Doctoral Dissertation

Research on building envelope for energy conservation by corncob materials in Qingdao Liyuan buildings

Huang Yi

2019DBB012

Graduate School of Environmental Engineering

Dewancker Bart Lab

The University of Kitakyushu,Japan

Forewords

Cities normally thrive on the opportunities for jobs and entertainment, filled with various convenient goods and services. Facing the great challenge from the virus threat and new living mode with social community distance, what we need is a new solution of 'contracting space. As the diversity between different countries and culture, architects and engineers are called for to conceive a healthy living environment where we can calmly and safely live together.

How the building environment express impacts on human beings' daily lives, how the building performance connect with the society attract interests in major research concerns. Meanwhile, sustainability embodied within existing buildings are considered more sensitively with environmental engineering scope. Architects and engineers are encouraged to penetrate different fields and industries from their focused subjects, such as architecture, construction, as well as other political social aspects on the general public. At the same time, it is believed that the materials, space and cultural characteristics of the building enable us to inspire them together.

It is obviously necessary to build up more inclusive social housing and facilities to achieve a safe living condition within interconnected urban environment. 2020 could be considered as a milestone bridging into a different future, many countries and cities have set new visions to prepare for the new challenge of epidemic prevention and energy shortage in the future. A proper systematic approach on restoration projects is crucial in the preservation of existing buildings.

The author presents this renovation project with sustainable assessment and express the sustainability embodied the contemporary buildings. The paper is expected to contribute the experimental calculation by building performance simulation and illustrated the properties embodied in the contemporary buildings and discusses the unity through restoration.

Abstract

This study investigated and optimized the energy-saving and indoor environmental conditions of Liyuan houses in Qingdao, China, with a trial of corncob material. Through literature review, in-field survey and experimental simulation, both of the energy saving characteristics and the indoor thermal environment of Liyuan houses were analyzed. The renovation methods of buildings for energy-saving and indoor environmental comfort improvement were carried out. It proved the insulation renovation could effectively improve building energy performance and indoor comfort. Meanwhile, agricultural wastes are treated as alternative supplement with consideration of realistic shortage of natural resource. Corncobs and construction wastes are co-processed to prepare recycled aggregate composite ecological concrete. With comparative analysis of the results, it discussed the feasibility of the corncob material as an energy-saving material. In conclusion, the envelope renovation with application of ecological concrete could improve the indoor environment with longer comfort time and reduce energy consumption.

The chapter 1 is to construct the background, to identify the state of energy consumption and to arise the purpose of the study. Using analytical methods, including global warming, more energy consumption in traditional buildings and the current status of corncobs in China is summarized. The status quo of traditional buildings makes designers rethink the issues of building comfort and building energy consumption reduction. The large number of corncobs production in China with relatively low cost, it provided possibility to study whether these materials can be used for building energy-saving renovation.

The chapter 2 is to propose the necessity of cultural relics' protection and the background knowledge for possibility of using agricultural wastes as energy-saving materials. The literature data collection and arrangement methods were used. There are many laws and regulations on the protection of cultural relics, especially emphasizing the regulations on energy consumption and residential suitability; there are also many academic contributions on corncobs or other agricultural waste materials used as energy-saving materials at home and abroad, which provide academic support to the research of this topic.

The purpose of the chapter 3 is to construct the whole method system. The research process is divided into two stages and three levels. The first stage is research hypothesis and investigation. The second stage is the field investigation. The research work is divided into three levels: investigation on the overall layout and situation of the courtyard with opinion polls; combination of possible materials for wall renovation;

simulation of envelop renovation with different materials. It provided the feasibility of the corncob material as an energy-saving material.

The chapter 4 described field investigation and questionnaire analysis, with purpose to reveal the current situation of architecture and living condition. It explained necessity of renovation and the starting point of material selection. The bad thermal comfort of Liyuan houses, and poor thermal performance of the envelope structure required serious renovation in the envelope structure; while the residents have lower incomes, they prefer materials with safety and economy, therefore, it is practical to apply energy-saving materials with low cost.

The chapter 5 is to conduct experiments on corncob materials, with the purpose to confirm the basic properties of corncob concrete materials. As the volume content of the corncob increases, the independent pores in the ecological concrete structure increases, the air content inside the concrete increases, and the thermal conductivity of the ecological concrete decreases. In general, the corncob concrete material with the cement-sand ratio 1:4, the water consumption of 218.3kg/m^3 and the corncob volume of 50% was selected, the suitable thermal conductivity was 0.18 (W/(m·K)).

The chapter 6 used energy consumption software to conduct simulation experiments, which tested whether the new recycled concrete can be used as an energy-saving material. The simulation software used are Ecotect, ladybug and honeybee, and three different peripheral structure coefficients are set respectively for experiments. With comparative analysis of the results, it proved that the corncob concrete blocks can perform better as an energy-saving material, which improves the thermal comfort of the Liyuan houses and reduces energy consumption.

The chapter 7 is the general summary of the thesis, which lists the main content of each chapter and clarifies the acquisition of the thesis. In general, the large quantities of Corncobs production in China and with low cost provided great potential application of agricultural waste as construction material. Corncob concrete can replace traditional bricks and stones as an energy saving material. It can also improve the indoor environment with longer comfort time. It can play an important role in the practical renovation of traditional buildings.

LIST OF CONTENT

LIST OF FIGURES

LIST OF TABLES

Chapter 1.

