EXPERIMENTAL INVESTIGATION OF DOUBLE LAYER TROMBE WALL IN WINTER IN SEVERE COLD REGION OF CHINA

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EXPERIMENTAL INVESTIGATION OF DOUBLE LAYER TROMBE WALL IN WINTER IN SEVERE COLD REGION OF CHINA

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Preface

As the world energy crisis becomes more and more serious, people gradually realize the importance of energy conservation and the full exploitation of alternative energy sources. At this stage, China advocates the concept of energy saving and environmental protection development, and the construction industry is also developing in this direction. The construction industry, as an industry that consumes a large amount of resources, naturally has to actively explore feasible paths to reduce resource losses and actively promote the green development of the entire industry. The use of renewable resources, especially solar energy resources and building wall insulation technology, can effectively reduce the loss of electricity and coal in the heating and cooling of buildings, which is of great significance in promoting the construction of a resource-saving society. In this paper, a footprint experiment to improve the Trombe WALL was conducted in Jilin Province, one of the "hardest hit" areas in terms of building energy consumption in China. The experimental room is designed to be 75% energy efficient and takes into account the overall environmental layout and the application of external insulation technology, which improves the accuracy of the data and provides valid data for its future application. The paper also presents a design for the optimum ventilation pattern in winter for this size, as well as an energy analysis.

Acknowledgement

Firstly, I would like to thank my two respected leaders, Professor Gao Weijun and Professor Fukuda. Professor Gao let me to open the door to doctoral studies and let know the importance of academic research, but also made me realize that there is a gap between me and many of my best colleagues, which made me realize that I should be more diligent. Professor Fukuda's rigour in approaching academics has taught me to treat academics with excellence, and Mr Fukuda's teaching has shown me that what I am doing is great and that I have to keep fighting. Professor Fukuda taught me the importance of staying positive in everything I do.

Secondly, I would like to thank Professor Zhang Tao, who, as the head of the Fukuda Research Office, cared for us from study to life. I was deeply touched by his guidance in writing my dissertation and taking care of the trivialities of life, and the way he put the interests of the group first, making us feel secure even when we were far away. I would also like to thank my fellow student, Mr. Xiao yuling, for his help in advising me on how to write my dissertation. I would also like to thank Ms Zhou Rui for her help and for suggesting better ways to handle the data.

Finally, I would like to thank my family for their support and understanding which has kept me warm. They are also my motivation to keep on doing this assignment.

EXPERIMENTAL INVESTIGATION OF DOUBLE LAYER TROMBE WALL IN WINTER IN SEVERE COLD REGION OF CHINA

ABSTRACT

Energy is the basis for social development and human survival, the structure of primary energy consumption has diversified, and the use of renewable energy has played an indispensable role in alleviating the energy crisis. However, the reserves of fossil energy are limited, and the amount that can be easily exploited is getting smaller and smaller. In the long run, an energy crisis is inevitable, and an important measure to solve the energy shortage and environmental problems is to increase the proportion of renewable energy in the primary energy consumption structure. In China, although oil, natural gas and other high-quality fossil energy resources are abundant, but because of the uneven distribution of these energy sources and the difficulty of extraction, can not meet the needs of the current rapid development of China's economy, still need to import

As the technological development of renewable energy applications continues to mature and benefit from decreasing costs, renewable energy is receiving attention from countries around the world. Many countries have made the attribution of renewable energy an important part of their long-term energy development strategies. The European Union has developed a series of policies to encourage the application of renewable energy in various sectors. In 2010, renewable energy accounted for 2%

of primary energy consumption in all major European countries, and member states have reached an agreement to increase this to 20% by 2020, with plans to reach 50% by 2050.

Trombe wall is also called heat collecting wall. The function of this kind of building is to improve the living environment of people in cold areas. Because the land area is very vast, some areas will be in the low temperature zone, and the living environment of the local residents is difficult for the human body to cope with alone, which makes the local people take precautions against the severe cold environment in which they are located . Such a natural environment makes the demand for buildings such as the trombe wall always exist. Similar to this, traditional buildings built to improve the living environment have developed a lot, and some are still solving the living environment and climate problems for local people

Chapter 1: Energy status and research significance

The first chapter focused on the progressive progression from world energy to building energy consumption in the harsh northern regions of China, with the main conclusions being.,In many developed countries, energy consumption in buildings is even greater than that in industry and transport. At the same time, surveys show that such high building energy consumption in China is caused by numerous factors, but even more so, it shows the huge potential for building energy efficiency in China. The combination of solar energy application technology and high energy consumption in buildings is an important measure to reduce the proportion of fossil energy in building energy consumption and an important condition to ensure the sustainable development of our economy.

Chapter 2: CURRENT DEVELOPMENTS IN THE APPLICATION OF RENEWABLE ENERGY AND THE DEVELOPMENT OF THE TROMBE WALL

Solar energy is energy emitted by the sun and transmitted to the earth's surface in the form of electromagnetic radiation, which can be converted into heat and electricity through photo thermal and photoelectric conversion. The basic forms of indirectly beneficial heat collection are: Trombe walls, water walls, water-carrying walls (water-filled walls) with additional sun rooms, etc. Here we focus on the Trombe l Wall.The double layer Trombe wall is less studied in colder regions and, thanks to the inner wall, it reduces heat loss very well.

Chapter 3: SIMULATION OF THE EFFECT OF A DOUBLE LAYER TROMBE WALL UNDER THE ACTION OF A DC FAN USING ENERGY PLUS

This chapter is devoted to the simulation of data with the ENERGY PULS software and prepares the ground for the comparison of experimental data in the next chapter, which introduces theoretical knowledge from two aspects: one is the theoretical knowledge of the software and the other is the knowledge of the operation mechanism of the TROMBE wall.

Chapter 4: EXPERIMENTS ON THE WINTER HEATING MODE OF THE DOUBLE LAYER TROMBE WALL SYSTEM

This chapter focuses on the design of the experimental room, the design of the experimental room in the cold region is different from other regions, the heat loss in the cold region is more serious, so in order to ensure the success and authenticity of the experiment, we have adopted the standard energy-saving insulation design.

Chapter 5: STATISTICS AND ANALYSIS OF EXPERIMENTAL DATA

This chapter has documented a lot of data, and through comparison it was found that the simulation data is realistic, and secondly

This chapter mainly investigates and analyses the optimum opening temperature of the fan and the optimum air velocity. In the event of a shortage of heat sources, it is possible to achieve temporary office occupancy by some auxiliary means and this design reduces the consumption of coal.

Chapter 6: OTHER FACTORS AFFECTING THE DOUBLE SANDWICH TROMBE WALL

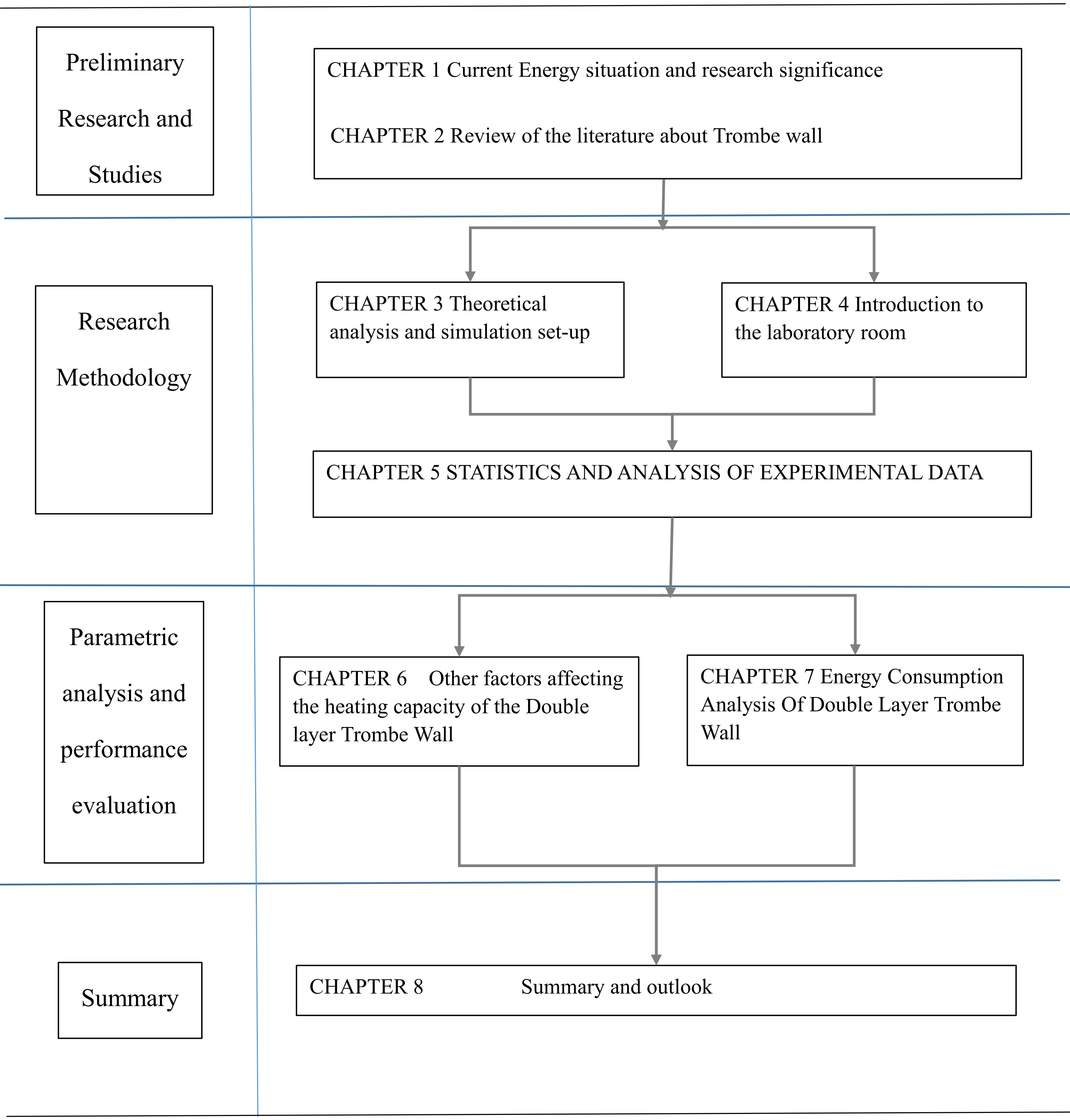
This sheet focuses on other factors affecting the double sandwich TROMBE WALL, mainly the thickness of the external walls, the height and thickness of the air layer, and the thickness of the internal walls are listed for comparison.

Chapter 7: ENERGY CONSUMPTION ANALYSIS OF A DOUBLE LAYER TROMBE WALL IN WINTER IN A SEVERE COLD REGION

The general expression of this chapter is the analysis of the energy consumption of the double mezzanine TROMBE wall. This chapter describes the energy consumption of this experiment through two expressions. During the whole life cycle of a building, the energy consumed by building materials and the construction process generally accounts for only about 20% of its total energy consumption, with most of the energy consumption occurring during the operation of the building.

Chapter 8: Summary and outlook

Flowchart of thesis



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Chapter 1

ENERGY STATUS AND RESEARCH SIGNIFICANCE

CHAPTER 1: CURRENT ENERGY SITUATION AND RESEARCH SIGNIFICANCE

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1.1 Background of the study

1.1.1 World energy profile

Energy is the basis for social development and human survival, the structure of primary energy consumption has diversified, and the use of renewable energy has played an indispensable role in alleviating the energy crisis. Figure 1-1 shows the consumption structure of primary energy in various regions of the world in 2017[1], from the data in the Figure 1-1, we can see that energy consumption in Europe and the United States is dominated by oil, the Middle East is mainly consumed by oil and natural gas, while in Asia and the Pacific, coal is still the dominant fuel, with a 48% consumption share. The data in the graph also illustrates that the global economy has grown largely thanks to the use of fossil fuels.

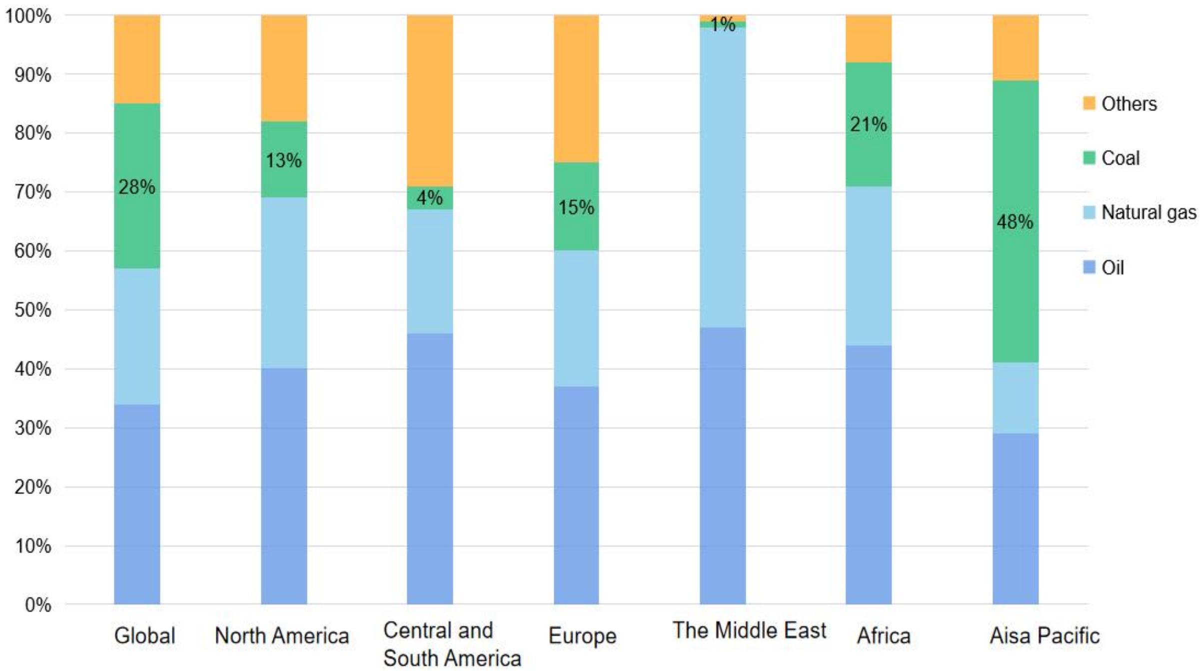

Fig 1-1 World energy consumption by region

Source:<Global first-time energy consumption mix by region 2017>

However, the reserves of fossil energy are limited, and the amount that can be easily exploited is getting smaller and smaller. In the long run, an energy crisis is inevitable, and an important measure to solve the energy shortage and environmental problems is to increase the proportion of renewable energy in the primary energy consumption structure. In China, although oil, natural gas and other high-quality fossil energy resources are abundant, but because of the uneven distribution of these energy sources and the difficulty of extraction, can not meet the needs of the current rapid development of China's economy, still need to import. China's imports of oil and natural gas and the degree of external dependence. It can be seen from the graph Figure1-2 that China's dependence on oil and natural gas imports is increasing year by year and there is a serious shortage[2], so it is urgent to develop new energy sources. China's coal resources are abundant, second only to the United States and Russia, and the current energy consumption structure of China is mainly based on coal.

Figure 1-3 shows the structure of China's energy consumption in 2018, it can be found that China's coal consumption accounts for more than 60%, China's consumption of coal is much larger than its consumption of other energy sources[3], and the sulphide, nitrogen compounds, dust and C02 produced in the production and use of coal are the main sources of greenhouse gases and atmospheric pollution. How to solve the current energy shortage has attracted the attention of all countries around the world. While dealing with energy shortages, the environmental pollution caused by energy use cannot be ignored. The natural material basis for a healthy and sustainable human existence is the ecological environment in which we live, which is also an important condition for the sustainable development of human society.

Fossil energy in the process of over-exploitation and use is accompanied by damage to the natural environment, such as carbon dioxide and other greenhouse gas emissions caused by the rise in global temperatures, as the total global emissions of greenhouse gases is increasing year by year, according to statistics in the last century, the total annual emissions of carbon dioxide in 1990 was 33.8 billion tons, by 2014 the data has exceeded 489 tons[4].

The latest report from Physicist.org shows that atmospheric C02 levels reached a new record high of 414.7 ppm in May 2019 [5] .Environmental pollution is a serious threat to human health and survival, and the development and use of clean and renewable energy sources is a matter of urgency.

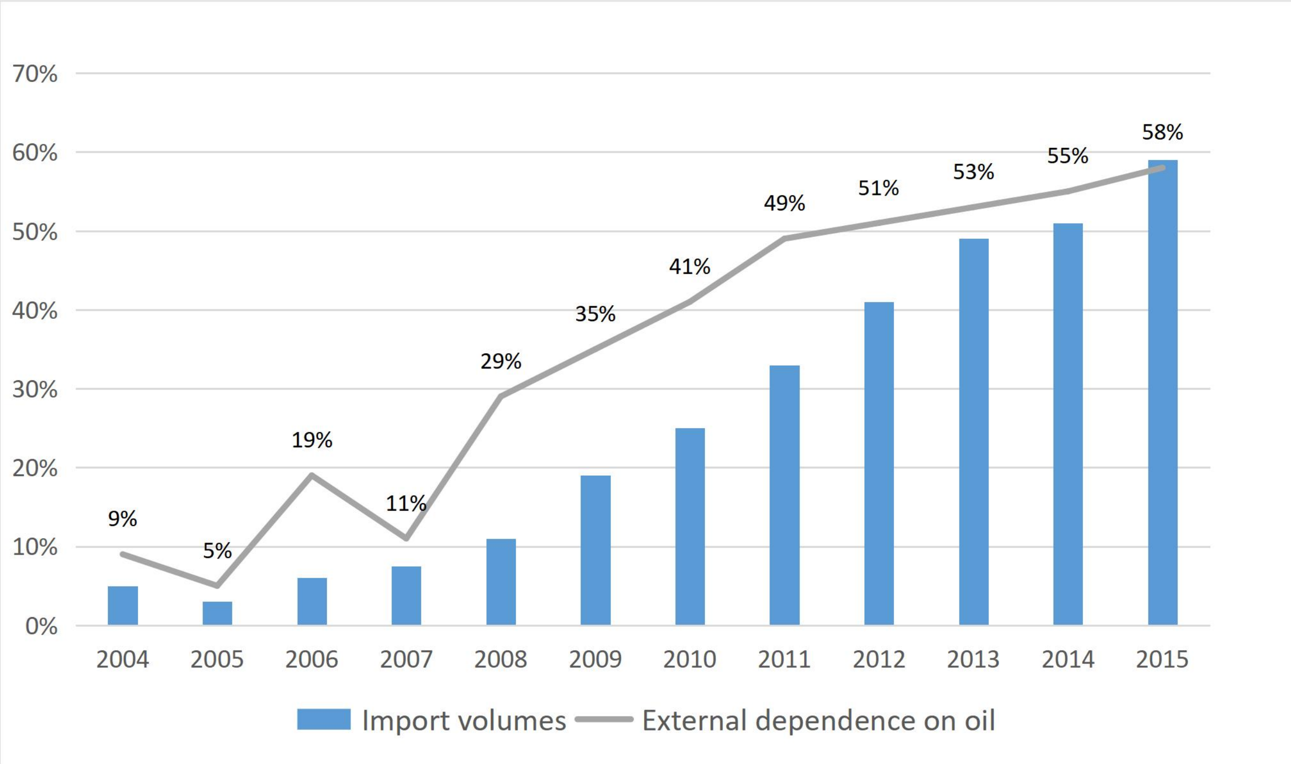

Fig 1-2 China's Energy Imports and External Dependence, 2004-2015

Source:<White Paper on Energy Distribution in Buildings in the 13th Five-Year Plan>

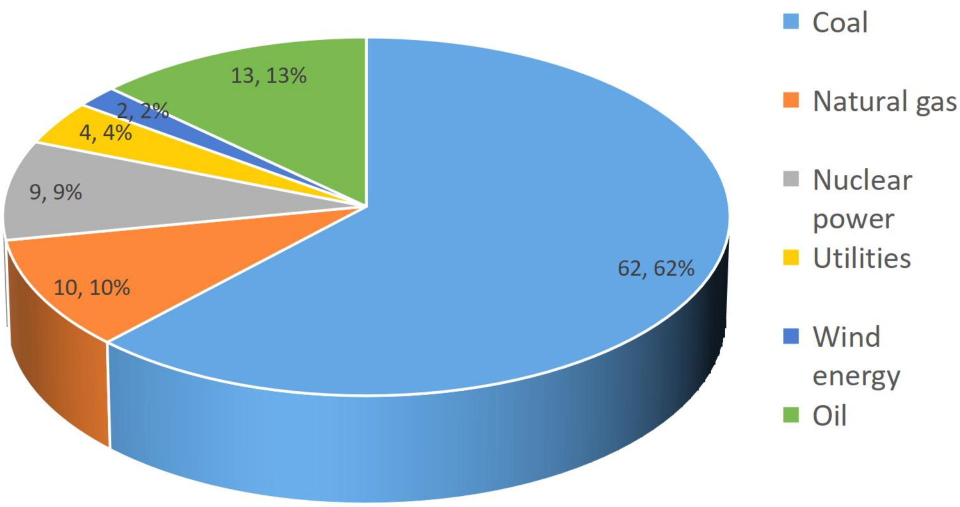

Fig 1-3 Map of China's first energy consumption

1.1.2 Status of energy consumption in buildings

Energy The oil crisis of 1973 gave a major boost to energy efficiency in buildings in many countries, in the form of energy efficiency standards for buildings, which were designed to reduce energy consumption and thus reduce dependence on oil through mandatory measures. Since the 1980s and 1990s, most developed countries have continued to improve their building energy efficiency standards, raising both the technical standards and the energy performance of their buildings.

Since the introduction of the concept of energy efficiency in buildings, the meaning of energy efficiency in buildings has gone through three stages, from shallow to deep, from simple to comprehensive: in the first stage, it was called "energy saving in buildings", which is what we now call energy efficiency in buildings; in the second stage, it was renamed "energy conservation in buildings, which means minimizing the dissipation of energy in buildings; and the third stage, commonly referred to in recent years as energy The third stage, commonly referred to in recent years as 'energy efficiency in buildings', is not about saving in a negative sense, but about improving the efficiency of energy use in a positive sense. Although it is still commonly referred to as energy efficiency in buildings, it has moved up to the third stage, i.e. the rational use of energy in buildings and the continuous improvement of energy efficiency.

In the past, it was common practice to refer to energy consumption in the production of building materials, in the construction and use of buildings, and in the demolition of buildings. This is an overly broad definition of building energy efficiency that spans different areas of industrial production and residential life, and is inconsistent with international understanding. Energy consumption in buildings in developed countries refers to the energy used in buildings, mainly in heating, ventilation, air conditioning, hot water supply, lighting, electricity and cooking. It is a part of people's energy consumption, alongside that of industry, agriculture and transport. Its proportion varies from country to country, generally ranging from 25% to 40%. The coverage of energy consumption in buildings in China is now in line with that of developed countries. At present, China's building energy efficiency work is mainly focused on building heating, air conditioning and lighting, and combines energy efficiency with improving the thermal environment of buildings, including comprehensive measures to improve energy use efficiency in the building itself and building equipment.

(1) Reduce pollution and improve environmental quality. China is a country where coal and oil are the main sources of energy, and these fossil energy sources produce large amounts of carbon dioxide, sulphur dioxide, nitrogen oxides and suspended particles during the combustion process. Carbon dioxide causes the "greenhouse effect" in the outer layer of the earth's atmosphere, seriously endangering the living environment of human beings; sulphur dioxide, nitrogen oxides and other pollutants are not only one of the root causes of respiratory diseases, but also easily form acid rain to damage forests, soil and buildings. During the winter heating period in the north of China, there is often serious pollution and hazy weather, which is directly related to the massive use of fossil-based energy. By reducing energy consumption, energy-efficient buildings reduce pollutant emissions, which in turn improves environmental quality and reduces the greenhouse effect. Therefore, from this perspective, building energy efficiency is about protecting the environment.

(2) Improving indoor thermal comfort and enhancing people's quality of life With the continuous improvement of people's living standards in China, a comfortable indoor thermal environment has become a common demand for people's lives and is conducive to their physical and mental health. In the north, the insulation performance of the envelope of energy-saving buildings has been greatly improved, and the insulation and air tightness of external doors and windows have also been improved, and the temperature of their internal surfaces has been significantly increased in winter, which are all very conducive to improving the indoor thermal comfort and the stability of the indoor thermal environment; in the south, the thermal insulation performance of the envelope of energy-saving buildings has been greatly improved, and the natural ventilation has been strengthened, and attention has been paid to the design of shading, and these measures have greatly In the south, the thermal insulation of the building envelope has been greatly improved.

In the workplace, the improvement of indoor thermal comfort is conducive to the improvement of work efficiency and labour productivity, and the improvement of workers' health.

(3) Promoting the sustainable development of the national economy. Energy is an important material basis for developing the national economy and improving people's lives.

It is also an important strategic resource for maintaining national security. At present, China's buildings use 27.5% of the country's total energy consumption, making them a major consumer of energy. If energy efficiency in buildings is not implemented, it will greatly increase China's energy burden in the long term, and it will not be possible to achieve the dual control targets of total building scale control and building operation energy intensity, nor will it be possible to achieve the goals of China's Strategic Action Plan for Energy Development (2014-2020), which is not conducive to the sustainable development of China's economy.

(4) A new economic growth point for the national economy. Energy-efficient buildings require a certain amount of incremental investment, but with less investment and more savings. Practice has shown that as long as local conditions are met and suitable energy-saving technologies are chosen, the cost per square metre of residential buildings can be increased by 5% to 8% of the construction cost, and the energy-saving target of 50% can be achieved. The payback period for energy efficient buildings is typically around 5 years, which is a significant economic benefit compared to the 50-100 year life cycle of a building. After a single investment, the savings in heating or air conditioning can be used to benefit the building over its life cycle. Therefore, new energy-efficient buildings and energy-saving renovation of old buildings will form a new growth point for the national economy with both investment and environmental benefits.

(5) The cause of building energy efficiency has greatly promoted the scientific and technological progress of the construction industry, and has also promoted social development.

Energy efficiency in buildings is achieved through the planning and design of buildings, the design of individual buildings and the adoption of comprehensive energy-saving measures for building equipment (including the selection and efficient operation of equipment and systems with high energy efficiency ratios), the continuous improvement of energy efficiency and the full use of renewable energy sources, in order to achieve the goal of continuously reducing energy consumption in building operations. Energy efficiency measures must be effectively implemented throughout the design, construction and management of buildings in order to achieve tangible results. The promotion of energy efficiency in buildings has many important implications.

Energy consumption in buildings accounts for an increasing share of primary energy demand, and in many developed countries, building energy consumption even exceeds that of industry and transport. For example, in 2004, in the United States, the Commonwealth and the European Union countries, the share of building energy consumption in primary energy consumption was 40%, 39% and 37% respectively [6]. In China, with the accelerated urbanization process, the share of building energy consumption in primary energy consumption is increasing year by year.

Figure 1-4 gives the change of building energy consumption in China in the last 20 years. According to the data in the figure, it can be found that the ratio of building energy consumption to total energy consumption in China rose from 16% in 2005 to about 33% in 2020, and if the building energy consumption in 2020 is converted into standard coal, it reached 1.1 billion tons. This high level of building energy consumption is caused by a number of factors, but is all the more reason why there is a huge potential for energy efficiency in China's buildings. The combination of solar energy application technology and energy-intensive buildings is an important measure to reduce the proportion of fossil energy in building energy consumption and an important condition for the sustainable development of our economy.

With the improvement of people's living standards in developed countries in Europe and America, the proportion of residential energy consumption in the national energy consumption is quite high, and there are considerable differences in residential energy consumption due to the differences in national conditions. For some countries and regions with long cold weather periods, such as the countries of Northwest Europe and Canada, heating and hot water consumption account for most of the residential energy consumption.

In developed countries, urban and rural buildings are generally equipped with heating equipment and the energy used is mainly gas, oil or electricity. The heating room temperature is generally 20 to 22°C[7], with a thermostat controller to automatically adjust the room temperature. Compared with China, in similar climatic conditions, developed countries have a longer heating time in a year, while supplying domestic hot water all year round; hot areas in the building are installed with air conditioning equipment.

In developed countries, where there are many more existing buildings than new ones built each year, it is essential to promote the retrofitting of existing buildings in order to achieve outstanding results. In the Nordic and Central European countries, the renovation of old buildings in accordance with energy efficiency requirements was already underway before 1980 and was largely completed by the mid-1980s. In Western Europe and North America, the retrofitting of existing houses has also been gradually organized. As a result, in some countries the energy consumption of buildings has fallen significantly, despite the fact that the floor space has increased year on year. For example, in Denmark in 1992 the heating floor space increased by 39% compared to 1972, but at the same time the total heating energy consumption was reduced from 322 PJ in 1992 to 222 PJ, a reduction of 31.1%; the proportion of heating energy consumption to the total national energy consumption also fell from 39% to 27%; the heating energy consumption per square metre of floor space was reduced from 1.29 GJ to 0.64 GJ, a reduction of 50%.The energy consumption of buildings in China is compared with the major developed countries in the world, as shown in Figure 1-4. As can be seen from the graph, the energy consumption of buildings in China is higher than the level of developed countries. Compared to European countries, which have done a better job of building energy efficiency in developed countries, China's building energy consumption per unit area is about 1.5 times that of Europe[8]. Taking into account the difference in the level of energy consumption between urban and rural buildings in China, even if the rural data is not taken into account and only the energy consumption data of urban buildings are used for comparison, the difference with developed countries is still significant. Therefore, it can be concluded that the current level of building energy consumption in China is 1.5 to 2 times higher than that of the major developed countries when compared per unit area.

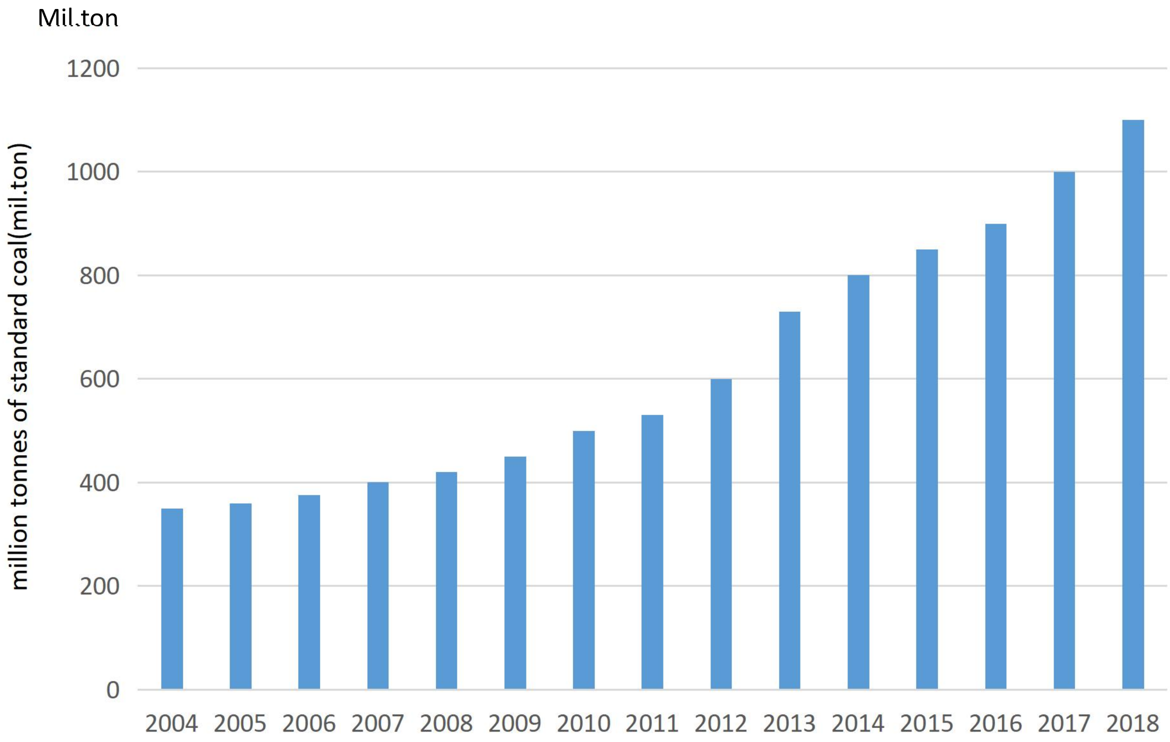

Figure1-4 Energy consumption of buildings in China (million tonnes of standard coal) From 2004 to 2018

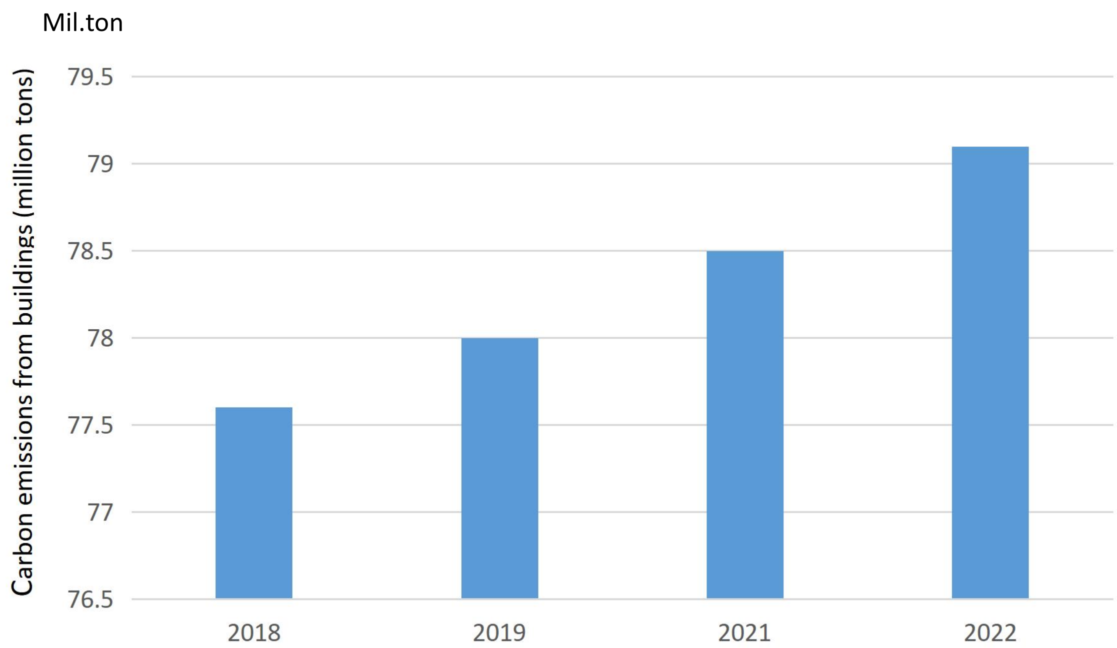

Fig1-5 Carbon emissions from buildings in Siping in recent years and planning Source<Thirteenth Five Building Carbon Emissions and Emission Reduction Plan for Siping City>

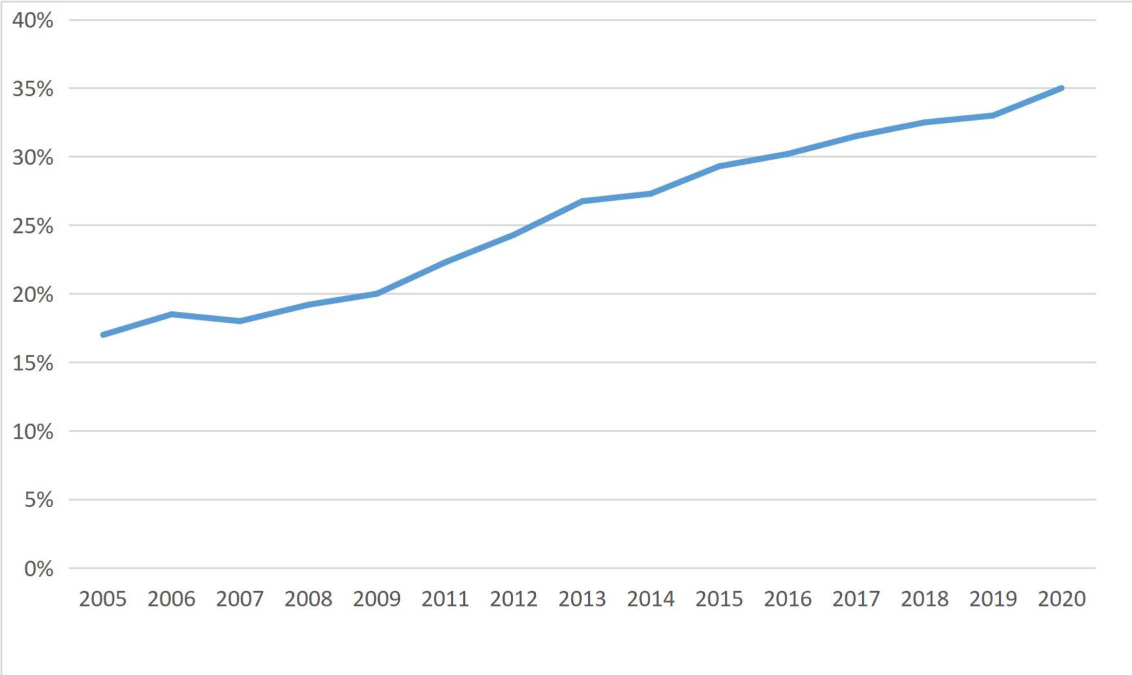

Fig 1-6 Comparison of annual energy consumption per unit of floor space in major countries.

1.1.3 The significance of building energy efficiency

The construction of a resource-saving society is a strategic decision made by China to achieve the goal of sustainable development. Energy conservation is an important part of a resource-saving society. China's building energy consumption has exceeded 1/4 of the country's total energy consumption and will gradually increase to 13 times 7 generations since the beginning of the energy crisis experts from various countries have conducted studies on the potential for energy saving in various energy-using fields, the results show that building energy is the energy-using field with the greatest potential for energy saving, so it should be the focus of energy-saving work.

Green Building Action Plan" for the "12th Five-Year Plan" during the new and renovation projects put forward clear requirements ① for new buildings, new buildings in urban areas to strictly implement mandatory energy-saving standards, the "12th Five-Year Plan" period to complete the new green building 1 billion square meters, to the end of 2015, 20% of new urban buildings to meet the requirements of green building standards[9]; ② for existing building energy-saving renovation projects, "Twelfth Five-Year" period to complete the northern heating areas of existing public buildings and public institutions office building energy-saving renovation 120 million m; ③ which the government investment projects and municipalities directly under the central plan and provincial capital cities (3) government-invested projects and large public buildings such as stations, hotels, restaurants, shopping malls and office buildings with a single building area of more than 20,000m have been fully implementing green building standards since 2014.

The design and construction of energy-efficient buildings is conducive to improving the thermal environment of buildings and increasing the efficiency of energy use. It is conducive to the sustainable, rapid and healthy development of the national economy and the protection of the ecological environment. The importance of building energy efficiency is reflected in the following three aspects:

1) The need for sustainable economic development

The oil crisis in the 1970s made people finally understand that we cannot afford to waste energy and that energy will be an important factor in modulating the sustainable development of the economy, and that the average growth of China's gross national product in recent years has been about 10%, but the growth of energy can only be 3% — 4% after continuous efforts. will undergo three important changes: entering a period of heavy industry, accelerating urbanization and becoming one of the world's manufacturing bases. The accelerated economic growth and urbanization will put great pressure on energy, with energy development lagging behind economic development. This is why we must rely on the widespread use of energy-saving technologies to ensure sustainable economic development.

2) The need for environmental protection of the atmosphere

The oxides of sulphur and nitrogen emitted during the combustion of fossil fuels can be harmful to human health and cause environmental codification. The CO_2 produced during combustion will cause major climate change on the planet and endanger human survival. These issues are of serious concern to many countries around the world and the fuels used to heat buildings are undoubtedly a major contributor to atmospheric pollution. The share of energy used in the construction and use of buildings in the national greenhouse gas emissions has reached 44%, and the air pollution index in northern cities in China in winter due to coal combustion is two to five times higher than the highest standard recommended by the World Health Organization[10], and the serious haze problems that have occurred in many areas of China in recent years are related to building emissions. Energy efficiency policies in various developed countries also have the explicit goal of reducing emissions from fuel combustion. Energy efficiency in buildings is of great importance in reducing pollution in the atmosphere.

3) The need for a pleasant thermal environment in buildings

A comfortable and pleasant thermal environment in buildings is a fundamental hallmark of modern life. Developed countries are constantly meeting people's needs by making increasingly efficient use of good energy. The demand for a pleasant thermal environment in buildings is also increasing in China. Due to the characteristics of geographical location, most of China's cold winters and hot summers, compared with the same latitude in the world, the average temperature in January in the northeast of China is 14 ~ 18 ℃, the lower middle and lower reaches of the Yellow River is 10 ~ 14 ℃, south of the Yangtze River is 8 ~ 10 ℃, the southeast coast is about 5 ℃ lower; in the summer average temperature in July, the vast majority of China's regions but 1.3 ~ 2.5 ℃ higher. The temperature is high throughout the eastern region on hot days, and remains high in the southeast on cold days, with stifling heat in summer and cold dampness in winter, so the problem of cold winters and hot summers in China is more prominent. To create a comfortable and pleasant indoor thermal environment, heating is needed in winter and air conditioning in summer, all of which need to be supported by energy. The country's energy supply is very tight and improving the quality of the indoor environment with the support of energy-saving technologies is the inevitable way forward.

Energy efficiency in buildings is a concrete manifestation of the concept of sustainable development, a worldwide trend in building design, and a new direction in building science and technology, and has become a common concern in the world of architecture. After decades of exploration, people's understanding of the meaning of energy efficiency in buildings has continued to grow. It has gone through three stages:

Initially it was called "energy saving";Later it was further defined as 'energy conservation in buildings', i.e. the reduction of energy dissipation in buildings;A more positive and widely accepted definition is "energy efficiency in buildings"[11], i.e. a proactive and aggressive strategy to save energy consumption and improve energy efficiency.

China is a vast country, from cold regions, cold regions, hot summer and cold winter regions, hot summer and warm winter regions to mild regions, the climatic conditions vary greatly from place to place and the amount of solar radiation varies, so the heating and cooling needs are different. Even in the same cold region, the cold time and cold degree also have considerable differences thus from the perspective of building energy-saving design, must be subdivided into a number of sub-climatic regions, different climate regions of the residential building envelope insulation requirements to make different provisions.

1.2 Winter heating measures and ways to save energy in harsh cold regions of China

1.2.1 Building Thermal Design Zones

According to the thermal design codes for civil buildings, building climate regions can be divided into five categories. Severe cold regions, cold regions, hot summer and cold winter regions, hot summer and warm winter regions and mild regions, as shown in Figure 1-7.

