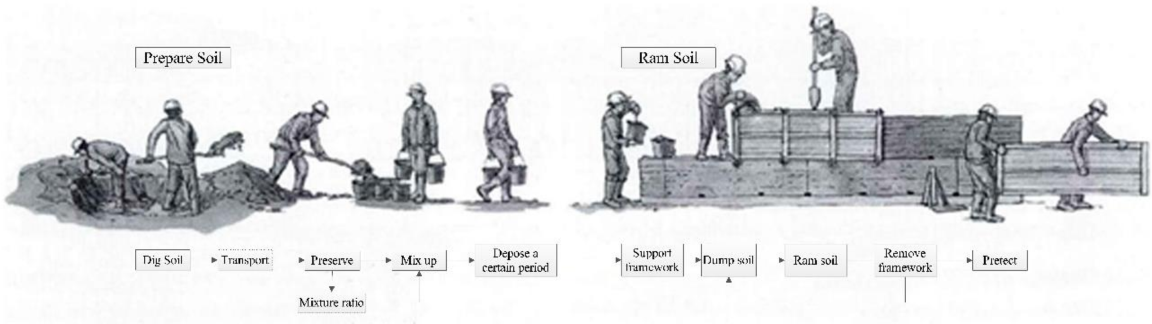
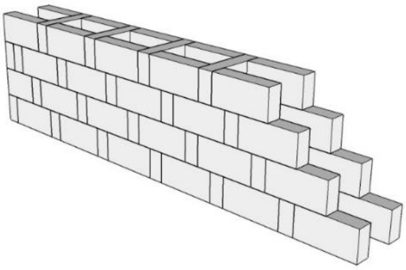


Fig. 4-14 The construction process of rammed earth wall [7]

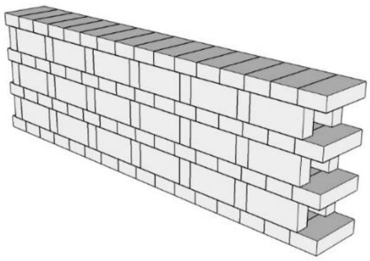
(3) Solid brick walls

After 1980s, red solid bricks are widely used in rural construction, which is a kind of solid, fired clay brick with the standard size of 240 mm × 115 mm × 53 mm. Different from traditional gray bricks, red solid bricks cool down naturally in the process of fired, the iron ions in the clay are oxidized completely, Fe_2O_3 is generated and the bricks appear red color. Since 1975, the brick enterprises develop rapidly in China. By 1980, the production of fired clay brick increased 17% than 1975. With the rapid increase of the fired clay brick production, the price has dropped. After the reform and opening up, rural economy began to recover in Zhejiang. Farmers gradually gave up traditional building materials and construction methods, which cost time and labor. The cheap and stable fired clay bricks became the most popular rural building wall materials. Even now, they are still the most common wall materials in Zhejiang rural area.

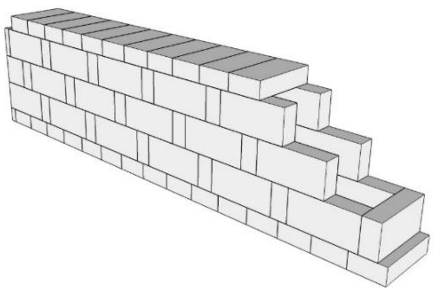
There are several construction methods of brick walls. Solid brick wall is the most common masonry method, with different thickness and arrangement. The thickness of 240 mm solid brick walls is used to be the load bearing walls, and the thickness of 120 mm solid brick walls are employed as nonbearing walls. In addition, there are four kinds of rowlock walls, which is also very common in Zhejiang rural areas (Fig. 4-15), because the rowlock walls need less bricks than solid brick walls. For example, it takes 123 pieces of standard solid bricks to build 1m^2 solid brick wall with thickness of 240mm. However, it only takes 88 pieces bricks to build the same wall in the way of rowlock wall Ⅲ(Fig. 4-15c). The rowlock walls are also employed as nonbearing walls.



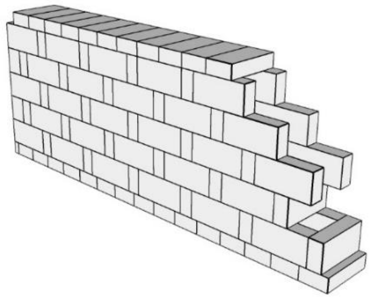
(a) Rowlock wall Ⅰ



(b) Rowlock wall Ⅱ



(c) Rowlock wall Ⅲ



(d) Rowlock wall Ⅳ

Fig. 4-15 The construction of rowlock walls

(4) Wooden wall

Wooden walls are employed as partition walls and interior walls facing the courtyard in historical and cultural buildings and traditional vernacular buildings. Traditional wooden walls are made of single-layer wooden board with thickness of about 10~20mm. Yang Xuegui et al. measured the thermal performance of 15mm thick single-layer cedar wooden wall in laboratory. The results showed that the thermal resistance is 0.16 W/(m^2·K), and the heat transfer coefficient is only 3.06 (m^2·K)/W[8]. It is thus clear that the thermal insulation performance of single-layer wooden wall is poor. In addition, wood has a strong absorption of moisture, and the wet expansion shrinkage is larger. It is prone to cause cracks, and result in poorer thermal performance.

In the traditional buildings under investigation, the majority of partition walls and interior walls are made of wooden walls. Some of them have exquisite wood carvings.

(5) Bamboo strips wall

Bamboos are some of the fastest-growing plants in the world, which can be utilized as building material in 3~5 years. It has a higher compressive strength than wood, brick or concrete and a tensile strength that rivals steel. In the "Yinzao Fashi" (the rules of construction) of Song dynasty, the construction processes are recorded: firstly, columns are set separately, and bamboo strips are compiled. Then, both sides of the bamboo strips wall are plastered with clay, which is mixed with plant fiber. After the clay is dry, lime mortar with plant fiber is plastered. The thickness of the bamboo strips wall can reach two inches (about 70mm). Bamboo strips walls are common in Zhejiang province before the reform and opening up, such as in Quzhou, Anji rural areas. Compared with wooden walls, bamboo strips walls are less in the traditional buildings under investigation. In the past, it is adopted in the poor family.

(6) New material walls

Influenced by the world's energy and environment crisis, since the early 1990s, Chinese government put forward the idea of saving resource, energy, environmental protection as the core of "innovation and promotion of wall materials and building energy consumption", and advocated the new wall materials instead of traditional solid clay bricks. After 2000, concrete products appeared in Zhejiang rural areas, mainly ordinary concrete hollow blocks with two holes in a row and ordinary solid concrete bricks. The standard size of ordinary solid concrete brick is 240mm×115mm×53mm, which can also be used as load bearing walls. The size of ordinary concrete hollow block is larger, with the standard size of 390mm×190mm×190mm. Due to the larger size, the masonry speed is quick, which is mainly used as nonbearing walls. Under investigation, they are not as popular so red solid bricks in rural areas. Because they are made of cement, sand, which are easy to shrinkage cracking, and breakage rate of the bricks is high during the transportation.

Fired bricks have a long history in China. As early as in Zhou Dynasty (1066 BC - 771 BC), the fired large air bricks have already appeared [9]. New fired products first originated in the 1920s~1930s such as modern fired hollow bricks, porous brick. Until the 1990s, as countries imposed building codes, new fired products gradually become mainstream, but almost exclusively in large and medium-sized cities and towns. Fired porous bricks and hollow bricks can reduce the use of resources and energy. There are several kinds of fired porous bricks and hollow bricks in Zhejiang. The most common types are the porous bricks with round holes or rectangular holes, with the size of 240mm×115mm×90mm, which is larger than standard solid bricks. Therefore, the masonry method is more simple and quicker. It takes 123 pieces of standard solid bricks to build 1m^2 solid brick wall with thickness of 240mm. However, it only takes 80 pieces fired porous bricks to build the same wall (Fig. 4-17). In addition, because of the air in the holes, they have better thermal performance than the solid clay brick. However, due to the higher price, farmers' backward concept and other reasons, according to the field survey, fired porous bricks are only widely used in Anji and Zhoushan.

4.5.1.3 Floor and Ground

The floor of historical and cultural buildings and the traditional vernacular buildings built before the 1980s are wooden, with a thickness of about 20mm. Wooden boards are put on the beams. Due to gaps between wooden boards, it's easy for dust to fall off. Nowadays, these same farmers decorate ceilings at the bottom of wooden floors.

After 1980s, steel and cement emerged in the countryside, and the cast-in-place concrete (CIPC) and precast concrete hollow slabs (PCHS) were used as floor slabs. In the early stage of employing CIPC floors, the construction mainly depended on a human labor force and was complicated because of the backwards mechanical equipment. With the emergence of precast concrete factories later, PCHS were adopted. Until now, in some remote mountain areas, PCHS are still the first choice to build the floor. For example, on the field survey, it is found that PCHS were still employed in Ligeng. It is known that, the seismic performance of PCHS floors is poorer than the CIPC floors. Therefore, the CIPC floors are the main structure of new rural residential buildings in Zhejiang rural areas at present. The construction of PCHS floor is shown in Fig. 4-17.

The ground of the historical and cultural buildings and traditional vernacular buildings are soil ground or gray bricks, depending on the family's economic condition. Since the 1980s, cement-plaster ground has been adopted, and a lot of soil ground in traditional rural residential buildings has been replaced with cement mortar. After the 1990s, cast-in-site terrazzo is used in some rural households. For modern rural residences, farmers mainly use ceramic tiles or stone slates for surface decoration of the ground. There are two types construction of ground. One is filled with stone, clay, sand directly. In some mountain area, such as Anji, the overhead grounds are employed for moisture proof, with the height of 600~700mm. The construction of overhead ground is shown in Fig. 4-17.

4.5.1.4 Doors and windows

The doors and windows of historical and cultural buildings and traditional vernacular buildings are made of wood. The traditional window is composed of a wooden frame and a solid wooden casement, and wooden shutters were historically employed to reduce solar infiltration and shading until glazing. Due to their age, most of them were broken, and the air tightness is poor. Some windows don't have glass, just have screen and polythene covering on them. Considering the space privacy, some special structures are used in the doors and windows. In modern buildings, plastic and ordinary aluminum alloy windows with single-layer glass have been used.

4.5.2 Building Structure and Thermal Bridge

There are several building structure forms, such as brick-wood structure, earth-wood structure, stone -wood structure, masonry-concrete structure, frame structure and so on. Brick-wood structure, earth-wood structure, and stone-wood structure are the main structures of historical and cultural buildings and traditional vernacular buildings before 1980s. Brick walls, rammed earth walls and stone walls are the periphery load bearing element of buildings, and wooden frame support the internal space. Therefore, there is no obvious heat bridge in the exterior walls. After 1980s, masonry-concrete structure is the main structure in the traditional vernacular building, and brick walls are the main load bearing component in both outside and inside. There's no reinforced concrete constructional column in buildings, only the reinforced concrete floors put on the exterior walls became the thermal bridge. In recent years, the ratio of thermal bridge has increased in rural residential buildings. The proportion of thermal bridge in rural residential buildings is different, which is relevant with the storey number, structure, built time and method. The probability of thermal bridge is lower in the buildings with masonry-brick (including stone, earth) structure (storey number is 1~ 3) built in the 1980s and 1990s, which is about 10% ~15%. But there's a great varies in modern buildings after 2000. The thermal bridge ratio of different structures is shown in Table 4-3.

Table 4-2 Thermal performance of hollow walls

Masonry	Filled Material	Heat Transfer Coefficient W/(m^2·K)			
		290×140×90	240×80×40	240×60×10	240×115×53
Rowlock wall-1	Air	2.359	3.503	5.054	3.628
	Clay, gravel	2.337	2.949	3.092	3.279
	Slag	1.647	1.580	1.256	1.915
Rowlock wall-2	Air	2.322	3.483	4.980	3.62
	Clay, gravel	2.308	2.943	3.080	3.282
	Slag	1.826	1.608	1.303	1.948
Rowlock wall-3	Air	2.342	3.397	4.880	3.598
	Clay, gravel	2.325	2.917	3.063	3.291
	Slag	1.719	1.730	1.364	2.090
Rowlock wall-4	Air	2.348	3.429	4.919	3.607
	Clay, gravel	2.330	2.927	3.070	3.287
	Slag	1.690	1.685	1.340	2.037

Note:1.Heat transfer coefficient is calculated according to the material performance and method in *Thermal design code for civil building[10]*.

Table 4-3 Thermal bridge ratio of different structure

Stories	Structure	Thermal bridge ratio (%)
1~3	Masonry-concrete /stone (in 80~90s)	10%~15%
2~3	Masonry-concrete structure / frame structure	15%~25%
4~6	Masonry-concrete structure	15%~20%
	Frame structure in some parts	20%~30%

Table 4-4 Construction of envelopes and thermal performance in Zhejiang rural areas

Types	Material and Construction	Heat transfer coefficient (W/(m²·K))	Thermal inertia	Thermal bridge ratio (%)
EW-1	20mm mortar + 300mm rammed earth wall + 20mm mortar + surface source	2.76	3.55	——
EW-2	20mm mortar +400mm stone wall+ 20mm mortar + surface source	3.25	3.41	——
EW-3	20mm mortar +240mm solid brick wall + 20mm cement mortar + 5mm anti-crack mortar + ceramic veneer	2.10	3.64	15%
EW-4	20mm mortar +240mm rowlock brick wall+ 20mm cement mortar + 5mm anti-crack mortar + ceramic veneer	2.28	2.97	15%
EW-5	20mm mortar +190mm hollow concrete block + 20mm cement mortar + 5mm anti-crack mortar + ceramic veneer	2.66	1.65	——
EW-6	20mm mortar +240mm fired porous brick (round hole) wall+ 20mm cement mortar + 5mm anti-crack mortar + ceramic veneer	1.95	3.79	15%
EW-7	20mm mortar +240mm Fired porous brick wall (rectangular hole) wall+ 20mm cement mortar + 5mm anti-crack mortar + ceramic veneer	1.88	4.01	15%
IW-1	Wooden board 15mm	3.89	0.55	——
IW- 2	20mm mortar +240mm solid brick wall +20mm mortar	2.04	3.64	——
R-1	Tile +purlin	5.18	0.56	——
R-2	Tile + 20mm cement mortar + 100mm concrete slab	3.10	2.83	——
F-1	20mm Wooden board + wooden joist	4.67	3.41	——
F-2	surface source +25mm cement mortar +120mmn precast concrete slabs + 10mm ceiling cement mortar	3.42	1.95	——

G-1	surface source +20mm cement mortar +80mm plain concrete + 60mm gravel+ rammed soil	3.79	2.13	——
G-2	surface source +25mm cement mortar + 120mm Precast concrete slabs+ overhead floor+ rammed soil	2.99	2.44	——
W-1	Wooden window + single layer glass	3.20	——	——
W-2	aluminum alloy frame without thermal break + single layer glass	4.70	——	——

Note:1.Heat transfer coefficient and thermal inertia is calculated according to the material performance and method in *Thermal design code for civil building[10]*.

2. EW refers to exterior wall; IW refers to interior wall; F refers to floor; G refers to ground; W refers to window.

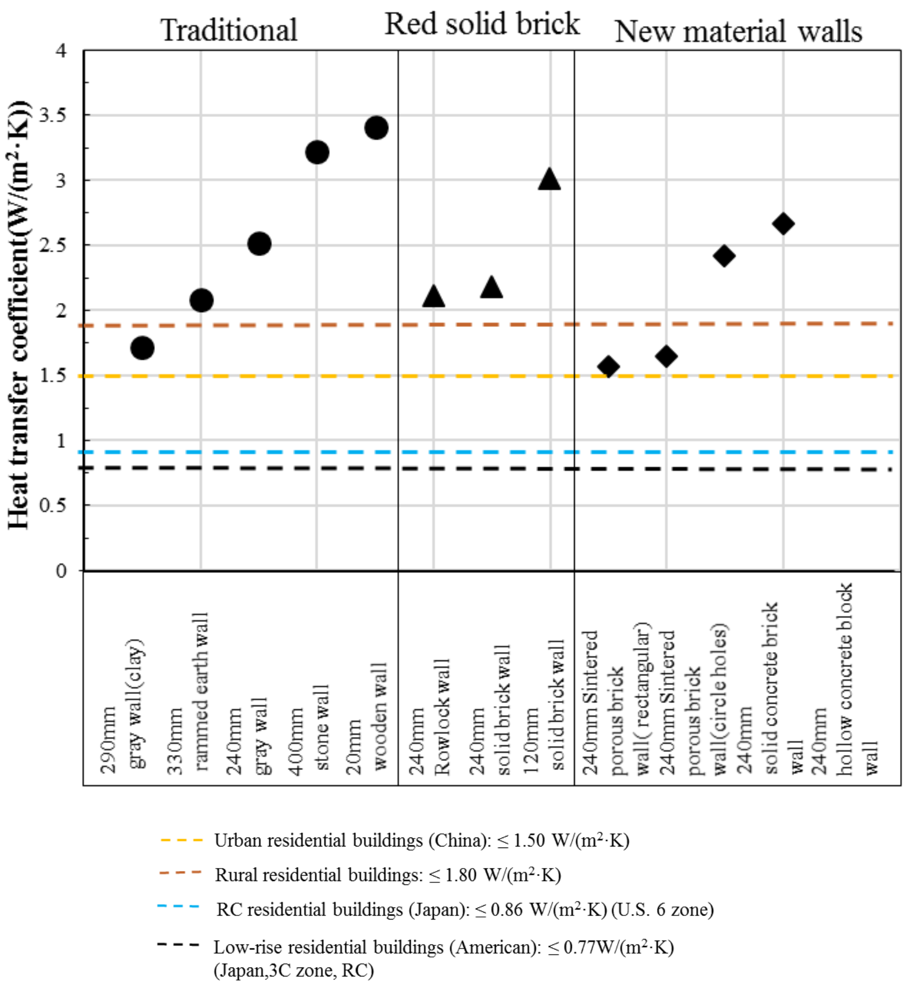
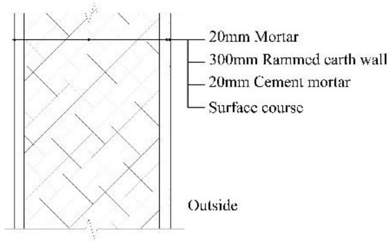
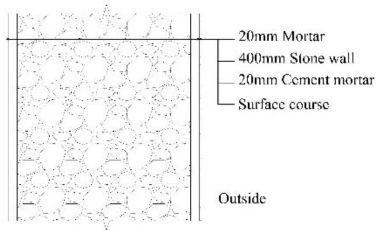
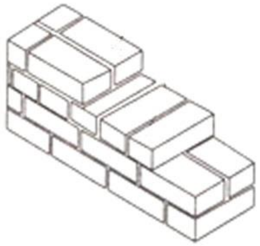
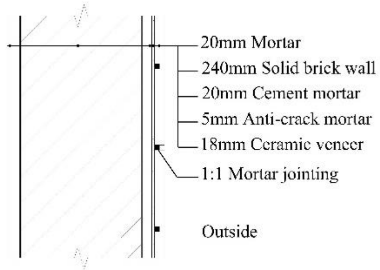
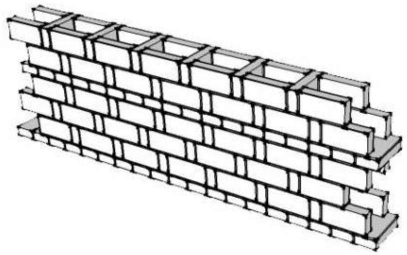
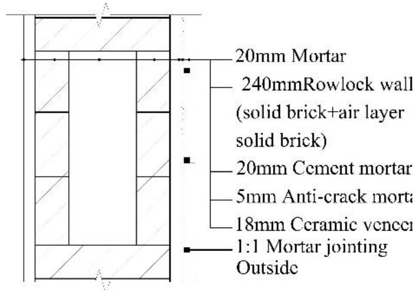
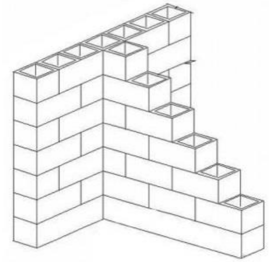
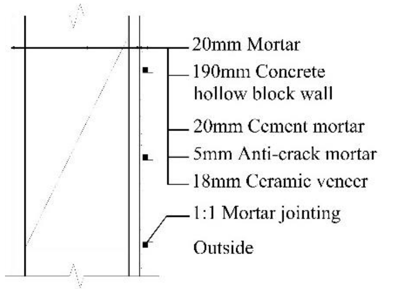
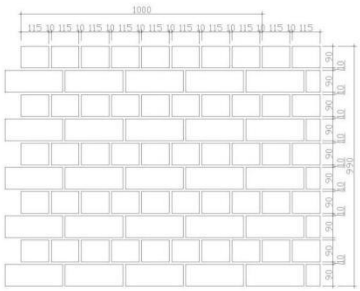
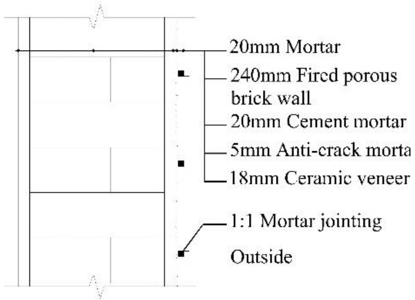


Fig. 4-16 Heat transfer coefficient of common walls and comparison with standards

Table 4-5 Materials and constructions of the main exterior walls

Types	Category	Material	Construction method	Construction
EW-1	 Bearing wall,300mm	 sand:clay:lime=7:2:1	 Human labor or mechanical	
EW-2	 Bearing wall,400mm	 Granite stone(400×400×600mm)	 Human labor or mechanical	
Wall-3	 Bearing wall,240mm	 Solid brick (240mm×115mm×53mm)	 1m^2 wall needs 123 piece of brick	

<table>
<tr>
<td>EW-4</td>
<td>
Nonbearing wall, 240mm</td>
<td>
Solid brick(240×115×53mm)</td>
<td>
1m² wall needs 88 piece of brick</td>
<td></td>
</tr>
<tr>
<td>EW-6</td>
<td>
Nonbearing wall, 190mm</td>
<td>
Ordinary concrete hollow block(390mm×190mm×190mm)</td>
<td>
1m² wall needs 13 piece of brick</td>
<td></td>
</tr>
<tr>
<td>EW-7</td>
<td>
Bearing wall,240mm</td>
<td>
Fired porous brick (round hole), 240mm×115mm×90mm</td>
<td>
1m² wall needs 80 piece of brick</td>
<td></td>
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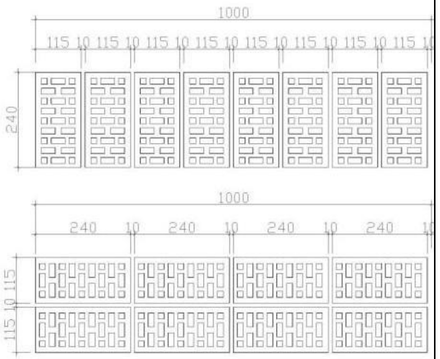
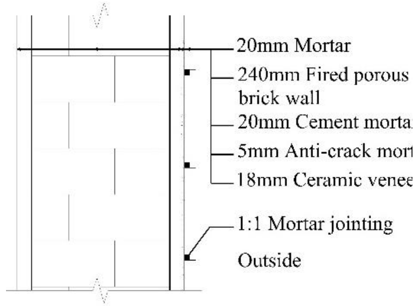
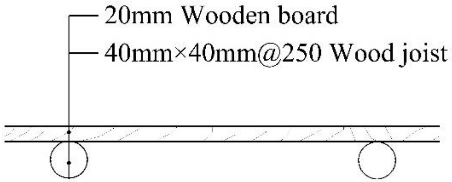
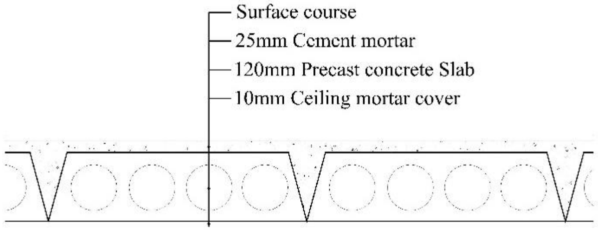
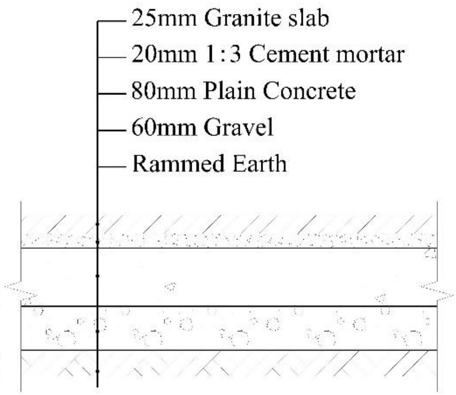
EW-7	 Bearing wall,240mm	 Fired porous brick (rectangular hole), 240mm×115mm×90mm	 $1m^2$ wall needs 80 piece of brick	



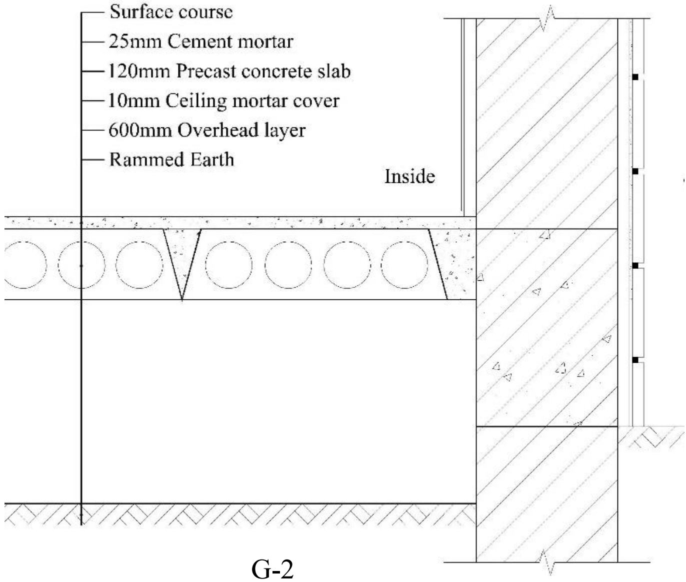
F-1



F-2



G-1



G-2

Fig. 4-17 Constructions of floors and grounds

4.6 Summaries

From the analysis of the basic situation of rural households and rural residential buildings in Zhejiang province, the results can be presented as following:

(1) The permanent resident population of an ordinary household is small, 2 people/household is the most common, and the proportion of migrant workers is large. The traditional primary industry has gradually changed into an economy fused of primary industry, secondary industry and tertiary industry to increase the rural income. But the family income of ordinary households is generally lower than rural tourism households, family income lower than 50,000 Yuan accounting for 50% ~ 75%.

(2) There are three types of rural residential buildings are historical and cultural buildings, traditional vernacular buildings, and modern buildings. Most of the rural tourism households are modern buildings and traditional vernacular buildings built after 1980s. The number of existing historical and cultural buildings is small, and the typical characteristic is axial symmetry in the courtyard and the central room as the center. The first floor is used for living, and the top floor is used for storing hay and others. Traditional vernacular building is divided into two types. One is buildings constructed before the 1980s and the other is built after 1980s. There's no courtyard in the traditional vernacular buildings, with a central room for axial symmetry. The traditional building built after the 1980s marks a transition from traditional buildings to modern buildings, and is the most common type in rural area currently. The plan for this kind of building is more abundant, and the number of layers increased (mainly 2 ~ 3 layers). The top floor has become the main living space, but the interior of the building is not perfect. The buildings remain axisymmetric to the central room, and have a side corridor gallery. After the 2000s, influenced by the modern urban building designs, there are more types of buildings, and the internal functions are the same as buildings in the city.

(3) The average floor area is between 100.3 m^2 to 153.5 m^2, and the average total building area is between 207.7 ~ 498.3 m^2. The area is quite different between buildings. The total area of rural tourism households is larger than ordinary households.

(4) The average window-to-wall ratio of historical and cultural buildings is about 0.03. The ratio of south is slightly larger, with an average of 0.07. The average shape coefficient of historical and cultural building is 0.72. The average window-to-wall ratio of traditional vernacular building is about 0.03. Compared with historical and cultural building, the ratio of south and north increased to

0.16 and 0.15 respectively. The shape coefficient is smaller than historical and cultural buildings, with an average of 0.69. Modern building pursuits more bright indoor environment, and the windows are larger. The window-to-wall ratio of south, east, north and west is 0.05, 0.12, 0.08 and 0.14 respectively. Modern buildings are more compact, and the shape coefficient of building is decreased, with the average of 0.65.

(5) There are several types of building materials and constructions of building envelopes, such as exterior walls, windows, floors, grounds and so on. The thermal performance of building envelopes was poorer than the requirement of standards both domestic and foreign.

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Chapter 5.

Survey on Indoor Thermal Environment of Rural Residential Buildings

5.1 Introduction

Indoor thermal environment is an important aspect influencing tourism business in rural areas. Compared with the studies and efforts related to urban buildings, research focusing on the conditions and issues of rural residential buildings is scarce, which have been neglected for many years [1]. As a result, comprehensive and detailed data on indoor thermal environment of rural residential buildings is inadequate, especially the studies on the buildings operating tourism business in rural areas. According to the research results of Chapter 4, historical and cultural buildings (HCB), traditional vernacular buildings(TVB), and modern buildings(MB) are different in terms of characteristics and thermal performance of envelopes. At present, the tourism business in rural area is mainly operated in modern buildings and traditional vernacular buildings, while the historical and cultural buildings are few. Despite the poor conditions, historical and cultural buildings have unique features of Chinese traditional buildings, and are very popular among the tourists. In this chapter, filed measurements and questionnaire investigations were carried out among ordinary households and rural tourism households in two villages of rural area in Quzhou (Fig.5-1) because of the hottest climate in Quzhou, Anji and Zhushan. The main objective of this chapter is to reveal the characteristics of the indoor thermal environment in different rural residential buildings, and the results would provide a basis for further simulation and optimization.

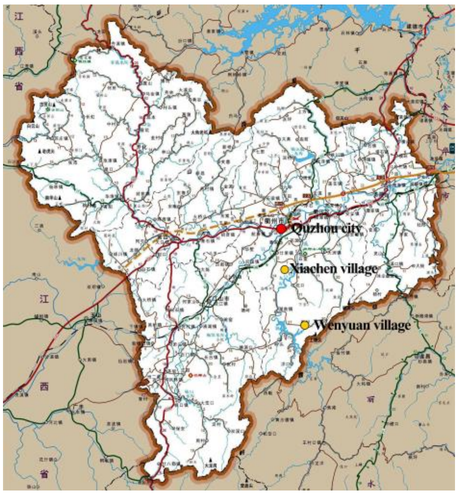


Fig.5-1 Measured villages (Quzhou)
(Source: modified from google map)

5.2Measurement Outline

5.2.1 Measured Villages

5.2.1.1 Xiachen Village

Xiachen village locates in the south of Huangtangkou Town, Quzhou city. It is characterized by 30°42′24.60″ north latitude, 122°30′08.24 north longitude, and the altitude of about 541m above the sea level. The average temperature in January is 5°C and the average temperature in July is 28.5°C. It is 34 kilometers away from Quzhou City (Fig.5-1). Xiachen village is a typical rural tourism village in local, and locates in the entrance of *Tianjilongmen* scenic spot, which is a national 4A scenic spot famous for natural landscape.The average temperature all the year round is 16.6°C. Xiachen village is a small village with natural scecery.There are 45 households and about 170 farmers in the village, 33 of which are rural tourism households, accounting for 73.3%. The total 775 guest beds can serve over 4,000 tourists once a time. It was appraised as province-level featured rural toursim village in

2006. The topographic map of Xiachen village is as shown in Fig. 5-2. Three buildings were selected for the field measurement. Two modern buildings are operating rural tourism business, and the remaining one is a traditional vernacular building. (Fig. 5-2.)

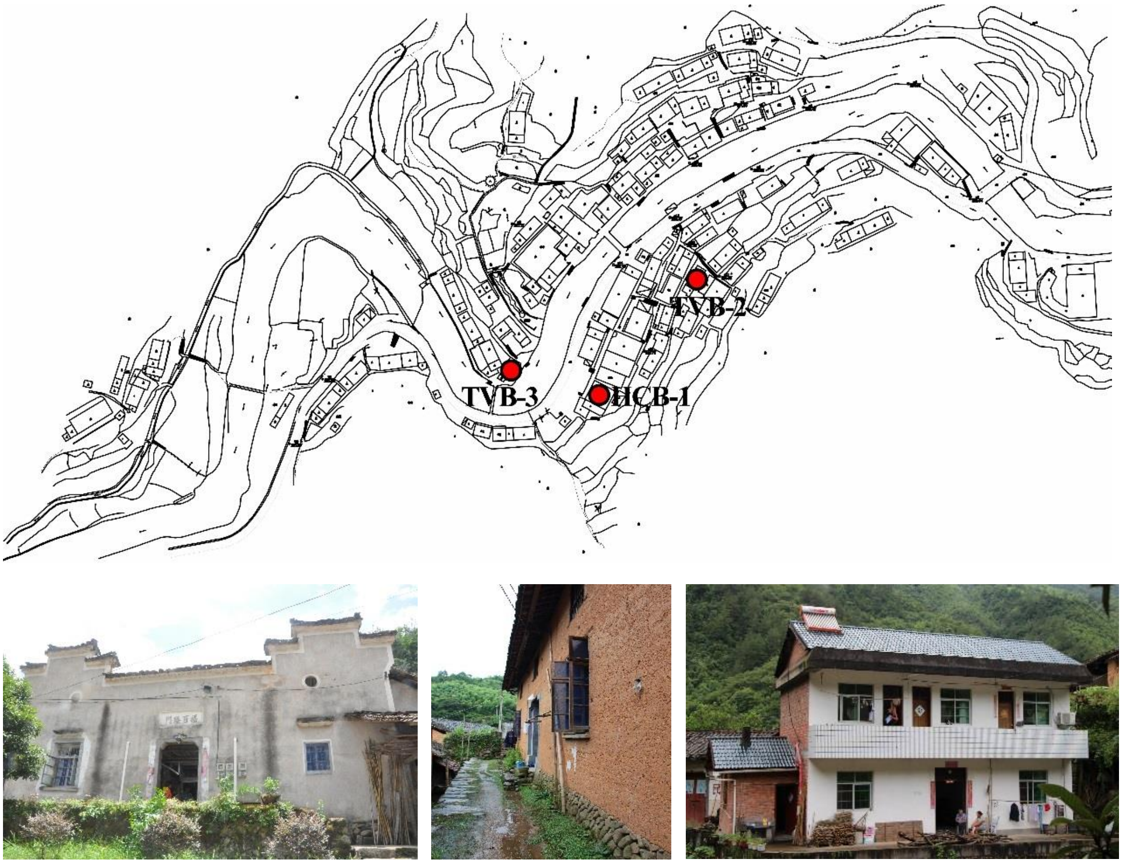
(a) MB-1 (b) MB-2 (c) TVB-1

Fig. 5-2 Topographic map of Xiachen village and the measured buildings

(The topographic map is provided by Quzhou Planning Bureau)

5.2.1.2Wenyuan Village

Wenyuan village is a natural village locating in the southern mountain area of Qujiang District, nearly 56 kilometers away from Quzhou City. The rural residential buildings are built along the river. There are 58 households with 230 residents. The majority of the young and middle-aged labor force flocks to big cities and towns. Owing to its remote site, the village is almost isolated from the outside world. Therefore, it is protected from external influence, especially the traditonal vernacular builings. More than 75% rurual residential buildings are traditional buildings, some of which were built before 1949, such as ancestral temples and traditional dewellings. The topographic map of Wenyuan village is as shown in Fig. 5-3. A total of three traditional buildings were selected for field measurement, and they are the major building forms in Wenyuan village. One is a historical and cultural building built in the Republic of China Period, and the other two traditional vernacular buildings were built before 1980 and in 1990s, respectively. The measured buildings are shown in Fig. 5-3.



(a) HCB-1 (b) TVB-2 (c) TVB-1

Fig. 5-3 Topographic map of Wenyuan village and the measured buildings

(The topographic map is provided by Quzhou Planning Bureau)

5.2.2 Measurement Period and Weather

Field measurements were conducted from January 19th to 21st in 2016 and July 22nd to 25th in 2016 in Xiachen village, and from July 15th to 18th in 2016 in Wenyuan village. January 19th to 21st is around the Greater Cold (January 20th), which is one of 24 solar terms [3], when is the coldest days in winter. Similarly, July 15th~25th is around the Great Heat (July 22nd-23rd), when is the hottest days in summer.

It was cloudy on January 19th, and then turned to rain on January 20th. In the late afternoon, it began to snow till January 21st. On July 15th, it was sunny, and turned to cloud and rain on July 16thto 18th. From July 22nd to 25th in 2016, it was sunny and very hot.

5.2.3 Measurement Contents

5.2.3.1 Measured Rooms

The measured rooms include the major activity space and some special space. The former refers to the rooms where the occupants mainly used the space such as bedroom, living room, and guest room. The latter refers to the rooms which are relatively special space, such as courtyard, attic, and sun room. The measuring points were distributed as mentioned in Section 5.2. The measuring instruments were set at the height of 1.5m. In order to prevent from human disturbance and not affect the daily life of occupants, the measuring meters were fixed to the furniture. The data were recorded every one minute.

5.2.3.2 Measured Items

(1) Field measurement

In summary, the measurement items include: 1) global solar radiation, 2) outdoor air temperature and relative humidity, 3) indoor air temperature and relative humidity, 4) indoor globe temperature, 5) indoor air velocity, and 6) indoor thermal comfort degree(PMV-PPD). The measuring instruments have been introduced in Chapter 3.

In order to evaluate the indoor thermal comfort, PMV index in major activity space in the summer and winter day was measured by IAQ (Chapter 3.3). Although PMV-PPD [4] model is the basis of comfort standards ISO 7730[5] and ASHRAE55[6,7], it was assumed to be inaccurate in predicting thermal sensation of the occupants in a naturally ventilated building in hot humid climate since it neglects the physiological, behavioral and psychological adaptation of human being. Thus, PMV results were corrected by two methods. One is proposed by Fanger with an expectancy factor [8], and it is 0.7 in this study. The other is aPMV index proposed by Chinese scholar Li et al [9] based on PMV index.

(2) Questionnaire investigation

The famers and tourists' subjective feelings of indoor thermal environment were studied by questionnaire investigation. The thermal sensation about winter and summer was divided into four levels. The field survey was conducted in summer 2016. A total of 138 households were surveyed and more than 300 farmers voted. The investigation of tourists was also carried out in Quzhou District. There was a total of 70 valid questionnaires. The questionnaire includes the questions about age, gender, career, thermal sensation, comfort, major cooling methods, the frequency of using air conditioning, and clothing.

5.3 Indoor Thermal Environment of Buildings in Xiacheng Village

5.3.1 TVB-1

5.3.1.1 Description of TVB-1

TVB-1 is next to MB-2. As a typical traditional vernacular building built in 1976, it consists of four "Jian" side by side: a kitchen, a vacant room, a living room, and a bedroom. The top floor (attic) is used for storage. The building has the width of 17.9m and the depth of 5.58m. The height of the first floor is 3.0m. On the attic, the height of exterior wall is 1.70m, and the height of ridge is 3.1m. The plans are as shown in Fig. 5-4. There is only an old couple over 70 years old living in this building, and there is no air conditioning. They mainly rely on charcoal and electric blanket to get warm in winter, and use electric fan to keep cool in summer.

The exterior walls are made of rammed earth with the thickness of 350mm. The inner walls adopt wooden boards with the thickness of 15mm. The floors are wooden boards with the thickness of 20mm. The windows are wooden frame with single-layer glass. However, the windows of the attic have no glass, and some of them are covered with plastic sheeting.

The measuring instruments of temperature and relative humidity were set in the living room and bedroom as shown in Fig. 5-4.

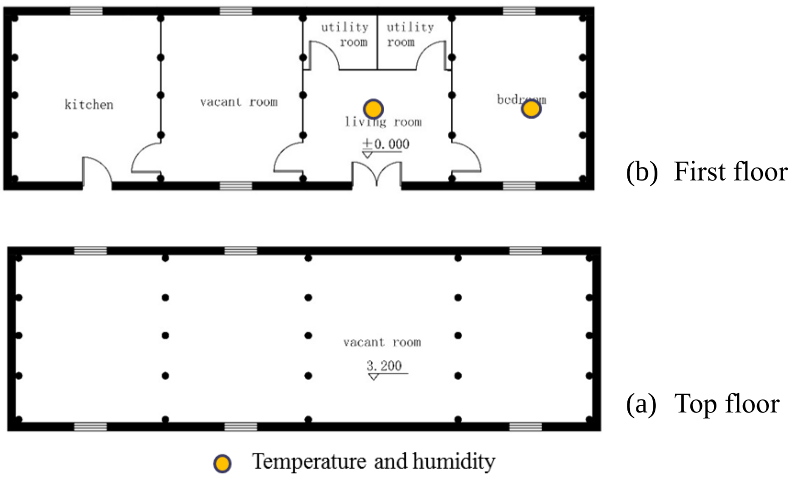


Fig. 5-4 Building plan and measuring point distribution (TVB-1)

5.3.1.2Winter Survey Results of TVB-1

The monitor data from 0:00 to 23:00 on January 20th were selected. The air temperature and relatively humidity of every half hour are shown in Fig. 5-5. TVB-1 is next to MB-2. Therefore, the outdoor meteorological data of MB-2 were compared.

It can be seen from Fig. 5-5 that the temperatures of living room and bedroom were higher than the outdoor temperature. The temperature of bedroom was higher than that of living room. The average temperature of the bedroom was 5.8°C, which was about 4.6°C higher than the outdoor temperature. The average temperature of the living room was 2.9°C, about 1.7°C higher than the outdoor temperature. The indoor temperature during daytime was higher than night. During the daytime (6:30am~17:00pm), the average temperature of the living room was 2.5°C, which was closer to the outdoor temperature. And it was 3.3°C at night (0:00am~6:00am, 17:30pm~ 23:30pm), which is about 2°C higher than outdoor temperature. The average temperature of the bedroom was 6.2°C during the daytime (6:30am~17:00pm) and 5.4°C at night (0:00am~ 6:00am, 17:30pm~ 23:30pm). The temperature of the living room was about 2.9°C lower than the bedroom. According to the living habits of the farmers, the door of the living room is generally opened during the daytime (6:30 am~17:00 pm), and closed at night. Because there are no windows in the living room, farmers have to open the door in order to get more lighting, while the windows are closed during the whole day.

Due to the influence of the open door at daytime, the relative humidity of the living room was lower than bedroom. The outdoor relative humidity (OD-RH) was between 60% and 100%. The relative humidity of the bedroom(BR-RH) was higher than the living room, with the average relative humidity of 90.5% and 71.6%, respectively. It is obvious that the relative humidity at night was higher than daytime. The high relative humidity of bedroom on the first floor is not good for health.

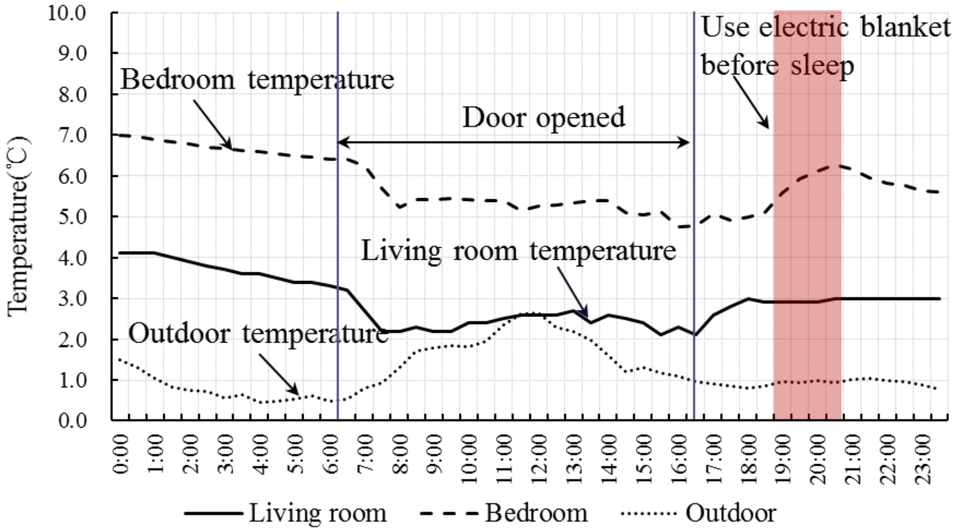


Fig. 5-5 Measured air temperature and relative humidity of TVB-1 in winter

5.3.1.3Summer Survey Results of TVB-1

The monitor data from 0:00am to 23:00pm on July 23th were selected. Due to instrument failure, the data of living room were lost, and the air temperatures of bedroom were shown in Fig. 5-6.The air temperatures of the bedroom ranged from 26.8°C to 32.2°C, with the average value of 30.5°C.

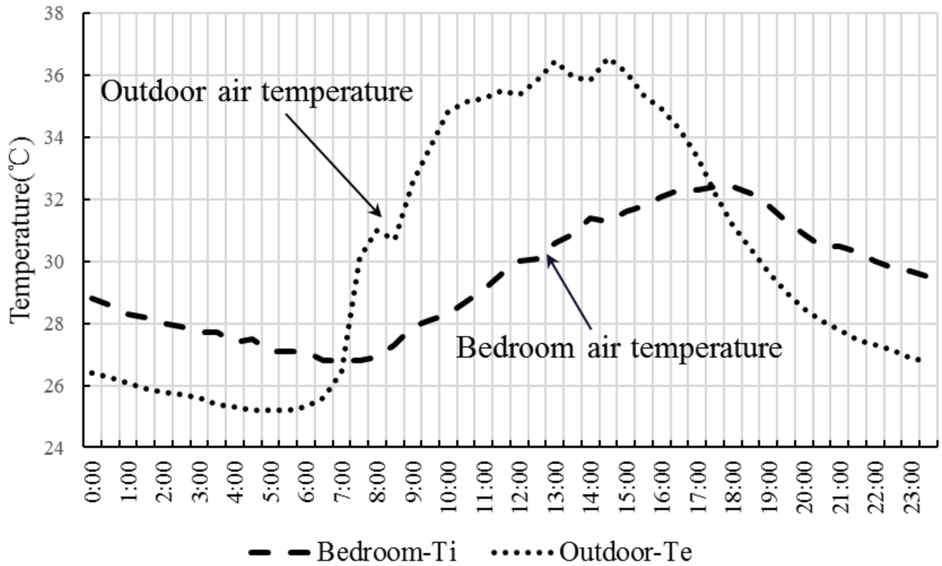
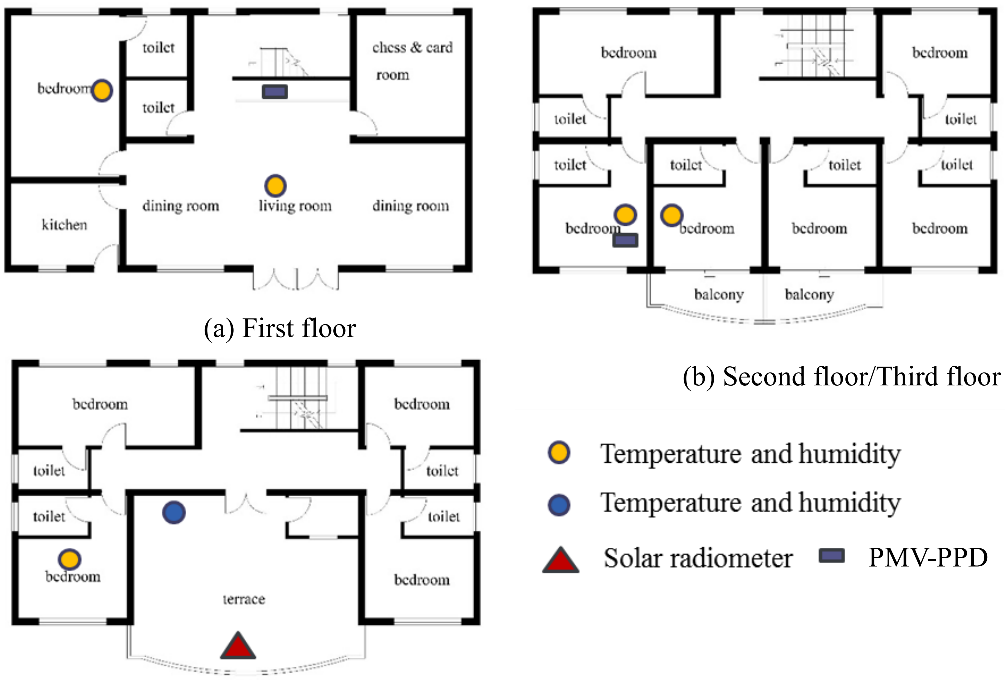


Fig. 5-6Measured air temperature of TVB-1 in summer

5.3.2MB-1

5.3.2.1 Description of MB-1

MB-1 is a modern rural residential building located in Xiachen village of Quzhou (Fig. 5-2,a). It is the most common building in local. Built in 2011, it started to operate rural tourism business in 2014. It has 4 floors, and the first floor is the public space, including living room, dining room, bedroom for the older, and kitchen, etc. The second and third floors are guest rooms for tourists and the bedroom for the hosts. The fourth floor is the attic, which has not been renovated and is idle at present. The width of the building is 16.6m, and the depth is 9.3m. The building covers an area of 153.8m^2, with the total construction area of 580.7m^2. The height of the first floor is 3.4m, while the second and third floors are 3.0m high. The plans of each floor are shown in Fig. 5-7. There are 4 people, 3 generations living in this building. Some of the rooms are equipped with air conditioning. The hosts do not use air conditioner in winter, except tourists in summer.



(a) First floor

(b) Second floor/Third floor

(c) Top floor

Fig. 5-7 Building plan and measuring point distribution(MB-1)

The walls are made of red solid bricks, with the thickness of 240mm. The wall interiors are plastered through mixed mortar (cement/lime) and white painted. Cast-in-place reinforced concrete is employed as the floor, and the thickness is 100mm. Doors and windows are the ordinary aluminum alloy frame with single-glass. Roof of the attic is tile roof without any decoration.

The instruments of air temperature and relative humidity were distributed in the major activity rooms, including the living room, bedroom for the older on the first floor, the guest room on each floor and the attic. PMV-PPD was measured in the living room and the bedroom of the hosts on the third floor. The measuring point distribution was as shown in Fig. 5-7. The mark of different measuring points and the status of the space were shown in Table 5-1.