Background and Purpose of This Study

1.1. Introduction

Many countries have realized the growing crisis from intensive energy consumption and environmental problem. There reached an agreement on developing a new "sustainable" strategy that can satisfy human development demands and simultaneously sustain the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depend.

In recent years, with the rapid advancement of social development and urbanization, China has been paying more and more attention to the use of heritage houses, striving to change the living conditions of traditional houses. Improving the living environment in traditional areas and building beautiful and habitable spaces are essential in implementing the revitalization strategy.

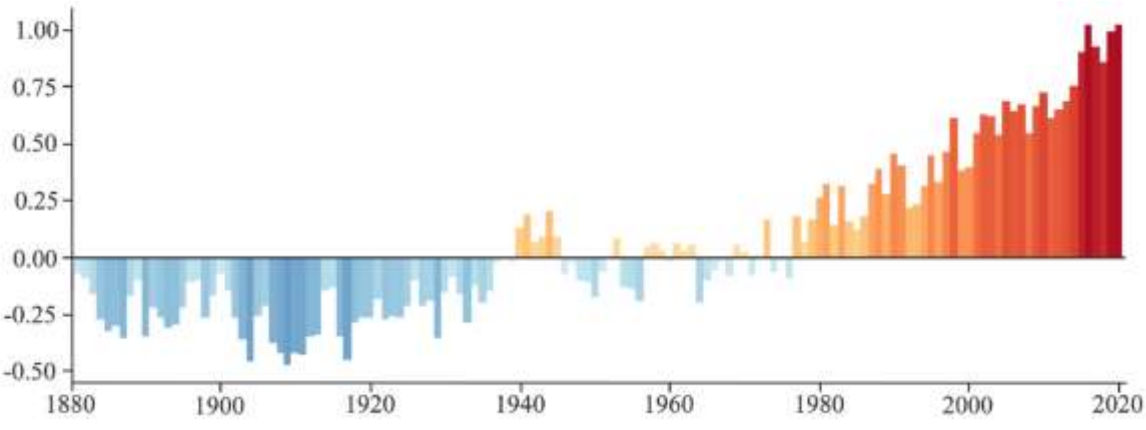
As the foundation for improving the living environment, energy-saving of buildings has a significant meaning in reducing energy consumption, improving the quality of life, and promoting the achievement of carbon peak and carbon-neutral targets and the green and sustainable development of the heritage houses. Because of the unique geographical environment and climatic conditions in cold areas of China, the traditional houses cannot meet the requirements of heat preservation.

There are huge differences between traditional buildings and modern society in terms of social structure, economic conditions, and population density, which means that traditional construction methods are difficult to use directly. The suitability of traditional architecture to the local human environment, geographical conditions, customs, local building materials, and construction technology is essentially the same as the construction concept of sustainable architecture, but it is relatively backward in technology. Based on modern science and technology, systematically excavate and sort out the regional construction wisdom of traditional buildings and use new materials to organically combine them with the construction of modern energy-saving and sustainable buildings. It is also one of the effective ways to realize the sustainable development of traditional architecture.

1.2. Research background

1.2.1. The state of energy consumption

With the background of global climate change and rapid urbanization, the deterioration of the human environment and energy shortage have become hot issues. In recent years, environmental damage has become increasingly severe, with carbon emissions exceeding the limit, leading to rising global temperatures and sea levels and extreme temperature events occurring frequently. Climate change has become a hot issue in the environment and health internationally. Air temperatures on Earth have been rising since the Industrial Revolution. While natural variability plays some part, the preponderance of evidence indicates that human activities—particularly emissions of heat-trapping greenhouse gases—are mostly responsible for making our planet warmer. According to an ongoing temperature analysis led by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by at least 1.1° Celsius (1.9° Fahrenheit) since 1880. The majority of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20°C per decade. The global temperature anomalies greatly in 2021, which is the 6th warmest year on record. Nine of the ten hottest years or record have occurred in the past decade[1] (Figure 1-1).



2021 ties 2018 for the sixth warmest year on record

Global temperature anomaly

Figure 1-1. The global temperature anomaly statistics (1880-2021)

Energy-saving and emission reduction have become urgent issues to be solved worldwide. Reducing energy demand is one major aspect of reducing emissions. If less energy is needed, there is more flexibility for clean energy development. In the building sector, the focus is on the better design of new buildings and higher levels of energy efficiency in retrofitting[2]. The use of technologies can also increase building energy efficiency[3].

The 2020 Buildings Global Status Report updates the drivers of CO_2 emissions and energy demand globally since 2018, along with examples of policies, technologies, and investments that support low-carbon building stocks. The buildings and construction sector moved away and not toward the Paris Agreement goal of keeping the global mean temperature rise to well below 2 °C. While the total final energy consumption of the global buildings sector remained at the same level in 2019 compared to the previous year, CO_2 emissions from the operation of buildings have increased to their highest level yet at around 10 Gt CO_2, or 28% of total global energy-related CO_2 emissions. With the inclusion of emissions from the building construction industry, this share increases to 38% of total global energy-related CO_2 emissions. The slightly lower proportion of buildings emissions compared with the 39% seen in 2018 was due to the increases in transport and other industrial emissions relative to buildings[4] (Figure1-2 , Figure 1-3).