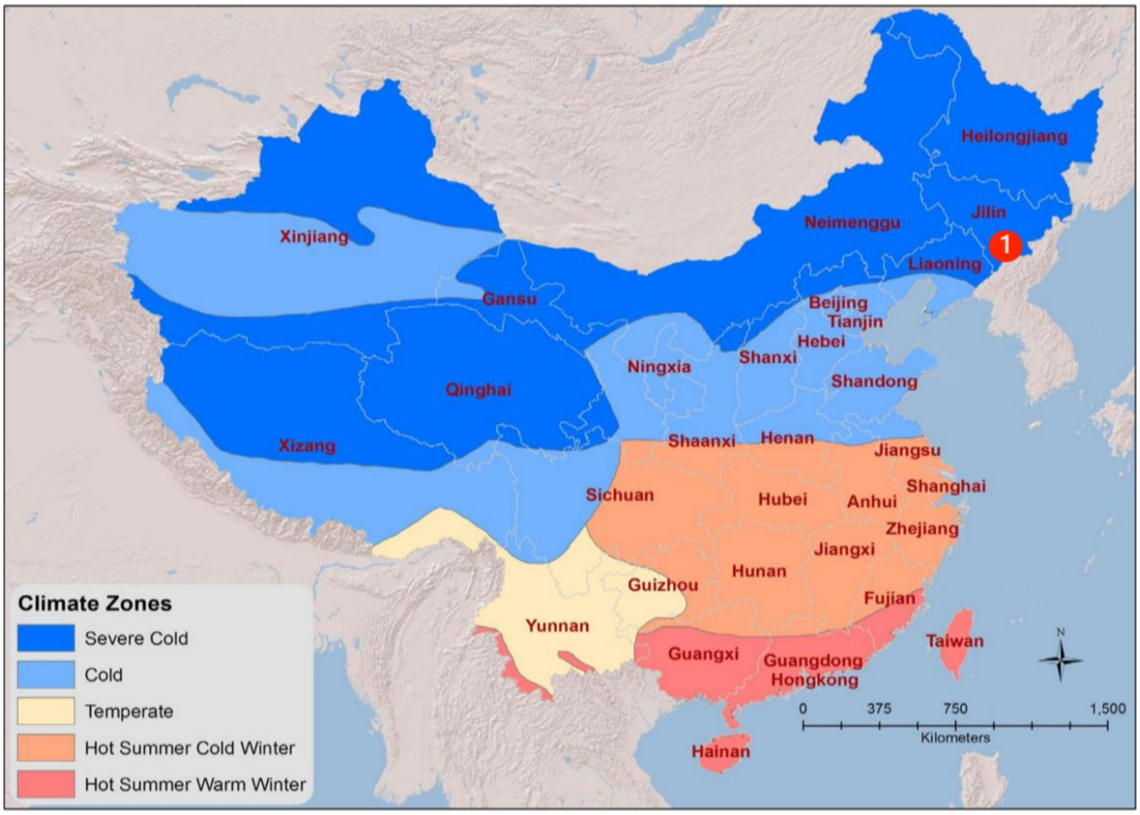

Fig 1-7 Climate zones in China.
Source: adapted from Yu et al.(2012).[14]

Building indicators, such as thermal environment standards, indoor air quality standards, energy consumption indicators and thermal engineering indicators, can vary greatly from one climatic zone to another, so energy efficiency standards cannot be applied equally to all regions. The thermal performance requirements for envelope materials must be taken into account in the process of developing standards. This paper is based on the Siping City area in Jilin Province, which is representative of a severe cold region.Table 1 represents the indicators for the different divisions of labour.

Table 1 Building Thermal Design Zones

Name of primary division	Zoning Indicators	
	Main indicators	Supporting indicators
Severe cold	T1≤-10℃	145 ≤d1
Cold regions	-10℃<T1 ≤0℃	90≤d1≤145
Hot summer and cold winter areas	0℃<T1 ≤10℃ 25℃<T2 ≤30℃	0≤d1≤90 40≤d2≤110

Hot summer and warm winter areas	10℃<T1 25℃<T2 ≤29℃	100≤d2≤200
Temperate	0℃<T1 ≤13℃ 18℃<T2 ≤25℃	0≤d1≤290

T1 indicates the average temperature of the coldest month; T2 indicates the average temperature of the hottest month; d1 indicates the number of days when the average daily temperature is ≤ 5℃; d2 indicates the number of days when the average daily temperature is ≥ 25℃

1.2.2 Energy consumption structure of heated residential buildings

The heat consumption of a heated residential building consists of the heat transfer heat consumption through the envelope structure and the air infiltration heat consumption through the gaps between doors and windows. Taking the three types of multi-storey residential buildings in Beijing, such as 80 Residence 2-4, 80 MDI and 81 Tower 1[16], for example, the heat consumption of the buildings is mainly composed of heat transfer heat consumption through the envelope structure, accounting for 73%～77%; followed by air infiltration heat consumption through the gaps between doors and windows, accounting for 23%～27%. Of the total heat transfer heat consumption, external walls account for about 23%～34%; windows account for about 23%～25%; stairwell partition walls account for about 6%～11%; roofs account for about 7%—8%; lower part of balcony doors account for about 2%～3%; and household doors account for about 2%～3% of the ground about 2%. The total heat consumption of windows, i.e. the heat transfer heat consumption of windows plus air infiltration heat consumption, accounts for about 50% of the total

From the above, it can be seen that windows are heat-consuming components and are the key part of energy saving. Improving the insulation performance of windows (including balcony doors) and strengthening the air tightness of windows are the key measures for energy saving. On the other hand, China has clear standards on the number of air changes required to ensure indoor air hygiene requirements, so strengthening the air tightness of windows to reduce the amount of cold air infiltration requires attention to ensure a minimum number of indoor air changes. The use of highly airtight windows should be considered with the addition of an active exhaust device[17].

In terms of the proportion of heat transfer to each part of the envelope, external walls are the largest, followed by windows, then stairwell partitions (in the case of unheated stairwells) and roofs. Therefore, external walls are still a key part of energy-saving design.

1.2.3 Fundamentals of energy efficiency in heating and residential buildings

In order to obtain a suitable indoor temperature for living in a heated building in winter, there must be a constant and stable means of obtaining heat. The majority of the total building heat is supplied by heating and heating equipment, followed by solar radiation and internal building heat (including cooking, lighting, appliances and human heat dissipation). Some of this heat is dissipated to the outside through heat transfer from the envelope and air infiltration through windows and doors[18]. When the total heat gain and loss of the building is balanced, the room temperature is maintained at a stable level. The basic principle of building energy efficiency is therefore to maxima heat gain and minimize heat loss to the outside.

In accordance with the climatic characteristics of cold and cold regions, the design of residential buildings must first ensure that the thermal performance of the envelope meets the requirements of winter insulation and takes into account summer insulation. By reducing the building form factor, adopting a reasonable window-to-wall ratio, improving the insulation performance of external walls and roofs and external windows, and using the sun's heat gain as far as possible, heating energy consumption can be effectively reduced. Specific winter insulation measures are:

(1) The planning and design of the building complex, the design of the flat and elevation of individual buildings and the setting of windows and doors should ensure the effective use of sunlight in winter and avoid the dominant wind direction;

(2) Minimizing the building form factor and avoiding excessive concave and convex surfaces on the flat and elevated surfaces;

(3) Secondary rooms should be arranged on the north side of the building, and the area of north-facing windows should be as small as possible, while the window-to-wall ratio and the size of single windows in the east-west direction should be properly controlled;

(4) Strengthen the thermal insulation capacity of the envelope to reduce heat transfer and heat consumption, improve the air tightness of doors and windows, and

reduce air infiltration and heat consumption.

(5) Improving the design and operation management of heating and heating systems, improving the operating efficiency of boilers, strengthening the insulation of heating pipelines and enhancing the regulation and control capacity of heat supply of heat networks.

Therefore, for residential buildings in cold areas, attention should also be paid to improving the design of the summer room by optimizing the design of the phase operation 13 day network heating regulation and control ability.

For residential buildings in colder regions, attention should also be paid to improving the thermal environment of the summer room by optimism the design in order to reduce the time spent on air conditioning. Simulations have shown that for most areas in cold and cold climates, it is possible to achieve a comfortable indoor environment without or with less air conditioning in summer through rational building design.

1.2.4 Technical ways to save energy in heating in harsh cold regions

The heating energy consumption of buildings accounts for a large proportion of the total energy consumption of buildings in China.The energy saving potential of heating in cold areas is the largest among all types of building energy consumption in China, and should be the focus of energy saving in China's current buildings[19].

The technical ways to achieve energy saving in heating are as follows:

(1) Improve the insulation performance of the building envelope to further reduce the amount of heat required for heating. A comprehensive renovation of the envelope structure can reduce the heating heat demand from the current 90kW.h/(m2year) to an average of 60kW.h/(m2.year).

(2) Promote all types of special ventilation and air exchange windows to achieve controlled ventilation and air exchange, avoiding the opening of windows for ventilation and air exchange, which causes excessive heat loss. This allows the actual ventilation exchange to be controlled to within 0.5 times/h.

(3) Improve the end regulation performance of heating to avoid overheating.

(4) Implement low temperature heating methods such as floor heating, thereby reducing the temperature of the heat source and improving the efficiency of the heat source.

1.3 Summary of this chapter

The first chapter focused on the progressive progression from world energy to building energy consumption in the harsh northern regions of China, with the main conclusions being.

1), Energy consumption in Europe and the USA is dominated by oil, in the Middle East consumption is dominated by oil and gas, while in Asia and the Pacific coal is still the dominant fuel with a consumption share of 48%. The survey data also illustrates how the global economy has grown largely thanks to the use of fossil energy. However, the reserves of fossil energy are limited and the amount that can be easily extracted and used is getting smaller and smaller, which will inevitably lead to an energy crisis in the long run.

2), In many developed countries, energy consumption in buildings is even greater than that in industry and transport. At the same time, surveys show that such high building energy consumption in China is caused by numerous factors, but even more so, it shows the huge potential for building energy efficiency in China. The combination of solar energy application technology and high energy consumption in buildings is an important measure to reduce the proportion of fossil energy in building energy consumption and an important condition to ensure the sustainable development of our economy.

3), China's building energy efficiency work started in the 1980s and has been steadily progressing according to the principles of first easy and then difficult, first in the north (cold and cold regions) and then in the centre (hot summer and cold winter regions) and then in the south (hot summer and warm winter regions), first in residential buildings and then in public buildings, first in new buildings and then in existing buildings, first in urban buildings and then in rural buildings, and first in civil buildings and then in industrial buildings, and has continuously established and improved the building energy efficiency standard system. At present, China's building energy efficiency standards cover all aspects of planning, design, construction, supervision, testing, acceptance, evaluation and operation management, basically meeting and adapting to the needs of energy efficiency work in residential and public buildings, and building energy efficiency design has become a necessary part of building design, as has architectural design, structure, water supply and drainage, electrical and HVAC design. Through the revision of standards or the development of stricter building energy efficiency standards in some regions, the rate of building energy efficiency in China has continued to rise. After more than 30 years of effort, China's building energy efficiency work has made great achievements with policy promotion, standard support and technical guarantee

4), The proportion of heating energy consumption in the country's total building energy consumption is large, and the potential for heating energy saving in cold and cold regions is high.The energy saving potential of heating in cold areas is the largest of all types of building energy consumption in China, and should be the focus of China's current building energy saving.

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Chapter 2

CURRENT DEVELOPMENTS IN THE APPLICATION OF RENEWABLE ENERGY AND THE DEVELOPMENT OF THE TROMBE WALL

Chapter 2: CURRENT DEVELOPMENTS IN THE APPLICATION OF RENEWABLE ENERGY AND THE DEVELOPMENT OF THE TROMBE WALL

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2.1 Current status of the development of renewable energy applications

As the technological development of renewable energy applications continues to mature and benefit from decreasing costs, renewable energy is receiving attention from countries around the world. Many countries have made the attribution of renewable energy an important part of their long-term energy development strategies. The European Union has developed a series of policies to encourage the application of renewable energy in various sectors. In 2010, renewable energy accounted for 2% of primary energy consumption in all major European countries, and member states have reached an agreement to increase this to 20% by 2020, with plans to reach 50% by 2050.

In 1974, Japan proposed the "Sunshine Plan" to develop hydrogen, geothermal and solar energy, with the aim of reducing the country's economic dependence on oil. And also successively with 1978 to develop a "moonlight plan" "environmental technology development plan", three plans focus on the development and use of renewable energy such as solar energy, wind energy, biomass and geothermal energy in the first place; the Indian government plans in 2022 to The Indian government plans to build renewable energy application projects in 2022, including 100GW of solar energy projects, 60GW of wind energy applications, and 15GW of other renewable energy use, and plans to reach 59% of primary energy use in India by 2030;

Latin America, which holds more than 20% of the world's oil reserves, is also starting to get rid of the dependence on oil, and the Brazilian government The Brazilian government plans to provide 90% of its electricity by renewable energy in 2024; the Argentine government plans to increase the proportion of electricity provided by renewable energy from the existing 8% to 20% in 2025; the Chilean government plans to provide 60% of its electricity supply by renewable energy in 2035. Nowadays, some countries in Europe and the United States annually increase more than 60% of the installed power generation from renewable energy [8], the average annual growth rate of installed power generation capacity of renewable energy is predicted to reach 2.6% by 2040. 171GW of all new renewable energy installations worldwide in 2018, including 94.3GW of new grid-connected photovoltaic installations, accounting for half of the installed renewable energy capacity. The total installed PV capacity accounts for about 1/3 of the global renewable energy.

In 1992, the Chinese government clearly stated that it would "develop and promote solar energy, wind energy, geothermal energy, tidal energy, biomass and other clean energy" [11]; in 2005, the Renewable Energy Law of the People's Republic of China was enacted to provide incentives, supervision measures, development planning and related industrial policies for renewable energy in the form of legal provisions. In September 2007, our government promulgated the Medium and Long-term

Development Plan for Renewable Energy, which mainly provides for the increase of the proportion of renewable energy in primary energy consumption and the development of the industrialization of renewable energy technology. The main content of the plan stipulates: to make more use of renewable energy sources such as solar energy, wind power, hydro power and biomass energy with mature technology, to increase the proportion of renewable energy in the primary energy consumption structure, and to strive for the strategic goal of reducing the proportion of fossil energy in total energy consumption to below 85% in 2020.

By 2018, the power output of renewable energy had reached 1.87 trillion kilowatt-hours, accounting for 26.7% of the total electricity generated in that year, of which 1.2 trillion kilowatt-hours were generated by hydro power, up 3.2% year-on-year; 366 billion kilowatt-hours were generated by wind power, up 20% year-on-year; and 17 billion kilowatt-hours were generated by photovoltaic power.

The theme of the 2017 World Solar Energy Conference in the United Arab Emirates was "Innovation for a 100 percent renewable energy transition", which aimed to effectively promote solar energy research and development and provide authoritative advice on global renewable energy issues. It aims to effectively promote solar energy research and development, provide authoritative advice on global renewable energy issues, and strive to achieve 100% renewable energy use.

China is rich in solar energy resources, except for Sichuan, Chongqing and Guizhou, which have less irradiation due to rainy weather, the total annual irradiation in most areas of the country exceeds 1050kWh/m^2, and the total annual sunshine hours in more than 2/3 of the areas exceeds 2000h, and the total solar irradiation in the Qinghai-Tibet Plateau, which has a high altitude, low Wei degree and long solar irradiation time, exceeds 1800kWh/m^2. If this solar energy can be used effectively, it will not only reduce the release of carbon dioxide, protect the ecological environment but also ensure a continuous and stable supply of energy for China's economic development. Solar energy utilization technology is mainly an application technology for the conversion of solar energy into heat, solar energy into electricity and solar energy into light. Solar thermal conversion technology is the most mature technology in solar energy utilization, high conversion efficiency and the lowest cost of a solar energy application, mainly solar thermal building integration, solar collectors for hot water, solar air conditioning, solar drying, etc.

The principle of solar photovoltaic conversion is to use solar cells to convert light energy into electricity through the photoelectric effect or chemical effect, the technology is more mature, the high cost and low conversion efficiency is the biggest drawback of photovoltaic conversion; photochemical conversion is mainly to convert solar energy into chemical energy to be used, mainly for hydrogen production technology of water decomposition, the application is less.

2.2 Forms of application of solar energy in building energy efficiency

Solar energy is energy emitted by the sun and transmitted to the earth's surface in the form of electromagnetic radiation, which can be converted into heat and electricity through photo-thermal and photoelectric conversion. Solar energy has the advantage of being inexhaustible, clean and environmentally friendly, so it is considered the best renewable energy source. The use of solar energy requires attention to:

(1) Solar energy flow density is low: in the surface water plane, its maximum power density (radiation intensity) is usually less than 1000W/m (less than the solar constant 1353W/m).

(2) Solar energy has unstable, periodic characteristics: the rotation of the Earth so that solar energy acquisition is limited to daytime (usually less than 12h); the Earth's rotation makes the radiation intensity fluctuates seasonally throughout the year; by the influence of cloud cover and atmospheric visibility, solar irradiation presents a strong randomness.

(3) Solar energy has a high grade due to the high temperature of the radiation source (5800K).

(4) Solar energy itself does not require payment, but its use requires consideration of investment costs and benefits.

On the one hand, the total annual solar radiation throughout China is 3340~8400MJ/m, compared with other countries at the same latitude, in addition to the Sichuan basin, the vast majority of areas are quite rich in solar energy resources, comparable to the United States, much more superior than Japan and Europe conditions, solar energy in China has a huge potential for development and application; on the other hand, China's large population, building area and building energy consumption is very large, some poor areas And remote areas are not yet connected to the power grid how from the whole country, reasonable and effective planning and use of solar energy, is worth exploring the problem.

The main applications of solar energy in the field of building energy efficiency are: (1) passive solar buildings; (2) active solar buildings; (3) solar water heaters; (4) solar photovoltaic utilization; and (5) solar heat pumps and air conditioning. According to the scope of this book, this chapter focuses on passive solar buildings and provides a general introduction to active solar buildings.

2.3 Passive solar buildings

Whether or not mechanical equipment is used to obtain solar energy is the main marker to distinguish between active and passive solar buildings. Buildings that do not require mechanical facilities to obtain solar heating through appropriate building design are called passive solar buildings; buildings that require mechanical equipment to obtain solar heating are called active solar buildings.

Passive solar heating design is the reasonable distribution of building orientation and surroundings, the clever handling of internal space and external form, as well as the appropriate choice of building materials and structure construction, so that it can collect, maintain, store and distribute solar heat in winter, thus solving the heating problem of the building. Passive solar heating systems are characterized by the fact that all or part of the building is used as both collector and storage and radiator, i.e. no pipes are connected and no pumps or fans are used to collect solar energy in an indirect way.

The basic idea of passive solar building design is to control the entry of sunlight and air into the building at the right time and to store and distribute the hot air. The design principles are an effective adiabatic shell and sufficiently large collector surfaces, the arrangement of as many heat storage bodies in the room as possible, and a reasonable plan position of the main and secondary rooms. According to the difference in heat transfer processes, passive solar buildings can be divided into two categories:

1), Direct benefit, which means that sunlight enters the heating room directly through the windows;

2), Indirect benefit, which means that sunlight does not enter the heating room directly, but first shines on the collector components and sends solar energy into the room through heat conduction or air circulation.

2.3.1 Direct benefits Approach

The simplest form of passive heating system is the "direct benefit". This type of heating is fast and

The construction is simple; no special heat collection devices are required; there is little difference in appearance with the general building and the artistic treatment of the building is flexible. It is therefore one of the easiest ways to promote the use of solar buildings.

The principle of heat collection in a direct benefit solar building . The room itself is a heat collecting and storing body; during the daylight phase, the sunlight enters the room through the south-facing glass windows, the floor and walls absorb the heat savings and the surface temperature rises; part of the absorbed heat is supplied to the indoor air in a convective manner, another part is exchanged with the internal surfaces of the other envelope structures in a radiant manner, and the third part is supplied by the The third part is stored internally by the thermal conductivity of the floor and walls. When there is no daylight, the absorbed heat is released, mainly to heat the indoor air and maintain the room temperature, while the rest is transferred to the outside.

The area of south-facing external windows and the amount of heat storage material in the building are key to the design of this type of building. In addition to following the key points of energy-efficient building design, special attention should be paid to the following points: the building should be oriented within 30° to the east and west of the south to facilitate heat collection in winter and avoid overheating in summer; the window area, glass type, number of glazing layers, window opening, window frame material and construction should be determined according to the thermal requirements; the window pane should be reasonably divided to reduce the window frame and window sash shading to ensure the air-tightness of the window; It is best to combine with thermal curtains and sunshades to ensure the use of winter nights and summer effects.

2.3.2 Indirect Benefit Approach

The basic forms of indirectly beneficial heat collection are: Trombe walls, water walls, water-carrying walls (water-filled walls) with additional sun rooms, etc. Here we focus on the Trombe Wall.

China's buildings consume a large amount of energy and consume a lot of energy, which has become a prominent problem restricting the sustainable development of China's economy and society . With the continuous acceleration of China's economic and social development and urbanization, building energy consumption is continuing to rise rapidly, and its share of energy consumption in the whole society is increasing, and it will continue to rise from the current 35% .

Solar energy is a kind of renewable energy. It refers to the heat radiation energy of the sun, which is mainly expressed as the sun's rays. Since the birth of life on the earth, it has mainly survived by the heat radiation provided by the sun . Since ancient times, humans have also understood that the sun can dry objects and use them as a method of making food, such as salt making and salted fish .

With the declining fossil fuels, solar energy has become an important part of human energy use and has been continuously developed. There are two ways to use solar energy: light-to-heat conversion and photoelectric conversion. Solar energy is the most direct and simple clean energy that can be used by buildings without secondary pollution.

Through reasonable architectural design and the use of advanced building components, it can ensure the maximum use of solar energy and reduce the energy consumption of buildings . Therefore, making full use of China's abundant solar energy resources and vigorously developing solar buildings has become an effective way to reduce building energy consumption at this stage. Among solar buildings, passive solar houses have a simple structure, economy, and significant energy-saving effects. The existing technology can already compete with conventional fuel heating, and has broad development space and prospects in China. In terms of climate, in China, the hot summer and cold winter area is a relatively special area, which belongs to the northernmost part of the non-centralized heating area, especially the area near the Qinling and Huaihe River, where the demand for warmth in winter is relatively high .

At the same time, this area is a developed area of the domestic economy, and its GDP is close to about half of the country. With the rapid development of the economy, these areas have more and more requirements for the thermal environment comfort of residential buildings in summer and winter [16-18]. Therefore, to control the indoor thermal environment in this area, it is a necessary and urgent task to select suitable energy-saving technologies.

1) Trombe Walls

Trombe Walls are a kind of facade system developed in recent years, which was proposed and experimented by Dr. Felix Trombe, director of the French Solar Energy Laboratory, in 1956, and is therefore commonly known as "Trombe Walls".

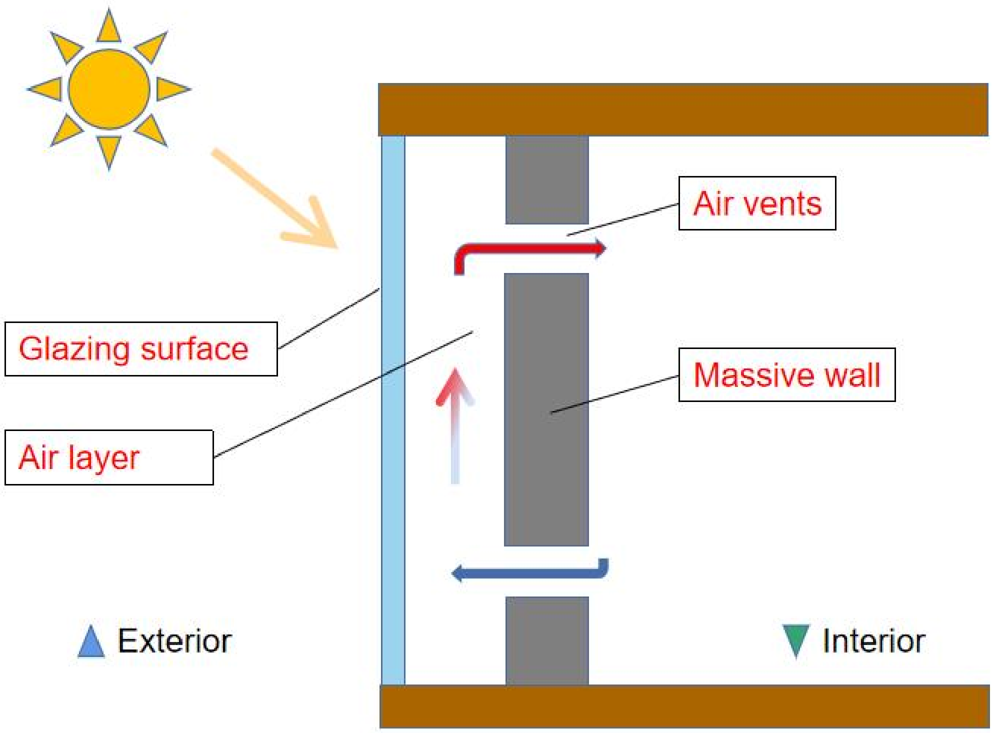


Fig 2-1 A classic Trombe wall system

These collector walls use the thermosphere/temperature circulation principle to circulate heat using natural hot air or water, thus reducing the burden on the heating system. The oldest solar heat-absorbing facades used thick, welcoming materials to maintain indoor temperatures, such as the earthen walls used in buildings in hot desert climates. Trumbull walls, on the other hand, absorb these traditional techniques while having a lighter image and higher thermal efficiency as well as the ability to adapt more actively to climate change. In colder weather, a welcoming wall can use its own ability to collect solar heat to heat the interior. Fresh air enters the air cavity from the base of the facade. The solar radiant heat absorbed by the welcoming material is heated and enters the room, circulating the hot air through the house. In hot climates, the Trumbull wall then prevents heat from entering the interior by allowing the air to rise directly and exhaust to the outside. This is when the wall draws cooler air from the north into the interior, achieving a natural cooling effect.

The dark selective coating absorbs heat and reduces radiant heat loss, making the wall a heat collector and storage heater. When required (e.g. at night), the wall becomes a heat ex changer. The wall is mounted 10cm from the outer surface or a transparent material sheet, which forms an empty inter layer with the outer surface. In winter, when the sun is shining during the day, the room is heated mainly by convection of the heated air through the top and bottom vents. At night it is mainly the heat storage of the wall itself that heats the room.

An advantage of thermal storage walls such as concrete is that there is a time delay between the absorption of the sun on its outer side and the release of that energy into the room. This is due to the fact that concrete is thermally inert and the length of the time delay depends on the thickness of the wall and is representative of 6 to 12 hours. Consequently, radiant heating is most effective at night when convection heating is ineffective.

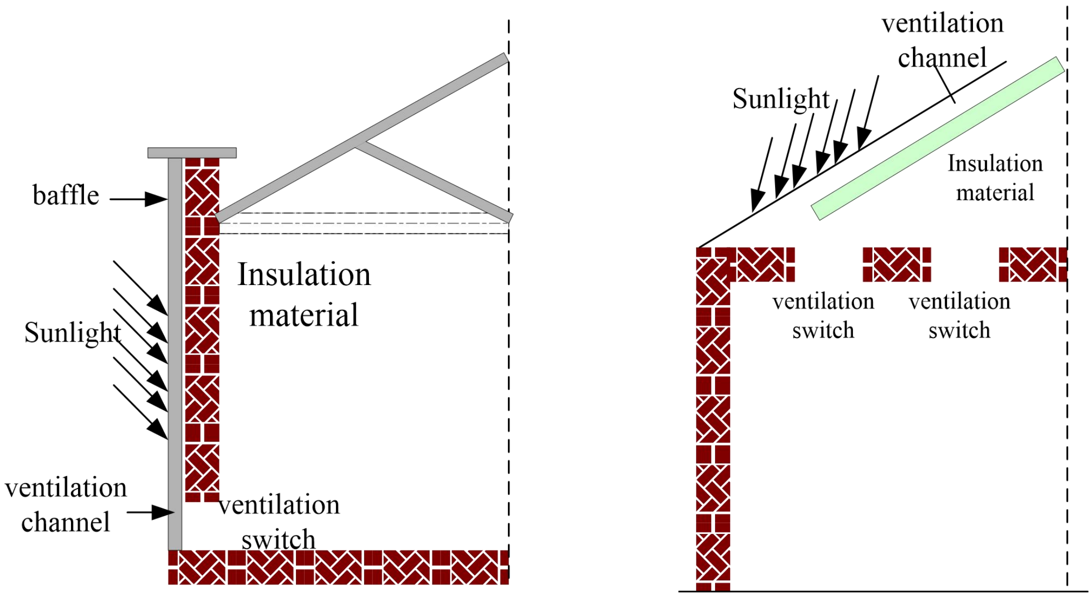
The thickness of thermal storage walls varies somewhat depending on the use of the building, Trombe used a wall thickness of 600mm for his first house in Bilirius, which provided 70% of the total heat required for a controlled room temperature of 20°C over a period of one year, later thinner walls were tested and Trombe and his colleagues concluded that 400—500mm was the most suitable thickness. Computer simulations by Balcomb and others in different parts of the USA have shown that a 300mm thick wall on a mixer can make the highest annual contribution to the total heat requirement (heating) if the room temperature varies between 18 and 24°C.

2.4 Research content and progress of TROMBE WALL

Trombe wall is also called heat collecting wall. The function of this kind of building is to improve the living environment of people in cold areas. Because the land area is very vast, some areas will be in the low temperature zone, and the living environment of the local residents is difficult for the human body to cope with alone, which makes the local people take precautions against the severe cold environment in which they are located . Such a natural environment makes the demand for buildings such as the Trombe wall always exist. Similar to this, traditional buildings built to improve the living environment have developed a lot, and some are still solving the living environment and climate problems for local people. In order to improve the traditional buildings constructed in the climatic environment, the following are listed in Figure 2-2:

Fig 2-2 Several traditional buildings to improve the living climate zone

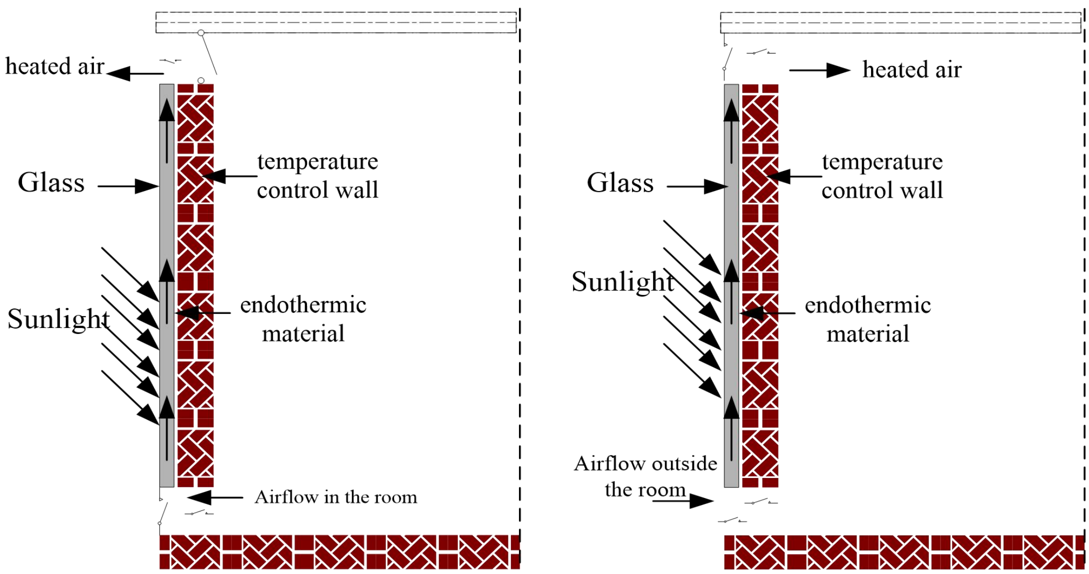
Figure 2-2 contains five traditional climate-improving buildings. These buildings are the products of local residents' long-term living experience and corresponding cultural connotations. Its practicality has also been confirmed by use and verification. Among them, Ayiwang in Xinjiang has very similar functions to the Trump Wall mentioned in this article. The former is used in hot areas all year round, and the temperature difference between day and night is huge. For people's lives, it is extremely important for buildings to dissipate heat at high temperatures and keep warm at low temperatures. The difference is that the Trombe collector wall in this article is mostly used in cold areas, and the principle is to make a reasonable transformation and use of solar energy. In this period, in addition to the consideration of improving the climate of houses, it is also necessary to combine the concept of modern development of environmental protection . For some severe cold regions, the climate improvement is usually by burning coal for heating, the use of this method will destroy the harmonious development of the environment, and this also occupies a lot of available natural resources.There is also a sun room, which includes two structures as shown in Figure 2-3:



a.upright b.normal

Figure 2-3 The main types of sun rooms

The structure of the two types of solar houses in Figure 2 belongs to the house type structure that passively absorbs sunlight, and the house type of this structure can help to collect and absorb the energy in sunlight . The characteristic of this type of house is that the energy consumption in temperature control can be adjusted in time through the original structure of the house, which can greatly reduce the use of unclean energy. The working process of the Trombe collector wall in the cold state and the high temperature state can be represented by Figure 2-4:



a.High temperature regulation b.cold regulation

Figure 2-4 Two types of working principles of Trombe collector walls

Figure2-4 briefly describes the state of the Trombe collector wall when the temperature is high and when the temperature is low. The working principle in the high temperature state corresponds to the temperature control operation in summer . At this time, the sunlight in the temperature control wall heats the air in the airflow duct, so that it generates natural wind flowing out of the room, so as to take away the heat inside the room. In a low temperature environment, that is, in winter, the working principle is to make the gas in the airflow duct be heated and flow through the heating effect of sunlight, but the flow direction of the heated air is changed to the inside of the room. In this way, the temperature inside the room can be raised by the action of sunlight.

Under different temperature climates, the effect of the Trombe thermal wall can achieve the effect of being warm in winter and cool in summer. By changing the Trombe heat collecting wall inside the house and the direction switch in the air circulation, the effect of controlling the temperature inside the room within a suitable range under different air temperature conditions is achieved. The construction of this type of house is also of great value from the perspective of environmental protection. In fact, the application and construction of the Trombe thermal wall has already been carried out, but the effects of different regions are different.

Edward Morse first proposed a classic Trombe wall, which is known as a solar heated wall or storage wall . The classic Trombe wall was popularized by Felix Trombe, from whom it takes its name . It was popularize as an architectural element in the 1960s and consists of vents, air channels, thick walls and glass panels. Trombe walls absorb solar radiation and transfer part of the energy into the building through conduction and natural convection . Rabani, M.studied the Rayleigh number, convective heat exchange coefficients and the number of Trombe walls with exchanged by convection, conduction and radiation heat transfer rates. The conclusion of this study was that radiation is the dominant heat transfer process from the tube wall. Heat transfer is more sensitive on cold days than on warm days.Hernandez et al. found that Trombe walls can store a maximum energy of 109 MJ on the coldest day and 70 MJ on the hottest day. Hassanain found that when Trombe walls were used as a greenhouse enclosure, the winter night The average indoor air and soil temperatures increased by 1.1°C and 4°C respectively. When used as a residential envelope,Trombe walls can reduce the energy heating demand of a home by nearly 16.36%

According to statistics, the energy consumption of buildings in China accounts for about 1/3 of the total energy consumption of society . With the growing socioeconomic development, the proportion of energy-intensive buildings is gradually increasing and the energy crisis is becoming more and more obvious, so the current situation of energy use in China's buildings needs to be improved urgently. Natural ventilation, as a means of enhancing indoor air flow in buildings, not only regulates indoor air quality, but also saves the energy consumed by the building itself due to air conditioning, thus reducing the environmental pollution caused by excessive energy consumption in buildings. The Trombe wall structure , which uses thermal pressure, has a simple structure and is a solar collector, reducing energy consumption for air conditioning in summer and heating in winter, while using green energy to improve the thermal comfort of the room and the quality of the air in which people live. Trombe wall structures play an important role in promoting green ecological construction and healthy living.

At present, scholars at home and abroad have conducted in-depth studies on the airflow velocity, airflow temperature and air exchange volume of Trombe wall structures through numerical simulations or experimental studies. In China, Wang Liping has simulated the ventilation, temperature and velocity fields of Trombe wall structures of different models and structural dimensions under steady-state operating conditions. Qin investigated the characteristics of the ventilation, thermal environment and air flow in the room when the solar radiation intensity obtained by the Trombe wall structure changes under natural ventilation conditions with the help of numerical simulation methods.

Xiaowei proposed a new Trombe wall structure with built-in photovoltaic cells, and established a simplified model of it, and then carried out a simulation study using CFD methods to summarize the general law of the model size, solar radiation intensity and other parameters on the ventilation performance and heat transfer performance of the model. Wang Dengjia tested the indoor and outdoor air temperature, the direct and scattered solar radiation intensity on the horizontal and south elevations, the temperature of the inter layer of the heat collecting and storage wall, the air velocity of the ventilation holes, the air temperature of the ventilation holes and the heat flow through the wall of the Trombe wall solar room on the Qinghai-Tibet Plateau.

The ventilation holes were opened within 2-3 h after sunrise and closed within 1 h before sunset, and the insulation effect was the best; the average daily thermal efficiency of Trombe wall structure in the region was 69.7%, and the energy saving rate was 72.8%. Liu Sen studied the effect of new energy-saving and environmentally friendly building materials of TCM on the indoor temperature of passive solar buildings, pointing out that TCM materials can better suppress the fluctuation of indoor temperature.

Jiang Bin proposed a new Trombe wall structure with PV function and established its theoretical model. Through experiments and simulation analysis, he found that: the indoor temperature of the test thermal box with PV-Trombe wall structure is 6 °C higher than that of the contrasting thermal box without this wall structure, and the maximum temperature difference with the environment is 18 °C; due to the cooling effect of the air flow channel, the working temperature of the PV cells is lower, and the daily The average power generation efficiency is 10.5% due to the cooling effect of the air runner. Li Jinping tested the indoor thermal environment parameters and air quality of the passive solar house in rural Gansu and evaluated the indoor comfort using Fanger thermal comfort.

Raban has improved the area of the traditional system by increasing the area of the west and east facades without changing the area of the south facade, increasing the thermal efficiency of the improved system by 27% compared to the traditional system. In order to reduce solar glare and avoid excessive heat gain in the room, the "zigzag" type Trombe wall system was proposed, a new Trombe wall system with a sunrise wall system consisting of a south, south-east and south-west wall, where the south-east and south-west walls are "V "The purpose of this design is to ensure the heating function of the Trombe wall, but also to obtain a more desirable effect of indoor lighting and temperature rise during the morning, the improved Trombe wall system can achieve both heating and lighting, breaking through the Duan et al. investigated the thermal performance of two types of Trombe wall systems by means of numerical simulations, the Type I system was designed with the heat-absorbing panel between the glass cover and the thermal storage wall, and the Type II system was designed with the heat-absorbing panel attached to the thermal storage wall.

The reason for this is that the Type I Trombe wall system has double air flow channels, which increases the thermal resistance of the envelope and correspondingly enhances the thermal insulation performance, improving the shortcomings of the traditional Trombe wall system with low thermal resistance.157 Bellos et al.157 proposed a new technical solution by adding a glazed window to the thermal storage wall of the traditional non-ventilated Trombe wall system, and by comparing their results with those of the traditional non-ventilated Trombe wall system, they used numerical simulations to evaluate the thermal performance of the improved system, and the results showed that the Trombe wall system with a window creates a more comfortable indoor thermal environment.Leang et al used Dymola/Modelica software to analyse the effect of the thermal storage wall material of the Trombe wall system on the energy performance of the system, and The results showed that the wall made of mortar phase change material had good heat recovery capability and could recover more than 50% of the energy compared to the wall made of concrete material. In response to the shortcomings of the Trombe wall system in the morning hours,

Jie Ji et al.159 proposed an improved Trombe wall with a vertical transparent porous media honeycomb, and conducted a comparison experiment between the heat storage material and the non-heat storage material in the heat box. It has the advantage of a faster heating rate and higher thermal efficiency in the room. To solve the problem of high room temperatures in summer caused by the Trombe wall system, Rabani et al proposed a Trombe wall with a solar chimney and a water spray, and they built an experimental platform and conducted a series of experimental tests in Yazd, Iran. In addition, the heat stored in the Trombe wall plays an important role in the ventilation between the room and the runners in cloudy and rainy weather, and it is calculated that the Trombe wall with water spray increases the thermal efficiency of the system by almost 30%. In addition, the addition of louvers to the Trombe wall system increases the total thermal resistance of the system and reduces the cooling load of the room, and of course the louvers also play a role in shading.

The blinds also act as a sunshade. The innovative Trombe wall has been the subject of extensive theoretical and experimental calculations, numerical simulations to optimize the system structurally and experiments to determine the optimum angle for different seasons by adjusting the angle of the louvers. The results show that the new system significantly reduces the cooling load in summer compared to a conventional Trombe wall system.

In addition, the performance of the Trombe wall system can be improved by the optimization of various components, such as the insulation of the thermal storage wall, the addition of fans, the inclusion of shading facilities, the imitation of the dimensions of each air outlet, the choice of material and thickness of the thermal storage wall, the choice of material and number of layers of the glass cover, the height and width of the air flow channels, etc. Ma et al proposed a system combining a fan with a temperature control device and a double Trombe wall.

The results of a simulation using the dynamic load calculation software THERB for HAM to estimate the heating capacity of an office building with such a system, located in Kitakyushu, Fukuoka, Japan, show that a system combining fans with temperature control and double Trombe walls can reduce the annual heating demand by 0.6 kWh/m3 and improve the performance of the new system by 5.6% compared to a double Trombe wall without fans.

Soussi used TRNSYS software to study an office building in Tunisia by installing roll-up curtains in the middle of the air ducts for shading and low-e argon glass coverings, showing a 60.3% reduction in heat load in winter and 47.7% reduction in cooling load in summer with this improvement.

Briga-Sá et al studied the effect of different thermal storage wall thicknesses on energy performance, comparing two different Trombe wall systems, ventilated and non-ventilated, and showed that for the non-ventilated Trombe wall system, the heat gain increased with increasing wall thickness, while for the ventilated system, the trend was the opposite. Liu et al investigated the opening/closing times of the vents for ventilated Trombe wall systems during winter operation, both theoretically and experimentally, and showed that the best time to open the vents was 2-3 hours after sunrise and to close them 1 hour before sunset. In order to take advantage of local climatic conditions and to be able to take measures to reduce the building's energy consumption, Mohamed used FLUENT software to investigate the effect of single and double glazing covers on the thermal performance of the system. Experimental tests were carried out on a prototype in a laboratory in Souses, Tunisia, where the author is based. The results showed that the maximum temperature in the test room of a Trombe wall with single glazing reached 25° C during the hours of maximum solar radiation, while the maximum temperature in the test room of a Trombe wall with double glazing was less than 22° C.