Table 5-1 Distribution of measuring points and the status of the rooms (MB-1)

Room	**Position**	**Status**
Living room	The first floor, south	**Winter:** Windows and door were closed in daytime, and door was opened during meal time; There was no air conditioner. **Summer:** Windows and doors were opened during daytime. The electric fan was utilized for cooling.
Bedroom (old couple's)	The first floor, north	**Winter:** The door was closed all day. There was no air conditioning. **Summer:** The door was closed all day, and the electric fan was used for cooling
Kitchen	The first floor, south	The door was opened, and it connected to the hall. Breakfast at 8:00 am, dinner from16:30 to 18:30
Stair	The first floor, north	The windows were closed, without doors
Bedroom(S) (Guest room)	The third floor, south	**Winter:** Uninhabited, doors and windows were closed **Summer:** Tourist used air conditioner on July 21st
Bedroom(N) (Guest room)	The third floor, north	**Winter:** Uninhabited, doors and windows were closed **Summer:** Tourists didn't use air conditioner, and the used electric fan
Attic	The top floor, north	Without decoration, vacant space
Outdoor	——	——

5.3.2.2Winter Survey Results of MB-1

The field measurement was carried out from January 19th to 21st. Finally, the monitor data from January 20th, 8:00 am ~ 21st 8:00 am were selected. The air temperature of every half hour is as shown in Fig. 5-8. Due to instrument failure, the outdoor temperature and relative humidity were not recorded. MB-1 locates in the same dimension as MB-2, and the surrounding environment is similar. Therefore, the outdoor meteorological data of MB-2 were adopted for comparison.

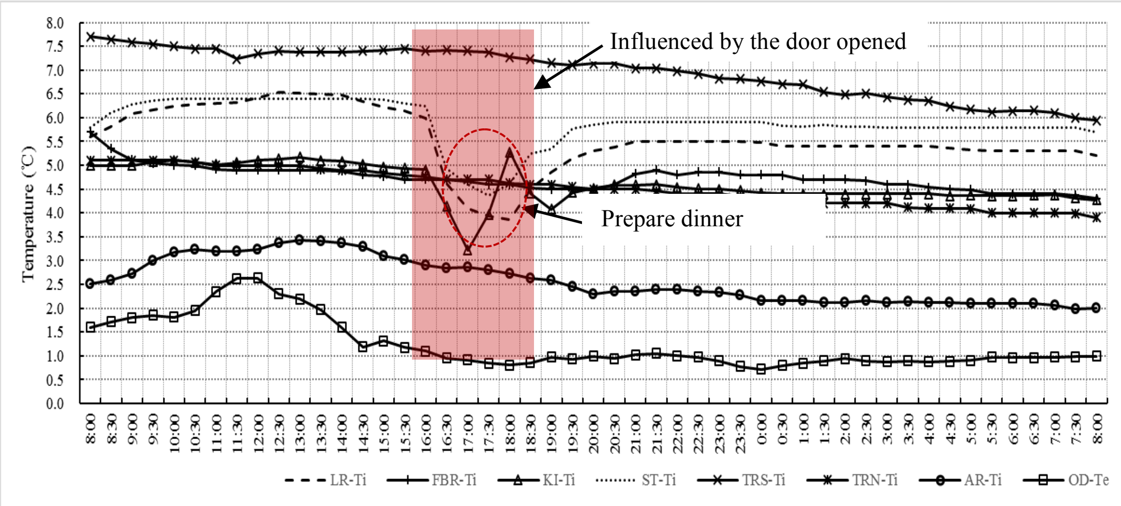


Fig. 5-8 Temperature in different rooms in a typical winter day(MA-1)

It was a typical cold winter day. The outdoor temperature (OD-Te) was lower than 2.6°C, with the average temperature of 1.2°C. The indoor temperature was higher than outdoor temperature. However, as shown in Fig. 5-8, it is clearly that the indoor temperature of different rooms in different orientations and floors are obviously different. The temperature of the south guest room on the third floor(TRS) was the highest, with the average temperature of 7.0°C, which was about 5.8°C higher than outdoor temperature(OD-Te). Then the second was the temperature of stair and the living room on the first floor. The average temperature of stair (ST-Ti) was 5.9°C, and the average temperature of the living room (LR-Ti) was 5.5°C. The temperature difference between the outdoor temperature(OD-Te) was about 4.5°C. The third level was the temperature of the bedroom on the first floor (FBR-Ti), the kitchen (KI-Ti) and the north guest room on the third floor (TBN-Ti). The average temperature was 4.7°C,4.6°C and 4.5°C respectively, which were about 3.4°C higher than outdoor temperature. The temperature of the attic was the lowest, with the average temperature 2.6°C, which was only 1.4°C higher than outdoor air temperature. Thus, it can be seen that the indoor thermal environment was poor. On the same floor, the temperature of rooms in south was higher than the north. Among the south rooms, the higher the floor is, the higher the temperature would be. However, due to the poor thermal performance of tile roof and the poor air tightness of the attic, the temperature of the attic was lower than others.

Influenced by occupants' behavior, the temperature of stair (ST-Ti) and kitchen (KI-Ti) were obvious dropped during 16:00~19:00. It was the dinner time, and the door was opened in order to get lighter. The temperature of the rooms connected with the living room decreased abruptly due to the cold air entering the living room. When the door was closed, the temperature would gradually increase. In addition, the temperature of kitchen (KI-Ti) was increased at 17:30~18:30, during which the dinner was prepared. Fig.5-9 shows the occupants' living style greatly influenced the indoor environment. At dinner time, when the door was opened, the temperature of living room (LR-Ti) dropped rapidly. When the occupant slept in the evening, the temperature was higher than daytime.

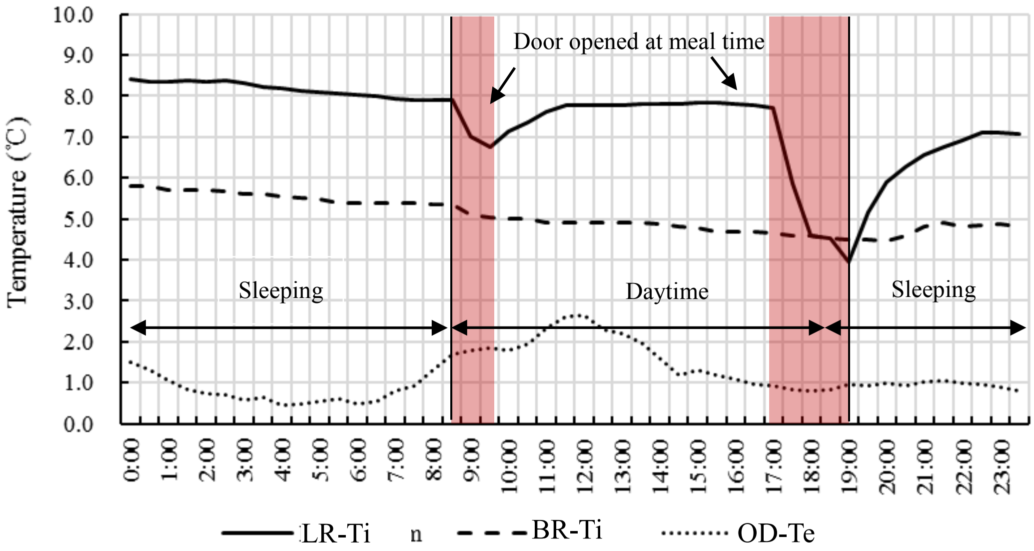


Fig.5-9 Influence of occupants' behaviors to the indoor environment (Jan.20th,0:00~23:00)

5.3.2.3Summer Survey Results of MB-1

MB-1 operates rural tourism business in summer. The distribution of the measuring points and the status of the rooms are list in Table 5-1. The instruments recorded the data every minute, and the data from 8:00am on July 22nd to 8:00am on July 24th were analyzed. Finally, the temperature of every half hour is shown in Fig. 5-10.

As shown in Fig. 5-10, the outdoor temperature was very high. The average temperature was 30.1°C and the maximum temperature was up to 36.6°C. The solar radiation temperature was up to 45°C. The average temperature of bedroom and living room was 29.2°C and 29.1°C, respectively. The average temperature of the guest room(N) on the third floor was 30.4°C, without using the air conditioner. The temperature of the first floor was about 1°C lower. The attic temperature was the highest. The temperature ranged from 29°C~ 34.1°C, with the average temperature of 31.8°C.

The temperature of the living room ranged from 25°C to 30.9°C, with the temperature difference of about 5.9°C. The temperature of the guest room (N) ranged from 26.9°C to 31.2°C, with the temperature difference of about 4.3°C. The temperature of the bedroom ranged from 27.3°C to

29.9°C, and the temperature difference was about 2.6°C. The temperature fluctuations of living room and guest room (N) are greater than the bedroom on the first floor.

The temperature of the guest room (S) on the third floor is higher than the others without using air conditioner. The highest temperature was up to 35.3°C. Tourists used the air conditioner for cooling at noon (12:00 pm to16:00 pm) on July 22nd, and in the evening (19:30pm~5:00am). The temperature obviously decreased, with the temperature between 26 and 28°C.

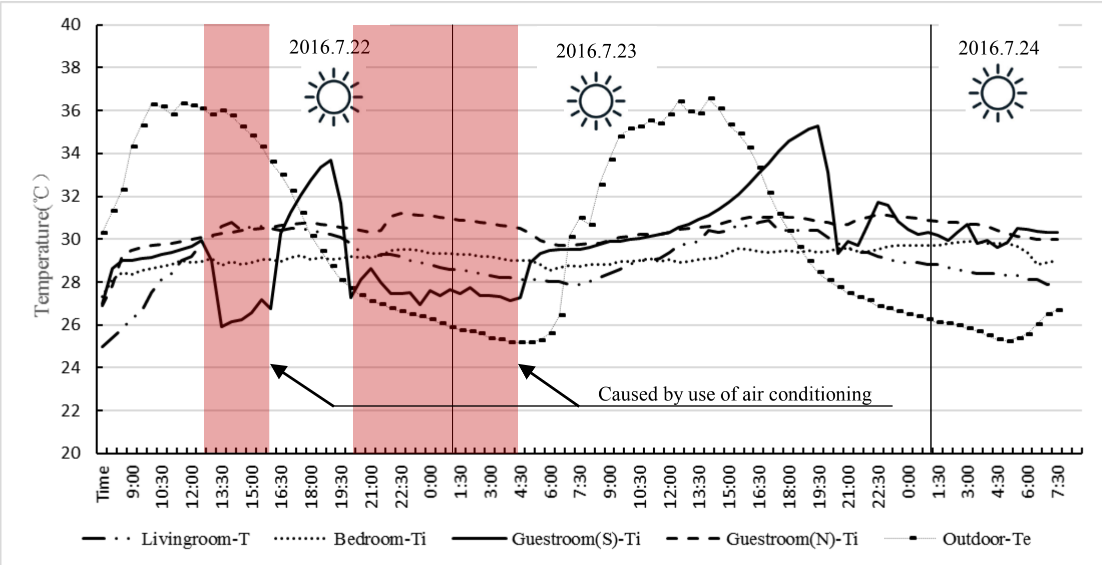


Fig. 5-10 Air temperature of different rooms on a typical summer day (MB-1)

5.3.2.4 PMV-PPD

MA-1 was utilized for rural tourism business. In winter, it is under naturally ventilated situation. However, in summer, most tourists used the air conditioner. PMV-PPD was measured in the living room on the first floor by IAQ. The ePMV and aPMV value were calculated according to Section 3.4 in Chapter 3. The PMV values of other rooms were calculated, and the parameters are shown in Table 5-2. The PMV results in winter are shown in Fig. 5-11. The ePMV results in summer are as shown in Fig. 5-12. As shown in Fig. 5-11, PMV values during the measurement in winter were in the uncomfortable range. The PMV values of the living room on the fourth floor were between -1.40 and -1.7, with an average value of -1.5. The fluctuation of PMV values in the living room was the largest, which was influenced by the door opened at meal time. The PMV values of bedroom on the first floor were between -1.5 and -1.70, and the average value was -1.6. The PMV values of guestroom on the south of third floor (Guestroom(S)) were between -1.30 and -1.50, with an average value of -1.4, which is the highest. The PMV values of the guestroom in the north of the third floor (Guestroom(N)) were between -1.60 and -1.70, with an average value of -1.7. The PMV values of attic on the fourth floor were between -1.80 and -2.00, with an average value of -1.9, which was the lowest. It can be seen that the indoor thermal environment in coldest winter days was poor. If the attic was decorated, the indoor thermal environment would be improved. (Table 5-3)

Table 5-2 The parameters for calculating PMV

Season	Rooms	Clothing (clo)	Metabolic rate (Met)	Air velocity (m/s)	Remarks
Summer	Living room	0.5	1.0	——	Measured on field
	Bedroom	0.5	0.8	0.10	1) The mean radiant temperature is assumed to be equal to air temperature. 2) Outdoor relative temperature is adopted instead of attic relative humidity 3) PMV is calculated under the condition of the indoor climate from 22th July to 24th July.
	Guestroom(S)	0.5	0.8	0.10	
	Guestroom(N)	0.5	0.8	0.10	
	Attic	0.5	0.8	0.10	
Winter	Living room	2.5	1.0	——	Measured on field
	Bedroom	2.0	0.8	0	1)The mean radiant temperature is assumed to be equal to air temperature. 2) PMV is calculated under the condition of the indoor climate from 22th July to 24th July.
	Guestroom(S)	2.0	0.8	0	
	Guestroom(N)	2.0	0.8	0	
	Attic	2.0	0.8	0	

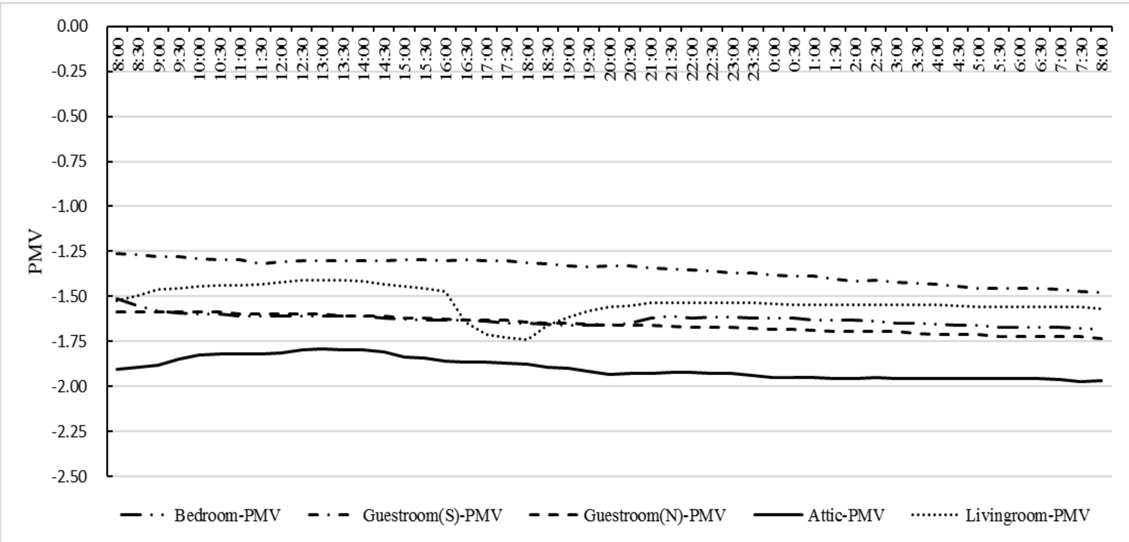


Fig. 5-11 Time variation of PMV in different rooms of MB-1 (in winter)

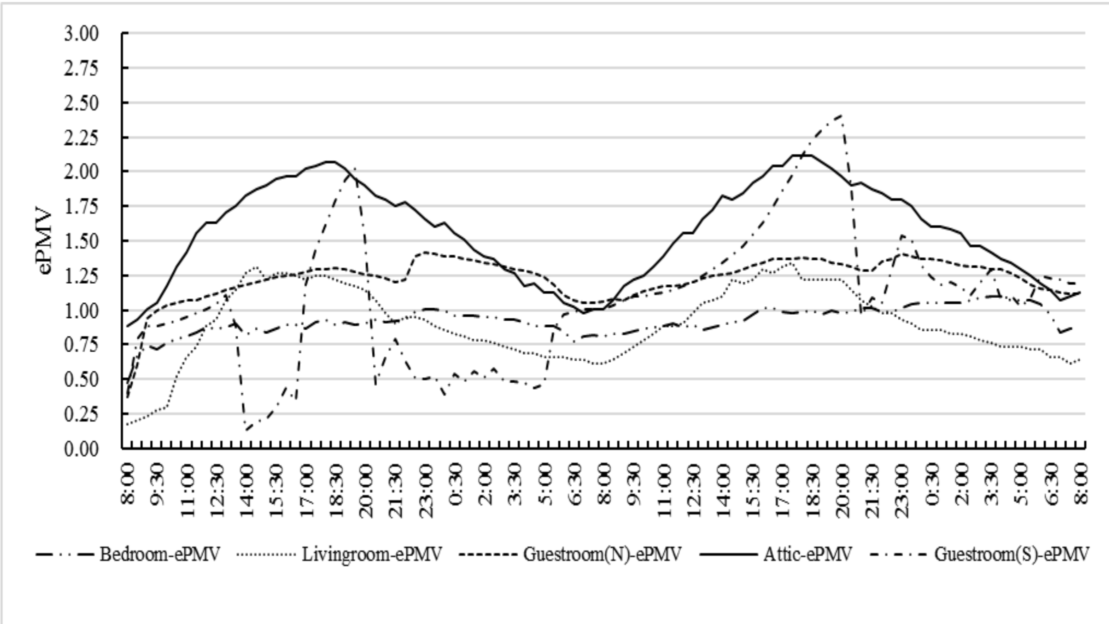


Fig. 5-12 Time variation of ePMV in different rooms of MB-1 (in summer)

As shown in Fig. 5-12, PMV values during the measurement in summer were in a larger thermal sensation range. The PMV values of living room on the fourth floor were between 0.2 and 1.3, with an average value of 0.9. The PMV values of bedroom on the first floor were between 0.5 and 1.1, with an average value of 0.9. The PMV values of guestroom in the south of the third floor (Guestroom(S)) ranged from 0.1 to 2.4, with an average value of 1.1. The fluctuation of PMV values in the Guestroom(S) was the largest, which was caused by the use of air conditioner. When the air conditioning was operated, the PMV values decreased quickly. However, when the air conditioner was out of work (from 8:00am on July 23rd to 8:00pm on July 24th,), the maximum PMV value was up to 2.4, and the average value was 1.4. The result was resulted from the solar radiation in summer. The PMV values of guestroom in the north of the third floor (Guestroom (N)) were between 0.4 to 1.4, and the average value was 1.2. The PMV value of the attic on the fourth floor was between 0.9 and 2.1, with an average value of 1.6, which was the highest. The indoor thermal environment in the hottest days in summer was poor and needs to be improved. The results show that the PMV values of the living room and bedroom were in the range of comfort in summer. The guestroom(S) and the attic should be improved. (Table 5-3)

The average PMV value and the range of the PMV value of different rooms during the measurement in summer and winter were listed in Table 5-3. The results reveal that the indoor thermal environment of MB-1 was bad in the coldest winter days and hottest summer days. It needs to be further improved. Two possibilities are proposed: (1) combining better thermal insulation for the enclosure with night ventilation; (2) employing mechanical support during extreme conditions.

Table 5-3 The average and the range of the PMV(ePMV) value of different rooms

Room	Living room	Bedroom	Guestroom(S)	Guestroom(N)	Attic
Winter (PMV)	-1.5 (-1.4~-1.7)	-1.6 (-1.5~-1.7)	-1.4 (-1.3~-1.5)	-1.7 (-1.6~-1.7)	-1.9 (-1.8~-2.0)
Summer (ePMV)	0.9 (0.2~1.3)	0.9 (0.5~1.1)	1.1/1.4 (0.1~2.4)	1.2 (0.4~1.4)	1.6 (0.9~2.1)

5.3.3MB-2

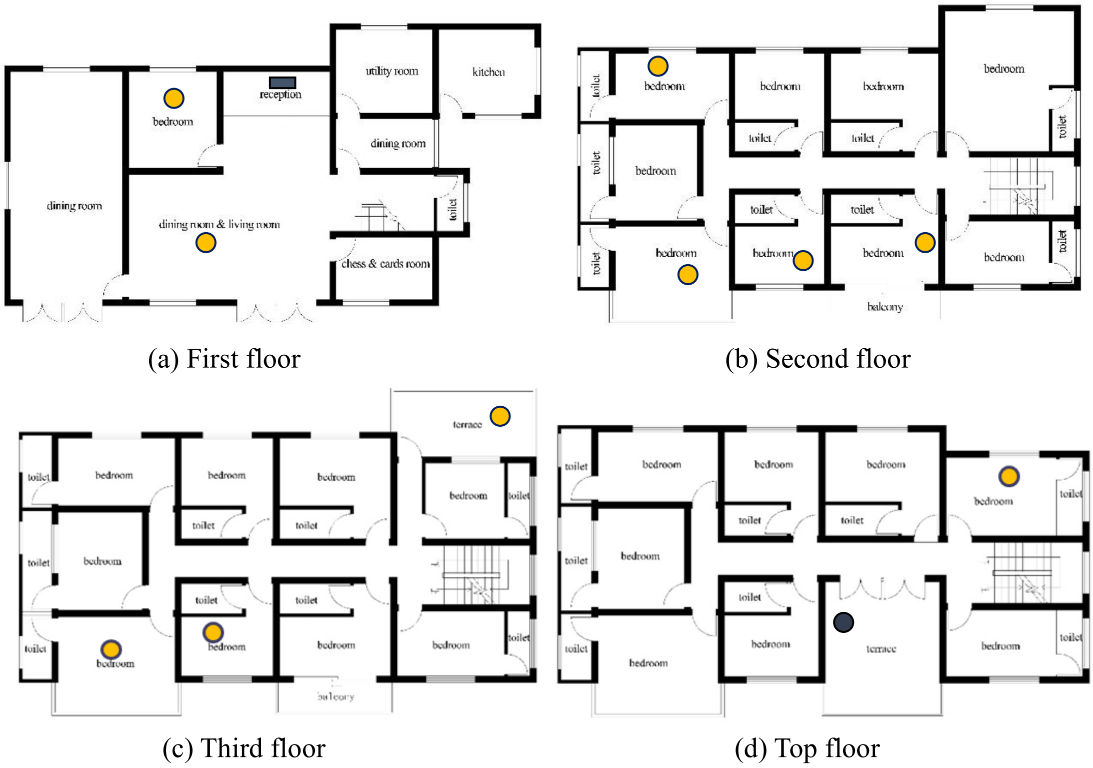
5.3.3.1Description of MB-2

MB-2 is also a modern rural residential building built in 2009, with the most common modern brick-concrete structure. The household began to be engaged in rural tourism business in 2011. There are 25 guest rooms, and two of them are for the hosts. It is a 4-storey building. The living room, dining room, entertainment room, bedroom for the older, and kitchen are on the first floor. From the second floor to the fourth floor are guest rooms for tourists and the bedroom for the hosts. In order to facilitate drying clothes, a sun room, commonly known as sunroom, was added on the third floor. The width of the building is 16.3m, and the depth is 9.2m. The building covers an area of 150m^2, with the total construction area of 600m^2. The height of the first, floor is 3.5m, and the second and third floors are 3.2m high. The fourth floor is 2.8m. Typical plans are shown in Fig. 5-13

The walls on the first floor are made of red solid bricks with the thickness of 240mm. Other floors are made of sintered porous bricks with circle holes. The wall interiors are plastered in mixed mortar (cement/lime) and white painted. The walls outside are white washed with exterior wall coating. Cast-in-place reinforced concrete is employed as the floor, and the thickness is 100mm. Doors and windows are the ordinary aluminum alloy frame with single-glass. The attic roof is tile roof, decorated with wooden ceiling.

There are 5 people, 3 generations living in this building. The building is equipped with air conditioners. Both the young couple and tourists use air conditioners in summer, and the former also use the air conditioner at night and in the morning in winter.

The instruments of air temperature and relative humidity were placed in the major activity rooms, including living room, bedroom for the older on the first floor, and the guest rooms on each floor. In addition, air temperature and relative humidity in some special rooms were also measured, such as the guest rooms with large windows, attic and sun room. PMV-PPD was measured in the living room on the first floor. The measuring point distribution was shown in Fig. 5-13.



Indoor air temperature and relative humidity

PMV-PPD

Outdoor air temperature and relative humidity

Fig. 5-13Typical building plan and measuring point distribution (MB-2)

Table 5-4 Distribution of measuring points and the status of the rooms(MB-2)

Room	Position	Status
Living room	south	**Winter:** Windows and doors were closed all day; the door of the living room was open during meal time but more frequently than MB-1. **Summer:** Windows and doors were opened during daytime, and the electric fans were used for cooling.
SSR9 (guestroom1)	The second floor, south	**Winter:** Uninhabited, door and window were closed **Summer:** Without tourist on July 21, tourists checked in on July 22
SSR5 (guestroom2)	south	**Winter:** Uninhabited, door and window were closed

SNR6	north	**Winter:** Uninhabited, door and window were closed
TNR2	Adjacent to the sunroom，north	**Winter:** uninhabited, door and window were closed
TR	The third floor, terrace, north	Drying clothes
Attic (Host room)	Top floor, north	**Winter:** The window was closed all day, and the door was opened during daytime. The air conditioner was used in the evening and morning. **Summer:** Window and door were closed all day. The air conditioner is used.
Outdoor	——	The balcony on the third floor.

5.3.3.2 Winter Survey Results of MB-2

Different from MB-1 and TVB-1, the farmers who live inMB-2 used the air conditioner in winter. In addition, there are some special rooms in MB-2, such as south guest rooms with large windows, attic decorated as bedrooms, and sun room. The measuring point distribution and the status of the measured rooms are shown in Table 5-4. The instruments recorded the data every minute, and the data from 0:00 to 24:00 on January 20th were analyzed. The air temperature of every half hour is shown in Fig. 5-14.

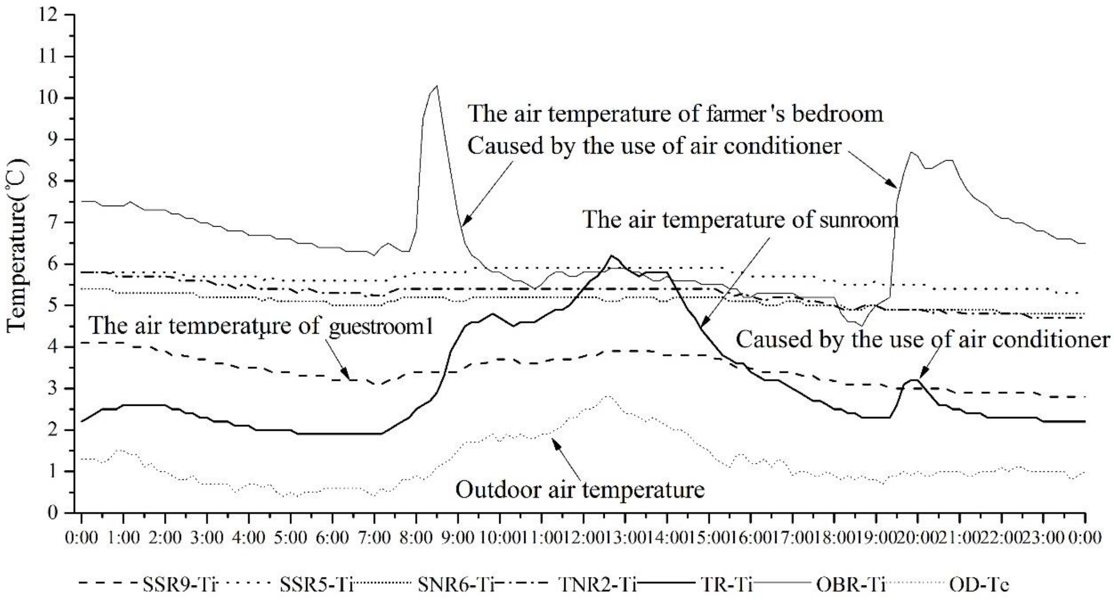


Fig. 5-14Air temperature of different rooms in a typical winter day(MB-2)

The terrace is reconstructed as a sunroom. The air temperature of the sunroom was significantly higher than the south guestroom with large windows (SSR9) during daytime, which was influenced by solar radiation. However, at other time, the temperature was the lowest compared with other rooms, which was only 1°C to 2°C higher than the outdoor temperature. From 19:30pm to 20:00pm, the temperature obviously increased. which was caused by the heat dissipation of the outdoor unit of air conditioner set in the sunroom.

The young couple' bedroom is in the north of the fourth floor, which is the attic decorated with wooden ceiling. They used the air conditioner in winter. As shown in Fig. 5-14, during night, the temperature was higher than other rooms, which was about 6°C higher than outdoor temperature. In the morning (8:00am~8:30am) and evening (20:00pm~21:00pm), the temperature increased quickly, which was caused by the use of the air conditioner when they got up in the morning, and went to bed in the evening. The results are consistent with the questionnaire. However, because the door was opened during the day time, the temperature decreased quickly.

On the left of the building, there are several south guest rooms with large windows and 120mm exterior walls. As shown in Fig. 5-14, the temperature of SSR9 was obviously lower than other rooms, which is between 2.8°C and 4.1°C, with the average temperature of 3.4°C. It was only 1~3°C higher than the outdoor temperature, which was caused by the large window-to-wall ratio and the poor thermal performance of windows and exterior walls.

The temperature of SSR5, SNR6 and TNR2 was similar. However, the temperature of SSR5 (on the south of second floor) was slightly higher, with the average temperature of 5.7°C. The average temperature of TNR2 (in the north of the third floor) was 5.3°C. The temperature of SNR6 (in the south of the second floor) was the lowest, and the average temperature was 5.1°C. The results show that the temperature of the south room is higher than the north one. The indoor thermal environment is also obviously influenced by window-to-wall ratio and the thermal performance of envelopes.

5.3.3.3Summer Survey Results of MB-2

MA-2 also engages in rural tourism business. The distribution of the measuring points and the status of the rooms are listed in Table 5-4. The data from 8:00am on July 22nd to 8:00am on July 24th were selected for analysis. The results are shown in Fig. 5-15.

The results show that, under the condition without using air conditioning, the temperatures of living room were the lowest. From 8:00am on July 22nd to 8:00am on July 23rd, the temperature of living room was between 26.2°C to29.6°C, with the average temperature of 28.6°C. The second is guest room(N), which ranged from 28.4°C to 30.6°C, with the average temperature of 29.9°C. The third is the guest room(S), and the temperature ranged from 29.2°C to 32°C, with the average temperature of 30.3°C. The temperature of the attic was the highest, between 26.5°C and 36.6°C, with the average temperature of 30.8°C. The highest temperature was up to 36.6°C, which was even higher than the outdoor temperature.

It can be seen that, since 17:00 on July 23rd, the temperatures of guest room (S) and guest room (N) on the third floor decreased quickly, which was caused by the tourists' use of air conditioner.

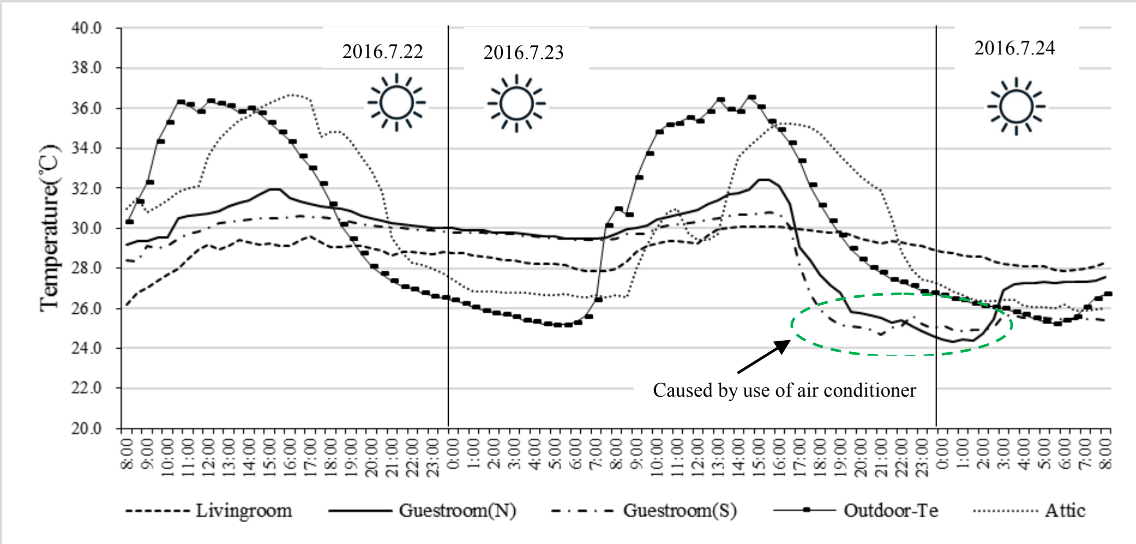
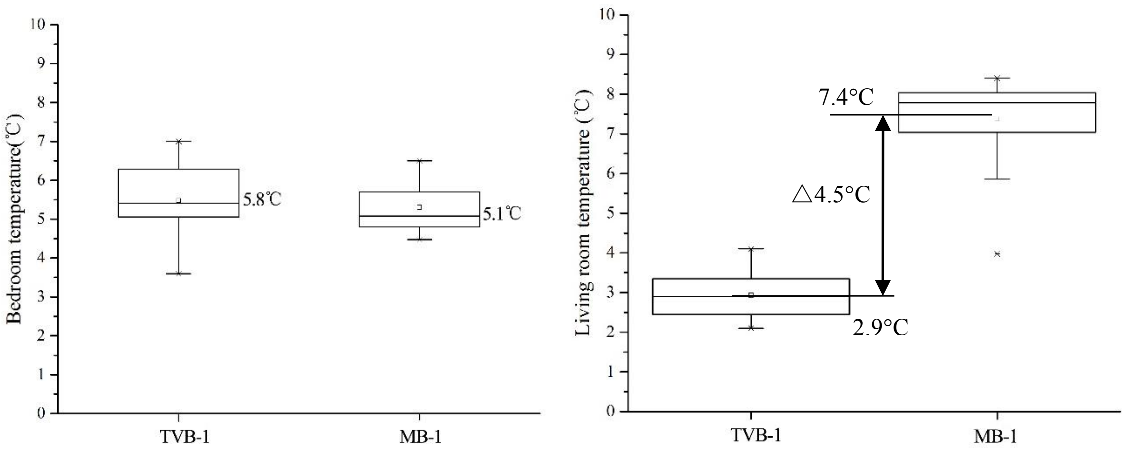


Fig. 5-15Air temperature of different rooms in a typical summer day (MB-2)

5.3.4 Comparison of Indoor Thermal Environment of Buildings

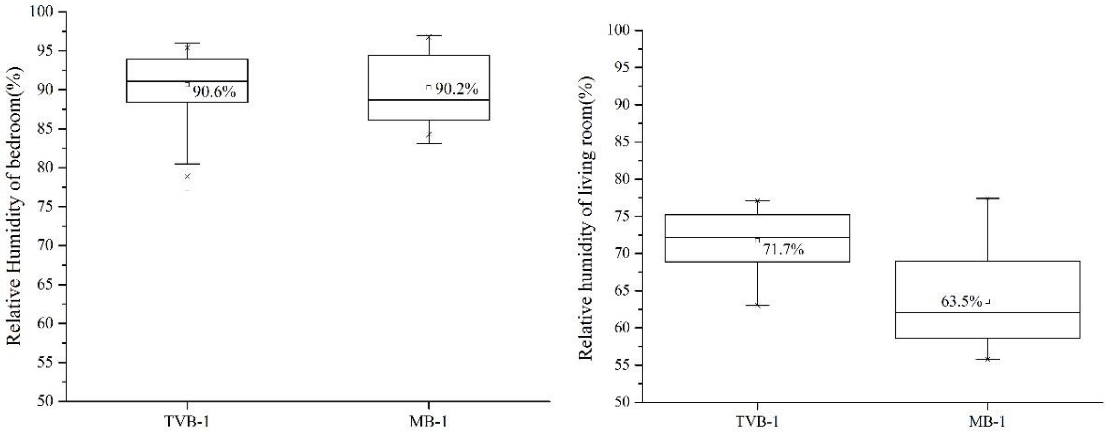
5.3.4.1 Comparison of the Indoor Environment between MB-1 and TVB-1 in Winter

The bedrooms for the elders in TVB-1 and MB-1 are on the first floor, and the doors and windows were closed all day. As shown in (Fig. 5-16,a), the average air temperature of bedroom in TVB-1 and MB-1 was 5.8°C and 5.1°C, respectively. It clearly shows that the bedroom temperature of TVB-1was higher than that of MB-1. It could be speculated that, if the door of living room in TVB-1 was also closed during the daytime, the bedroom temperature of TVB-1 would be higher. Because the thermal performance of rammed earth wall is better than red solid brick wall, the average relative humidity of bedrooms in TVB-1 and MB-1 was 90.6% and 90.2%, respectively. (Fig. 5-17,a).



(a) bedrooms (b) living rooms

Fig. 5-16 Comparison of air temperature between MB-1 and TVB-1(in winter)



(a) bedrooms (b) living rooms

Fig. 5-17Comparison of relative humidity between MB-1 and TVB-1 (in winter)

The results showed that the average temperature of the living room in MB-1 and TVB-1 was 7.4°C and 2.9°C. The temperature of MB-1 was about 4.5°C higher than TVB-1(Fig. 5-16,b). The average relative humidity of the living rooms of TVB-1 and MB-1 was 71.7% and 63.5% (Fig. 5-17,b). The main reason was that the door of the living room in TVB-1 was opened during the daytime, but the door of the living room in MB-1 was opened only during the meal time.

5.3.4.2Comparison of Air Temperature of Attic between MA-1 and MA-2 in Summer

The roofs of the model buildings are commonly designed as double-pitched roofs in Zhejiang. The roof of MB-1has no decoration, which is as shown in Fig. 5-18,a. The construction is put the tiles on the purlins directly. The roof of MB-2 is decorated as shown in Fig. 5-18,b. The air temperatures of the top floors (attic) in MB-1 and MB-2 from 0:00~23:00 on July 23rd are shown in Fig. 5-19.

The air temperature of the attic in MB-1 was between 28.8°C and 34.4°C, with the average of 31.4°C. The temperature of the attic in MB-2 was between 29.5°C and 35.2°C, with the average of 31.9°C. The average temperature of MB-2 was slightly higher than MB-1. This is because the attic without decoration is more benefit for dissipation of heat.

(a) Roof of MB-1 (b) Roof of MB-2

Fig. 5-18 Roofs of MB-1 and MB-2

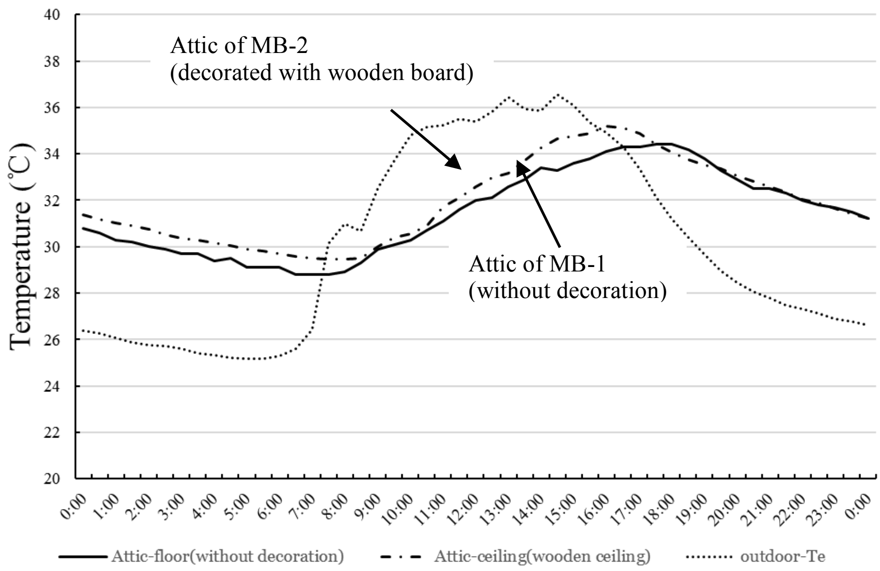


Fig. 5-19 Temperature of different roofs in a typical summer day (0:00~23:00, July 23)

5.4 Indoor Environment of Buildings in Wenyuan Village

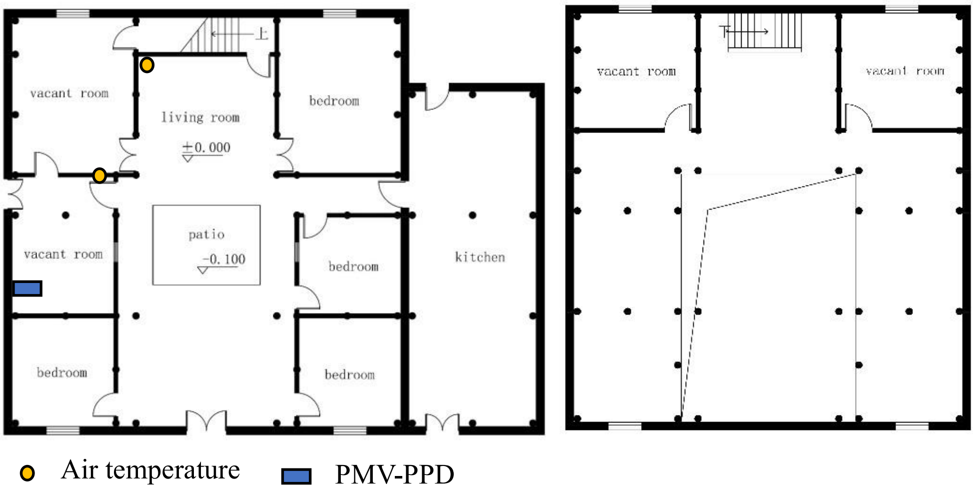
5.4.1 HCB-1

5.4.1.1 Description of HCB-1

HCB-1 is a typical historical and cultural building, which has not been used for rural tourism business yet. The main part of the building was built in the Republic of China, dating back more than 100 years (Fig. 5-3,a). The kitchen was added in 1980s. The building covers an area of 195.5m^2. The first floor is the major activity space around the courtyard (Fig. 5-20,a). The living-room is the major activity space for eating, meeting, sacrificing and socializing; the inner veranda acts as a transitional space between the courtyard and the most intimate spaces [2]. The height of the first floor is 2.9m. The top floor is used for storage (Fig. 5-20,b). The height of the exterior wall is 1.80m, and the height of the ridge is 3.1m.

(a)courtyard (b)top floor

Fig. 5-20 Courtyard and attic of the rural residence (HCB-1)



(a) The first floor (b) The top floor

Fig. 5-21 Building plans and measuring point distribution (HCB-1)

The exterior walls of the main part of the building are rowlock walls made of gray bricks, with the thickness of 350mm. The partition walls and the interior walls are made of wooden boards, with the thickness of 15mm. The exterior walls of the kitchen are built with rammed earth with the thickness of 350mm. The attic roof and the pitched roof of kitchen are all tile roofs, covered by small gray tiles and directly put on the purlins. The east and west facades have no windows. There are several small windows in the north and south exterior walls with the size of 1000mm × 1400mm. There are two smaller windows in the internal wooden walls on the first floor, facing the courtyard, with the size of 600mm × 1000mm. The windows are wooden frame, with single-layer glass. However, the windows on the attic have no glass, and some of them have been destroyed seriously. There are only 2 elders 60 years old living in this building. There is no air conditioner or other electric heating facility. They mainly rely on charcoal to get warm in winter, and electric fans to keep cooling in summer.

The measuring instruments for temperature and relative humidity were set in the living room, bedroom and courtyard. For the sake of sun exposure, the meter on the courtyard was put under the eaves and covered with aluminum foil. PMV-PPD was measured in the bedroom on the first floor. The measuring points are shown in Fig. 5-21.

5.4.1.2Summer Survey Results of HCB-1

(1) Air temperature and relative humidity

The field measurement was carried out from July 15th to July 17th in 2016. The door of the main entrance was opened during daytime, and closed at night. The windows were open on sunny days and close on raining days. The door of bedroom was always closed. The data from 8:30am on July 16th to 8:30am on July 17th were selected for analysis. The results are shown in Fig. 5-22.

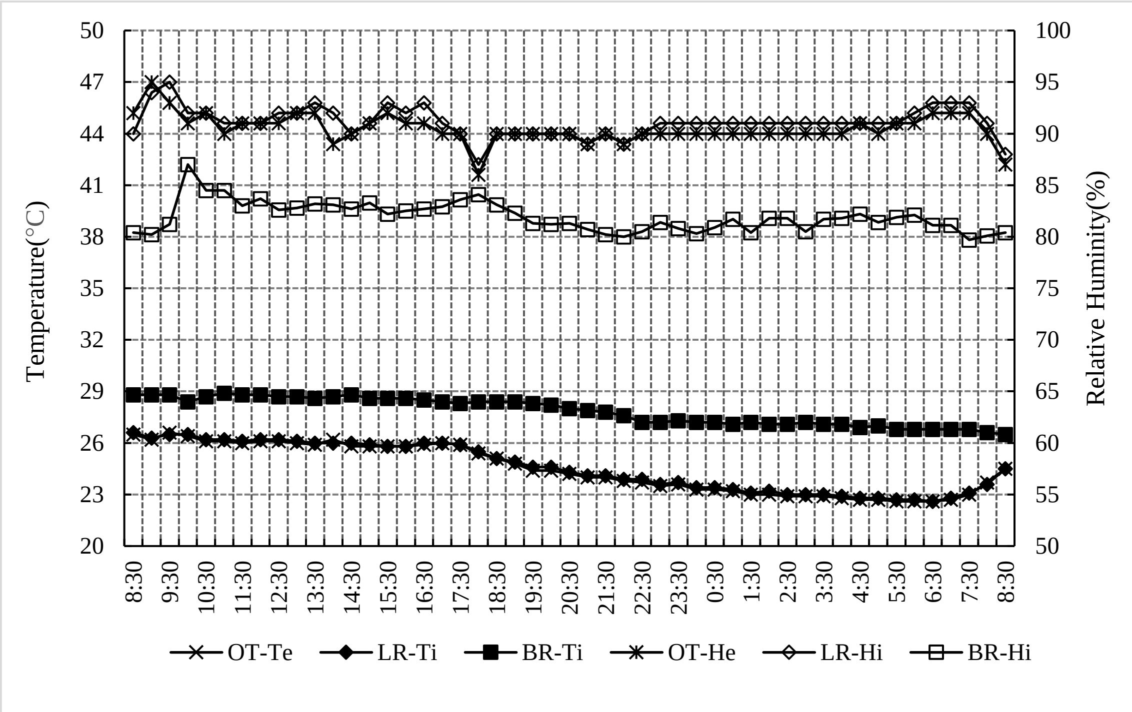


Fig. 5-22Air temperature and relative humidity of different rooms in summer (HCB-1)

It can be seen from Fig. 5-22 that, the air temperature of the bedroom(BR-Ti) was higher than the living room(LR-Ti) and outdoor air temperature (courtyard, OT-Te). The air temperature of the living room and the courtyard was very close, and almost the same. Because Wengyuan village is located in Quzhou mountainous area, vegetation around the village is rich, and it rained during the measurment. The outdoor temperature was low, between 22.6°C and 26.6°C, with the average air temperature of 24.5°C. The air temperature of the bedrooms ranged from 26.5°Cto 28.9°C, and the average air temperature was 27.8°C, which was 3.3°C higher than the temperature of courtyard. The average air temperature of living room was 24.6°C, which was similar to outdoor temperature. The reason is that the living room is a semi-open space, and influenced by the courtyard greatly.

As shown in Fig. 5-22, the relative humidity of the living room(LR-Hi) and the courtyard(OT-He) was quite close. Indoor and outdoor relative humidity cyclically changed. Affected by the rain, the relative humidity of courtyard and living room was larger, between 86% and 95%, with the average of 90.5%. The relative humidity of bedroom(BD-He) was between 79.7% and 87%, with the average of 81.9%. The relative humidity of bedroom was lower, owing to its relatively closed environment.

(2) PMV-PPD

HCB-1 is a natural ventilated building. Farmers use electric fan for cooling in summer. PMV-PPD was measured in the bedroom by IAQ. The ePMV and aPMV values were calculated according to Chapter 3 (Section 3.4). The results are shown in Fig. 5-23.

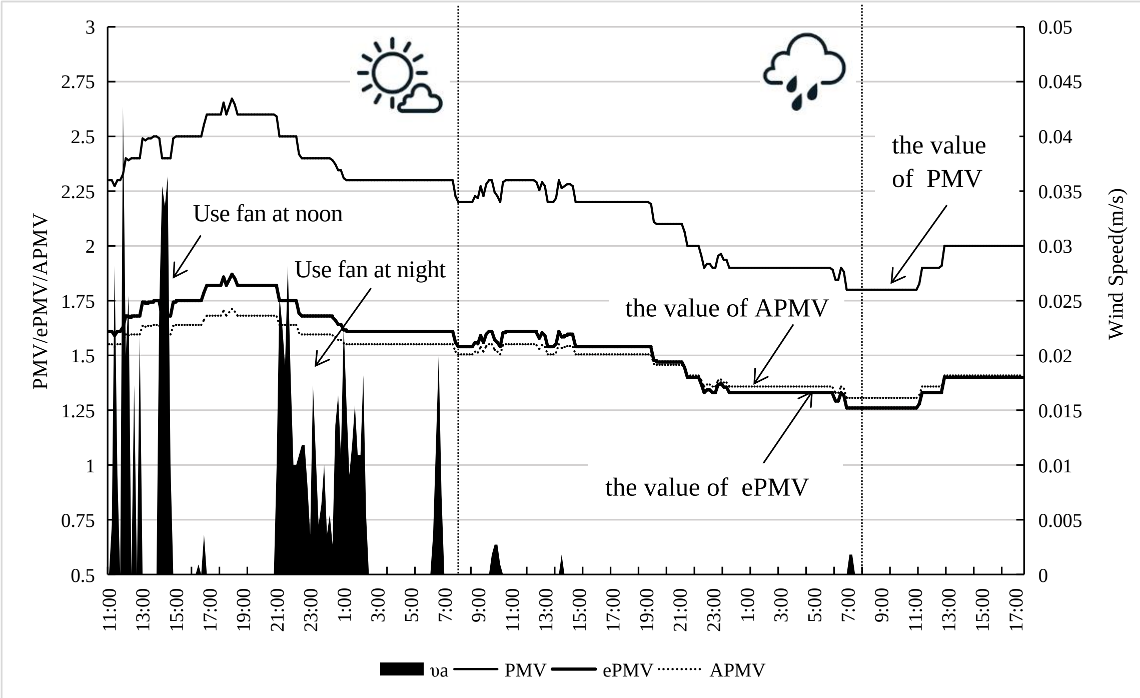


Fig. 5-23 Time variation of PMV/ePMV/APMV in bedroom of HCB-1(in summer)

It can be seen that the PMV values were between 1.80 and 2.67, with the average value of 2.18. The ePMV values were between 1.26 and 1.87, with an average of 1.53. The APMV values were between 1.31 and 1.71, and the average value was 1.49. ePMV and APMV were coincident with each other, especially when the value was below 1.5. The results show that the thermal sensation is in the comfortable range.