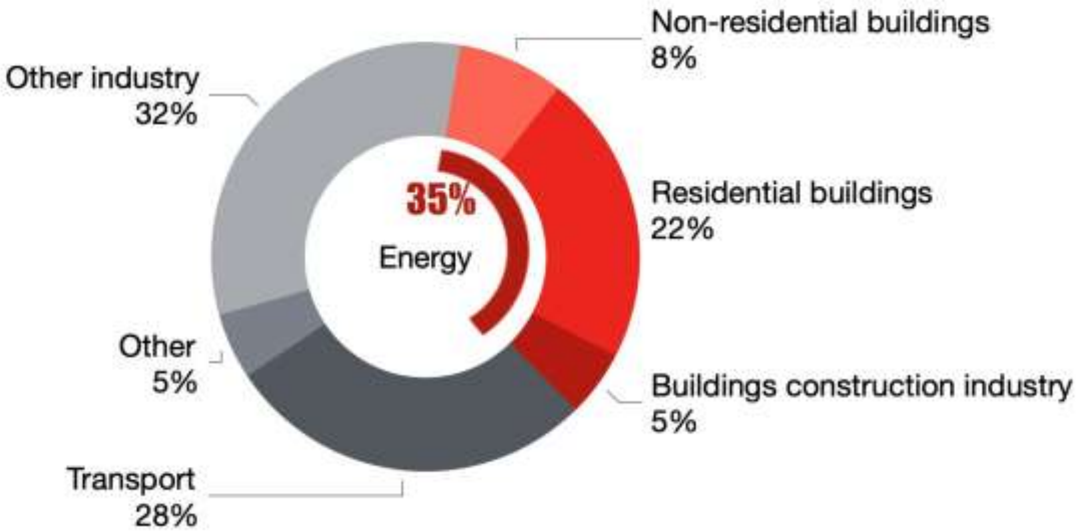


Figure 1-2. The construction industry is the portion of the overall industry devoted to manufacturing building materials (estimated)

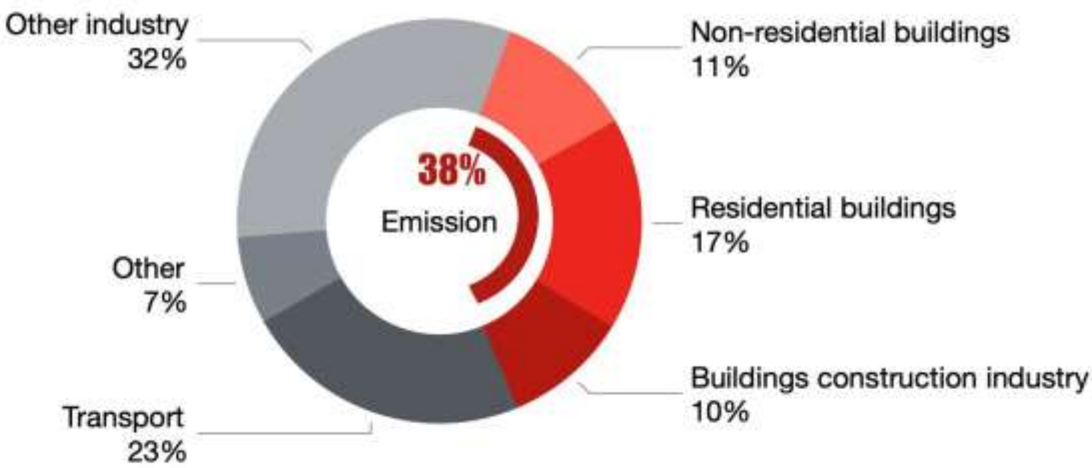


Figure 1-3: The indirect emissions from power generation for electricity and commercial heat (estimated)

The buildings sector emission increase is due to the continued use of coal, oil, and natural gas for heating and cooking combined with higher activity levels in regions where electricity remains carbon - intensive, resulting in a steady level of direct emissions but growing indirect emissions. Electricity consumption in building operations represents nearly 55% of global electricity consumption. This underlines the importance of a triple strategy to aggressively reduce energy demand in the built environment while decarbonizing the power sector and implementing materials strategies that reduce lifecycle carbon emissions, which together will drive down both energy demand and emissions.

1.2.2. Population composition and energy consumption

Many countries have realized the growing crisis from intensive energy consumption and environmental problem. There reached an agreement on developing new "sustainable" strategy which can both satisfy human development demands and simultaneously sustain the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depends [5].

On September 25, 2015, the United Nations Summit on sustainable development was held at its headquarters in New York. At the summit, 193 member states of the United Nations officially adopted 17 sustainable development goals. These sustainable development goals aim to completely solve the development problems in the three dimensions of society, economy and environment in a comprehensive way from 2015 to 2030 and turn to the path of sustainable development.[6].

The new changes in living mode brought greater population movement tendency toward cities. Based on the data obtained from official webpage at National Bureau of Statistics in China (Table 1-1), the urban population was continuous increasing in the past 20 years, while the rural population was kept declining. There is an obvious trend line from the plotted data figure of the general variation in the population (Figure 1-4). The situation of fast urbanization is calling for more construction projects to meet the basic residential demand and better living environment in the urban development.

Table 1-1. The Population Data from National Bureau of Statistics of China
(Resource: https://data.stats.gov.cn/english/adv.htm?m=advquery&cn=C01,) [Accessed in 2021.11.30])
(The situation of fast urbanization is calling for more construction projects to meet the basic residential demand and better living environment in the urban development.)