This was due to the higher transmission rate of solar radiation through the single glazing, which resulted in a higher level of thermal comfort in the room. the level of thermal comfort is increased. However, Stazi et al, using the climate of Ancona as a starting point in terms of global warming potential, found that the performance of Trombe walls improved with the use of double glazed coverings and the use of low-e glass. Rabani et al,studied the insulation of Trombe wall rooms made of different materials during non-sunny periods and showed that the insulation time was 8 hours and 55 minutes for Trombe wall rooms made of paraffin, 8 hours and 30 minutes for Trombe wall rooms made of salt, 8 hours and 11 minutes for Trombe wall rooms made of brick masonry and 8 hours and 11 minutes for Trombe wall rooms made of concrete.

Zhou and Pang used an experimental study to analyse the thermal behaviour of a heat storage wall made of phase change material (CaCl-6H2O). Bojic et al discussed the optimal design thickness of Trombe walls for different primary energy consumption during the heating period, based on energy and environmental performance.Nwosu analyzed the influence of the physical properties of the thermal storage wall material on the performance based on the heat transfer equilibrium of the Trombe wall. Burek and Habeb experimentally analyzed the air mass flow rate and heat transfer processes in the channels of a Trombe wall system. increased with increasing transported heat flow and channel depth, but when the transported heat flow exceeded to 1000 W/m2 the change in air channel depth no longer had an effect on the thermal efficiency of the Trombe wall system.

In the above review of Trombe walls, various types of Trombe walls and corresponding improvements are included which contribute to the efficiency of the system and overcome some of the shortcomings of conventional Trombe walls. Yu et al developed a new catalytic Trombe wall system by coating the surface of the Trombe system's glazing with a catalyst that decomposes organic matter in the room, which decomposes organic matter in the room based on thermal or photochemical principles. The system heats the house and purifies the air in the room at the same time. The experimental platform of the thermostatically Trombe wall system was set up at the West Campus of the University of Science and Technology of China, and members of the group conducted a lot of experimental and theoretical research.

The thermal efficiency of the system was reduced compared to the conventional single-function Trombe wall system, which decreased by 15.8% throughout the heating season; in addition, they built an experimental platform for the photo catalytic Trombe wall system and used TiO as the catalyst, and under the experimental conditions of a real climate with an average radiation intensity of 631 W/m^2 and an average ambient temperature of 20.5°C, the average daily heat collection efficiency of the system and the mass of decomposed formaldehyde 35.1% respectively. With this catalytic Trombe wall system, the traditional Trombe wall system is broken from its single heating function, allowing the system to deliver heat to the room and at the same time achieve a self-purifying function of the indoor air.

The combination of solar photovoltaic technology and Trombe wall technology, the PV-Trombe wall system, was developed in order to improve the energy quality of the Trombe wall and to make the traditional Trombe wall more attractive for obtaining high quality electricity.

The following is a compilation of Trombe wall categories:

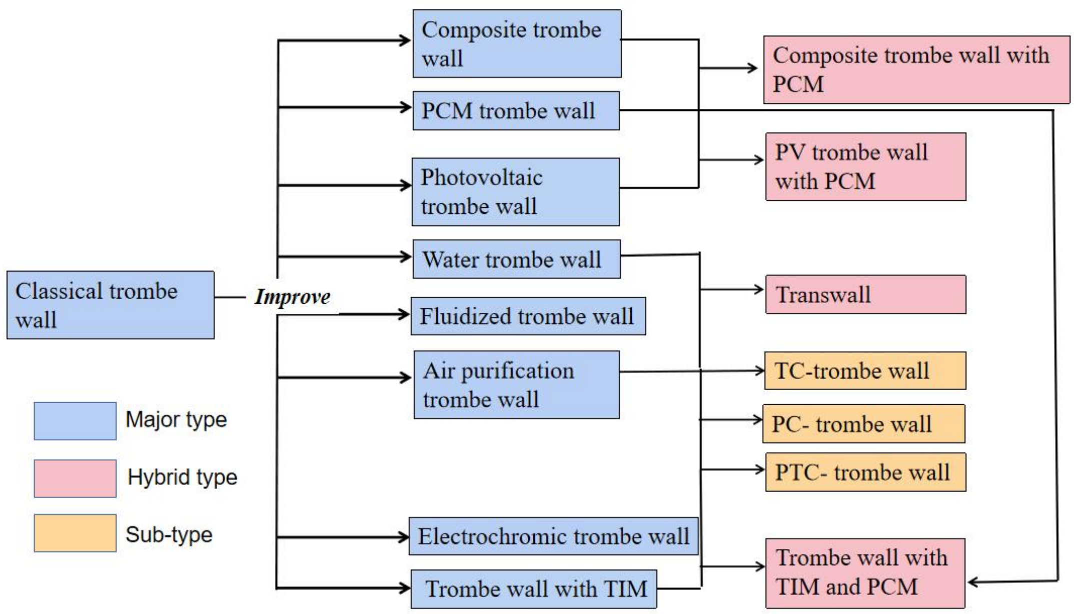


Fig2-5 Classification of Trombe wall

2.5 Research methods for the Trombe wall

Since the introduction of solar Trombe walls in 1957, Composite Trombe are also appearing one after another as shown Figure2-6.A large number of scholars at home and abroad have conducted research on their heat transfer flow characteristics, and the research methods used can be summarized into three main types of malefactors:

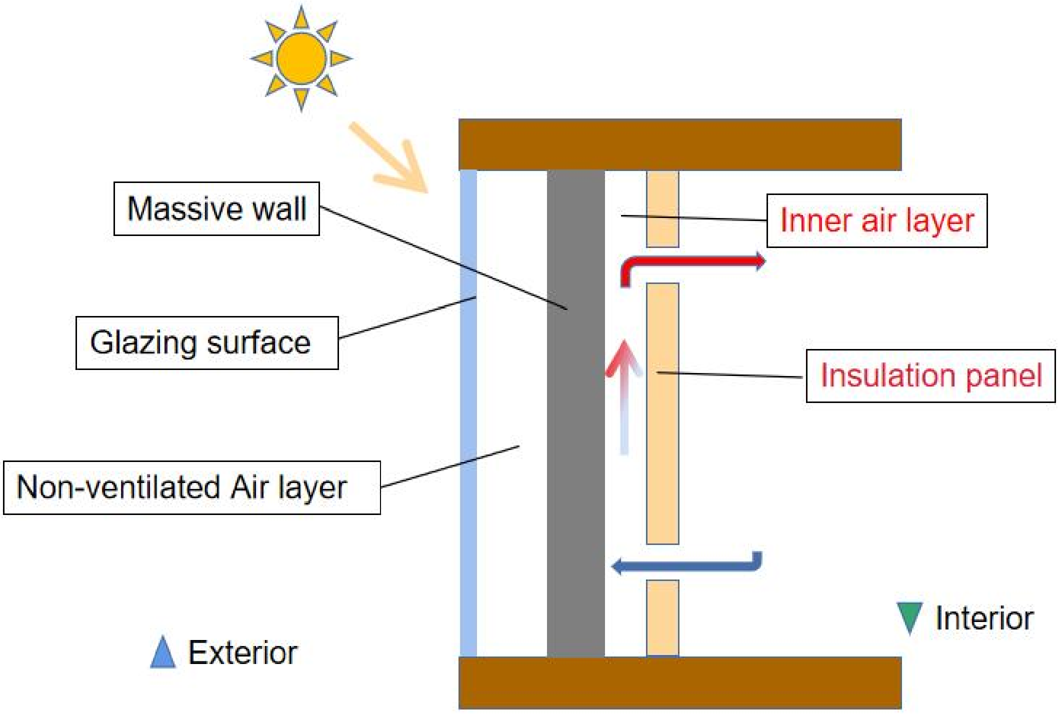


Fig 2-6 Composite Trombe wall (Trombe-Michel wall)

(1) Experimental research methods Experimentation is a direct and effective way to study the performance of solar Trombe walls, most of the experimental research on solar Trombe walls in the literature is conducted in outdoor natural environments. Zalewski et al. built a composite solar Trombe wall system and tested the performance of the composite solar Trombe wall system under changing outdoor conditions throughout the year and found that there were air back flow problems during its winter operation. In addition, the thermal performance of the composite solar Trombe wall was tested separately for heat flow into the room by convection and conduction, providing a better understanding of the thermal performance of the composite solar Trombe wall.

Chen Bin et al. experimentally tested the effect of solar Trombe walls on the relative humidity of the indoor environment and found that the use of solar Trombe walls could alleviate the problem of condensation on the surface of internal walls caused by high external relative humidity. Francesca Stazi et al. investigated, through a series of experiments, the effect of changing the Laurent Zalewski et al. investigated the performance of a PCM-Trombe wall system in a natural environment and concluded that the use of multiple shading devices could improve the performance of the solar Trombe wall in summer. Laurent Zalewski et al. studied the thermal performance of a PCM-Trombe wall system in a natural environment and found that the introduction of a PCM material resulted in a smaller thickness of the thermal storage wall in the solar Trombe wall system, which allowed for rapid heating of the room, and that the thermal efficiency of the PCM-Trombe wall system could be improved by reducing heat loss and increasing the heat transfer between the PCM and the inter layer air.

Mehran Rabani et al. propose a system combining a solar Trombe wall with a solar chimney and verify its advantages in tropical desert areas through outdoor experiments in winter and summer. In addition to experimental studies of solar Trombe wall systems in natural environments, a small number of experimental studies have been conducted in controlled laboratory environments. serinaAdams et al. studied the effect of the thickness of a water wall on the thermal performance of a water wall in a controlled experimental environment. Zhou Guobing et al.used a solar simulator to control the solar radiation intensity and added triangular wings to the surface of the PCM-Trombe wall to enhance the heat transfer coefficient between the PCM wall and the air in the air flow channel, and measured the thermal performance of the PCM-Trom be wall system before and after the PCM phase change, the changes in the temperature of the PCM wall, the air temperature in the air flow channel and the exit flow rate. The advantage of the experimental research method is that it can truly reflect the performance of the solar Trombe wall system and the problems that exist after a long period of operation. However, there are also many disadvantages of the experimental research, such as once the experimental platform is built, it is difficult to correct its design scheme, especially for large 1:1 experimental platforms; there are more uncontrollable factors in the experimental process and it takes longer, especially when the experiments are conducted under natural environment The experiments in the natural environment; the initial investment cost of the experiment is large, and the maintenance cost is also high.

(2) CFD (Computational Fluid Dynamics) simulation CFD is a very powerful numerical simulation tool commonly used to solve fluid flow, heat transfer and component transport problems. In recent years there has been much literature on the

use of CFD to study the temperature and flow rate distribution of solar Trombe wall systems. Hong et al. used CFD to build a three-dimensional steady-state model of a louvered solar Trombe wall module and optimized its structure. The variation of air velocity and temperature in the mezzanine layer of the built-in solar PV-Trombe wall system was simulated by Su Yaxin et al. using CFD for different solar radiation intensities, air channel thickness and heights. Tamara Bajc et al. used CFD to simulate the steady-state and non-steady-state conditions of the solar Trombe wall system respectively. ZerrinYilmaz et al. used CFD to develop a two-dimensional model of a translucent solar PV-Trombe wall system. The temperature and flow fields in the room were analyzed. In addition, ZerrinYilmaz et al. also analyzed the performance differences of the solar Trombe wall system under three types of glass (single glass, double glass and PV glass) by CFD. Liu Yanfeng et al. investigated the temperature change of the wall during the heat absorption and exothermic phases of the solar Trombe wall by CFD method.

Although CFD software simulations provide good access to the variation of parameters such as the flow field of the air within the solar Trombe wall system and the temperature field of the building wall, CFD calculations require good expertise and allowable calculation errors naturally need to be introduced during the calculations in order to converge. In addition, for some particularly complex structures, special treatment must be applied to the modelling and computer calculation times can be long.

(3) Thermal equilibrium model plus experimental verification

Heat balance modelling is based on the principle of energy conservation to establish the energy balance equation of a model, taking into account the convection, conduction and radiation heat exchange between the components of the model. This approach includes steady state thermal models, unsteady state thermal models and building energy simulation software based on the heat balance equations, such as TRNSYS and Energy-Plus etc.

MehranRabani et al. developed an unsteady state thermal model for a solar Trombe wall system and used FORTAN to write a calculation program to obtain the energy balance of a solar Trombe wall constructed from different They used FORTAN to calculate the duration that a solar Trombe wall constructed of different materials could last to heat the room during rainy days. Yang Hongxing et al. developed a dynamic thermal model for a room with a temperature-controlled solar PV-Trombe wall system, calculated the temperature variation of the wall, and analyzed the effect of the air runner thickness on the solar PV-Trombe wall system. Bias Zamora et al. developed a dynamic thermal model for a solar Trombe wall system with a certain inclination angle. A two-dimensional unsteady state model was developed for a solar Trombe wall system with a certain inclination angle.

The accuracy of the model developed was verified experimentally, and equations were derived for the relationship between the solar Trombe wall outlet flow rate and the height of the Trombe wall, the thickness of the sandwich and the height of the air inlet. Milorad Boji used Energy-Plus to compare the impact of solar Trombe walls on building energy and the environment, and to investigate the performance of solar Trombe walls with different wall construction materials. Yan Ding et al. used TRNSYS to model the thermal performance of a solar Trombe wall for a typical building envelope in Tunisia and validated the model through experiments. The modeled heat balance equation allows for a quick understanding of the temperature distribution of the main components of the solar Trombe wall system, and then simple small-scale experiments are used to verify its accuracy. However, the main disadvantage of this method is that it requires a number of empirical or semi-empirical equations, such as the convective heat transfer coefficient between the air and the components, which may be relevant to the operating environment of the solar Trombe wall.

2.6 Innovation points in this paper

1), The innovation of this paper is to propose a new intelligent temperature-controlled ventilated Trombe wall system for cold climate zones. This system c omprises three types of Trombe wall structures with different ventilated conditi ons of the inner and outer air layers. Type 1 has a ventilated inner air layer, and therefore is called inner circulation Trombe wall. Type 2 is called double circulation Trombe wall, which has ventilated inner and outer air layers.Type 3 is named as the outer circulation Trombe wall due to its ventilated outer air layer.According to the temperature of air channels, the temperature-controlled f an can automatically control the air circulation between air channels and room s.

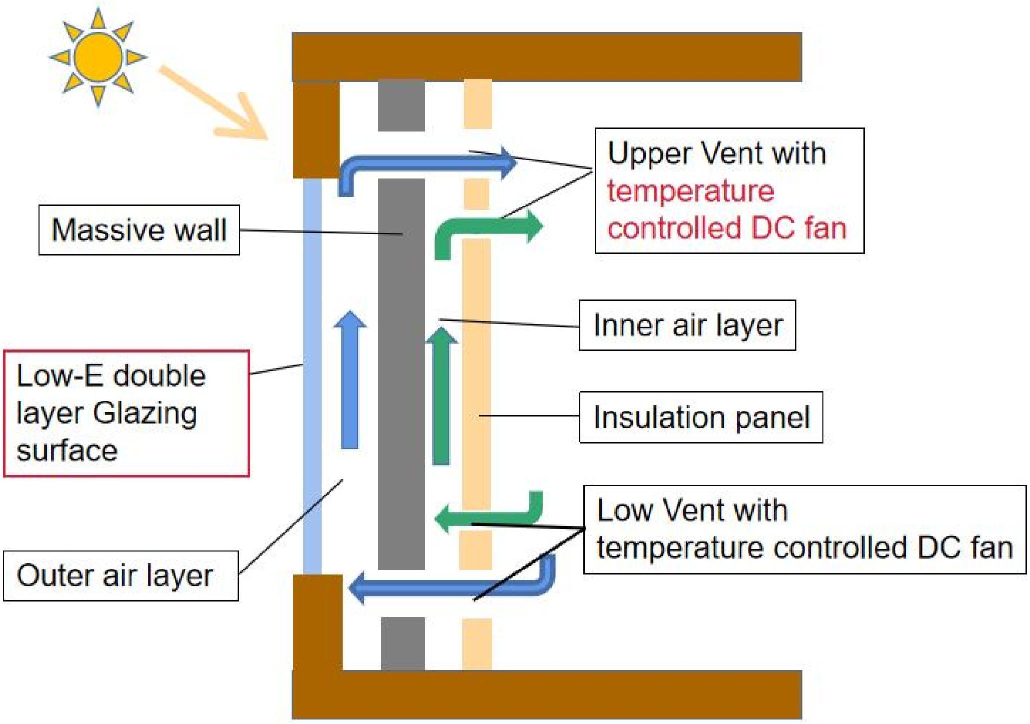


Fig2-7 Double layer Trombe Wall with DC fans

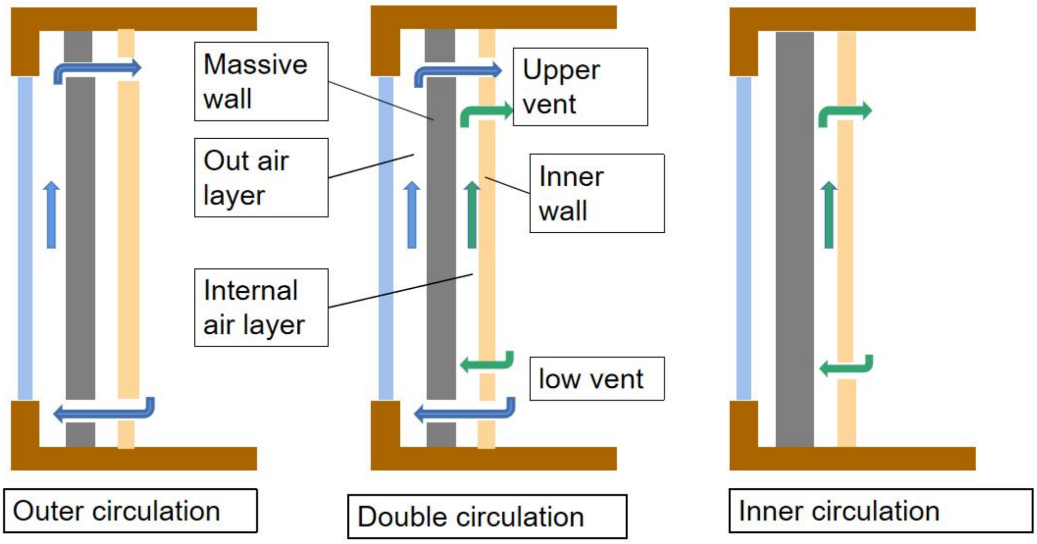


Fig2-8 Diagram of the three different air circulation modes

2), The basic design of the experimental room is based on the《Design Standards for Building》《Design in Severe Cold Regions and Energy Efficiency Design Requirements for Residential Buildings》to ensure the accuracy of the experimental data and to calibrate the accuracy of the simulation data, and to provide basic data and reference for the practical application of the double mezzanine Trombe wall in severe cold regions.

3), This paper combines experiments and simulations to calculate the optimal wind speed for the size of this laboratory room in winter in a severe cold region, and conducts temperature tests at the optimal wind speed.

4), This paper provides statistics on the number of days and unit hours that the double layer Trombe wall reaches and exceeds the human "cold tolerance" temperature in winter in non-heating modes, providing a "least favourable principle" for the future integration of other energy saving forms with the double layer Trombe wall.

2.7 summary

1) The use of renewable resources has been actively explored and developed in countries around the world, and many good scientific results have been achieved.

2) The Trombe wall makes full use of solar energy for indoor heating and many

different types of Trombe wall have been developed.

3) This paper presents a new TROMBE WALL (Double layer trombe wall with DC fans) which adds air circulation patterns and also raises the room temperature more quickly in winter by DC fans.

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Chapter 3

SIMULATION OF THE EFFECT OF A DOUBLE LAYER TROMBE WALL UNDER THE ACTION OF A DC FAN USING ENERGY PLUS

CHAPTER 3: SIMULATION OF THE EFFECT OF A DOUBLE LAYER TROMBE WALL UNDER THE ACTION OF A DC FAN USING ENERGY PLUS

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3.1 Introduction to the ENERGY PLUS software

Energy Plus is based on BLAST and DOE-2 and is funded by the US Department of Energy as a professional building energy simulation software. Dynamic load calculations are the theoretical basis of Energy Plus, which is based on the reaction factor method and takes into account a wide range of factors. As long as the parameters are set and entered, Energy Plus can carry out simulations and then generate files and outputs based on the results and user input requirements, which are more accurate. Because of the accuracy of Energy Plus simulations, it is widely recognized and used in the building energy efficiency sector.

Energy Plus is widely recognized in the industry for its combination of DOE-2 and BLAST, but also for its unique features, including a comprehensive analysis of the overall building energy system, which is very innovative, most notably the improvements to the internal modules and the simulation methodology. The source code of Energy Plus is open source and users can add new modules as they see fit. As a result, Energy Plus is a very powerful software for building energy analysis. However, all software is not perfect and Energy Plus has some shortcomings of its own. The Energy Plus user interface is not very user friendly, it only allows for parameter input and the construction of models is not as intuitive as 3D modelling, which is prone to errors and requires careful checking. When entering the wall parameters, the different components need to be entered separately, resulting in a large workload. The output tables are very complex and all in English, requiring later manual processing into images to analyse their trends.

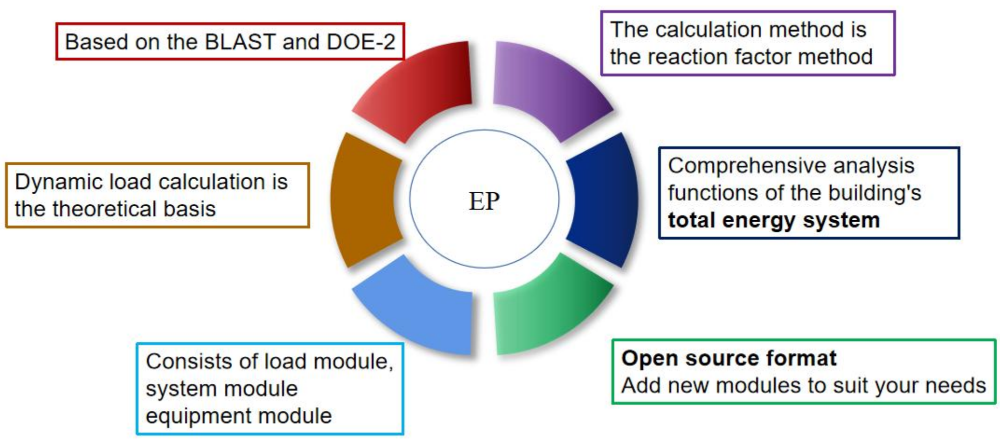

Fig3-1 Introduction to the main functions of Energy Plus

3.2 Trombe walls in EP

Trombe walls are clever devices that collect and store solar heat during the day and release it into the building space at night; they are a free form of solar space heating. The wall is usually located on the south side of a building (in the northern hemisphere) to maximize the amount of solar exposure throughout the year. Overhangs are used to shade the wall in summer to prevent overheating, but in winter allow sunlight to hit the wall at a lower angle. Heat is collected and stored in the thick concrete walls.

One or more layers of glazing on the external wall and an optional optional surface turn the wall into a one-way heat valve. The inset glazing creates an air gap between the wall surface and the exterior and is used to isolate the wall from external convection. The selective surface adheres to the wall surface (i.e. a large flat transparent envelope on the exterior) and is characterized by a very high absorption rate and a very low emission rate, allowing solar radiation to be absorbed but preventing it from being re-emitted as long-wave radiation.

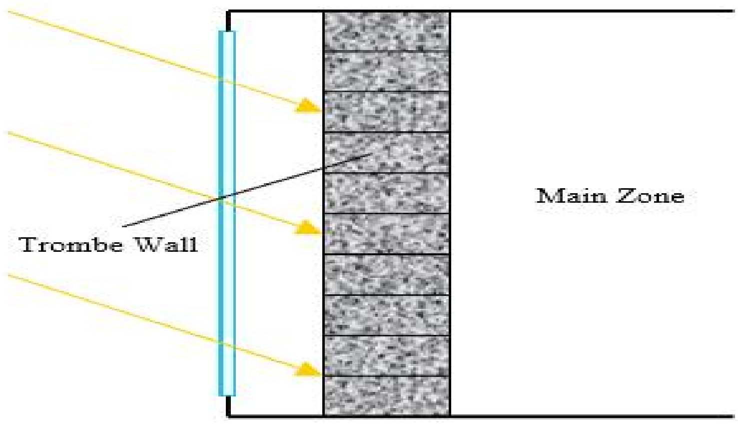

Fig 3-2 Simple Wall models

At night, the heat stored in the walls eventually spreads through the concrete into the building space. This passive solar strategy is known as indirect gain. As most of the heat from the walls is transmitted radially, occupants report higher levels of thermal comfort compared to convective forms of heating.

Ventilation holes are sometimes placed at the bottom and top of the walls to allow air to circulate through the Trombe air gap in some areas. The chimney effect draws cooler air in through the bottom vents and pushes hotter air (heated by the walls) out the top. This is considered a Passive Trombe wall system due to the natural convection driving the airflow. The addition of an electric fan forces the air flow and converts the system to an active Trombe wall system. Both types of ventilation help to bring the heat into the building space earlier, not just by conduction.

Trombe walls are modeled using standard Energy Plus objects. a special Trombe zone is defined in the air gap between the Trombe wall and the inset glazing. The wall and the glass are standard Energy Plus surfaces. The wall is connected to the main zone as an internal partition. The glazed window is essentially a very large window that covers most of the external wall of the zone. If a selective surface is used, it is defined only as a material that has relevant thermal properties in the definition of the wall construction.This approach was chosen to take advantage of the heat transfer capabilities available in Energy Plus and to allow flexibility in modelling unique wall designs such as recessed windows, glazing variations, non-vertical walls, etc.

The key difference between a Trombe zone and a normal zone is their unique geometry. the Trombe zone has a much larger aspect ratio. The aspect ratio of the normal zone is usually 1 or less. the aspect ratio (defined as the ratio of the vertical wall height to the air gap width) of the Trombe zone can be between 10 and 100. The effect of this high aspect ratio changes the basic convective heat transfer phenomenon in this region. Therefore, special convection algorithms must be used in the Trombe zone.

The problem is complicated by the fact that the ventilated Trombe walls circulate air into the main area. Although a ventilated model has also been implemented in Energy Plus, this is beyond the scope of this paper; only the ventilated Trombe wall model is discussed.

3.2.1 Analysis of the algorithm for the convective heat transfer section

In the air gap of the ventilated Trombe walls, convection occurs entirely by natural convection. Solar radiation transmitted through the inset glass heats the wall surface, while the inset glass remains cooled by the outdoor environment. The temperature difference creates a complex convection pattern within the air gap, the Trommel zone. The standard Energy Plus internal convection correlation applies to full-size rooms and is no longer applicable.

The type of convection within the Trom zone has been studied in depth by other researchers and is referred to as natural convection in high aspect ratio cavities (also known as shells or channels). A number of empirical and numerical studies have been reported. Hollands et al. (1976), Raithby et al. (1977) and ElSherbiny et al. (1982) are a few of the frequently cited studies.

The natural convective heat transfer coefficient is directly related to the Nussle number.

$$Nu = \frac{h_c L}{k} \rightarrow h_c = \frac{kNu}{L} \quad \textbf{(3.1)}$$

The Nusser number is related to the Rayleigh and Planter numbers.

$$Nu = f(Ra, \Pr) \quad \textbf{(3.2)}$$

The Rayleigh number based on the air gap spacing L is defined as

$$Ra_L \equiv \frac{g\beta(T_1 - T_2)L^3}{\alpha v} \quad \textbf{(3.3)}$$

The Rayleigh number can also be expressed in terms of the Grashov number

$$Ra_L = \Pr Gr_L \quad \textbf{(3.4)}$$

The Grashof number is defined as follows:

$$Gr_L \equiv \frac{g\beta(T_1 - T_2)L^3}{\nu^2} \quad \textbf{(3.5)}$$

Assuming that the Prandtl number of air is sufficiently constant in the normal building temperature range of 0.71

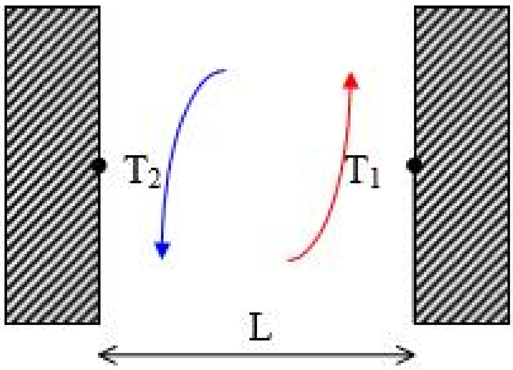

Fig 3-3 Convection heat transfer in the cavity

Fig 3-3 A review of the existing empirical correlations for Trombe walls led to the decision to use the correlations already used by EnergyPlus for the windows. The correlation (ISO 15099 2000) determines the Nussel number of convective heat transfer in the air gap of a multi-pane window, which also has a high aspect ratio. the advantage of the ISO 15099 correlation is that it is a recognized standard and can be interpreted for different tilt angles.The ISO 15099 correlation consists of three different correlations, depending on the angle of inclination. In the following equation, a is the aspect ratio H/L.

For vertical cavities, i.e. most Trombe walls, the correlation based on Wright (1996) is used.

$$Nu_1 = 0.0673838 Ra^{1/3} \qquad 5x10^4 < Ra < 10^6$$

$$Nu_1 = 0.028154 Ra^{0.4134} \qquad 10^4 < Ra < 5x10^4$$

$$Nu_1 = 1 + 1.7596678x10^{-10} Ra^{2.2984755} \qquad Ra \leq 10^4$$

(3.6)

$$Nu_2 = 0.242\left(\frac{Ra}{a}\right)^{0.272}$$

$$Nu = Max(Nu_1, Nu_2)$$

For a 60 degree tilt, using the correlation of ElSherbiny, Raithby and Hollands (1982).

$$Nu_1 = \left[1 + \left(\frac{0.0936 Ra^{0.314}}{1+G}\right)^7\right]^{1/7}$$

$$where: G = \frac{0.5}{\left[1 + \left(\frac{Ra}{3160}\right)^{20.6}\right]^{0.1}}$$

(3.7)

$$Nu_2 = \left(0.104 + \frac{0.175}{A}\right) Ra^{0.283}$$

$$Nu = Max(Nu_1, Nu_2)$$

Nussle numbers for inclination angles between 60 and 90 were obtained by interpolating between the above correlations.

For inclination angles below 60 degrees and Ra < 10^5 and a > 20, the correlations are (Hollands, Unny, Raithby and Konicek 1976).

$$Nu = 1 + 1.44\left(1 - \frac{1708}{Ra\cos\theta}\right)^{\bullet}\left(1 - \frac{1708\sin^{1.6}(1.8\theta)}{Ra\cos\theta}\right) + \left(\left[\frac{Ra\cos\theta}{5830}\right]^{1/3} - 1\right)^{\bullet} \quad \textbf{(3.8)}$$

$$where: (x)^{\bullet} = \left(x + |x|\right)/2$$

The resulting Nusser number is used to calculate the net convection coefficient hcnet from one surface to another.

$$h_{c,net} = \frac{kNu}{L} \quad \textbf{(3.9)}$$

The net convection coefficient determines the total heat flux through the cavity.

$$q'' = h_{c,net}(T_1 - T_2) \quad \textbf{(3.10)}$$

In order to correctly model the Tromsberg zone, convection coefficients between each surface and the air zone are required. In order to derive the convection coefficients for the two inner surfaces, a thermal network analogy is necessary.

One of the aims of the validation is to determine whether the ISO 15099 correlation and the above method of selecting convection coefficients is applicable to Trombe walls. The following theoretical validation section will partially address this issue.

The remaining secondary surfaces in the Trombe zone are correlated using the standard Energy Plus internal convection correlation: ASHRAE Detailed. this is not accurate, but as the secondary surfaces represent only a small fraction of the total surface area of the zone, they do not have a significant impact on the net heat transfer.

3.2.2 Internal radiate heat gain

Energy Plus does not calculate an exact view factor for the radiate exchange between surfaces within a partition. Instead, approximate view factor surface emissions are calculated based on area and area and then 'fixed' to the requirements of reciprocity, integrity and adversative balance. The approximate view factor is most accurate for cube-like partitions. As the aspect ratio of the partition deviates from the cube, so does the accuracy of the approximate view factor.

The accuracy of the approximate view factor should be verified due to the very high aspect ratio of the Trombe region. a comparison of the exact and approximate view factors for the geometry of the Los Alamos Trombe region is shown below Fig3-4.

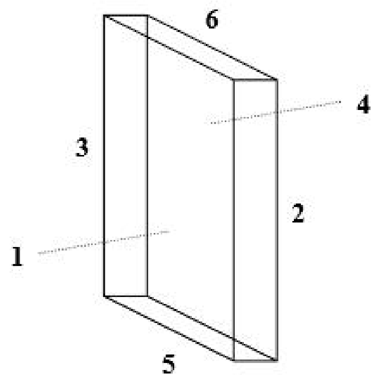

Fig3-4 Trombe area surfaces for view factors

All approximate view factors are within 0.01 of the exact value. In this extreme case of high aspect ratios, the main surfaces 1 and 4 show almost no errors. These surfaces are also the most important as they have the largest area and dominate the radiation exchange. Secondary surfaces 2, 3, 5 and 6 show smaller errors but contribute little to the radiate exchange due to their small infrared area. For the high aspect ratio regions the approximate view factor is very accurate.

Although the validity of the approximate view factor for the Trombe region has been established, the simulation results may still be in error if the geometry of the adjacent region is anomalous. This is of course true whether or not there is a Trombe wall attached to the region.

View Factor	Exact	Energy Plus	Error
F_{11}	0.000	0.000	0.000
F_{21}	0.492	0.497	0.005
F_{31}	0.492	0.497	0.005
F_{41}	0.983	0.983	0.000
F_{51}	0.489	0.497	0.008
F_{61}	0.489	0.497	0.008
F_{12}	0.005	0.005	0.000
F_{22}	0.000	0.000	0.000
F_{32}	0.004	0.002	-0.001
F_{42}	0.005	0.005	0.000
F_{52}	0.010	0.002	-0.008

F_{62}	0.010	0.002	-0.008
F_{13}	0.005	0.005	0.000
F_{23}	0.004	0.002	-0.001
F_{33}	0.000	0.000	0.000
F_{43}	0.005	0.005	0.000
F_{53}	0.010	0.002	-0.008
F_{63}	0.010	0.002	-0.008
F_{14}	0.983	0.983	0.000
F_{24}	0.492	0.497	0.005
F_{34}	0.492	0.497	0.005
F_{44}	0.000	0.000	0.000
F_{54}	0.489	0.497	0.008
F_{64}	0.489	0.497	0.008
F_{15}	0.003	0.003	0.000
F_{25}	0.006	0.001	-0.005
F_{35}	0.006	0.001	-0.005
F_{45}	0.003	0.003	0.000
F_{55}	0.000	0.000	0.000
F_{65}	0.001	0.001	0.000
F_{16}	0.003	0.003	0.000
F_{26}	0.006	0.001	-0.005
F_{36}	0.006	0.001	-0.005
F_{46}	0.003	0.003	0.000
F_{56}	0.001	0.001	0.000
F_{66}	0.000	0.000	0.000

Fig 3-5 comparison of exact and approximate view factors

3.2.3Theoretical verification

The complexity of the Trombe wall model makes it difficult to carry out a full theoretical validation of the model. However, some validation can be carried out independently by comparing the EnergyPlus convective correlations with other empirical correlations.The unverified Trombe wall model in both BLAST (Walton 1981) and DOE-2 (Moore et al. 1981) uses empirical correlations cited by Krieth

(1973, 1976) and Jakob (1949), but derived from the experimental work of Mull and Reisher (1930).

The correlation equation for turbulence is:

$$Nu = 0.065 Gr^{1/3} a^{-1/9}$$
$$2x10^5 \le Gr \le 1.1x10^7 \qquad \textbf{(3.11)}$$
$$10.6 < a < 42.2$$

Or, according to the Rayleigh number:

$$Nu = 0.065\left(\frac{Ra}{\mathrm{Pr}}\right)^{1/3} a^{-1/9}$$
$$1.4x10^5 \le Ra \le 7.8x10^7 \qquad \textbf{(3.12)}$$

Other researchers have recognized the problem of conflicting experimental results (MacGregor and Emery 1969). One possible explanation for this discrepancy may be due to the effect of surface roughness. Roughness increases the convection coefficient. The experimental literature is usually unclear ads to what surface material was used.

Trombe walls with selective surfaces can be expected to be almost as smooth as glass and the ISO 15099 correlation should apply. Trombe walls with masonry surfaces may be sufficiently rough to increase convective heat transfer. In this case, the ISO 15099 correlation may underestimate the Nusser number and convection coefficient. The effect of roughness should be further investigated.

The TRNSYS correlation seems unlikely. The equations found in the procedure paper do not correlate clearly with the correlations described by Randall et al. (1979). The results found in the actual paper are more consistent with other correlations.

3.3 Boundary condition setting for simulation

In Energy plus, heat transfer calculations for walls are all done in one dimension, so this results in heat transfer calculations not being possible if there are heterogeneous walls in the modelling. Therefore, when modelling from CAD drawings or Sketch up, the following principles should be followed.

(1) When the area of the window is guaranteed to be equal to the actual, the specific location can be determined without. (2) For dormer windows and closed balconies, the process can be simplified. (3) For structural columns, thermal bridges and other complex connection parts can be set without drawing, and the heat transfer coefficient of the wall is set using the integrated heat transfer coefficient of the wall. (4) For complex roofs, the settings can be simplified. (5) For the same function room to be combined processing.

3.4 Setting of the building envelope

The setting of the parameters mainly includes the setting of the envelope. The setting of the envelope of the foundation model consists mainly of the following Table 3-1.

Table 3-1 Enclosure settings for the base model

Type	Materials	Heat transfer coefficient K（$W/m^2 \cdot K$））
External wall	100mm thick benzene sheet + 10mm cement mortar + 200mm thick concrete block	0.230
Roof	120mm double sandwich colour steel roofing + 100mm through-length steel reinforcement + 80mm thick benzene sheet	0.287
Internal wall	20mm cement mortar + 100mm red brick + 20mm cement mortar	1.17
Massive wall	20mm cement mortar + 200mm red brick + 20mm cement mortar	3.134
External Window	signle hollow window	5.87

3.5 Indoor thermal disturbance and algorithm settings

The setting of the thermal disturbance in the room includes the following elements: people, lighting, equipment and infiltration ventilation Table3-2.

Table 3-2 Indoor thermal disturbance settings

Type	Parameters	Timetable (typical)
Personnel	4	18:00—8:00(Next day)
Lighting	15	18:00—23:00
Equipment	12	7:00—9:00
Penetration	0.5 arh	Presence throughout the year

The relevant Energy plus algorithms are set up as follows.

Table 3-3 Energy plus algorithm settings

Type	Parameters
Load convergence tolerance difference	0.04 J
Temperature convergence tolerance difference	0.4℃
Solar radiation	Total reflection on internal and external surfaces
Shading calculation method	Calculation of the average number of days
Frequency of shading calculations	20
Sky radiation modelling algorithm	Simple Sky Radiation
Internal surface algorithms	TAPP
External surface algorithms	DOE-2
Thermal balancing algorithms	Conduction Finite Difference
Steps per hour	20

3.6 Room settings and 3D model

The model was modeled in Sketch

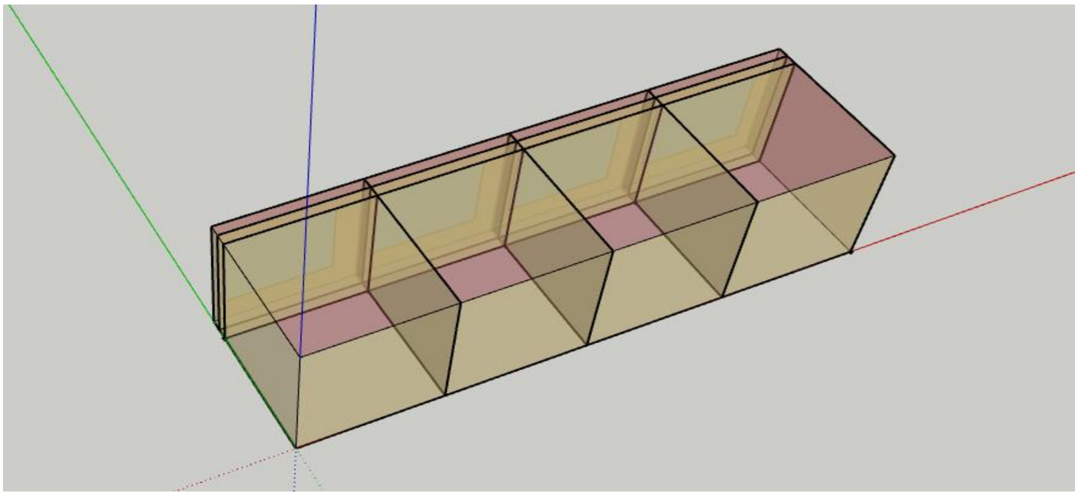

Fig. 3-5 3D model of the building

The model was modeled in Sketch Up Pro 2021 using the Open studio Application 1.3.1 plug-in, with a model width of 2400mm, length of 2400mm, height of 2500mm and an external window size of 1800*1500. the void width was 200mm, where the following points were addressed to the model.

1), The internal walls between rooms N, A, B and C are set up as adiabatic surfaces to avoid the influence of neighbouring rooms through the internal walls. 2), The external walls of rooms N and C are also both set as adiabatic surfaces. 3), The glazed windows in rooms N, A, B and C face south.