From 11:00am on July 15th to 7:00am on July 16th, it was sunny to cloudy. The air temperature of the bedroom was between 28.4°C and 31.1°C. The farmers used electric fan when they had a noon break and in the evening. This shows that the PMV value decreased obviously when the fan was used. From 20:00pm on July 16th, the PMV values decreased, and the average ePMV value was about 1.3 when the famers felt cool and did not use electric fan. Based on the comparison between ePMV and APMV of urban residents, it can be seen that rural residents have a large rang for thermal tolerance.

The PMV value of living room was calculated according the equations (8~11) of Section 3.3.1 in Chapter 3 based on the following assumptions: wearing clothes is assumed to be 0.5 clo. Metabolic rate is 1.0 met. The mean radiant temperature is equal to the air temperature. The air temperature and relative humidity are according to the measured results. The air velocity is assumed to be 0.15 m/s. The average ePMV value is 0.54, and the average APMV value is 0.7, which are in the range of comfort. The thermal sensation in living room is more comfortable than bedroom.

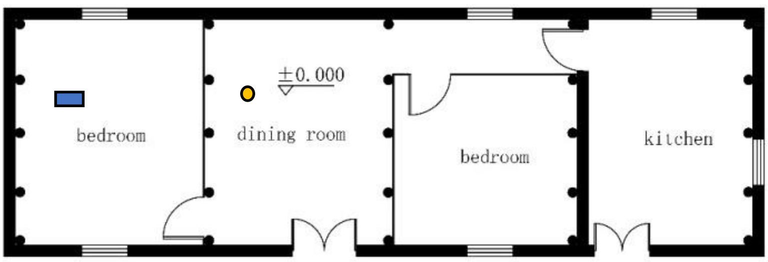
5.4.2 TVB-2

5.4.2.1 Description of TVB-2

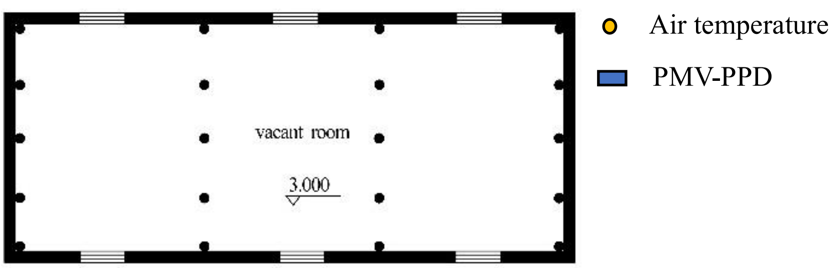
TVB-2 is a traditional vernacular building built in 1970s (Fig. 5-3,b). The main part consists of three "Jian" side by side: the living room and two bedrooms. The second floor is the attic, which was used for storage. The kitchen adhere to the main parts was built earlier than the main part. The width of the building is 15.4m, and the depth is 5.10m. The height of first floor is 3.0m. As for the attic, the height of exterior wall is 1.50m, and the height of ridge is 2.7m. The plans are shown in Fig. 5-24.

The exterior walls are made of rammed earth, with the thickness of 350mm. The inner walls are wooden boards with the thickness of 15mm. 20mm wooden boards are employed as the floors, which have been decorated with plastic ceilings. The windows are wooden frame with single-layer glass. However, the windows on the attic have no glass, and some of them are covered with plastic sheeting.

There is only one old person living in this building, who has been over 60 years old. Her daughters and son-in-lows are migrant workers, and come back on holidays and weekends. There is no air conditioner or other electric heating facility. They mainly rely on charcoal to get warm in winter, and electric fans to keep cooling in summer. The measuring instrument for air temperature and relative humidity was set in living room. PMV-PPD was measured in the elder's bedroom. The position of measuring points is as shown in Fig. 5-24.



(a) The first floor



(b) The top floor

Fig. 5-24 Building plans and measuring point distribution (TVB-2)

5.4.2.2Summer Survey Results of TVB-2

(1) Air temperature and relative humidity

The field measurement was carried out from July 15th to July 17th in 2016. The door of the living room was opened when the host was at home during daytime, and closed at night. The windows were opened on sunny day and closed on raining day. The door of bedroom was always closed. The data from 9:00am on July 16th to 9:00am on July 17th were selected for analysis. The results are shown in Fig. 5-25.

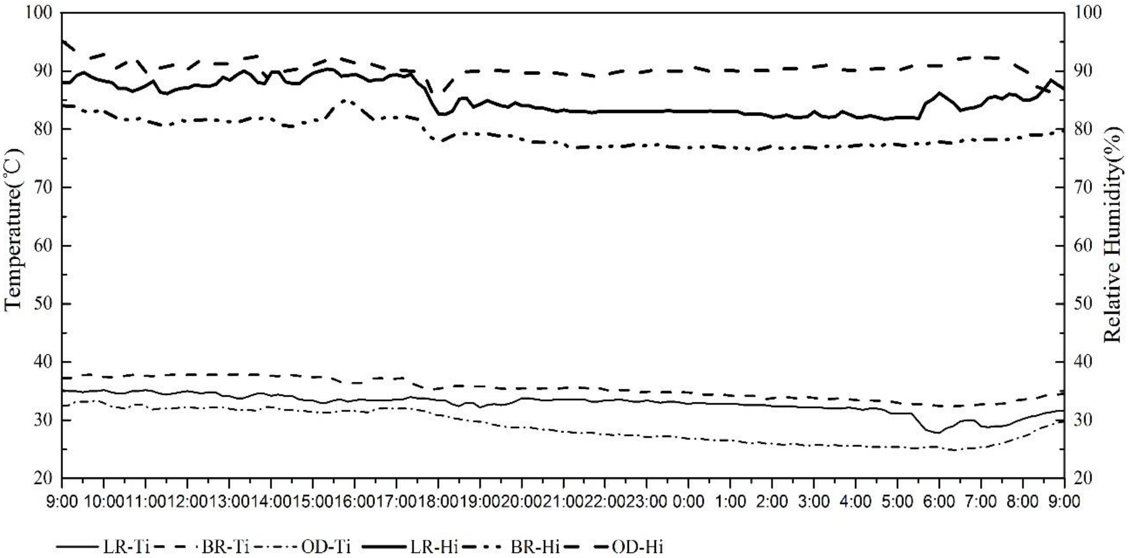


Fig. 5-25Air temperature and relative humidity of different rooms in summer(TVB-2)

The air temperature of the bedroom (BD-Ti) was higher than the air temperatures of the living room(LR-Ti) and outdoor temperature(OD-Te). The air temperature of the bedroom (BD-Ti) was between 26.2°C and 29°C, with the average temperature of 27.7°C. The air temperature of living room (BD-Ti) was between 23.9°C and 27.6°C, and the average temperature was 26.4°C. Outdoor air temperatures ranged from 22.4°C to 26.7°C, with the average temperature of 24.4°C. The average temperature of bedroom was about 3.3°C higher than the average outdoor temperature.

The relative humidity of bedroom was lower than of living room and outdoor relative humidity. The outdoor relative humidity (OD-He) ranged from 85.4% to 95%, with an average relative humidity of 90.3%. As it was rainy during the measurement, the outdoor relative humidity was high. The relative humidity of the bedroom (BD-Hi) ranged from 76.5% to 85.1%, with an average relative humidity of 79.2%. The relative humidity of the living room (LR-Hi) was 81.7% to 90.3% and the average relative humidity was 85.3%.

In addition, as shown in Fig. 5-25, from 20:00pm on July 16th to 5:30amon July 17th, the temperature of living room decreased, and the relative humidity increased slightly, when the doors were closed at night.

(2) PMV-PPD

TVB-2 is also under naturally ventilated situation. Farmers use electric fan for cooling in summer. PMV-PPD was measured in the bedroom by IAQ. The ePMV and aPMV values were calculated according to Section 3.4 in Chapter 3. The results are as shown in Fig. 5-26.

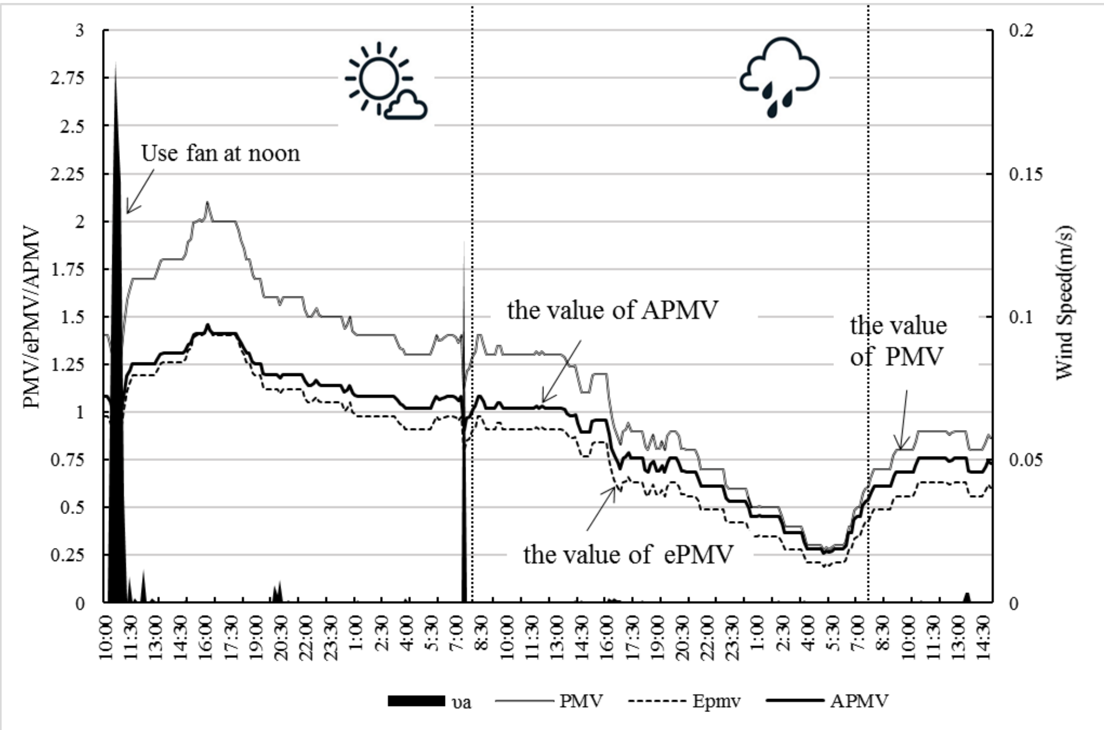


Fig. 5-26 Time variation of PMV/ePMV/APMV in bedroom of TVB-2(in summer)

It shows that, the PMV values of bedroom were between 0.27 and 2.10, with the average value of 1.14. The ePMV values were between 0.19 and 1.47, with the average value of 0.80. The APMV values ranged from 0.26 to 1.46, with the average value of 0.9. According to the ePMV value and the APMV value, the thermal sensation is in the range of comfort.

As shown in Fig. 5-26, from 10:00 am on July 15th to l6:00 pm on July 16th, the ePMV values and the APMV values were above 0.75. After l6:00 pm, the PMV values decreased quickly because it turned to rain.

The PMV value of living room was also calculated as HCV-1. Different from the living room of the HCV-1, it isn't a semi-outside space. The air velocity is assumed to be 0.10 m/s. The average ePMV value is 0.79, and the average APMV value is 0.91, which is in the range of comfort. Compared with the bedroom, the thermal sensation in the living room is similar.

5.4.3 TVB-3

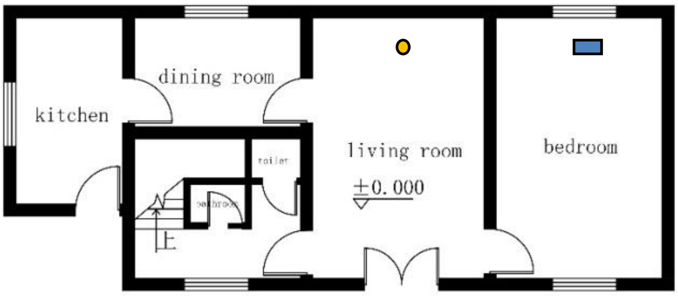
5.4.3.1 Description of TVB-3

TVB-3 is a veranda style rural residential building built in 1990s (Fig. 5-3,c). It is a 2-floorbuilding, the first floor is the major activity space, including living room, dining room, bedroom for the elders, and kitchen, etc. The second floor is the bedrooms for the youth. The width of the building is 13.3m, and the depth is 5.5m. The building covers an area of 73m^2, with the total construction area of 133m^2. The height of the first floor is 3.4m, and the height of the second floor is 3.2m. The plans are as shown in Fig. 5-27.

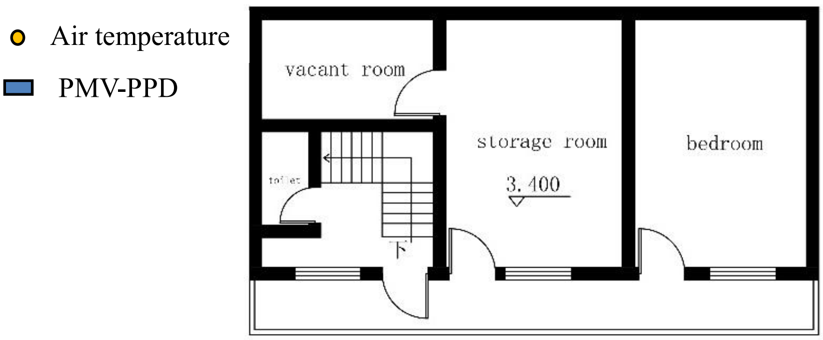
The walls are made of red solid bricks, with the thickness of 240mm. The wall interiors are plastered in mixed mortar (cement/lime) and white painted. The exterior walls on the façade are white washed with lime, but the walls on the other side are not painted. Precast concrete hollow slabs are employed as floor slabs and roof slabs, with thickness of 120mm. The pitched roof is added on the concrete slabs. The windows are made of wooden frame, with single-layer glass. The doors are made of wood.

There are 4 people in this family. The old couple is permanent residents. The host is the village's hairdresser and the hostess is a farmer. Their son and daughter are migrant workers, and come back on holidays and weekends. There is only one bedroom equipped with an air conditioner. However, the elders mainly rely on charcoal and electric blanket to get warm in winter, and electric fans to keep cooling in summer.

The instruments for air temperature and relative humidity were set in living room. PMV-PPD was measured in the bedroom. The measuring point distribution is as shown in Fig. 5-27.



(a) The first floor



(b) The top floor

Fig. 5-27 Building plans and measuring point distribution (TVB-2)

5.4.3.2Summer Survey Results of TVB-3

(1) Air temperature and relative humidity

The field measurement was carried out from July 15th to July 17th in 2016. The door of living room was opened during daytime when there was someone at home. The windows were opened on sunny day and closed on rainy day. The door of bedroom was always closed. The data from 9:00am on July 16th to 9:00am on July 17th were selected for analysis. The results were as shown in Fig. 5-25.

It can be seen from Fig. 5-28 that the air temperature of the bedroom (BD-Ti) was higher than that of the living room (LR-Ti) and outdoor temperature(OD-Te). The air temperature of the bedroom (BD-Ti) was between 27.1°C and 29.6°C,with the average temperature of 28.5°C. The air temperature of the living room (BD-Ti) was between 24.6°C and 27.7°C,with the average temperature of 26.5°C. The average air temperature of bedroom was about 2°C higher than the outdoor temperature.

The relative humidity of bedroom was the lowest. The second was the living room, was the relative humidity of which was lower than outdoor relative humidity. The outdoor relative humidity (OD-He) ranged from 85.4% to 95%, with an average relative humidity of 90.3%. As it was raining during the measurement, the outdoor relative humidity was high. The relative humidity of bedroom (BD-Hi) ranged from 73.2% to 79.8%, with an average relative humidity of 75.6%. The relative humidity of living room (LR-Hi) was 79.5% to 89.9%, and the average relative humidity was 83.7%. Similar to TVB-2, as shown in Fig. 5-28, the temperatures of living room were reduced from 7:30pm on July 16th to 6:00am on July 17th, and the relative humidity increased slightly at night.

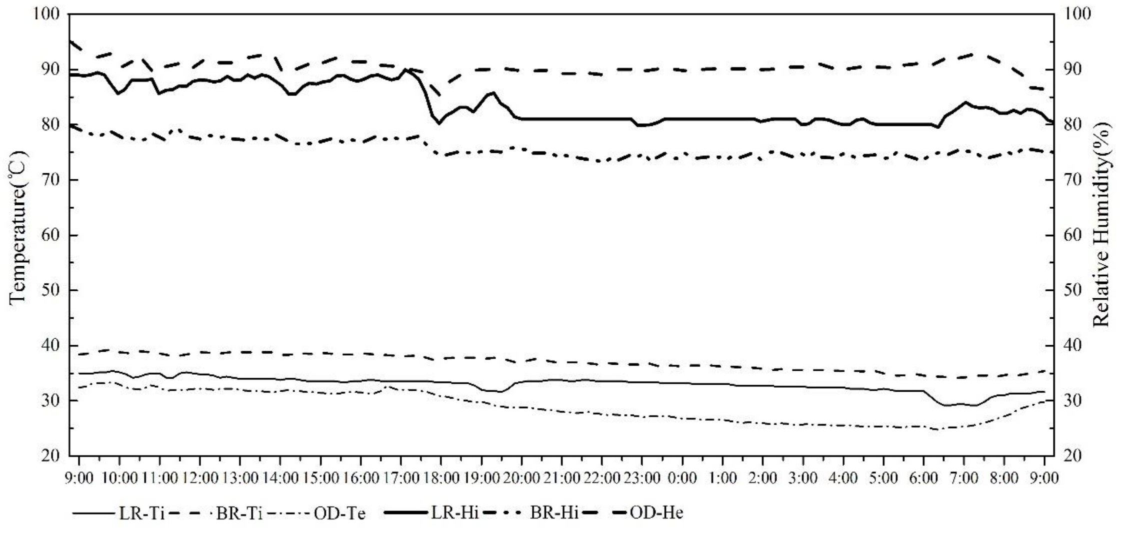


Fig. 5-28Air temperature and relative humidity of different rooms in summer (TVB-3)

(2) PMV-PPD

TVB-3 is also a naturally ventilated building. Farmers use electric fan for cooling in summer, but they didn't use electric fan during the measurement. PMV-PPD was measured in the bedroom by IAQ. The ePMV and aPMV value were calculated according to Section 3.4 of Chapter3. The results are as shown in Fig. 5-29.

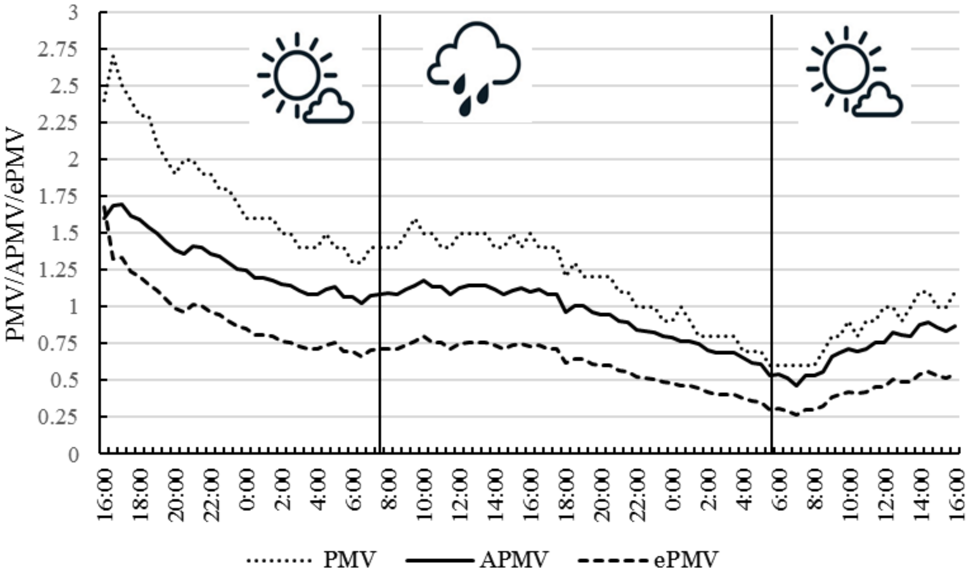


Fig. 5-29 Time variation of PMV/ePMV/APMV in bedroom of TVB-3 (in summer)

As shown in Fig. 5-29, the PMV values of bedroom were between 0.60 and 2.70, with the average value of 1.31. The ePMV values were between 0.47 and 1.69, with the average value of 1.01. The APMV values ranged from0.26 to 1.68, and the average value was 0.67. According to the ePMV value and the APMV value, the thermal sensation was in the range of comfort.

It shows that the ePMV values and the APMV values were above 0.75 from 10:00 am on July 15th to l6:00 pm on July 16th. After l6:00 pm, it began to rain, and the PMV value decreased quickly.

The PMV value of living room was also calculated as TVB-1. The air velocity is assumed to be 0.10 m/s. The PMV values of bedroom were between 0.67 and 1.42, with the average value of 1.14. The ePMV values were between 0.47 and 0.99, with the average value of 0.80. The APMV values were from 0.60 to 1.10, and the average value was 0.92. Compared with the bedroom, the thermal sensation in the living room is similar, both of which are in a category of comfort.

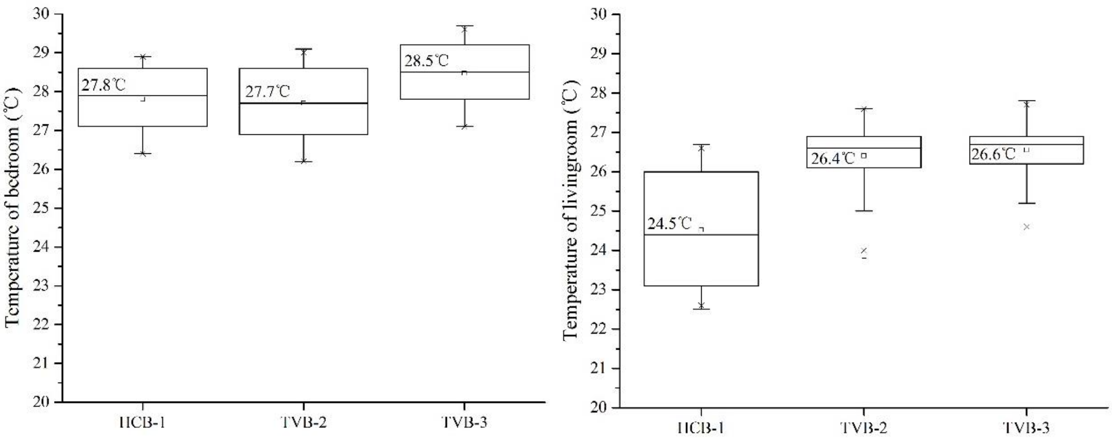
5.4.4 Comparison of the Indoor Thermal Environment of Buildings

The comparison results of HCB-1,TVB-2 and TVB-3 of the indoor air temperature and relative humidity of bedrooms and living rooms in summer are as shown in Fig. 5-30,Fig. 5-31.

The bedrooms of HCB-1, TVB-2 and TVB-3 are on the first floor. During measurement, the doors were closed. Through comparison, the bedroom temperature of TVB-3 was the highest, with the average temperature of 28.5°C. The bedroom air temperatures of HCB-1 and TVB-2 were similar to each other, with the average temperature of 27.8°C and 27.7°C, respectively. Since the exterior walls of HCB-1and TVB-2 are 350mm gray bricks walls and rammed earth walls respectively, the thermal performance of them was better than that of TVB-3(240mm brick walls). (Fig. 5-30,a)

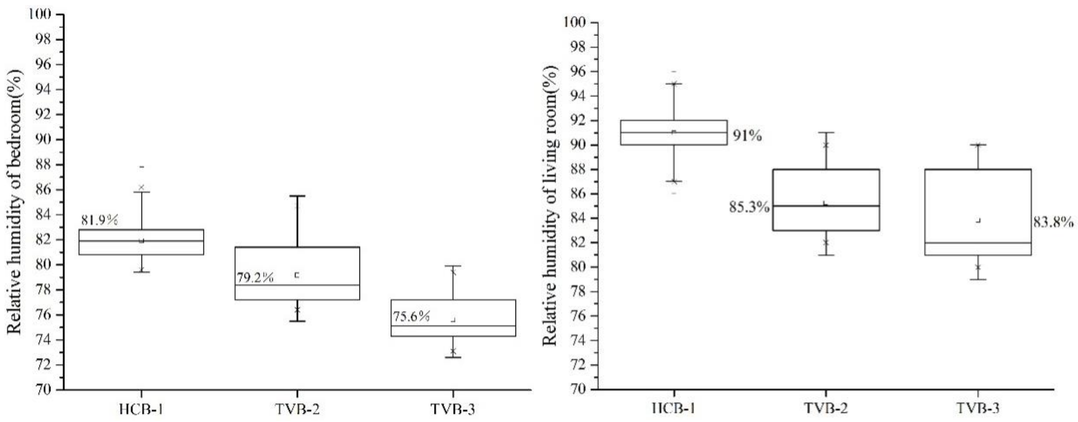
The relative humidity of TVB-3 was the lowest, with the average of 75.6%. The second was TVB-2, with the average relative humidity of 79.2%. The relative humidity of HCB-1 was the highest, and the average value was 81.9%. It can be seen that the average relative humidity of the three buildings was above 70%, which was a high humidity environment and not good for human health.

Different from TVB-2 and TVB-3, the living room of HCB-1 is a semi-open space. The results show that the average air temperature of HCB-1 was the lowest, with the average of 27.8°C. The farmers have similar living styles: when there was someone at home, the door of living room was opened during daytime. Therefore, the air temperatures of the living rooms were very close. The average air temperatures of TVB-2 and TVB-3 were 26.4°C and 26.6°C. The average relative humidity of living room in HCB-1 was the highest, with the average of 91.0%. The average relative humidity of TVB-2 was 79.2%, slightly higher than TVB-3 with the average relative humidity 75.6%. The average relative humidity of the three buildings was all above 80%, which was in a high humidity condition and bad for human health.



(a) bedrooms (b) living rooms

Fig. 5-30 Comparison of temperature of HCB-1, TVB-2 and TVB-3 (in summer)



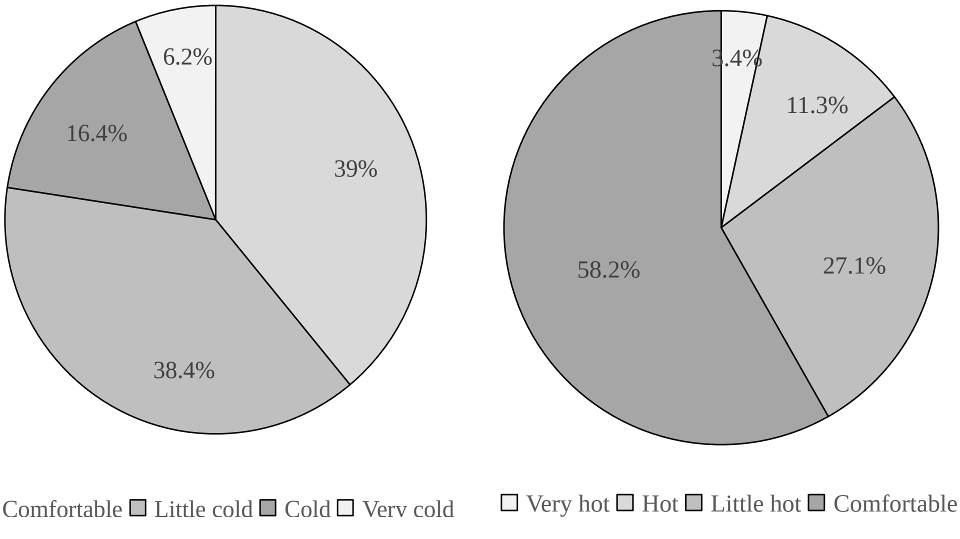
(a) bedrooms (b) living rooms

Fig. 5-31Comparison of relative humidity among HCB-1, TVB-2 and TVB-3 (in summer)

Table 5-5 The average and the range of the PMV(ePMV) value of different rooms

Building forms		Bedroom	Living room
HCB-1	PMV	2.18(1.80～2.67)	0.78(0.25～1.64)
	ePMV	1.53(1.26～1.87)	0.54(0.18～1.15)
	APMV	1.49(1.31～1.71)	0.65(0.20～1.20)
TVB-2	PMV	1.14(0.27～2.10)	1.13(0.54～1.77)
	ePMV	0.80(0.19～1.47)	0.79(0.38～1.24)
	APMV	0.90(0.26～1.46)	0.91(0.50～1.30)
TVB-3	PMV	1.31(0.60～2.70)	1.14(0.67～1.42)
	ePMV	1.01(0.47～1.69)	0.80(0.47～0.99)
	APMV	0.67(0.26～1.68)	0.92(0.60～1.10)

The average PMV/ePMV/APMV value and the range of PMV/ePMV /APMV value of bedrooms and living rooms in different buildings are as shown in Table 5-5. The average ePMV value of the bedrooms and living rooms were below or around 1.0, which means that the indoor thermal environment was in a good thermal performance. However, it is obvious that the average PMV of the bedroom of HCB-1 was the highest. The results contradicted to the previous statement from literature which says the historical buildings are cooler than modern buildings in summer.



(a) Farmers' thermal sensation in summer (b) Farmers' thermal sensation in winter

Fig. 5-32 Thermal sensation of local farmers

5.5Questionnaire Investigation on Thermal Sensation of Farmers and Tourists

5.5.1QuestionnaireInvestigationon Thermal Sensation of Farmers

Farmers' thermal sensation of indoor thermal environment was investigated by questionnaire. The results of thermal sensation of local farmers in summer and winter are shown in Fig. 5-32. As shown in Fig. 5-32,most farmers feel comfortable in summer. The farmers who feel comfortable account for

58.2%. 27.1% of the farmers feel hot, and 11.3% of the farmers feel a little hot. Only 3.4% of the farmers feel very hot. Compared with the thermal sensation of the indoor thermal environment in winter, the rate of farmers who feel comfortable is obviously lower than that in summer. The farmers feeling comfortable accounts for 38.4%, which is 19.8% lower than that in summer. The ratio of the famers who feel little cold is 58.2%. 16.4% of the farmers feel cold in winter, and 6.4% of the farmers feel cold.

5.5.2Questionnaire Investigation on Thermal Sensation of Tourists

The tourists' satisfaction of the indoor thermal environment was also investigated by questionnaire. The basic information of tourists and the thermal sensation are shown in Fig. 5-33.

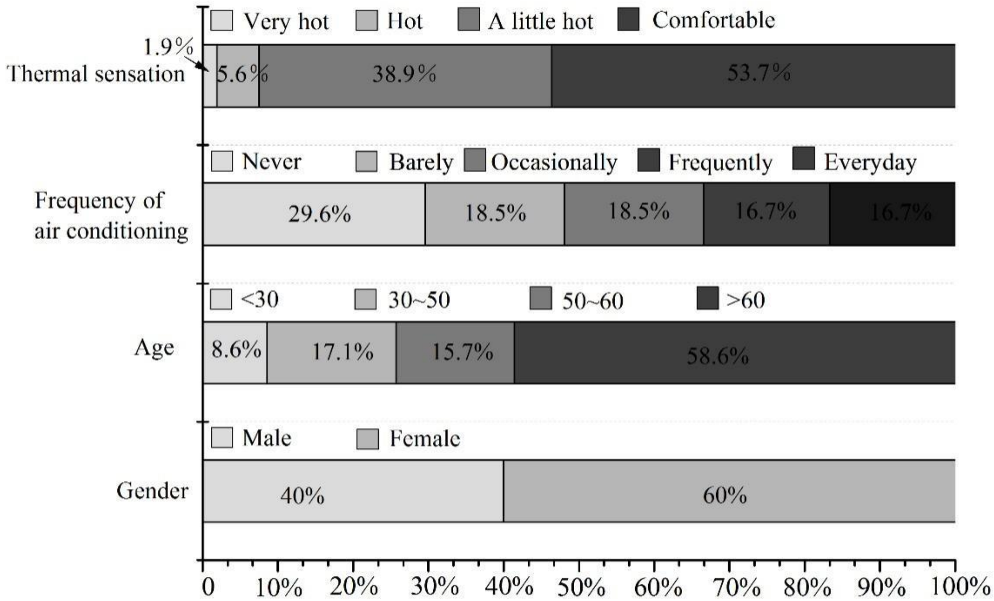


Fig. 5-33 Basic information and thermal sensation of tourists

Among all the tourists surveyed, the male tourists account for 40%, and the female tourists take up of 60%. Most of them are over 60 years old, accounting for 58.6%, and they are the retire people from Shanghai, Hangzhou, and Jianshu, etc. The tourists from 50 to 60 years old account for 15.7%, and the tourists between 30 and 50 years old account for 17.1%. The tourists under 30years old account for 8.6%.

It can be seen from Fig. 5-33 that 48.1% of the tourists don't use air conditioners. Since most of the tourists surveyed are old people, 29.6% tourists never use air conditioner. They think it's cool in the rural tourism households. The tourists who barely or occasionally use air conditioners account for 18.5%. The tourists who frequently use air conditioners or use air conditioners everyday account for 16.7%.

As shown in Fig. 5-33, in terms of the thermal sensation of the indoor environment, most tourists feel comfort, accounting for 53.7%. 38.9% tourists feel it is just a little hot, and 5.6% feel it is hot. Only 1.9% of tourists feel it is very hot. The results mentioned above show that the old people who are over 60 years old are the major tourists in Quzhou. Based on the analysis on their thermal sensation, it can be found that tourists who feel it is comfortable accounted for 32.4%, and 23.5% tourists feel it is a little hot. The rate of the tourists feeling hot is only 2.9%. Compared with the thermal sensation of the farmers, the rate of tourists feeling comfortable is lower.

5.6 Summaries

In this chapter, field survey and questionnaire investigation were carried out to study the indoor thermal environment by taking Quzhou District as an example in summer and winter. The following conclusions can be drawn:

(1)The living room of HCB-1 was a semi-opened space. Affected by the outdoor environment, the air temperature and relative humidity were similar to the outdoor environment. The air temperature of the bedroom on the first floor was about3°C higher than living room in summer.

(2) Farmers' living habits have a great impact on the indoor thermal environment. Due to the poor lighting of living room in TVB-1, farmers are accustomed to open the door during daytime, which leads to low indoor temperature in winter.

(3) The relative humidity of bedroom and living room on the first floor in traditional buildings was high, which was above 75% in summer and not good for health. The relative humidity of the bedroom in HCB-1 was even up to 81.9%.

(4) By comparing HCB-1 and TVB-2, and TVB-3, the bedroom temperature of TVB-3 (made of solid red bricks) was about 1 to 2°C higher than HCB-1 and TVB-2(made of solid red bricks). The temperature of HCB-1 and TVB-2 was very close.

(5) The indoor thermal environment of modern buildings in the coldest winter days (outdoor temperature below 3°C)was poor, and the indoor air temperature was lower than 8°C. Since the farmers close the doors during the cold days in winter. The air temperature of the living room was about 3 to 4.5°C higher and the relative humidity was 2% to 7% lower than the rammed earth building. Thermal performance of living room, bedroom on the first floor and the south guestroom on third floor were better. The top floor without decoration was the worst.

(6) In the hottest days of summer (outdoor temperature was up to 36°C), the indoor temperature and PMV value varied greatly. The temperature of bedroom on the first floor of modern buildings was below 30°C. The temperature of the room in the south of the top floor was over 30°C, which is in uncomfortable range.

(7) PMV values during measurement in winter were completely in the uncomfortable range. The PMV values of attic were the worst in both winter and summer. Indoor thermal performance was slightly better in summer compared that in winter. In addition, the result also demonstrates that rural residents have a large range of thermal tolerance.

(8) Questionnaire investigation was carried out among farmers and tourists. The results show that farmers' thermal sensation in summer is more comfortable than that in winter. 58.2% farmers feel comfortable in summer, but only 39% of them feel comfortable in winter. However, there 46.4% of the tourists feel the indoor thermal environment is not comfortable. 33.4% of them use air conditioners in summer.

Most of rural residential buildings were designed and built by the farmers. The unreasonable design and poor thermal performance of envelope lead to poor indoor thermal environment. Especially for the rural tourism households, it is necessary to perfect building envelopes to improve the indoor thermal environment and reduce the energy consumption.

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Chapter 6.

Survey on Energy Consumption of Rural Residential Buildings

6.1 Introduction

Rural tourism has become an important pillar industry in Zhejiang rural areas. According to the statistics released by the Tourism Bureau of Zhejiang Province, by the end of 2014, 3246 rural tourism villages (spots) had been set up in total, which included 14,840 rural tourism households, 200 thousand reception beds and 1.13 million seats for dining [1]. In 2014, Zhejiang province witnessed coming of 180 million tourists, an increase of 25.1% over the previous year, with direct revenue reaching 14,120 million yuan, representing a year-on-year growth of 26% and direct practitioners increased by 6.7% to 143 thousand. Villages (spot) featuring rural tourism increased to 4065 in 2015, nearly doubling that of 2009, when the number was only 2,331. Obviously, the development of rural tourism will definitely have profound effects on energy consumption patterns of farmer households. Moreover, the rapid growth in rural tourism has increased the demand for energy and attracted the attention to environmental protection.

The purpose of the chapter is to discuss current energy consumption situation in both ordinary households and rural tourism households and all these data were acquired through questionnaire and field measurement in Quzhou, Anji, and Zhoushan. Altogether, 230 households were surveyed, and 185 ordinary households and 45 rural tourism households were included. The result was analyzed from the perspective of general trend, energy consumption patterns, energy structure and renewable energy development induced by the development of rural tourism. Then the research results were compared with those from other surveys. In addition, factors which may exert impacts on energy consumption were analyzed.

6.2 Survey Outline

6.2.1 Survey Contents

Energy can be divided, in terms of its types, into commercial energy, including coal, LPG as well as electricity, and non-commercial energy, including firewood, straw as well as biogas [2]. Terminal energy consumption is composed of lighting, cooking, hot water, heating and cooking, and household appliances [2]. Solar energy is a kind of renewable, clean and widely-used energy structure and household energy consumption are related to family size, building features, energy usage habits and so on. The survey was conducted from the following aspects:

(1) Energy consumption: the consumption of electricity, LPG, firewood, stalk etc.

(2) Household appliance: the quantity of household appliances, model and power etc.

(3) Human behavior: the frequency and time of using household appliance.

6.2.2 Data Collection

Without national data on individual household information and energy consumption in China, the authors had to make some surveys in person to collect relevant data. The surveys consisted of two parts. The first part was carried out from July 2014 to August 2016 by working out questionnaires.

On-site surveys were made by investigators, who had been trained, to collect the data house by house. The investigators conducted a face-to-face survey by asking people to fill out questionnaires, and carefully recorded the data. About 10 undergraduates and graduates from Zhejiang A & F University were professionally trained before being assigned field investigations. To ensure that the acquired information was valid, the survey team also talked with the village leaders to make out and gain a command of the overall status of the village, and, whenever possible, they would check the validity of the collected data for at least two times. Thankfully, the local Planning Department provided their assistance throughout the investigation.

The second part is field measurement. Two rural tourism households in Quzhou and Zhoushan were involved in terms of electricity consumption and energy-consuming behaviors of farmers and tourists by using measurement instruments.

The analysis methods are introduced in Chapter 3. All the energy consumption was transferred into standard coal energy consumption (GJ). In addition, some details were gained from the government for more detailed and accurate data. For example, the monthly electricity consumption of the rural households surveyed was provided by local Power Supply Bureau, and the village topographic map was provided by local Planning Department.

6.3 Basic Status of the Surveyed Objects

6.3.1 Basic Status of the Households

6.3.1.1 Basic Status of Rural Residential Buildings

The basic features of rural residential buildings in Zhejiang have been studied in detail in Chapter 3. Rural tourism households are either traditional vernacular buildings built after 1980s or buildings built in modern time. Initially, farmers made use of vacant rooms to develop rural tourism. With the development of rural tourism, the newly built buildings are in bigger scale, which can perform the function of small hotel and have more guest rooms.

In Quzhou (Donghaiyucun village), the traditional vernacular buildings where rural tourism business is operated have only a few guest rooms with about 4 to 9. However, the modern buildings have more guest rooms with over 13 generally which averages 10.6 guest rooms. The rural residential buildings in Quzhou (Xiacheng village) that conduct rural tourism are modern buildings built after 2000. However, they were seldom used for residence at the beginning and had few guest rooms (4 rooms at minimum). More guest rooms have been built later and as a result, there are 25 rooms at maximum, with guest rooms averaging 11.6, almost the same number as that of Donghaiyucun village in Zhoushan.

6.3.1.2 Basic Status of Household Appliances

As a result of promulgation and implementation of "home appliances going to the countryside" policy, more and more ordinary households have become able to have access to household appliances. On the other hand, with the improvement of living standards and changes in consumption concept within rural areas, the number of people who develop awareness of using household appliances is increasingly rising. As is shown in Table 6-1, the ownership of air conditioner, washing machine, lampblack absorber, refrigerator, solar water heater and so on nearly reaches one set per household. Some appliances like TV, electric fan is more than one set for each household.

Table 6-1 Family-owned appliances per household in different types households

Appliance		Ordinary Household			Rural tourism household		
		Quzhou	Anji	Zhoushan	Quzhou	Anji	Zhoushan
Cooking & Hot water	Rice Cooker	0.7	0.8	1.0	2.0	2.0	2.4
	Lampblack Absorber	0.6	0.8	1.0	1.0	1.0	1.0
	Electric kettle	1.0	1.1	1.3	12.0	11.0	9.5
	Solar water heater	0.8	0.9	0.9	1.15	1.2	1.25
	Air source heat pump water heater	0	0	0	0.6	0	0.6
Cooling & Heating	Air conditioner	0.8	0.9	1.1	11.3	8.5	11.7
	Electric warmer	0.5	0.8	0.6	0.1	0.2	0.1
	Electric blanket	1.0	0.9	0.5	0	0.2	0.1
	Electric fan	2.1	2.4	2.5	12.7	3.5	2.8
Lighting	Energy-saving lamp	8.0	8.5	7.0	31.5	28.1	35.2
	Incandescent lamp	3.0	2.5	2.3	1.5	1.5	1.2
Others	TV	1.5	1.8	2.2	12.0	9.0	11.6
	PC	0.2	0.3	0.4	1.4	0.3	1.5
	Washing machine	1.0	1.0	1.0	1.1	1.0	1.2
	Refrigerator	1.0	1.0	1.0	2.1	1.8	2.6

Among rural tourism households, the farmers purchase a large number of household appliances to meet the needs of tourists who seek for accommodation and entertainment there. The ownership of TV, air conditioners, washing machines, lampblack absorbers, refrigerators and so on amounts to more than one set per household, which is obviously higher than that for ordinary household. Considering the fact that most of the tourists are from cities and towns and they have higher demand for the quality of life requirements, some families have installed air conditioners and solar water heaters, even more one set for each household. For example, the average ownership of air conditioners in ordinary household reaches about 0.8 set in Quzhou, 0.9 set in Anji, 1.1 set in

Zhoushan, and in rural tourism households, the number is about 11.3 sets, 8.5sets and 11.7 sets respectively. In recent years, air-sourced water heaters are popular in rural tourism household, because they can save more electricity and provide hot water throughout the whole year.

The energy efficiency of the appliances is rated in terms of their energy efficiency classes labeled from 1 to 5 in China, which provides useful information for the customers when they make choices about which one to buy among various models. Label one represents the most efficient energy, while five is the least efficient one. The main appliances per household and their energy efficiency label (EEL), etc. are shown in Table 6-2. It can be seen that most of the appliances' EEL adopted in rural household are in low level. For example, air conditioner and solar water heater are in three and four respectively.

Table 6-2 Power and energy efficiency label (EEL) of household appliances

Type	Appliance	Power	EEL (surveyed level/standard levels)
Cooling	Air conditioner	1100W	3/5
	Electric Fan	50 W	——
Lighting	Energy saving bulb	50 W	——
Cooking &Hot water	Rice Cooker	900 W	2/5
	Lampblack Absorber	250 W	——
	Electric kettle	1500 W	——
	Solar water heater	1500 W	4/5
Heating	Air conditioner	1100 W	3/5
	Electric heater	1800 W	——
	Electric blanket	100 W	——
Household appliance	Refrigerator	0.5kwh/24h	1/5
	Washing machine	0.12kwh/circle	2/5
	TV	200 W	——
	PC	200 W	——

6.3.2 Individual Behavior

6.3.2.1 Individual Behavior of Farmers

Survey on daily routine of 230 ordinary households has been conducted in Quzhou, Anji and Zhoushan. The activity timetable of both tourists and people living rural areas is shown in Fig. 6-1. Energy consumption has something to do with the frequency and time of using appliances. The research results about equipment usage frequency and timetable in a whole day is shown in Fig. 6-10. The part in bold represents the household appliances under operation.

(1) Ordinary household

As is shown in Fig. 6-1, farmers in ordinary households get up early in the morning. To show it in detail, 33% farmers get up at around 5:00 am and 55% farmers go to bed at round 20:00pm. 37% of them take noon break. Farmers' activities can be divided into three periods typically: ordinary times, busy seasons, as well as holidays and festivals. The activity is signified by in-building rate, namely proportion of in-building members to total family members of each family. At ordinary times, the young and the middle-aged go out just like migrant workers, as a result of which, the in-building proportion is small with only 24%. April is a season when people will enjoy the happiness of tea harvest. But their work location is far away from house so they have to bring lunch with them when going to the farm and have it outdoors. Therefore, the in-building rate is rather low from 6:30 am to 4:00 pm in April with only 5% in average. The villagers who work outside return home only during holidays and festivals and the average in-building rate is 66%. Besides, there are few households working outside nearly for the whole year and coming back only in spring festival.

(2) Rural tourism household

Rural tourism households have changed their traditional production style, and life style and the law of personnel activity have also experienced many changes. At ordinary times, they get up and go to bed one hour later than people in ordinary households. During peak season, the working and rest time for rural households is earlier than tourists and they go to bed later than tourists.

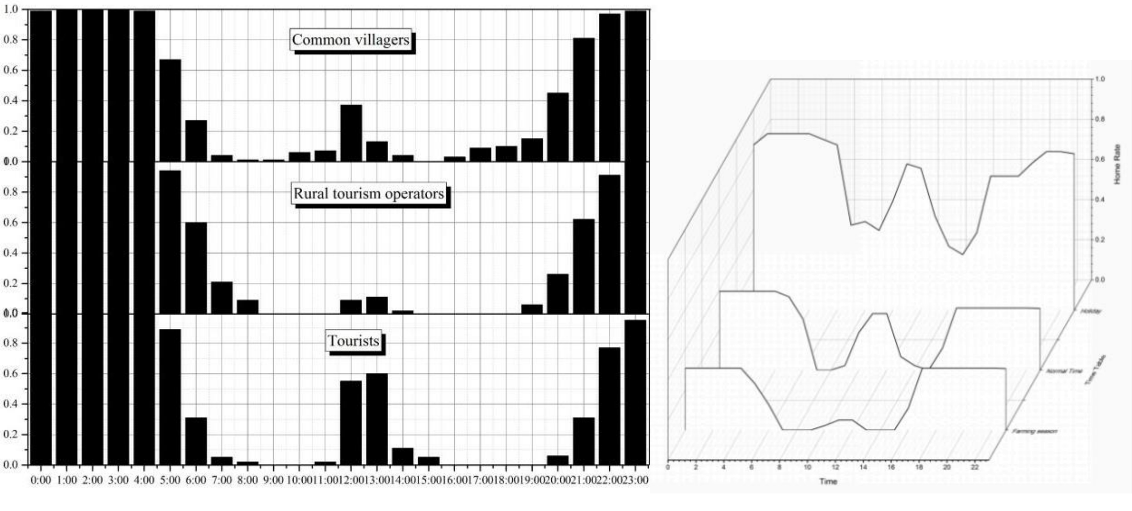


Fig. 6-1 People's activity timetable of rural households and tourists

6.3.2.2 Individual Behavior of Tourists

70 questionnaires were collected from tourists. They mainly go to rural areas for enjoying their holidays in summer. The tourists' activity timetable is shown in Fig. 6-1. They usually lead a relatively regular life. Specifically, they get up between 5:00 am and 6:00am, and then have breakfast between 7:00 am and 8:00am, while have lunch between 11:30 am and 12:00 pm, and super time is from 17:00pm to 18:30pm. They often go to bed at a very different time from local people and that

is often from 21:00pm to 23:00pm. 60% of tourists will take a little snap after lunch for one or two hours between 12:00 pm and 13:00 pm.

6.4 Energy Consumption and Structure

The major energy resources consumed in investigated households include electricity, LPG, firewood and solar energy. In addition, only a few rural households still use coal briquettes, which is very rare. Therefore, they are not taken into account.