Indicators	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001
Total Population (year-end) (10000 persons)	141,178	141,008	140,541	140,011	139,232	138,326	137,646	136,726	135,922	134,916	134,091	133,450	132,802	132,129	131,448	130,756	129,988	129,227	128,453	127,627
Urban Population (10000 persons)	90,199	88,426	86,433	84,343	81,924	79,302	76,738	74,502	72,175	69,927	66,978	64,512	62,403	60,633	58,288	56,212	54,283	52,376	50,212	48,064
Rural Population (10000 persons)	50,979	52,582	54,108	55,668	57,308	59,024	60,908	62,224	63,747	64,989	67,113	68,938	70,399	71,496	73,160	74,544	75,705	76,851	78,241	79,563

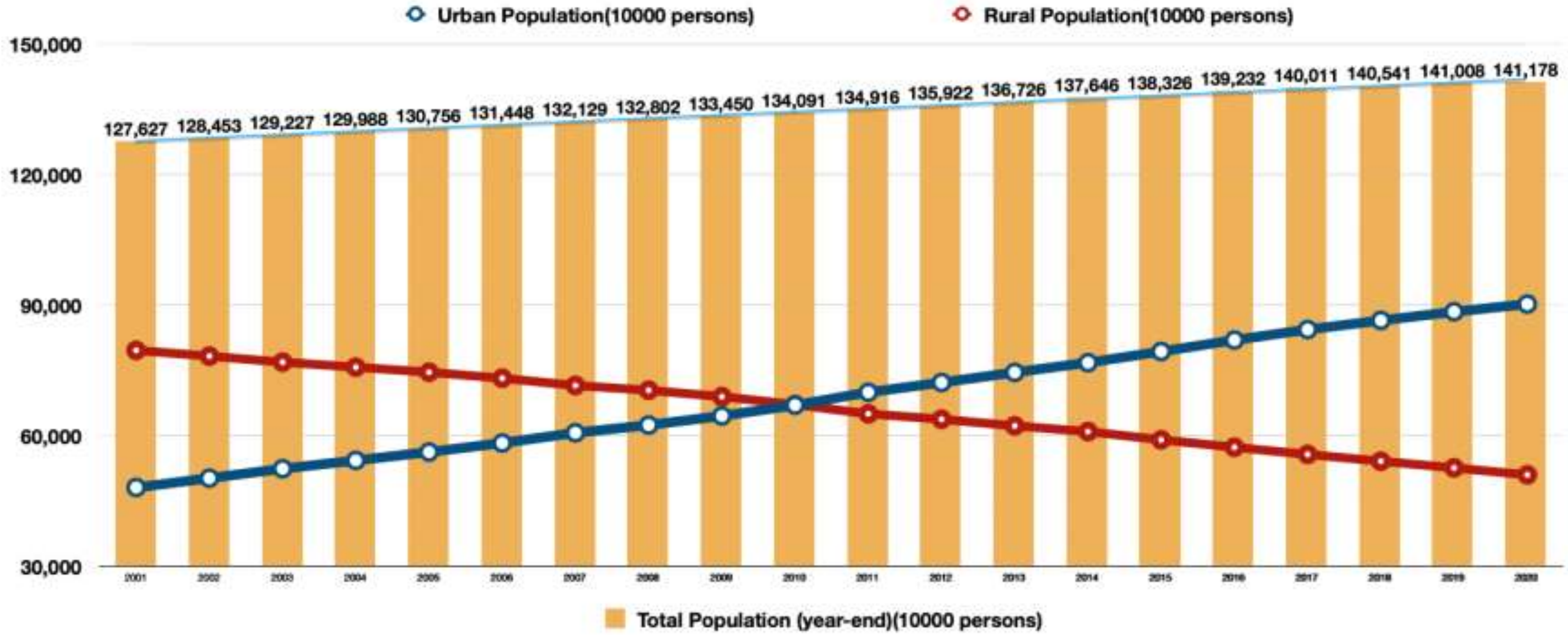


Figure 1-4. The total population data of past 20 years from National Bureau of Statistics of China
[Same resource as Table 1-1, Accessed on 2021.11.30].

With the rapid development of the economy, people's requirements for the quality of life are getting higher and higher, and the per capita residential floor area in China: 2019 urban data report is 39.800 square meters. This is an increase from the previous 2018 of 39.000 m^2. China's per capita residential floor area: Urban data is updated annually, from December 1956 to 2019, with an average of 17.780 square meters, with 41 observations. The figure hit an all-time high of 39.800 m^2 in 2019[7] (Figure 1-5). Existing houses generate a lot of energy consumption, mainly including heating energy consumption and daily energy consumption such as daily lighting, cooking, domestic hot water, home appliances, and air conditioners. The energy supply is under enormous pressure. In 2020, the Energy Consumption Statistics Committee of the China Building Energy Conservation Association released the "China Building Energy Consumption Research Report[7]" in Shanghai. Consumption of energy reached 4.98 billion tons of standard coal equivalent, up by 2.2% compared to 2019 [8], 56.8% of the total. Energy consumption and carbon emissions from building operations also tend to rise.