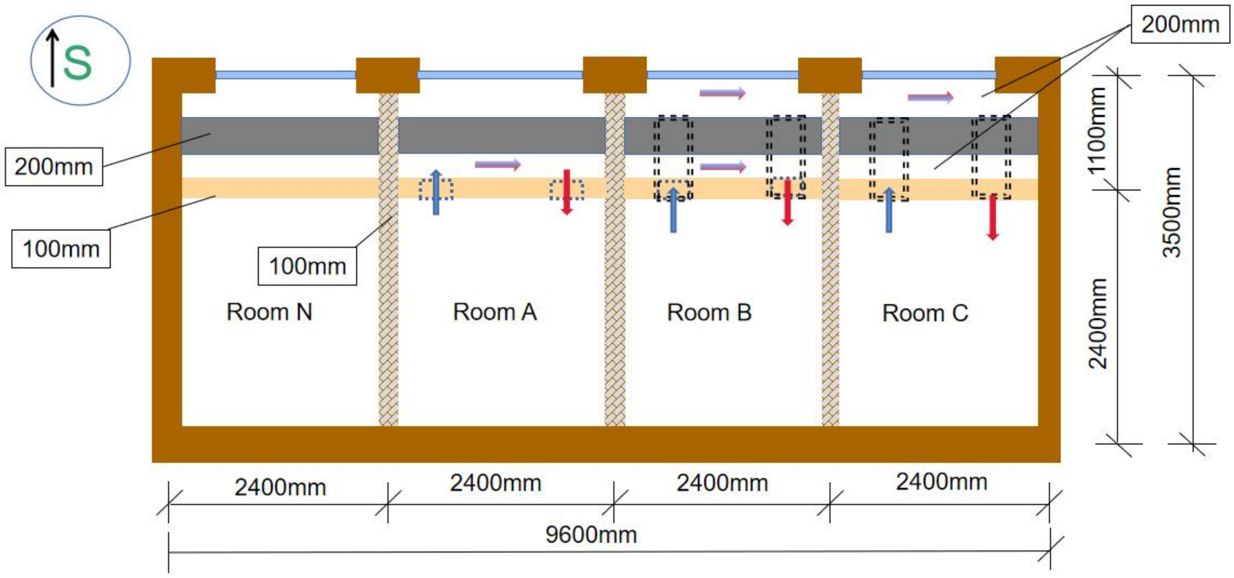

Fig3-6 Diagram of the building plan

3.6 Setting of the room (The layout of each room)

The basic conditions for the simulation of the project were set as above, the main difference being the type of ventilation of the walls.

Room N: No other ventilation, only infiltration ventilation exists.As shown in Figure 3-7.

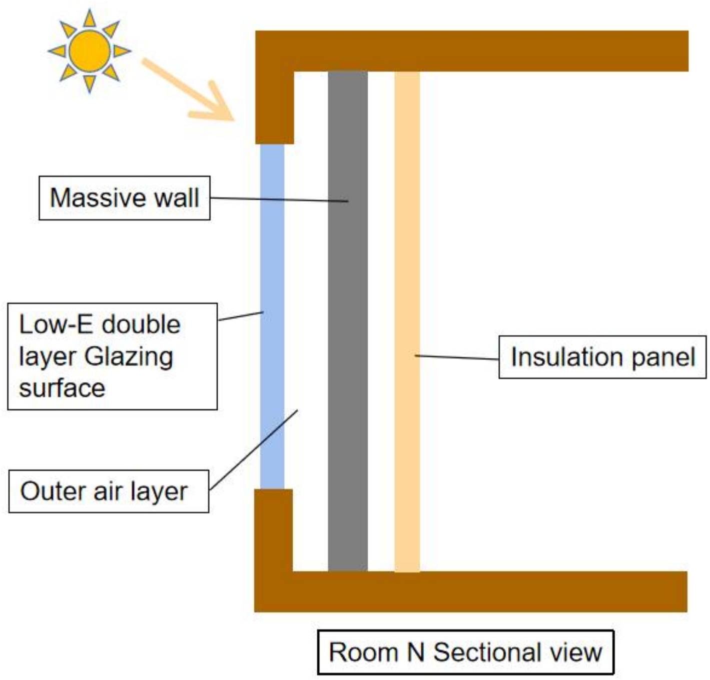

Fig 3-7 No other ventilation

Room A: Internal circulation ventilation. Internal circulation ventilation is ventilation between the room and the cavity close to the room, where cold air enters the inner cavity through the lower part of the room, is heated by the wall between the outer cavity and the inner cavity and then flows into the room through the upper non-cavity, heating the room by convective heat exchange processes.As shown in Figure 3-8.

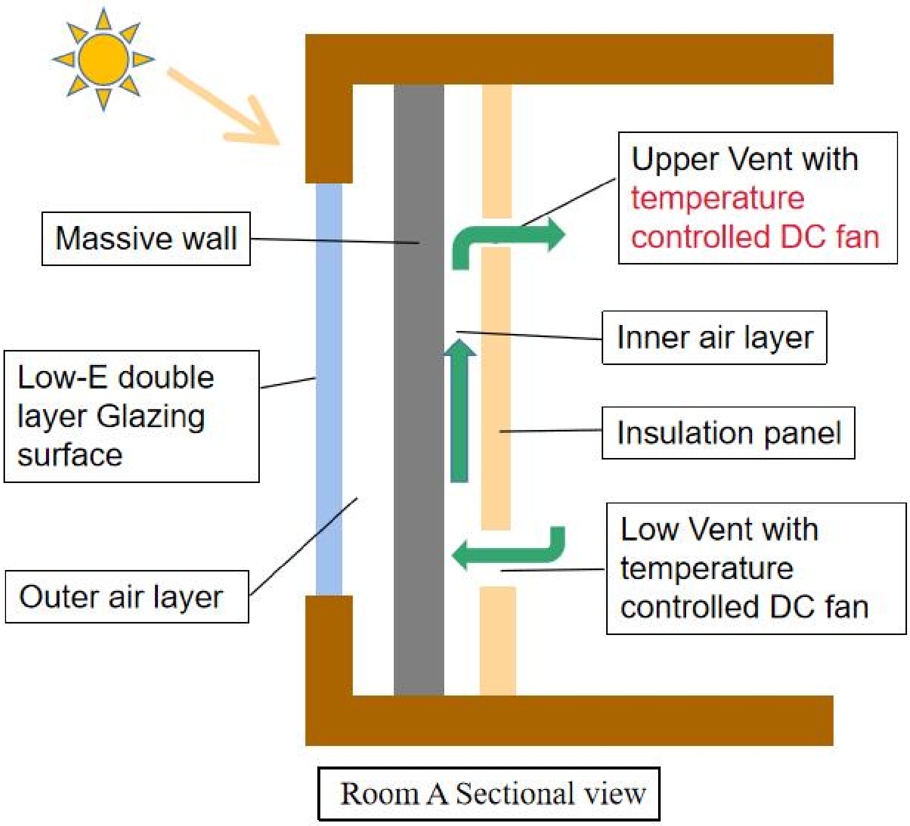

Fig 3-8 Inner circulation ventilation

Room B: Double circulation ventilation. Double circulation ventilation is the simultaneous ventilation of the inner cavity and the outer cavity. The principle is the same as that of single inner cavity ventilation, where the air inside the room circulates into the inner cavity and the outer cavity for heating.As shown in Figure 3-9.

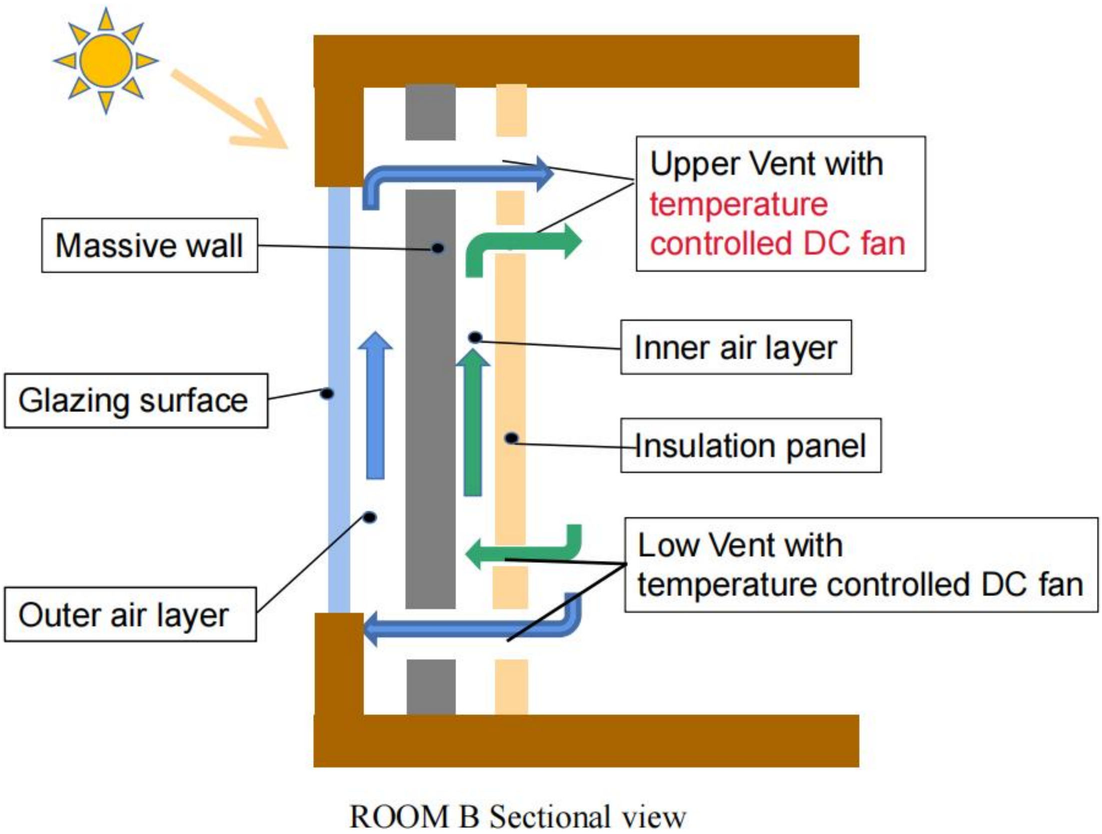

Fig 3-9 Double circulation ventilation

Room C: External circulation ventilation. The principle of external circulation ventilation is the same as that of single internal cavity ventilation, where the air circulating inside the room enters the external cavity for heating and then flows back inside the room.As shown in Figure 3-10.

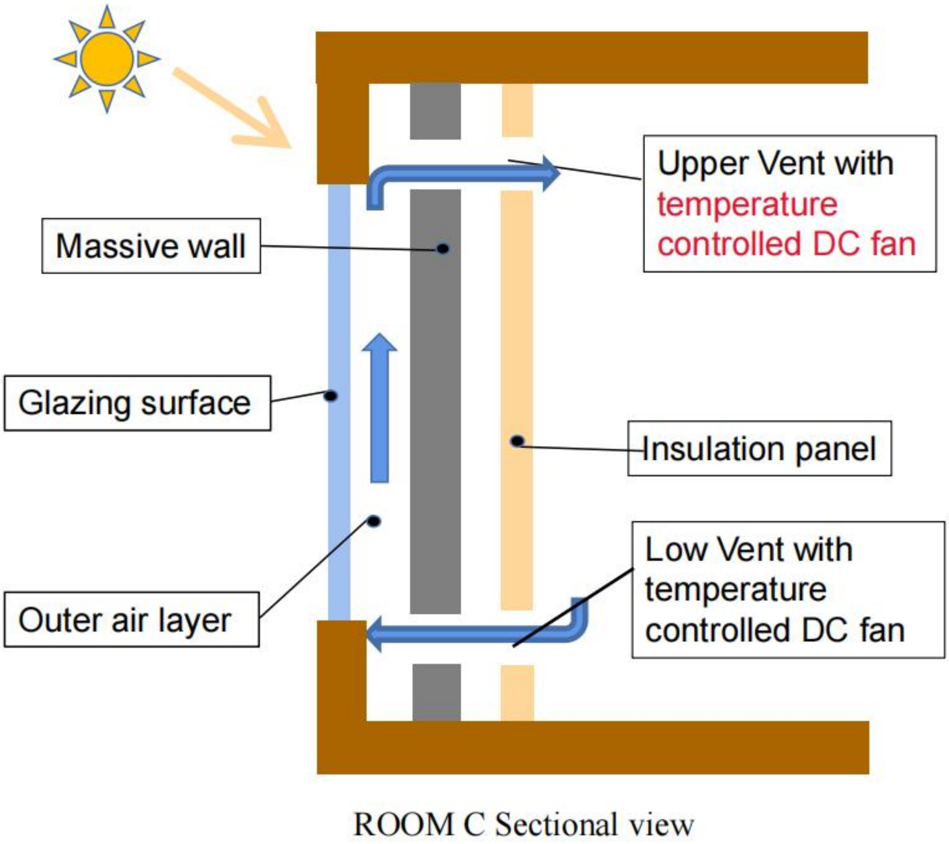

Fig3-10 Outer circulation ventilation

3.7 Numerical analysis of the simulation under natural ventilation

The diagram ,as shown in Figure 3-11 shows that the four rooms were first simulated without the addition of air conditioning, with the fan operating according to the temperature inside the ventilated air chamber, and when the temperature of the heated air chamber is greater than the room temperature, the fan starts to operate, otherwise it does not, thus achieving the purpose of controlling air circulation. ACB represents the measures of internal circulation, external circulation and internal and external circulation respectively. The results show that the continuous operation of the fan helps to increase the temperature of the room and that the temperature fluctuations in the room with double cavity walls show a sinusoidal function, while the temperature of the room in the natural state does not fluctuate too much in the simulated time range and behaves more gently. This is mainly due to the fact that, on the one hand, the acceleration of the air flow inside the cavity by the fan accelerates the inflow of air from both internal and external cavities into the room, while at this time the temperature of both cavities is influenced by the outdoor environment (e.g. solar radiation (the sun rises in the east and sets in the west every day), etc.) The influence of the outside cavity, especially the external cavity, including glass windows, fluctuates more.So this influence, through the linkage of the fans, affects the temperature of the room.

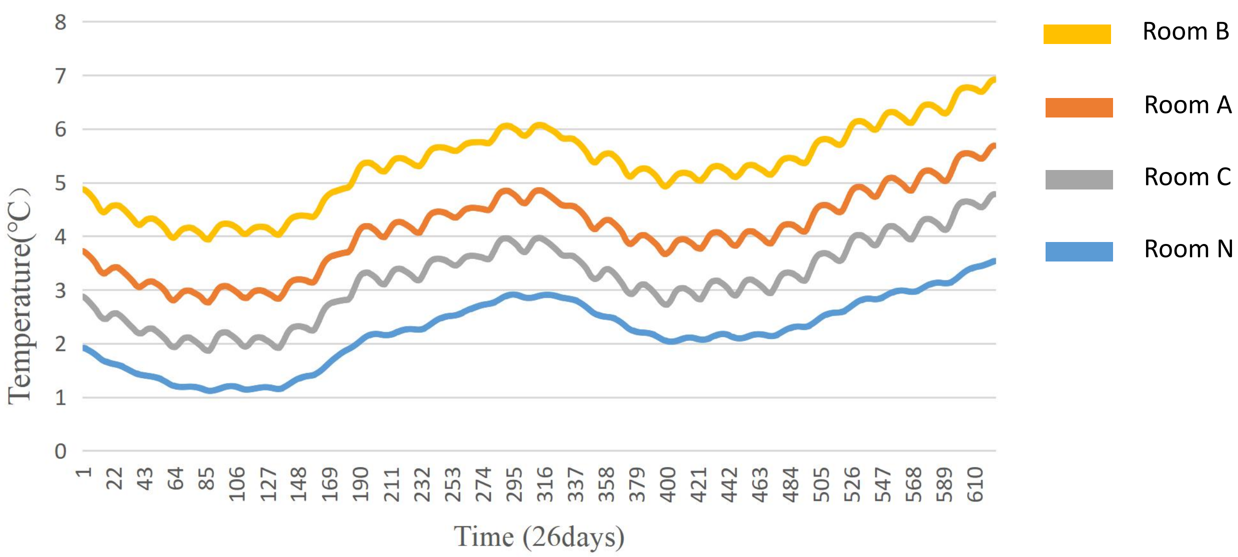

Fig 3-11 Indoor temperature changes in four rooms in February

In addition, a graph Fig3-12 of the temperature difference between the room with a double-layer heat-absorbing curtain wall and the room in its natural state reveals that during the heating season, the temperature of the room under internal circulation increases by about 1.9°C, the temperature of the room under external circulation increases by about 1°C and the temperature under double circulation inside and outside increases by 3.1°C, compared to the double-layer Trombe wall with a DC fan and without air supply. From the results, the external circulation did not increase the temperature as much as the internal circulation, mainly because the glass in the external cavity has a high thermal conductivity and dissipates heat as quickly as it gains heat, so heat is not easily stored. But in any case, in the absence of air conditioning, it is very effective to keep the fan running. And the fact that the temperature difference in the raised temperature does not vary much, regardless of the type of circulation used, is further evidence of the characteristics of a double wall with a circulating fan to maintain a stable room temperature.

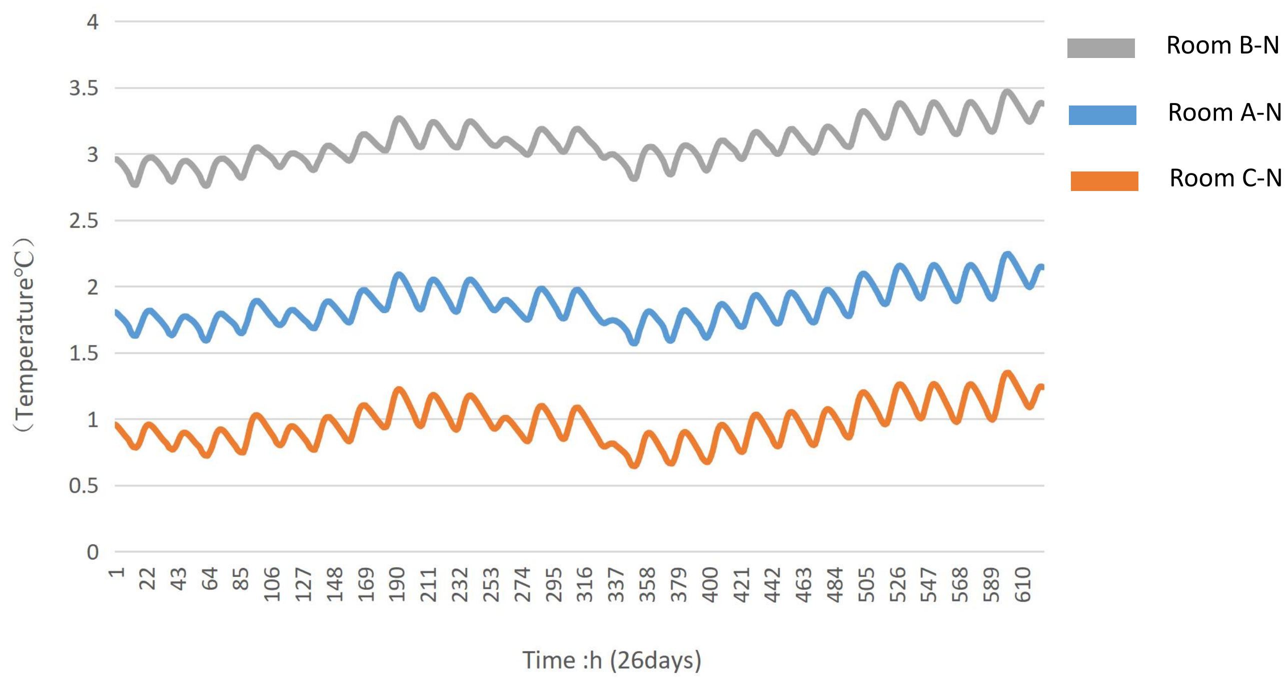

Fig3-12 Temperature difference between a room with a double-layered heat-absorbing curtain wall and a room in its DC fans off

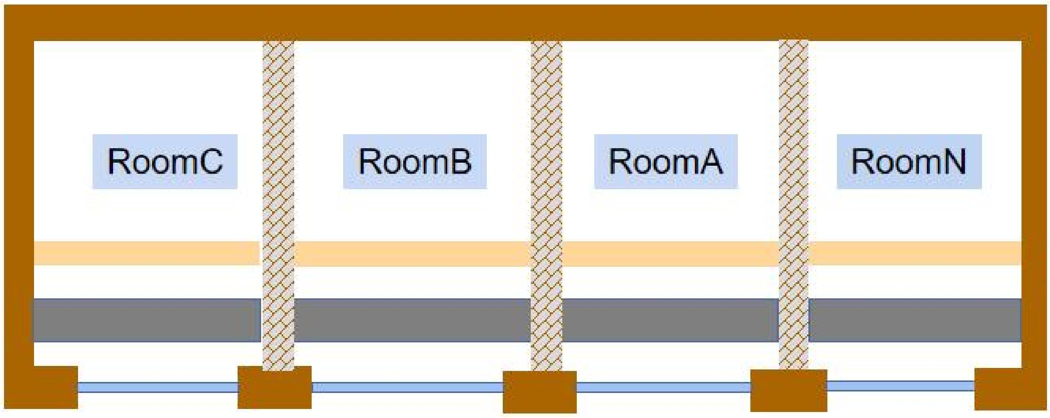

Fig3-13 Temperature difference correction factor（α）

Room C and N belong to the west and east wall rooms respectively, so there is a factor adjustment for the temperature difference,According to the< HVAC design and construction> specifications, the correction factor for temperature differences between rooms adjacent to unheated rooms with external windows is 0.7.

3.8 Summary

This chapter is devoted to the simulation of data with the ENERGY PULS software and prepares the ground for the comparison of experimental data in the next chapter, which introduces theoretical knowledge from two aspects: one is the theoretical knowledge of the software and the other is the knowledge of the operation mechanism of the TROMBE wall.

1, On ENERGY PLUS software, this chapter compares in detail the advantages and disadvantages of each software, from which this one is chosen, because of its simple calculation, high accuracy and can be well calculated to simulate temperature changes and energy analysis, the relevant important formulae are as follows：

Table 3-4 Energy plus Analysis steps

Type	Parameters
Load convergence tolerance difference	0.04 J
Temperature convergence tolerance difference	0.4℃

Solar radiation	Total reflection on internal and external surfaces
Shading calculation method	Calculation of the average number of days
Frequency of shading calculations	20
Sky radiation modelling algorithm	Simple Sky Radiation
Internal surface algorithms	TAPP
External surface algorithms	DOE-2
Thermal balancing algorithms	Conduction Finite Difference
Steps per hour	20

2, about the theoretical knowledge of TROMBE WALL, this part mainly introduces how TROMBE WALL heats and flows the gas from the perspective of heat transfer, the important body formulae are as follows：

1） $$Q_{qs}\rho_s\eta_s\frac{\Delta d}{2}c_{\varpi}\frac{Dt_{s,1}}{Dt}=k_{g,q-s}\frac{\Delta d}{2}c_{\varpi}\left(t_{1,1}-t_{s,1}\right)+k_{g,q-s}\frac{\Delta d}{2}k_s\left(t_{l,1}-t_{s,1}\right)+\rho_s uQ_{qs}\left(t_m-t_{s,1}\right)$$

$$u=r_{\delta}H\sqrt{2Gl\frac{\left|t_{s,a}-t_m\right|}{t_m}}$$

$$Q_{qs}\rho_s\eta_s\Delta dc_{\varpi}\frac{Dt_{s,j}}{Dt}=k_{g,q-s}\Delta dc_{\varpi}\left(t_{1,i}-t_{s,j}\right)+k_{g,q-s}\Delta d_{\varpi}\left(t_{g,j}-t_{s,j}\right)+\rho_s\mu Q_{qs}\left(t_{s,j}-t_{s,j+1}\right)$$

3,A simple simulation of the TROMBE WALL under natural ventilation, the basic data was obtained.

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Chapter4

EXPERIMENTS ON THE WINTER HEATING MODE OF THE DOUBLE LAYER TROMBE WALL SYSTEM

CHAPTER 4 EXPERIMENTS ON THE WINTER HEATING MODE OF THE DOUBLE LAYER TROMBE WALL SYSTEM

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4.1 Overview of the experimental platform

4.1.1 Principles of experimental design

The design of the laboratory room has a direct impact on data collection, and attention to the design of the laboratory room can effectively improve the accuracy of the experiment.Buildings must be adapted to the characteristics of the local climate, and energy efficient buildings are no exception.

China is a vast country with a complex topography. Due to differences in geographical latitude, terrain and geographical conditions, solar radiation, wind conditions, precipitation, temperature and humidity vary greatly from place to place. To create a suitable indoor thermal environment and save energy in such a climate difference, different climatic conditions put forward different design requirements for energy-efficient buildings, such as energy-efficient buildings in hot areas need to consider comprehensive measures to prevent indoor overheating in summer; energy-efficient buildings in cold, cold and some mild climate areas need to consider comprehensive measures for building insulation to prevent indoor over cooling in winter; In hot summer and cold winter regions and some cold regions, where the summers are hot and the winters are cold, some energy-efficient buildings in these regions need to consider mainly summer heat insulation and winter heat insulation, while others need to consider mainly winter heat insulation and summer heat insulation [1]. Of course, due to the different climatic characteristics of the above areas, the degree of priority and ways to consider insulation and thermal insulation (or insulation plus thermal insulation) may vary. In order to reflect the scientific link between energy-efficient buildings and regional climates and to tailor them to local conditions, it is necessary to consider the climatic characteristics of energy-efficient design and thermal zoning, so that all types of energy-efficient buildings can make full use of and adapt to local climatic conditions, while preventing or weakening the impact of unfavourable climatic conditions.

In order to obtain a suitable indoor temperature for living in a heated building in winter, there must be a constant and stable means of obtaining heat. The majority of the total building heat is supplied by heating and heating equipment, followed by solar radiation and internal building heat (including cooking, lighting, appliances and human heat dissipation). Some of this heat is lost to the outside through heat transfer from the envelope and air infiltration through windows and doors. When the total heat gain and loss of the building is balanced, the room temperature is maintained at a stable level. The basic principle of building energy efficiency is therefore to maximize heat gain and minimize heat loss to the outside.

In accordance with the climatic characteristics of cold and cold regions, the design of residential buildings must first ensure that the thermal performance of the envelope meets the requirements of winter insulation and takes into account summer insulation. By reducing the building form factor, adopting a reasonable window-to-wall ratio, improving the insulation performance of external walls and roofs and external windows, and using the sun's heat gain as far as possible, heating energy consumption can be effectively reduced [2]. Specific winter insulation measures are:

(1) The planning and design of the building complex, the design of the flat and elevation of individual buildings and the setting of windows and doors should ensure the effective use of sunlight in winter and avoid the dominant wind direction;

(2) Minimizing the building form factor and avoiding excessive concave and convex surfaces on the flat and elevated surfaces;

(3) Secondary rooms should be arranged on the north side of the building, and the area of north-facing windows should be as small as possible, while the window-to-wall ratio and the size of single windows in the east-west direction should be properly controlled;

(4) Strengthen the thermal insulation capacity of the envelope to reduce heat transfer and heat consumption, improve the air tightness of doors and windows, and reduce air infiltration and heat consumption [3].

(5) Strengthen the insulation capacity of the envelope to reduce heat transfer heat consumption [4], improve the air tightness of doors and windows, and reduce air infiltration heat consumption;

(6) Improving the design and operation management of the heating and heating system, improving the operating efficiency of boilers, strengthening the heat insulation of heating pipelines and enhancing the regulation and control ability of the heat supply of the heat network

4.1.2 Planning for the architectural design of the laboratory room

When designing energy-efficient buildings, we must first have a comprehensive understanding of the climatic conditions, topography, geological and horological information, local building materials and other information about the location of the building.Location: Siping City, Jilin Province, China Located about 1300 km northwest of Kitakyushu city .East longitude:124°35′E.Latitude North:43°10′N.

Fig 4-1 Climate zones in China.Source: adapted from Yu et al.(2012)

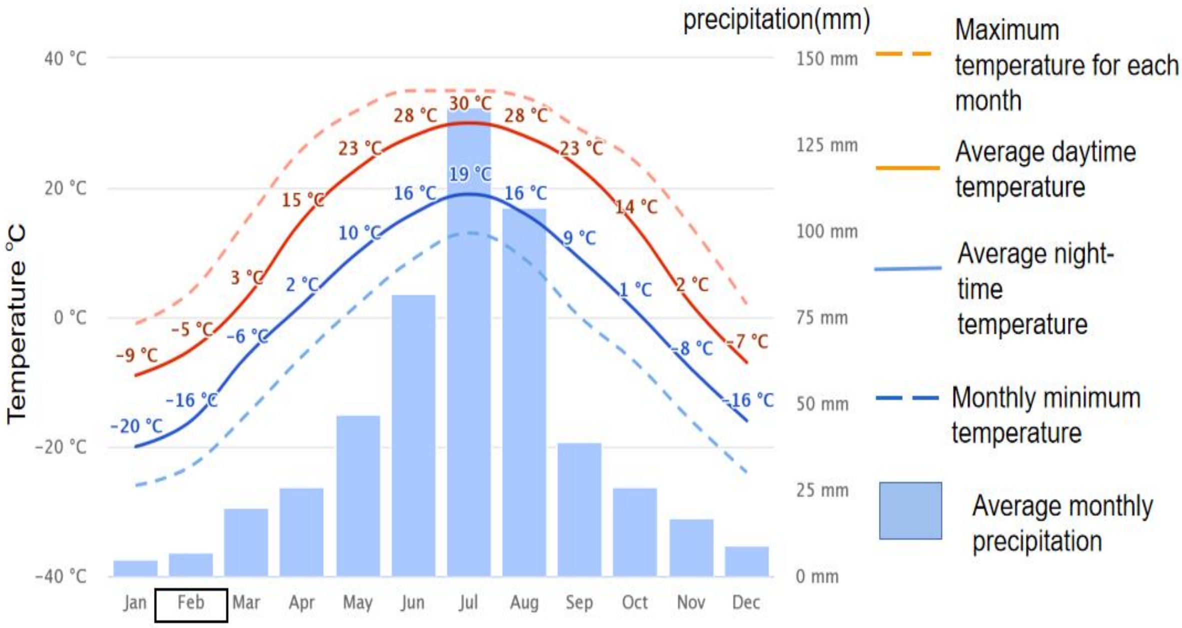


Fig 4-2 Temperature and precipitation statistics for 2021 in the Siping

The experimental room in this paper is located in a construction site in Siping City, Jilin Province, China, with a full sunny south orientation and an east-west inclination of 20 degrees in order to ensure more sunlight hours, and a distance of more than 50 meters between the south and the front building, which will not block the experimental room.The total length of the laboratory room is 10 m, width 3.5 m, sloping roof design, the net height of the north side is 2.4 m, the net height of the south side is 2.5 m. The interior of the laboratory room is divided into four small experimental rooms, indoor suspended thermal insulation roof, the net size of each room is 2.4×2.4×2.4 m, the partition wall of each individual laboratory is 0.1 m thick, the outer wall of the Trombe wall is 0.2 m thick, the inner wall is 0.1 m thick, the windows and The windows are spaced 0.2 m from the outer wall and 0.2 m from the inner wall to the outer wall. See drawing below for details.

Fig 4-3 South facing floor plan of the laboratory

Fig 4-4 Laboratory room interior structure

Fig4-5 East side of the laboratory room

Fig4-6 Diagram of the west and north sides of the laboratory room

As shown in Figure 4-6.Only one door has been set up on the north side of the laboratory room, which significantly reduces heat loss. The small doors of each individual laboratory room are separated by heavy insulated panels during experiments, making it easier to check the instruments in each room and at the same time achieving the requirement of independent experiments in each room.

As shown in Figure 4-7， Ventilation ducts are located 30 cm from the floor and 30cm from the wall edge.

Fig 4-7 Diagram of the installation of ventilation ducts on the external walls

Fig 4-8 External wall of internal circulation system

As shown in Figure 4-8. No external ventilation ducts for internal circulation external walls.If analogies are required for future research, the wall can also be perforated without prejudice to future investigations. Figure 4-9 shows a diagram of the fan opening in the inner wall of the external circulation system, the opening in other rooms is basically the same, see the following chapter for details.

Fig 4-9 Diagram of the inner wall of the external circulation

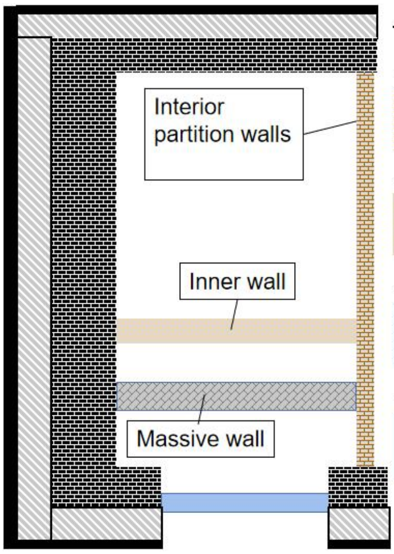
4.1.3 Design of the envelope of the laboratory room

The traditional building construction of the external wall insulation problem is the construction period of the heavy difficulties, and the application of external wall insulation energy-saving technology to provide a solution to this construction problem, but with the further expansion of the scale of the building and the upgrading of construction technology, the application of external wall insulation energy-saving technology must also keep pace with the times, in order to enhance the quality of the building, improve the energy efficiency of the building itself and reduce energy consumption.

Fig 4-10 Material details of the external wall envelope (Unfinished)

Materials / Parameters	Autoclaved aerated concrete 	Mortar 	B1 grade insulated benzene board 
ρ(kg/m³)	560	0.0012	20
δ (m)	0.2	0.01	0.1
λ (W/m·K)	0.15	0.97	0.035
R(m²· k/W)	1.33	0.1	2.85
K(W/m²· k)	K=1/(R1+R2+R3+.....)=0.238		

Fig 4-11 External wall insulation practices



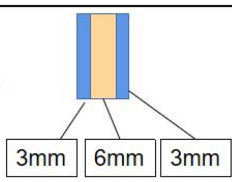
	Material	δ (m)	λ (W/m·K)	K(W/m²· k)
Interior partition walls	Autoclaved aerated concrete	0.1m	0.15	1.5
Inter wall (insulating panel)	Autoclaved aerated concrete	0.1m	0.15	1.5
Massive wall	concrete	0.2m	1.6	8
Double Layer Low-E Glazing **Highly translucent Type for winter**			Size 1.8m*1.5m Light transmittance 70%	

Fig 4-12 Plan view of structural material properties

(1) About external wall insulation design

As shown in the diagram, the process of insulation construction of the external wall of the laboratory room from inside to outside is, 200 thick autoclave aerated concrete blocks, special repair materials to repair the wall, 10 to 20 thick special plastering mortar leveling, 100 thick BI-grade insulation benzene board (insulation this version is fixed by means of bonding), and finally plastering compound glass fibre mesh cloth.

In the construction of building projects, exterior wall insulation construction technology plays a key role, in order to meet the construction requirements, the need to increase the strict management of construction personnel, to meet the quality and efficiency of exterior wall insulation construction. The use of external wall insulation construction technology application to enhance the quality of living in the building, reduce the emergence of waste of resources, while to a certain extent to meet the service life of the building requirements. External wall insulation construction is mainly reflected in the construction of the external wall of the building, to meet the comfort of the building, while meeting the optimal allocation of resources, in the sunlight under the insulation layer of the building can not only play a good role in heat insulation, but also to ensure the stability and balance of the internal temperature of the building, to enhance the building envelope structure with frost and crack resistance, to ensure that the building is more comfortable to live in, and to reduce the risk of the building envelope. It also reduces damage to the building envelope.

Building insulation is mainly used in the external construction of buildings and does not affect the use of internal lighting, but it can have an impact on the thermal performance of the building system, thus affecting the effectiveness of the building heating in winter and cooling in summer. The choice of insulation materials for buildings includes PUR, EPS, XPS and rock wool. According to scientific research, XPA insulation has the highest building carbon footprint and rock wool the lowest, given equal thickness of building materials. For this reason, without considering the thickness of the building insulation material, rock wool should be used as the building insulation material in order to reduce the building's carbon footprint.

The thickness of the building insulation has a significant impact on the carbon emissions of the building. When a uniform material is chosen as the building material, the carbon footprint of the building decreases as the thickness of the insulation material increases. However, when the thickness of the building material reaches a certain level, the carbon emissions of the building remain constant. At the same time, when the thickness of the building material is high, the reduction in building carbon emissions is not significant even when the thickness of the building insulation is increased. In addition, thicker building insulation will affect the aesthetics of the building and increase the cost of construction. Therefore, for reasons of cost and building aesthetics, the thickness of the building insulation layer should be between 160mm and 260mm if the building material is EPS insulation.

(2) Window design and selection of LOW-E glass for laboratory rooms

The window size of the laboratory room is 1.8*1.5m, which meets the wind ow-to-wall ratio in cold regions while achieving the size of the opening.Severe cold winters are longer buildings with greater heating energy, and the require ments of the window-to-wall area ratio should be limited. Table 4-1 shows the window-to-wall area ratio limits for residential buildings in colder regions. Th e north-facing values are smaller, mainly because of the need for light when t he living room is located in the north.

From an energy saving point of view, the area of windows should be minimized in the north-facing and near-north-facing main walls that are subject to cold winter air currents. East and west-facing values are mainly considered to protect against the effects of sunlight in summer and cold wind penetration in winter. In cold and cold areas, when the K value of external windows is reduced to a certain level, solar radiation heat entering from the south-facing external windows can be obtained in winter, which is conducive to energy saving, so the south-facing window wall area is larger. As there is currently a trend for windows in residential living rooms to get bigger and bigger, the heat transfer coefficient of the windows should be reduced in order to reduce the heat consumption of the windows and to ensure energy saving.

Table 4-1 Limit values for window-to-wall ratios in residential buildings in severe cold regions

Orientation	Window to wall area ratio
North	≤0.25
East, West	≤0.3
South	≤0.45

Once the designed building exceeds the specified window-to-wall area ratio, it is required to improve the thermal insulation performance of the building envelope, (e.g. choosing window frames and glass with good thermal insulation performance to reduce the heat transfer coefficient of the windows, thickening the thickness of the insulation layer of the external walls to reduce the heat transfer coefficient of the external walls, etc.) and should carry out a weighing judgment of the thermal performance of the building envelope to check whether the heat consumption index of the building can be controlled within the specified range.

More widely used today is low-e coated (Low-E) glass. Low - E glass, is the use of vacuum deposition technology, in the glass surface deposited a low radiation coating, generally by a number of metal or metal oxide thin layer and the substrate layer composed of. Ordinary glass has an infrared impassivity of approximately 0.8 and transmits up to 84% of the sun's radiant energy, while Low-E glass has a minimum infrared impassivity of 0.03 and reflects over 80% of the infrared energy. As the glass surface coated with Low-E film has a very low long-wave emissivity, it can greatly increase the thermal resistance of radiation heat transfer between glass surfaces and has good thermal insulation properties. Therefore, this type of coated glass is widely used in the world. In recent years, with the development of energy-saving buildings in China, this type of energy-saving glass has been gradually accepted by people.

According to the different transmission characteristics of Low-E coated glass, Low-E films are divided into winter Low-E films, high-transmittance sunlight-controlled Low-E films and sun-shading Low-E films.

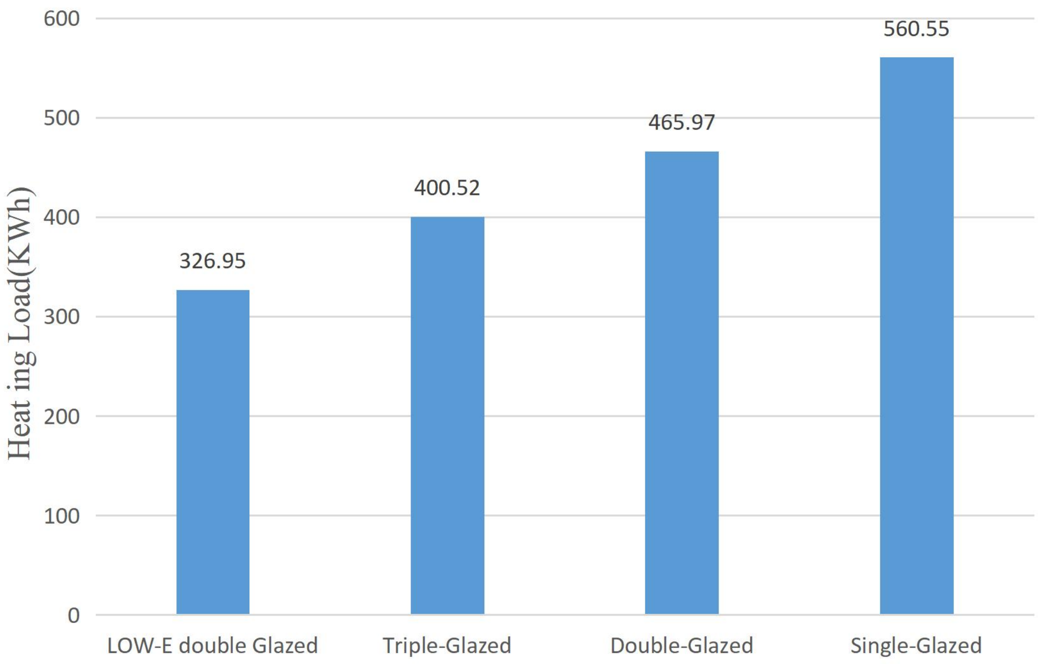


Fig 4-12 Heating load from different types of glass

Multi layer glass was better than single-layer glass regarding the thermal insulation performance, and the more layers, the better the thermal insulation performance. In addition, the use of low-E glass greatly reduced the indoor heat transfer to the outdoor caused by radiation, thus achieving the desired energy saving effect. During the whole heating season, compared with the single layer glass window, the energy ratios that were saved using the double- glazed window, triple-glazed window, and low-E double-glazed window were 18.37%, 29.6%, and 41.53%, respectively.

Buildings can choose from different window constructions such as timber-framed windows, aluminium-framed windows, PVC windows and various window glazing types. The carbon emissions of buildings with different window frame constructions are measured for the same glass material. The aluminium frame has the highest building carbon emissions and the wooden frame has the lowest building carbon emissions. Taking into account the appearance of the building, the durability of the frame and the functionality of the window in terms of thermal insulation, aluminium frames should be chosen for building windows. At the same time, the number of layers and the performance of the glass are considered together in terms of their impact on the building's carbon emissions. Regardless of the type of glass, the carbon emissions from the glass manufacturing process are much higher than the carbon emissions from the use of the glass in the building.

For this reason, in order to achieve the goal of near-zero energy building carbon emissions, the number of layers of glass in building windows and the number of layers of windows should not be excessive. The carbon emissions caused by building windows are divided into two main components: on the one hand, it may be the poor insulation of the windows and the increased carbon emissions caused by cooling the building in summer and heating it in winter.

On the other hand, the light-transmitting function of the windows is able to receive solar radiation, resulting in an increase in carbon emissions from summer cooling. Experiments have shown that, under the same conditions, as the ratio of windows to walls increases, the building's carbon emissions decrease and then increase. For this reason, the ratio of windows to walls should be controlled within a reasonable range, and the design of the building envelope should pay attention to the thermal insulation of windows and choose the appropriate ratio of wall to window area

(2) Other envelope designs

As you can see from the chart above.To increase the heat-absorbing capacity of the walls, black heat-absorbing fabric was attached to the external walls of the trombe wall system during the experiments, black being better at absorbing heat.Roofing practices, 120 thick double-layer sandwich steel roof, 100 purlins through-length arrangement, 100 thick BI grade EPS insulation benzene board, plastered glue paste compound glass fibre mesh cloth, indoor ceiling insulation shed.

4.2 Measuring instruments and measurement procedures used in the experiment

4.2.1 Product introduction to solar radiometers

This experiment was carried out using the RS-RA-JT solar radiation instrume nt, a device that records daily solar radiation, which was set up in a comparis on room. Due to the close proximity of the experimental rooms, it is possible to approximate a uniform solar radiation.