6.4.1 Commercial Energy Consumption

6.4.1.1 Electricity Consumption

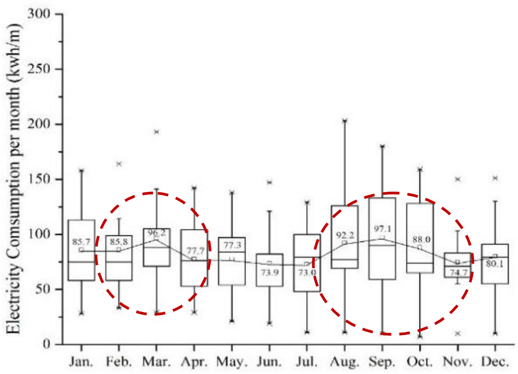
(1) Electricity consumption of ordinary households

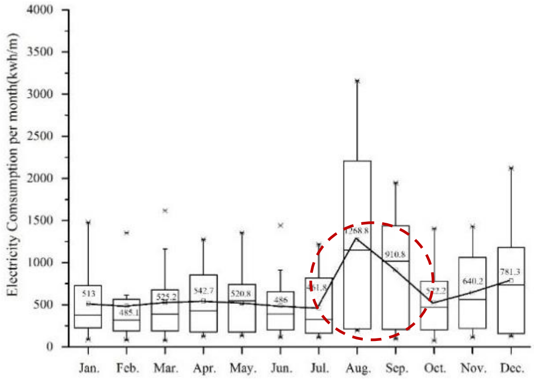
According to the questionnaire survey, the electricity consumption of the most ordinary households is low, because most of the young labors are migrant workers. Electricity consumed by households under survey is provided by Local Power Supply Bureau. The annual electricity consumption per square meter is 4.5kWh in Quzhou, 6.0kWh in Anji, and 5.7 kWh in Zhoushan. As is shown in Fig. 6-2, the annual electricity consumption will reach its summit in two peak seasons, which is winter and summer. The electricity consumption of heating system in winter is slightly lower than that of cooling system in summer. Late spring and early summer (April, May, June and July) and autumn (October, November and December) are transitional seasons and electricity consumption at these times is relatively lower. However, the electricity consumption in autumn is higher than those in late spring and early summer.

(2) Electricity consumption of rural tourism households

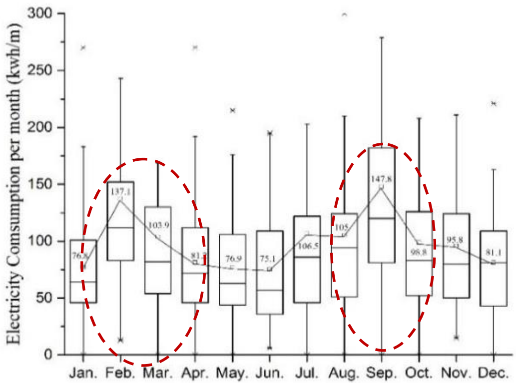
According to the monthly electricity consumption by the households under investigation in 2015, the average annual electricity consumption is 21.6kWh in Quzhou, 12.6kWh in Anji, 31.2 kWh in Zhoushan. The electricity consumption of rural tourism households only has one peak season, mainly from August to October. It is obvious that the electricity consumption by rural tourism households in heating and cooling period is unbalanced, and electricity consumption of cooling period in summer is obviously higher than that of heating period in winter. Compared with the electricity consumption of Quzhou, Anji and Zhoushan, the electricity consumption in Anji is about 2 to 3 times lower than Quzhou and Zhoushan.

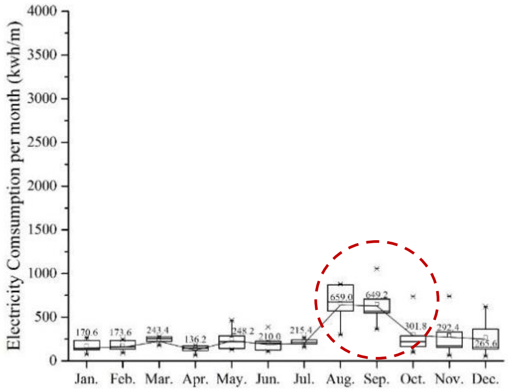
The results show that electricity consumption of ordinary households is about 2 to 5.5 times lower than that of rural tourism households, and of course that is caused by different numbers of the tourists. Electricity consumption varies in different types of rural tourism households because they have different regional characteristics. In mountainous areas, the biomass energy is abundant, while the electricity consumption is relatively lower.



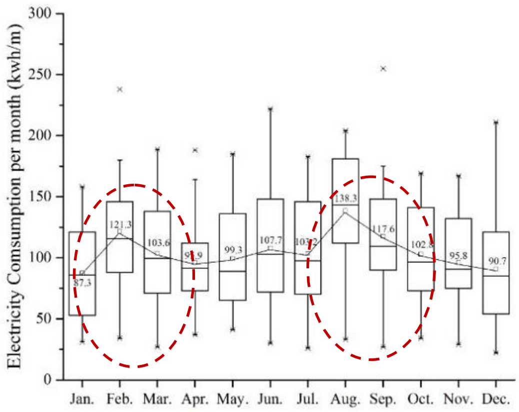


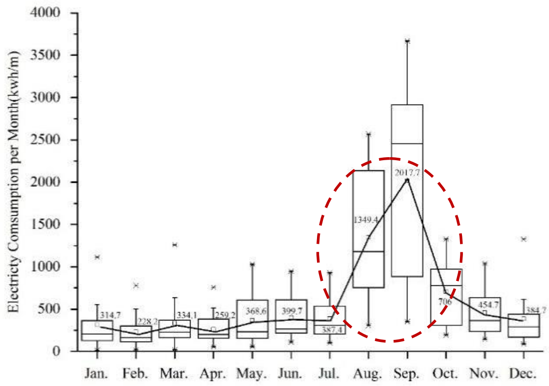
(a) ordinary household in Quzhou (n=120) (b)rural tourism household in Quzhou (n=20)





(c) ordinary household in Anji (n=45) (d) rural tourism household in Anji (n=45)





(e) ordinary household in Zhoushan (n=20) (f) rural tourism household in Zhoushan (n=20)

Fig. 6-2 Monthly electricity consumption of ordinary households and rural tourism households

6.4.1.2 LPG Consumption

Pipe-line gas has become a very common energy source in cities and towns. However, farmers mainly use canned liquefied LPG which is more convenient for delivery. The official file *Liquefied Petroleum Gas Cylinder* (GB5842-2006) stipulated five standard models of cylinder and the one that villages in Zhejiang Province commonly use is YSP35.5, whose volume is 35.5L and maximum filling weight is 14.9kg. Per capita LPG consumption of households in surveyed villages is clearly shown in Fig. 6-3.

(1) Most of ordinary households use LPG. The annual LPG consumption is 0.40GJ per capita in Quzhou, 0.24 GJ per capita in Anji, and 0.75 GJ per capita in Zhoushan. As is shown through the data, LPG consumption of Zhoushan is higher than the others. Different households are quite different from each other in terms of LPG consumption. Some may use up to 13 bottles at most, while others barely use it. And as a result, the average number of LPG consumption is 2.8 bottles.

(2) The annual LPG consumption among rural tourism households is 3.52GJ per capita in Quzhou, 3.26 GJ per capita in Anji, and 5.85 GJ per capita in Zhoushan. LPG consumption in Zhoushan is higher than in other areas. In conclusion, LPG consumption of rural tourism households is higher than ordinary household on average, about 8.8 times, 13.6 times and 7.8 times higher, respectively.

The comparison above shows that the LPG consumption of rural tourism households is far higher than that of ordinary households. The LPG consumption of rural tourism households in Zhoushan is the highest, followed by Quzhou. That is because the rural tourism households in mountainous areas are rich in biomass energy, so people there are used to using firewood and stalks as their energy sources instead of LPG. However, due to a lack of biomass energy and as a result of their economic development, rural tourism households in Zhoushan mainly use LPG for cooking.

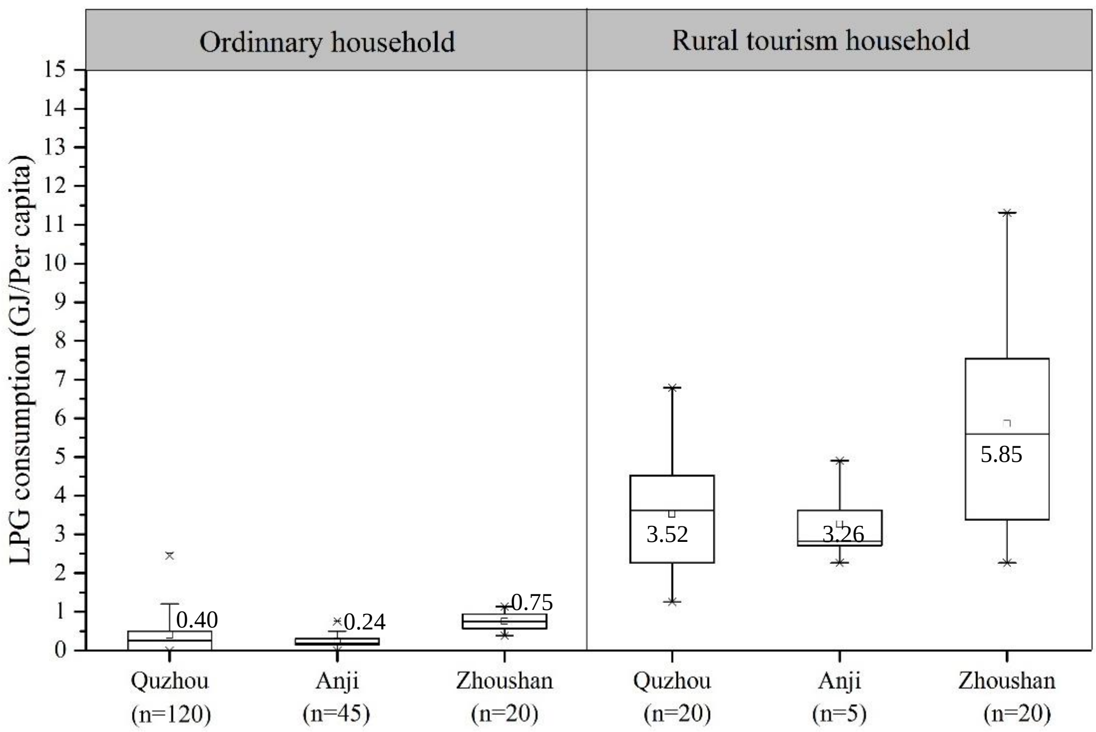


Fig. 6-3 LPG consumption of ordinary household and rural tourism household

6.4.2 Non-commercial Energy Consumption

Different from cities and towns, rural households are more abundant and more colorful in types in energy resources. In addition to commercial energy, farmers can use all kinds of old materials, like waste woods, stalks, pick-up dried firewood, and firewood that is cut or purchased as fuel in daily family lives. Among them, firewood and stalks are most widely used. The consumption of firewood is quite different in different types of households. The comparison of firewood consumption between ordinary households and rural tourism households is shown in Fig. 6-4.

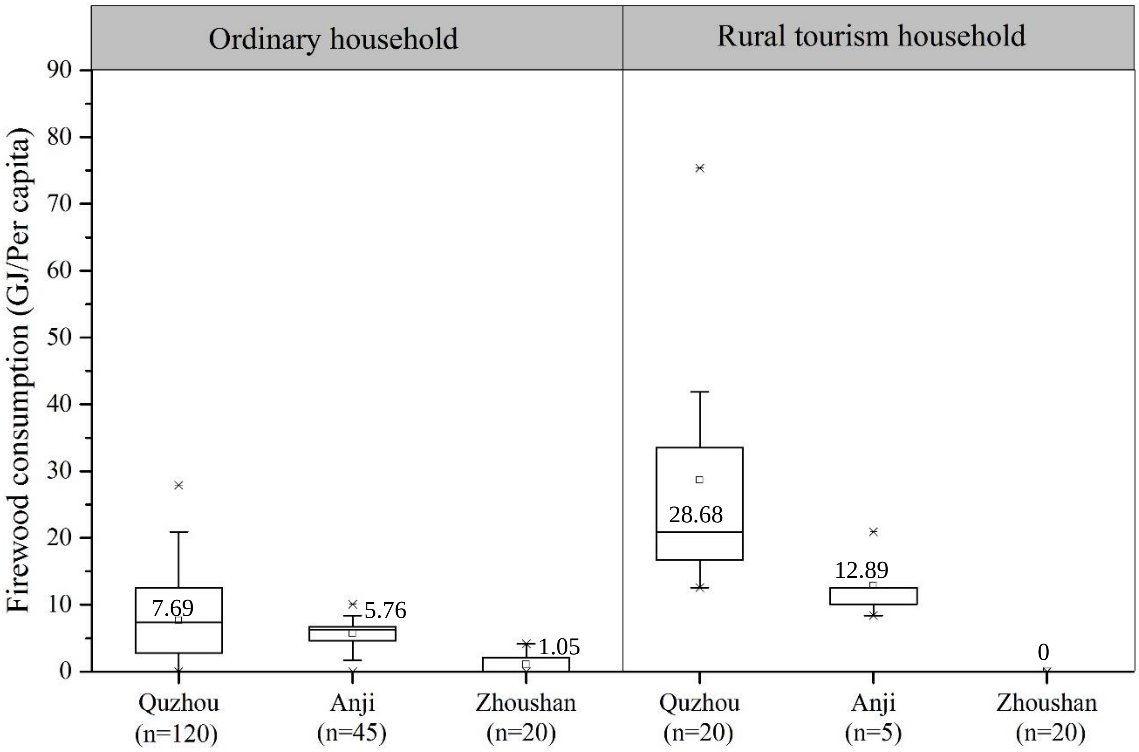


Fig. 6-4 Firewood consumption of ordinary households and rural tourism households

(1) The annual firewood consumption of ordinary households is 7.69GJ per capita in Quzhou, 5.76 GJ per capita in Anji, and 1.05 GJ per capita in Zhoushan. Firewood consumption in Quzhou and Anji is higher than that in Zhoushan. Some households use even less firewood as their energy resources, because they mainly use LPG and electricity. On the contrary, some households still mainly consume firewood and barely use LPG and electricity. According to the investigation, farmers use 7.5kg to 10kg of firewood per day on average. They mainly use LPG in summer and firewood in winter.

(2) The annual firewood consumption of rural tourism households is 28.68GJ per capita in Quzhou, and 12.89 GJ per capita in Anji. But there are no rural tourism households which consumes firewood in Zhoushan. Traditional hearth is seldom seen in kitchens, especially those of modern buildings and also their kitchen facilities share the same features as those of urban residence. Rural households in mountainous areas still use traditional hearth and as a result, firewood is still an important energy

resource. However, the kitchen facilities are similar to urban residence too.

According to the investigation, people in some ordinary households in Quzhou still use straw, but the number is very low. Coal (primarily briquettes) is still used on a sporadical basis but it takes only a small portion of all energy resources and, therefore, can be ignored in statistical analysis.

6.4.3 New Energy Consumption

New energy that rural households consume in Zhejiang rural areas is mainly solar energy and bio-gas. Solar energy is a kind of clean and renewable energy and it is the major new energy adopted in rural households. People in Quzhou and Anji rural areas are encouraged to use bio-gas and they even further the development of such new energy. However, bio-gas is produced by processing livestock waste which is not good for protecting environment. Therefore, bio-gas is developed in some villages which are specialized in poultry breads. In the surveyed households, there is no use of bio-gas.

(1) Solar energy consumption of ordinary households

Solar water heater is the most common way of using solar energy. It has been very common in the villages with the average of 0.8 to 0.9 sets per household among ordinary households. However, greatly influenced by whether, it is very difficult to ensure the water supply for people living there. Therefore, solar water heater is always used with the help of electrical heating.

At present, solar energy mainly provides domestic hot water for people for shower. It is quite difficult to make a survey on the usage of hot water for shower. According to the standard *Minimum allowable values of water efficiency and water efficiency grades for shower(GB28378-2012),* it is supposed that the flowing rate of water should be 0.04L/s[3], and people usually take shower 3 times a week, with 15 minutes each time. According to the questionnaire survey, electric water heaters were mainly used in supplying hot winter. After analysis of the data acquired, it is supposed that the total amount of heat supplied by the solar energy was 75%. Conclusion can be reached, according to Chapter 3, that the solar energy was 0.63GJ per capita in Quzhou, 0.71GJ per capita in Anji and 0.52 GJ per capita in Zhoushan.

(2) Solar energy consumption of rural tourism households

There are 1.5 sets of solar water heater in each household for rural tourism households in Quzhou, while only 1.2 sets for that in Anji and 1.25 sets in Zhoushan. But as is mentioned above, greatly influenced by weather, it is quite difficult to ensure the water supply. With promotion and application of air source heat pump, an increasing number of rural tourism households adopt assemble system of solar energy and air-sourced heat pump, which has reached 0.6 sets per household in Quzhou and Zhoushan. The working principle of the system is that solar water heater serves as the first heating system so as to increase water temperature. Then, the air source heat pump works as the second heating system to ensure the stability of terminal water supply. In order to guarantee sufficient supply of the hot water, people in rural tourism households always keep the air source heat pump open. Hot water is provided by both solar energy and air- sourced heat pump simultaneously, which makes it difficult to analyze all the data acquired through the investigation according to tourists' water consumption. After investigation, it is assumed that solar energy is utilized almost in every aspect, while the insufficient part is provided by air-sourced heat pump. The calculation is made according to the quantity of solar radiance in both Quzhou and Zhoushan which is provided by *Typical Meteorological Database for China's Building Energy Efficiency*, and what's more, the calculation is made according to the equation which is provided in Chapter 3. The solar energy consumption in Quzhou, Anji and Zhoushan is 4.95 GJ per capita, 2.52GJ per capita and 6.04GJ per capita, respectively.

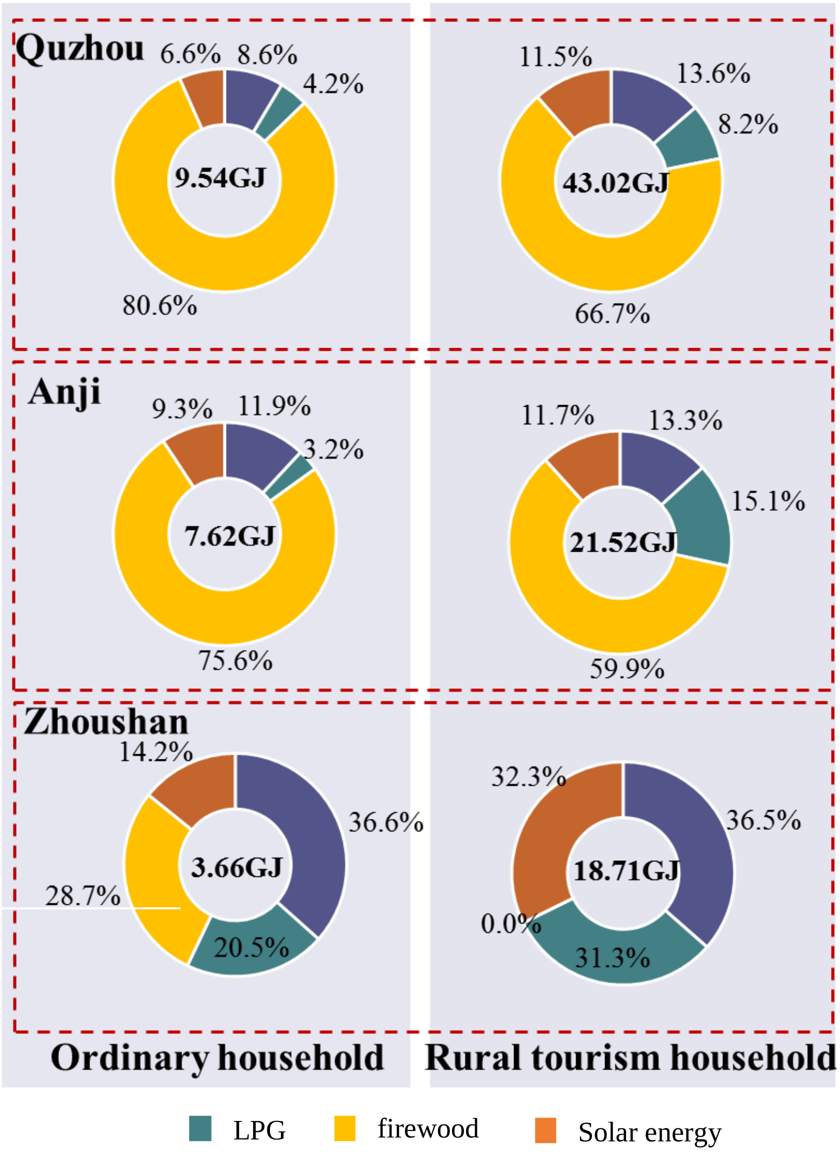


Fig. 6-5 Energy consumption structure of ordinary households and rural tourism households

6.4.4 Structure of Energy Consumption

6.4.4.1 Energy Consumption Structure of Ordinary Households

Consumption of commercial energy, non-commercial energy and new energy in ordinary households is shown in Fig. 6-5. Total annual energy consumption is 9.54GJ per capita in Quzhou. And specifically, electricity consumption is 0.82GJ per capita, accounting for 8.6%; LPG is 0.4GJ per capita, accounting for 4.2%; firewood is 7.69 GJ per capita, accounting for 80.6%; solar energy is 0.63 GJ/per capita, accounting for 6.6%. Total annual energy consumption is 7.62GJ per capita in Anji. Specifically, electricity is 0.91GJ per capita, accounting for 11.9%; LPG is 0.24GJ per capita, accounting for 3.2%; firewood is 5.76 GJ per capita, accounting for 75.6%; solar energy is 0.71 GJ per capita, accounting for 9.3%. Total annual energy consumption is 3.66GJ per capita in Zhoushan; electricity is 1.34GJ per capita, accounting for 36.6%; LPG is 0.75GJ per capita, accounting for 20.5%; firewood is 1.05 GJ per capita, accounting for 28.7%; solar energy is 0.52 GJ per capita, accounting for 14.2%. As can be seen from the data, the energy consumption in Zhoushan is lower than that in Quzhou and Anji, which is because of the higher consumption of firewood.

6.4.4.2 Energy Consumption of Rural Tourism Households

As is shown in Fig. 6-5, total annual energy consumption of rural tourism households is 43.02GJ per capita in Quzhou; among the total consumption, electricity is 5.87GJ per capita, accounting for 13.6%; LPG is 3.52GJ per capita, accounting for 8.2%; firewood is 28.68 GJ per capita, accounting for 66.7%; solar energy is 4.98 GJ per capita, accounting for 11.5%. The total annual energy consumption of rural tourism households in Anji is 21.52GJ per capita; electricity is 2.85GJ per capita, accounting for 13.3%; LPG is 3.26GJ per capita, accounting for 15.1%; firewood is 12.89 GJ per capita, accounting for 59.9%; Solar energy is 2.52 GJ per capita, accounting for 11.7%. The total annual energy consumption of rural tourism households is 18.71GJ per capita in Zhoushan; electricity is 6.82GJ per capita, accounting for 36.5%; LPG is 5.85GJ per capita, accounting for 31.3%; but no firewood is consumed in this city; solar energy is 6.04 GJ per capita, accounting for 18.71%. Therefore, energy consumption in Zhoushan is lower than that in Quzhou and Anji. Annual energy consumption per capita for rural tourism households is 3 to 5 times higher than that for ordinary households.

6.5 Characteristics of Terminal Energy Consumption and Structure

6.5.1 Cooking and Hot water

6.5.1.1 Cooking

Cooking energy consumption meets the basic demand of rural family life. In recent years, with improvement of living standard for farmers, LPG and electricity consumption grows substantially. Different from cities and towns, people living in rural households make use of various energy resources when cooking. According to the investigation, there are several kinds of energy combinations there: LPG, LPG + Firewood, LPG + Firewood＋Electricity, LPG＋Electricity, Coal + Firewood, Firewood, Firewood＋Electricity and Electricity. The details of energy consumption for cooking in 120 ordinary households in Quzhou are shown in Fig. 6-6.

Energy consumption for cooking is mainly based on LPG, firewood and electricity. The proportion of LPG, firewood and electricity altogether forms the highest one, accounting for 38.5%, which is followed by LPG＋Firewood and Firewood, accounting for 18.9%. The smallest consumption in proportion is LPG＋Electricity and Electricity, accounting for 0.8%. Among the most commonly used energy for cooking, firewood occupies the highest proportion, which is 68.9%, followed by LPG, whose proportion is 18.9%; while the proportion of electricity and coal is less, accounting for 7.4% and 0.8% respectively. In addition, 3.3% households often use firewood, LPG and electricity for cooking. It is obviously shown that ordinary households still take firewood as main energy resource for cooking.

Compared with ordinary household, rural tourism become more and more abundant in facilities related to cooking. The number of electric cookers has increased by 150% and 200% to 2 to 2.4 sets per household respectively. Electric kettle has enjoyed the largest increase in terms of its proportion in cooking facilities, which reaches 9.5 to 12 sets for each household. Owing to the development of rural tourism, rural households must provide tourists with tailored service so that tourists will become interested and attracted, as a result of which, energy consumption for every rural tourism household has increased substantially.

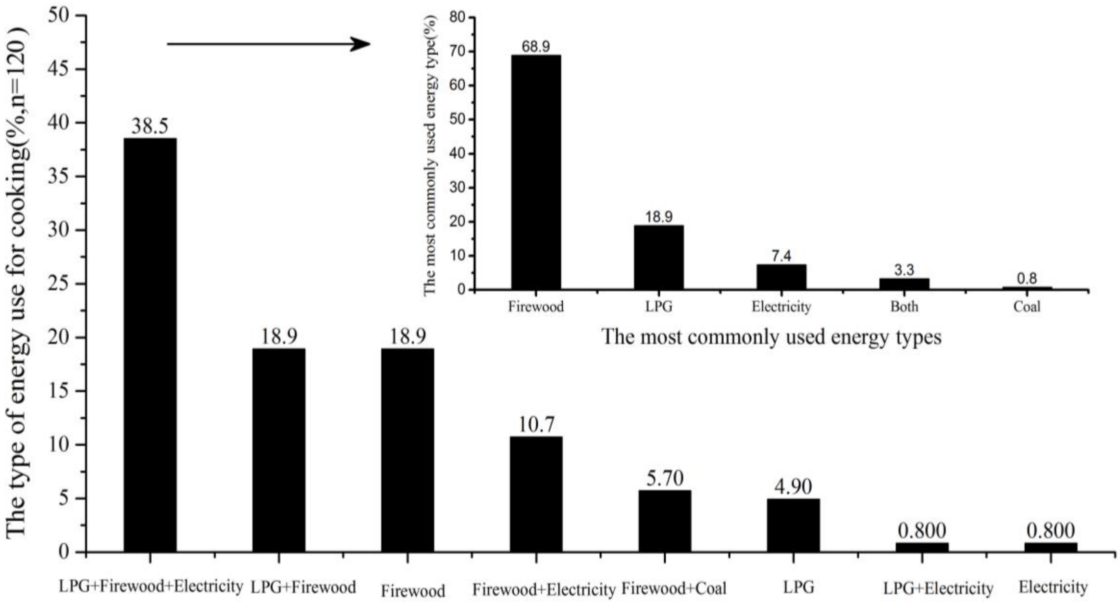


Fig. 6-6 Energy consumption for cooking in ordinary households

6.5.1.2 Hot Water

Solar water heater has become very common in rural households. From the investigation on hot water supply situation conducted in 120 ordinary households in Quzhou area (Fig. 6-7), domestic hot water is still acquired by burning firewood (FW), accounting for 33.6%; the second is solar water heater (SWH), accounting for 27.9%; the third is electric water heater (EWH), accounting for 15.6%. However, air-sourced heat pump (ASHP) is barely used in ordinary households. The consumption of firewood is close to solar water heater, with the former accounting for 42.6% and the latter 40.2%. Electric water heater accounts for 27.9%. Although solar water heater is very common in ordinary households, old people, who often take firewood as their first choice when they want hot water, occupy a largest number of the permanent population among ordinary households in mountainous areas, and their second choice to firewood will be solar water heater and electric water heater.

Relatively speaking, rural tourism households have more sets of solar water heater, with 1.15, 1.20 and 1.25 sets per household in Quzhou, Anji and Zhoushan. Therefore, they have greater demand for hot water, but the hot water provided by solar water heater couldn't satisfy people's demand anymore, so they have to use air-sourced heat pump. The investigation shows that the proportion of air-sourced heat pump in rural tourism households has reached 0.6 set per household.

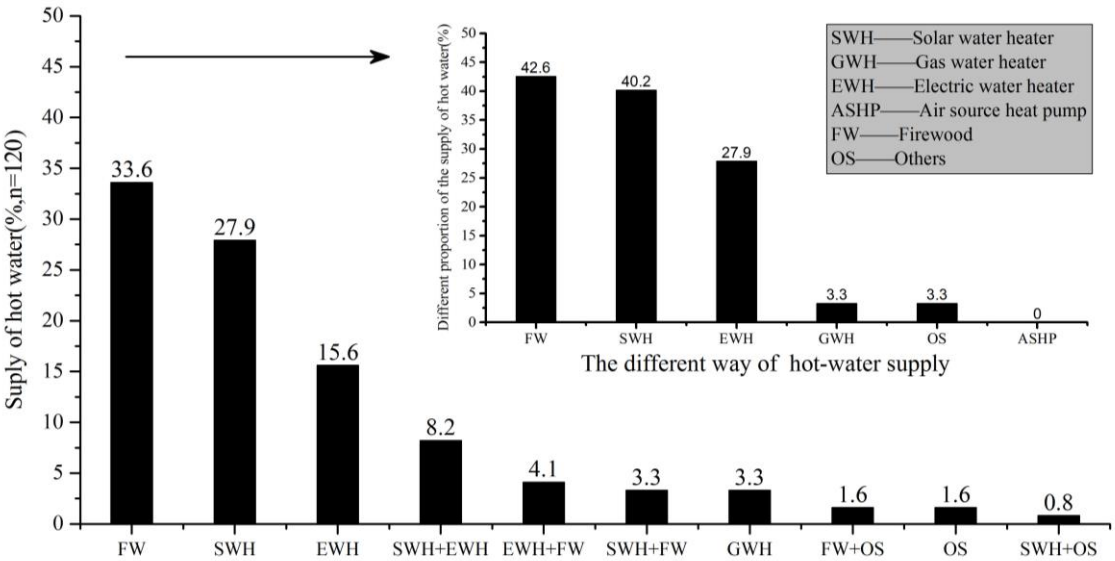


Fig. 6-7 Supply of hot water in ordinary household

6.5.2 Heating and Cooling

6.5.2.1 Heating

(1) Heating of ordinary households

In addition to charcoal fire, ordinary households in mountainous areas also turn to air conditioner, electric warmer, electric blanket and other heating appliances to keep warm. Air conditioner has reached 0.8, 0.9 and 1.1 set per household in Quzhou, Anji and Zhoushan, respectively. Electric warmer is 0.5, 0.8, 0.6 set for each household in three regions; electric blanket is1.0, 0.9 and 0.5 set per household respectively. The use frequency of air conditioners is shown in Fig. 6-8.

(2) Heating of rural tourism households

The number of air conditioners increases obviously in rural tourism households in Quzhou. The proportion of electric warmer and electric blanket is very small, with only 0.1 set per household. Therefore, throughout the whole investigation, the energy consumption for heating, the usage of electric warmer and electric blanket is not taken into consideration. Among the investigated 52 people (20 rural tourism households), 36 people showed that they never used electric warmer and electric blanket, and the proportion of these people to the total number of those investigated is 69.2%; 13 people expressed that they occasionally used them, and the number of these people accounts for 25%; only 3 people expressed that they often used them in winter, only a small proportion of 5.8%.

Rural tourism households in Zhoushan barely use traditional energy resources such as charcoal fire. They mainly use air conditioners to keep warm in winter, with 11.7 sets of air conditioner per household; the proportion of electric warmer and electric blanket is very small, with only 0.1 set per household. Therefore, the consumption for electric warmer and electric blanket is not considered. Among the 42 investigated people (20 rural tourism households) , 35 people clearly stated that they didn't use them, and the number of these people accounts for 83.3%; 4 people expressed that they occasionally used them in a few days, the number accounting for 9.5%; 3 people expressed that they often used them, accounting for 7.1% , and these people are mainly the young and the middle-aged. Farmers over 50 years old seldom use air conditioners.

6.5.2.2 Cooling

(1) Cooling of ordinary households

The main cooling facilities include air conditioner and electric fan. In Quzhou, Anji and Zhoushan, the ordinary household has an average of 2.1, 2.4 and 2.5 sets of electric fans respectively. In fact, electric fan has been the most commonly used cooling facility in ordinary households because as long as people are in the room, they will use electric fans.

(2) Cooling of rural tourism household

The number of electric fans in rural tourism households is much larger than that in ordinary households, which reaches about 12.7 sets per household in Quzhou. In comparison, the number of air conditioning is 11.3 sets per household, suggesting that electric fan is the main cooling facility in summer. Among the 52 investigated farmers of the 20 rural tourism households, 36 people said that they didn't use air conditioner in summer, which accounted for 69.2%; 9 people expressed that they occasionally used it in a few days, accounting for 17.3% and only 7 people often used it, accounting for 13.5%. The number of electric fans of rural tourism households in Zhoushan and Anji stands at about 3.5 and 2.8 sets per household. The number of air conditioner in Zhoushan is about 11.7 sets per household, which is similar to Quzhou. Among the 42 investigated people of the 20 rural tourism households, 32 people said that they didn't use air conditioner, accounting for 78.5%; 5 people expressed that they occasionally used it in a few days, accounting for 11.9% and4 people said that they often used it, accounting for 9.5%. Besides, the probability of using the air conditioner in summer is higher than in winter.

According to the questionnaires on tourists (Fig. 6-8), 35.4% of them use electric fans for cooling; 15.4% use both air conditioners and fans and 38.5% mainly use air conditioners. Besides, 18.5% of tourists use fans, electric fans and air conditioners, which shows that tourists mainly use air conditioners for cooling. In addition, the lowest frequency of using air conditioner is between 7:00am and 9:00am, the highest between 12:00 pm and 15:00 pm and the second highest is before sleeping. Besides, most tourists usually set the temperature of air-conditioner at between 25°C to 28°C in summer and a few set between 23°C to 24°C.

Air temperature and air conditioner usage of 10 guest rooms in a rural tourism household in Quzhou were monitored for three successive days (from July 21st, 2016 to July 24th, 2016), the data of which were recorded every one minute. Air conditioner use was monitored by "storage type smart metering socket". As is shown in Fig. 6-9, between 7:30am to 9:30am, the frequency of using air-conditioner is the lowest and at night it is relatively high. However, in actual measurement, the frequency of using air-conditioner is not the highest, which is quite different from the survey result.

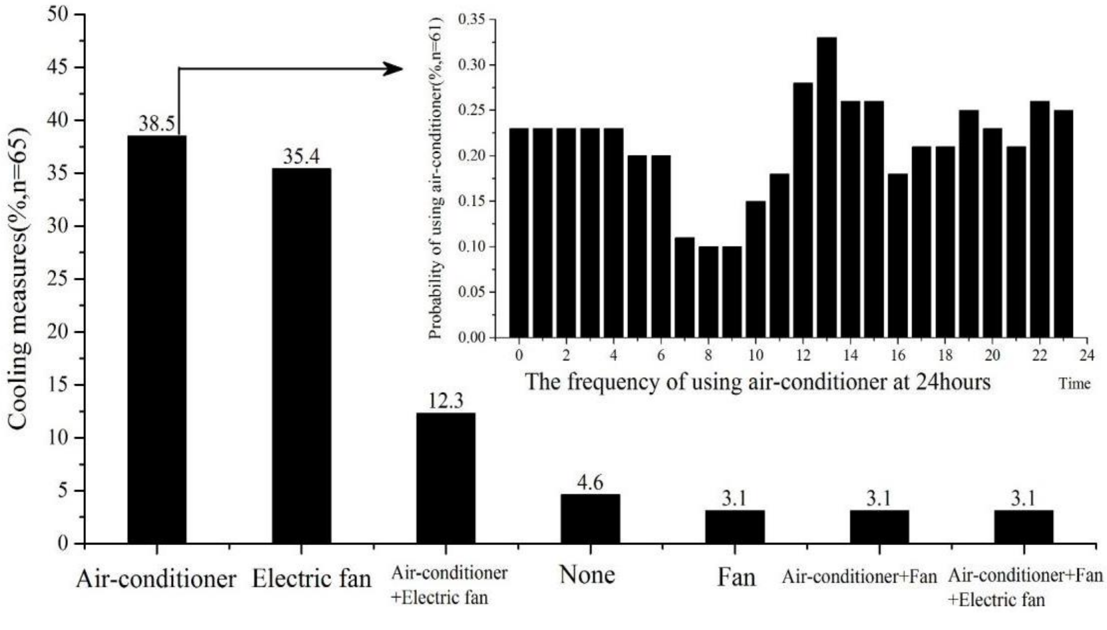


Fig. 6-8 Main cooling facilities and probability of using air conditioner of tourists in summer

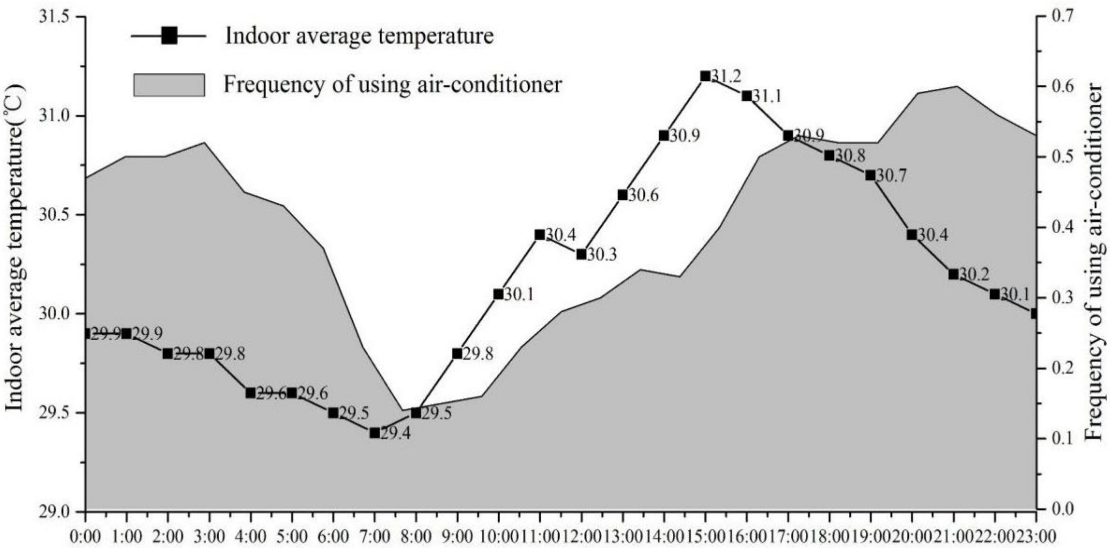


Fig. 6-9 Monitor indoor air temperature and frequency of using air-conditioner of tourists

6.5.3 Lighting

Because of the large amount of lighting fixtures and the arbitrary service time, it is difficult to monitor the use of lighting, especially in rural tourism households. In the survey, the main lights in a room are counted, but the decoration lights with smaller power are not counted. The timetable of using lights is accounted according to that of farmers and tourists. Rural residential buildings have quite the same facilities as urban residences and particularly, in order to attract tourists, rural tourism households use the same auxiliary facilities as those of small hotels. According to the survey, the average ownership of lights in ordinary households is about 11 sets. The ownership of energy-saving lamp is 8.3 sets per household, accounting for 75.3%and that of the incandescent lamp is 2.7 sets per household, accounting for 24.6%. The survey conducted by Tsinghua university found that the average number of incandescent lamp is 1.9 sets per household in rural households, and that of energy-saving lamp is 2.7 sets per household, accounting for 76%[2].

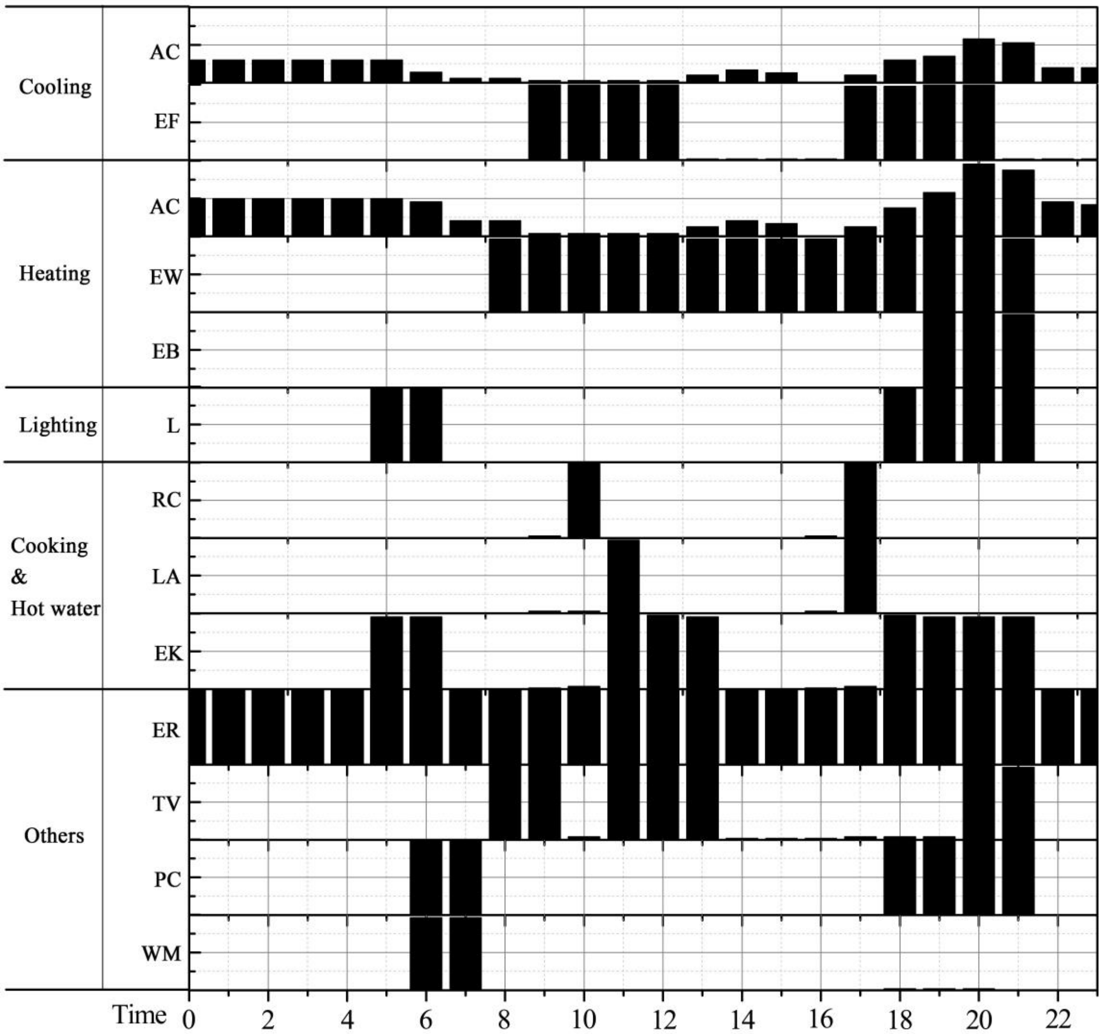
Ownership of lights and penetration rate of energy-saving lamp in rural tourism households are higher than ordinary households. In Quzhou, the energy-saving lamp is 35.2 sets per household, accounting for 94.5%. The incandescent lamp is 35.2 sets per household, accounting for 97.6%.

6.5.4 Other Household Appliances

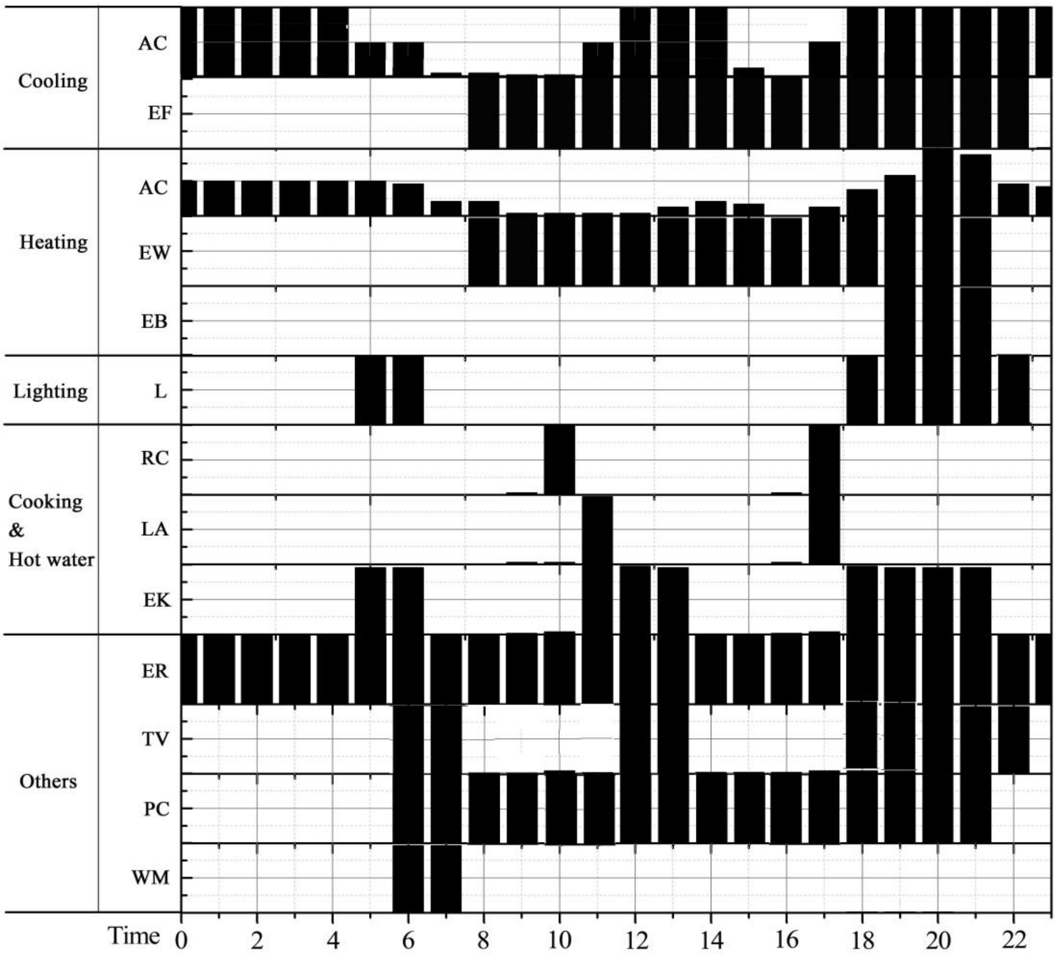
Enjoyment energy consumption refers to the energy used to improve life quality and comfort, which is mainly reflected in the use of appliances like TV set, washing machine, refrigerator, computer and so on. With the growth of living standard of farmers, large quantities of electric appliances which used to be symbols of cities make the presence in rural households. The number of TV set, washing machine and refrigerator is more than 1 set per household in ordinary households. Appliances in rural tourism households are far more than ordinary households. The numbers of TV sets per household are 12, 9 and 11.6 respectively in Quzhou, Anji and Zhoushan.

6.5.5 Terminal Energy Consumption and Structure

Firewood, LPG and solar energy are usually consumed for cooking and hot water. Electricity covers five aspects of rural residential energy consumption, which is the most difficult part in decomposition. As the service time of equipment comes from the general estimation of respondents, and it is influenced by factors such as depreciation of equipment, it is very difficult to count up the exact proportion. Therefore, the calculation is based on appropriate assumptions.



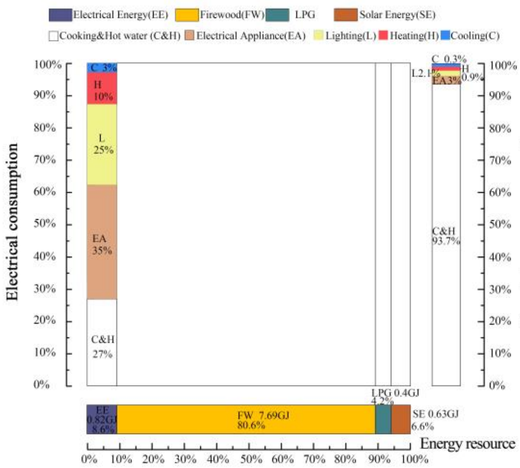
(a) ordinary household



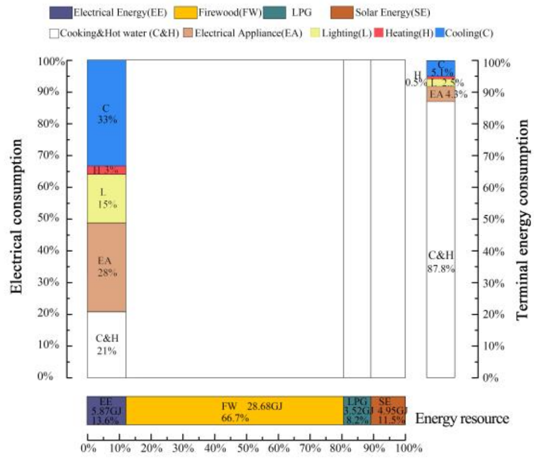
(b) rural tourism household

Fig. 6-10 Household appliance usage frequency

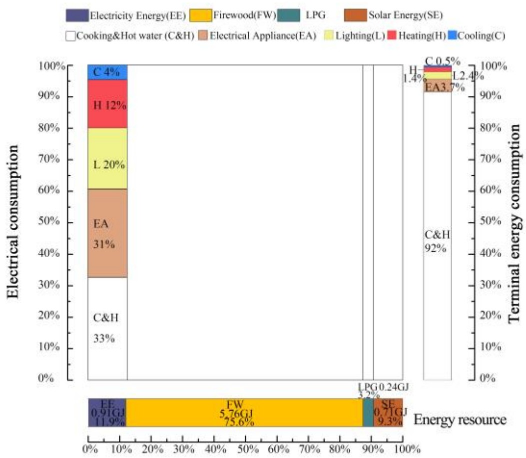
The calculation of terminal energy consumption is made in accordance with the sets of appliances, appliance power, total service time (service time per day multiples the number of days) and usage probability under investigation. The methods of analysis and equations are introduced in section 3.4 in Chapter 3. According to the survey, due to the absence of heating conditions, the indoor temperature is lower than 30°C in summer, and is higher than 8°C in winter in areas with a hot summer and cold winter. The indoor thermal environment is considered to be relatively comfortable. Therefore, the service time of air conditioner, electric blanket and electric warmer sees an increase when outdoor temperature is over 35°C or below 5°C when the air conditioner works in summer and winter. The exact running time is available according to the probability of use within 24 hours. Some appliances have relatively fixed usage time, such as TV, refrigerator, rice cooker, washing machine, etc. The usage time is counted in accordance with the average time. During the estimation, depreciation of equipment is not taken into consideration and the estimation is revised according to the use frequency of all the equipment and the usage habits of farmers. The use frequency of the appliance is shown in Fig. 6-10.