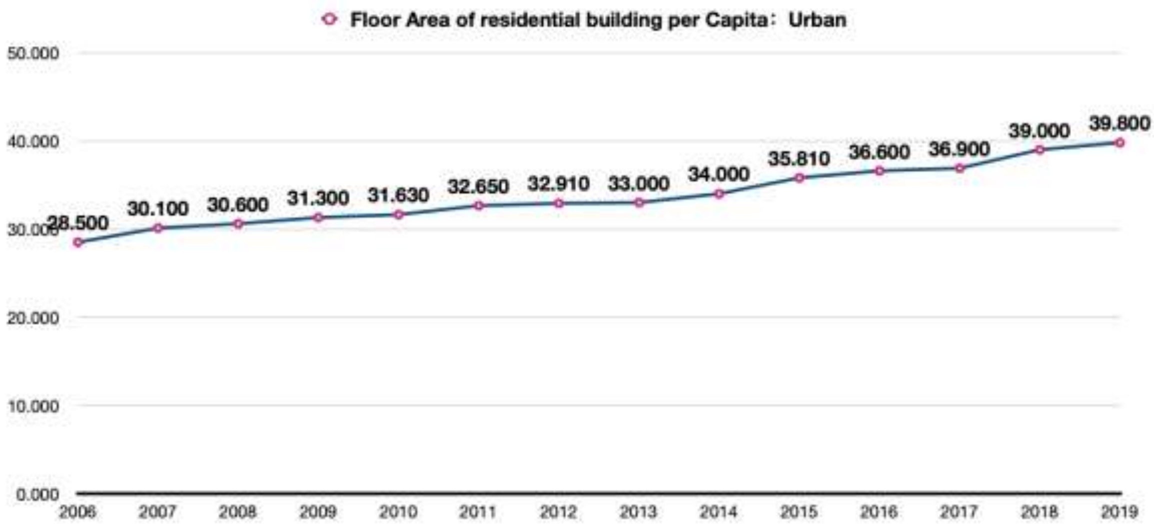


Figure 1-5. The urban floor area of residential building per capita in China

1.2.3. Development and energy consumption

China ranks second in world building energy consumption and first in residential energy consumption [9]. China is undergoing rapid urbanization and unparalleled urban construction. Rapid urbanization, population growth and increase in residents' disposable income are also accompanied by the continuous expansion of building area and related energy consumption. Consequently, this has led to a dramatic increase in energy use and corresponding emissions in the building sector, especially in the urban residential building sector. Energy conservation and emission reduction in the building industry is directly related to China's commitment to peak greenhouse gas emissions, and the rapid growth in building energy consumption also poses a huge challenge to China's energy conservation and emission reduction.

With the continuous development progress in urbanization, there are certainly increasing demand for better living environment. The building sector has become the biggest portion in total energy consumption in Chinese energy resource structure. Take 2017 as example, China's total building energy consumption was 947 million tons of standard coal, accounting for 21.10% of the country's total energy consumption, of which public building energy consumption was 363 million tons of standard coal, accounting for 38.37% of total building energy consumption; urban residential buildings Energy consumption is 361 million tons of standard coal, accounting for 38.09%; rural residential building energy consumption is 223 million tons of standard coal, accounting for 23.55% (Figure1-6).

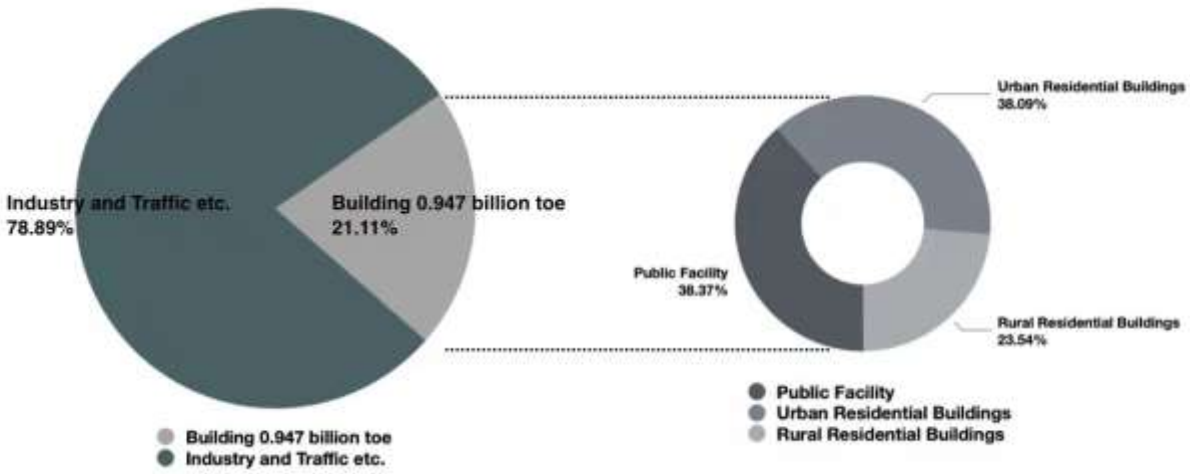


Figure 1-6. The national energy consumption proportions in China

The total amount of building energy consumption shows a continuous growth trend, but the average annual growth rate slows down significantly during the 10 years' period from 2005 to 2015. Based on the National Annual Energy Report, from 2000 to 2017, the total construction energy consumption in the country showed a continuous growth trend, from 288 million tons of standard coal equivalent in 2000 to 947 million tons of standard coal equivalent in 2017, which is an increase of about 3.2 times in number, with an average annual increase of 7.25%.