Table 4-2 Solar radiometer parameters

Product parameters	Model	Scope of electricity supply	Measurement range	Size
Date	RS-RA-JT	10V—30V DC	0-1800W/m2	80*46*51 mm

The image above shows the product observing the data on the mobile phone by scanning the QR code and getting a graph of the data, which is placed behind the glass in the laboratory room.

Fig 4-13 Images related to Solar Radiometer

4.2.2 Introduction to the thermometer

The product can display data on the mobile phone via the internet and the product can be calibrated and found in practice to have an error of 0.5 degrees Celsius. It can also measure atmospheric pressure and humidity, and in subsequent studies the effect of humidity can be analyzed, due to the geographical location of the laboratory room, the moderation is relatively low and the ups and downs are not considered for the time being.This is a thermometer placed in the air mezzanine and in the experimental room respectively.

Table 4- 3 Temperature measuring instrument parameters

Product parameters	Model	Measurement range	size
date	JAALEE	-04℃ to 85℃	40*40*20mm

Fig 4-14 Bluetooth thermometer and data display

4.2.3 Introduction to DC fans and temperature controllers

The fans used for the experiments are bi-directional controllable fans for easy adjustment and to check the difference between the theoretical fan speed and the experiment.

Table 4-4 Temperature controller parameters

Product parameters	Model	Measurement range	size
date	tc-05b	-32℃to95℃	160*80*40mm

Table 4-5 Fan parameters

Product parameters	Mode 1	Wind speed gearing	Opening diameter	Maximum speed
date	bV	0 to 100m^3/h	120mm	0 to 2450r/min

As the temperature controller is DC operated, it is important to choose a fan with bi-directional ventilation, and this fan can be controlled to help when studying the optimum air speed.

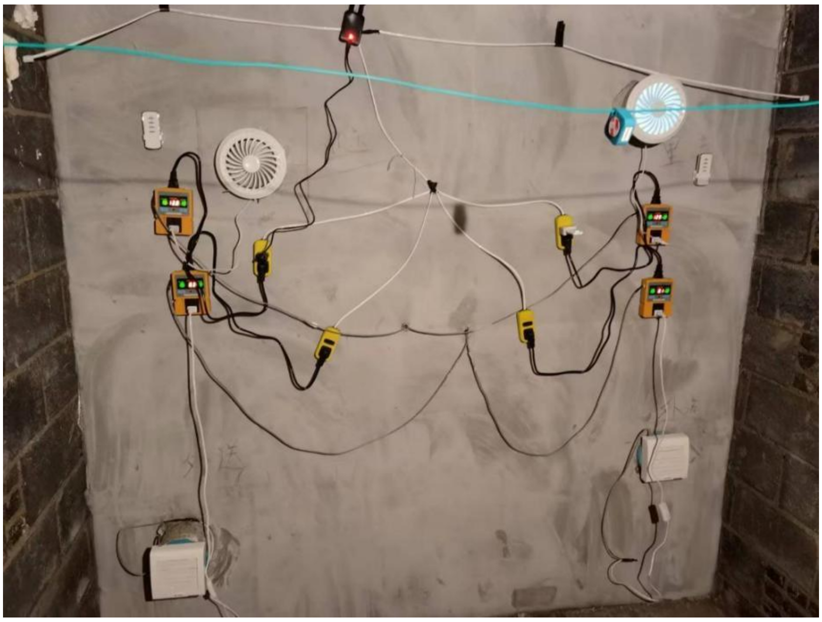


Fig 4-14 The internal apparatus arrangement of the laboratory room is shown in the diagram,

4.2.4 Measurement process

The switch of the fan is connected to the temperature controller, the probe of the temperature controller senses the temperature of its location, according to the experimental requirements, when the temperature reaches the experimental requirement temperature, the temperature controller will start, and at the same time the fan starts to rotate according to the fixed wind direction.The fan located above the wall transports the hot air to the room and the fan located below the wall transports the room air to the air mezzanine.Of course, when the thermostat sensor detects that the temperature is not up to standard, it will stop working and the fan will automatically switch off and the air blades will automatically close to maintain the room temperature.

4.3 Error analysis of experimental data

Table4-6 Uncertainty of each parameter

Parameters	Unit	Uncertainty
Solar radiation	WM	±2%
Inlet and outlet air flow rates	m^3/h	±2%
Heat yield	kWh	±2.1%

4.4 Comparison of room temperatures under natural ventilation

The above diagram shows that the four rooms were first simulated without the addition of air conditioning, with the fan operating according to the temperature inside the ventilated air chamber, and when the temperature of the heated air chamber is greater than the room temperature, the fan starts to operate, otherwise it does not, thus achieving the purpose of controlling air circulation. ACB represents the measures of inner circulation, outer circulation and inner and external circulation respectively. The results show that the continuous operation of the fan helps to increase the temperature of the room and that the temperature fluctuations in the room with double cavity walls show a sinusoidal function, while the temperature of the room in the natural state does not fluctuate too much in the simulated time range and behaves more gently. This is mainly due to the fact that:

On the one hand, the acceleration of the air flow inside the cavity by the fan accelerates the inflow of air from both internal and external cavities into the room, while at this time the temperature of both cavities is influenced by the outdoor environment.The influence of the external cavity, which contains the glass window, is particularly influential. This influence therefore affects the temperature of the room through the linkage of the fans.

In addition, a graph of the temperature difference between the room with a double-layer heat-absorbing curtain wall and the room in its natural state reveals that during the heating season, the temperature of the room under internal circulation increases by about 1.9 ° C, the temperature of the room under external circulation increases by about 1 ° C and the temperature under double circulation inside and outside increases by 3.1 ° C, compared to the double-layer Trombe wall with a DC fan and without air supply. From the results, the external circulation did not increase the temperature as much as the internal circulation, mainly because the glass in the external cavity has a high thermal conductivity and dissipates heat as quickly as it gains heat, so heat is not easily stored. But in any case, in the absence of air conditioning, it is very effective to keep the fan running. And regardless of the type of circulation used, the temperature difference in the raised temperature does not vary much, which is further evidence of the characteristics of a double wall with a circulating fan to maintain a stable room temperature.

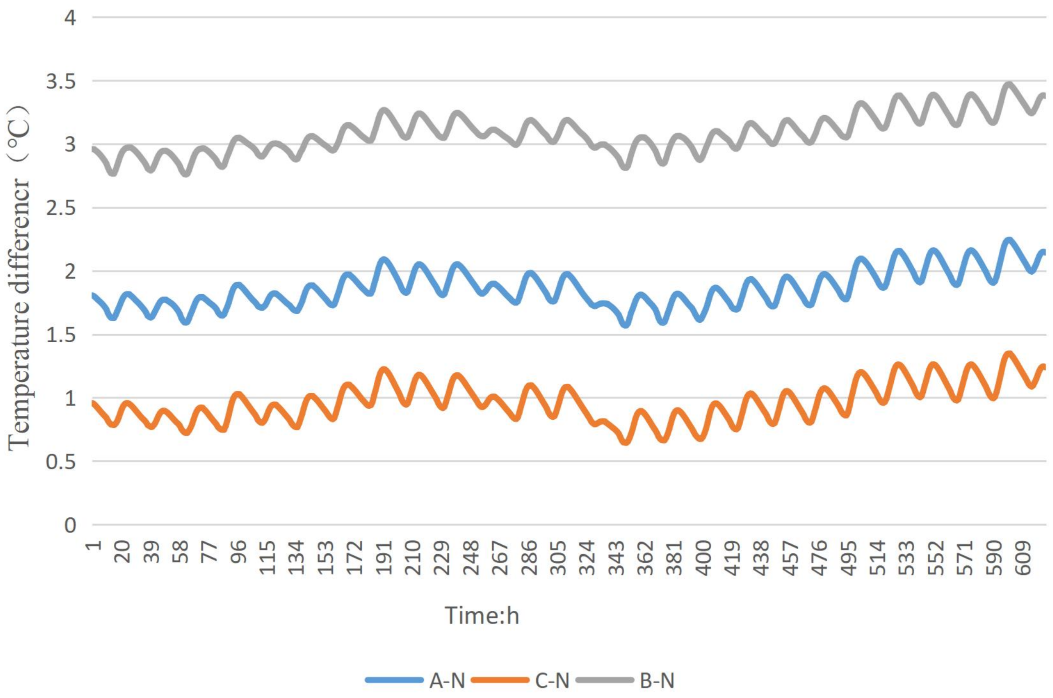


Fig4-15 Temperature variation graph

4.5 Summary

Buildings must be adapted to the characteristics of the local climate, and energy efficient buildings are no exception. China is a vast country with a complex topography. Due to differences in geographical latitude, terrain and geographical conditions, solar radiation, wind conditions, precipitation, temperature and humidity vary greatly from place to place.

To create a suitable indoor thermal environment and save energy in such a climate difference, different climatic conditions put forward different design requirements for energy-efficient buildings, such as energy-efficient buildings in hot areas need to consider comprehensive measures to prevent indoor overheating in summer; energy-efficient buildings in cold, cold and some mild climate areas need to consider comprehensive measures for building insulation to prevent indoor over cooling in winter; In hot summer and cold winter regions and some cold regions, where the summers are hot and the winters are cold, some energy-efficient buildings in these regions need to consider mainly summer heat insulation and winter heat insulation, while others need to consider mainly winter heat insulation and summer heat insulation. Of course, due to the different climatic characteristics of the above areas, the degree of priority and ways to consider insulation and thermal insulation (or insulation plus thermal insulation) may vary. In order to reflect the scientific link between energy-efficient buildings and regional climate, and to tailor the design to local conditions, it is necessary to consider the climatic characteristics of energy-efficient design thermal zoning, so that all types of energy-efficient buildings can make full use of and adapt to local climatic conditions, while preventing or weakening the impact of unfavourable climatic conditions.

1), This chapter focuses on the design of the experimental room, the design of the experimental room in the cold region is different from other regions, the heat loss in the cold region is more serious, so in order to ensure the success and authenticity of the experiment, we have adopted the standard energy-saving insulation design, summarized in the main points are：

a, The planning and design of building groups, the design of the flat and elevation of single buildings and the setting of doors and windows should ensure the effective use of sunlight in winter and avoid the dominant wind direction;

b, Minimising the building form factor and not having too many concave and convex surfaces on the flat and elevated surfaces;

c, Secondary rooms should be arranged on the north side of the building, and the area of north-facing windows should be as small as possible, while the window-to-wall ratio and the size of single windows in the east-west direction should be properly controlled;

d, Strengthen the thermal insulation capacity of the envelope to reduce heat transfer and heat consumption, and improve the air tightness of doors and windows to reduce air infiltration and heat consumption;

2), Summary of the introduction of the material parameters of the laboratory room

Table 4-7 Structural Parameters of Trombe Collector Walls

Construct name	Thickness(m)	Thermal Conductivity(W/m·k)	Density(kg/ m^3)	specific heat capacity(J/kg)
glass wall	0.003	0.78	2540	770
Outer air spacer	0.02	—	—	—
thermal storage wall	0.02	0.14	1050	500
Inside air spacer	0.02	—	—	—
temperature control wall	0.01	0.14	1050	500

Table4-8 Structural parameters of construction materials

Material name	Thickness(m)	Thermal Conductivity(W/m)	Density(kg/ m^3)	specific heat capacity(J/kg)
cement mortar	0.02	0.87	1700	1050
red brick	0.23	0.81	1800	1050
200 thick concrete block	0.02	0.81	1800	1050
60 thick benzene board	0.06	0.032	35	1380
80 thick benzene board	0.08	0.032	35	1380
100 thick benzene board	0.10	0.032	35	1380
Double-layer sandwich color steel roof	0.12	0.22	700	870

Table4-9 Trombe wall dimensions

Size part	Unit	Numerical value
Length	m	1.2
Radiation area	m^2	0.9
Upper vent size	m^2	0.038
Lower vent size	m^2	0.038

3), A simple experimental test with natural ventilation was carried out and the results were similar to the simulation results, indicating that the construction and design of the laboratory room met the requirements and also verifying the accuracy of the simulation.

References

[1] <Code of Practice for the Design of Buildings in Severe Cold Areas>

[2] <Principles and Specifications for Energy Efficient Building Design 2020 Edition>

[3] <Design specifications for brick structures>

[4] <Building load design codes>

Chapter 5

STATISTICS AND ANALYSIS OF EXPERIMENTAL DATA

CHAPTER 5 STATISTICS AND ANALYSIS OF EXPERIMENTAL DATA

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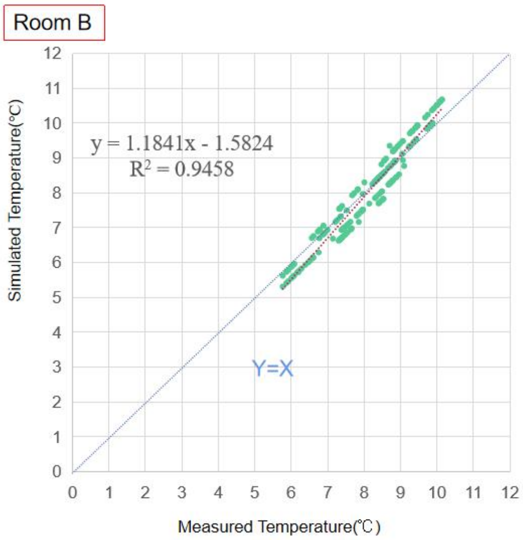
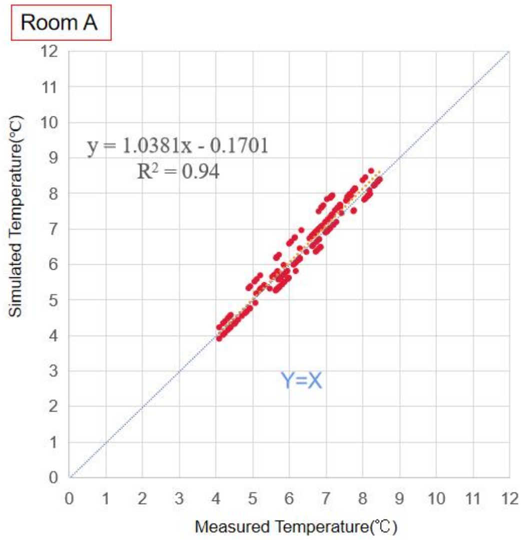
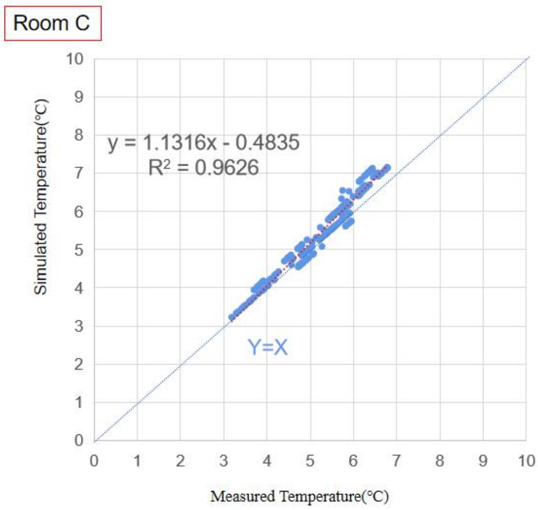
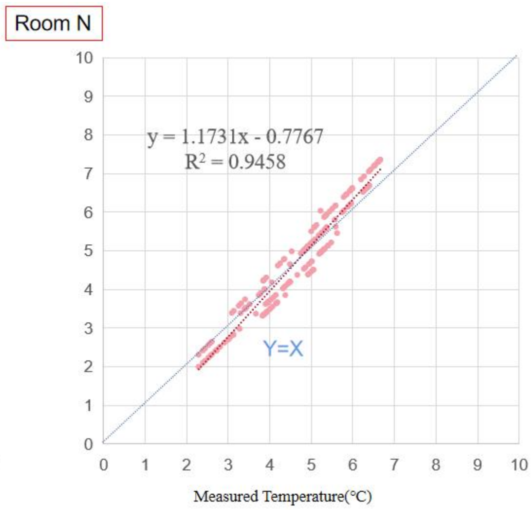
5.1 Average temperature, radiation, experimental statistics of outdoor temperature throughout the year

For the accuracy of the simulation, the paper first made a fitted curve to observe the realism and correlation with the calibration data, and from the graphs, the theoretical data and the experimental data have a high degree of similarity









As you can see from the graph above the average temperature in November was 2 degrees Celsius. The average temperature in December is -7 degrees Celsius. The average temperature in January is -9 degrees Celsius. The average temperature in February is -5 degrees Celsius. The average temperature in March is 3 degrees Celsius.

As you can see from the graph above, the Changchun area of Jilin has hot summers and cold winters, with large temperature differences throughout the year. The lowest outdoor temperature in winter can reach just under -20 degrees Celsius, but the intensity of solar radiation in the region is more even throughout the year, but denser in summer and less dense in winter.

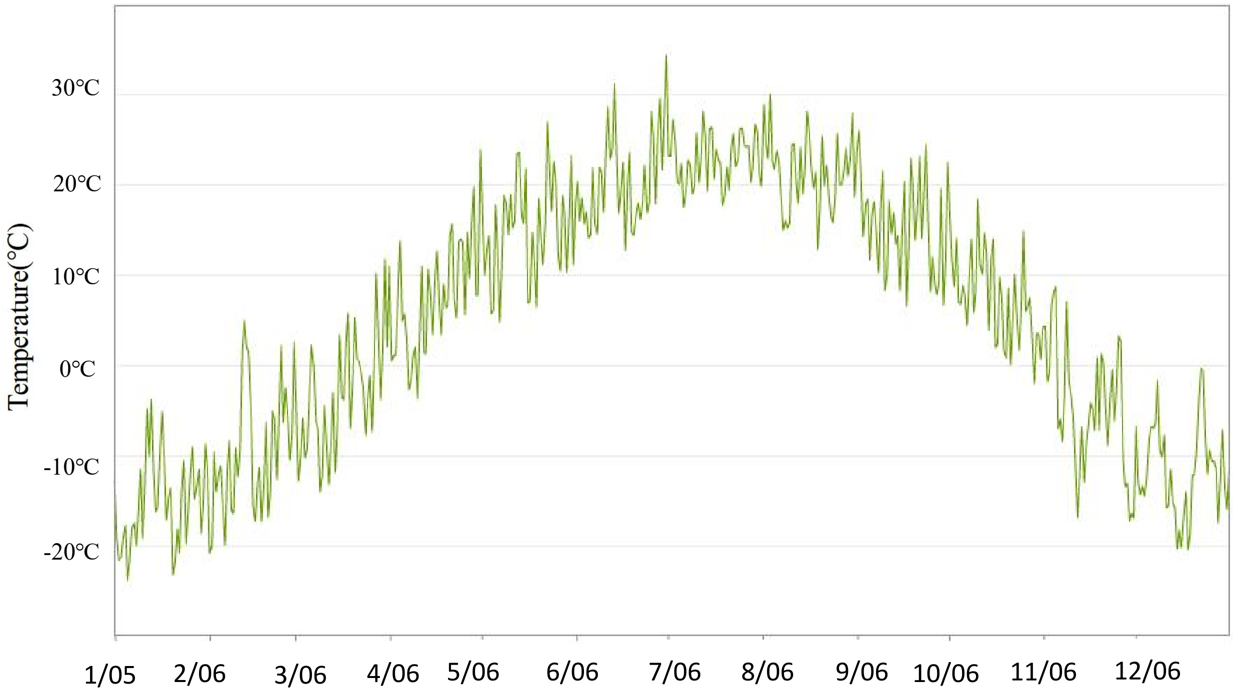


Fig5-1 Annual temperatures in Siping in 2021

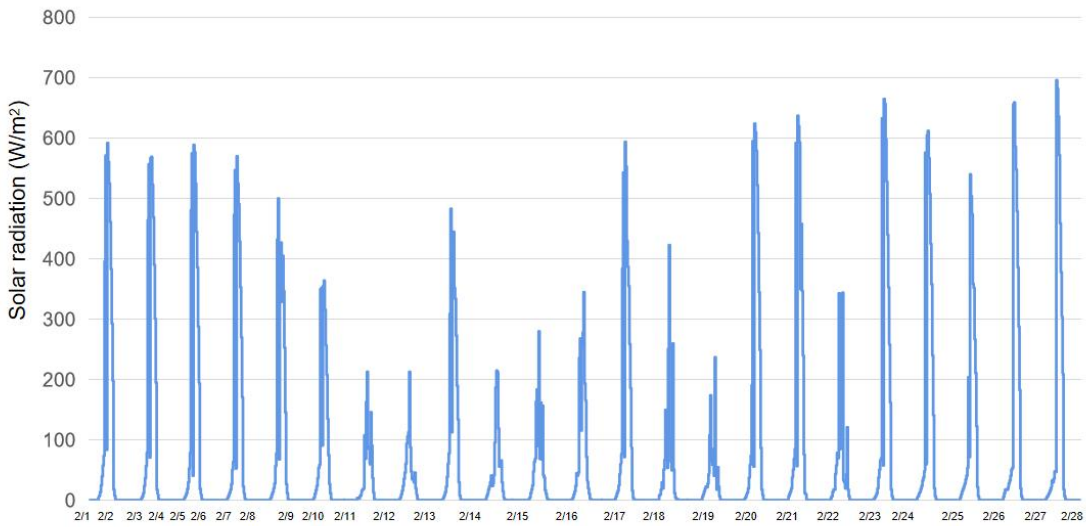


Fig5-2 Solar radiation intensity throughout the Feb(2021)

5.2 Temperature variation over time at temperature measurement points

Combined with the statistics of the relevant data in 5.1 as a basis, this chapter did measurement experiments, mainly to observe the temperature change of the four measurement points, while simulating the location of the measurement points, to verify the credibility of the simulation data, the simulation data temperature is almost consistent, the next step will be carried out temperature experimental tests to further determine the reliability of the simulation.

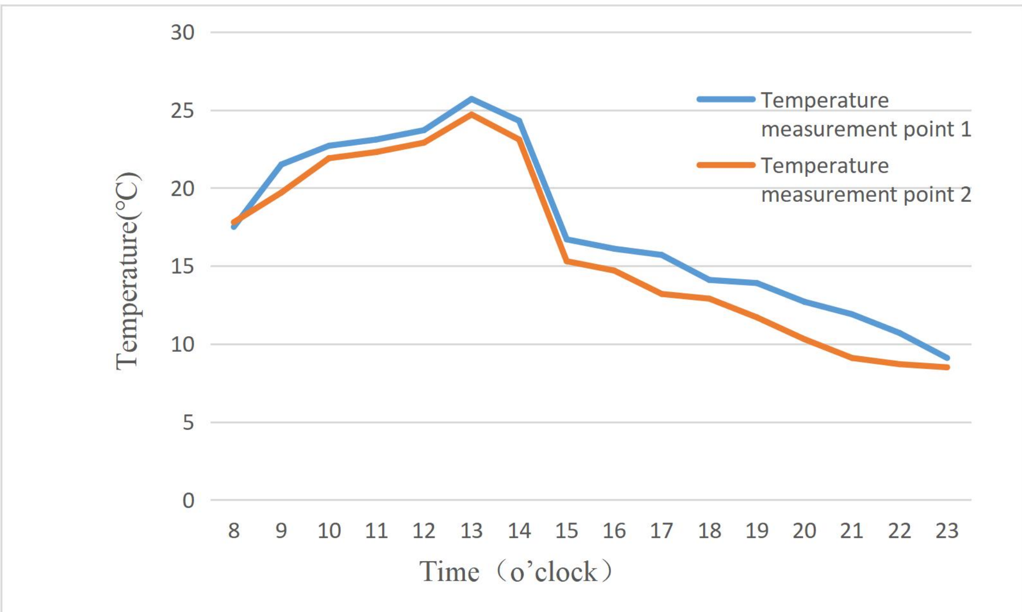


Fig 5-3a Plot of temperature at measurement points against

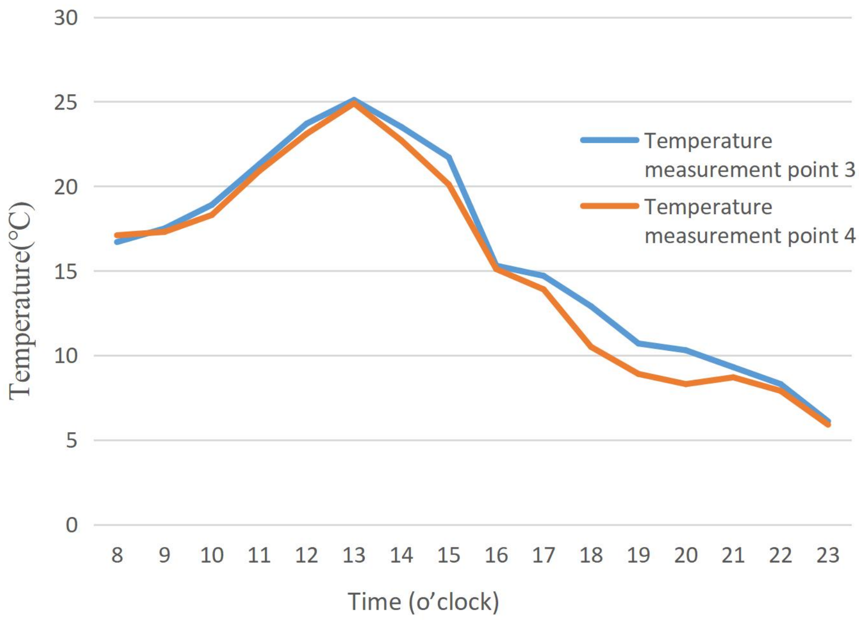


Fig 5-3b Plot of temperature at measurement points against time(2021)

The temperature of the four temperature measurement points on the Trombe wall followed a trend of increasing and then decreasing. The temperature at temperature measurement point 1 was the highest of the four points, at 25.7°C. Temperature measurement point 2 had the highest temperature of 24.7°C. Temperature measurement point 3 had the highest temperature of 25.1 °C. Temperature measurement point 4 had a maximum temperature value of 25.1 °C. The maximum temperature reached at these temperature measurement points was at 13.00 noon and the temperature rise also took place between the hours of 8-13.00. These temperature measurement points are set up in different locations according to their location and the amount of radiation in the sunlight is different in each section, so the final reflected temperature change will vary in each section.The chart below Figure 5-4 shows.

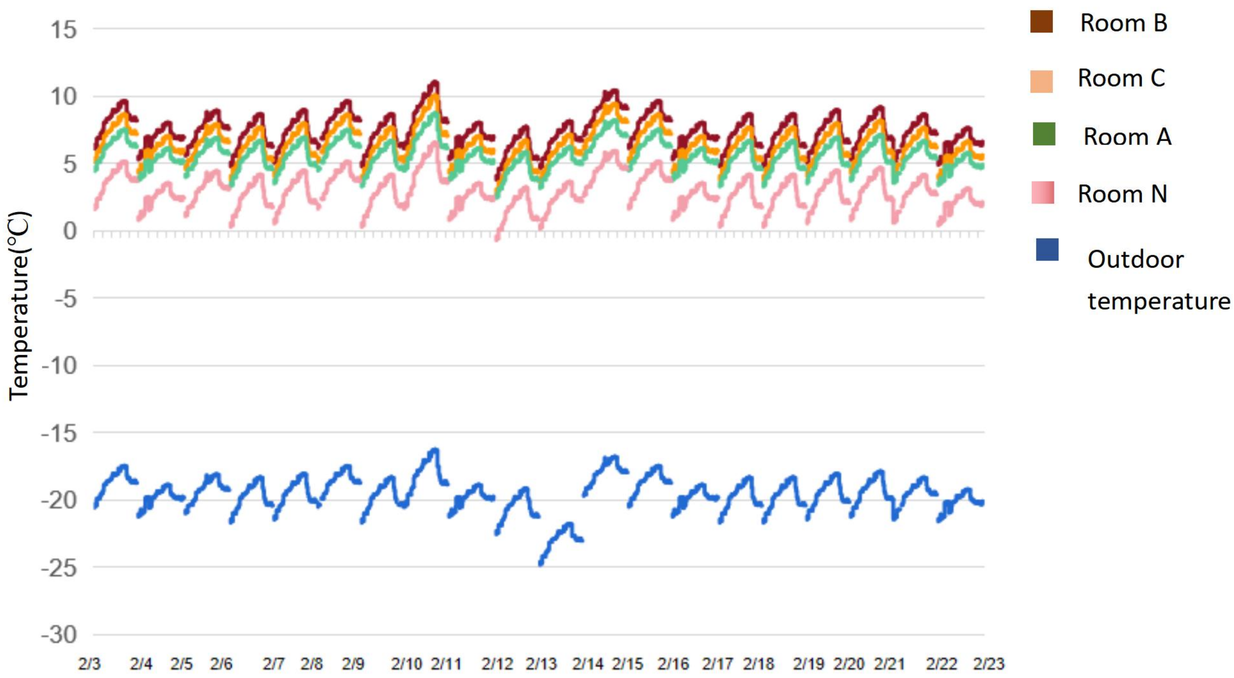


Fig 5-4 Change in room temperature in February with different room ventilation patterns(2021)

The relevant data are set as follows.Time: 8:00~16：00，Frequency ：10mins. Date:February 3rd to 23rd,2021.DC fans Wind speed: 90 m³/h.Maximum solar r adiation:597W/m². Minimum solar radiation:120W/m².

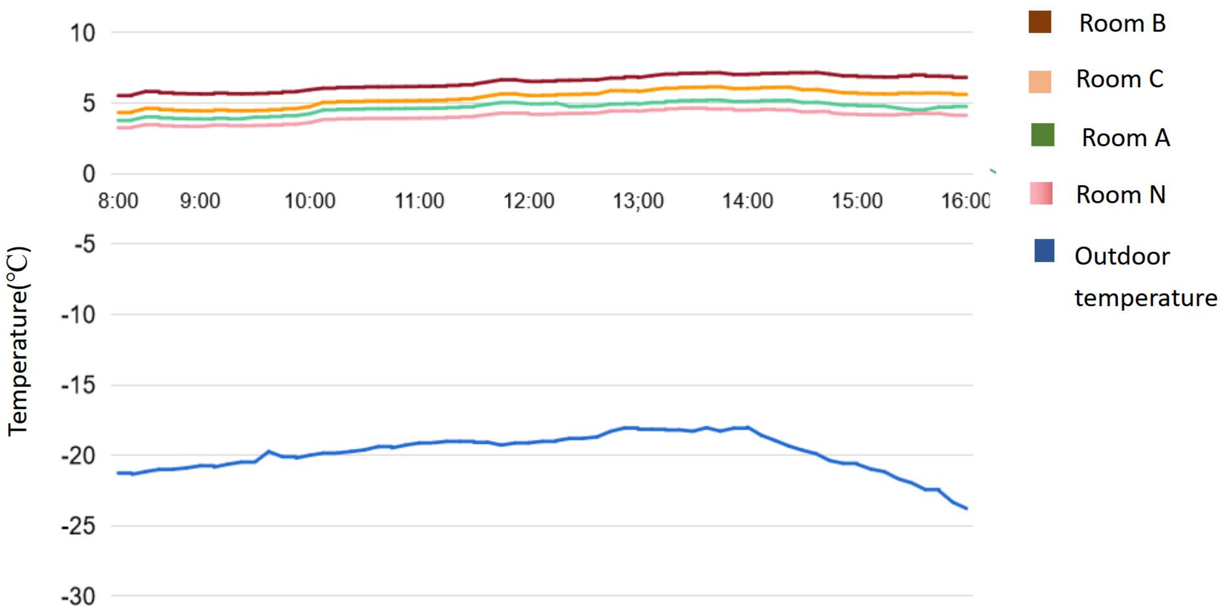


Fig 5-5 Inter Room temperature in different circulation modes with DC fans off

The relevant data are set as follows.Time: 8:00~16：00，Frequency ：10mins. Date: February 3rd to 23rd,2021.DC fans Wind speed: 90 m³/h. Maximum solar radiation:636W/m^2. Minimum solar radiation:175W/m^2.

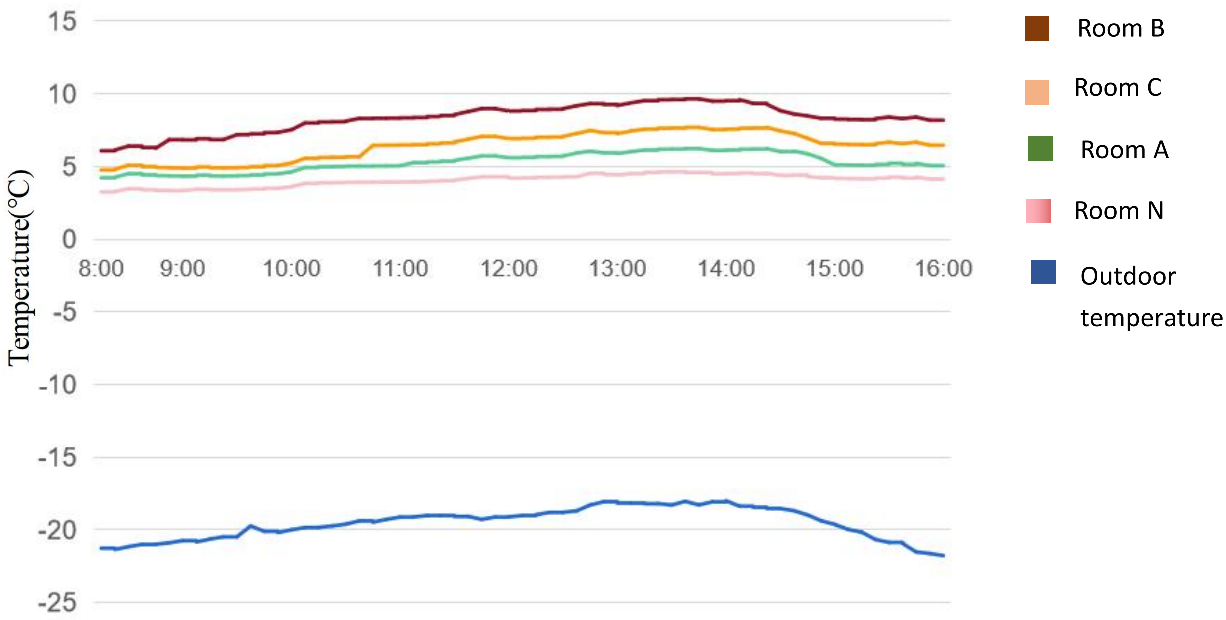


Fig 5-6 Inter Room temperature in different circulation modes with DC fans off

5.3 Wall heat exchange with Trombe wall

To better deal with the heat exchange occurring at the Trump wall at different times in terms of how its data is collected, the corresponding relationship between solar radiation and heat exchange above the wall is shown in the figure.

The sun's radiant energy gradually increases to 1059 and then decreases, which is consistent with the changes in radiant energy in everyday life.

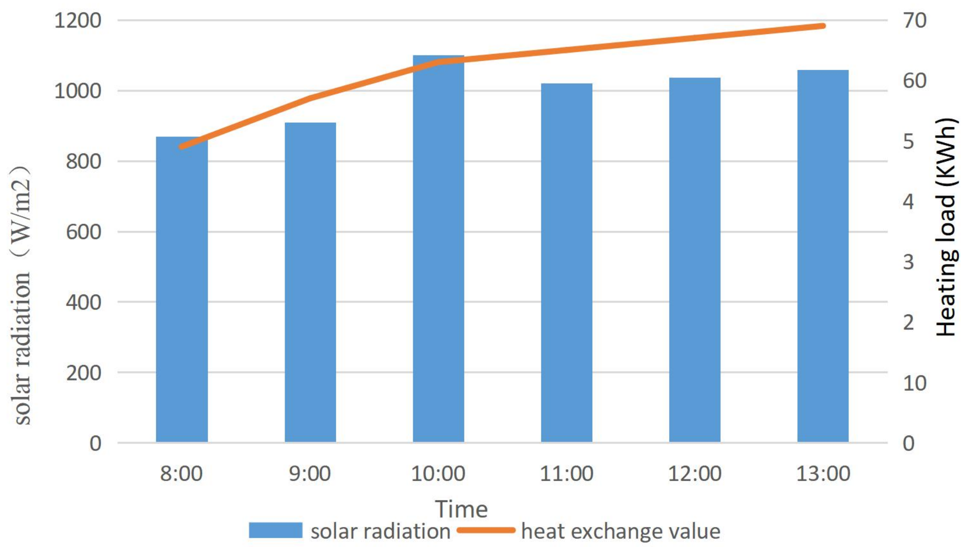


Fig 5-7a Wall heat exchange with TROMBE wall

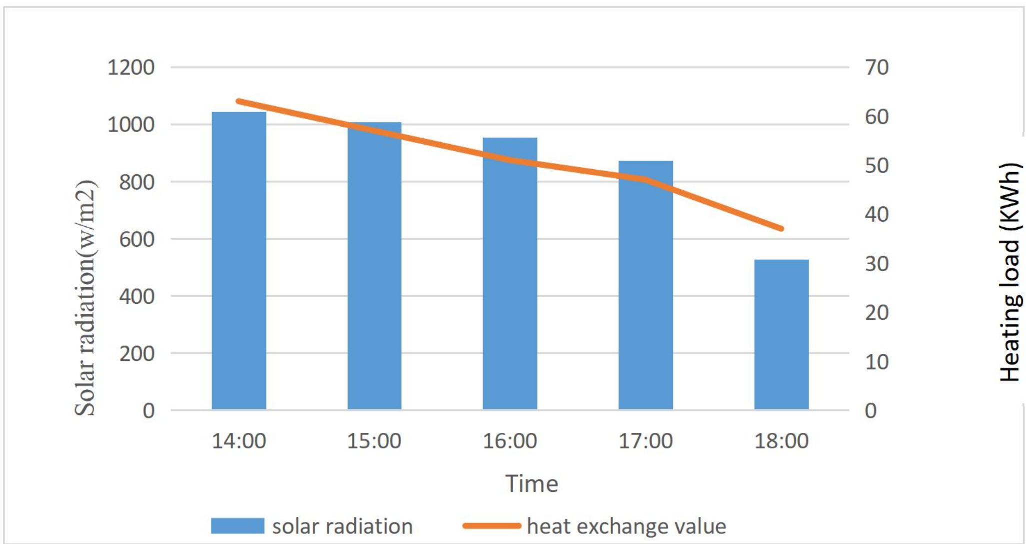


Fig 5-7b Wall heat exchange with TROMBE wall

The above diagram shows that the four rooms were first simulated without the addition of air conditioning, with the fan operating according to the temperature inside the ventilated air chamber, and when the temperature of the heated air chamber is greater than the room temperature, the fan starts to operate, otherwise it does not, thus achieving the purpose of controlling air circulation. ACB represents the measures of internal circulation, external circulation and internal and external circulation respectively. The results show that the continuous operation of the fan helps to increase the temperature of the room and that the temperature fluctuations in the room with double cavity walls show a sinusoidal function, while the temperature of the room in the natural state does not fluctuate too much over the simulated time range and behaves more gently. This is mainly due to the fact that, on the one hand, the acceleration of the air flow inside the cavity by the fan accelerates the inflow of air from both internal and external cavities into the room, while at this time the temperature of both cavities is influenced by the outdoor environment (e.g. solar radiation (the sun rises in the east and sets in the west every day), etc.) The influence of the external cavity, which contains the glass window, is particularly influential. This influence therefore affects the temperature of the room through the linkage of the fans.

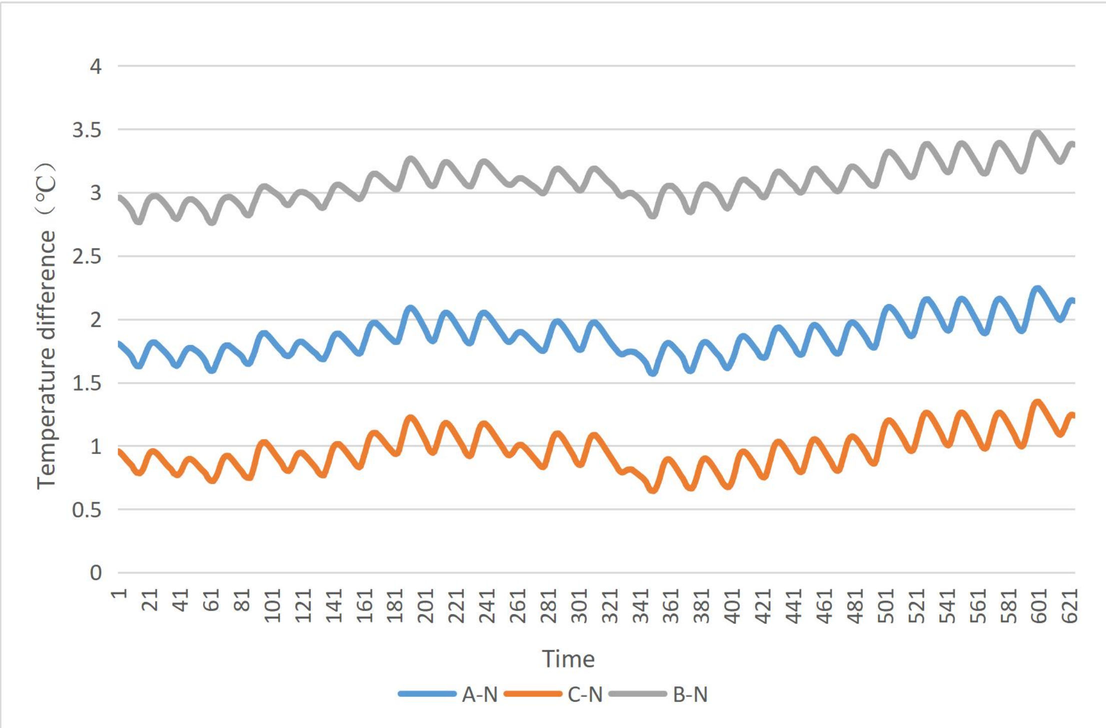


Fig 5-8 Wall heat exchange with TROMBE wall

Furthermore, a graph of the temperature difference between the room with a double-layer heat-absorbing curtain wall and the room in its natural state reveals that during the heating season, the temperature of the room with a double-layer Trombe wall with a DC fan increases by about 1.9° C under internal circulation, by about 1° C under external circulation and by 3.1° C under double circulation, both inside and outside. From the results, the external circulation did not increase the temperature as much as the internal circulation, mainly because the glass in the external cavity has a high thermal conductivity and dissipates heat as quickly as it gains heat, so heat is not easily stored. But in any case, in the absence of air conditioning, it is very effective to keep the fan running. And the fact that the temperature difference in the raised temperature does not vary much, regardless of the type of circulation used, is further evidence of the characteristics of a double wall with a circulating fan to maintain a stable room temperature.