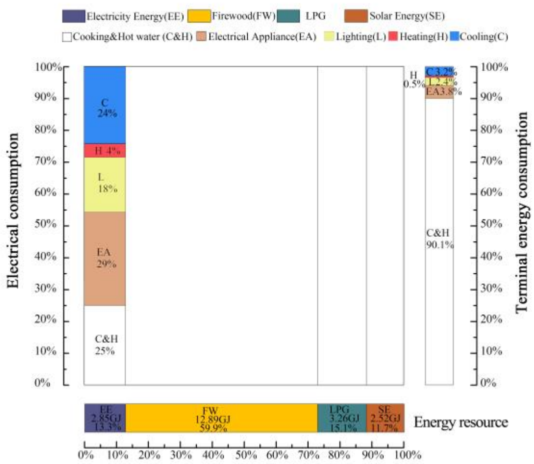
(a) Ordinary household in Quzhou



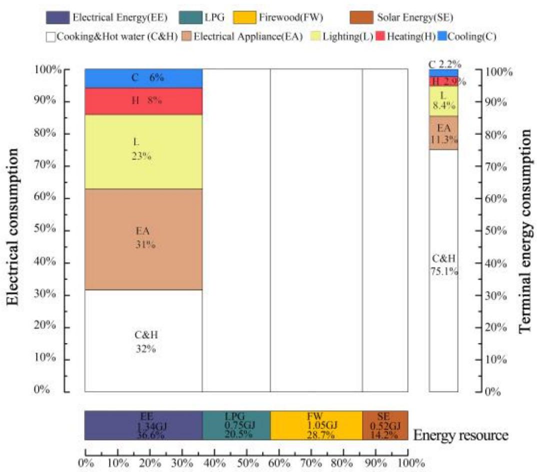
(b)Rural tourism household in Quzhou



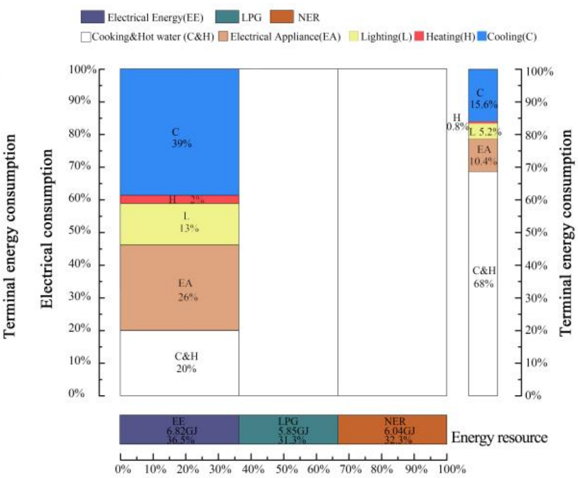
(c) Ordinary household in Anji



(d)Rural tourism household in Anji



(e) Ordinary household in Anji



(f)Rural tourism household in Anji

Fig. 6-11 Energy consumption and the structure of rural residential buildings

6.5.5.1 Terminal Energy Consumption and Structure of Ordinary Households

As shown in Fig. 6-11, the annual electricity consumption of the ordinary household is 0.82GJ per capita in Quzhou. The proportion of electric appliance is the highest, accounting for 35%, followed by cooking and hot water, which account for 27%. The electricity consumption for lighting accounts for 25% while heating and cooling account for the lowest, with10% and 3% respectively. The total annual terminal energy consumption is 9.54GJ per capita. Cooking and hot water, accounting for 93.7%, takes up the highest, which is followed by electric appliances and lighting, accounting for 3% and 2.1% respectively. Heating and cooling account for the lowest with only 0.2% and 0.1% respectively. It suggests that the energy consumption of heating and cooling of ordinary households is very little. In fact, energy is used primarily for the consumption of cooking and hot water.

The annual electricity consumption of ordinary households in Anji is 0.91GJ per capita. The proportion of cooking and hot water is the highest, accounting for 33%, which is followed by electric appliances, reaching 31%. Lighting accounts for 20% while heating and cooling are the lowest, accounting for 12% and 4% respectively. Total annual terminal energy consumption is 7.62GJ per capita, in which the proportion of cooking and hot water is the highest, accounting for 92%; the following is electric appliances, accounting for 3.7%; lighting, accounting for 2.4%; heating and refrigeration, which is the lowest, accounting for 2% and 1% respectively.

The total annual electricity consumption of ordinary households in Zhoushan is 1.34GJ per capita, in which the proportion of cooking and water is the highest, accounting for 32%, which is followed by appliance, accounting for 31%. The electricity consumption for lighting accounts for 23% and heating and refrigeration accounting for the lowest, with 8% and 6% respectively. The total annual terminal energy consumption is 3.66GJ per capita, in which the proportion of cooking and hot water is the highest, accounting for 75.1%; the appliances is the next, accounting for 11.3%; lighting, accounting for nearly 8.4% and energy consumption of heating and refrigeration is the lowest, accounting for 2.9% and 2.2% respectively.By comparison, Zhoushan claims higher electricity consumption than Anji and Quzhou, Quzhou claims higher total annual terminal energy consumption than Anji and Zhoushan, where households are still mainly consuming firewood. In addition, cooking and heating consume more energies than others.

6.5.5.2 Terminal Energy Consumption and Structure of Rural Tourism Households

(1) Investigation results

As is shown in Fig. 6-11, the annual electricity consumption of rural tourism households in Quzhou is 5.87GJ per capita. Cooling, reaching33%, accounts for the highest, which is followed by electric appliance, accounting for 28%. Cooking and hot water accounts for 21%; lighting 15%while heating is the lowest, accounting for 3%. The total annual terminal energy consumption is 43.02GJ per capita. The proportion of cooking and hot water is the highest, accounting for 87.8%and that of cooling, electric appliance, lighting and heating accounts for 5.1%, 4.3%, 2.5%and 0.5% respectively.

The annual electricity consumption of rural tourism households in Anji is 2.85GJ per capita. Electric appliance accounts for 29%, which is the highest, and is followed by cooking and hot water, accounting for 25%. Cooling accounts for 24%; lighting 18%; heating 4% which is the lowest. The total annual terminal energy consumption is 21.52GJ per capita. Cooking and hot water, accounting for 90.1%, is the highest and electric appliance, which is the next, accounts for 3.8% For cooling, lighting and heating, the numbers are 3.2%,2.4%, and 0.5% respectively.

The annual electricity consumption of rural tourism households is 6.82GJ per capita. Cooling is the highest, accounting for 39%, which is followed by electric appliance, accounting for 26%. Cooking and hot water account for 20%; lighting 13%; heating 2%, which is the lowest. The total annual terminal energy consumption is 18.71GJ per capita. Cooking and hot water is the highest, accounting for 68%; the following three are cooling, electric appliance and lighting, accounting for 15.6%, 10.4% and 5.2% respectively. Heating is at the lowest level, accounting for 0.8%.

By comparison, Zhoushan claims higher electricity consumption than Anji and Quzhou, and Quzhou claims higher total annual terminal energy consumption than Anji and Zhoushan, which mainly consume firewood. With regard to electricity consumption, cooling is the highest, with a number between 29% and 39%. In terms of annual terminal energy consumption, cooking and heating are higher than others.

(2) Monitor results

According to the results mentioned above, commercial energy consumption of rural tourism households in Zhoushan is higher, especially for cooling, which shows that tourists' use of air conditioner has a significant impact on the total electricity consumption. A field measurement was conducted in a typical rural tourism household in Zhoushan from September 4th, 2016 to September 6th, 2016. In the building, which has 9 guest rooms (one was for themselves, which didn't use air conditioner), there are 4 family members with two permanent residents.

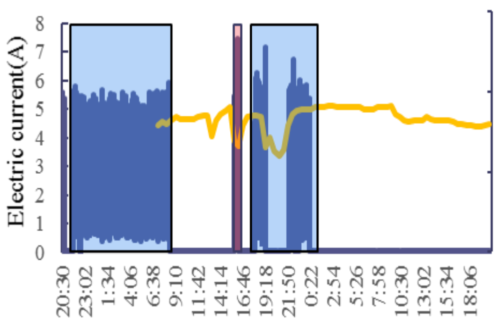
Indoor air temperature and electricity consumption of the air conditioner were recorded by smart meters once a minute. The total electricity consumption of the family was recorded by means of the electricity meter at 20:00 pm by manual record. The usage of air conditioner and the indoor air temperature is show in Fig. 6-12. The result shows that total electricity consumption of the family is 65.6kWh from 20:00pm September 4th to 20:00pm September 5thand is 72.74kWh from 20:00pm September 5th to 20:00pm September 6th. It can be seen that, the average electricity consumption for air conditioner is 4.75 kwh/d from September 4th to September 5thand is 4.87 kWh/d from September 5th to September 6th, with an average of 4.81 kwh/d. Besides, electricity consumption of air conditioner takes up 55.8% of total household consumption.

According to the records of tourists in recent five years in this household, room occupancy rate is 50% in April and May, 70% in June, 95% from July to September, 50% from October to November. There are no tourists from December to next March in the following year. In addition, according to the statistics of the total electricity consumption per month of the household from 2010 to 2015 provided by the local Power Supply Bureau, the electricity consumption per unit floor area of the household is 36kwh/m^2 which is close to the average level of electricity consumption per unit area in the rural tourism households. According to statistical data of typical meteorological year of Zhoushan, there are 90 days that outdoor peak temperature is more than 30°C. The annual energy consumption of cooling can be calculated according to the equation below:

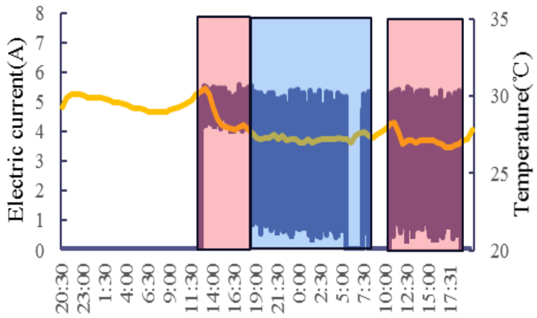
$$E_{cooling} = E_{av} \times r \times n \qquad \text{Equation (1)}$$

Where, $E_{cooling}$ stands for annual energy consumption of cooling; r stands for occupancy rate of tourists and n stands for the days of using air conditioner.

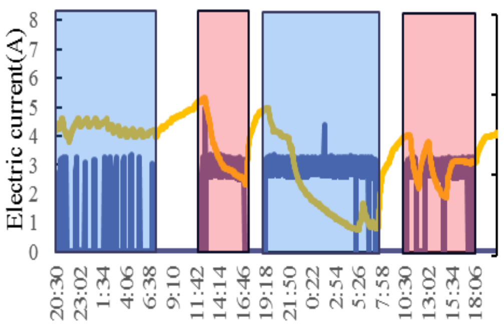
According to the formula above, a calculation is carried out and the result shows that energy consumption of air conditioner accounts for 40.7% of the total and lighting accounts for 25.9%. It shows that energy consumption of cooling in rural tourism households witnesses an obvious increase in summer, accounting for about 39% of the total consumption in the whole year.



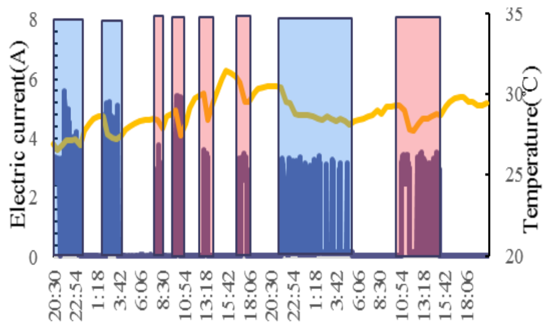
(a) Room1



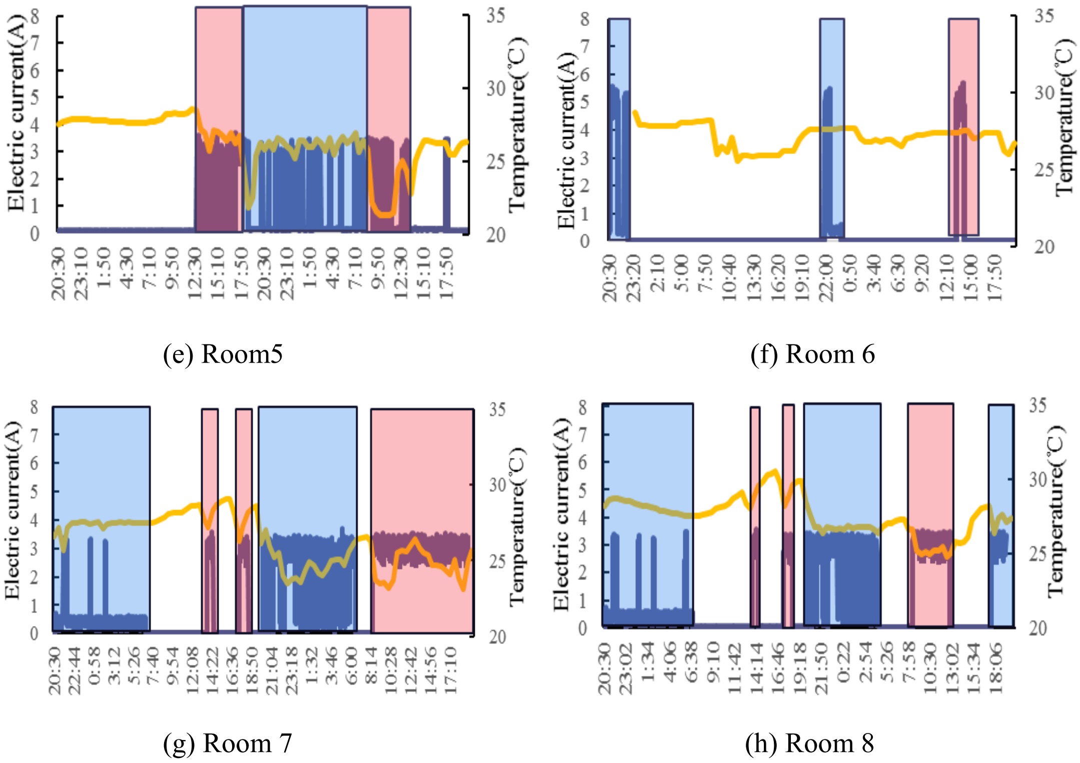
(b) Room2



(c) Room 3



(d) Room 4

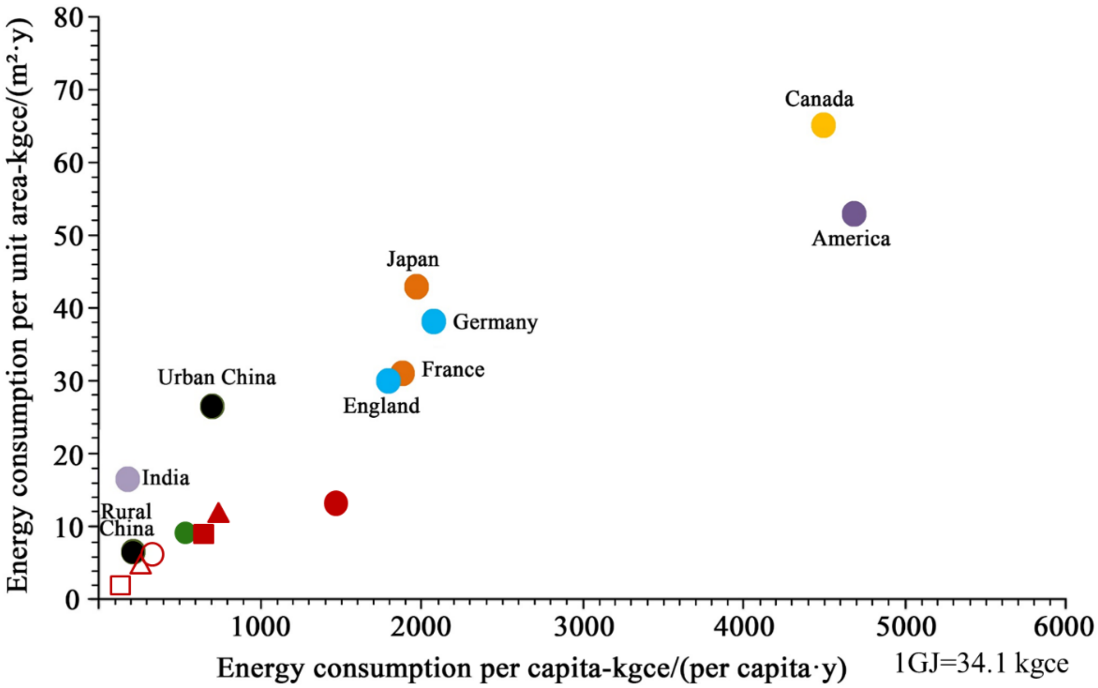


Use air conditioner at night   Use air conditioner at daytime

Fig. 6-12 The relationship between using of air conditioning and indoor air temperature

6.6 Comparison with Other Surveys

A comparison was made between the survey results and the average energy consumption of Zhejiang rural areas. The energy consumption was estimated based on the statistical data provided by Rural Energy Office of Zhejiang province in 2013 and the Statistical Yearbook of Zhejiang Province. According to the results, in 2013, the annual consumption of energy per household is 47.5GJ, per capita is 15.5GJ (528.55kgce), and per m^2 is 0.26GJ (8.7kgce), which is higher than the average of Chinese rural areas. The annual energy consumption of ordinary households surveyed is 9.54GJ (325.25kgce) per capita and 0.19GJ (6.44kgce) per m^2 in Quzhou,7.62GJ (259.8kgce) per capita and 0.17GJ(5.88kgce) in Anji, 3.66GJ (124.74kgce) per capita and 0.06GJ (1.92kgce) per m^2 in Zhoushan, which is lower than the provincial average. Ordinary households surveyed are mainly living on traditional agriculture or migrant work, whose energy consumption is low. However, in rural tourism households surveyed, energy consumption is about 43.02GJ (1466.83kgce) per capita and 0.41GJ (13.84kgce) per m^2 in Quzhou, 21.52GJ (733.91kgce) per capita and 0.34GJ (11.65kgce) per m^2 in Anji, 18.71GJ (638.18kgce) per capita and 0.27GJ (9.19kgce) per m^2 in Zhoushan. It suggests that, energy consumption of ordinary households is on a par with the national average. What is more, energy consumption of rural tourism households is higher than the national average in rural areas, or even higher than the urban areas. (Fig. 6-13)



● Zhejiang rural area: 528.55 kgce/(per capita·y)/8.7 kgce/(m^2·y)

Ordinary household:

○ Quzhou:325.25 kgce/(per capita·y) / 6.44kgce/(m^2·y)

△ Anji:259.8 kgce/(per capita·y) /5.88kgce/(m^2·y)

□ Zhoushan:124.74 kgce/(per capita·y) /1.92kgce/(m^2·y)

Rural tourism household:

● Quzhou:1466.83 kgce/(per capita·y) /13.84kgce/(m^2·y)

▲ Anji:733.91kgce/(per capita·y) /11.65kgce/(m^2·y)

■ Zhoushan:638.18 kgce/(per capita·y) /9.19kgce/(m^2·y)

Fig. 6-13 Comparison of building energy consumption between different countries

(Modified from *Simulation Research on Occupant Energy-related Behaviors in Building*)

In 2015, electricity consumption of ordinary households is only 4.5kWh/(m^2·y) in Quzhou, 6kWh/(m^2·y) in Anji and 5.7kWh/ (m^2·y) in Zhoushan; electricity consumption of rural tourism household is 21.6 kWh/ (m^2·y), 12.6kWh/ (m^2·y), 31.2kWh/ (m^2·y) in these three regions respectively. According to an investigation conducted by Sun Yulin on rural residential building in Shanghai and nearby areas, annual electricity consumption is 9.0kWh/(m^2·y) [15]. Usage rate of commercial energy has reached over 90% in Shanghai rural areas, which is a little higher than that of ordinary households. It is evident that electricity consumption is relatively lower in ordinary households in developing rural areas. According to an investigation of electricity consumption of 18 urban residents of Hangzhou by Zhu Li in 2012, the minimum value is 11kWh/(m^2·y), and the maximum value is 80.1kWh/(m^2·y) [11]. Jiang Yi and other members investigated energy consumption of urban residential building of 1000 households in Shanghai, which showed that annual total electricity consumption of residents on average was 33kWh/(m^2·y) and heating and air conditioner accounted for 10~20kWh/ (m^2·y). It can be seen that, electricity consumption in rural tourism household is close to the urban residential buildings, some of which are even higher.

Wang et al. compared the building energy consumption of Chinese rural areas and urban areas with other countries (Fig. 6-13). The energy consumption per capita of Chinese rural households is lower than that of developed countries, such as Canada, the U.S. and Japan, but is higher than India. Ning Yadong and others, from the macro perspectives, analyzed the energy consumption characteristics of the residence in our country from 1995 to 2010 based on the statistical data of urban energy consumption of the country. In 2010, urban residential energy consumption is 5.59GJ per capita in which heating accounts for 25%, cooking and hot water, 56%, domestic appliances, 10%, refrigeration, 6% and lighting 3%. According to the one-year tracking measurement on consumption of electricity and fuel gas of two residences in Shanghai from 2002 to 2003, Li Zhenhai and other people proposed that the energy consumption structure in Shanghai residential building is cooking (25%~33%), air conditioner (19%~21%), lighting (5%~6%), and refrigerator, entertainment and other equipment (33%~43%). In Chongsheng area in Jiuzhou, the energy consumption per building accounts for 35%. It suggests that rural residential energy consumption is lower than urban residential energy consumption in Zhejiang province, which is far below the level of developed countries.

6.7 Correlation Analysis

Rural energy consumption is influenced by various kinds of factors such as weather conditions, production modes, availability of energy, income level, energy cost, availability of energy-saving technology, policies and systems, etc. Energy consumption of building is related to building, family background and the use of equipment. To be specific, factors relating to building are the shape, window-to-wall ratio and average gross floor area per capita and so on. Factors related to family include the proportion of permanent residents and the population age structure. The factor associated with equipment is mainly the number of air conditioner. The impact of all the factors on building energy consumption is analyzed as follows.

Pearson's correlation coefficient (r) is a measure of the strength of linear dependence between two variables by means of a value between −1 and +1 (inclusive). The proportion of shared variance (R^2) can be calculated by squaring the Pearson's r. In other words, R^2 represents the proportion of variability in one variable accounted for by another variable. The values range from 0 to 1, in which 1 indicates a perfect fit. The p-value is a measure of the probability of obtaining a result at least as extreme as the one that is actually observed, so the lower the value is (usually below 0.05 or 0.01), the more significant the result will be.

6.7.1 Influence Factor of Energy Consumption of Ordinary Households

Taking ordinary households in Anji as an example, as shown in Table 6-3, six parameters were analyzed to have the correlation with annual energy consumption per household: frequent used area (r = 0.593, p=0.000<0.01); family size (r = 0.199, p=0.170); number of AC (r = 0.246, p = 0.088); income level (r = 0.412, p =0.004<0.01); permanent population (r = 0.323, p =0.024<0.05); total building area (r = 0.198, p =0.172). It can be seen that three variables are significantly correlated with energy consumption: which are frequent used area, income level, and permanent population. Frequent used area has a significant correlation with energy consumption (r >0.5). As indicated by the positive correlation coefficient, it is easily understandable that as frequent used area grows, the energy consumption also grows. When it comes to income level (0.3<r<0.5), it shows that the higher the family income is, the higher the energy consumption is, which is different from previous studies that showed no correlation between income and energy consumption [4]. Besides, permanent population has a weaker correlation (r<0.3) than frequent used area and income level. Family size does not have a significant correlation with energy consumption, because young labors are working outside. The scatter plot of annual energy consumption per household and frequent used area, income level and permanent population are shown in Fig. 6-14.

Although the total building area does not have a significant correlation with energy consumption, it cannot be ascertained that there are no indirect connections between them. As is shown in Table 6-3, the total building area is significantly correlated to frequent used area, while the latter is significantly correlated to energy consumption. As a result, the total building area has an indirect impact on energy consumption.

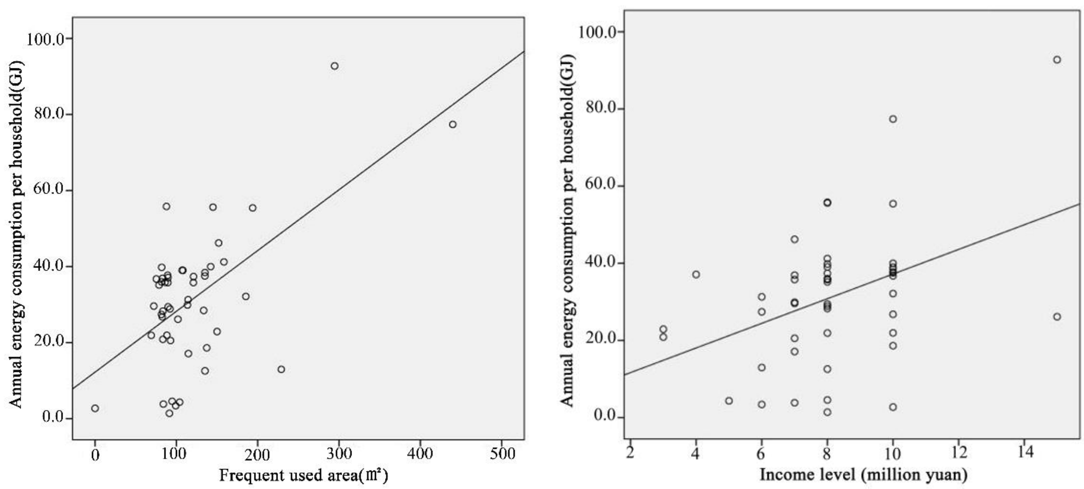
In addition, though the number of air conditioner shows no correlation with annual energy consumption per household, it has a negative correlation with annual electricity consumption per household, which is weak (R^2<0.1) (Fig. 6-14). The previous study conducted by Chen et al. [5]also showed that there was a positive correlation between air conditioner and electricity consumption.

Table 6-3 Correlations between household variables and energy consumption (Ordinary household)

		Frequent used area	Total building area	Family size	Permanent population	Number of AC	Incom e level	ATN CPH
Frequent used area	Pearson	1	.584**	.198	.165	.234	.264	.593**
	p value		.000	.173	.256	.105	.070	.000
	N	49	49	49	49	49	48	49
Total building area	Pearson	.584**	1	.283*	-.152	.060	.288*	.198
	p value	.000		.049	.297	.680	.047	.172
	N	49	49	49	49	49	48	49

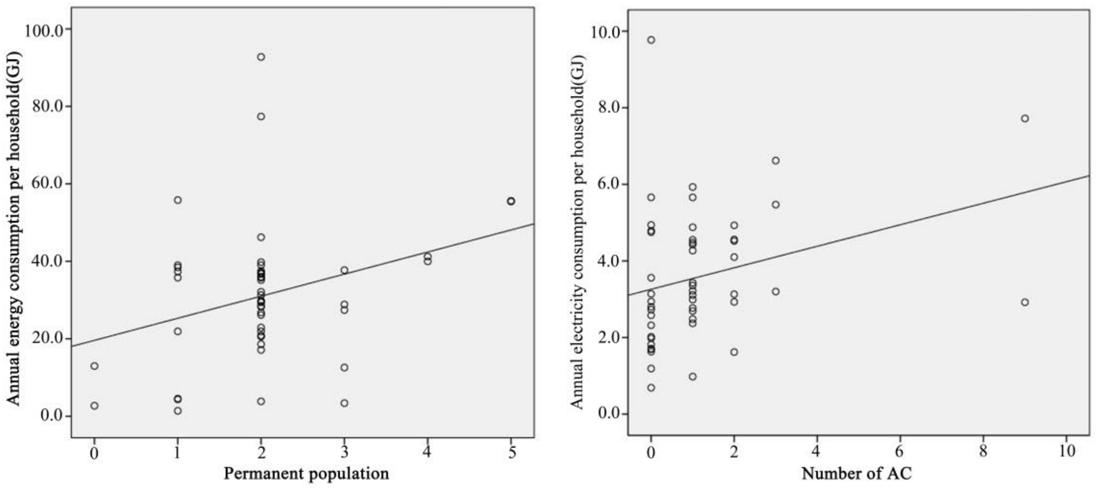
Family size	Pearson	.198	.283*	1	.304*	-.032	.330*	.199
	p value	.173	.049		.034	.826	.022	.170
	N	49	49	49	49	49	48	49
Permanent population	Pearson	.165	-.152	.304*	1	-.105	.071	.323*
	p value	.256	.297	.034		.472	.633	.024
	N	49	49	49	49	49	48	49
Number of AC	Pearson	.234	.060	-.032	-.105	1	.271	.246
	p value	.105	.680	.826	.472		.063	.088
	N	49	49	49	49	49	48	49
Income level	Pearson	.264	.288*	.330*	.071	.271	1	.412**
	p value	.070	.047	.022	.633	.063		.004
	N	48	48	48	48	48	48	48
ATNCPH	Pearson	.593**	.198	.199	.323*	.246	.412**	1
	p value	.000	.172	.170	.024	.088	.004	
	N	49	49	49	49	49	48	49

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). (ATECPC: Annual total energy consumption per capita)



(R^2=0.352; r=0.593, p=0.000)
(a) Frequent used area

(R^2=0.170; r=0.412, p=0.004)
(b) Income level



(R^2=0.352; r=0.593, p=0.000) (R^2=0.170; r=0.412, p=0.004)

(c) Permanent population (d) Number of AC

Fig. 6-14 Scatter plot of energy consumption and frequent used area, income level, permanent population and number of air conditioner. (n=45)

6.7.2 Influencing Factors of Energy Consumption of Rural Tourism Households

Taking rural tourism households in Zhoushan as an example, it has been shown in the table above that the total annual energy consumption per household is significantly correlated with: total building area (r = 0.779, p =0.000); number of AC (r = 0.755, p = 0.000); number of guestroom (r = 0.671, p = 0.001); income level (r = 0.661, p =0.001). The scatter plot of annual energy consumption per household and total building area, number of AC, number of guestroom and income level are all shown in Fig. 6-14. It is not difficult to find that energy consumption has no correlation with family size or permanent population, which suggests that the farmers of the rural tourism households use less energy than the tourists.

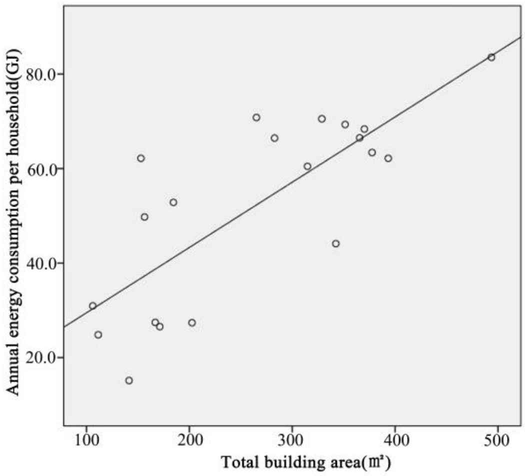
Among those four variables, total building area and number of AC have had the most significant correlation with annual energy consumption per household, which is followed by the number of guestroom and income level. As indicated by the positive correlation coefficient, it can be easily understood that, when the factors such as area, air conditioner ownership, the number of guestroom and income grow, the energy consumption also increases. In addition, the four variables appear to be significantly correlated with each other. Households which have higher income have greater investment into rural tourism business.

Table 6-4 Correlations between variables and energy consumption (Rural tourism household)

		Income level	Total building area	Number of guestroom	Family size	Permanent population	Number of AC	ATN CPH
Income level	Pearson	1	.554*	.466*	-.047	.071	.510*	.661**
	p Value		.011	.038	.843	.767	.022	.001
	N	20	20	20	20	20	20	20
Total building area	Pearson	.554*	1	.834**	-.130	-.069	.949**	.779**
	p Value	.011		.000	.585	.773	.000	.000
	N	20	20	20	20	20	20	20
Number of guestroom	Pearson	.466*	.834**	1	-.485*	-.283	.947**	.671**
	p Value	.038	.000		.030	.226	.000	.001
	N	20	20	20	20	20	20	20
Family size	Pearson	-.047	-.130	-.485*	1	.602**	-.300	-.148
	p Value	.843	.585	.030		.005	.199	.532
	N	20	20	20	20	20	20	20
Permanent population	Pearson	.071	-.069	-.283	.602**	1	-.148	-.203
	p Value	.767	.773	.226	.005		.535	.390
	N	20	20	20	20	20	20	20
Number of AC	Pearson	.510*	.949**	.947**	-.300	-.148	1	.755**
	p Value	.022	.000	.000	.199	.535		.000
	N	20	20	20	20	20	20	20
ATNCPH	Pearson	.661**	.779**	.671**	-.148	-.203	.755**	1
	p Value	.001	.000	.001	.532	.390	.000	
	N	20	20	20	20	20	20	20

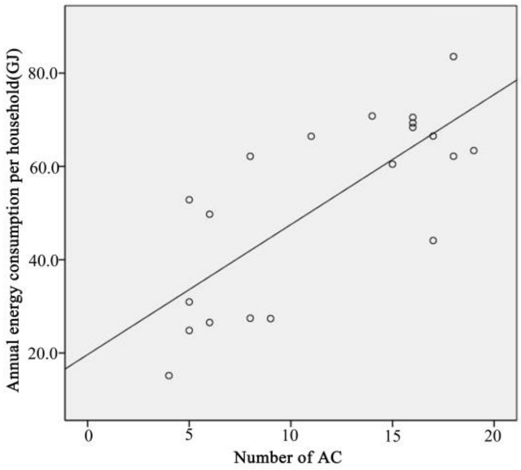
Note:*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). (ATECPC: Annual total energy consumption per capita)

Additionally, as is suggested by the survey (Table 6-5), the number of guestrooms is an important parameter, which has a significant positive correlation with annual energy consumption per capita, annual electricity consumption per capita as well as annual LPG consumption per capita, with the Pearson's correlation coefficient of 0.732,0.719 and 0.476 respectively. It reveals that the number of guestroom has a more significant influence on electricity consumption than LPG consumption. The results of terminal energy consumption in section 6.4.4 show that cooling energy consumption accounts for 39%, and the use of air conditioners has a dominant effect on energy consumption in summer. Therefore, special attention should be paid to tourists' use of air conditioner in summer.



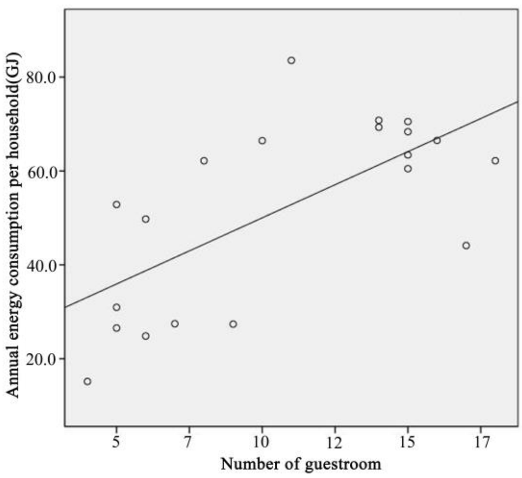
(R^2=0.607; r=0.779, p=0.000)

(a) Permanent population



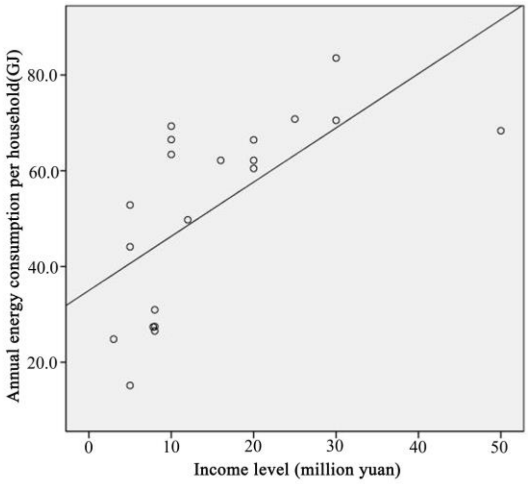
(R^2=0.570; r=0.755, p=0.004)

(b) Number of AC



(R^2=0.450; r=0.671, p=0.001)

(c) Number of guestroom



(R^2=0.437; r=0.661, p=0.001)

(d) Income level

Fig. 6-15 Scatter plot of total annual energy consumption per household and total building area, number of AC, number of guestroom, income level (n=20)

Table 6-5 Correlations between number of guestroom and energy consumption

		Annual total energy consumption per capita	Annual electricity consumption per capita	Annual LPG consumption per capita
Number of guestroom	Pearson	.732**	.719**	.476*
	p Value(2-tailed)	.000	.000	.034
	N	20	20	20

Note: *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the

0.01 level (2-tailed).

6.8 Summaries

Based on the above investigation and analysis, conclusions can be arrived at as follows:

(1) Energy consumption of ordinary households is about 3 to 5 times lower than that of rural tourism households. Electricity consumption of ordinary households is about 4.5 kWh/(m^2·y) in Quzhou, 6kWh/(m^2·y) in Anji, and 5.7kWh/(m^2·y) in Quzhou. Annual energy consumption of ordinary households per capita is about 9.54GJ in Quzhou, 7.62GJ in Anji, 3.66GJ in Zhoushan, which are lower than the average of rural residence in Zhejiang. Electricity consumption of rural tourism households is about 21.6kWh/(m^2·y) in Quzhou, 12.6 kWh/(m^2·y) in Anji and 31.2kWh/(m^2·y) in Zhoushan. Annual energy consumption of rural tourism households per capita is about 43.02GJ in Quzhou, 21.52GJ in Anji, 18.71GJ in Zhoushan, which is higher than the average level of rural residence in Zhejiang and actually, some residence are even higher than urban residence.

(2) Non-commercial energy consumption of ordinary households is high, while commercial energy consumption accounts for a small proportion. In these three regions, firewood accounts for 28.7% to 80.6%; electricity accounts for 8.6% to 36.6%; LPG accounts for 4.2% to 20.5%; solar energy accounts for 6.6% to 14.2%. In rural tourism households, firewood accounts for 59.9% to 66.7%; electricity accounts for 13.3% to 36.5%; LPG accounts for 8.2% to 31.3%; solar energy accounts for 11.5% to 32.3% in the three regions.

(3) Electricity consumption for heating and cooling in rural tourism households is higher than ordinary households, especially for cooling. In the three regions, electricity consumption for cooling in rural tourism households is about 24% to 39%. According to the field monitor which last for three days in a rural tourism household in summer, electricity consumption for heating and cooling takes up 55.8%. Electricity consumption for heating and cooling in ordinary households is very low, at about13% to 16%, in which heating is slightly higher than cooling. Cooking and hot water claim far higher energy consumption than others.

(4) Energy efficiency grade of air conditioner with less use frequency is relatively low, while that of the refrigerator, washing machine, electric cooker and others which have higher use frequency is high. It indicates that farmers prefer to adopt simpler energy conservation measures in the selection of electric appliances.

(5) For ordinary households, energy consumption is related to frequent used area, income level as well as permanent population. For rural tourism households, it is related to the total building area, number of AC, number of guestroom as well as income.

In a word, energy consumption of ordinary households in Zhejiang rural areas is very low. As a matter of fact, "green energy-saving" of them is achieved at the cost of comfort. In comparison, energy consumption of rural tourism households is high, which is even higher than urban residence. With the development of rural tourism industry in Zhejiang, there will be more pressure for rural building energy consumption in the future.

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Chapter 7.

Sensitive Analysis of Energy Saving in Rural Residential Buildings

7.1 Introduction

In recent years, facing the risk of global warming and the depletion of fossil fuels, reduction in energy consumption along with sustainable development has become a priority for many countries, including China. It is acknowledged that building energy consumption occupies about one-third of the total energy consumption all over the world and this figure may vary with the type and location of buildings [1]. Compared with urban residential buildings, rural residential buildings relying on self-built and self-sufficient energy supply are widely distributed in the rural areas of China. The field survey results in Chapter 6 indicated the low annual energy consumption of ordinary household, which is only 3.66 to 9.84GJ per capita, and the annual electricity consumption is 4.5 to 6kWh/m^2. However, energy consumption increases with the development of farmers' living standard. Energy consumption of rural tourism households is about 3 to 5 times higher than ordinary households, and even higher than urban residential buildings. According to the field survey, cooling energy consumption accounts for 24% to 39% of the total electricity consumption. With the rapid development of rural tourism, increasing ordinary households are engaged in rural tourism business, which is considered as an important way to prosper the rural economy [2]. Under this condition, the energy consumption caused by the adjustment of industrial structure in rural areas shall not be ignored.

The International Energy Agency (IEA), Energy in the Buildings and Communities Program (EBC), Annex 53 mentioned that (1) climate, (2) building envelope, (3) building energy and services systems, (4) indoor design criteria, (5) building operation and maintenance, and (6) occupant behavior are identified as the driving factors of energy use in buildings. Üllar Alev et al. conducted a combination of field measurements and simulations of renovation alternatives to improve energy performance of historic rural houses in three countries from these aspects [3]. This section mainly discussed the optimization strategies based on actual energy behavior: One is the energy consumption based on different building functions of ordinary household and rural tourism household, and the other is the energy consumption based on different building forms and regions.

7.2Phases and Methods

7.2.1 Phases

Three rural residential buildings are taken as examples: One is an ordinary household in Anji, which is planned to start rural tourism business. The other two are rural tourism households in Quzhou and Zhoushan, which have operated rural tourism business for several years. The research was carried out in the following phases: Simulation and comparison of the energy consumption based on different building functions; Simulation and comparison of the energy consumption based on different building forms and climate.

7.2.1.1 Energy Consumption Based on Different Building Functions

With the same building envelope, the electricity consumption of air-conditioners varied in different buildings. The difference was caused by the operating mode of the air conditioner. A building where the occupant kept the air conditioner running for longer durations or in larger spaces consumed more energy than that for a shorter period of time and/or in smaller spaces. Thus, the occupant is the influencing factor of the energy consumption. The survey in Chapter 4 shows that the thermal performance of the envelopes of rural residential buildings is poor, and it is not conductive to energy saving.

A typical rural residential building in Anji was chosen for study under two conditions: ordinary household and rural tourism household. Several strategies of improving envelope were analyzed, such as external walls, roofs and windows. In this study, the heating and cooling energy consumption was caused by the use of air conditioners, without considering the use of electric fan for cooling and firewood or other electric appliances for heating.

7.2.1.2Energy Consumption Based on Different Building Forms and Climate Zone

At present, most households operating tourism in rural areas are modern buildings and traditional vernacular buildings built after 1980s, which have different building forms and envelopes. Also, Quzhou and Zhoushan are significantly in terms of the outdoor climate. Quzhou belongs to the inland mountain area, while Zhoushan is on an island. Quzhou is hotter than Zhoushan in summer.

Two typical rural residential buildings operating rural tourism business were selected. One is located in Quzhou, and is a modern building built in 2011 for the purpose of operating rural tourism business. The other is a traditional vernacular building built in 1980s in Zhoushan. It was built for living at first, and then engaged in rural tourism business with the development of rural tourism in local area.

7.2.2 Study Method

Energy consumption was simulated by *Designbuilder* software, which has been introduced in Section 3.5 of Chapter 3. The location and climate of the site, basic situation of the buildings, people, and air condition system, were set according to the field survey. The questionnaire investigation results show that most tourists visiting the rural areas come from cities and towns, and they generally visit in summer. Also, they have higher living standards and have been used to use air conditioners. According to *Design Standard for Energy Efficiency of Residential Building in Zhejiang Province (DB 33/1015-2015) [4],* the temperature of the indoor air conditioner is set as 26°C in summer. The upper limit of the indoor temperature is 30°C. In winter, famers contribute the most to the heating energy consumption. The elders are not used to use air conditioner. According to *Design Standard for Design Standard for Energy Efficiency of Rural Residential Buildings (GB/T 50824-2013) [5],* the temperature of indoor air conditioner is set as 8°C in winter. The lower limit of the indoor temperature is 5°C.Young farmers use air conditioners for heating. According to *(DB 33/1015-2015)*

[4], the temperature of indoor air conditioner is set as 16°C.The lower limit of the indoor temperature is set as 12°C. The timetable of air conditioner is set according to the living styles of tourists and farmers. In other time, the buildings run under nature ventilation.

7.3 Strategies for Energy Saving Based on Different Building Functions

7.3.1Methodology

As shown in Table 7-1, the typical rural residential building was simulated under the conditions of ordinary household and rural tourism household, respectively. In the condition of ordinary household, the number of occupants, occupants' activities, and air conditioning system were set according to the average level on this site. Under the condition of rural tourism household, some parameters were the same as those of ordinary household, such as thermal performance of envelopes and air tightness. The number of tourists was set according to the number of bedrooms+1.

Different strategies of improving envelopes were adopted, including the thermal performance of external walls, roofs, windows, and air tightness. The simulation results were compared with the base building. Then, according to the energy saving rate, the efficient of different strategies was compared and the top 20 strategies were listed.

Table 7-1Condition of ordinary household and rural tourism household

Condition	People	Activity	HVAC
Ordinary household	Old couple	At home (whole year)	Not Use
	Young couples and Child	Work outside (weekend and holidays)	Use
Rural tourism household	Old couple	At home (whole year)	Not Use
	Young couples and Child	At home (whole year)	Use
	Tourists	Accommodation (April to November)	Use

7.3.2 Typical Building and Model Setting

7.3.2.1 Location and Climate of the Site

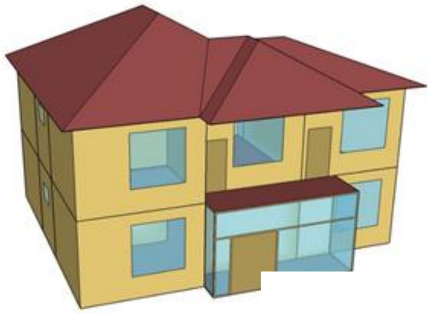
The typical building is located in Anji. Since the Energyplus database lacks hourly meteorological information of Anji, the meteorological data provided by the local government is incomplete. Therefore, the meteorological parameters of Hangzhou near Anji are chosen for simulation.

7.3.2.2 Description of the Building

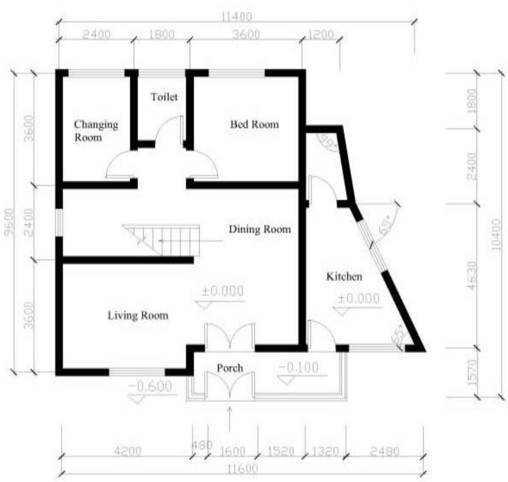
(1) Outline of the building

The typical building is a two-story rural residential building in Zhejiang rural area. The kitchen, bedroom for the elders, living room and dining room are on the first floor, and bedroom for the young couple, living room, study room and guest room are on the second floor(Fig.7-1). The building was built in 2005. The total building area is about 183m^2, and the area of the first floor is 90 m^2, with the height of 3m. The shape coefficient of the building is 0.64, and the window-to-wall ratio is 0.14.

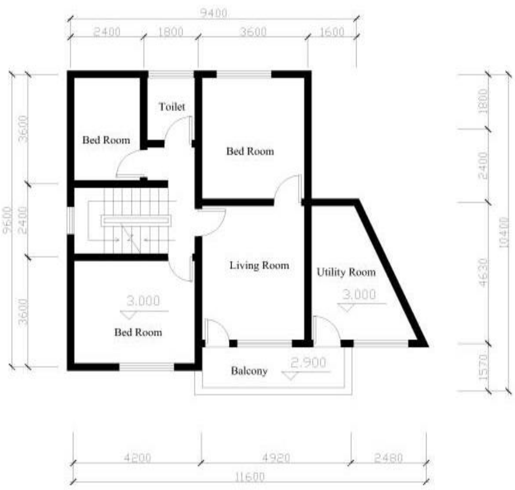
(a) The simulated building



(b)The model of the building



(c) The first floor



(d) The second floor

Fig.7-1 The model and plans of the typical building

(2) Materials and construction

Both of the external and internal walls were built with 240mm red solid bricks, without any insulation measures. The windows are made of common aluminum alloy with single-pane glass. The pitched roof is tile roof, putting tiles on purlins directly. The attic under the tile roof is mainly used to for storage. The floors are made of 120mm concrete precast hollow slab. The ground is a kind of overhead ground, and there is a 60mm overhead layer preventing from moisture.

The detailed description of the construction data assumed in *Designbuilder* is presented in Table 7-1 and Table 7-2, which is based on the investigation. The U-value and D-value were calculated according to the *Thermal design code for civil building(GB 50176)[6]*.

(3) Building airtightness and Infiltration

As there is no airtightness regulation in China and field measure on residential building, according to the *Design Standard for Design standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[5]*, the air permeability graduation should be higher than graduation 4, thus the value of graduation 4 was adopted in this simulation, Therefore, the corresponding air exchange rate was set as 0.7ac/h, respectively. The infiltration was obtained by means of examination and correction. Finally, the infiltration was 1ac/h.

Through the investigation, it is found that farmers kept the building ventilated by opening windows or doors in summer, namely, the natural ventilation. While in winter, they seldom opened windows or just opened the windows to a seam for fresh air entering into the indoor when the residential room was under occupation, thus there is no certain air exchange rate. According to the *Design Standard for Energy Efficiency of Residential buildings in Zhejiang Province (DB33/1015-2015)[4]*, the air exchange rate should be 1.0 ac/h when the air condition is in operation. This value was set the same as the zone ventilation value with the operation schedule of air-conditioner.

7.3.2.3 People

Based on the field investigation, there are commonly five members in a family, with the family structure of 2(elders)-2(young parents)-1(child). The young couple is migrant workers, and only comes back home in holidays or weekends. The elders are basically at home all the year round. Considering their daily life and sleep habits, the indoor occupants reach the maximum amount during meal time at 6:00~7:00am, 11:00~12:00am, and 5:00~6:00pm.