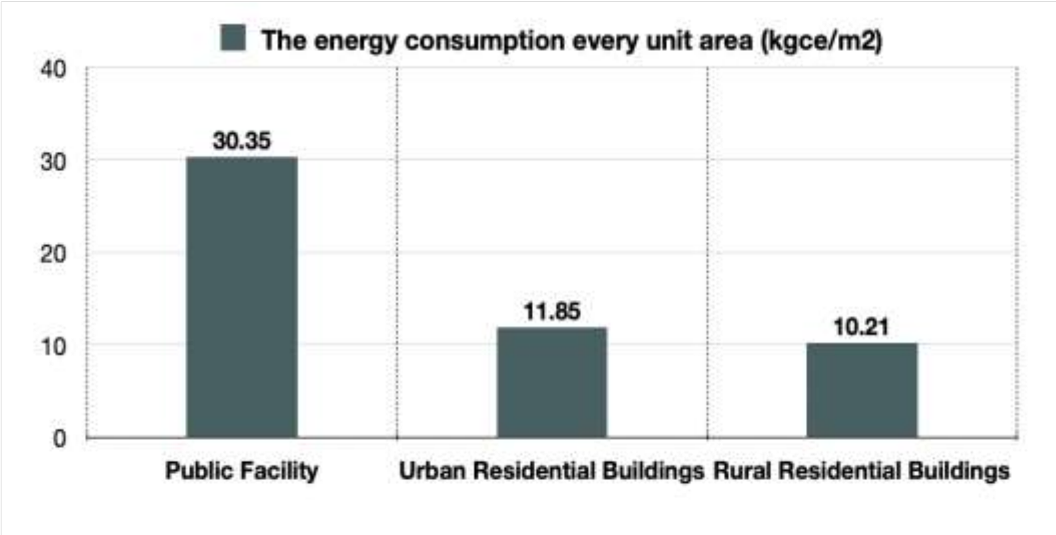
China's carbon emission reduction work has entered the stage of total control. As one of the three “giants” of energy consumption, construction is an important source of greenhouse gas emissions. Building energy efficiency will be a key area for my country to achieve the 2030 carbon emission reduction target. Energy consumption and carbon emission data are the basis for scientifically promoting energy efficiency in buildings.

At present, China Building Energy has made great progress in the construction of laws, regulations, incentive policies, technical standards and other systems, but the construction of building energy consumption and carbon emission statistical systems needs to be further strengthened. At the current stage of total carbon emission control, formulating total energy consumption control targets and promoting the innovation and development of the building carbon emission trading market mechanism require scientific energy consumption and carbon emission data as the basic support for building energy efficiency.

In 2017, the total construction area of the country reached 64.247 billion square meters, of which public construction area was about 11.959 billion square meters, accounting for 18.61%; urban residential construction area was 30.452 billion square meters. It accounts for 47.40%; rural residential buildings are 21.837 billion square meters, accounting for 33.99%.

From the perspective of energy intensity per unit area, the intensity of energy consumption in public buildings is the highest among the four types of building energy consumption and has been increasing in recent years. In 2017, the energy consumption per unit area of public buildings was 30.35kgce/m^2, which is twice that of urban residential buildings (11.85kgce/m^2) and 2.4 times of rural residential buildings (10.21kgce/m^2). The energy consumption intensity is the caliber of coal consumption method for power generation. The electricity consumption per unit area of public buildings in 2017 was 61.94kWh/m^2, which was 3.8 times (16.29kWh/m^2) for urban residential buildings and 3.3 times (18.82kWh/m^2) for rural residential buildings (Figure 1-7).

From 2000 to 2017, the total national building energy consumption showed a continuous growth trend (Figure 1-8), from 288 million tons of standard coal in 2000 to 947 million tons of standard coal in 2017, an increase of about 3.2 times, an average annual increase 7.25%



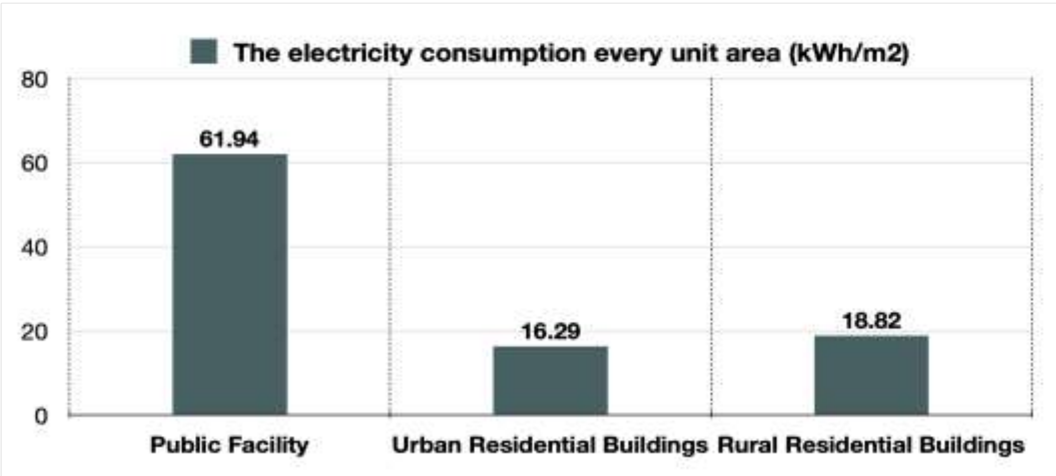


Figure 1-7. The energy and electricity consumption of classified buildings in China