5.4 Fans start-up temperature analysis

5.4.1Time required to raise the room by one degree Celsius in three circulation modes at different temperature bands

Traditional TROMBE wall after the sun rises, the temperature of the air layer will gradually rise, at the same time the temperature of the heat collection wall itself also rises, at this time open the ventilation holes, the cold air will gradually rise, the hot air will pass into the room through the cavity and gradually fall, forming a gas circulation, double sandwich Trombe wall follow the same reasoning.But in cold climates the DC wind accumulation opening time superior speed is different.

The opening temperature of the ventilation holes varies in hot regions, mainly to meet the indoor human comfort or the Chinese heating season when the indoor temperature is above 18°C. However, in cold regions, the outdoor temperature is so cold that the indoor temperature cannot be met under non-heating conditions only under Trombe wall to meet the heating indoor temperature requirements. Therefore, regional differences do not allow for a fixed optimum opening temperature. The collector wall does not heat up quickly when the sun rises, the collector itself needs a "buffer period", this time to turn on the fan is not the best time, but will cause unnecessary waste, this paper took February as an example, experimental research on the best fan on the temperature.

The three different circulation modes take about the same amount of time to raise the indoor temperature by one degree when the outside air layer temperature is controlled at 1 to 5 degrees Celsius, i.e. during this time, the heat collection wall is still in the "buffer period", so there is little point in starting the fan at this time and it does not raise the indoor temperature quickly and significantly.

To conclude, when the outdoor temperature is very low in the morning, even with daylight radiation, it is not suitable to turn on the fan in the first place. The above-mentioned experiments show that in winter in severe cold regions, when the outdoor temperature is -20 degrees Celsius, the TROMBE wall temperature buffer period is about 45 minutes, and the best start-up temperature is when the outside air layer temperature is between 10 and 15 degrees Celsius, when the start-up can improve the indoor temperature to improve efficiency and save energy.

The table above demonstrates the performance of the entire laboratory room in different ventilation modes for different temperature bands of the outer air layer using a thermal diagram. A longitudinal comparison will show that when the temperature of the outer air inter layer is 1-5 degrees Celsius, no significant room temperature change is produced in either circulation mode. When the temperature of the outer air layer reaches 5-10 degrees Celsius, we can see that the temperature changes fastest in the double circulation mode, which indicates that the double inter layer has the highest heat transfer efficiency when the temperature of the collector wall and the air inter layer rises, and also double inter layer Trombe wall is more sensitive to temperature. This is followed by the external circulation system. The internal circulation system has a slower rise in temperature because most of the heat absorption comes from the wall itself.

A comparison of lateral observations shows that as the temperature of the air inter layer rises, the double circulation system can transfer the absorbed heat energy into the room more quickly. The external circulation system is more capable of transferring heat after controlling the temperature of the air layer than the internal circulation mode.

5.5 Optimum speed analysis

Firstly, we carried out a preliminary analysis of the change in indoor temperature throughout the year without air conditioning. Using the month of January as an example in Figure5-9, we found that air circulation effectively increased the room temperature. The highest unheated indoor temperature was maintained when the ventilation rate was 95 m^3/h. Within this range, it can be tentatively determined that the higher the ventilation rate in the indoor air circulation, the higher the efficiency of the chamber walls.

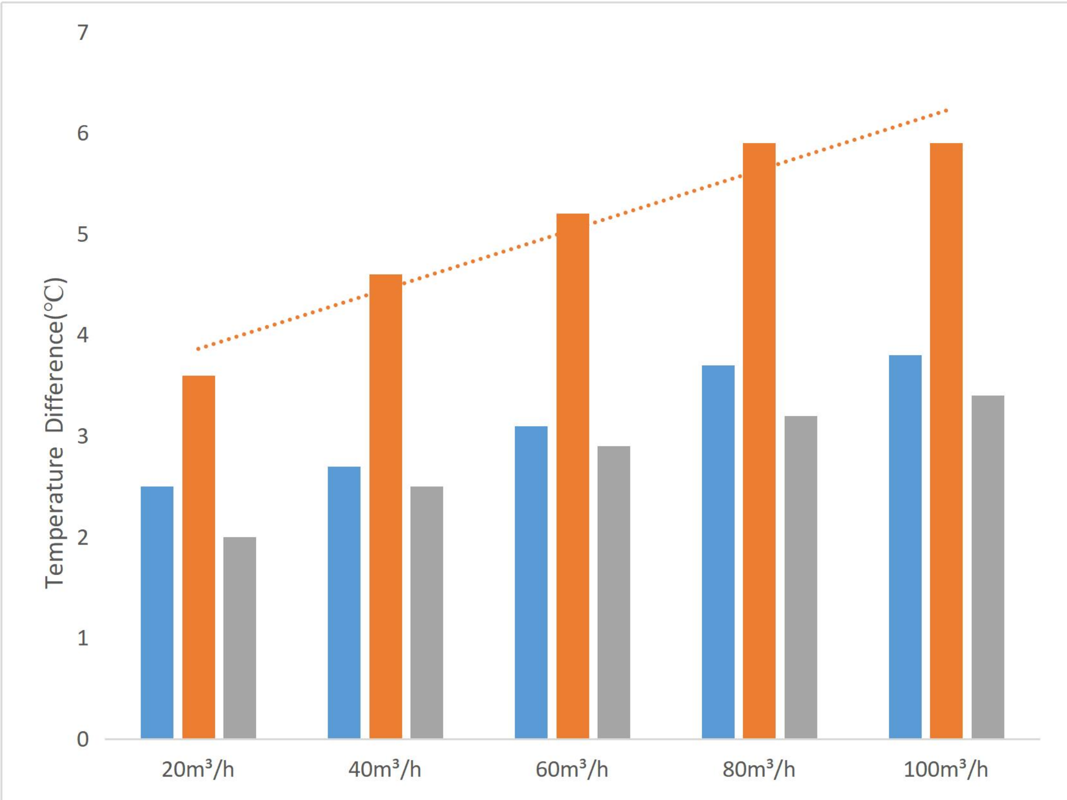


Fig 5-9 Differences in room temperature due to different wind speeds

In this paper, the method used to calculate the optimal wind speed in winter is as follows. The optimal wind speed is estimated by adjusting the fan to different gears and measuring the difference in indoor temperature caused by different wind speeds during the same time period. Due to the severe cold climate in the Northeast, the temperature difference in the room was significant. The above data shows that the optimum speed of the Trombe wall is around 90 m^3/h, which is significantly lower than in other regions. Due to the climate, the building has a high capacity for heat dissipation in winter, and even with insulation technology, it is important to reduce heat dissipation as much as possible in the absence of sufficient heat sources.

The best wind speed experiment also measured the best wind speeds for other months in the same way, comparing the best wind speed graphs for different months as follows.

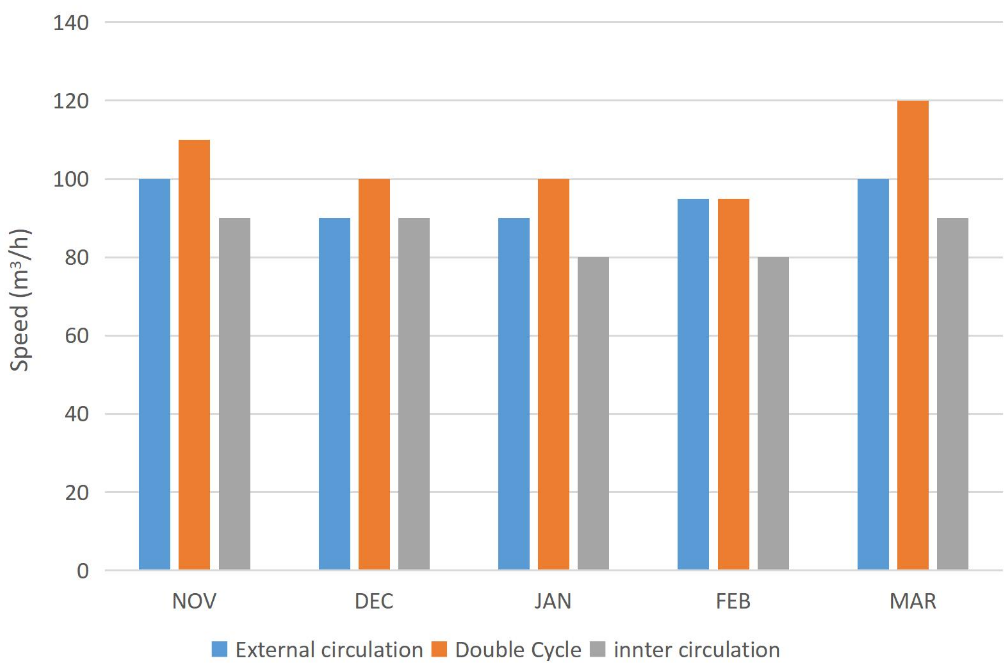


Fig 5-10 Optimum wind speed parameters for other months

From the above data we conclude that the optimum wind speed is related to the outdoor temperature and solar radiation. As the outdoor temperature rises, the room absorbs more heat and the increase in wind speed will directly affect the indoor temperature.

5.6 Double layer trombe wall number of days beyond the coldest tolerances to humans.

The significance of this section of the study, first of all, the severe cold areas to be heated in winter, residential living indoor temperature requirements 18 ± 2 degrees Celsius, but the experimental room is a non-heated building, so not according to the heating residence requirements to control the indoor temperature. This paper relates to the actual situation, according to the human living reasonable temperature survey, the human body's coldest tolerance temperature is 11 degrees Celsius, heat tolerance temperature is 32 degrees Celsius, human living comfortable temperature is about 19 degrees Celsius to 24 degrees Celsius, this paper made the following statistics.

number	NOV	DEC	JAN	FEB	MAR
With fan	7	6	2	1	8
No fan	5	3	0	0	6

The number of days mentioned above allows us to conclude that trombe wall makes full use of natural energy to raise the room temperature, and through practical experimentation, even on days when the standard is not met, it is possible to use some auxiliary tools to achieve temporary office use, which saves a large part of resources compared to central heating.

5.7 Test for correlation between theoretical and experimental data

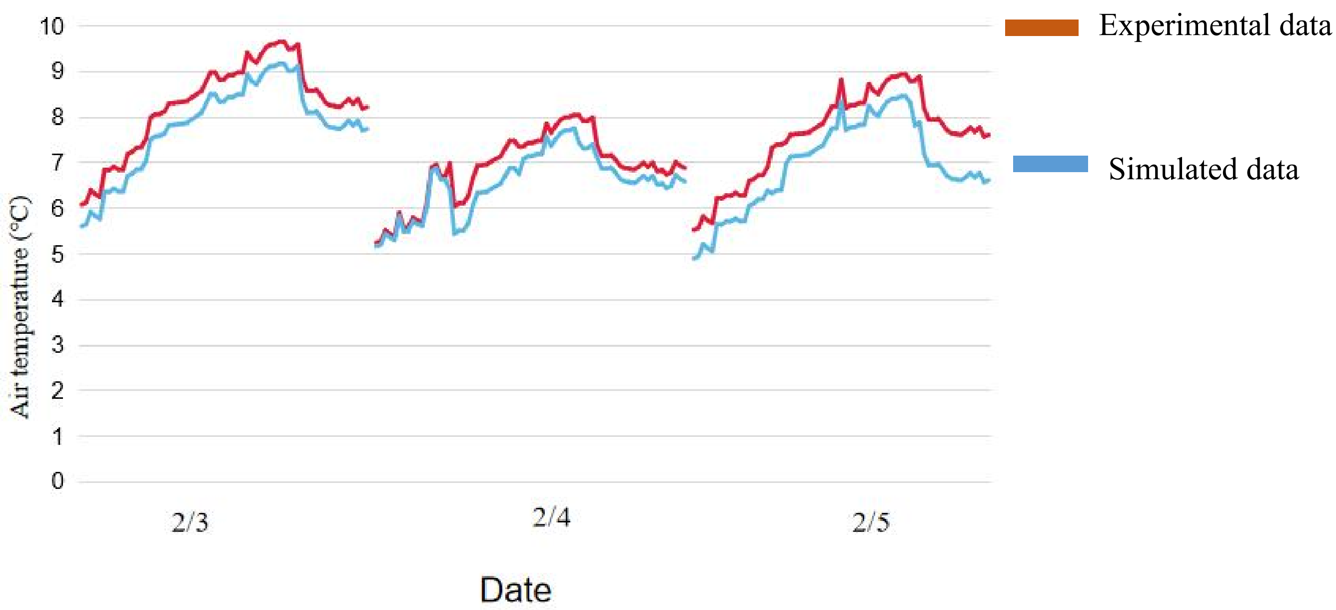


Fig 5-11 Theoretical and experimental data on the double-cycle ventilation model from 3th to 6th in February

The prerequisites for testing are Dc fan speed;90m^3/h.Frequency:10minsTime: 8:00-16:00(February 3rd to 6th, 2021)Theoretical and experimental data on the double-cycle ventilation model from 3th to 6th February.From the comparison results, the similarity between theory and simulation is high, and the p-value is also less than 0.05, which basically meets the t-test requirement.

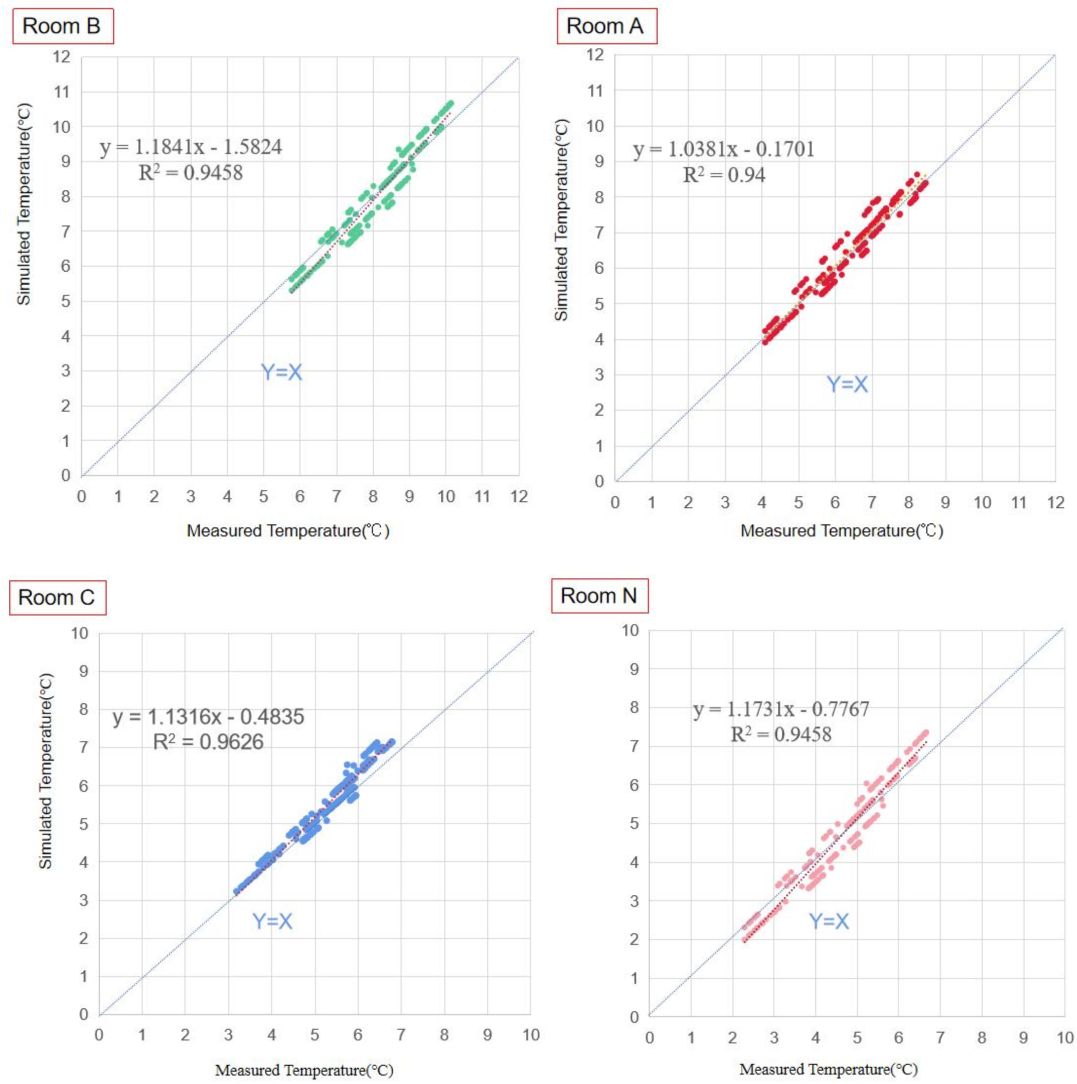


Fig 5-12 Fitted curves of theoretical and experimental data for four different rooms

5.7 Summary of this chapter

1,The experimental data are for the month of February in a harsh region with an average temperature of -20°C, but with sufficient solar radiation

A double Trombe wall with a DC fan increases the room temperature by around 1.9°C with internal circulation, around 1°C with external circulation and 3.1°C with dual internal and external circulation compared to a double Trombe wall without air supply.

The best start-up temperature is when the outside air layer temperature is between 10 and 15 degrees Celsius.

2.A comparison shows that rooms with circulation mode are more effective in increasing room temperature under natural ventilation conditions

3.The theoretical data and the experimental data are known by t-test and the p-value in the t-test is greater than 0.05, so it shows that the theoretical model is feasible

4.Changing the ventilation of the DC fans can increase the efficiency of double-circulation Trombe wall.Within a certain range, the greater the ventilation, the higher the thermal load that can be saved.

Chapter 6

OTHER FACTORS AFFECTING THE DOUBLE LAYER TROMBE WALL

CHAPTER 6:OTHER FACTORS AFFECTING THE DOUBLE SANDWICH TROMBE WALL

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6.1 Theoretical analysis of the main factors affecting the thermal performance of Trombe walls in traditional Chinese houses

Passive solar energy technologies such as Trombe wall can use the role of solar energy as a renewable resource to optimize indoor comfort through heat storage and ventilation as needed. Therefore, it is necessary to analyze and study the applicability of Trombe wall in apartment buildings in this area. This article researches The application of double layer Trombe wall in Chinese apartments through literature research and field investigation. The temperature, relative humidity, and wind speed test results show that the design of the double mezzanine Trombe-wall apartment can effectively use good draught wind, and the design is more reasonable. When the height is constant, the design parameters for maximizing the utilization of solar light and heat on the exterior surface of the building are as follows: the minimum area width is 54 m and the maximum depth is 21 m, and the utilization rate is 72.8%; The maximum design parameters for the surface solar photovoltaic utilization rate are 105 m for the surface width and 21 m for the depth, and the utilization rate is 29.6%.

China's buildings consume a large amount of energy and consume a lot of energy, which has become a prominent problem restricting the sustainable development of China's economy and society [1]. With the continuous acceleration of China's economic and social development and urbanization, building energy consumption is continuing to rise rapidly, and its share of energy consumption in the whole society is increasing, and it will continue to rise from the current 35% [2-5]. Solar energy is a kind of renewable energy. It refers to the heat radiation energy of the sun, which is mainly expressed as the sun's rays. Since the birth of life on the earth, it has mainly survived by the heat radiation provided by the sun [6]. Since ancient times, humans have also understood that the sun can dry objects and use them as a method of making food, such as salt making and salted fish [7]. With the declining fossil fuels, solar energy has become an important part of human energy use and has been continuously developed. There are two ways to use solar energy: light-to-heat conversion and photoelectric conversion. Solar energy is the most direct and simple clean energy that can be used by buildings without secondary pollution. Through reasonable architectural design and the use of advanced building components, it can ensure the maximum use of solar energy and reduce the energy consumption of buildings [8-12]. Therefore, making full use of China's abundant solar energy resources and vigorously developing solar buildings has become an effective way to reduce building energy consumption at this stage [13]. Among solar buildings, passive solar houses have a simple structure, economy, and significant energy-saving effects [14]. The existing technology can already compete with conventional fuel heating, and has broad development space and prospects in China. In terms of climate, in China, the hot summer and cold winter area is a relatively special area, which belongs to the northernmost part of the non-centralized heating area, especially the area near the Qinling and Huaihe River, where the demand for warmth in winter is relatively high [15]. At the same time, this area is a developed area of the domestic economy, and its GDP is close to about half of the country. With the rapid development of the economy, these areas have more and more requirements for the thermal environment comfort of residential buildings in summer and winter [16-18]. Therefore, to control the indoor thermal environment in this area, it is a necessary and urgent task to select suitable energy-saving technologies.

The Trombe wall is an indirect revenue type solar heating system. The outermost layer of the Trombe wall is a layer of transparent glass, which preserves heat while not blocking the penetration of sunlight. The inner side of the glass uses better heat storage performance [19-21]. The material is used as a heat-collecting wall, and the outer surface of the heat-collecting wall is coated with absorption paint to enhance the heat absorption capacity. The upper and lower ends of the heat-collecting wall are equipped with open and closed vents to exchange indoor and outdoor air. There is an air layer space between the hot wall and the glass. When the sun shines directly on the air in the air layer, the temperature of the air is heated and the density of the air is different from that of the outdoor air [22]. The hot air rises, in this way the air forms a circulation. To achieve the effect of heat collection and ventilation of the Trunbu wall.

The shortcomings of the traditional Trombe wall are: the heat-collecting wall materials are mostly concrete and bricks, and the heat storage capacity needs to be improved. The heat-collecting wall uses dark paint, which is opaque and affects the appearance of the facade. The thickness of the heat-collecting wall Most of them are 16 inches, which is too bulky; the disadvantages of ordinary flat glass are: summer sun can not be solved; the light entrance surface is narrow [23].

The purpose of this research is to overcome the shortcomings of the existing technology and provide a double mezzanine Trombe wall, which has strong heat storage capacity, is light and beautiful, and saves costs, and studies its application in Chinese apartments.Literature research: Collect and summarize useful information and data and conduct research through literature search on databases such as Web of Science, ScienceDirect, SpringerLink, Wiley Online, Scopus, CNKI, etc.

Field inspection: through visits and surveys of apartments in more than 10 major cities in China, exchanges and communications with designers, engineers, construction experts and construction personnel, and obtained first-hand information.

How the Trombe wall works. Summer ventilation mode. In summer, when the Trombe wall is made to cool, the buoyancy generated by the air between the wall and the glass causes the indoor air to be sucked out from the air outlet at the bottom of the wall, and the indoor air can get fresh outdoor air through the window or other ventilation holes. Complete the entire process of pulling out and ventilating. In very hot areas, the temperature during the day is very high. At this time, the cooling effect of ventilation is not obvious. Fortunately, the Trombe wall can provide considerable heat insulation, while at night, the ventilation effect will be greatly reduced. The effect of the heat absorbed by the Trombe wall during the day on the interior, bringing the hot indoor air to the outside.

Winter heat storage mode. In the winter heat storage mode, air enters the space between the glass layer and the wall from the air intake at the bottom of the Trombe wall. If the outdoor air is relatively cold, open the air vent at the bottom of the wall for indoor air. In order to maintain the temperature, if the outdoor temperature is still relatively moderate, open the vent of the glass layer.

Test Analysis of Typical Chinese Apartment. Analysis of temperature, relative humidity and wind speed test results. When the outdoor wind speed is high, the indoor wind speed increases accordingly. The indoor wind speed in the living room and study room is larger than other rooms. The average indoor wind speed in each room is 0.16 m/s in the living room, 0.13 m/s in the study, 0.10 m/s in the master bedroom, 0.10 m/s in the second bedroom, and 0.07 m/s in the kitchen (Figure 6-1). This is because the apartment is facing north-south, and the dominant wind direction is northwest wind. The wind enters the room from the north-facing living room window and the master bedroom window, and flows out of the room through the study window and the second bedroom window. Affected by the wind pressure, in these 2 rooms There is a higher wind speed in the room. This shows that the design of the apartment can effectively use good draught, and the design is more reasonable.Figure 6-1 shows the initial temperature and its fluctuation range in a cloud diagram with the horizontal and vertical coordinates indicating a scale of 0.5m/s.

In the morning, the outdoor temperature did not fluctuate much, until 15:00 the weather turned into light rain, the outdoor temperature dropped, and it became clear after the rain, and the temperature began to rise after 15:40. When doors and windows are opened, they are affected by the outdoor temperature and fluctuate. When the doors and windows are closed, the indoor temperature is relatively stable throughout the day. The fluctuation range is 28.3～28.7℃. The indoor temperature difference between opening doors and windows and closing doors and windows after rain is large, reaching 1.9℃ at the maximum (Figure6-2). It can be clearly seen from the figure that in rainy weather, the indoor temperature after opening doors and windows and using natural ventilation is significantly lower than that of closing doors and windows.

Combining the test data, it can be seen that the wind speed of the outdoor and the windows of each room is relatively high at this time, indicating that t he use of natural ventilation in rainy weather and after rain can effectively red uce the indoor temperature and improve the indoor thermal environment.

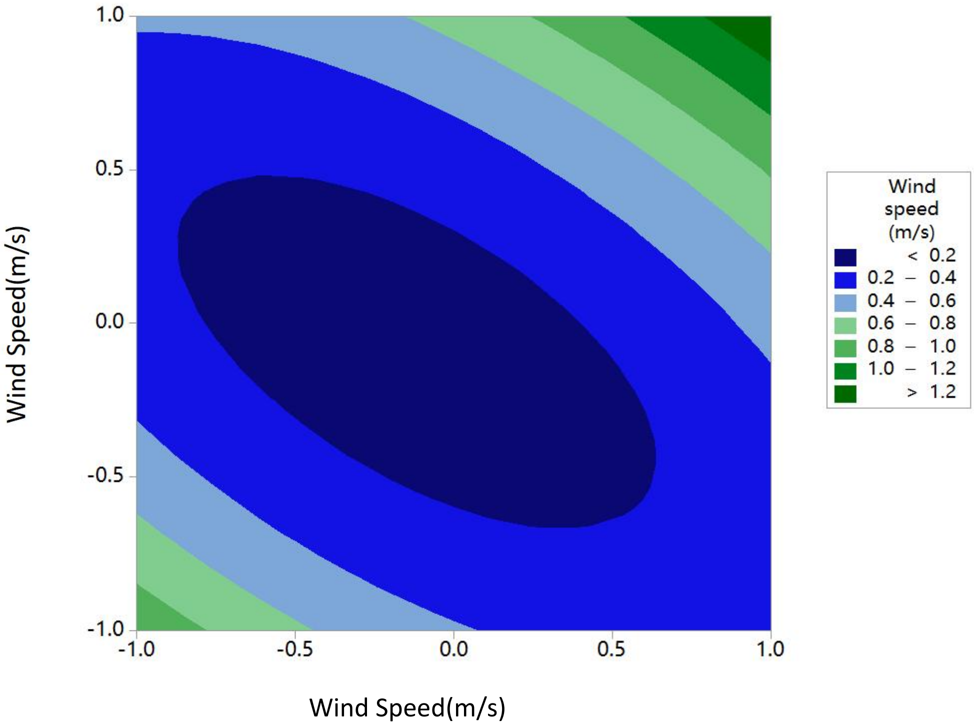


Fig6-1Variation of wind speed in different parts of the room

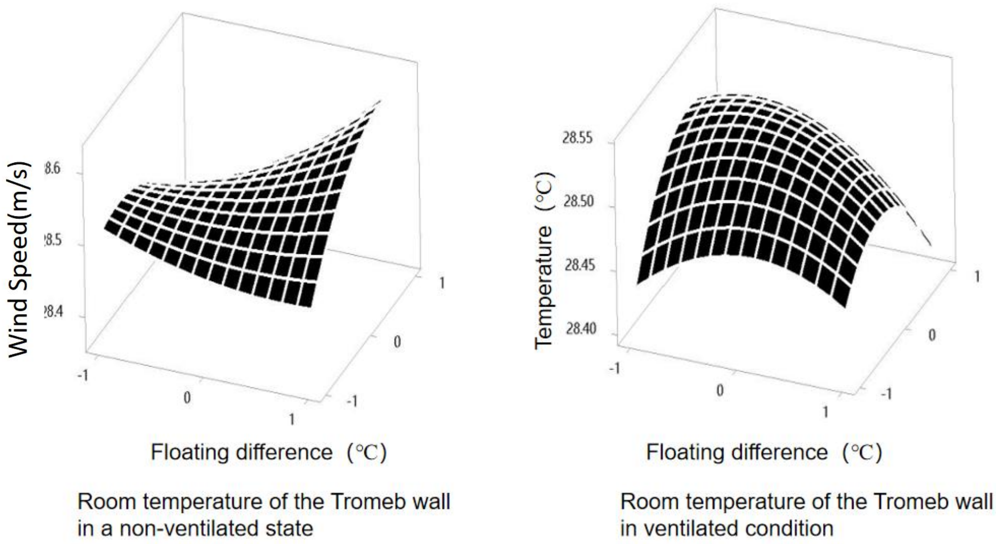


Fig6-2 Room temperature variation for different ventilation conditions in a room

It is a scatter diagram of the indoor and outdoor humidity changes in the apartment, which is similar to the indoor and outdoor humidity changes. When the doors and windows are closed, the indoor relative humidity changes smoothly, and the opening of doors and windows is greatly affected by the outdoor, especially during the period of light rain, the relative humidity of the outdoor and doors and windows is large when the doors and windows are opened, the maximum outdoor is 88.9%, and the indoor is 80.89%.

1), Analysis of factors affecting ventilation. Width of air inter layer. When the width of the inlet and outlet is always the same as the width of the air inter layer, that is to say, when the area of the inlet and outlet is equal to the cross-sectional area of the air inter layer, the amount of ventilation will increase as the width of the air passage increases. The reason is to increase the import and export area and reduce the loss caused by the main resistance. For a certain heat flow, the increase in ventilation will result in a decrease in the temperature of the heat collecting surface, which will result in a decrease in the air thermal compression power. The reduction of air thermal compression power and the increase of inlet and outlet area lead to the decrease of average air velocity. Therefore, when the width of the air passage is increased to a certain extent, the ventilation volume will also decrease (Fig.3). The effect of ventilation is better when the air passage is around.

2), Solar radiation intensity. The physical quantity that represents the strength of solar radiation is called solar radiation intensity, that is, the solar radiation energy projected vertically onto a unit area in a unit time. The solar radiation intensity of the upper boundary of the atmosphere depends on the altitude of the sun, the distance between the sun and the earth, and the duration of sunshine. The greater the solar altitude, the greater the intensity of solar radiation.

The ventilation rate increases as the heat collecting surface absorbs solar radiation heat. The average temperature of the Trombe wall also increases as the heat collecting surface absorbs solar radiation heat. However, because of the heat dissipation of the wall, the temperature increase is not linear.

3), Height of collector. The height of the collector body of the Trombe wall has an effect on the buoyancy of the air in the channel, which in turn affects the ventilation volume. The higher the heat collector, the lower the average temperature of the air in the air interlayer, and the lower the density, the greater the buoyancy and the greater the ventilation.thermal insulation

The glass cover of the Trombe wall and the number of insulation layers of the collector have an effect on the temperature of the collector surface, which in turn affects the ventilation. The Trombe wall absorbs more heat in the double-layer glass cover than the single-layer glass cover. The more absorbed heat can increase the ventilation rate to 11%-17%.

4), Calculation and Evaluation of Solar Radiation of Single Apartment. The flat width of the apartment building is 54 ~ 105 m, the building depth is 15 ~ 21 m, the number of floors is 6 and the height is 21 m. Therefore, according to the value range of the surface width and depth, take the minimum surface width depth and the maximum surface width depth to model separately, that is, create two rectangles of 54 m×15 m×21 m and 105 m×21 m×21 m. Use this as a basic model for the potential of solar energy utilization. Simultaneously model the above two basic models in the analysis software. The orientations are both positive south. The weather parameters call Weather DATA database data. The calculation content is set to calculate the annual solar radiation reception on the building surface. The calculation time is January 1 to December 31.

In the case of a certain building height, regardless of the value of the surface width and depth of the building plan, the solar radiation per unit area of the south-facing facade of the building is equal, that is, the solar radiation per unit area of the south-facing facade is unobstructed. Not affected by changes in design parameters. The external surface of the building of the 54 m×15 m×21 m initial model is calculated for solar radiation, and the compassion standard is used as the evaluation index.

Significance of the application of Trombe wall in Chinese apartments. The large total energy consumption and high energy consumption of Chinese buildings have become a prominent problem restricting the sustainable development of our country. The hot summer and cold winter area is a decentralized heating area at the northern end of our country. In winter, the indoor temperature of apartment buildings is relatively low. In addition, this area is an economically developed area. The increasing living standards and environmental awareness of people also make Trombe passive solar technology such as the wall has the potential for development in this area. The Trombe wall has the function of accumulating solar heat during the day and radiating heat indoors at night to achieve the purpose of heat preservation. Therefore, from the perspective of the building type and the function of the Trombe wall, the combination of the Trombe wall and the apartment building is also very good. suitable. At the same time, as a kind of passive solar technology, the trombo wall, whether it is a heat storage function or a ventilation function, the source of energy is from the sun, a renewable clean energy, and it is appropriate to use clean energy to assist in regulating the apartment interior. It can save a considerable part of energy, and as an economically developed area in China, the hot summer and cold winter area has particularly higher requirements for indoor comfort. Therefore, whether it is based on environmental protection or energy conservation, this area is very suitable for solar energy. The need for clean energy to replace non-renewable energy is very urgent. The Trombe wall can be successfully applied, which is of far-reaching significance to this region.

This article researches The application of double layer Trombe wall in Chinese apartments through literature research and field investigation. The temperature, relative humidity, and wind speed test results show that the design of the double mezzanine Trombe wall apartment can effectively use good draught wind, and the design is more reasonable. When the height is constant, the design parameters for maximizing the utilization of solar light and heat on the exterior surface of the building are as follows: the minimum area width is 54 m and the maximum depth is 21 m, and the utilization rate is 72.8%; The maximum design parameters for the surface solar photovoltaic utilization rate are 105 m for the surface width and 21 m for the depth, and the utilization rate is 29.6%.

6.2 Influence of air layer height on double layer Trombe wall

The thermal performance of a double sandwich Trombe wall at different inter layer heights is shown in Fig 6-4.

The convective heat transfer and thermal conductivity increase significantly with increasing inter layer height.

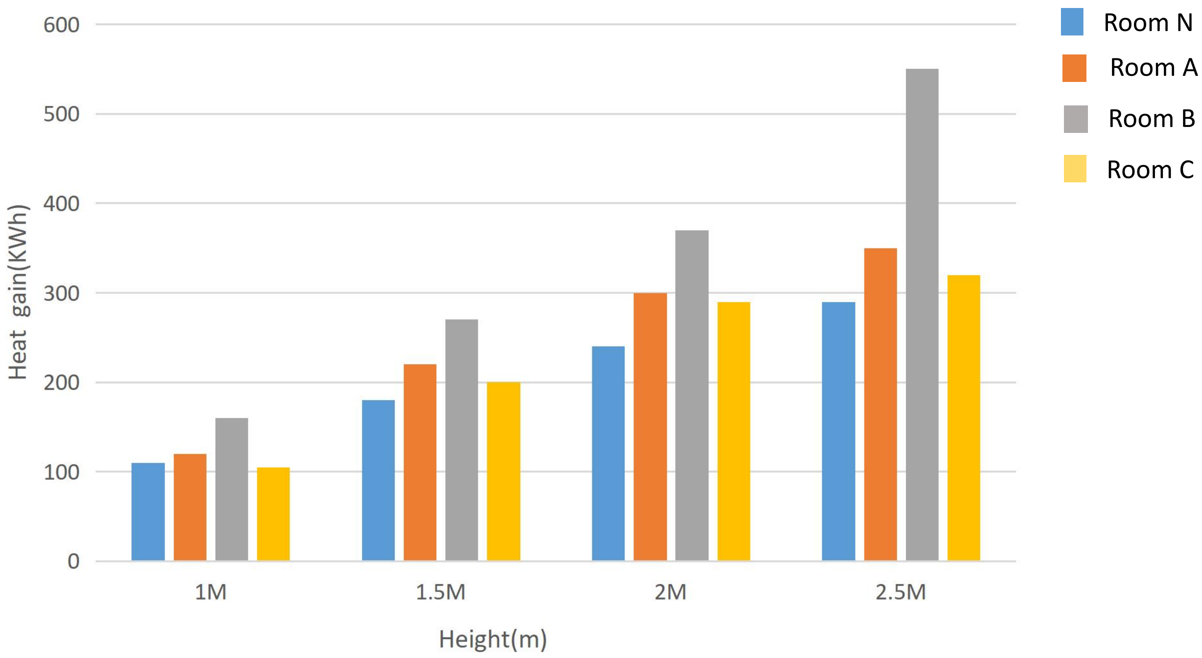


Fig 6-4 The effect of different air layer heights on the heat in the room

As can be seen from the above graph, the height of the external air layer has a direct effect on the increase in heat transfer, especially in the double circulation mode, where the heat gain is almost twice as high at 2.5 m as at 1.5 m.

It can also be seen that the room without a fan is also affected by the height of the air layer, but this does not change much compared to the room with a fan, which also shows that the double sandwich Trombe wall with direct air flow is more beneficial for the heat gain in the room. When comparing the rooms with fans, the heat gain in the room with internal circulation is less than in the room with external circulation, most notably in the case of the Trombe wall with double circulation.

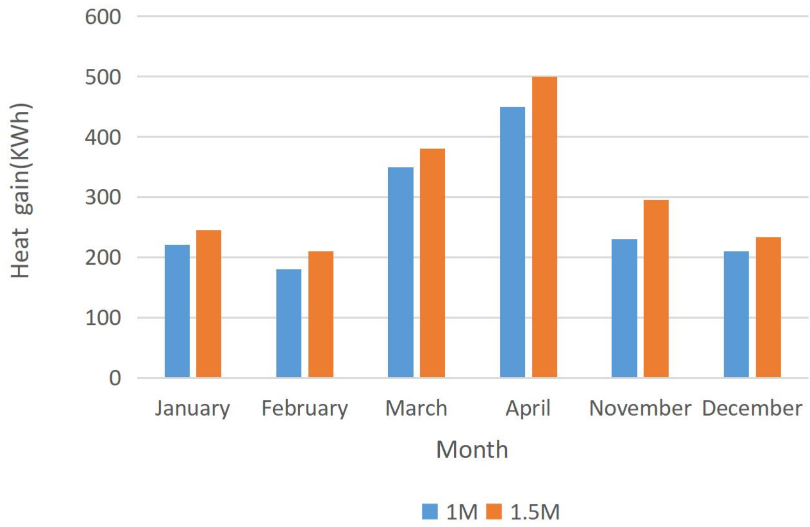


Fig 6-5 a Comparison of heat in rooms with different air layer heights(1M,1.5M)

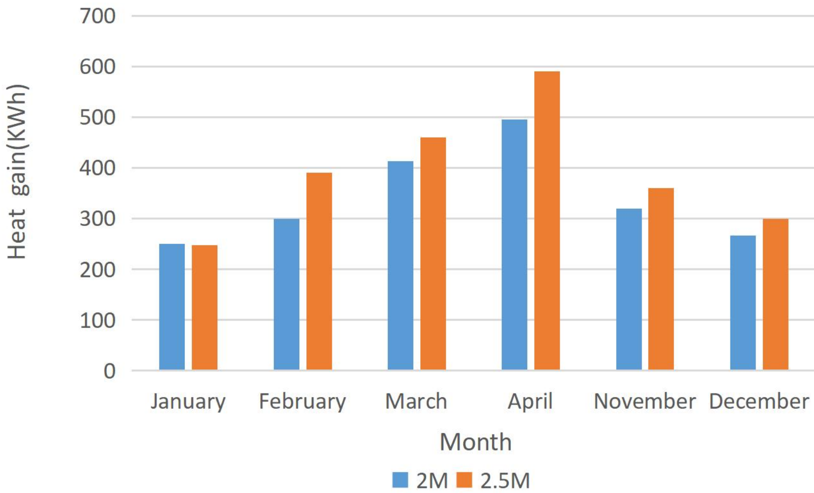


Fig 6-5 b Comparison of heat in rooms with different air layer heights(2M,2.5M)

As can be seen from the two graphs above, the amount of heat gained indoors increases steadily as the height of the air layer increases. The maximum indoor heat gain is reached when the air layer height reaches 2.5 m and in April the heat gain is 19.5% higher at an air layer height of 2.5 m than at an air layer height of 1.5 m. In February, the effect of air layer height is even more pronounced, with 2.5 m.generating 33.3% more heat than 1.5 m.

6.3Influence of the height of the external vents and inner vents

The height and position of the vents are not random, as the height of the vents determines the rate and flow of air exchange between the interior and exterior.

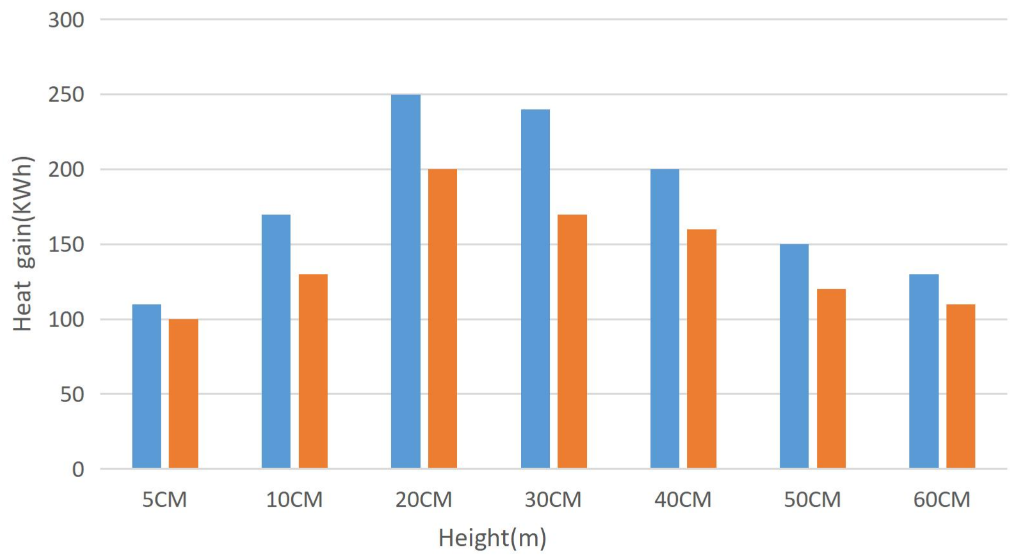


Fig6-6 Different height of the external vents and inner vents

This paper simulates the simulation of different external fan heights on the heat in the room, the prerequisite for this simulation design is the location of the experimental room, the data analysis in January, the wind speed is set to 30m3/h, the resulting data shows that the first experiment can only compare the double circulation experimental room and the external circulation experimental room, from the data can be seen that different fan heights have a certain influence on the indoor heat gain, the best fan location should be The optimum position of the fan should be around 20 cm above the floor, and the data shows that when the fan is more than 30 above the floor, the heat in the room does not continue to increase. This is because, when the fan is positioned too high, the distance heated by the lower fan becomes shorter and the heat flow from the upper fan is reduced, thus directly affecting the transfer of heat flow to the room.