7.3.2.4 Equipment

As the development of rural area in China, TV, refrigerator, washing machine, electric heater, lampblack machine, and air conditioner are very common in ordinary household. Among them, the electric appliances, namely, air conditioner, small electric heater and electric fan, are concerned with the cooling and heating energy consumption of buildings. This building was very well equipped as a wedding house for their son in 2010. The elders seldom used the air conditioner. They mainly used the small electric heater and electric blanket for heating in winter, and electric fan for cooling in summer. The small electric heater and electric blanket are a kind of local heating equipment, and the effect area is very small. The principle of electric fan is to enhance the air flow to accelerate the evaporation of sweat of human body. Both of them have little influence on energy saving by improving the thermal performance of building envelopes. In this study, cooling and heating energy consumption refers to the energy consumed by the use of air conditioner.

(1) HVAC

The bedrooms, living rooms and guest rooms are equipped with split air conditioners. The heating and cooling set point was 16°C and 26°C in winter and summer, respectively. The operation schedule was set according to the field survey in Chapter 5.

(2) Electric equipment

The household appliances such as television, refrigerator, washing machine, cooking equipment and other electricity-consumed equipment known as “plug loads” can be specified. According to the investigation and the calibration of energy breakdown, the electric equipment gains were simplified set at the total design level. According to *(DB 33/1015-2015)[4]*, the average heat gain was 4.3W/m^2.

(3) Lights

In the lights statement of Energy Plus, the specified information that should be given includes the design power level and operation schedule, which were set based on the investigation. The energy-saving lights are very common in Zhejiang rural area, accounting for 75.6%. The light is set as 7W/m^2. The schedule of lighting in ordinary household was set at 6:00~7:00 and 18:00~21:00. Most tourists go to sleep at about 22:00, and get up at 6:00. The schedule of lighting in rural tourism household was set at 6:00~7:00 and 18:00~22:00.

Table 7-2 Parameters for simulation

Items	Contents
Climate	Typical meteorological year data of Hangzhou（from *Energy plus software*）
Building information	Latitude: N 30.23°; Longitude: E120.17°; Altitude: 41.70m; Orientation: North and South. Total building area:183m^2; Shape coefficient:0.640; Window-to-wall ratio:0.14
Building Construction	● External/ wall: 20mm composite mortar+240mm brick wall+20mm cement mortar, brick tile, U-value =2.10W/(m^2·K), D=3.64 ● Roof: tile+wood purlin, U-value =5.98W/(m^2·K), D=0.22 ● Floor:120mm Cast- in-place reinforced concrete slab, U-value =2.17W/(m^2·K), D=1.35 ● Ground: soil+200mm gravel cushion+120mm Cast- in-place concrete+20mm composite mortar + brick tile, U-value =2.22W/(m^2·K), D=1.23 ● Window: Aluminum alloy frame, U-value =6.4W/(m^2·K),SC = 0.85
Airtightness	● Ventilation schedules: door and windows always closed, Infiltration:1ac/h ● Airtightness: 0.7 ac/h

7.3.2.5 Model Validation and Correction

After the model definition and simulation parameters were input, the simulation results of indoor thermal environment should be verified by comparing with the field-measured results. If the simulated data are in the accordance with the field-measured data, the model can be used for the further simulation. Otherwise, it needs further calibration. The measurement was carried out in May. 2014, and the data from 8:00 May 28th to 8:00 on May 29th was selected for model validation and correction. The field measured temperature and the simulated temperature in the bedroom on the first floor was compared before further simulation. The results were shown in Fig.7-2.

The simulation temperature of the Bedroom(BD-ST) on the first floor was slightly higher than the field measurement result (BD -MT). The maximum fitting error between BD-ST and BD-MT was

2.3°C. Obviously, the field-measured and simulated temperature trends were similar. Thus, the simulation results of the model can predict the real situation to a large extent.

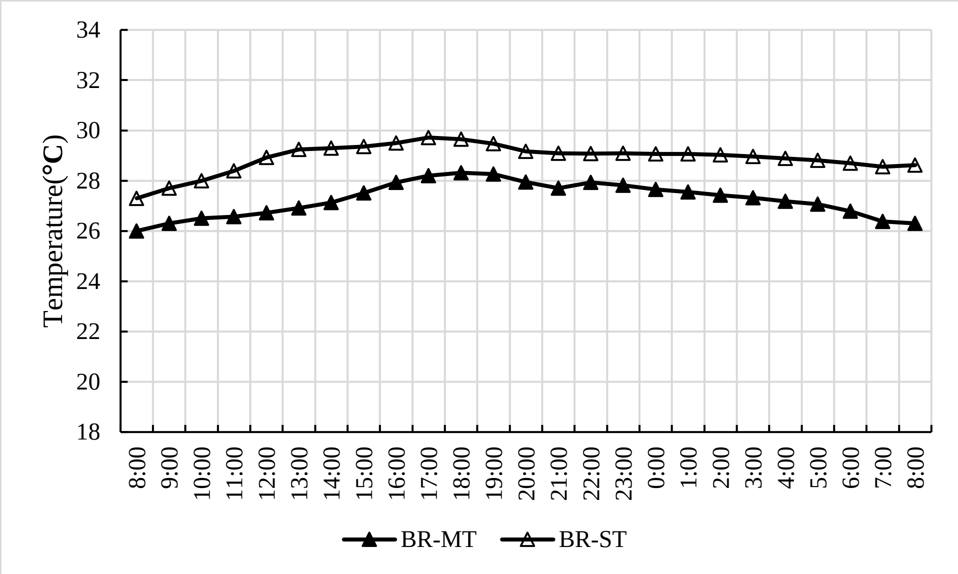


Fig.7-2 The simulation and field measurement results of living room (Anji)

7.3.3 Optimization Strategies for Envelops

The field surveys in Chapter 3 show that the poor thermal performance of building envelopes. The envelopes, external walls, roofs, windows are all the most important components. Heat preservation design mainly refers to the heat transfer coefficient of the envelopes and the thermal performance of envelope thermal bridges. The improvement of envelope thermal performance includes the external walls, roof, external windows (both frame and glazing), external doors, and the thermal bridge. If the heat transfer of the building is significantly higher than that of the surrounding materials. overall thermal insulation of the building will be reduced. *Design Standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[5]*regulates the limit value of heat transfer coefficient and the thermal inertia index of t building envelopes in HSCWZ, as shown in Table7-3. The current building envelope is lower than the standard, and the poor thermal performance would certainly consume more energy, leading to uncomfortable indoor thermal environment.

Table7-3 Limit value of heat transfer coefficient, thermal inertia index and shading coefficient

Zone	Heat transfer coefficient U (W/(m^2 • K)), thermal inertia index D and shading coefficient (SC)				
	External wall	Roof	Door	External windows	
				BR, LR	K, WC, S
HSCWZ	K≤1.8, D≥2.5; K≤1.5, D<2.5	K≤1.0, D≥2.5; K≤0.8, D<2.5	K≤3.0	K≤3.2	K≤4.7

Note: BR refers to bedroom, LR refers to living room, K refers to kitchen, S refers to storage room.

7.3.3.1 Walls

Modern buildings in Zhejiang rural areas were commonly built by solid clay bricks. Even so far, red solid bricks are still one of the most important wall materials in rural areas in Zhejiang. Since solid clay bricks will cause land destruction and environment pollution in the production process, China achieved the target of banning the use of clay brick in all the cities in 2010, and the ban has been gradually extended to small towns and rural areas. Also, solid clay brick will result in high energy consumption because of its poor thermal insulation performance.

There are three ways to optimize external walls:1) Draw the advantages of traditional building materials. For example, rammed earth is the most widely used building material in the history of construction, and there are still many adobe buildings in the world. Xi'an University of Architecture and Technology has carried out systematic research on the traditional rammed earth material, and fully utilized its characteristics of cool in summer and warm in winter in novel cave dwellings. 2) Make full use of a variety of new wall materials and thermal insulation system. The United States and developed countries in Europe focus on the use of new energy-saving technologies in the process of rural construction. At present, China's urban construction has taken active measures to promote the use of new wall materials. In addition, thermal insulation of external walls has become a widespread energy-saving measure for village buildings in China. 3) Adopt new materials to improve the deficiencies of traditional materials or traditional structures. 4) Minimize the influence of thermal bridges.

According to the actual situation in Zhejiang province, two kinds of possible measures were proposed: One is to improve the traditional walls, and the other is to utilize new wall materials. Therefore, three types of walls were proposed, and the bridge ratio was also considered in simulation. The thermal performance is as shown in Table 7-4.

The interior and exterior walls of the original building were built by 240mm solid bricks without any thermal insulation measure. It has t become a widespread energy-saving measure for Chinese rural buildings to improve the thermal insulation of exterior walls. The standard regulates that when the thermal inertia index of external walls is larger than 2.5, the U-value should be smaller than 1.8 (W/ ($m^2 \cdot k$)). According to the previous surveys, the thermal insulation mortar and board are generally used as the insulation materials for exterior walls in Zhejiang Province. Thus, inorganic thermal insulation mortar (ITIM) and EPS were selected as the insulation materials for simulation because of their low costs and good adhesive properties. The thermal conductivity of inorganic thermal insulation mortar is 0.085 W/ (m·k), with the thickness from 15mm to 40mm. The thermal conductivity of EPS is 0.042 W/ (m·k), with the thickness from 20mm to 60mm. In addition, the Chinese government is committed to promoting new wall materials in rural areas, especially the self-insulation wall materials, such as perforated brick, air brick and thermal insulation air brick, which have been widely used in cities and towns.

The thermal bridge ratio of traditional walls made of solid clay bricks with the thickness of 240mm is about 15%. Traditional walls, including solid wall and rowlock walls, were built in different ways. The self-insulation walls are made of new wall materials with the thickness of 240mm, and the bridge ratio of perforated brick, namely, the load bearing, is about 25%. In contrast, the bridge ratio of other unload-bearing walls is 35%.

Table 7-4 Heat transfer coefficient and thermal inertia index of different external walls

Types		Main Material/ Construction method	Thermal Insulation Material	Heat Transfer Coefficient (W/ ($m^2 \cdot k$))	Thermal inertia index
Traditional walls	TWa1	Brick,Solid	_______	2.10	3.64
	TWa2	Brick, Rowlock wall Ⅰ	_______	2.27	2.04
	TWa3	Brick,Rowlock wall Ⅲ	_______	2.23	2.47
	TWa4	Brick,Rowlock wall Ⅱ	_______	2.21	2.74
Improved traditional walls	IWa1	Brick,Solid	ITIM,15mm	1.71	3.55
	IWa2	Brick,Solid	ITIM,20mm	1.58	3.62
	IWa3	Brick,Solid	ITIM,25mm	1.47	3.69
	IWa4	Brick,Solid	ITIM,30mm	1.38	3.76
	IWa5	Brick,Solid	ITIM,35mm	1.33	3.81
	IWa6	Brick,Solid	ITIM,40mm	1.22	3.91
	IWa7	Brick,Solid	EPS,20mm	1.14	3.5
	IWa8	Brick,Solid	EPS,30mm	0.91	3.58
	IWa9	Brick,Solid	EPS,40mm	0.76	3.65
	IWa10	Brick,Solid	EPS,50mm	0.65	3.73
	IWa11	Brick,Solid	EPS,60mm	0.57	3.81
New material walls	NWa1	Perforated Brick	_______	1.93	3.01
	NWa2	Air Brick Ⅰ	_______	1.79	3.45
	NWa3	Air Brick Ⅱ	_______	1.62	3.9
	NWa4	Thermal Insulation Air Brick	_______	1.52	5.04

7.3.3.2 Attic and Roofs

According to the analysis of indoor thermal environment in Chapter 4, it can be seen that the thermal environment of the top-floor is the poorest compared with other rooms. Therefore, the vacancy rate of the top floor room is high, and the waste is serious. It is quite urgent to improve the indoor thermal environment of the room on the top floor. Roof transformation can be realized by setting insulation layer, green roof and ventilation double roof. These effective measures can be easily promoted. From the perspective of preventing heat transfer, all of them can increase the thermal resistance of the structural layer (XPS insulation board, covering vegetation layer or air layer, etc.) to meet the needs of protecting heat in summer and preserving heat in winter.

In Zhejiang rural areas, the tile roof is most commonly used, laying the tiles on the wooden purlins directly without any wooden sheathing (the original roof). Some roofs are built with cast-in concrete slab. Both of them are poor in thermal insulation (U-value 5.98 (W/ ($m^2 \cdot k$)). Attic is very common in rural residential buildings, and it is set on the top mainly for storing things in local area. The standard regulates that when the thermal inertia index of roof is smaller than 2.5, the U-value should be smaller than 0.8 (W/ ($m^2 \cdot k$)). EPS was selected as the thermal insulation material for simulation. The thickness of thermal insulation material and the thermal performance are as shown in Table 7-5.

Table 7-5 Heat transfer coefficient of different roofs (W/ ($m^2 \cdot k$))

Types	Main Material	Thermal Insulation Material	Heat Transfer Coefficient
Original	Tile+Purlin	________________	5.98
Rf1	RC roof slab	________________	3.72
Rf2	RC roof slab	EPS 20mm	1.57
Rf3	RC roof slab	EPS 30mm	1.22
Rf4	RC roof slab	EPS 40mm	1.00
Rf5	RC roof slab	EPS 50mm	0.84
Rf6	RC roof slab	EPS 60mm	0.73
Rf7	RC roof slab	EPS 70mm	0.65
Rf8	RC roof slab	EPS 80mm	0.58
Rf9	RC roof slab	EPS 100mm	0.48

7.3.3.3 Floors and Ceilings

There is no specific regulation of the U-value of floors/ceilings for rural residential buildings. Floors/ceilings regarding the simulation was mainly compared. The overhead ground and floors are made of precast concrete slab with the thickness of 120mm.The floors are improved by laying inorganic thermal insulation mortar (ITIM) on the top floor with the thickness from 20mm to 60mm. The thermal performance of different floors is shown in Table7-6.

Table 7-6 Heat transfer coefficient of different floors/ceilings (W/ ($m^2 \cdot k$))

Types	Main Material	Thermal Insulation Material	Heat Transfer Coefficient
Original	Precast concrete slab	__________	2.30
Fl1	Precast concrete slab	ITIM 20mm	1.67
Fl2	Precast concrete slab	ITIM 30mm	1.55
Fl3	Precast concrete slab	ITIM 40mm	1.44
Fl4	Precast concrete slab	ITIM 50mm	1.35

Fl5	Precast concrete slab	ITIM 60mm	1.27

7.3.3.4 Windows

Windows are the weakest components in a building, where heat goes through easily. The results of computer simulation show that more than 30% of the heat loss in winter occurs at windows[7]. Besides controlling the window-to-wall ratio, windows can be optimized by adopting new windows system and improving the traditional windows by enhancing the heat transfer coefficient and the solar heat gain coefficient.

Table 7-7 Performance of different windows

Types	Material	Heat Transfer Coefficient U, W/ (m^2·k)	Solar Heat Gain Coefficient
original	Aluminum alloy frame; Single-glazing	6.5/5.7	0.82
Wi1	Aluminum alloy frame; Heat absorbing glass (blue, 6mm)	6.5/5.7	0.62
Wi 2	Aluminum alloy frame; High reflective glass (6mm)	6.5/5.7	0.56
Wi 3	Aluminum alloy frame; Hollow glazing	4/2.8	0.75
Wi 4	Aluminum alloy frame; Hollow glazing	4/2.8	0.47
Wi 5	Aluminum alloy frame; Hollow glazing	4/2.4	0.29
Wi 6	Thermal break aluminum alloy frame; Low-e hollow-high transmission glazing	3.2/1.8	0.47
Wi7	Thermal break aluminum alloy frame; low-e hollow transmission glazing	3.2/1.8	0.37(middle transmission)
Wi8	Thermal break aluminum alloy frame; Low-e hollow glazing	3.2/1.8	0.2(low transmission)

Single-layer glass windows with large window-to-wall ratio are commonly sued in rural residential buildings, especially in modern buildings. These windows are also poorly sealed and the heat loss is significant due to the substantial infiltration of cold air. The heat transfer coefficient of a window with single-layer glass is about 5.7 W/ (m^2·k), which is much higher than that of windows typically used in urban buildings (U-value 2.8 W/ (m^2·k)). Windows made of aluminum alloy frame with single glass are very common in local area. Aluminum alloy thermal break frame is widely used in cities but rarely used in rural areas for its high cost, let along the hollow glass and low-e glass, etc. The heat transfer coefficient, solar heat gain coefficient and shading coefficient of windows are the main factors affecting the energy consumption. Air permeability is assumed to be the same in the simulation.

According to *Design Standard for energy efficiency of rural residential buildings (GB/T 50824-2013)[5]*, U-value of external windows in hot summer and cold winter should be larger than 3.2W/ (m^2·k) for bedroom and living room, larger than 4.7 W/ (m^2·k)for kitchen, washing room and storage room. The thermal performance of different windows is listed in Table 7-7. Single glazing windows with aluminum alloy frame from original windows to Wi2 have the same heat transfer coefficient but different shading coefficients. Hollow glazing windows with aluminum frame from Wi3 to Wi5 have similar heat transfer coefficient but different shading coefficients. Thermal break aluminum alloy frame windows from Wi 6 to Wi 8 have three different levels of transmission glazing, with similar heat transfer coefficient but different shading coefficients.

7.3.3.5 Airtightness

There is no standard about airtightness of buildings in China, instead of the requirements of airtightness for doors, windows and curtain walls. The reason is probably that most of the existing buildings are built by masonry or cast-in-place concrete in China. The air exchange rate (ACH) can reach 1 to 1.5ac/h in winter, which is also higher than that in urban buildings[7]. The standard [8] divides the airtightness of doors and windows into eight grades, according to the volume of air flow through the unit joint length of the opening part (m^3/(m·h)) and the volume of air flow through a unit area(m^3/(m^2·h)). Besides, air exchange rate shall be different in different zones and seasons. For urban residential buildings, it is 0.5ac/h in cold areas in winter, and 1 ac/h in hot-summer and cold-winter areas and hot-summer and warm-winter areas. For rural residential buildings in cold areas, it is 0.5 ac/h in winter. In hot-summer and cold-winter areas, it is 1 ac/h in winter and 5ac/h in summer.

7.3.4 Simulation Results

7.3.4.1 Walls

The heat transfer coefficient of the external walls ranges from 2.10W/ (m^2·k) to 0.57W/ (m^2·k) with the thermal insulation performance improved by about 3.7-fold. The annual energy consumption of cooling and heating were calculated in ordinary household condition and rural tourism household, respectively. The results are shown in Fig.7-3.

In the condition of ordinary household, the annual cooling and heating energy consumption of base building is 901.5kWh. The traditional walls are not conducive to building energy efficiency. The energy consumption increased by 0.7% for TWa2 and TWa3, and 0.1% for TWa4. The annual cooling and heating energy consumption decreased obviously by improving traditional walls and adopting new material walls. From IWa1 to IWa11, the energy consumption decreased from 5.9% to 22.7%. From NWa1 to NWa4, the energy consumption decreased from 3.3% to 7.5%.

In the condition of rural tourism household, the annual cooling and heating energy consumption of base building is 7622.2kWh. In the case of traditional walls, the energy consumption increased 1.0% for TWa2, 0.5% for TWa3, and 0.3% for TWa4. The annual cooling and heating energy consumption also decreased obviously by improving traditional walls and adopting new material walls. From IWa1 to IWa11, the energy consumption decreased from 5.1% to 20.6%. From NWa1 to NWa4, the energy consumption decreased from 2.7% to 7.2%.

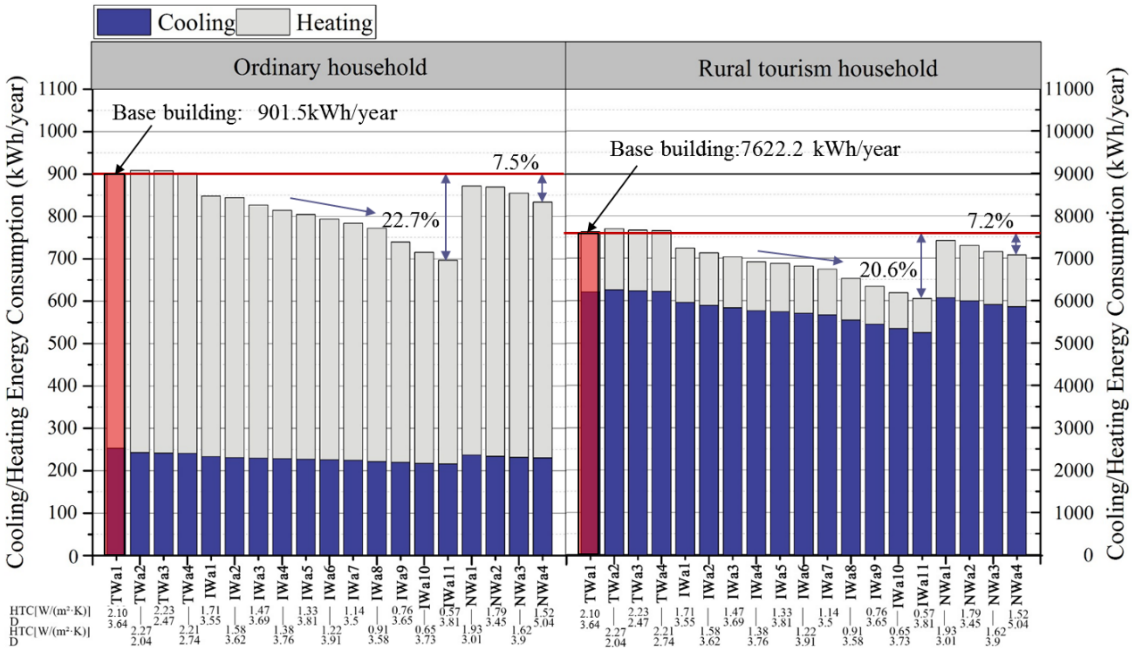


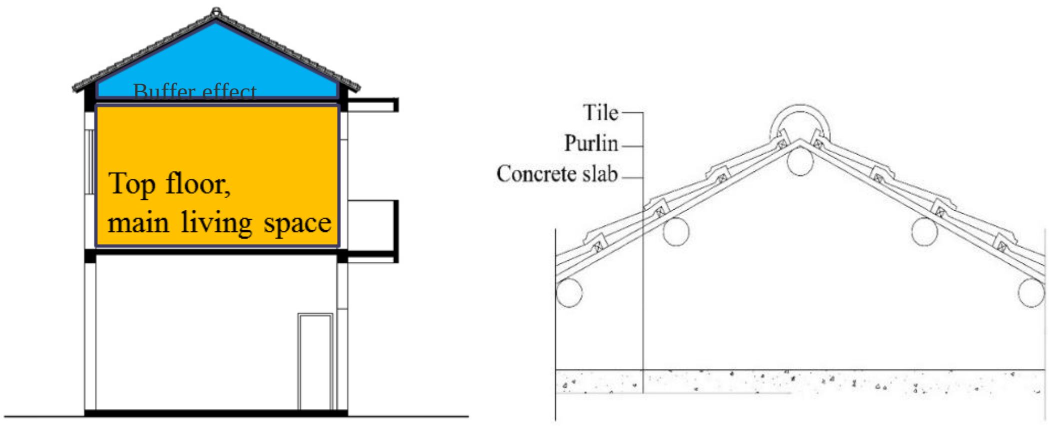
Fig.7-3Energy saving by improving walls under OH condition and RTH condition

It is apparent that both cooling and heating energy consumption were decreased by improving traditional walls or using self-insulation walls. The heating energy consumption of rural tourism household decreased more sharply compared with the ordinary household. This indicates that the thermal performance of building envelope can significantly influence the cooling and heating energy saving. In addition, it is apparent from the figure that the heating consumption decreased more sharply than cooling consumption, although the cooling and heating energy saving rate of ordinary household is higher than that of rural tourism household. However, the original cooling and heating energy consumption of base building of rural tourism household is about 8.5 times higher than ordinary household. Therefore, the total energy saving will be greater.

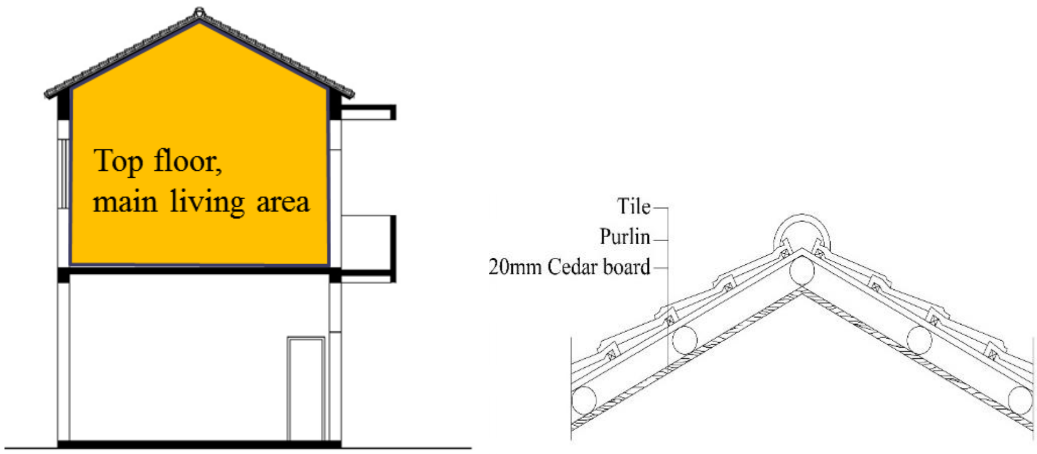
7.3.4.2 Roofs

From Rf1 to Rf9, the EPS thickness ranges from 0mm to 100mm, with the heat transfer coefficient ranging from 5.98W/(m^2·k) to 0.48 W/(m^2·k). The top floor of the building is shown as Fig. 7-4, a. The annual cooling and heating energy consumption is as shown in Fig.7- 5,a. Under the two conditions, the annual energy consumption was reduced, but the energy efficiency was not obvious. It can be seen that the further improvement of the roof had no effect on energy saving of the whole building. On the contrary, the energy consumption increased slightly. This is because the thermal insulation of air layer in attic plays a buffer effect. Furthermore, the improvement of the attic floor by using ITIM with thickness from 0mm to 60mm, the heat transfer coefficient ranges from 2.30W/ (m^2·k) to 1.27 W/ (m^2·k), which is about 1.8-fold. However, the annual cooling and heating energy consumption changed slightly.

Top floor B is also very common in rural residential buildings. By improving the thermal performance of roof, the annual cooling and heating energy consumption obviously decreased. However, the annual cooling and heating energy consumption of the base building increased. In the condition of ordinary household, the annual cooling and heating energy consumption of the base building is 1771.17kWh, which decreased by 20.3% from original roof to Rf9. In the condition of rural tourism household, the annual cooling and heating energy consumption of the base building is 8225.38kWh, which decreased by 33.7% from the original roof to Rf9.

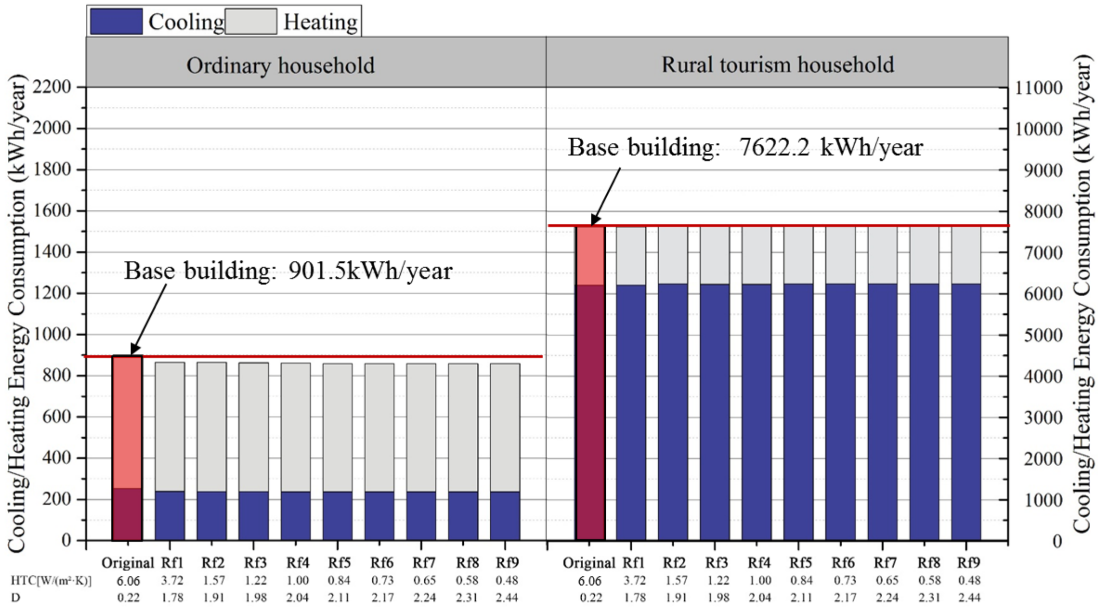


(a) Top floor A

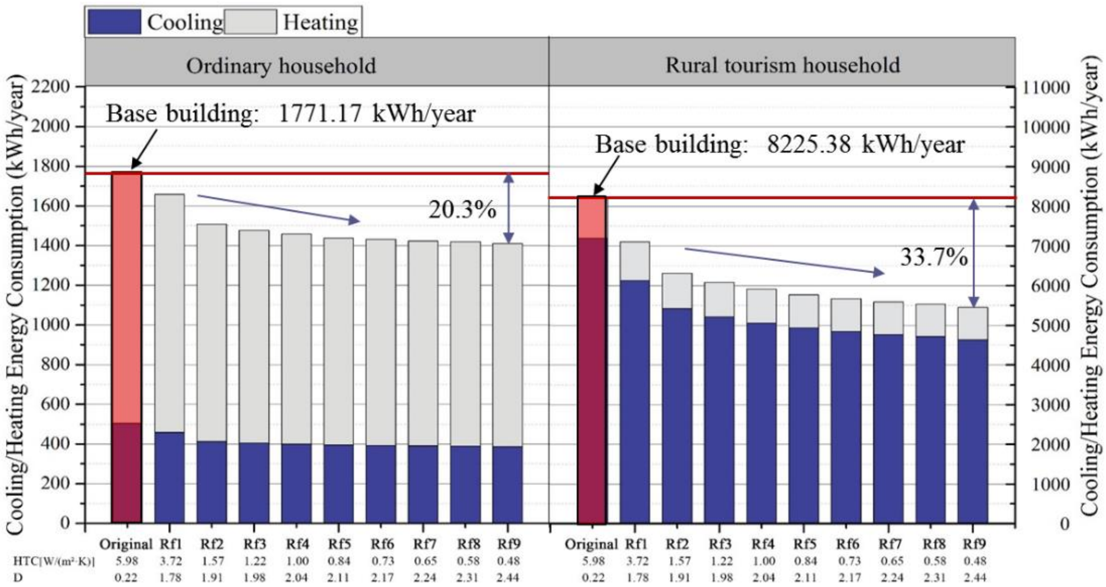


(b) Top floor B

Fig. 7-4 Different forms of top floor



(a) Top floor A



(b) Top floor B

Fig.7- 5 Energy saving by improving roofs under OH condition and RTH condition

7.3.4.3 Windows

In the condition of OH, the measures of improving the thermal insulation performance or SHGC have little influence on the energy consumption. From the original window to the Wi8, the cooling energy consumption decreased, but the heating energy consumption increased, except for Wi3 and Wi6. The annual cooling and heating energy saving rate ranges from 0.2% to 5.3%. The maximum rate is Wi7 for the thermal break aluminum alloy frame (U=3.21W/ ($m^2 \cdot k$)) with low-e hollow-middle transmission glazing (SHGC 0.37). When the SHGC is kept fixed and the thermal performance is improved, the total energy consumption decreased obviously than the case that the U-value is fixed and SHGC is improved. This indicates that it is more useful to improve U-value than improving SHGC in the condition of OH.

Under the condition of RTH, it is obvious that the energy saving rate is higher than that of OH. It is apparent that the heating consumption changes more significantly than the cooling consumption. From the original window to the Wi8, the cooling energy consumption decreased, but the heating energy consumption increased, except for Wi3 and Wi6. The annual cooling and heating energy saving rate ranges from 3.6% to 17.5%. When U-value is kept fixed but SHGC is reduced, the energy consumption of RTH is more obvious than that of OH. It indicates that improving SHGC is more favorable than improving U-value under the condition of RTH and improving SHGC is more beneficial under RTH condition than OH condition.

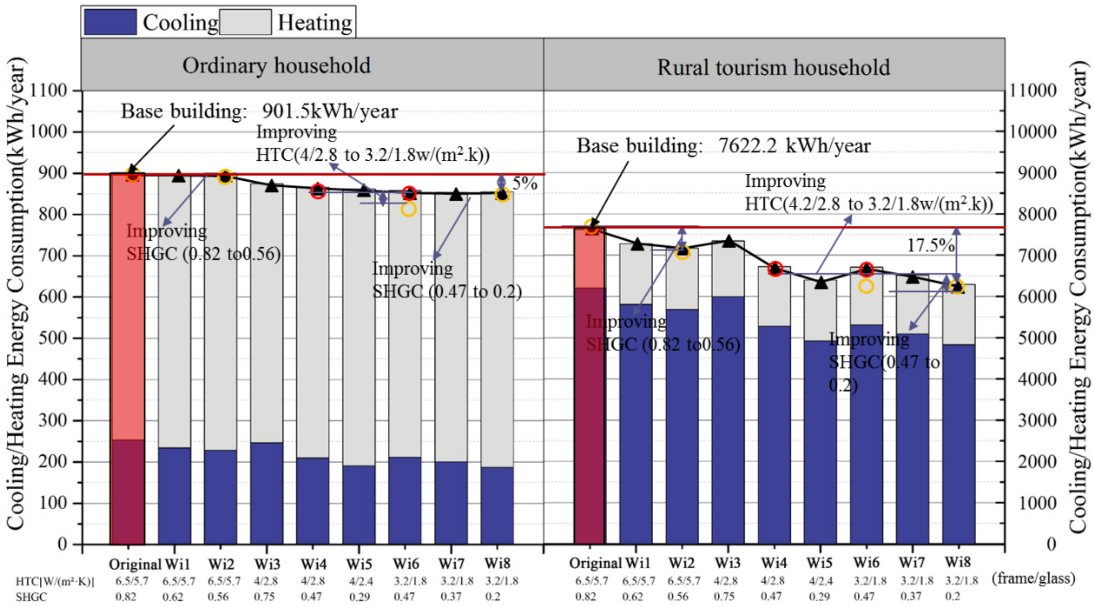


Fig.7-6Energy consumption by improving windows under OH condition and RTH condition

7.3.4.4 Airtightness

The energy consumption was simulated according to different air exchange rates from 0.3 ac/h to 1.5 ac/h. The original airtightness of the base building was 0.7ac/h. The annual cooling and heating energy consumption is shown in Fig.7-7. By improving the building airtightness, the heating consumption changes more obviously than cooling consumption. Also, in the condition of RTH, the energy saving rate raised more quickly than OH condition.

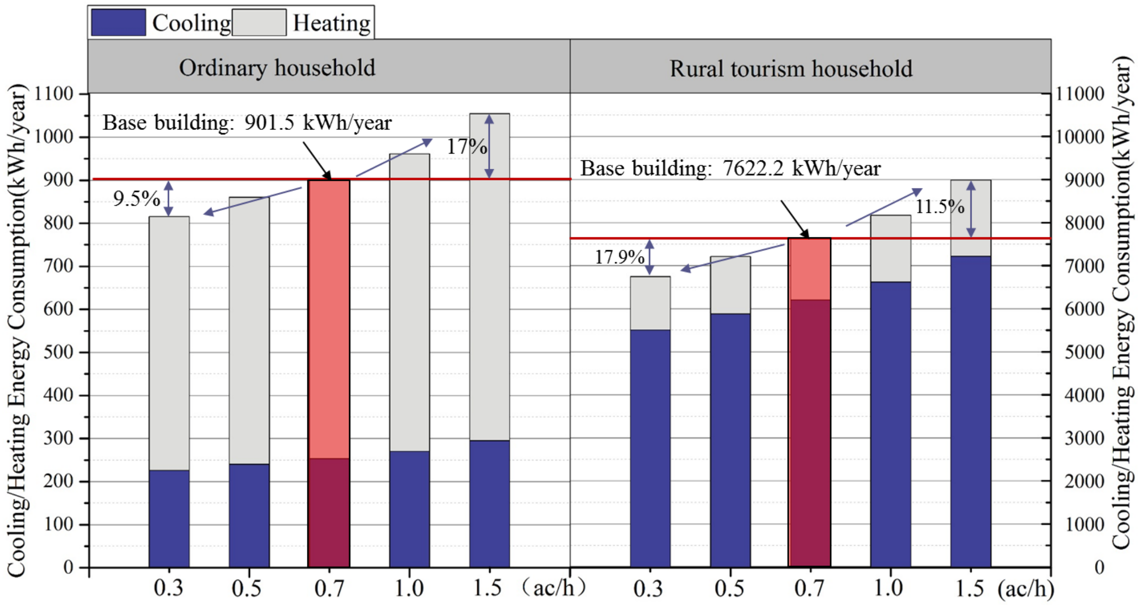


Fig.7-7Energy consumption by improving airtightness under OH model and RTH model

Table 7-8 The priority strategies for OH and RTH (TOP 20)

Priority strategies		1	2	3	4	5	6	7	8	9	10
OH	Strategies	IWa11	IWa10	IWa9	IWa8	IWa7	IWa6	IWa5	IWa4	AT1	IWa3
	W/(m²·k)	0.57	0.65	0.76	0.91	1.14	1.22	1.33	1.38	0.3ac/h	1.47
	ESR (%)	22.7	20.6	18.0	14.4	13.0	11.9	10.8	9.6	9.5	8.3
RTH	Strategies	IWa11	IWa10	Wi8	IWa9	Wi5	Wi7	IWa8	Wi6	Wi4	IWa7
	W/(m²·k)	0.57	0.65	3.2/1.8, 0.2	0.76	4/2.4,0.29	3.2/1.8, 0.37	0.91	3.2/1.8,0.47	4/2.8,0.47	1.14
	ESR	20.6	18.8	17.5	16.9	16.1	14.5	14.4	12.0	11.8	11.5
Priority strategies		11	12	13	14	15	16	17	18	19	20
OH	Strategies	NWa4	IWa2	IWa1	Wi7	NWa3	Wi8	Rf7	Rf6	Rf5	Wi6
	W/(m²·k)	1.52	1.58	1.71	3.2/1.8, 0.37	1.62	3.2/1.8, 0.2	0.65	0.73	0.84	3.2/1.8, 0.47
	ESR (%)	7.5	6.3	5.9	5.3	5.1	5.1	4.9	4.9	4.8	4.8
RTH	Strategies	AT1	IWa6	IWa5	IWa3	IWa4	NWa4	IWa2	NWa3	Wi2	AT2
	W/(m²·k)	0.3 ac/h	1.22	1.33	1.47	1.38	1.52	1.58	1.62	6.5/5.7, 0.56	0.5ac/h
	ESR	11.5	10.6	9.8	9.3	7.7	7.2	6.5	6.1	6.0	5.4

Note: ESR refers to total cooling and heating (C+H) energy saving reduced rate.

Under the condition of OH, when the air exchange rate was increased from 0.7ac/hto 0.3 ac/h, both cooling and heating energy consumption decreased. The annual cooling and heating energy consumption decreased from901.5kWh to 815.6kWh, and the energy saving rate was 9.5%. However, when the air exchange rate increased to 1.5ac/h, both cooling energy consumption and heating energy consumption increased. The annual cooling energy consumption and heating energy consumption increased to 1054.5kWh with an increase of 17%.

In the condition of RTH, when the air exchange rate was enhanced from 0.7ac/hto 0.3 ac/h, both cooling and heating energy consumption increased. The annual cooling and heating energy consumption reduced to 6744.2kWh, and the energy saving rate was 11.5%. When the building airtightness is better, the cold air infiltration will be fewer, and the heating energy consumption will be lower. However, when the air exchange rate increased to 1.5ac/h, both of cooling and heating energy consumption increased sharply. The annual heating and cooling energy consumption was increased to 8984.7kWh with an increase of 10.65%.

7.3.4.5 Priority strategies

According to total annul cooling and heating energy consumption, the top 20 priority strategies were listed in Table 7-8. It shows that, in the condition of OH, the most effective measure is to improve the thermal insulation performance of the external wall, and U-value was from 0.57 W/(m^2·k) to 1.71W/(m^2·k). The second is to improve the building airtightness(0.3ac/h). The third is to improve the thermal performance of windows, with thermal break aluminum alloy frame(3.2W/(m^2·k)), and low-e hollow-middle transmission glazing (1.8 W/ (m^2·k)), SHGC 0.37~0.2. Compared with GB/T 50824-2013, the U-value of external wall for 1.8W/(m^2·k), and 3.2W/(m^2·k) for windows in living-room and bedroom are required.

Under the condition of RTH, the most effective measure is also to improve the thermal insulation performance of the external wall, but U-value is lower (from 0.57 W/(m^2·k) to 1.62W/(m^2·k). The second is to improve the building airtightness(0.3ac/h), which is more effective than windows. The third is to improve the thermal performance of windows, with thermal break aluminum alloy frame(3.2W/(m^2·k)), and low-e hollow-middle transmission glazing (1.8 W/ (m^2·k)), SHGC 0.2. Compared with GB/T 50824-2013, the requirements on envelops are stricter. Due to the actual function of MB-1 exchange form ordinary household to rural tourism household, the energy consumption increased greatly, which means that it needs better thermal performance of envelopes.

7.4Strategies for Energy Saving Based on Different Building Forms and Regions

7.4.1 Methodology

Two typical buildings were selected as examples for further simulation and analysis. One was a three-story traditional vernacular building in Zhoushan, which was built by local granite stone in 1980s. The other was a four-story modern rural building, which was built by solid bricks in 2011.

In this study, the two buildings were simulated and compared by different strategies and in different regions. First of all, the annual cooling and heating energy consumption was simulated according to the original situation and climate zone. Afterwards, the energy consumption was simulated by taking different strategies in Quzhou and Zhoushan, respectively.

In the study of Section 7.3, the results show that the improvement of thermal performance of external walls, windows and airtightness has an obvious effect on saving energy consumption. According to the research results of Section 7.3.5 and the standards of *DB 33/1015-2015[4], GB/T 50824-2013[5]*and *GB 50189-2015[9]*, finally four levels of thermal performance of envelopes were chosen and listed in Table 7-9.

Table 7-9 Thermal performance of envelopes in different levels

Types		Level 1	Level 2	Level 3	Level4
Thermal performance of envelopes (U, W/(m^2·K))	External walls	1.8	1.5	1.0	0.8
	Roof	1.0	1.0	0.7	0.5
	Windows	3.2	2.8	2.8	2.6

7.4.2 Typical Buildings and Model Setting

7.4.2.1 Typical Buildings

(1) Modern building (MB-1) in Quzhou

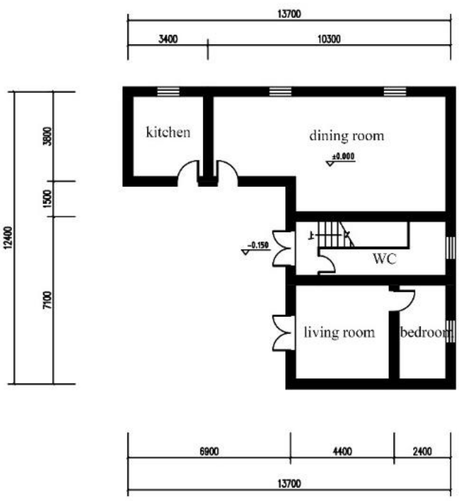
The typical building (MB-1) is located in Xiachen Village of Quzhou City, and it is a typical rural tourism management household in local place. It is a four-story building built in 2011 with 240mm solid brick wall, cast-in-place reinforced concrete floor 100mm thick, ordinary aluminum alloy glass windows and doors, and tile attic roof. The living room, dining room, reception, and kitchen are on the first floor. The floors above the second floor are guestrooms. The indoor thermal environment of MB-1 has been studied in Chapter 5.

MB-1 has 12 guestrooms. Most of the guestrooms were equipped with electric fans and air conditioners. The fee for air conditioner has not been included in the total price, and tourists have to pay if they want to use the air conditioners. Farmers rarely use air the conditioner in winter, and mainly rely on charcoal for heating.

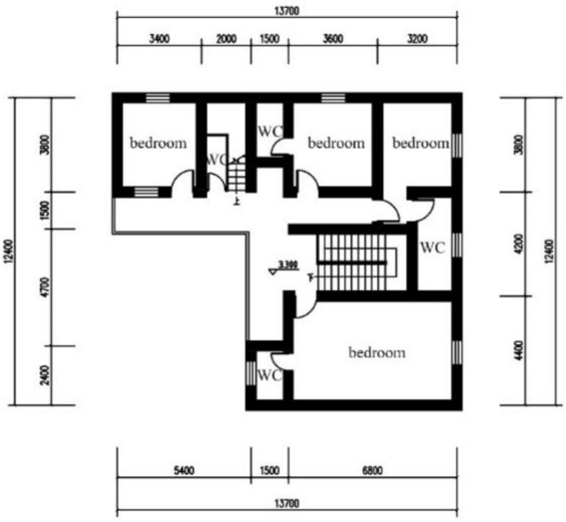
(2) Traditional vernacular building (TVB-4)

The typical building which is a traditional vernacular building (TVB-4) locates in a typical rural tourism village in Zhoushan City. It is a three-story building made of 400 granite walls, 25mm rosewood board for the floor, and 120mm cast-in-place concrete slab for the roof and terrace. The living room, dining room, reception, and kitchen are on the first floor. The guestrooms are on the second floor and third floor. Fig.7-8 shows the building plans of the typical building.

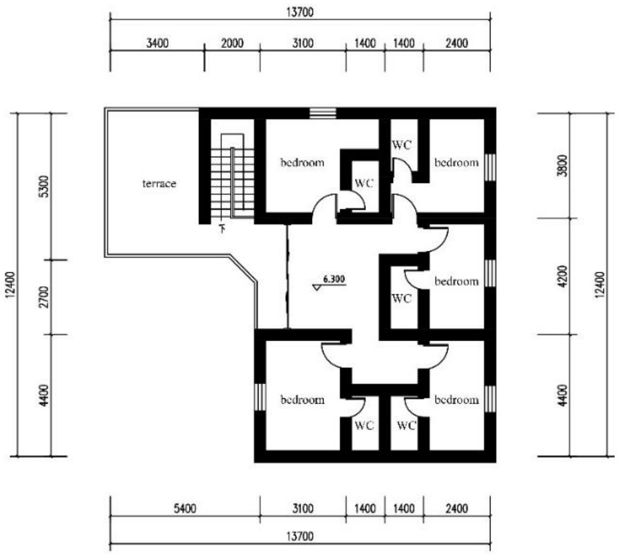
It started rural tourism business from 2004, and has 9 guestrooms equipped with air conditioners without electric fan. The fee for air conditioner is included in the total price. LPG and electricity are the main energy resource for cooking. The hot water for tourists is heated by air-source heat pumps and solar water heater.



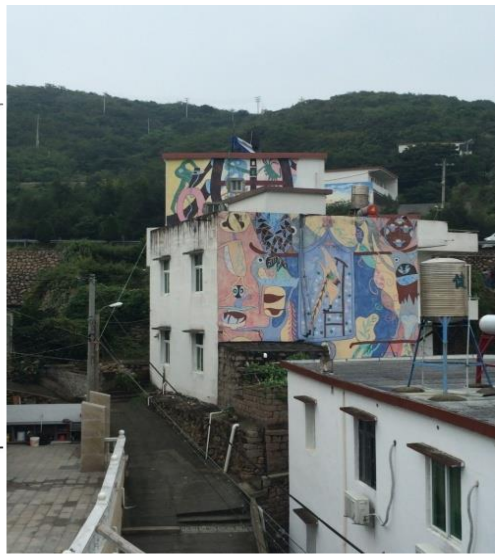
(a) First floor



(b) Second floor



(c) Third floor



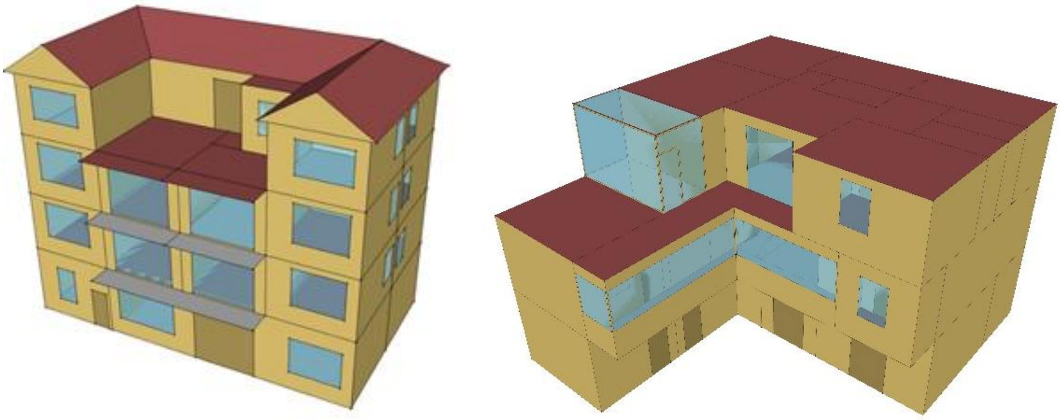
(d) TVB-4

Fig.7-8 The building plan of TVB-4

7.4.2.2 Model Setting

(1) Parameters

The models were built according to the building plan of each building. The original parameters were listed in Table 7-10 and Table 7-11. The target indoor temperature of the guestroom in the cooling season was set at 26°C and only 16°C in the heating season in the farmers' bedroom. The use of domestic hot water (DHW) was 45 l/(d·person). The number of tourists was calculated according to the number of beds. The temperature difference of domestic hot and cold water was 50°C. Internal heat gains were set as 4.3W/m^2 in the occupied room according to *DB33/1015-2015[4]*. The schedule was set according to the tourists' living style. The air exchange rate was 1 ac/h. The models are as shown in Fig.7-9.