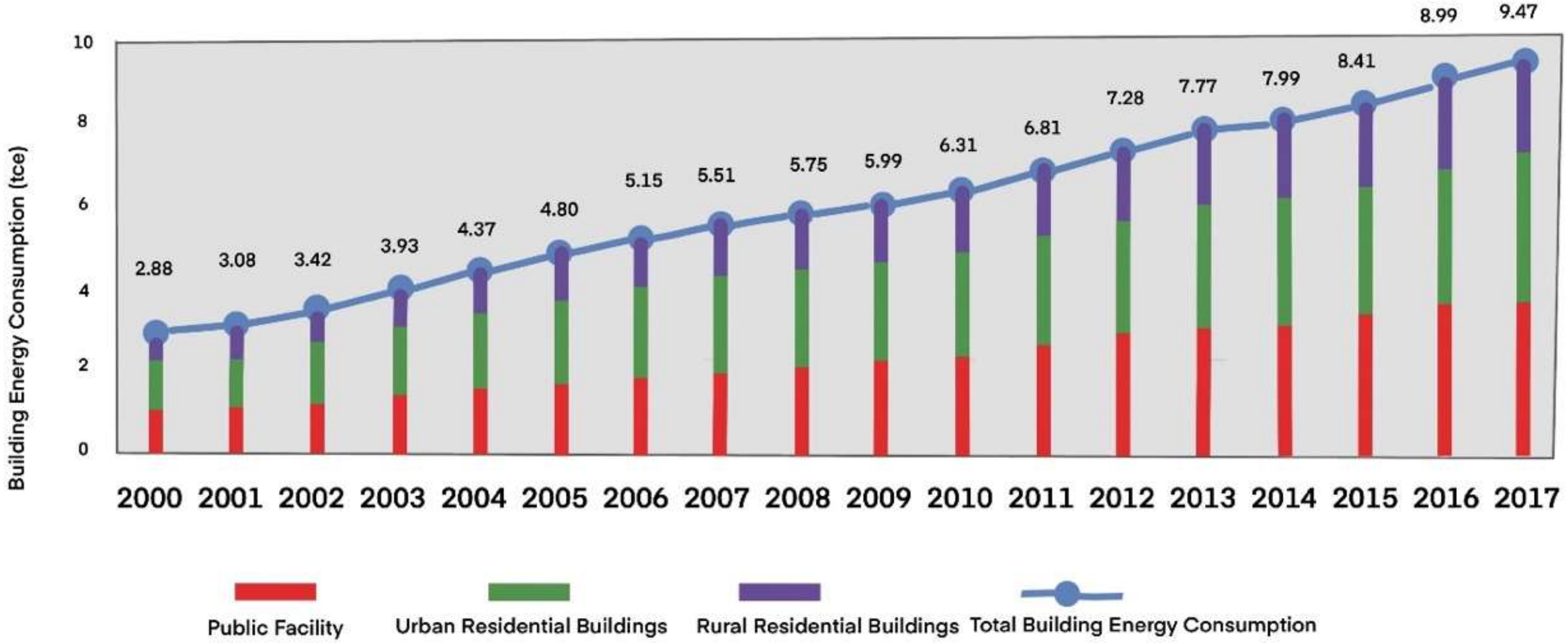


Figure 1-8. The classified energy consumption from 2000 to 2017

Exploring the energy-saving possibilities offered by retrofitting historic buildings is a milestone in meeting the targets of a low-carbon economy. Considering the limited land resources available for constructing new residential and many existing buildings, successfully retrofitting buildings instead of demolishing them has excellent energy-saving potential. The shortage of natural resources and global warming become international concerns, encouraging the innovation of sustainable development methods. Meggers F. et al[10] appraised the possibilities of CO_2 emissions reductions from the buildings sector in 2010, covering the challenges of cutting emissions from building construction, operation, and maintenance throughout the whole life cycle. Mazria concluded [11] that once a building's life cycle has been considered, more than half of its emissions are related to the building sector. Roodman and Lenssen concluded that 35% of energy in the world is used by buildings, while they are directly responsible for one-third of global emissions based on the consumption level[12].

Protecting historical heritage buildings is still relatively arduous, and the situation of low investment in protection is bound to exist for a long time. According to the existing cultural relics' designation system, many modern architectural heritages could not be designated as cultural relics for protection during this period. They thus may face the fate of being demolished. The registration system can significantly expand the scope of preservation of architectural heritage under the premise of more flexible protection and control. The contemporary buildings are typically built for about 100 years, representing recent history. They are considered footprints of time that still can be seen by eyes, but not that old with rare materials or old construction technology. Therefore, such contemporary buildings could still be classified as ancient heritage but could be recovered with reasonable efforts. Compared with repairing ancient buildings that generally use traditional Chinese construction techniques, modern facilities are more accessible regarding structural reinforcement and material selection. Therefore, the protection of modern architectural heritage should embody the new concept of "let history survive in the contemporary living environment", and proper reuse is the only way to protect modern architectural heritage. Freezing or specimen preservation methods cannot meet the current needs of contemporary architecture. In terms of the creative reuse of modern architectural heritage, many countries in the world have achieved apparent results, and China has also made some valuable attempts. The creative reuse of architectural heritage can restore the vitality of modern architectural heritage and tap the potential value of historical buildings to a greater extent.