The location of the fan hole in the protective layer of the inner wall of the double cycle should first be separated from the vent of the outer wall, so the design of the vent of the inner wall, this paper chose to be arranged in a vertical direction with the line of the outer cycle vent, the main reason for this is to try to independent vent heat transfer, is that the data is more relevant.

From this diagram we can see that the position of the fan in the inner insulation wall has a certain influence on the indoor heat gain, but compared to the position of the fan on the outer side, it is obvious that the position of the fan in the inner insulation wall does not effectively influence the indoor heat gain, mainly because, the temperature increase of the inner air inter layer mainly comes from the heat absorption ability of the outer wall and the heat dissipation ability of the outer wall, in the absence of direct sunlight In the absence of direct sunlight, the temperature of the inner air layer increases very slowly, so the heat transmitted by the fan is very little, which leads to the fan position not effectively affecting the indoor heat, but we can also see that when the fan position is 40 cm, the relative indoor heat has a certain increase, which is also because the middle area of the outer wall is the main area of heat absorption and dissipation, so the height of the inner wall fan position can be higher than the height of the outer wall. The height of the fan opening can be higher than that of the external wall.

6.4 Influence of protective layer thickness on internal walls

The main function of the internal wall of a double layer Trombe wall is to minimize the heat loss of the room temperature and its thickness should not be too thick because, firstly, it increases the cost too much from an economic point of view and, secondly, too thick a wall reduces the use of space in the room.

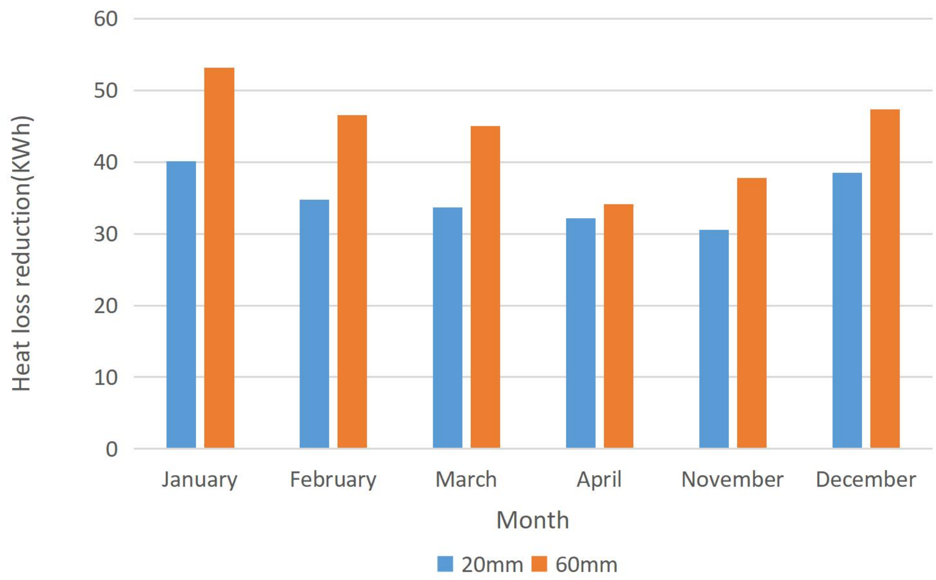


Fig6-7 Different height of the external vents and inner vents

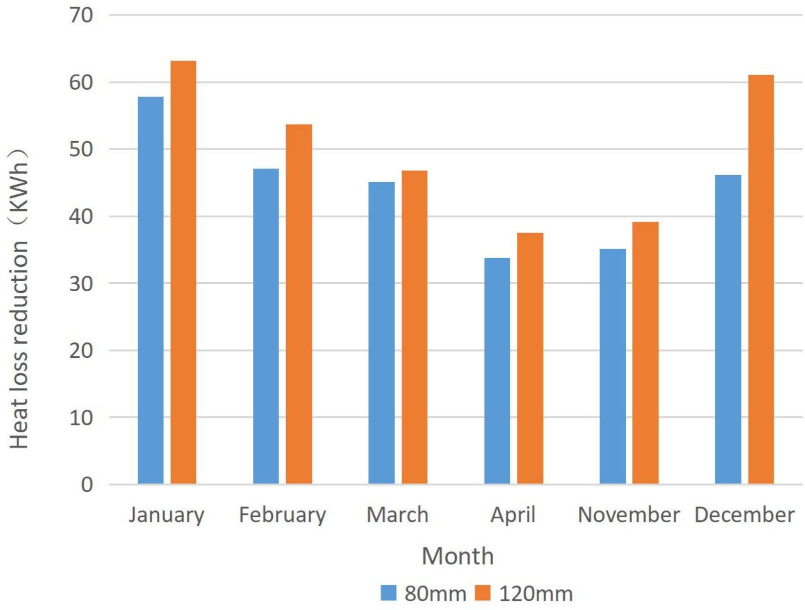


Fig6-8 Heat gain by month for different wall thicknesses

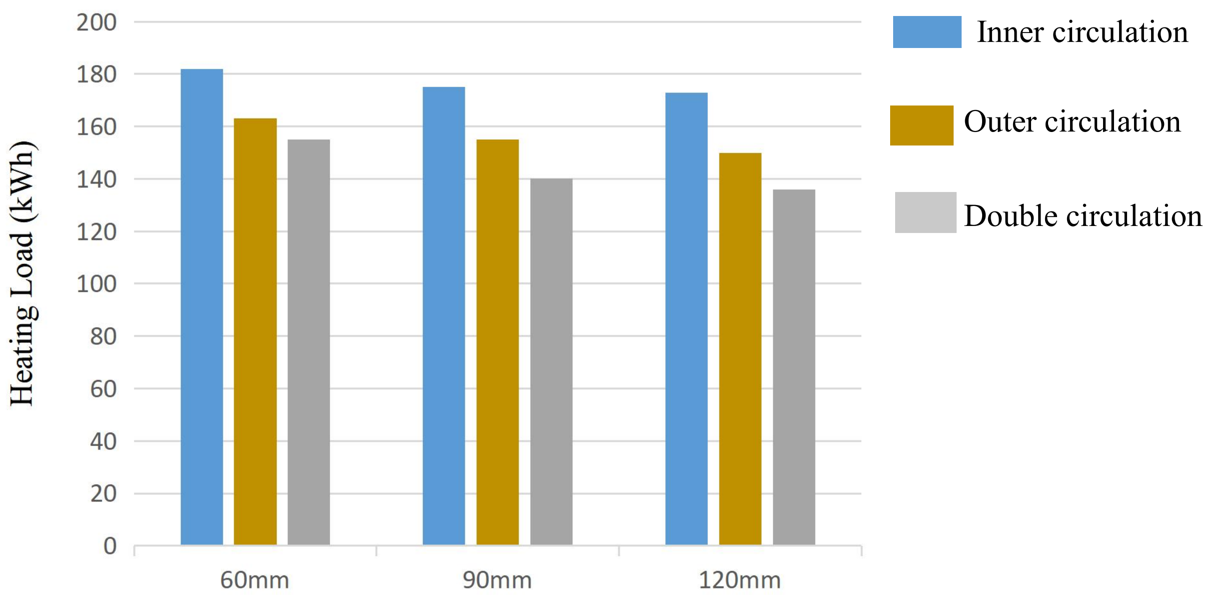


Fig6-7 Heat loads from different wall thicknesses in different circulation patterns

The different inner protective layer thicknesses influence the heat transfer to the room and also the heat loss from the room to the outside, in combination,90mm thick concrete walls are more suitable for internal insulation.

In this chapter, the authors simulate a comparative study of different months and different thicknesses of internal walls in a severe cold region. The results in the graph show that the layer of insulation in the wall has a significant effect on the heat storage capacity of the wall. the heat storage capacity of Trombe walls increases with the thickness of the insulation layer. The reason for this is that the insulation prevents the heat from being dissipated in the wall and the greater the thickness of the material, the more effective the thermal storage of such Trombe walls. The article also shows that the internal insulation walls were designed to reduce heat loss and that the internal walls are more effective in colder areas than in warmer areas.

When the thickness of the insulation material reaches 20 mm, the corresponding heat loss reduction value is essentially the same as for a Trombe wall without insulation. At this point, the corresponding heat loss reduction value in this paper reaches 31.1% of the original.

6.5 Influence of air layer thickness

6.5.1 Influence of external air layer thickness

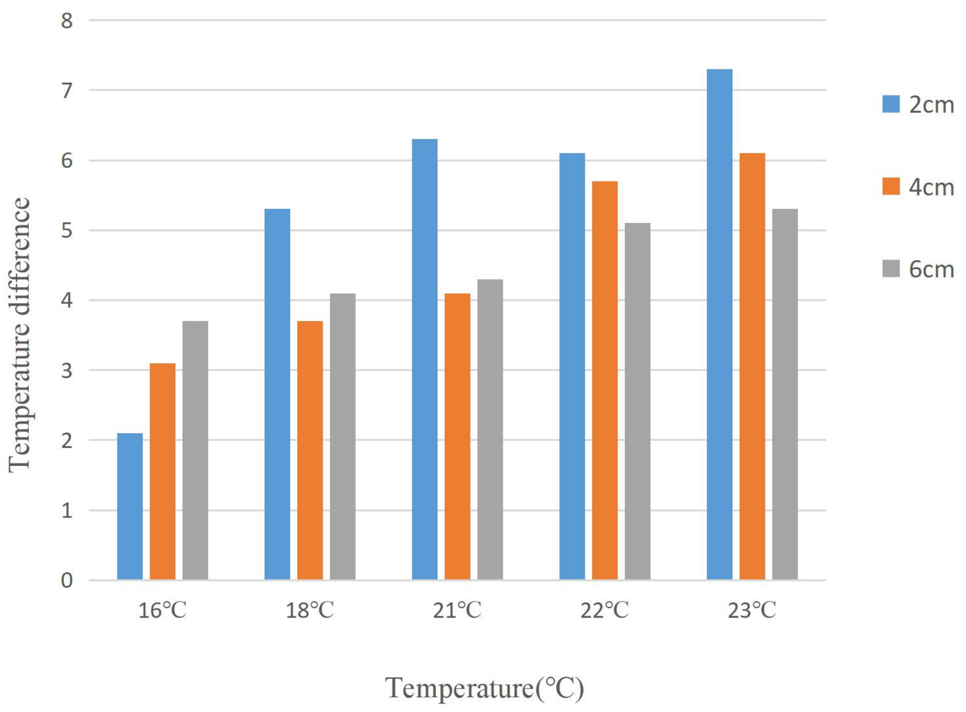


Fig6-8a Temperature difference between different circulation patterns at different temperatures

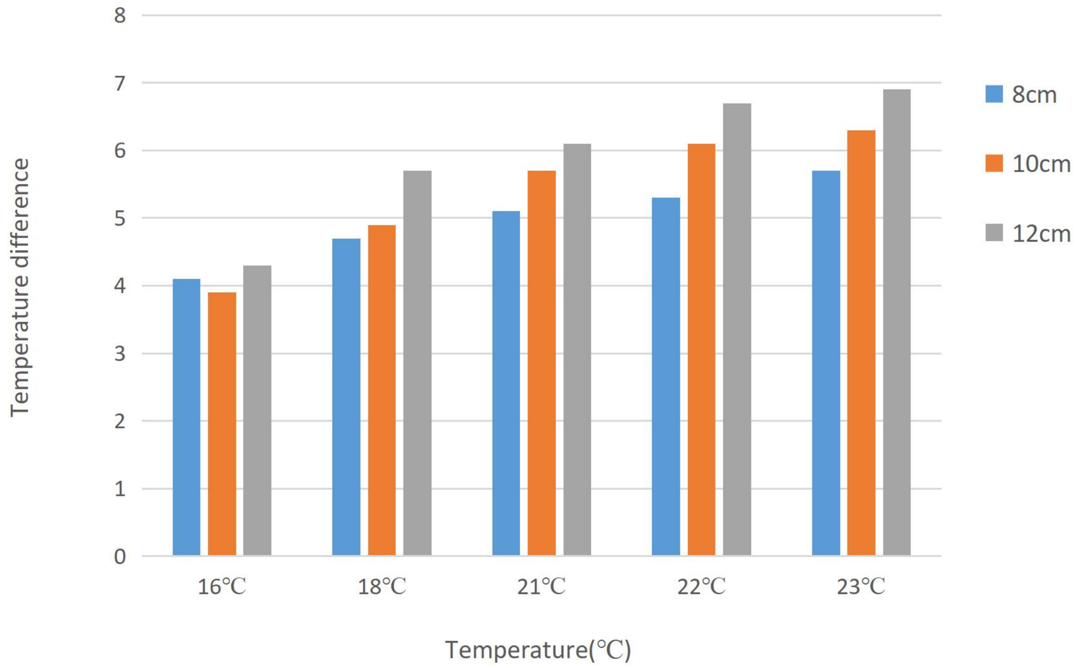


Fig6-8 Temperature difference between different circulation patterns at different temperatures

Different thicknesses of the outer air layer affect the heat transfer to the room, and in practical terms, the heat load is low when the thickness of the outer air layer is 200mm.

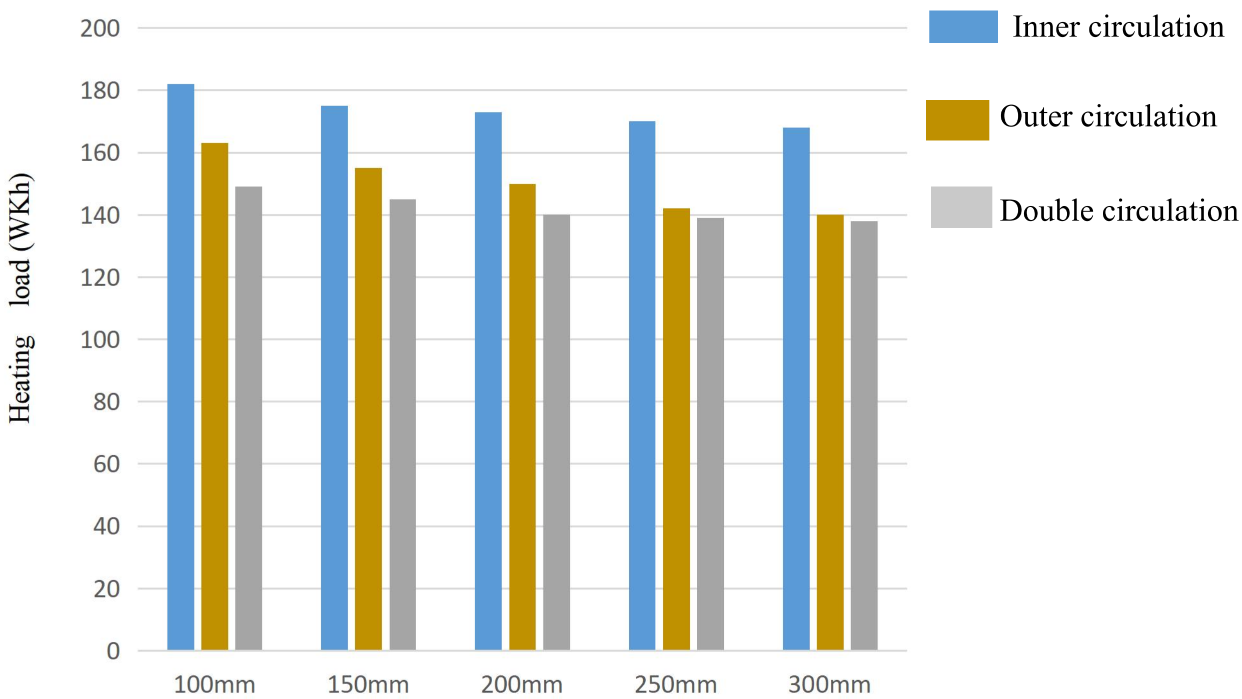
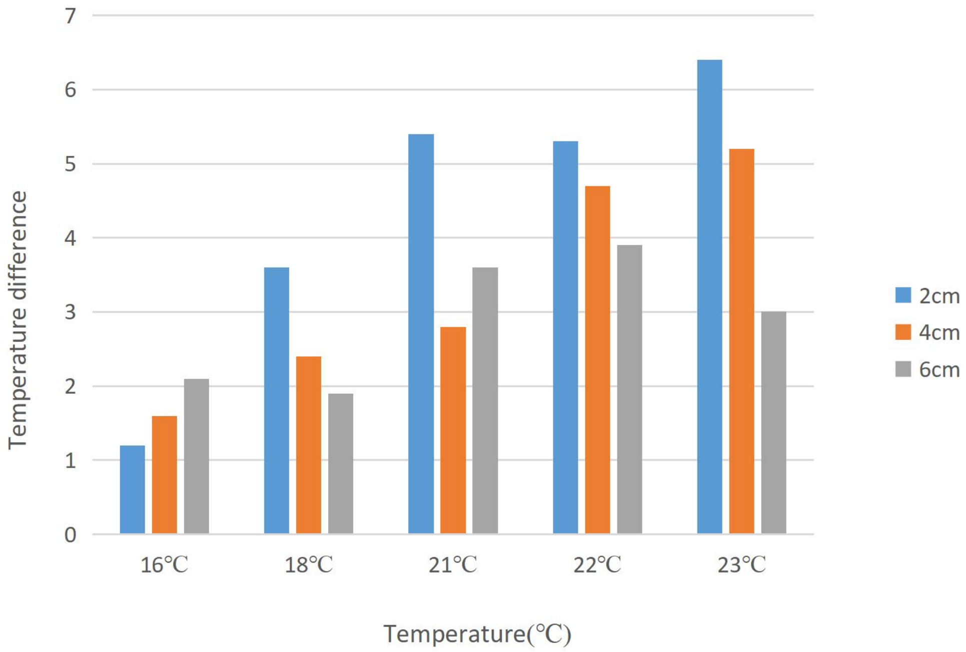


Fig. 6-8 Effect of different air layer thicknesses on indoor thermal loading

6.5.2 Influence of the thickness of the internal air layer



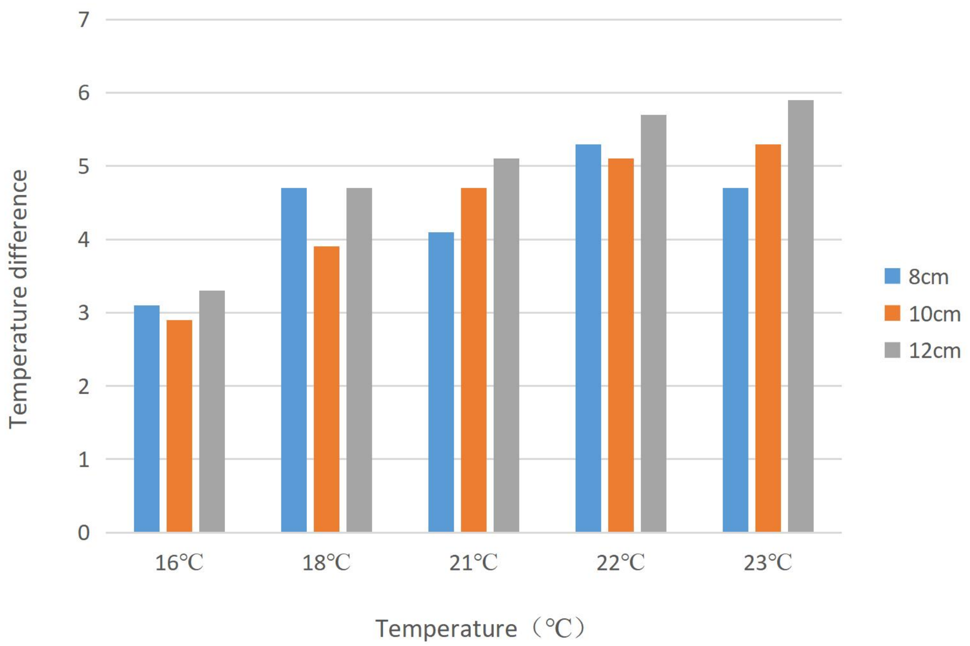


Fig6-9 Temperature change due to internal air wind thickness

The thickness of the internal air layer also affects the temperature variation in the room, and depending on the heat load due to the thickness of the different internal walls, a wall of around 8 cm thickness produces a relatively low heat load

6.6 Optimum wind speed explored

The simulation of the optimal speed of the fan is a simulation for different circulation patterns, different wind customs, the lowest heat load generated at a reasonable wind speed is considered the best wind speed, due to the different climate of the experimental site, the simulation results of the best wind customs will also be different, in cold areas to minimize the indoor wind speed compared to the southern region.

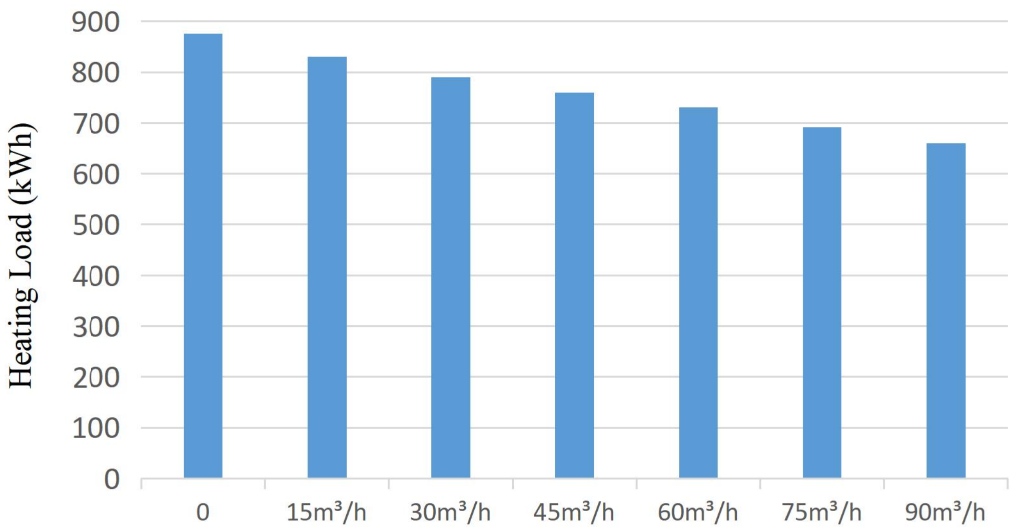


Fig6-10 Relationship between wind speed and indoor heat load

The air circulation speed should not be too high in winter in harsh regions, and the optimal fan speed of 90m^3 per hour is reasonable according to simulations.

6.7 Summary of this chapter

This chapter begins with a simulation of a simple traditional Chinese house, through which it is found that factors such as ventilation patterns, wind speed, solar radiation, and wall height affect the heat transfer from the trombe wall to the interior, followed by related simulations, where the more influential factors are

1,Different thicknesses of the outer air layer affect the heat transfer to the room, and in practical terms, the heat load is low when the thickness of the outer air layer is 200 mm.

2,The different inner protective layer thicknesses influence the heat transfer to the room and also the heat loss from the room to the outside, in combination,90mm thick concrete walls are more suitable for internal insulation

3,The air circulation speed should not be too high in winter in harsh regions, and the optimal fan speed of $90m^3$ per hour is reasonable according to simulations.

Chapter 7

ENERGY CONSUMPTION ANALYSIS OF A DOUBLE SANDWICH TROMBE WALL IN WINTER IN A SEVERE COLD REGION

CHAPTER 7 ENERGY CONSUMPTION ANALYSIS OF A DOUBLE LAYER TROMBE WALL IN WINTER IN A SEVERE COLD REGION

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7.1 Definition of energy consumption analysis and energy efficiency evaluation methods for buildings in China

Building-related energy consumption includes: energy consumption for the production of building materials, energy consumption for the transport of building construction materials, energy consumption for building operation (maintenance), and energy consumption for building demolition and disposal. China is currently at the peak of urban construction, and the rapid development of urban construction has led to the rapid development of the building materials and construction industries, resulting in energy consumption that accounts for 20% — 30% of China's total commodity energy consumption. However, this energy consumption is entirely dependent on the development of the construction industry and is in a completely different category to the energy consumption of building operation. Energy consumption for building operation, i.e. for heating, air conditioning, lighting and all types of electrical appliances used in the building, will always occur during the building's use. During the whole life cycle of a building, the energy consumed by building materials and the construction process generally accounts for only about 20% of its total energy consumption, with most of the energy consumption occurring during the building's operation. Therefore, building operation energy consumption is the main concern in the task of building energy efficiency.China's Green Building Evaluation Methodology.

The evaluation of green buildings in China is carried out in accordance with the Green Building Evaluation Standard GB/T50378-2014. This standard specifies the definition, evaluation index and evaluation method of green buildings, and establishes the development concept and evaluation system of green buildings in China with the core content of "four savings and one environmental protection". The evaluation of green buildings is divided into design evaluation and operation evaluation, with the design evaluation to be conducted after the construction drawing design document of the building project has been examined and approved, and the operation evaluation to be conducted one year after the building has been completed and accepted and put into use. The green building evaluation index system consists of seven types of indicators: land saving and outdoor environment, energy saving and energy use, water and water use, material saving and material resource use, indoor environmental quality, construction management and operation management.

Energy-efficient design based on the building environment The energy-efficient design of near-zero energy-consuming buildings with carbon emissions should take full account of the external conditions of the building's environment. Firstly, the climate of the building environment should be fully examined, including data information such as the average temperature of the building environment, the average hours of sunlight in the building, the temperature difference ratio between inside and outside, the direction and frequency of the wind, the average annual rainfall, and the average annual number of days spent cooling in summer and heating in winter. The building designer can use relevant software to analyse the climate data to achieve adjustments to the layout, green environment and orientation of the building design to maximize the use of external environmental conditions and reduce building energy loss in order to minimize the building's carbon footprint and realize the concept of green, low-carbon and environmentally friendly environmental development.

Energy-efficient design based on the building wall mechanism According to the climate data collected from the building field survey, the building peripheral structure should also take into full consideration the influence of climate conditions to carry out the design work related to energy saving and emission reduction. For example, if the area where the building is located is hot all year round, the building wall and other peripheral structures should mainly use heat insulation materials, external shading design, windows and internal building airflow ventilation design, to avoid carbon emissions caused by indoor temperature cooling. If the area where the building is located is colder all year round, the building walls and windows should be made of materials with better thermal insulation and lower thermal conductivity to improve the sealing of the building interior and to ensure the light hours and light intensity of the building interior. According to the above analysis, the building wall structure should be designed differently according to different climatic conditions to achieve energy saving and emission reduction, and further reduce the building carbon emissions.

Upgrading and innovation of energy-saving equipment in building systems The main source of carbon emissions from buildings is the use of indoor air conditioning and cooling and winter heating equipment, where traditional energy heating methods such as natural gas and coal consume more energy and have a huge impact on the environment. For this reason, the carbon footprint of near-zero energy buildings should be optimized and driven by innovation in relation to the building's characteristics. For example, if the building is located in an area that is hot all year round, a combination of fans and air conditioning can be used inside the building to increase the speed of indoor air flow, expand the cooling effect and range of air conditioning, and reduce the energy consumption of air conditioning as a complement to make up for the lack of objective conditions.

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7.2 Analysis of the hourly and cumulative energy consumption of the double layer Trombe wall

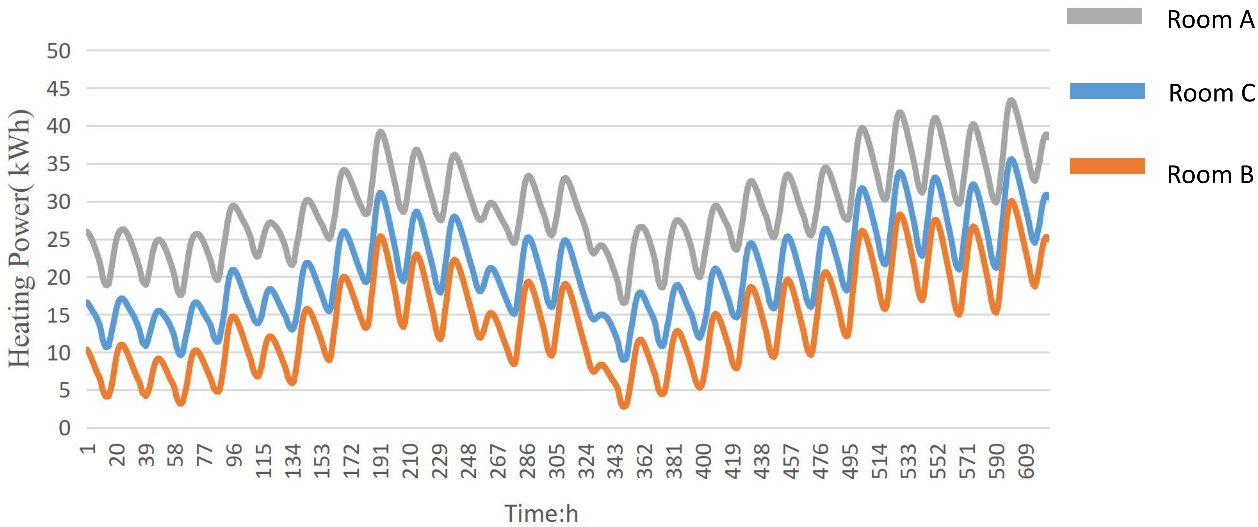

Fig 7-1 Heating power versus time graph

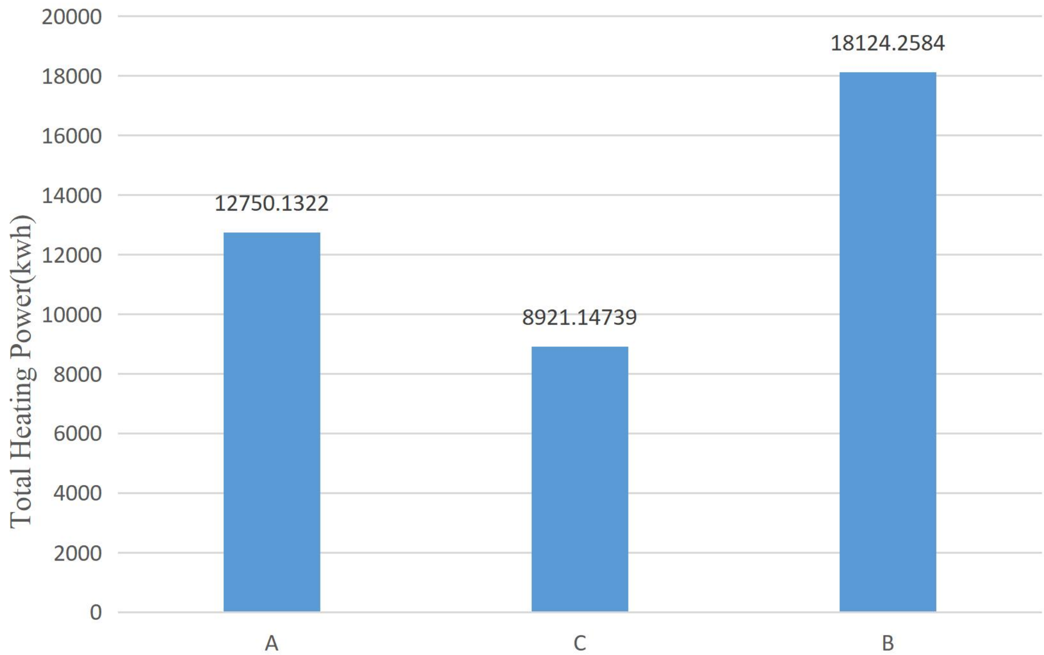

Fig 7-2 Accumulated calorific value

The heating power of the air circulating through the ducts is also determined by the type of circulation, and the general trend is the same for rooms A, B and C. The heating power of room A with internal circulation is better than that of room C with external circulation, and second to room B with internal and external circulation. In terms of cumulative heating power, the cumulative heating power of room A is 42%

higher than that of room C for 26 days and 29.6% lower than that of room B for both internal and external circulation, while the cumulative heating power of room C is 50.7% lower than that of room B for 26 days.

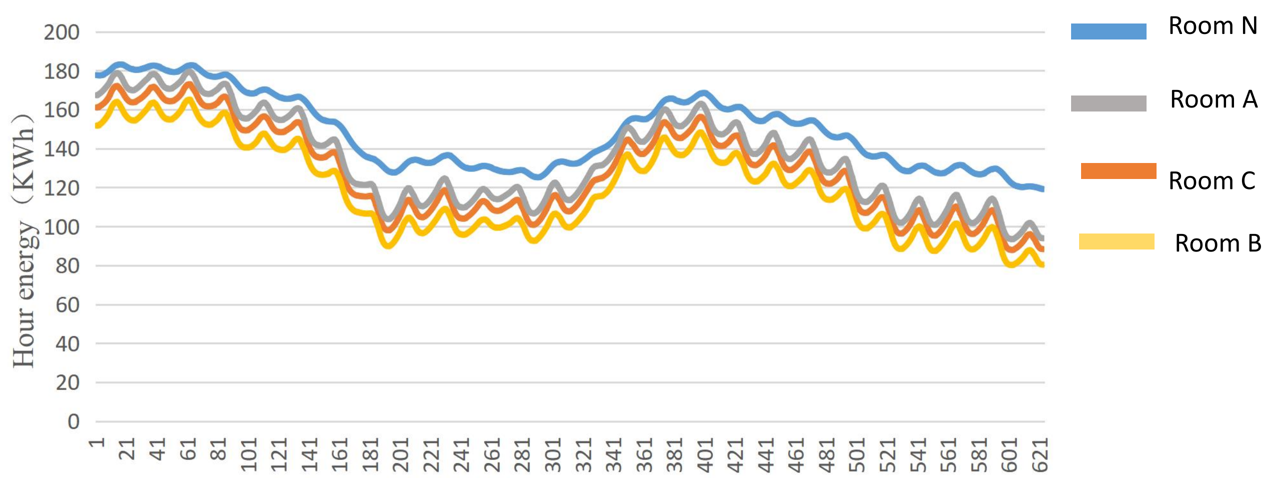

Fig 7-3 Hourly energy consumption

The graph above shows and FIG the hourly and cumulative energy consumption of the three rooms with heating measures in N,A,B,C. The heating temperature is set to 18°C in all four rooms and the settings for people, lights and equipment are set according to the default operating conditions. The logic for starting the circulating air fans is as follows.

1). When no one is present, the heating is not switched on and the circulating fan is started to maintain the room temperature.

2). When people are in the room, first the circulating fan is switched on and then the heating equipment inside the room heats up the circulating air to the specified temperature of the room.

The graph above shows that the energy consumption for heating when circulating ventilation is significantly lower than the hour-by-hour energy consumption without any ventilation. The energy consumption of the internal circulation ventilation in room A is 13.89 kW/m2, which is 13.7% compared to room N. The energy consumption of the external circulation in room C is 14.55 kW/m2, which is 9.6% compared to room N. The energy consumption of the internal and external circulation in room B is 12.96 kW/m2, which is 19.5% compared to room N. It can therefore be seen that the energy saving efficiency of simultaneous ventilation inside and outside the double storey is even more pronounced.

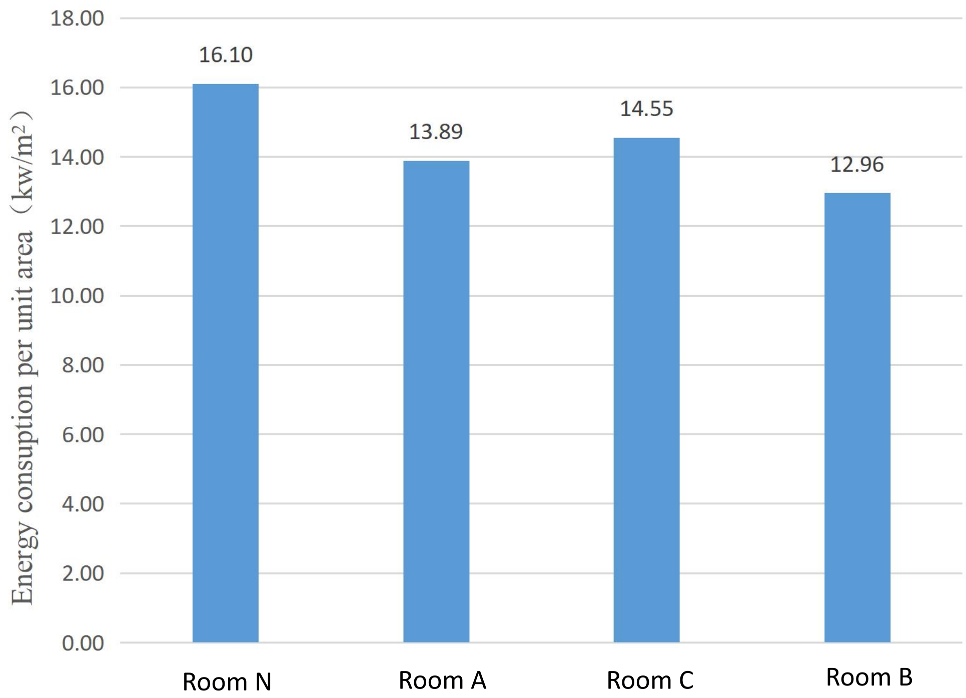

Fig 7-4 Energy consumption per unit area

The above analysis leads to the conclusion that double-decker internal and external circulation ventilation has more energy saving benefits, therefore the following in-depth analysis is carried out on this basis, the impact of different ventilation temperature difference measures on energy consumption. It goes without saying that the most energy-efficient temperature difference ventilation settings to achieve double-decker ventilation must be: the channel temperature is greater than the room temperature and the temperature difference between the inner channel is met or the outer channel is met. In other words, as long as there is a temperature difference to be satisfied, ventilation is possible. The analysis above shows that the maximum temperature difference for both internal and external channels to be ventilated is 3.5 degrees Celsius. Therefore set the temperature difference ventilation main working conditions as follows

X: The temperature difference between the inner channel or the outer channel meets 0°C, i.e. as long as there is no negative value, ventilation is possible.

Y: The temperature difference between the inner and outer channels meets 1°C. Z: the difference in temperature between the inner channel or the outer channel meets 2°C. O: Inner or outer channel temperature difference meets 3°C.Based on the above four operating conditions, the final simulation results are as follows.

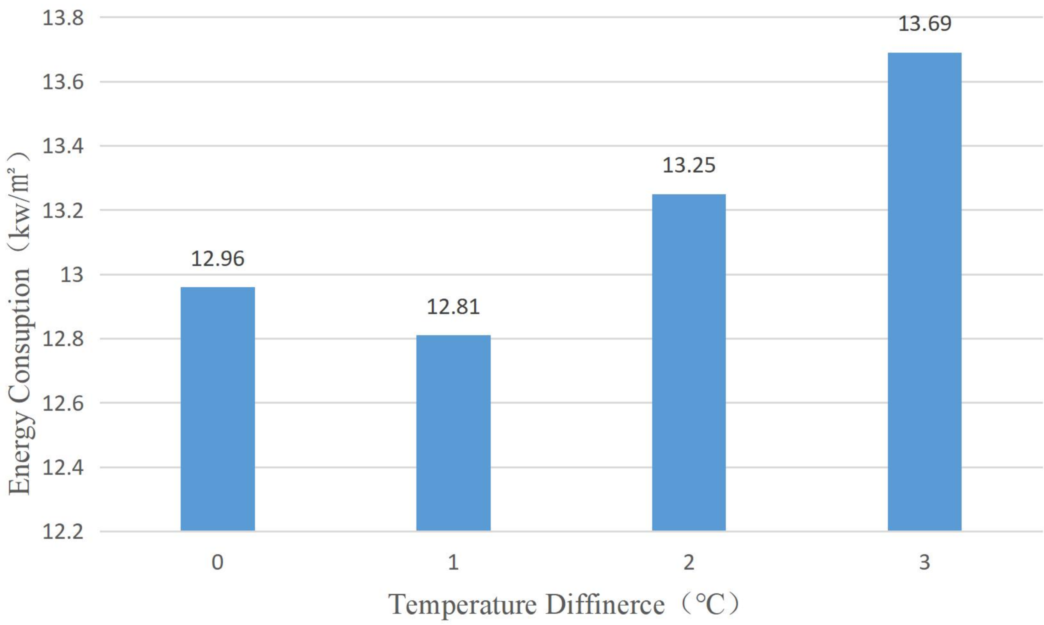

Fig 7-5 Final energy consumption

The above analysis shows that when the temperature difference is 1°C, the energy consumption is 12.81 kW/㎡ and the energy saving rate is 1.15%, when the temperature difference is 2°C and 3°C, the energy consumption is 13.25 kW/㎡ and 13.69 kW/㎡ respectively, which does not achieve the energy saving effect. Only when the temperature difference is 1°C will the energy saving effect appear, this is because at 0°C, although there is no negative temperature difference between the cavity temperature and the room temperature, but because the cavity is in a certain concept belongs to the HVAC inside the duct, the air in the transmission process there is heat loss or even stored in the wall again, so that in fact through the cavity in the room after sending the temperature inside slightly lower or even lower than the This not only does not save energy, but may also increase the thermal load. And when the temperature is 1°C higher (it could be lower and slightly higher, but this simulation is based on a temperature difference of 1°C operating conditions, so this conclusion can only be drawn from the simulation.)

When the transported air heat, even if it is partly lost, is sent into the room, the temperature will be higher than the air temperature in the room, so it is beneficial to heat the room, but if the temperature difference is even higher, for example 2°C or 3°C, instead, it has been decided in the early stage when the fan is judged to start and stop that some of the heat cannot be sent into the room, so the probability of the room being heated is reduced and the heating load is increased.

7.3 Sensitivity analysis

7.3.1 Definition of Sensitivity Analysis

Sensitivity analysis methods are primarily used to analyse the strength of the impact of independent variables on target outcomes and were first proposed in the field of economics. Today sensitivity analysis is used in a wide range of disciplines including chemistry, engineering and ecology. Using this method to analyse the sensitivity factors affecting building loads is used to achieve the aim of helping designers to capture the key elements of energy efficient design in the design process. Only by capturing the key elements of energy efficient design can we effectively save energy in buildings and help to control investment costs.

Sensitivity analysis is essentially a method of looking at the pattern of how key indicators are affected by changes in these factors by varying the values of the relevant variables one by one. Sensitivity analysis is divided into single-factor sensitivity analysis and multi-factor sensitivity analysis: single-factor sensitivity analysis examines only the extent to which a single variable affects the model; multi-factor sensitivity analysis examines the sum of the effects of multiple variables on the model and analyses the impact of the interactions between attributes on the model output. Single-factor sensitivity analysis is simple, quick and operational in terms of calculation, and has a much wider impact in research.