(a) The model of MB-1 (b) The model of TVB-4

Fig.7-9 The models of MB-1 and TVB-4

Table 7-10 Simulation parameters for original MB-1

Items	Contents
Climate	Typical meteorological year data of Quzhou（from Energy plus software）
Building information	Latitude: N28°44′2.60″; Longitude: E118°55′42.01″; Altitude:701m, Orientation: NW 11 degree; Total building area: 577.3m^2; Shape coefficient: 0.52； Window-to-wall ratio:0.20.
Building Construction	● External wall: 20mm composite mortar+240mm brick wall+20mm cement mortar, brick tile, U-value =2.10W/(m^2·K), D=3.64 ● Internal wall: 20mm composite mortar+240mm brick wall+20mm cement mortar, U-value =1.78W/(m^2·K), D=3.64 ● Roof: tile+wood purlin, U-value =5.98W/(m^2·K), D=0.22 ● Floor:120mm Cast- in-place reinforced concrete slab, U-value =2.17W/(m^2·K), D=1.35 ● Ground: soil+200mm gravel cushion+100mm Cast- in-place concrete+20mm composite mortar+brick tile, U-value =2.22W/(m^2·K), D=1.23 ● Window: Aluminum alloy frame, U-value =6.4W/(m^2·K),SC = 0.85
Airtightness	● Ventilation schedules: 1ac/h ● Airtightness: 0.7 ac/h
Tourists	● 24 tourists+4 family members

Table 7-11 Simulation parameters for original TVB-4

Items	Contents
Climate	Typical meteorological year data of Dinghai (from Energy plus software)
Building information	Latitude: N 30.03°; Longitude: E122.12°; Altitude: 37m; Orientation: North and South; Total building area:261.83m^2; Shape coefficient:0.87; Window-to-wall ratio:0.09, room height:3m
Construction	● External wall: 20mm composite mortar+400mm brick wall+20mm cement mortar, brick tile, U-value =3.25W/(m^2·K), D=3.41 ● Flat roof and floor:100mm Cast- in-place reinforced concrete slab, U-value =2.17W/(m^2·K), D=1.35 ● Ground: soil+200mm gravel cushion+100mm Cast- in-place concrete+20mm composite mortar + brick tile, U-value =2.22W/(m^2·K), D=1.23 ● Window: Aluminum alloy frame, U-value =6.4W/(m^2·K),SC = 0.85
Airtightness	● Ventilation schedules: 1ac/h ● Airtightness: 0.7 ac/h
Tourists	● 23 tourists+4 family members

(2) Model validation and correction

The field measurement of indoor thermal environment in MB-1 was carried out in Jan. 2016, and the data from0:00 to 24:00 on January 20th was selected for model validation and correction. The outdoor air temperature and relative humidity of the weather file of Quzhou were replaced by the field-measured data. The simulation was conducted by using the weather data. The living-room on the first floor was selected for comparison. Doors and windows were always closed during the measurement, except the meal time. The results were shown in Fig. 7-10. The simulation temperature of the living room(LR-ST) on the first floor was slightly higher than the field measurement result (LR-MT). The maximum fitting error between LR-ST and LR-MT was 3.4°C. Obviously, the field-measured and simulated temperature trends were similar. Thus, the simulation results of the model can predict the real situation to a large extent.

The field measurement of indoor thermal environment in TVB-4 was carried out in Sep. 2016, and the data from 0:00 to 24:00 on September 5th was selected for model validation and correction. The bedroom on the second floor was selected for comparison. Doors and windows were always closed and the farmers didn't use air conditoner during the measurement. The results were shown in Fig. 7-11. The simulation temperature of the bedroom(BD-ST) was slightly higher than the field measurement result (BD-MT). The maximum fitting error between BD-ST and BD-MT was 3.5°C. The simulation results of the model can predict the real situation to a large extent.

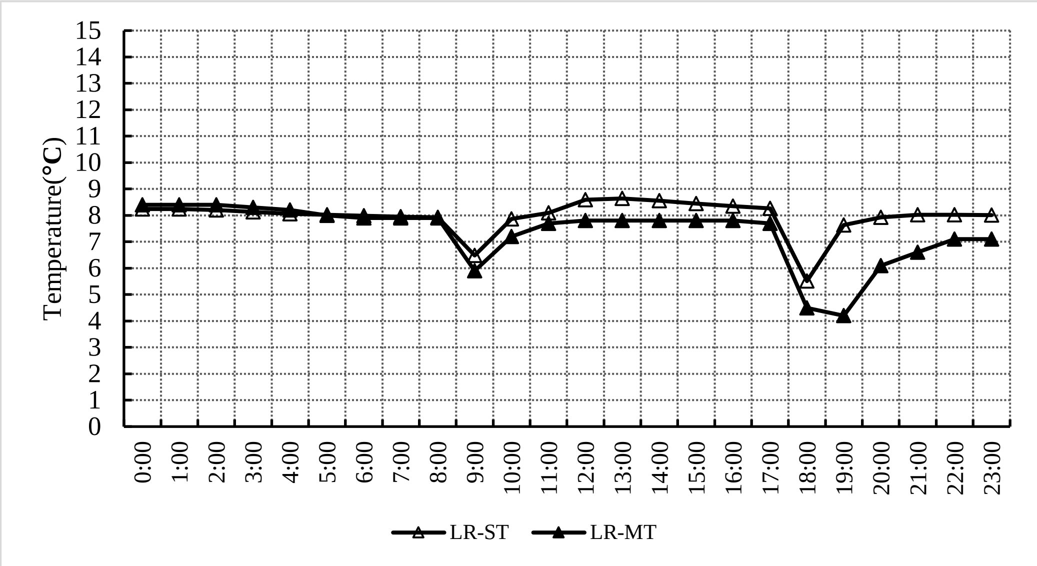


Fig. 7-10 The simulation and field measurement results of living room (MB-1)

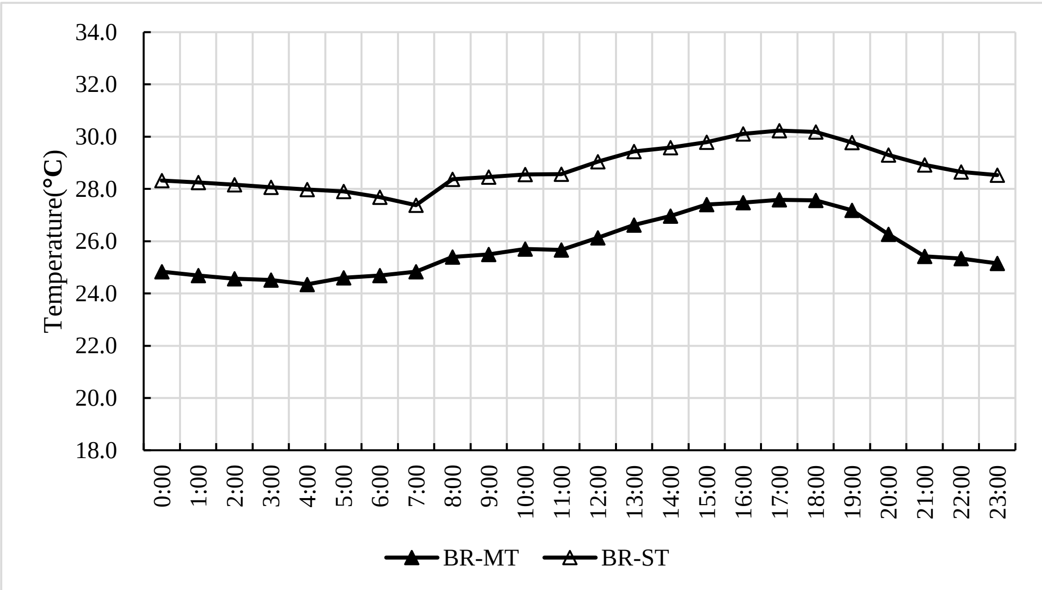


Fig. 7-11 The simulation and field measurement results of bedroom (TVB-4)

7.4.3Simulation Results

(1) Simulation results of MB-1

MB1 were simulated at different levels (level 1~level 4) and in different regions (Quzhou and Zhoushan), respectively. The results are as shown in Table 7-12, and the cooling and heating energy consumption per area is as shown in Fig.7-12.

Table 7-12 Cooling and heating energy consumption of TB1 in Quzhou and Zhoushan

Level	Quzhou Weather file			Zhoushan Weather file		
	Cooling	Heating	C+H	Cooling	Heating	C+H
Original	14592.39 ±0%	127.64 ±0%	14720.03 ±0%	10360.91 ±0%	164.88 ±0%	10525.79 ±0%
Level 1	8709.01 -40%	168.17 +31.8%	8877.18 -39.7%	5536.19 -46.6%	194.19 +17.8%	5730.38 -45.6%
Level 2	7997.57 -45.2%	158.14 +23.9%	8155.71 -44.6%	5134.68 -50.4%	185.94 +12.8%	5320.62 -49.5%
Level 3	6767.56 -53.6%	138.52 +8.5%	6906.08 -53.1%	4364.5 -57.9%	171.96 +4.3%	4536.46 -56.9%
Level 4	6250.71 -57.2%	125.65 -1.6%	6376.36 -56.7%	4010.4 -61.3%	163.94 -0.6%	4174.38 -60.3%

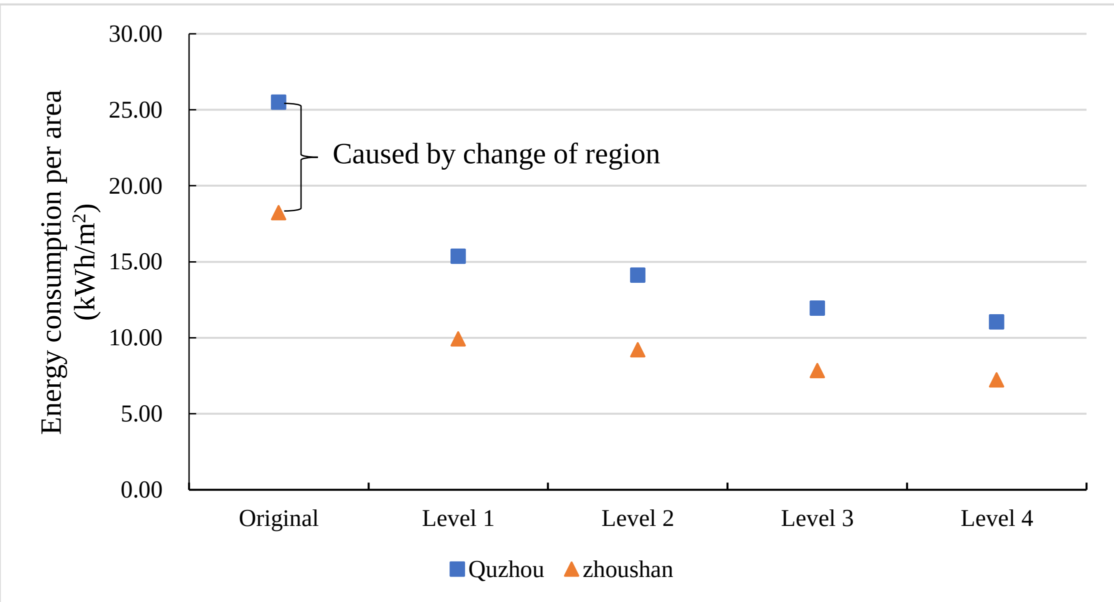


Fig.7-12 Cooling and heating energy consumption of MB-1 in Quzhou and Zhoushan

Based on the comparison of different strategies from original to level 4, it can be seen that the annual heating and cooling energy consumption decreased from 14720.03 kWh (25.5 kWh/m^2) to 6376.36kWh (11.05kWh/m^2) in Quzhou, which was decreased by about 39.7%, 44.6%, 53.1% and 56.7%, respectively. The simulation was carried out under the climate of Zhoushan, and the annual heating and cooling energy consumption decreased from 10525.79 kWh (18.23kWh/m^2) to 4174.38 kWh (7.23kWh/m^2), which was decreased by about 45.6%, 49.5%, 56.9% and 60.3%, respectively. This shows that the energy consumption reduced obviously by taking different strategies. By comparing the results of different regions, the cooling and heating energy consumption in Quzhou is higher than Zhoushan, which is caused by the difference of climate.

(2) Simulation results of TVB-4

TVB-4 was also simulated at different levels (level 1~level 4) and in different regions (Quzhou and Zhoushan). The simulation results are shown in Table 7-13 and the cooling and heating energy consumption per area is shown in Fig.7-12.

Table 7-13 Cooling and heating energy consumption of TVB-4 in Quzhou and Zhoushan

Level	Quzhou Weather file			Zhoushan Weather file		
	Cooling	Heating	C+H	Cooling	Heating	C+H
Original	19202.59 ±0%	81.49 ±0%	19285.92 ±0%	14540.21 ±0%	62.79 ±0%	14603 ±0%
Level 1	18916.57 -1.5%	87.95 +7.9%	16763.38 -2.3%	14348.16 -1.3%	69.26 +10.3%	14417.42 -1.3%
Level 2	18712.35 -2.6%	98.78 +21.2%	16480.32 -4.5%	14110.77 -3.0%	80.61 +28.4%	14191.38 -2.8%
Level 3	18449.47 -3.9%	103.86 +27.5%	16134.36 -6.3%	13951.1 -4.1%	86.18 +37.3%	14037.28 -3.9%
Level 4	15634.89 -18.6%	136.52 -67.5%	15772.91 -12.3%	14035.77 -3.5%	94.66 -50.8%	14130.43 -3.2%

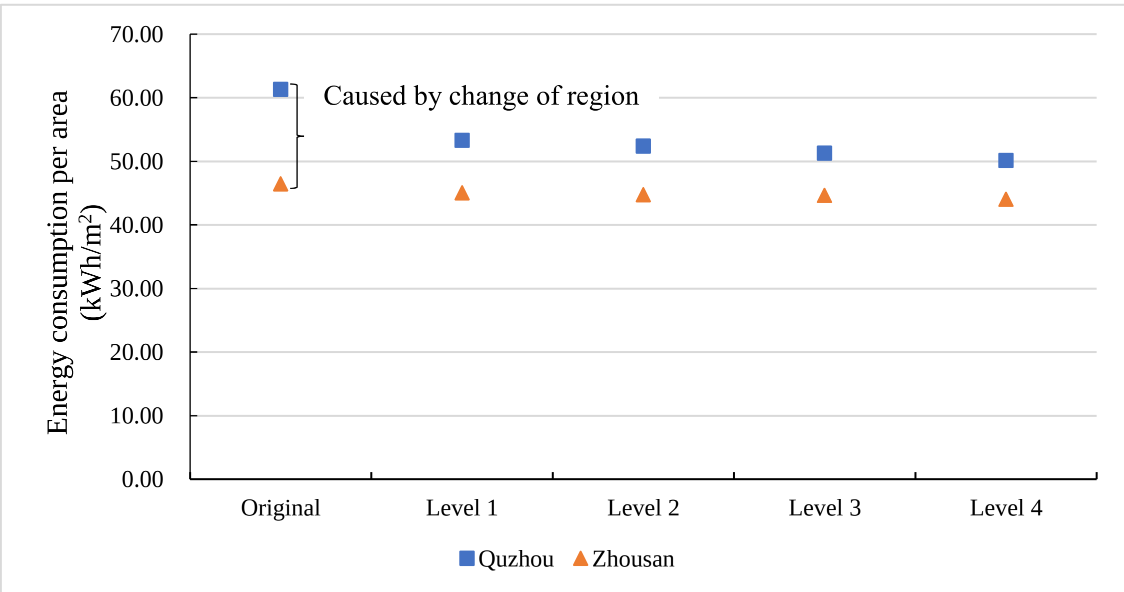


Fig. 7-13 Cooling and heating energy consumption of TVB-4 in Quzhou and Zhoushan

with the comparison of different strategies from original to level 4 indicates that the annual heating and cooling energy consumption decreased from 19285.92 kWh (61.3 kWh/m^2) to 15772.91kWh (50.15kWh/m^2) in Quzhou, which was reduced by about 2.3%, 4.5%, 6.3% and 12.3%, respectively. The simulation was conducted under the climate of Zhoushan, and the annual heating and cooling energy consumption decreased from 14540.21 kWh (46.3kWh/m^2) to 4174.38 kWh (44.03kWh/m^2), which reduced by about 1.3%, 2.8%, 3.9% and 3.2s%, respectively. It shows that, the energy consumption reduced obviously by taking different strategies. By comparing the results of different regions, the cooling and heating energy consumption of Quzhou was higher than Zhoushan, which is caused by the difference of climate. The annual cooling and heating energy consumption of MB-1 and TVB-4 in the same region was compared, and the energy consumption of TVB-4 was higher than MB-1. This is because the shape coefficient of MB-1(0.52) is smaller than TVB-4(0.87), and the west window-to-wall ratio of MB-1(0.071) is smaller than TVB-4(0.149).

7.5Summaries

The energy saving based on different functions (ordinary household condition and rural tourism household condition), different building forms (modern building and traditional vernacular building) and regions (Quzhou and Zhoushan) were studied. The following conclusions can be drawn from the above analysis:

(1) Cooling and heating energy consumption of ordinary household is very low, which is caused by the lifestyle of the elders and the large number of migrant workers in the villages. If the idle rooms were used for rural tourism business, the total cooling and heating energy consumption would be obviously increased. Therefore, it is necessary to reduce the building energy consumption by improving the thermal performance of building envelopes.

(2) The top 20 priority strategies show that the most effective energy saving measure is to improve the thermal insulation performance and airtightness of the external walls and windows. Under the condition of OH, the up limited U-value of the external wall is 1.71W/(m^2·k), the airtightness is 0.3ac/h, the frame and glass of window are 3.2W/(m^2·k) and 1.8 W/ (m^2·k), with SHGC of 0.37 to 0.2. Under the condition of RTH, the up limited U-value of external wall is 1.62W/(m^2·k). The airtightness and windows are the same as OH condition.

(3) Under the condition of OH, the energy saving by improving SHGC is more effective than improving HCT. The improvement of SHGC under RTH condition is more favorable than that in the condition of OH.

(4) The improvement of the thermal performance of roof and attic floor of Top floor A has little influence on building energy consumption. However, for top floor B, the energy saving rate is obviously affected.

(5) Energy consumption of modern building(MB-1) is lower than that of the traditional vernacular building(TVB-4), which is caused by the lower building shape and the window-to-wall ratio in the west. For the same building, the energy consumption in Quzhou is higher than that in Zhoushan because of the cooler climate.

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Chapter 8.

Strategies for Improving Indoor Thermal Environment

8.1 Introduction

The field survey shows that the thermal performance of building envelopes is currently poor in Zhejiang (Chapter4). Moreover, the indoor thermal environment is also bad (Chapter 5), especially on the top floor. As indicated by energy survey results, the energy consumption of ordinary household is lower than that of rural tourism household (Chapter 6). Under such occasion, what strategies should ordinary households and rural tourism households take? As shown in Fig. 8-1, for ordinary households, the building energy consumption is low, but the indoor thermal comfort is poor. The optimization objective is to improve the indoor environment on the condition of keeping lower energy consumption. For the rural tourism households, the characteristic is that the building energy consumption is high, yet the indoor thermal comfort is poor. Thus, the optimization objective is to reduce energy consumption, particularly the cooling energy consumption in summer, and improve indoor thermal environment. The improvement of indoor thermal environment is also beneficial for energy saving.

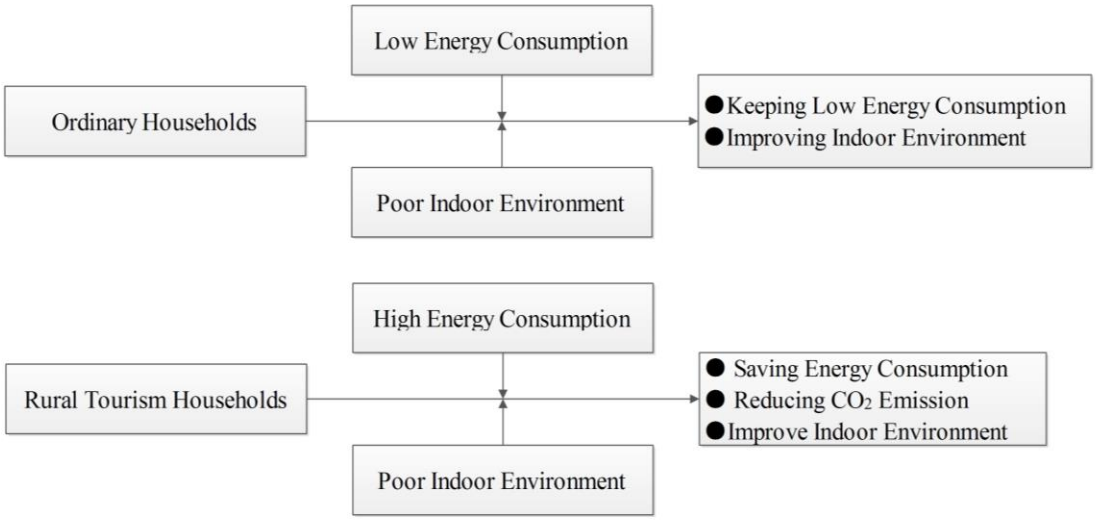


Fig. 8-1 The strategies of ordinary households and rural tourism households

However, a short-time on-field survey cannot always provide an overview of the buildings' performance [1]. For example, in Chapter 5, the field measurement in Wenyuan village in Quzhou from July 15th to 18th shows that the indoor thermal environment was comfortable. By contrast, the field measurement in Xiacheng village, which was also in Quzhou, displays that the indoor thermal environment was poor from July 22nd to 25th because of different outdoor conditions.

In this chapter, a multidisciplinary study was carried out, including analytical simulations of the current indoor thermal environment of rural residential buildings, and analytical simulations of indoor thermal environment by improving the thermal performance of building envelopes. Finally, to improve the indoor thermal environment on the top floor, the roof of Anji eco-house was renovated using traditional and new materials.

8.2 Phases and Methods

8.2.1 General Approach

In this section, the study is based on a multidisciplinary methodology, which involves simultaneous analysis from different aspects. The indoor thermal environment of rural residential buildings is studied from three aspects: simulation of current situation, optimization simulation, and practice of roof renovation. Furthermore, the indoor thermal environment is simulated and evaluated from each aspect by different methods (dynamic simulation, field measurement, and lab measurement). Table 8-1 shows the methods and scenarios studied for each aspect in detail.

Table 8-1 Methods and scenarios studied for each aspect

	Current situation simulation	Optimization simulation	Roof renovation
Objects	MB-1, HCB-1	MB-1, HCB-1	Anji eco-house
Method	Dynamic simulation in the whole year (8760h)	Dynamic simulation in the whole year (8760h)	1)Field measurement 2) Lab measurement 3) Dynamic simulation
Target	Evaluate current situation in the whole year	Evaluate the effectiveness of different measures	Improve the indoor thermal environment of top floor
Tools	Energy plus	Energy plus	1) JTRG-Ⅱ 2) JTKD-I 3) Energy plus
Climate	Quzhou	Quzhou	Anji(Hangzhou)
Standards	GB/T 50824-2013 DB 33/1015-2015 ISO 7730	GB/T 50824-2013 DB 33/1015-2015 ISO 7730	GB/T 50824-2013

8.2.2 Simulation of Current Situation and Optimization Simulation

In Chapter 5, field surveys were carried out in Quzhou in winter (the coldest days) and summer (the hottest days), respectively. As mentioned above, a short-time on-field survey cannot always provide an overview of a buildings' performance. Therefore, the annual indoor environment was simulated and analyzed in winter, summer, and transitional season. In this study, MB-1 was selected as an example. At present, increasing numbers of famers build modern building to meet the needs of modern life and rural tourism business. It has been assumed that the building is under natural ventilation condition. The settings for simulation are introduced below. Meanwhile, the setting for optimization simulation is almost the same as that of current situation.

(1) Patterns and people's lifestyle

Simulation of current situation means simulating the indoor thermal environment based on the current situation. According to the previous survey, there are two typical patterns: ordinary rural households and rural tourism households. They have different lifestyles and behaviors of energy use. The farmers and tourists have different lifestyles. To be specific, the famers who operate rural tourism business get up later. Farmers usually get up at 6:00 and go to sleep at 20:00. For the tourists, they get up at 6:00 and go to sleep at 21:00. From previous questionnaire survey, it shows that the travelling period is from April to November.

(2) Simulated Rooms

According to the results of previous survey in Chapter 5, it shows that the indoor environment of attic (top floor) and the south bedroom on the third floor was the worst. Therefore, the attic (top floor) and the south guestrooms were chosen for simulation.

(3) Metabolism and cloth

Metabolism is related to people's activities. In the living room, the main activities of occupants include sitting, talking, and watching TV. The human's metabolic rate is set as 1.0 met (58.15W/m^2). When they stay in the bedroom, the main activity is lying or reclining, and the human's metabolic rate was set as 0.8 met (46.52W/m^2).

According to the field survey, both of the farmers and tourists wear short-sleeved shirt, light trousers, and thin skirt in summer. The clothing insulation (I_{cl}) is set as 0.5clo, about 0.08(m^2·K)/W. In winter, farmers used to wear thick clothes, and the clothing insulation (I_{cl}) equals to 2.5clo in the bedroom.

(4) Climate zone

The weather is quite different in the island and inland mountain area. Among the three regions, Quzhou is the hottest in summer. Therefore, the simulation was conducted under weather files of Quzhou. All the climatic data used in this analysis is gathered from *Energy Plus* software, which is based on monitoring data over several years from Meteorological stations.

(5) Lights

The lighting power density was set 7 W/m^2. According to the field survey, most of tourists will go to sleep about 22:00pm and get up at 6:00am. Thus, the schedule of lighting in guestroom was set at 6:00am~7:00am and 18:00pm~22:00pm, while the schedule of lighting in bedroom of farmers was set at 6:00am~7:00pm and 18:00am~21:00pm.

(6) Natural ventilation

In this study, it has been assumed that the building is under natural ventilation, and tourists do not use air conditioner. Beyond that, the guestrooms in the rural tourism household are all taken, and the windows are opened for natural ventilation every day in summer. In winter, the windows were closed.

Table 8-2 Simulation parameters and simulation process

Items	Farmers	Tourists
Peoples' activity	farmers' activity	tourists' activity
Metabolic rate	0.8	0.8
Clothing (I_{cl})	winter 2.5; Summer 0.5	winter 2.5; Summer 0.5
Stay	Whole year	April 1st~November 30st
Density	0.2 people/m^2	0.2 people/m^2
Lights	7 W/m^2,6:00~7:00& 18:00~21:00	7 W/m^2,6:00~7:00& 18:00~22:00
Climate zone	Quzhou	
Simulated Rooms	Top floor (TF); South guestroom on the third floor (3FSR); North guestroom on the third floor(3FNR);	
Strategies	Improving airtightness: 0.5 ac/h Improving thermal performance of envelope (U, W/(m2·K))/ SHGC: Level 1: exterior walls—1.8; roof—1.0; windows:3.2/0.5 Level 2: exterior walls—1.5; roof—1.0; windows:2.8/0.5 Level 3: exterior walls—1.0; roof—0.7; windows:2.8/0.5 Level 4: exterior walls—0.8; roof—0.5; windows:2.6/0.5	
Evaluation method	Hours of the indoor air temperature below 8°C and above 30°C in the whole year; PMV in winter (December 15th ~ February 15th of the following year); ePMV in summer (June 1st ~ September 1st)	

(7) Strategies

The research results in Chapter 7 shows that improving thermal performance of exterior walls, windows, roofs, and airtightness exerts an obvious effect on energy saving. For improving the indoor thermal environment, four levels were set as Chapter 7. The strategies can be shown in Table 8-2.

(8) Evaluation method

The building was simulated under natural ventilation condition. According to the vast surveys [2], it is acceptable with the indoor temperature between 8°C and 30°C without air-conditioner for farmers. According to *Design Standard for Energy Efficiency of Rural Residential Buildings (GB/T 50824-2013)*[2], the main activity spaces were selected for simulation, in which the natural ventilation was set as 5/h-1 and 1/h-1 respectively in summer and winter. Air temperature is one of the most simple and effective parameters to evaluate the indoor thermal environment. The hours that indoor air temperature is above 30°C and below 8°C were simulated and calculated in the whole year in Microsoft Excel. Furthermore, the uncomfortable hour rate (UHR) was calculated in accordance with the proportion of uncomfortable hours and the total hours of the whole year (8760h) (Equation 1). Additionally, in winter (from January 1st to February 15th, December 15th to December 31st), the thermal comfort was simulated and evaluated by PMV. In light of ISO 7730, the comfort range of PMV is from -1 ~ 1. In summer (from June 15th to September 1st), the thermal comfort was assessed by ePMV with *e* equaling to 0.7. Also, the comfortable hour rate (CHR) was calculated according to the hours of PMV/ ePMV from -1 ~ 1 during winter and summer (Equation 2).

$$UHR = \frac{Hours(>30℃) + Hours(<8℃)}{8760} \times 100\% \qquad \text{Equation (1)}$$

$$CHR = \frac{Hours(PMV_{win}) + Hours(ePMV_{sum})}{3408} \times 100\% \qquad \text{Equation (2)}$$

Additionally, a typical traditional rural residential building, which has distinct characteristics of traditional architecture located in Wenyuan village, was taken as a study example. The current indoor thermal environment in the whole year was simulated. Furthermore, several strategies for improving the attic were also simulated and compared.

8.2.3 Roof Renovation

As indicated by previous study, the indoor thermal environment of the top floor is the worst, no matter in winter or summer. A practice of roof renovation using traditional and modern material was carried out to improve the indoor thermal environment in Anji eco-house.

At present, the domestic and foreign research evaluates indoor thermal environment from three ways: experimental research, micro climate laboratory based on field measurement of conditions (including questionnaire survey and field survey), and numerical simulation analysis using software. This research was carried out through experimental activities and analytical simulations according to the following phases: First of all, the indoor environment of top floor and the thermal performance of the roof were measured in winter. Furthermore, the material for renovation was tested on lab. Then, the roof renovation was implemented in summer and measured in winter. The effect of the roof renovation was compared by field measurement and simulation.

8.3 Current Situation and Optimization Simulation

8.3.1 Modern Building (MB-1)

8.3.1.1 Current situation

As shown in Table 8-3 and Fig.8-2, on the top floor, the air temperatures below 8°C and above 30°C are 1911 hours and 861 hours, respectively. Moreover, the total uncomfortable hours are 2772 hours, accounting for 31.6%. The comfortable hours during the cooling and heating period occupy 36.4%. On 3FSR, the air temperatures below 8°C and above 30°C are 191 hours and 2857 hours, respectively. The total uncomfortable hours are 3048 hours, accounting for 34.8%. The comfortable hours during cooling and heating period occupy 11.9%. On 3FNR, the air temperatures below 8°C and above 30°C are 1606 hours and 660 hours, respectively. The total uncomfortable hours are 2266 hours, accounting for 25.9%. The comfortable hours during cooling and heating period occupy 37.9%. The uncomfortable hours of 3FSR are more than TF and 3FNR. The uncomfortable hours of TF and 3FNR in winter are more than 3FSR. On the contrary, they are less than TF and 3FNR in summer.

8.3.1.2 Improving Thermal Performance of Envelopes

As shown in Table 8-3 and Fig.8-2, when Level 1 was adopted to improve the thermal performance of MB-1, the uncomfortable hours were reduced, accounting for 29.5% on TF, 31.9% on 3FSR, and 25.3% on 3FNR. When Level 2 was utilized, the uncomfortable hours were also reduced, accounting for 29.9% on TF, 32.9% on 3FSR, and 24.6% on 3FNR. Except 3FNR, UHR was increased slightly on TF and 3FSR compared with Level1. When Level 3 was adopted, the uncomfortable hours were also reduced, but not obvious on TP and 3FSR, accounting for 30.3% and 34.6% respectively. Compared with Level 2, the UHR was increased on TF and 3FSR. The UHR was decreased on 3FNR, about 22.3%. When Level 3 was adopted, the uncomfortable hours were decreased on TF and 3FNR, accounting for 31.1% and 20.3%. However, on 3FSR, they were increased to 36.3%.

From current situation to Level 3, on TF, the CHR during cooling and heating period was decreased from 36.4% to 35.5%. However, it was slightly increased in Level 4. On 3FSR, the CHR was slightly decreased in Level 1 and Level2, accounting for 11.8% and 11.3%, respectively. Also, it was increased in Level 3 and Level 4, about 13.3% and 12.7%. On 3FNR, the CHR was always increased from 37.9% to 41.8%.

Improving the thermal performance of MB-1 could help improve the indoor thermal environment of north guestrooms. However, it was uncertain for the top floor and the south guestrooms. In general, Level1 was the most effective for the top floor, and it was the most useful for 3FSR to reduce uncomfortable hours in the whole year. However, Level3 was the most favorable for 3FSR to increase comfortable hours during the cooling and heating period.

8.3.1.3 Improving Airtightness

As shown in Table 8-3 and Fig.8-2, on the top floor, the air temperatures below 8°C and above 30°C are 1916 hours and 861 hours, respectively. The total uncomfortable hours are 2777 hours, accounting for 31.7%. The comfortable hours during cooling and heating period occupy 36.2%. On 3FSR, they are 180 hours and 2906 hours, respectively. The total uncomfortable hours are 3086 hours, accounting for 35.2%. The comfortable hours during cooling and heating period occupy 11.7%. On 3FNR, they are 832 hours and 942 hours respectively. The total uncomfortable hours are 2279 hours, accounting for 26.0%. The comfortable hours during cooling and heating period occupy 11.7%.

The uncomfortable hour of TF and 3FNR in winter is more than that in summer. For 3FSR, it is on the contrary. The uncomfortable hours on 3FSR are the most, followed by TF and 3FNR. In winter, the uncomfortable hours of 3FSR are less than TF and 3FNR, yet they are more than TF and 3FNR in summer. Compared with the current situation, the uncomfortable hours increased, indicating that for rural residential building in hot summer and cold winter zone, smaller airtightness of building maybe not good for the indoor thermal environment.

Table 8-3 Uncomfortable hours and rate of different strategies

Strategies	TF	3FSR	3FNR
Current situation	2772(1911+861)	3048(191+2857)	2266(1606+660)
	31.6%	34.8%	25.9%
Level1	2588(1533+1055)	2796(180+2616)	2220(1613+607)
	29.5%	31.9%	25.3%
Level12	2621(1590+1031)	2879(144+2735)	2155(1469+686)
	29.9%	32.9%	24.6%
Level3	2652(1521+1131)	3035(115+2920)	1952(1128+824)
	30.3%	34.6%	22.3%
Level4	2720(1443+1277)	3181(93+3088)	1774(832+942)
	31.1%	36.3%	20.3%
Airtightness	2777(1916+861)	3086(180+2906)	2279(1606+673)
	31.7%	35.2%	26.0%

Note: 1. TF refers to the top floor; 3FSR refers to the south guestroom on the third floor; 3FNR refers to the north guestroom on the third floor. 2. *(**+***), * is the total hours of indoor air temperature above 30°C and below 8°C; ** is the total hours of indoor temperature below 8°C in winter; *** is the total hours of indoor temperature above 30°C in summer.

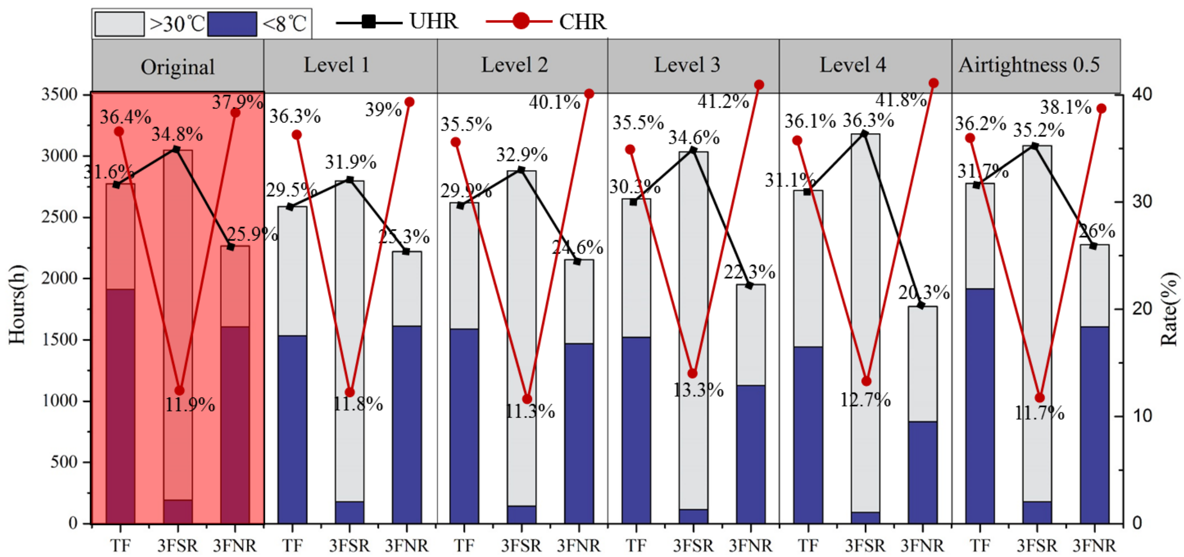


Fig.8-2 Uncomfortable hours and rate of different strategies

8.3.2 Traditional Building (HCB-1)

The historical and cultural building (HCB-1), located in Wenyuan village of Quzhou City, has been introduced. Meanwhile, the indoor thermal environment has been measured in section 5.4.1 in Chapter 5. Table 8-4 shows the parameters for simulation.

Table 8-4 Parameters for simulation (traditional rural building)

Items	Contents
Climate	Typical meteorological year data of Quzhou(from *Energy plus* software)
Building information	latitude: N28°44′2.60″, longitude:E118°55′42.01″,altitude:701m,orientation: north and south, total building area:327.7m^2; shape coefficient:0.52; window-to-wall ratio: 0.065.
Construction	● Exterior wall (main parts): 20mm composite mortar＋240mm brick wall＋20mm cement mortar,brick tile, U-value =2.10W/(m^2·K),D=3.64 Exterior wall (for kitchen): 350mm rammed earth wall, U-value =2.76W/(m^2·K),D=3.55 ● Interior wall: 15mm cedar board,U-value =3.89W/(m^2·K), D=3.41 ● Roof: tile＋wood purlin,U-value =5.98W/(m^2·K), D=0.22 ● Floor: 20mm cedar board,U-value =4.67W/(m^2·K), D=3.41 ● Ground: soil＋200mm gravel cushion＋100mm Cast- in-place concrete＋20mm composite mortar＋brick tile,U-value =2.22W/(m^2·K), D=1.23 ● Window: wood frame,U-value =3.2W/(m^2·K),SC＝0.85
Ventilation and airtightness	● Ventilation schedules: 5ac/h in summer and 1ac/h in winter; ● Airtightness 0.8 ac/h
Activity	● Livingroom: Density: 0.03People/m^2; Schedules: 7:00~17:00 100%; 0:00-7:00,18:00-24:00 0% ● Bedroom1: Density: 0.2People/m^2 Schedules: 7:00~18:00 0%; 0:00~6:00,12:00~13:00,18:00~24:00 100%

8.3.2.1 Current situation

The indoor air temperatures of living room, bedroom, and attic (top floor) in the whole year were listed on Fig.8-3. The indoor air temperature above 30°C and below 8°C is 712 hours and 1700 hours in the living room, and the UHR accounts for 27.5%. As demonstrated by the results, it is more comfortable in summer than in winter, which is coincident with the questionnaire. In the bedroom, the indoor temperature above 30°C and below 8°C is about 1488 hours and 1202 hours in the whole years, and the UHR is 30.6%. On the top floor, the indoor air temperature above 30°C and below 8°C is nearly 955 hours and 1969 hours, and the UHR accounts for 33.3%.

The indoor thermal environment on the top floor (attic) was the worst, followed by bedroom. The indoor thermal environment of living room is the best, especially in summer. Due to the poor thermal performance of tile roof, the highest temperature on attic was up to 54.7°C. On the contrary, it was conductive to dissipating heat. For the bedroom, due to the buffer effect of the attic and the heat-accumulation effect of the rammed earth walls, it is warmer than the other rooms in winter.

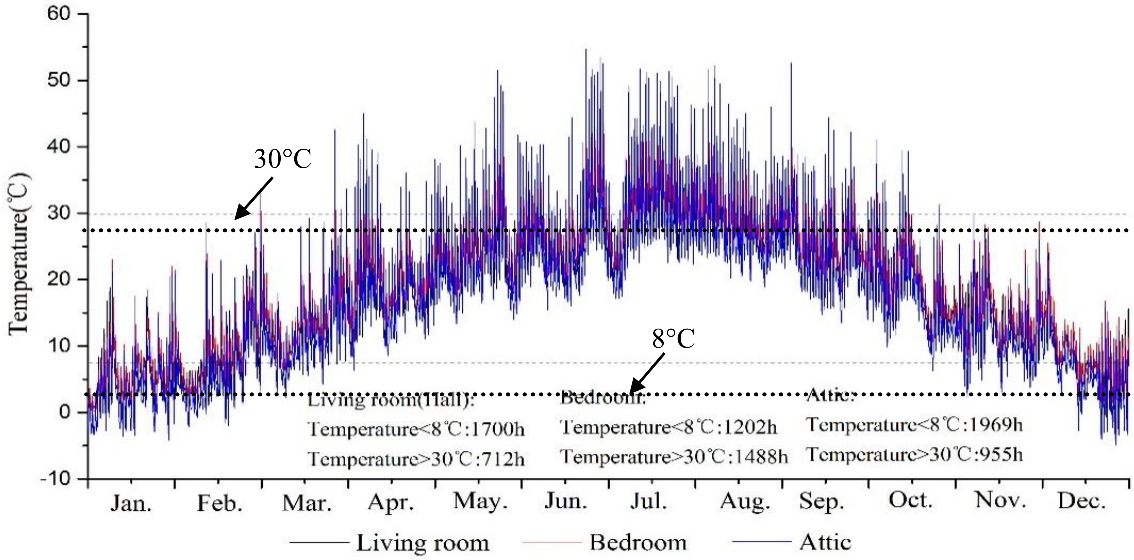


Fig.8-3 Indoor air temperature of HCB-1 in the whole year

8.3.2.2 Improving Thermal Performance of Roof

In Chapter 5, the field surveys on indoor thermal environment of top floor with tile roof show that, it was bad in summer and winter, and the simulation result in section 8.3.2.1 was also bad. With the development of rural tourism, the top floor has been utilized. How to improve the indoor thermal environment?

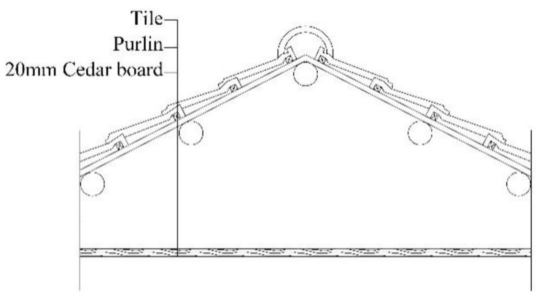
The construction of traditional tile roof is to put tiles directly on the purlins, without any fixing. Some rural tourism households decorated the roof and changed the attic to guestrooms. There are three ways for decoration. Specifically, one is to decorate the roof with cedar board in horizontal direction (RF1). There is an air layer between the board and roof. RF2 means putting glass wool on the cedar board. RF3 is decorated along with the purlin, and there is about 50mm air gas between the roof and tile, which is the height of the purlin. RF5 is also very common in modern rural buildings. The construction and thermal performance are listed in Table 8-5 and Fig. 8-4.

The simulation results can be shown in Fig.8-5. To be specific, the indoor air temperatures of the original roof below 8°C and above 30°C are 1969 hours and 955 hours, respectively, and the total uncomfortable hours are 2924 hours. The highest temperature is 53.3°C in summer, while the lowest temperature is -4.7°C in winter. The indoor air temperatures of RF1 below 8°C and above 30°C are 1731 hours and 1041 hours, respectively, and the total uncomfortable hours are 2772 hours. The highest temperature is 44.6°C in summer, while the lowest temperature is -2.4°C in winter. The indoor air temperatures of RF2 below 8°C and above 30°C are 1588 hours and 1158 hours, respectively, and the total uncomfortable hours are 2746 hours. The highest temperature is 44.6°C in summer, while the lowest temperature is -1.1°C in winter. The indoor air temperatures of RF3 below 8°C and above 30°C are 1416 hours and 1361 hours, respectively, and the total uncomfortable hours are 2777 hours. The highest temperature is 41.5°C in summer, while the lowest temperature is 0.1°C in winter. The indoor air temperatures of RF4 below 8°C and above 30°C are 1653 hours and 1121 hours, respectively, and the total uncomfortable hours are 2774 hours. The highest temperature is 40.4°C in summer, while the lowest temperature is -0.8°C in winter.

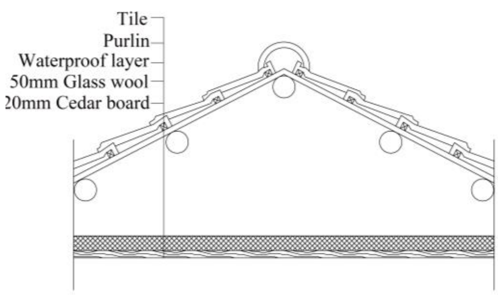
Table 8-5 The construction and thermal performance of the roofs.

Numbering	Material and Construction	U-value W / (m^2·K)	D
Original roof	Tile+purlin	6.06	0.25
RF1	Tile+purlin+ air layer＋20mm cedar board	1.89	0.8
RF2	Tile＋purlin+20mm cedar board＋50mm glass wool	0.52	1.3
RF3	Tile+purlin+50mm air layer+ 20mm cedar board	1.82	0.8
RF4	Tile+purlin＋air layer＋100mm concrete slab	1.52	1.24

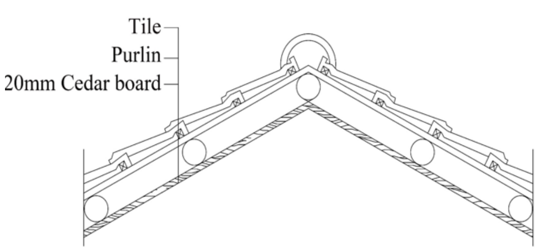
Note: 1. The thermal resistance above the ceiling, RF2 is set as 0.23 (m^2·K)/W, RF1is set as 0.21(m^2·K)/W. 2. D stands for thermal inertia index.



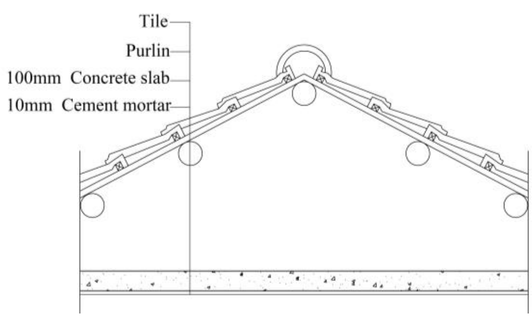
(a) Construction of RF1



(b) Construction of RF2



(c) Construction of RF3



(d) Construction of RF4

Fig. 8-4 Construction of different roofs

The uncomfortable hours of top floor with original roof were the most, and the hours below 8°C were more than the hours above 30°C. Among the five types of roofs, the highest temperature of the top floor with original roof was higher than the other roofs in summer, and it was lower in winter. Compared with original roof, the uncomfortable hours of top floor were decreased after application of RF1 to RF4, which was similar to each other. Besides, the highest temperature decreased and the lowest temperature rose. The top floor with RF3 and RF4 has lower highest temperature and higher lowest temperature. In a word, the lower HTC-value and higher D-value is beneficial for the indoor thermal environment of the top floor.

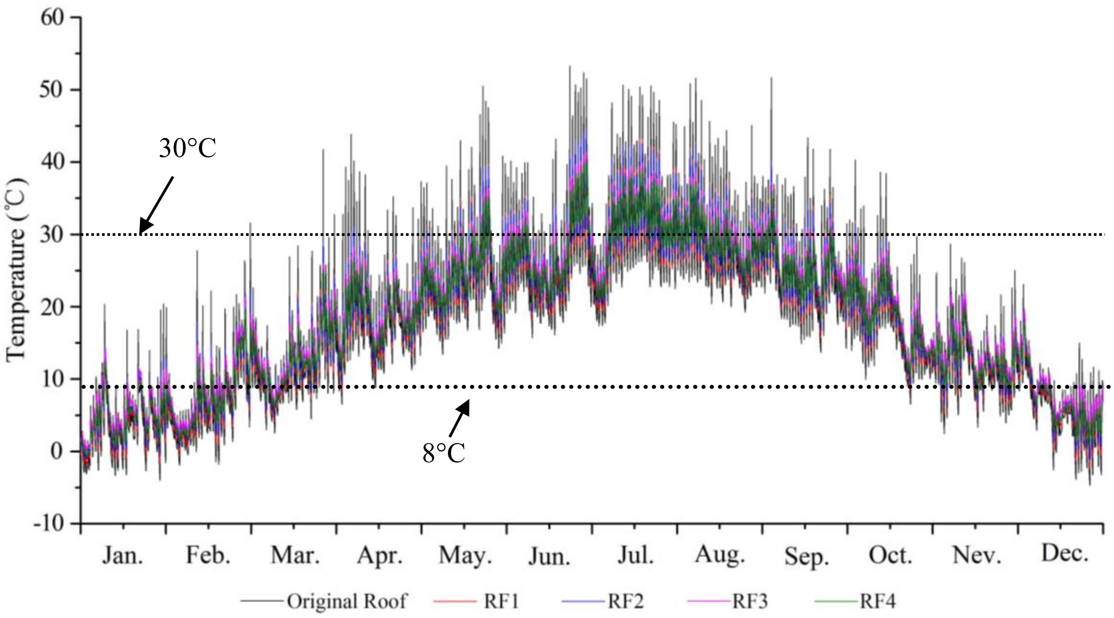


Fig.8-5 Indoor air temperature of the top floor with different roofs in the whole year

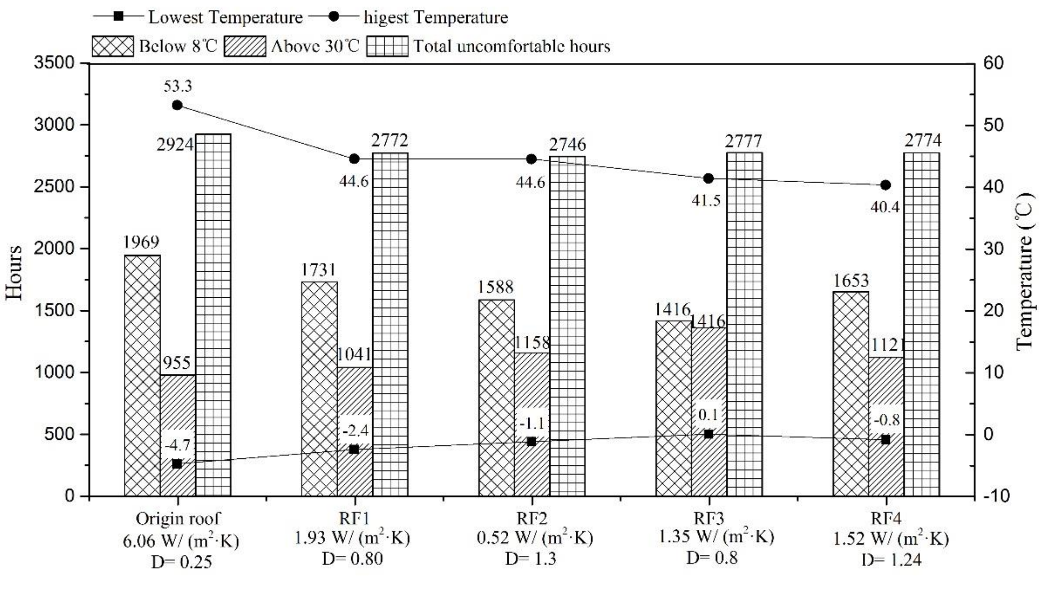


Fig. 8-6 Indoor thermal environment of the top floor with different roofs

8.4 Roof Renovation

8.4.1 Description of Anji Eco-house

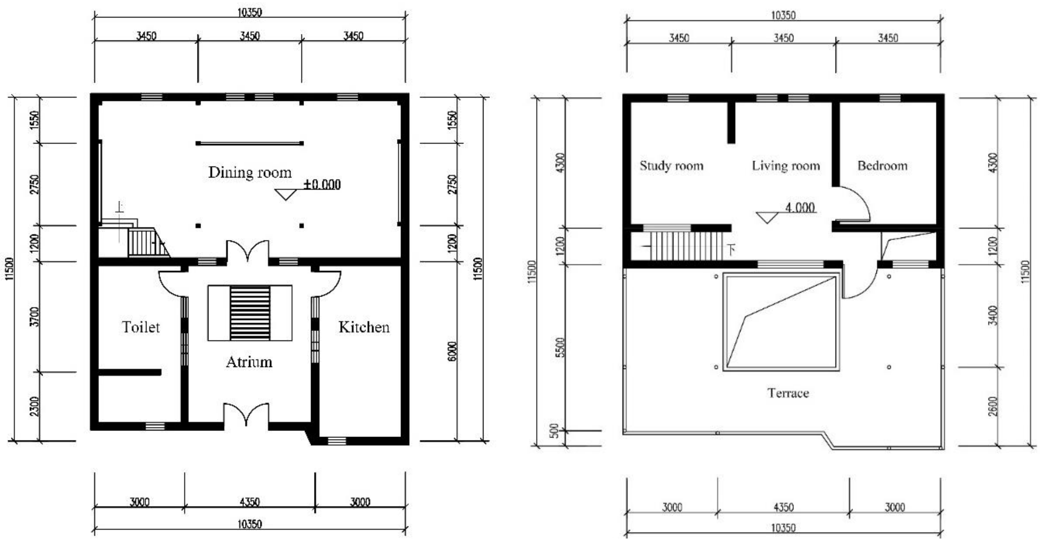
Anji eco-house, named by the owner, locates in Jianshan Village near Anji City. It is a new vernacular rural residential building built by Ren Weizhong in 2005 with traditional materials. Officials of the United Nations Environment Program(UNEP) spoke highly of the ecologically rural building, and Mr. Ren won the SEE-TNC Price in 2007. (Fig. 8-7)

It is a two-story rural residential building, with the total building area of 152.6m^2, and the window-to-wall ratio is about 0.095. On the first floor, there are dining room, a small reception room, kitchen, toilet, and courtyard. The bedroom, living room, study room, and terrace are on the second floor. Fig. 8-8 shows the building plan of Anji eco-house.

(1) Material and construction

Anji eco-house was completely built with the local materials. Exterior walls were built with rammed earth mixed with yellow clay, sand and hydrated lime with the mass ratio of 5:4:1. All the materials can be reused without construction waste.

Fig. 8-7 Anji eco-house



(a) The first floor (b) The second floor

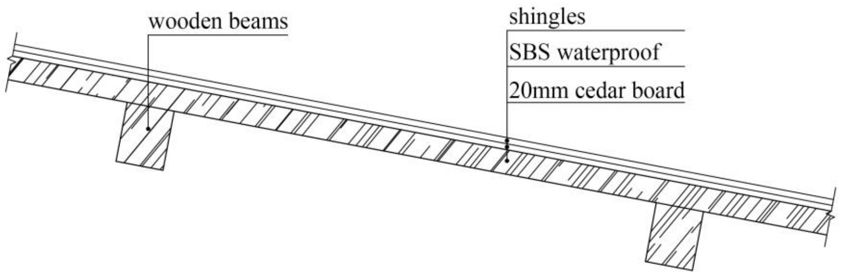
Fig. 8-8 Building plans of Anji eco-house

(2) Structure and envelope of eco-house house

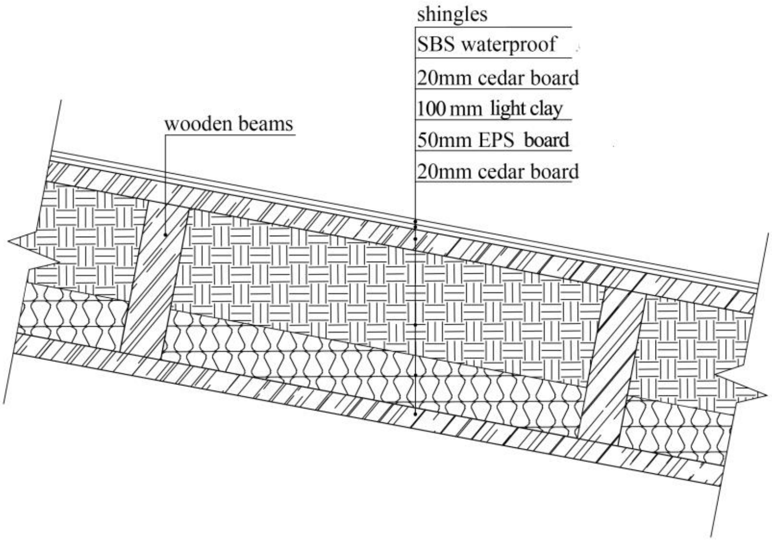
The exterior walls of the eco-house are load-bearing rammed earth walls 330mm thick, painted with white coating. The interior walls of the second floor are cedar board 20mm thick. All of the walls are painted with mortar 20mm thick. There are two types of pitched roofs. The exiting roof(ER) of the main parts on the second floor (living room, study room and bedroom) consists of cedar board 20mm thick, SBS waterproofing membrane, and asphalt shingles, and there is no thermal insulation layer (Fig. 8-9,a). The pitched roof with a thermal insulation layer is on the stair room made of light clay (Fig. 8-9,b). It was a skylight made of single glass when the eco-house was built. Anji locates in Hot Summer and Cold Winter zone. The sunshine through the skylight and makes the second floor very hot in summer. Later, the skylight was replaced by a thermal insulated roof. The flat roof on the first floor(terrace) is an overhead roof with an air layer 300mm thick. In summer, the cool water can be pumped from the well (in the courtyard) and circulates in the air layer to cool the roof. All the windows are wood-framed with double-glazed windows. The thermal performance of the building envelopes before renovation is shown in Table 8-6.

Table 8-6 Thermal performance of the building envelopes before renovation

Envelope	Construction	Thermal performance
Exterior walls	20mm mortar +330mm rammed earth ＋ 20mm mortar	U-value:1.20W/(m^2·K) D-value:8.9
Windows	Wood frame,3mm+13A+3mm hollow glass	2.8W/(m^2·K), SHGC:0.6
Exiting roof(ER)	20mm cedar board (main part)	U-value:3.41W/(m^2·K) D-value:0.69
Exiting insulated roof(EIR)	20mm cedar board +100mm light clay+50mm EPS+20mm cedar board	U-value:0.4W/(m^2·K) D-value:6.71
Flat roof	25mm cedar board+300mm air layer+ 100mm concrete slab+20mm mortar	U-value:1.41W/(m^2·K) D-value:4.13



(a) Exiting roof(ER)



(b) Exiting insulated roof (EIR)

Fig. 8-9 The construction of pitched roofs of Anji eco-house before renovation

8.4.2 Renovation of the Pitched Roof

8.4.2.1 Experiment of the Light Clay for Renovation

Tile roof is a kind of traditional roof in China, and its constructions vary with different areas. In Northern China, the tile is fixed to the board by clay. In the Northwest and Southwest China, where the climate is cold and cloudy but low rainfall, clay is spread on the wood board, reed matting or stalk, where the purlins are placed. In Southern China where bamboo Abounds, bamboo strips are spilt and then clay is put on it. In Germany, the earth building technique is improved. At the end of 1980s, a mixture made of wood powder and clay was utilized as a kind of heat insulation material on the roof. In this renovation, light clay mixed up with clay and bamboo powder was utilized as the thermal insulation material.

(1) Samples

Bamboo is very common in Zhejiang Province, especially in mountain areas. Bamboo powder is a kind of waste material manufactured by bamboo products plant. It is very cheap and insulated, and can be utilized to improve the insulation of the roof [2]. Also, the bamboo power can be mixed with clay, which can protect it from rot and warm erosion. In this experiment, the mass ratio of clay and bamboo powder was 1:2, 1:3, and 1:4, respectively. Three samples were prepared for each type with the size of 150mm×150mm×60mm. Few research reports the use of modified rammed earth material on roof because of the different ratios of materials. A typical rammed earth wall300 mm thick was studied by scholars, with the R-value of 0.27~0.70 ($m^2 \cdot K$)/W [3-5]. The rammed earth samples were also made at the same time, and the ratio was 1:3:6.

(2) Lab measurement

In order to get the optimum performance of the material before renovation, the samples were measured in the lab by using JTKD-I quick thermal conductivity meter based on the *Transient hot-strip method(THS)*. Before the measurement, the samples were dried in the drying box. The test was carried out in a relatively stable environment with the temperature between 18 and 20°C and the relative humidity between 45% and 50%. Each sample was measured for five times, and then recoded and calculated. The results are as shown in Table 8-7. The average thermal conductivity of the rammed earth was 0.5092W/(m·K). The thermal conductivity coefficients of the three types of samples were 0.207W/(m·K), 0.121W/(m·K) and 0.112 W/(m·K), respectively, with the average density of 892.9 kg/m^3, 800.3 kg/m^3, and 700.6 kg/m^3. Sample Three has the best thermal performance, but it cannot be joined together easily. This means that there would be relatively large shrinking and cracking after drying. Finally, Sample Two with the mass ratio of 1:3 was chosen as the thermal insulation material to improve the thermal performance of the ordinary roof.

Table 8-7 The thermal conductivity coefficient of the samples

Samples	Thermal conductivity coefficient(W/(m^2.k)	Density (kg/m^3)	Test environment(average)	
			Temperature (°C)	Relative humidity (%)
Sample 1 (1:2)	0.207	892.6	19.4	44%
	0.207	893.4	19.6	43%
	0.208	892.8	19.6	43%
Average	0.207	892.9		
Sample 2 (1:3)	0.119	800.2	18.6	46%
	0.126	798.5	18.4	47%
	0.127	801.3	19.1	45%
Average	0.121	800.3		
Sample 3 (1:4)	0.109	701.1	17.8	48%
	0.112	700.9	18.1	48%
	0.113	699.8	18.2	47%
Average	0.112	700.6		

8.4.2.2 Roof Renovation

There were two types of pitched roofs before renovation (Fig. 8-10). The existing roof without thermal insulation layer was renovated. The light clay roof was made up of light clay 150mm thick mixed with bamboo powder when the building was built. In the renovation, the purlins were heightened to 150mm, and the light clay was laid on the cedar board, which was fixed to the purlins. Although the light clay is lighter than the ordinary clay, the light clay 150mm thick is still too heavy for the ceiling. Therefore, the final construction was shown as Fig. 8-10. A part of the light clay was replaced by EPS which has higher insulation performance. Clay mixed with bamboo powder can not only reduce the weigh, but also prevent from pests and fire. A ventilation air layer was set to promote the ventilation in summer. The air layer can also be utilized as the insulation layer. In addition, protective nets were set in the outlet to prevent birds, rats or leaves from entering into the air layer thus weakening the role of ventilation and cooling.

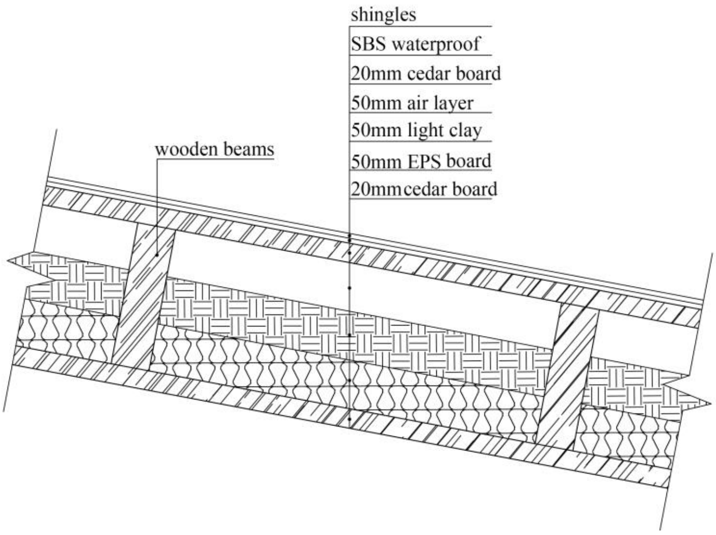


Fig. 8-10 Construction of roofs after renovation

The renovation was carried out in the summer of 2013, which is beneficial to drying. Light clay was mixed on site by hand. Soil is a mixture of minerals, organic matter, gases, liquids, and countless organisms that together support life on the earth. It is composed of different components as shown in Fig. 8-11. However, only clay has the ability of sticky. Therefore, the soil was first collected from nearby and the big stones, plant root and other waste were screened. Then, the soil was washed in water to get the clay which is very thin and sticky. The third step is to mix up the washed clay and bamboo powder. (Fig. 8-12)

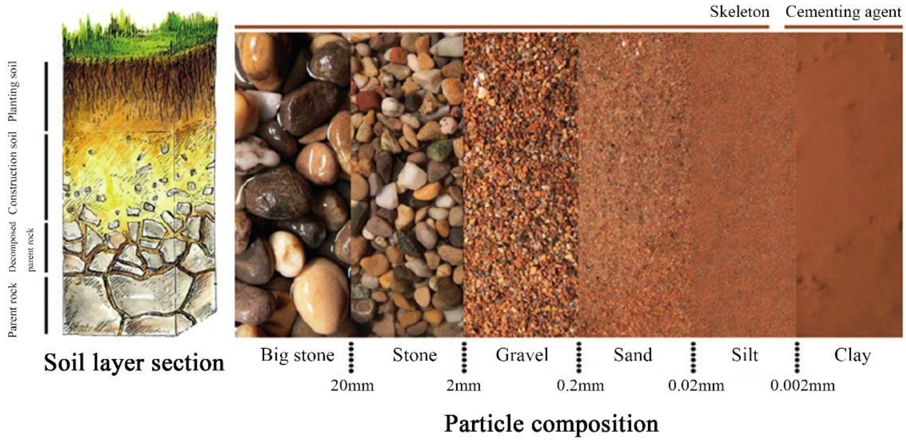


Fig. 8-11 Composition of soil

(Source: *Clay Concrete: Earth Material and Rammed Earth Construction [6]*)

(a) Collect and screen (b) Wash (c) Mix

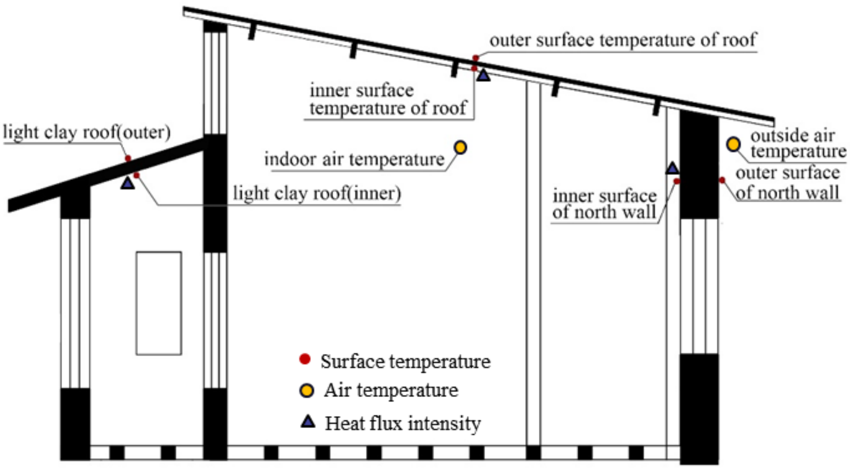
Fig. 8-12 Process of making light clay

Fig. 8-13 Construction process

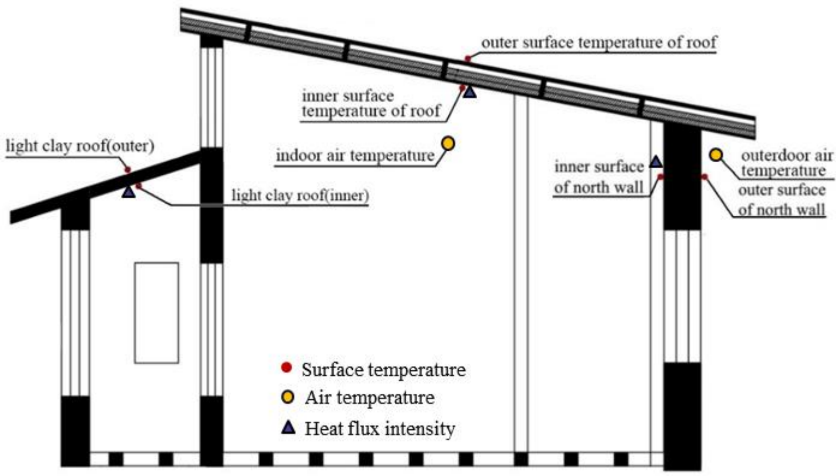
The height of beams under the roof was enhanced to150mm, and the cedar board 20mm thick was fixed to the beams. Then the EPS boards with the thickness of 50mm were put on the cedar board. The light clay was laid on the board 50mm thick.

8.4.3 Field Measurement Before and After Renovation

The field measurements were carried out by using the JTRG-II building thermal temperature and heat flux circuit automatic detector before and after renovation. The principle of the instrument takes the generally international copper thermocouple as the temperature sensor, and it can record the data from one-minute to sixty-minute intervals. The indoor air temperature, outdoor air temperature, inner surface temperature and outer surface temperature of the pitched roofs and north rammed earth walls, as well as the heat flux intensity were measured. The distribution of measuring points before and after renovation is as shown in Fig. 8-14.



(a) Before renovation



(b) After renovation

Fig. 8-14 Distribution of measuring points before and after renovation

8.4.3.1 Measurement Results before Renovation

The field measurement before renovation was carried out from February 1st to March 9th in 2013, and the data was recorded once an hour. Finally, the data from February 6th to February 7th was selected for analysis. The results are shown in Fig. 8-15.

It was cloudy on February 6th and 7th. The outdoor air temperature was from 6°C to12.2°C, with an average temperature of 8.7°C, and the temperature decreased quickly. The indoor air temperature was from 8.4°C to 14.3°C, with the average temperature of 11.7°C, which was about 3°C higher than the outdoor air temperature. The surface air temperature of the rammed earth wall was lower than that of the roofs, which ranged from 7.2°C to 12°C, with the average temperature of 9.7°C. The surface temperatures of roofs were very close to the indoor air temperature, which was influenced by the heat coming from the southern windows. The surface temperature of ER ranged from 8.4°C to 14.3°C, with the average temperature of 11.5°C.The surface temperature of EIR was from 7.8°C to 14.1°C, and the average temperature was 11.4°C.

The indoor air temperature was higher than the outdoor air temperature, and the heat transferred from inside to outside. However, the heat influx significantly varied with different parts. It shows that the heat influx of the rammed earth wall and EIR was more stable than that of ER. The bigger the indoor and outdoor temperature difference was, the larger the heat influx intensity would be. This means that the heat is more easily to go through the ER. The heat flux intensity of ER was the largest, ranging from 2.3W/m^2 to 7.7 W/m^2, and the average intensity was 5.1 W/m^2. The second was the rammed earth wall, and its heat flux intensity varied from 5W/m^2 to 0.2 W/m^2, with the average of 1.74 W/m^2. The heat flux intensity of EIR ranged from 0.2 W/m^2 to 7.4W/m^2, and the average heat flux intensity was 0.73 W/m^2. Based on the calculation according to inner and outer surface temperature and the heat flux intensity (section 3.3.2), the heat transfer coefficients of rammed earth wall, ER, EIR are 2.46 W/(m^2·K), 3.70 W/(m^2·K) and 0.45 W/(m^2·K), respectively.

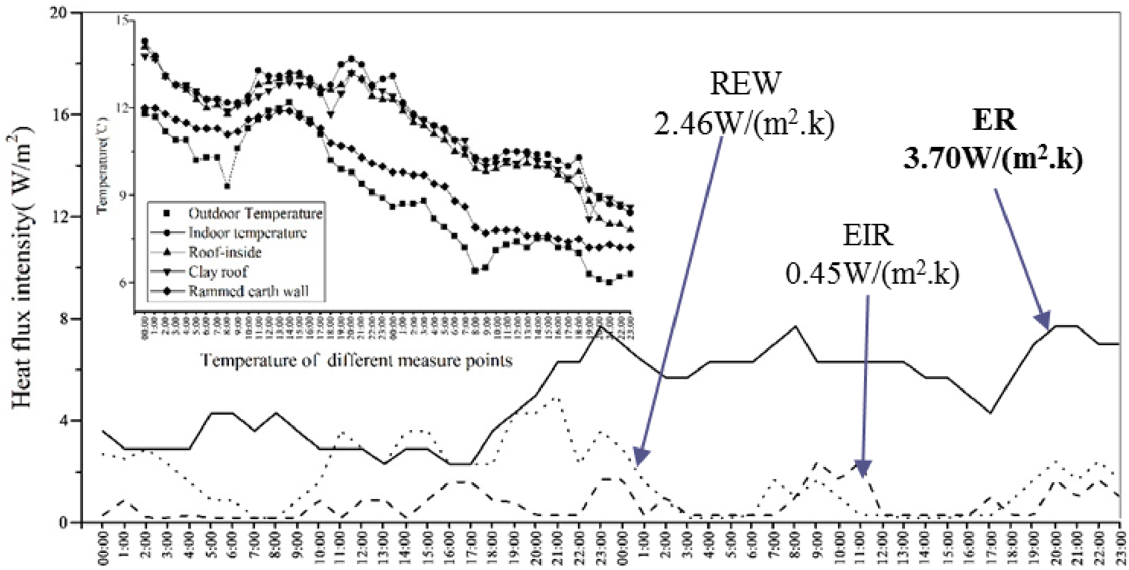


Fig. 8-15 Air temperature and heat flux intensity of roofs and rammed earth walls before renovation

8.4.3.2 Measured Results After Renovation

After renovation in the summer of 2013, the field measurement was conducted to evaluate the effect in the winter of 2014. The measurement started from February 1st to March 9th in 2014. Finally, the data on February 5th was selected for analysis, which was also a cloudy day, and the weather condition was close to that from February 6th to 7th in 2013. The results are as shown in Fig. 8-16.

The outdoor air temperature was from 5.5°C to 10.5°C, with the average temperature of 10.1°C. The indoor air temperature ranged from 6.7°C to 12.1°C, and the average temperature was11.1°C. It was about 1.0°C higher than outdoor air temperature. The surface temperature of IOR ranged from

6.4°C to 12.4°C, with the average temperature of 8.7°C. The surface temperature of EIR ranged from 6.5°C to 12.7°C, with the average temperature of 13.1°C. The surface temperature of the rammed earth in the north ranged from 6.2°C to 13.6°C, and the average temperature was 9.2°C. According to the comparison between the roofs and walls, the surface temperature of the rammed earth was the lowest.

As shown in Fig. 8-16, the heat influx intensity of the rammed earth wall was the highest. It ranged from 0.2 W/m^2 to 7.1 W/m^2, with the average value of 4.0 W/m^2. The second was IOR, and the heat flux intensity varied between 4.3W/m^2 and 1.6 W/m^2, with the average of 2.83 W/m^2. The heat flux intensity of EIR ranged from 0.2 W/m^2 to 5.7W/m^2, and the average heat flux intensity was 1.67 W/m^2. The results show that, the roof was more stable and insulative than the rammed earth wall after renovation. According to the relationship between inner and outer surface temperature and the heat flux intensity (section 3.3.2), the heat transfer coefficients of rammed earth wall, IOR, EIR were 2.35 W/(m^2·K), 0.63 W/(m^2·K) and 0.58 W/(m^2·K), respectively. The results show that the thermal performance of the roof after renovation was improved obviously.

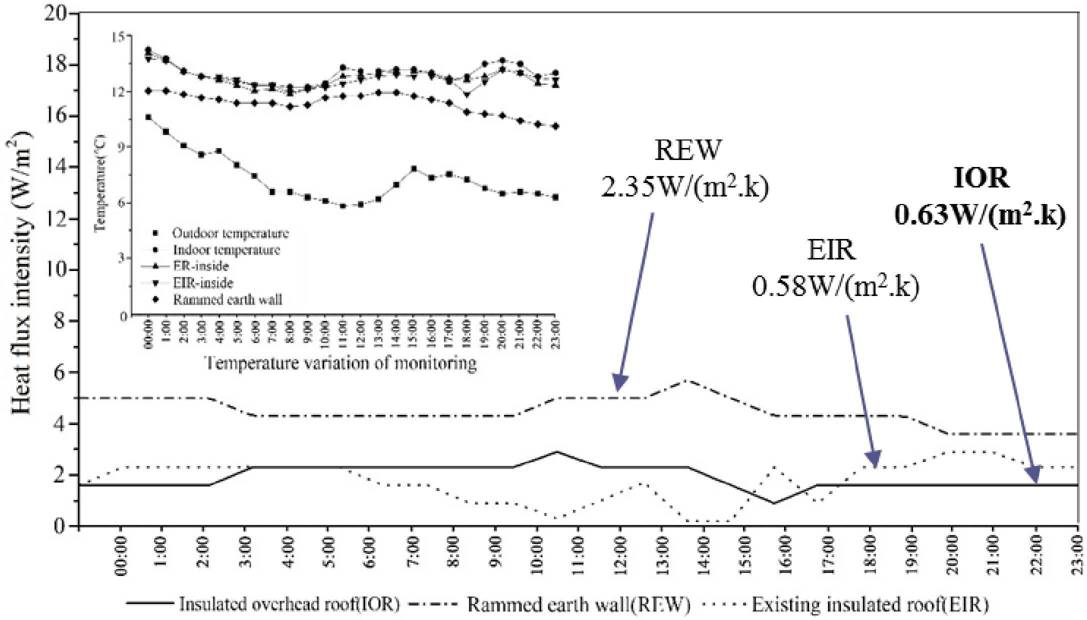


Fig. 8-16 Air temperature and heat flux intensity of roofs and rammed earth walls after renovation

8.4.4 Simulation and Comparison Before and After Renovation

8.4.4.1 Typical Building and Model Setting

The field measurements indicate that the thermal performance of the roof was improved. However, the measurements were carried out at different time in winter, and it was unreasonable to compare the thermal performance before and after renovation. In order to compare the effects, the indoor thermal environment of the top floor before and after renovation was simulated in the whole year. Since the heat transfer coefficient of roofs and walls would be changed with the environment, the U-value and D-value were calculated according to the physical parameters from the laboratory measurements or relevant reference. Since there was no weather file of Anji in Energy plus software, the typical meteorological year data of Hangzhou was used. Anji is near Hangzhou, and the climate is similar to each other. The parameters for simulation were listed in Table 8-8.

The simulation and field measurement results of bedroom on second floor were shown in Fig.8-17. The simulated temperature of the bedroom(BD-ST) was higher than the field measured result (BD-MT), with the maximum fitting error of 3.5°C. The field-measured and simulated temperature trends were similar, and the simulation results of the model can be used for further simulation.

Table 8-8 Parameters for simulation (Anji eco-house)

Items	Contents
Climate	Typical meteorological year data of Hangzhou (from *Energy plus* software)
Building information	latitude: N 30.23, longitude: E120.17, altitude: 41.70m, Total building area: 152.6m^2; shape coefficient: 0.52; window-to-wall ratio: 0.095.
Construction	● Exterior wall: 20mm mortar +330mm rammed earth＋20mm mortar, U-value =2.04W/(m^2·K),D=3.64 ● Interior wall: 15mm cedar board, U-value =3.89W/(m^2·K), D=3.41 ● Roof 1(ER): 20mm cedar board, U-value:3.41W/(m^2·K), D-value:0.69 Roof2 (EIR): 20mm cedar board +100mm light clay+50mm EPS+20mm cedar board, U-value:0.4W/(m^2·K), D-value:6.71 Roof3(IOR): 20mm cedar board +50mm EPS+50mm light clay +50mm air layer +20mm cedar board, U-value =0.52W/(m^2·K), D-value:3.75 Flat roof: 25mm cedar board+300mm air layer+ 100mm concrete slab+20mm mortar, U-value =1.41W/(m^2·K), D-value:4.13 ● Floor: 20mm cedar board,U-value =4.67W/(m^2·K), D=3.41 ● Ground: soil＋200mm gravel cushion＋100mm Cast- in-place concrete＋20mm composite mortar＋brick tile,U-value =2.22W/(m^2·K), D=1.23 ● Window: wood frame+3mm+13A+3mm hollow glass, U-value =2.8W/(m^2·K),SC＝0.60
Ventilation and airtightness	● Ventilation schedules: 5ac/h in summer and 1ac/h in winter ● Airtightness 0.7 ac/h
Activity	● Livingroom (on the first floor): Density: 0.03People/m^2; Schedules: 7:00~20:00 100%; 0:00~6:00, 21:00-24:00 0% ● Bedroom: Density: 0.2People/m^2 Schedules: 7:00~20:00 0%; 0:00-6:00,12:00-13:00,18:00-24:00 100%

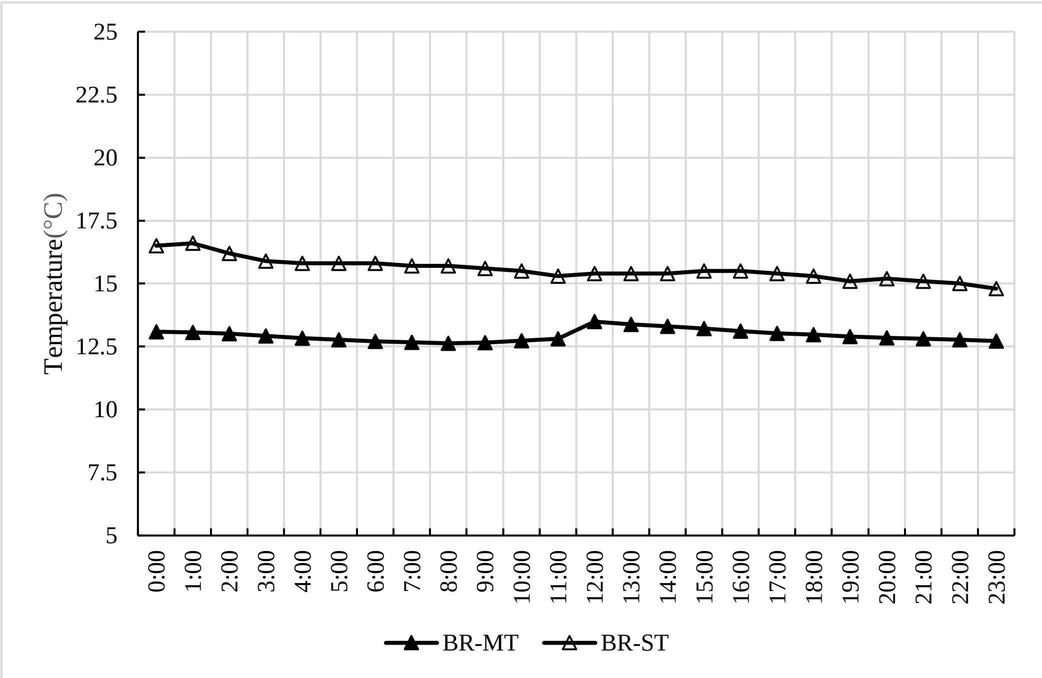


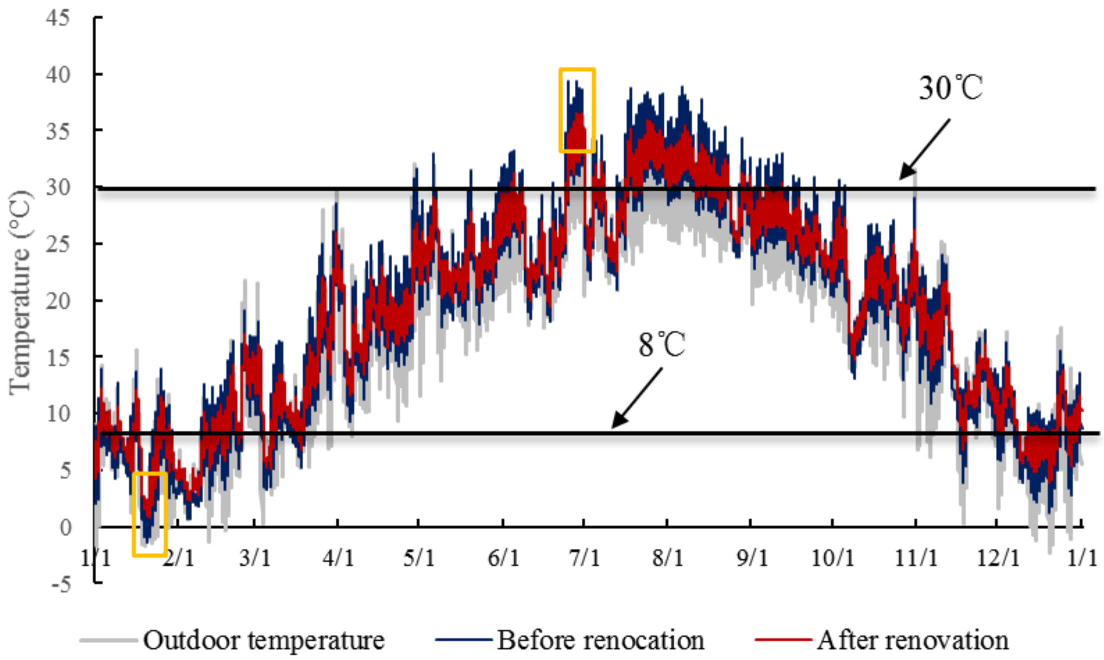
Fig.8- 17 Simulated and field measured indoor air temperature of bedroom (Anji eco-house)

8.4.4.2 Measurement Results Before and After Renovation

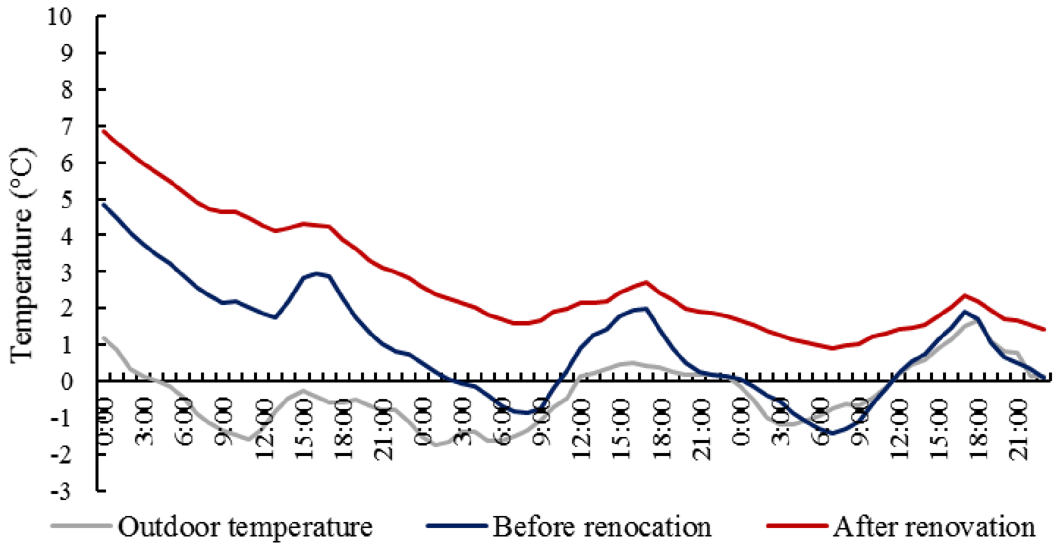
The simulation results are shown in Fig. 8-18. Before the renovation, the indoor air temperatures below 8°C and above 30°C lasted for 1543 hours and 1145 hours in the whole year, respectively; The total uncomfortable duration was 2688 hours, with the UHR of 30.7%. After the renovation, the duration below 8°C was reduced to 1252 hours, which have dropped by 291hours. The duration above 30°C was 1059hours, which dropped by 86 hours. The thermal performance in both winter and summer was improved. However, after the renovation, the duration below 5°C was still 357hours (about 15 days), and farmers would get warm by themselves, such as stoves, firewood, electric heater, and air-conditioner. This also means that it is difficult to keep the building in a comfortable situation all the time, and the passive technologies will be adopted due to the serious climate in Hot Summer and Cold Winter zone.

The air temperatures during the coldest days in winter from January 18th~20th before and after the renovation are shown in Fig. 8-18, b. The outdoor air temperature was below 2°C, with the average temperature of -0.34°C. Before the renovation, the indoor air temperature ranged from -1.42°C to 4.86°C, with the average temperature of 1°C. After the renovation, the indoor air temperature ranged from 0.92°C to 6.85°C, and the average temperature was 2.7°C. The average indoor air temperature increased by 1.7°C.

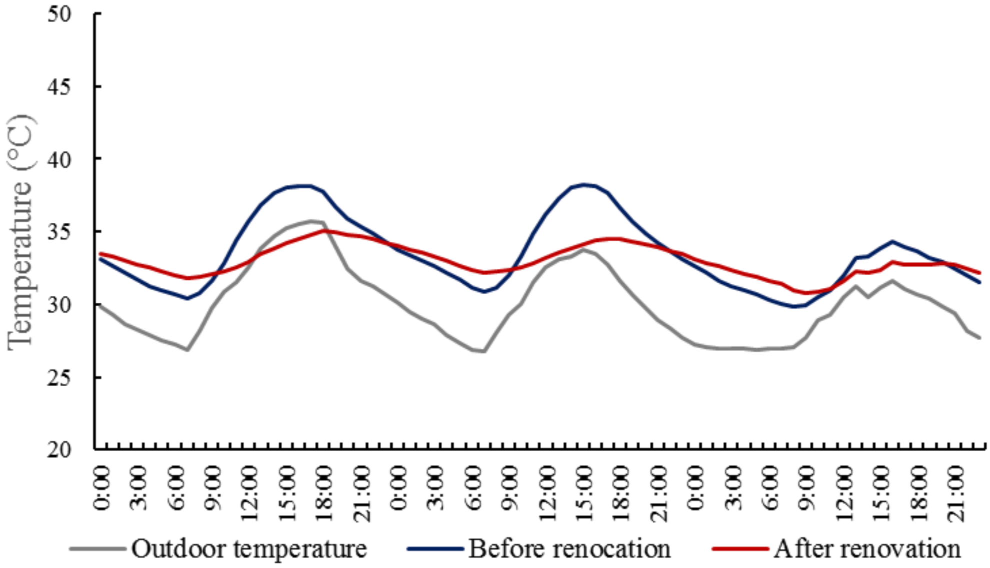
The air temperatures of the hottest day in summer from July 29th~31th after the renovation are as shown in Fig. 8-18, c. The outdoor air temperature was from 26.8°C to 35.6°C, with the average temperature of 30°C. Before the renovation, the indoor air temperature ranged from 29.8°C to 38.2°C, and the average temperature was 33.5°C. After the renovation, the indoor air temperature ranged from 30.8°C to 35.1°C, with the average temperature of 33°C. The highest indoor air temperature and the average temperature decreased by 3.1°C and 0.5°C, respectively. It can be seen that the air temperature was more stable after the renovation.



(a) In the whole year



(b) Winter: January 18th~20th



(c) Summer: July 29th~31th

Fig. 8-18 Simulation of indoor air temperature of the top floor in the whole year

8.5 Summaries

In this chapter, the study was carried out by multi-approach methods. A typical modern building(MB-1) which is a very common rural tourism household in local area and a traditional rural residential building which has the distinctive style and is very popular among tourists were simulated in the current indoor thermal environment and the effect of adopting different improvement strategies based on the field measurement. In addition, the roof of a new vernacular rural building (Anji eco-house) was renovated and simulated. Through the study, the following results can be obtained:

The simulation of MB-1 shows that the indoor thermal environment of the top floor and the guestroom in the south was poor in the whole year, which is in accordance with the field measurement. The improvement of building envelopes was beneficial to the indoor thermal environment of north guestrooms. However, it was not sure for the top floor and the south guestrooms. Level1 was the most effective for the top floor, and it was the most useful for 3FSR to reduce the uncomfortable hours in the whole year. However, Level3 was the most favorable for 3FSR to increase the comfortable hours during cooling and heating period. By improving the airtightness of the building, the uncomfortable hours were increased. This suggests that for rural residential building in hot summer and cold winter zone, smaller airtightness of building maybe not conductive to indoor thermal environment. Therefore, the selection among different conflicting prospects shall depend on the specific case study and climatic location [7].

For the traditional rural building, it is more comfortable in summer than in winter. According to the total uncomfortable hours, the thermal performance of the top floor was the worst, the second was the bedroom. The thermal performance of the living-room was the best. However, the temperature of the living room was poor in winter, because the living room is a semi-opened space which is connected with the courtyard. Five types of roofs of the top floor were simulated and compared. The results show that lower U-value and higher D-value are conductive to improving the indoor thermal environment of the top floor.

Finally, the roof of Anji eco-house was renovated by using light clay and EPS as the insulation materials. Light clay mixed up with clay and bamboo powder can determine the optimum mass ratio of 1:3 in Lab. The field measurements and simulation on the indoor thermal environment and the thermal performance of the roofs were carried out before and after the roof renovation. The results show that the passive strategies like improving the thermal performance of building envelopes could improve the indoor environment to some extent. However, it is difficult to keep the building in a comfortable situation all the time because of the serious climate in HSCW area.

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Chapter 9.

Conclusions and Future Work

9.1. Conclusions

In view of the lack of systematic research regarding rural households transformed from agriculture to rural tourism businesses in China, in this thesis, energy saving and indoor thermal environment of rural tourism household were surveyed, using Zhejiang province as an example. Numerical analysis was conducted to simulate and compare the energy consumption and indoor thermal environment by taking different envelope strategies. The main conclusions are shown as follows:

Chapter one, Background and purpose. Official data shows that rural population and rural housing areas take up a large proportion of the total population and total building area in China, and rural energy consumption grows quickly, which has been consistent with towns and cities. With the change of the rural economic structure and industrial structure, rural energy consumption is also changed. In recent years, rural tourism has developed rapidly, and farmers' lifestyles have changed. The purpose of this thesis is to study energy saving and the indoor thermal environment of rural tourism households, and to put forward corresponding optimization measures.

Chapter two, Policy and design standard for energy conservation of residential buildings. The developing process and current situation of building energy conservation standards were introduced. Then, the developing progress, climate zones, and main contents of residential buildings were introduced and compared. China is divided into five climate zones; Zhejiang belongs to the HSCW zone, which is similar to the 3C zone in the U.S. and the 6,7 zone in Japan. Energy efficiency standards for rural residential buildings in China were set later than those for urban residential buildings, which is a voluntary standard. The thermal performance requirements of envelopes in energy conservation standards for rural residential buildings (GB/T 50824-2013) are lower than the standards for urban residential buildings in China (JGJ 134-2010, DB 33/1015-2015) in the HSCW zone and the U.S. (IECC2015) in the 3C zone and Japan (BECS2013) in the 6 zone.

Chapter three, Theory and method of energy saving and environment improvement. There is a close relationship among human behavior, building energy consumption and indoor thermal environment. With the change of ordinary household to rural tourism household, building energy consumption and indoor thermal environment changed. The study was carried out in two steps; the first step was "field survey and analysis", and the second step was "simulation and optimization". 230 ordinary households and rural tourism households in Quzhou, Anji and Zhoushan were studied and analyzed. Field measurements regarding the indoor thermal environment and energy consumption were carried out on 10 households. The basic information; indoor thermal environment and energy consumption of rural residential buildings etc. were surveyed by a questionnaire, field mapping and field measuring and analyzed by statistical analysis, theoretical calculation analysis. Designbuilder software (based on Energyplus) was used for simulation analysis.

Chapter four, Investigation on situation of rural residential buildings. A survey was conducted on ordinary households and rural tourism households in Quzhou, Anji and Zhoushan. It showed that 1) The most common family size is 5 individuals, with the permanent residential population of 2 individuals in an ordinary household, and a higher population in a rural tourism household. The primary industry is replaced by the rural tourism business gradually, and the income of rural tourism household is higher. 2) Among three typical types of rural residential buildings, most rural tourism households are modern buildings and traditional vernacular buildings built after the 1980s. 3) The average total building area of rural tourism household is about 1.2 to 2.4 times larger than an ordinary household. Modern buildings have larger window-to-wall ratios and smaller building shape coefficient, about 0.65. 4) Thermal performances of rural residential envelops are poorer than the thermal requirements of both domestic and foreign standards.

Chapter five, Survey on indoor thermal environment of rural residential buildings. The indoor thermal environment of ordinary households and rural tourism households were surveyed and measured in winter and summer. 1) In the coldest days of winter (outdoor temperatures below 3°C), the indoor temperature was below 8°C, and the PMV value was below -1.5, which was in the uncomfortable range. The thermal performances of the living room, the bedroom on the first floor and the south guestroom on third floor were better. The top floor without decoration was the worst. 2) In the hottest days of summer (outdoor temperatures reached up to 36°C), the indoor temperature and PMV value varied greatly. The temperature of the bedroom on the first floor was below 30°C, with the ePMV in the comfortable range. Most of time, the indoor air temperature of the top floor and the south room was over 30°C, which was in the uncomfortable range. 3) Thermal feelings of farmers and tourists showed that it was more comfortable in summer than winter.

Chapter six, Survey on energy consumption of rural residential buildings. Energy consumption of ordinary households and rural tourism households, and the energy use behaviors of farmers and tourists were surveyed and compared. 1). Annual electricity consumption is 21.6kWh/m2, 12.6kWh/m2, 31.2kWh/m2 in rural tourism households in Quzhou, Anji and Zhoushan respectively, which is 4.5kWh/m2, 5.7kWh/m2, 6kWh/m2 in ordinary households. Total annual energy consumption of rural tourism households is 43.02 GJ, 21.52GJ and 18.71GJ in Quzhou, Anji and Zhoushan respectively, which is about 3 to 5 times higher than ordinary households (9.54GJ, 7.62GJ and 3.66GJ). 2) In terminal energy consumption, cooking and hot water is the largest consumer, accounting for 93.7%, 92% and 75.1% in ordinary households, and 87.8%, 90.1% and 68% in rural tourism households. 3) In electricity consumption, cooling energy consumption of rural tourism household accounts for 24% to 39%. The field monitoring in a rural tourism household shows that the air-conditioner takes up to 55.76% of the electricity consumption, mainly used at night. 4) Compared to other studies, energy consumption of rural tourism households is higher than Zhejiang and China's rural areas, even higher than in urban areas. 5) For ordinary households, energy consumption is related to frequently used area, income and permanent population. For rural tourism households, it is related to total building area, number of ACs, number of guestrooms and income.

Chapter seven, Sensitive analysis of energy saving in rural residential buildings. Under different building functions (ordinary/ rural tourism) and under different regions (Quzhou/ Anji) and building forms (modern/ traditional). 1) The cooling and heating energy saving rates reach from 5% to 22.7% by improving external walls, windows and air tightness under the ordinary household model, and 17.5% to 20.6% under the rural tourism household model. 2) For the top floor with attic (space for storage), the cooling and heating energy saving by improving roofs is not obvious, because of the buffer effect of the air layer. Without an attic, energy consumption is reduced to 20.3% under the ordinary household model and 33.7% under the rural tourism household model. 3) The improving of SHGC is more effective under the rural tourism households model than the ordinary households model. 4) The cooling and heating energy consumption of modern building is lower than the traditional building, due to the smaller shape coefficient and W-to-W rate; building energy consumption in Zhoushan is lower than Quzhou, because Quzhou is hotter than Zhoushan.

Chapter eight, Strategies for improving indoor thermal environment. The roof of the Anji eco-house was renovated by using traditional and new materials. Lab experiments were conducted to determine the optimum ratio, which was mixed up by clay and bamboo powder. The optimum mass ratio is 1:2, with the thermal conductivity of 0.121W/(m·K). Field measurement were carried out before and after renovation, the thermal performance of roof was improved from 3.70W/ (m2. k) to 0.63W/ (m2. k). Finally, indoor thermal environment of top floor over the whole year was simulated before and after renovation, and the air temperature in the hottest days and coldest days were compared.

Chapter nine, Conclusions and future work, summarized the results in every chapter, and discussed the insufficient work and future work.

9.2. Future work

Firstly, in the investigation stage, there exists inevitable errors about the information collected. For example, the energy consumption and the appliances using schedule was not as regular as office buildings. Secondly, single energy saving measures are insufficient and unbalanced, and it's better to take orthogonal experiments of the combined scenarios rather than adopting the different single energy saving measures for different envelope components.

Thus, in the future work, the field-measures of the electricity consumption of appliances and full-scale indoor thermal environment will be considered. Other technological measures for shading systems, building chambers, as well as renewable energy will also be discussed and simulated. With the different energy saving measures introduced, the full-scale evaluation will not only impact on energy consumption variation and indoor thermal comfort, but also other aspects such as economic analysis and environmental impact.

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