The specific steps: 1) identify the sensitivity analysis indicators; 2) select uncertainties that are more likely to change and will have a greater impact on the analysis indicators; 3) analyse the degree of impact on the analysis indicators when the uncertainties change; 4) identify the sensitivity factors; and 5) identify the project or programme. In the process of single-factor sensitivity analysis, one of the uncertainty factors is changed on the premise that other factors remain unchanged, and then one of the uncertainty factors is changed on the premise that other factors remain unchanged, so as to find out the influence of various uncertainty factors on the target value of the analysis index and the degree of influence. In this way, we can identify sensitive factors, analyse them and take measures to improve the stability of technical solutions.

The above settings are the basic settings of the model and are used to carry out energy consumption simulations and analysis of various energy saving strategies. In particular, the basic settings of this model are based on the relevant local codes and experience, and the simulation data does not represent the actual energy consumption level of the building or the actual type of building in the area, and the simulation data is only used for relative analysis and comparison to compare relevant energy saving strategies.

This chapter uses sensitivity analysis as a method of data validation and sensitivity analysis for the double ventilated walls in this chapter, with internal circulation, external circulation, internal and external circulation and temperature differential ventilation as uncertainty factors, and analyses the trend and degree of influence of each major factor on building energy consumption, both vertically and horizontally respectively. A horizontal comparison of the degree of influence of each factor on the energy consumption of a building. The vertical comparison of the influence of a single factor on the annual energy consumption of a building envelope is used to analyse the sensitivity of this factor to the annual load of the building. The horizontal and vertical sensitivity analyses are then combined to develop an optimized design for the building energy efficiency.

7.3.2 Sensitivity calculation formula

In the baseline model, the design parameters are selected to common values, keeping the other input parameters fixed at the baseline values, changing one of the parameters and observing the change in the simulation results of the simulated system, the basic definition of parameter sensitivity is shown in equation（3.13）

$$IC = \frac{ChangeInOutput}{ChangeInInput} = \frac{\partial OP}{\partial IP} \approx \frac{\Delta OP}{\Delta IP} \quad \textbf{(7.1)}$$

ΔOP：Amount of change in building load

ΔIP：Amount of variation of variable parameters

On the basis of the basic defining formula, further expressions for sensitivity are shown in the other five shown in Table 3-4. From a magnitude perspective, sensitivity and impact coefficients are more convenient for vertical single-factor analysis, while point elasticity, mid-arc point elasticity, arc-mean elasticity and interval elasticity are suitable for horizontal comparisons of the strength of sensitivity between different factors.

Table 7-1 Forms and formulae for each type of sensitivity

Form	Calculated formula	Dimensions
Sensitivity	$\frac{\Delta OP}{\Delta IP}$	Measurable
Impact factor	$\frac{\Delta OP \div OP_{BC}}{\Delta IP}$	Measurable
Point elasticity	$\frac{\Delta OP \div OP_{BC}}{\Delta IP \div IP_{BC}}$	dimensionless
Elasticity at the mid-point of the arc	$\frac{\Delta OP \div (\frac{OP_1 + OP_2}{2})}{\Delta IP \div (\frac{IP_1 + IP_2}{2})}$	dimensionless
Arc-mean elasticity	$(\frac{\Delta OP}{\Delta IP}) \div (\frac{\overline{OP}}{\overline{IP}})$	dimensionless
Interval flexibility	$\frac{\Delta OP \div OP_{BC}}{\Delta IP \div (IP_{UB} - IP_{LB})}$	dimensionless

Note: ΔOP indicates a value belonging to a parameter change, ΔIP indicates a value belonging to a parameter change; OP_{BC} indicates an output parameter base value, IP_{BC} indicates an input parameter base value; OP_1 indicates an output value before a word change, OP_{12} indicates an output value after a word change, IP_1 indicates an input parameter value before a word change, IP_2 indicates an input parameter value before a word change; $\overline{OP}$ indicates a mean value within a range of output parameter changes, $\overline{IP}$ indicates a mean value within a range of input parameter changes; IP_{UB} indicates an upper limit of a range of input parameter changes, IP_{LB} indicates a lower limit of a range of input parameter changes.

In order to facilitate the analysis of the influence of the cumulative annual energy consumption of a building in both vertical and horizontal directions, the arc-average elasticity is chosen as its main indicator and the concept of arc-average elasticity of annual cumulative load is introduced according to the corresponding calculation formula.

With the above model as the research object and the arc-average elasticity of heating energy consumption per unit area of the building as the specific measurement index, a sensitivity analysis is carried out on the heating energy consumption per unit area of the building under different design parameters for each factor to determine the influence law of each factor on the heating energy consumption per unit area of the building, and to comprehensively compare the sensitivity of the ventilation type to the building energy consumption in Changchun, so as to identify the key factors affecting the energy-saving design of the building. Only by grasping the key factors can the building load be better reduced.

A single-factor sensitivity analysis was carried out on the basis of the parameters set. The impact of each single factor on the heating energy consumption per unit area of the building was analyzed by category, i.e. when exploring a single factor, only the level of that factor was changed, while other factors remained unchanged, and the results of the annual cooling and heating loads of the building were simulated and calculated at different levels of that factor, using the annual cumulative load arc mean elasticity to analyse the degree of change and trend of heating energy consumption per unit area of the building.

Set a single factor level value$x_j$for,=1,2,...,n, at the jth level by EnergyPlus calculate the value of the heating energy consumption under the unit area of the building is Q_j,then the arc mean elasticity MAE of the heating energy consumption under the unit area of the building under the factor is calculated by formula 8.14.

$$MAE=\left(\frac{\Delta OP}{\Delta IP}\right)\div\left(\frac{\overline{OP}}{\overline{IP}}\right)=\left(\frac{\Delta Q_{j,j+1}}{\Delta x_{j,j+1}}\right)\div\left(\frac{\bar{P}}{\bar{x}}\right)$$

$$\frac{\Delta OP}{\Delta IP}=\frac{\Delta Q_{j,j+1}}{\Delta x_{j,j+1}}=\frac{|Q_{j+1}-Q_j|}{x_{j+1}-x_j} \quad \textbf{(7.2)}$$

$$\overline{OP}=\bar{P}=\frac{\sum_{j=1}^{n}Q_j}{n}$$

$$\overline{IP}=\bar{x}=\frac{\sum_{j=1}^{n}Q_j}{n}$$

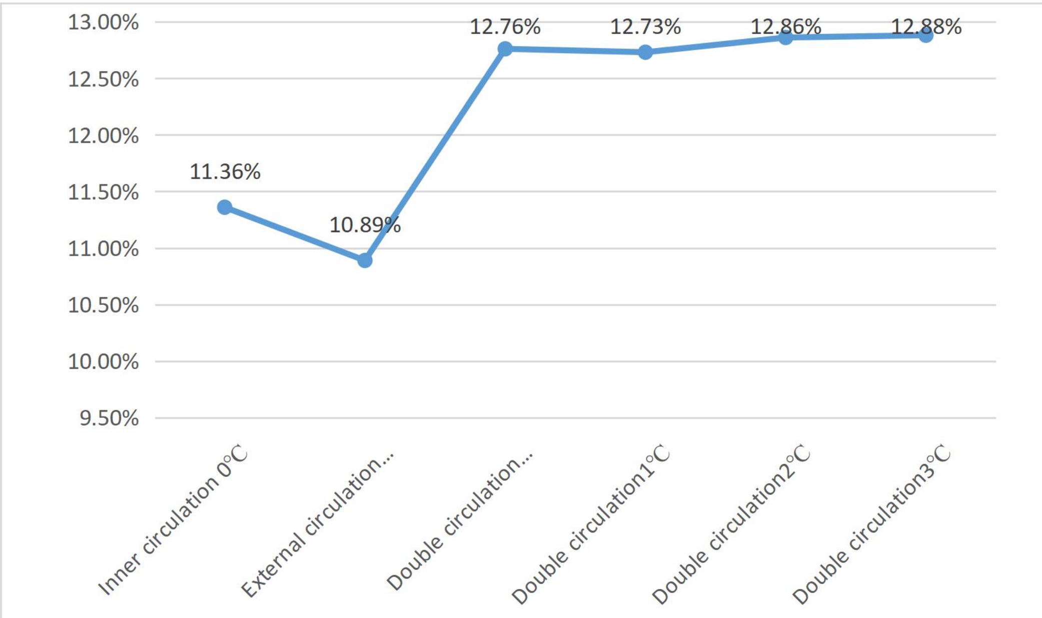

Fig 7-6 Arc mean elasticity of heating energy values per unit area

As can be seen in the graph above, the different ventilation schemes have an arc mean elasticity on the heating energy values under the building unit area. Internal cycle 0 indicates that the internal cycle is ventilated at a temperature difference of 0°C, the other cycles are the same. Internal and external circulation 1 indicates ventilation by both internal and external circulation at a temperature difference of 1°C. As can be seen from the above, the sensitivity of the type of cycle to the heating energy consumption value per unit area of the building is very high, reaching a minimum of 10.8%, while the sensitivity of the temperature difference to the heating energy consumption value per unit area of the building is relatively low for the same type of cycle (e.g. internal and external cycles 0-3). Thus the accuracy of the above data trends is also verified in terms of sensitivity analysis.

7.4 Double layer Trombe wall Comprehensive energy efficiency evaluation

Based on the existing solar energy utilization technology, this paper takes into account the influence of technical, architectural and economic factors, coordinates the efficient use of solar energy and indoor thermal comfort, and proposes a solar thermal building suitable for cold winter regions. The thrombus wall is a form of building shell for passive solar house heat collection and storage, which can make full use of solar energy and effectively reduce building energy consumption.

Comprehensive evaluation is the basic means to test the effect of greening function, and the construction of evaluation index system is the basis and key of comprehensive evaluation. Taking the road section as the evaluation unit, the evaluation system is constructed based on FNN (Fuzzy Neural Network) from four aspects: engineering design, ecological environment, landscape greening and management. The evaluation system can scientifically and objectively measure and evaluate the present situation and development level of highway ecological greening in a certain region to a certain extent.It is important to note that in the Green Building Assessment Criteria, energy efficiency in buildings is not limited to the 'energy saving and energy use' section of the 'Four Sections and One Environmental Protection'. As energy efficiency needs to be based on meeting the environmental comfort of the building in terms of wind, light, heat and sound, and energy savings cannot be made at the expense of environmental quality, there are many other parts of the standard that are closely related to building energy efficiency.There is also a large amount of this content in 'Indoor Environmental Quality'. Energy efficiency in buildings is therefore a key element of the <Green Building Assessment Criteria>

7.4.1 Establishment of evaluation index system

The index system not only covers the research content, but also reflects the relationship between the indexes. There is a causal relationship and hierarchical structure between evaluation indexes and evaluation index groups.

Establishment of neural network evaluation model FNN evaluation model is the core of heating potential. Its design idea is to express fuzzy rules and membership functions by neural network, and the generated neural network is used to realize fuzzy reasoning.Determination of index weight of heating potential.

Because the indexes of heating potential are primary and secondary, and they play different roles in the evaluation of heating potential, the weights of each green principle index are different, so it is necessary to find a suitable method to determine the weights [22]. It is more suitable to calculate the index weight of heating potential using the sequential relationship analysis method.

According to the classification of the indicators of the first pressure layer, status layer and response layer, the hierarchical structure is established, as shown in Figure 7-7:

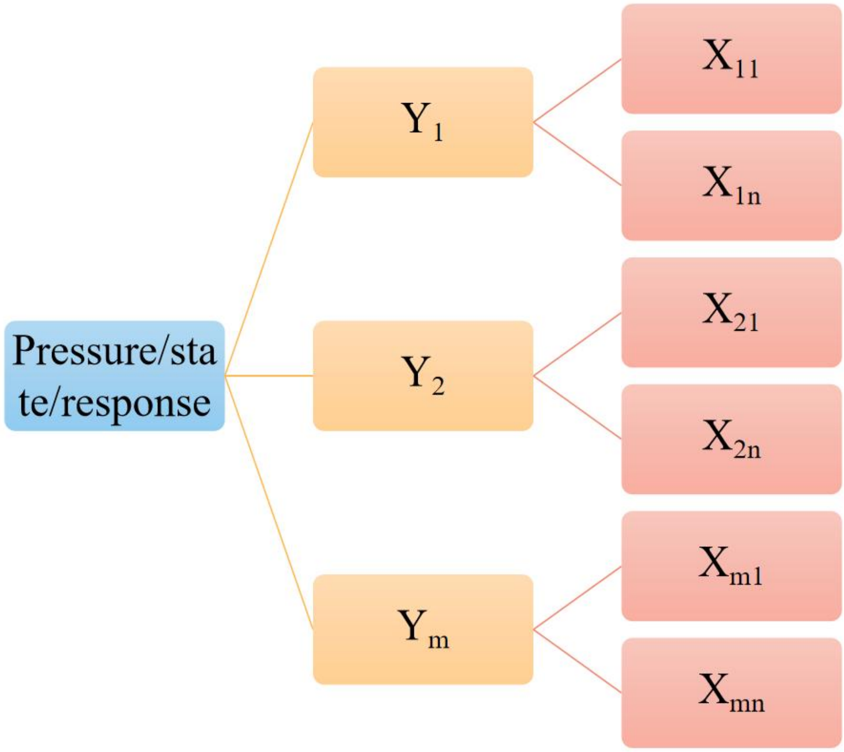

Fig 7-7 Structural hierarchy of relational analysis method

Assuming that the element $x_{i1}, x_{i2}, \cdots, x_{in}$ of the next layer is related to the target element Y_i of the previous layer, it is necessary to determine their proportion in Y_i.

According to the scores of each index, in the index set $\{x_{i1}, x_{i2}, \cdots, x_{in}\}$, the index with the highest score under the target Y_i is selected as x_{i1}^*, and then among the remaining $n-1$ indexes, the index with the highest score under the target Y_i is selected as x_{in}^* after $n-1$ selections, and the unique order relationship is as follows:

$x_{i1}^* > x_{i2}^* \cdots > x_{in}^*$

Then, the comparative judgment of the relative importance degree between indexes is given. Under the target Y_i, the ratio $w_{i,k-1} / w_{i,k} = r_{ik}, k = n, n-1, \cdots, 3, 2$ of the importance degree of the index element $x_{i,k-1}, x_{ik}$, when n is larger, $r_{in} = 1$ can be taken from formula (1).

If the rational assignment of r_{ik} obtained which satisfies the relation $r_{i,k-1} > 1/r_{ik}, k = n, n-1, \cdots, 3, 2$, then:

$$w_{in} = \left(1 + \sum_{k=2}^{n} \prod_{i=k}^{n} r_{ij}\right)^{-1}$$

$w_{i,k-1}/w_{ik}, k = n, n-1, \cdots, 3, 2$, one-to-one correspondence is made between the calculated results and the healthy ecological greening indexes of each highway, and the weights of the target layers corresponding to each index are obtained.

Determination of membership function through the presentment of input knowledge and post-processing of output structure, FNN can dissolve fuzzy concepts into the expression of knowledge input [23]. Commonly used function forms include normal distribution, rectangular distribution, trapezoidal distribution, triangular distribution, S distribution, etc. Of course, the selected distribution function should conform to the essential characteristics of fuzzy sets as much as possible. We can choose the distribution function as the membership function according to the actual situation of the problem. In this paper, Gaussian function is selected as membership function, and its definition is as follows:

$$\mu(x) = \exp\left(-\left(\frac{x-a}{\sigma^2}\right)^2\right)$$

Where a, σ is the adjustment parameter, and a, σ represents the center and width of the membership function respectively. It is very important to choose the appropriate a, σ value, which is generally determined by expert experience.

Reasoning calculation process of neural network model

Firstly, the experimental samples are input to the input layer, that is, the first layer

$x=(x_1,x_2,\cdots,x_n)^T$, where x_i represents the value of the i the input parameter. In this paper, the length, width and depth of the crack are taken as input parameters, so node $N_1=3$.

The second fuzzy layer, each node x_i of the first layer corresponds to the i -th group of nodes of the second layer, each group of nodes represents the corresponding relative membership degree, and the membership function is calculated by Gaussian function:

$$\mu_{A_i^k}=\exp\left(-\left(\frac{x_i-a_i^k}{\sigma_i^k}\right)^2\right)$$

a_i^k,σ_i^k represents the center and width of membership function respectively, and the number of nodes in the second layer is 10 nodes.

The third layer is the rule layer, in which each node represents a rule, which is used to match the antecedents of fuzzy rules and calculate the applicability of each rule. namely

$$a_j=\wedge\left(\mu^{i_1},\mu^{i_2},\cdots,\mu^{i_n}\right)$$

The number of nodes in Layer 4 is the same as that in Layer 3, that is, $N_4=N_3=36$, which realizes normalized calculation. Namely:

$$\bar{a}_j=\frac{a_j}{\sum_{j=1}^{m}a_j},j=1,2,\cdots,m$$

The fifth layer is the output layer, which realizes clear calculation, namely:

$$y_i=\sum_{i=1}^{M}w_{ij}\bar{a}_j,i=1,2,\cdots,r$$

w_{ij} here is equivalent to the weight of the membership function of the j linguistic value of y_i. Classification and quantification levels are shown in Figure 7-7:

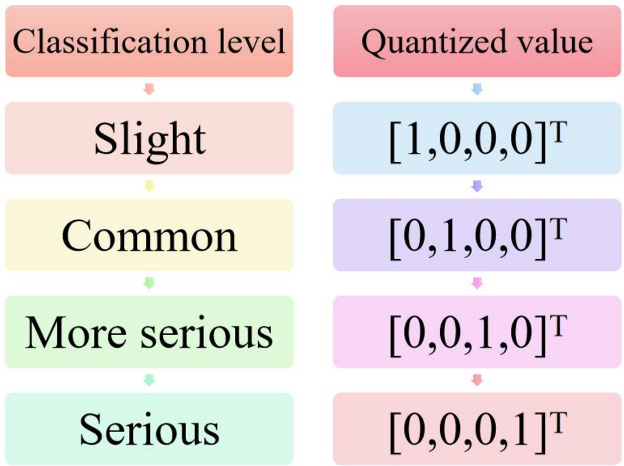

Fig 7-8 Classification and quantification level

Learning process of neural network

The learning process of FNN is also the process of determining the free parameters in the system according to the training samples. Because the free parameters set in the model are the weight matrix w_{ij} of the 4th to 5th layers, a gradient descent algorithm is used to determine the value of w_{ij}.

Specification error function:

$$e^p = \frac{1}{2}\left[f\left(x^p - y^p\right)\right]^2$$

Where $\left(x^p - y^p\right), p = 1,2,\cdots,N$ is an input-output pair in the sample set.

According to the gradient descent method, we can get:

$$w_{ij}(k+1) = w_{ij}(k) - \eta \frac{\partial e}{\partial w_{ij}}$$

Where η is the learning step, $0 < \eta < 1, i = 1,2,\cdots,r; j = 1,2,\cdots,m$.

In the learning process, the training initial value w is a matrix with 4 rows and 36 columns, and all the initial values of the matrix are 0.5. Take multiple learning steps for training, and finally determine that the value is $\eta = 0.5$.

7.4.2 Results analysis and discussion

FNN evaluation model analysis

According to the above calculation method of evaluation index values, the investigated data are calculated into three evaluation index values, which are used as the input vector of FNN, and the output vector is the urban highway healthy ecological greening factor calculated by the following methods [24].

Referring to the actual survey data, through the calculation of the corresponding formula, the measured values of the evaluation indexes of 10 groups of sample road sections, that is, the input and output vector values of FNN, are obtained.

When FNN is used to evaluate highway healthy ecological greening degree, because each index vector has different orders of magnitude and dimensions, it is not comparable and cannot be compared directly, so these evaluation indexes must be normalized and dimensionless before evaluating highway healthy ecological greening degree [25]. The data is normalized by linear function transformation method, and 10 groups of dimensionless normalized data are obtained, as shown in Figure 8-8.

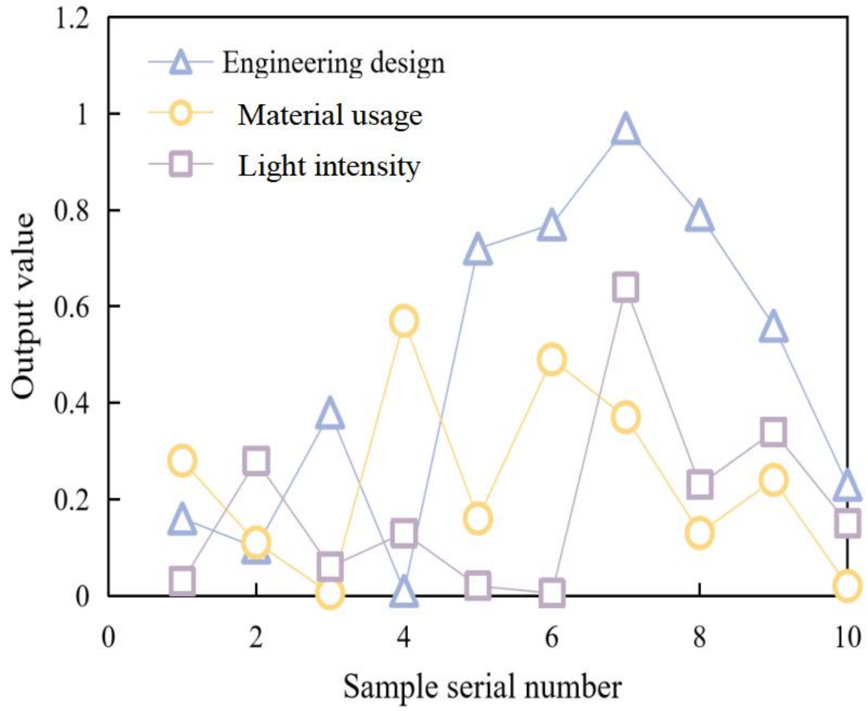

Figure 7-9 Normalized sample data

The number of input and output layers of FNN depends on the established evaluation index system of heating potential. Five groups of sample data are taken as training data, and the expected error is 0.000001. Since the process of establishing the network is the training process, the network obtained at this time is already trained. After the training is completed, simulate the trained network. Comparing the result with the value (true value) calculated by the heating potential factor, the evaluation result of this neural network is shown in Figure 7-10.

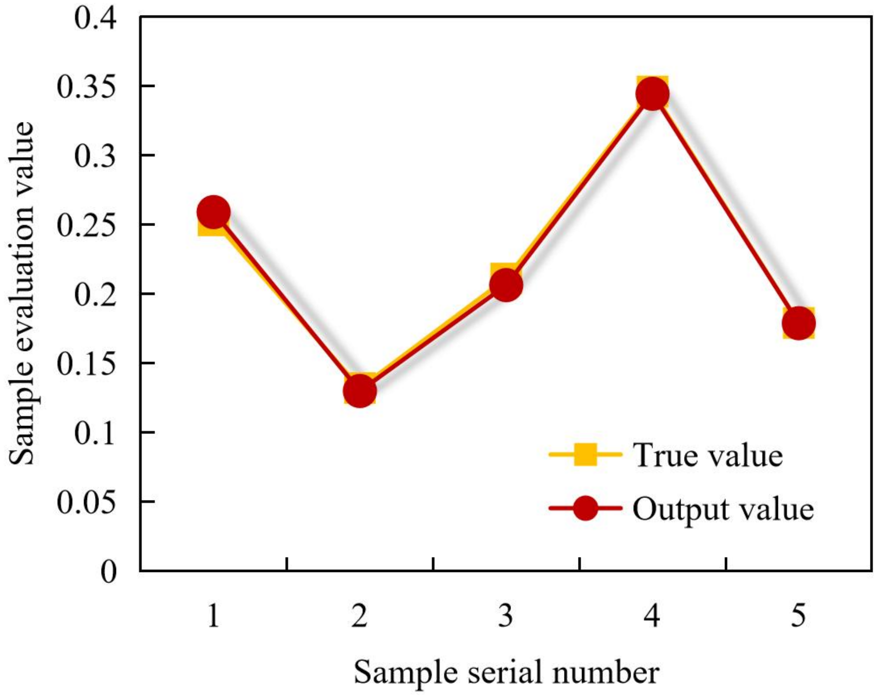

Figure 7-10 Sample evaluation results of FNN

The training results show that this FNN is a radial basis function neural network with good performance, fast convergence speed, small training error and high calculation accuracy, which shows that this evaluation model is reasonable and reliable, and can be used to evaluate the heating potential.

According to the trained FNN with good performance mentioned above, first normalize the traffic operation index survey value of the sample road section to be evaluated in the same time period (together with the training sample and test sample data), and then input it into the trained FNN. The output result is shown in Figure 8-10.

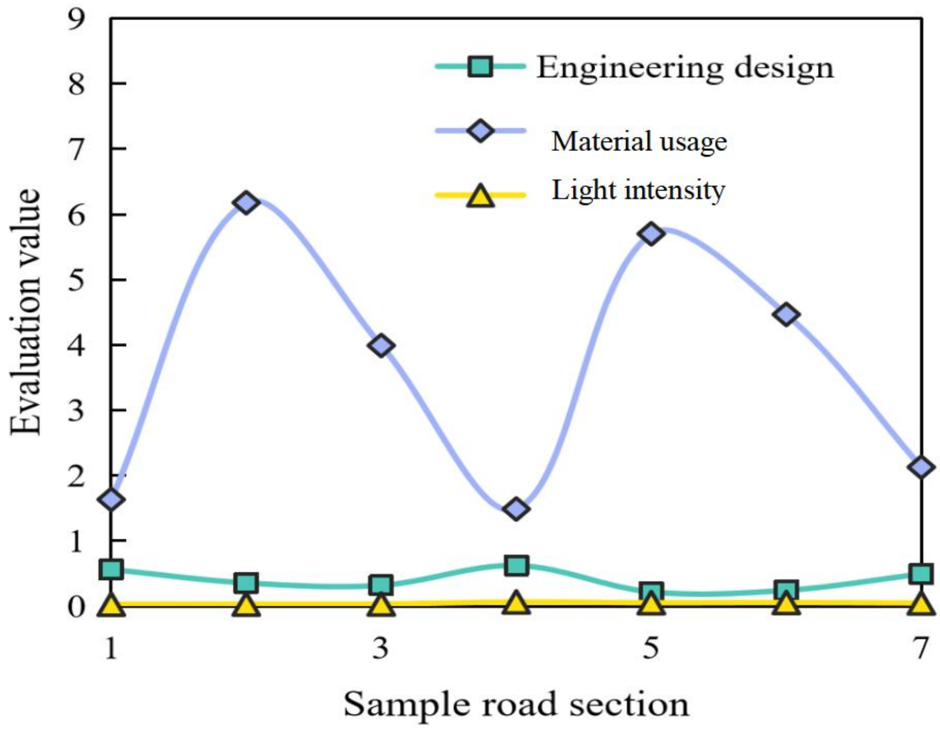

Figure 7-11 Evaluation results of heating potential index

Hierarchical analysis of relational analysis structure

According to the weight calculation method described in the previous article, the weight value of heating potential evaluation index system is calculated by using the order relation analysis method. According to the total score of each index, the relationship is sorted, and the weight of each index of case engineering is obtained by using the sequential relationship analysis method. Details of the evaluation results are shown in Figure 6, and those in the construction and operation stage are shown in Figure 8-11.

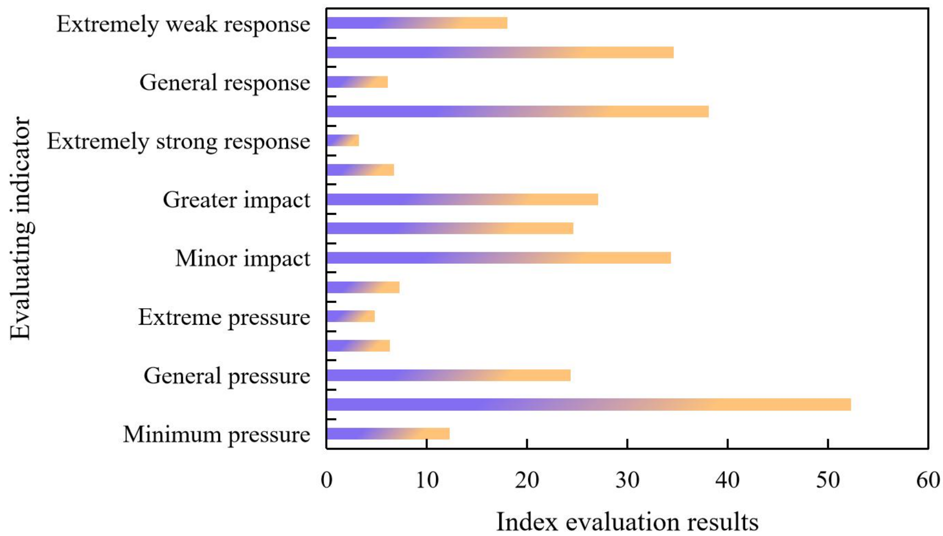

Figure 7-12 Evaluation results in planning and design stage

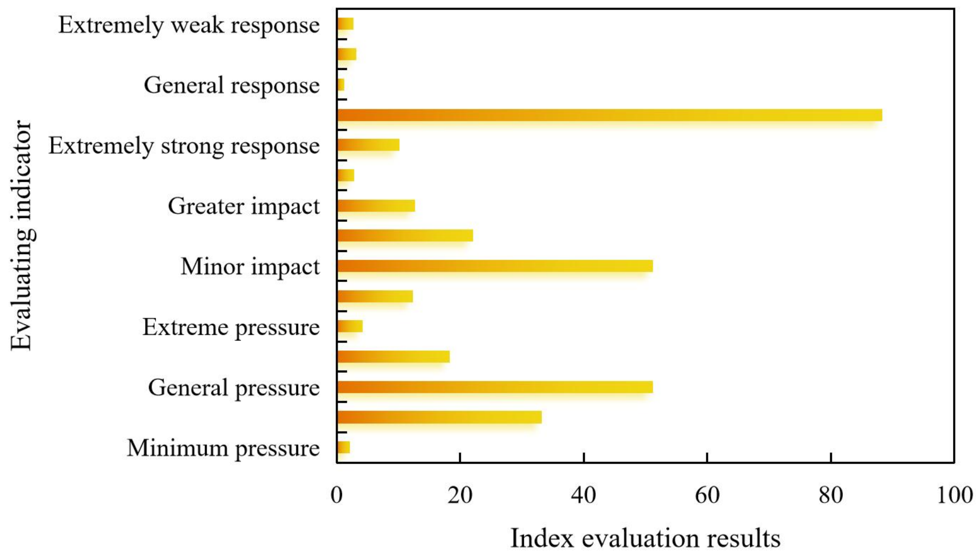

Figure 7-13 Evaluation results of operation stage

Then the degree of membership corresponding to the comprehensive evaluation of heating potential (dark green, green, fresh green, light green and yellow) is (0,0.341,0,0.656,0), which shows that the case project is considered as green at the planning and design stage of 33.4% and light green at 65.6%. According to the evaluation results, the heating potential of the project in the planning and design stage is light green.

Then the corresponding membership degree of the comprehensive evaluation of heating potential (dark green, green, bright green, light green, yellow) in the construction and operation stage is (0,0.646,0.337,0,0), which shows that the ratio of project in the construction and operation stage is considered as green 64.6%, and the ratio of it is considered as bright green 33.7%. According to the evaluation results, the greenness of the project in the construction and operation stage is green.

According to the criteria of heating potential, this paper establishes FNN (Fuzzy Neural Network) evaluation model of heating potential, and takes data of inner and outer air layer thickness as sample input model for fuzzy evaluation, and obtains the evaluation result of heating potential. The experimental results verified the feasibility and applicability of FNN model, and put forward the suggestions of heating according to the indexes in each stage.

7.5 Summary

The general expression of this chapter is the analysis of the energy consumption of the double mezzanine TROMBE wall. This chapter describes the energy consumption of this experiment through two expressions. During the whole life cycle of a building, the energy consumed by building materials and the construction process generally accounts for only about 20% of its total energy consumption, with most of the energy consumption occurring during the operation of the building. Therefore, building operation energy consumption is the main concern in the task of building energy efficiency. This is why this chapter has been sensibly sub-chapters. The conclusions obtained are as follows

1, Regarding the energy consumption of the building operation, we have listed the hour-by-hour energy consumption of the double mezzanine TRombe wall in January and the cumulative energy consumption. Through the above analysis, we can conclude that when the temperature difference is 1°C, the energy consumption is 12.81 kW/㎡, with an energy saving rate of 1.15%, and when the temperature difference is 2°C and 3°C, the energy consumption is 13.25 kW/㎡ and 13.69 kW/㎡ respectively, which does not achieve the energy saving The energy saving effect is not achieved. This is because at 0°C, although there is no negative temperature difference between the cavity temperature and the room temperature, the cavity is conceptually a duct inside the HVAC and the air is dissipated or even stored again in the wall during the transmission process, which makes the temperature inside the room after passing through the cavity slightly lower or even lower than the room temperature. This not only does not save energy, but may also increase the thermal load. When the temperature is 1°C higher (it may be slightly higher if it is lower, but this simulation is based on a temperature difference of 1°C, so this conclusion can only be drawn from the simulation.)

2, Sensitivity analysis, the significance of this chapter is to verify that ventilation patterns do affect indoor temperature and energy consumption by means of sensitivity analysis, as an aid to give realism to the simulation, the conclusions drawn.

The different ventilation schemes have an arc mean elasticity on the heating energy consumption values under the building unit area. Internal circulation 0 indicates ventilation by internal circulation at a temperature difference of 0°C, other cycles are the same. Internal and external circulation 1 indicates ventilation by both internal and external circulation at a temperature difference of 1°C. As can be seen from the above, the sensitivity of the type of cycle to the heating energy consumption value per unit area of the building is very high, reaching a minimum of 10.8%, while the sensitivity of the temperature difference to the heating energy consumption value per unit area of the building is relatively low for the same type of cycle (e.g. internal and external cycles 0-3). Thus the accuracy of the above data trends is also verified in terms of sensitivity analysis.

3, The FNN evaluation model is at the heart of the heating potential. It is designed with the idea of expressing fuzzy rules and membership functions using neural networks and using the generated neural networks for fuzzy reasoning. The final determination of the feasibility of the scheme and the overall energy saving evaluation concluded that the project is 64.6% green and 33.7% bright green during the construction operation phase. Based on the evaluation results, the project is green during the construction and operation phases. It is a very energy efficient experimental design .

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Chapter 8

CONCLUSION AND PROSPECT

CHAPTER 8 CONCLUSION AND PROSPECT

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8.1 Conclusion

Energy is the basis for social development and human survival, the structure of primary energy consumption has diversified, and the use of renewable energy has played an indispensable role in alleviating the energy crisis. However, the reserves of fossil energy are limited, and the amount that can be easily exploited is getting smaller and smaller. In the long run, an energy crisis is inevitable, and an important measure to solve the energy shortage and environmental problems is to increase the proportion of renewable energy in the primary energy consumption structure. In China, although oil, natural gas and other high-quality fossil energy resources are abundant, but because of the uneven distribution of these energy sources and the difficulty of extraction, can not meet the needs of the current rapid development of China's economy, still need to import

As the technological development of renewable energy applications continues to mature and benefit from decreasing costs, renewable energy is receiving attention from countries around the world. Many countries have made the attribution of renewable energy an important part of their long-term energy development strategies. The European Union has developed a series of policies to encourage the application of renewable energy in various sectors. In 2010, renewable energy accounted for 2% of primary energy consumption in all major European countries, and member states have reached an agreement to increase this to 20% by 2020, with plans to reach 50% by 2050.

Trombe wall is also called heat collecting wall. The function of this kind of building is to improve the living environment of people in cold areas. Because the land area is very vast, some areas will be in the low temperature zone, and the living environment of the local residents is difficult for the human body to cope with alone, which makes the local people take precautions against the severe cold environment in which they are located . Such a natural environment makes the demand for buildings such as the Trombe wall always exist. Similar to this, traditional buildings built to improve the living environment have developed a lot, and some are still solving the living environment and climate problems for local people

Chapter 1: Energy status and research significance

The first chapter focused on the progressive progression from world energy to building energy consumption in the harsh northern regions of China, with the main conclusions being.,In many developed countries, energy consumption in buildings is even greater than that in industry and transport. At the same time, surveys show that such high building energy consumption in China is caused by numerous factors, but even more so, it shows the huge potential for building energy efficiency in China. The combination of solar energy application technology and high energy consumption in buildings is an important measure to reduce the proportion of fossil energy in building energy consumption and an important condition to ensure the sustainable development of our economy.

Chapter 2: CURRENT DEVELOPMENTS IN THE APPLICATION OF RENEWABLE ENERGY AND THE DEVELOPMENT OF THE TROMBE WALL

Solar energy is energy emitted by the sun and transmitted to the earth's surface in the form of electromagnetic radiation, which can be converted into heat and electricity through photo thermal and photoelectric conversion. The basic forms of indirectly beneficial heat collection are: Trombe walls, water walls, water-carrying walls (water-filled walls) with additional sun rooms, etc. Here we focus on the Trombe l Wall.The double layer Trombe wall is less studied in colder regions and, thanks to the inner wall, it reduces heat loss very well.

Chapter 3: SIMULATION OF THE EFFECT OF A DOUBLE LAYER TROMBE WALL UNDER THE ACTION OF A DC FAN USING ENERGY PLUS

This chapter is devoted to the simulation of data with the ENERGY PULS software and prepares the ground for the comparison of experimental data in the next chapter, which introduces theoretical knowledge from two aspects: one is the theoretical knowledge of the software and the other is the knowledge of the operation mechanism of the TROMBE wall.

Chapter 4: EXPERIMENTS ON THE WINTER HEATING MODE OF THE DOUBLE LAYER TROMBE WALL SYSTEM

This chapter focuses on the design of the experimental room, the design of the experimental room in the cold region is different from other regions, the heat loss in the cold region is more serious, so in order to ensure the success and authenticity of the experiment, we have adopted the standard energy-saving insulation design.

Chapter 5: STATISTICS AND ANALYSIS OF EXPERIMENTAL DATA

This chapter has documented a lot of data, and through comparison it was found that the simulation data is realistic, and secondly.This chapter mainly investigates and analyses the optimum opening temperature of the fan and the optimum air velocity. In the event of a shortage of heat sources, it is possible to achieve temporary office occupancy by some auxiliary means and this design reduces the consumption of coal.

Chapter 6: OTHER FACTORS AFFECTING THE DOUBLE SANDWICH TROMBE WALL

This sheet focuses on other factors affecting the double sandwich TROMBE WALL, mainly the thickness of the external walls, the height and thickness of the air layer, and the thickness of the internal walls are listed for comparison.The main conclusions are that the optimum outer air layer thickness is 200 mm, the optimum inner wall thickness is 90 mm and the optimum fan speed is 90 m^3/h.

Chapter 7: ENERGY CONSUMPTION ANALYSIS OF A DOUBLE SANDWICH TROMBE WALL IN WINTER IN A SEVERE COLD REGION

The general expression of this chapter is the analysis of the energy consumption of the double mezzanine TROMBE wall. This chapter describes the energy consumption of this experiment through two expressions. During the whole life cycle of a building, the energy consumed by building materials and the construction process generally accounts for only about 20% of its total energy consumption, with most of the energy consumption occurring during the operation of the building.

8.2 Prospect

1,Conduct research on low carbon construction technologies and promote their application. Focused research on low carbon materials, particularly cementation materials that can replace high carbon emitting cement materials, such as polymers, which can significantly reduce the carbon emissions caused by cement production.emissions from cement production. There is also a need for research into efficient construction equipment, low carbon construction techniques, low-carbon building construction forms, low-carbon demolition, and the and waste water, and ways to extend the life of buildings and The research should also look at ways to extend the life of buildings and increase the life of working materials. In addition, carbon reduction technologies should be researched in relation to regional characteristics.The research should take into account the differences in temperature between the north and the south, and the differences between arid and humid zones, so as to In addition, carbon reduction technologies should be tailored to regional characteristics, taking into account differences in temperature between the north and the south, and between arid and humid zones.The advantage of the double mezzanine TROMBE WALL in colder regions is that the internal walls improve the outflow of heat, but for market use it is better to make an assembled wall, which is simple, economical and more useful.

2,The design of the building form should also implement the principle of energy saving and emission reduction, in order to implement this more efficiently and scientifically, designers are required to choose materials and colors that are truly suitable for the overall planning of the building according to the structure of the wall in their daily work. More importantly, it is necessary to improve the function of the building while being aesthetically pleasing, and to reduce the consumption of energy in building construction as far as possible, so as to realize the concept of green development and sustainable development. In practice, building designers can realize the construction of green and energy-saving networks according to the characteristics of walls and roofs, so that the whole building can practise the concept of environmental protection and energy saving, and maintain the quality of construction works while producing a positive effect on the construction of the local ecological environment. For example, in the design of thermal insulation, overheads, cladding and water storage can be effectively integrated into the architectural design process, which not only ensures the aesthetics of the building and gives it an aesthetic effect, but also enables the efficient use of sunlight and water resources, thus realizing the rational use and control of resources and reducing the waste of resources to a large extent. The design requires active exploration and excavation of new resources and energy-saving resources, etc. In the actual construction, according to the characteristics and features of the resources, reasonable building materials can be selected in the construction of specific buildings, and the effective use and selection of resources can also be released according to local conditions. For example, in the construction of solar energy and other resources can be used to achieve the use of water heaters, through the effective absorption and use of the sun's light source so that it can be converted into heat in practice, to further meet the needs of people's lives for hot water, to a certain extent to achieve the effective replacement of electricity, in line with the concept of low-carbon environmental protection in construction project.

3,The double sandwich TROMBE WALL can be used in more retrofitting projects in old houses.The development of the external coating has a great influence on the double sandwich Trombe wall, and a lighter and more efficient heat-absorbing coating would make the Trombe wall more effective.

4,Renewable energy can reduce the loss of other non-renewable energy sources, can reduce the building's carbon footprint and reduce the pressure on the ecological cycle. For example, if the area where the building is located is colder all year round, the building can be heated by a combination of solar energy and ground source heat pumps, especially in higher latitudes where the average daily heating time is longer and the building is heated for 1/2 of the year, and the building is under greater heating pressure. Based on this, the building can be equipped with solar equipment on the roof of the building to take advantage of the light conditions for building electricity supply and to maximize the conversion of solar energy. In addition, under the future development plan of the carbon cycle and carbon peaks, science and technology innovation will drive more focus on the conversion and efficiency of new clean energy sources such as solar energy, reducing the cost of building development and use, and achieving near-zero energy consumption in buildings.

5.On the effect of indoor humidity on heat transfer performance

Simulation of humidity by simulating a traditional simple Trombe wall in a traditional over Chinese flat.The temperature change in the room is related to the temperature moderation. The experiments revealed that the temperature difference between day and night is extremely high because the area where the experiments were carried out is a cold area, and the difference in temperature between the air layer during the day and the night is 40 degrees, which causes a lot of dew to adhere to the outer glass and affects the temperature transfer..windows is greatly affected by the outdoor, especially during the period of light rain, the relative humidity of the outdoor and doors and windows is large when the doors and windows are opened, the maximum outdoor is 88.9%, and the indoor is 80.89%.