1.3. Introduction of Chinese corncob resources

Corncob is the cob after the corn ear has been removed from the kernel. As one of the three major food crops in China, corncobs, a by-product of corn, are rich in nutrients and easy to collect. Corncob mainly consists of 35% to 40% hemicellulose, 32% to 36% cellulose, 17% to 20% lignin and 1.2% ~ 1.8% of the ash constitutes. For a long time, corncobs have been mostly used as living fuel in the vast rural areas of China. With the advancement of biomass resources development and utilization technology, the types of industrialized deep-processing products of corncobs are increasing, mainly including high value-added products such as xylose, xylitol, xylooligosaccharides, furfural, and cellulose ethanol. Corncob edible fungus planting technology and bio-fermentation feed technology have also been applied to a certain extent. In terms of new energy utilization, corncob is favored by straw gasification stations and straw power plants due to its higher calorific value compared with ordinary straw, while corncob is relatively less used in fertilizer use. The utilization, commercialization, and high-value utilization of corncobs have considerable development potential.

1.3.1. Corncob resource estimation

Accurately mastering the quantity of corncob resources is the basis for its comprehensive utilization and management. In this paper, the literature review method was used to determine the ratio of corncob yield to corn yield, and then to estimate corncob yield based on corn statistical yield.

Corncob yield is often estimated based on corn statistical yield. Under the condition that the ratio of corncob yield to corn yield and corn yield are known, the corncob yield can be calculated by formula (1):

$$W_{corncob} = W_{corn} \times \lambda \tag{1.1}$$

in which:

$W_{corncob}$ is corncob yield;

W_{corn} is corn yield;

λ is the ratio of corncob yield to corn yield.

According to literature search, 78 effective sample data about the ratio of corncob yield to corn yield were obtained from 7 literatures, with an average value of 0.2105 (Table 1-2) and a standard deviation of 0.056. The standard deviation is mainly due to the different varieties of corn and the limited number of samples. The calculated results are basically equivalent to the measured results of the ratio of corncob yield to corn yield by Liang Yesen et al.[13]. In this study, when estimating corncob yield based on corn yield, the ratio of corncob yield to corn yield was taken as 0.21.

Table 1-2. The effective samples of the ratio of corncob yield from corn yield obtained from the literature on corn planting experiments

Source	Number of samples	Sample value	Average value
	12	0.26,0.23,0.23,0.24,0.28,0.28,0.25,0.21,0.20,0.25,0.21,0.19	0.22
	20	0.32, 0.33, 0.29, 0.28, 0.23, 0.30, 0.30, 0.22, 0.19, 0.22, 0.33, 0.32, 0.33, 0.33, 0.32, 0.23, 0.18, 0.19, 0.23, 0.18	0.27
	8	0.28, 0.26, 0.22, 0.21, 0.28, 0.23, 0.24, 0.23	0.24
	7	0.22, 0.17, 0.17, 0.19, 0.20, 0.18, 0.19	0.19
	16	0.18, 0.15, 0.16, 0.12, 0.14, 0.16, 0.15, 0.16, 0.16, 0.15, 0.18, 0.14, 0.15, 0.16, 0.13, 0.14	0.15
	10	0.23, 0.12, 0.15, 0.18, 0.16, 0.16, 0.23, 0.20, 0.14, 0.18	0.18
	5	0.20, 0.20, 0.21, 0.18, 0.20	0.20
Total/ Average	78	/	0.215

1.3.2. Corncob resource and its regional distribution

Corn production in China was about 277 million tons each year, and the total national corncob production was calculated by formula (1) to be 58.17 million tons, which was equivalent to 4.90% of the national total straw production, which was equivalent to the national total corn straw production. (Figure 1-9) 19.10% of the total straw production in Hunan (40.04 million t), Guangxi (41.08 million t), Inner Mongolia (42.46 million t), and Jilin (49.36 million t). In terms of provinces (municipalities and autonomous regions), the output of corncobs in Heilongjiang ranks first in the country, reaching 6.7544 million tons, accounting for 14.72% of the national corncob production. In 2022 there were 7 provinces with corncob output exceeding 3 million tons, namely Heilongjiang, Jilin, Inner Mongolia, Shandong, Henan, Hebei and Liaoning. 69.08% of the total; the provinces with corncob production of 1 million to 3 million tons are Shanxi, Sichuan, Yunnan, Xinjiang, Shaanxi and Gansu, and their combined corncob production is 8,986,500 tons, accounting for 100%

of the national corncob production 19.59%; the provinces with 500,000 to 1 million tons of corncobs are Anhui, Guizhou, Hubei, Guangxi, and Chongqing respectively, and their corncob production is 3.1897 million tons, accounting for 6.95% of the country's total corncob production; The provinces (municipalities and autonomous regions) with output less than 500,000 tons produced 2.012 million tons of corncob, accounting for 4.39% of the national corncob production(Table 2). China's corncob is mainly used in four aspects: one is industrial raw material, the other is edible fungus-based material, the third is biological feed, and the fourth is fuel. The price of corncobs in Hebei province is about 700-800 Yuan per ton; the price in Liaoning and Jiangsu is about 850-900 Yuan per ton; the price of in Anhui is about 600 Yuan per ton; the price in Fujian is about 800 Yuan per ton. The price of corncobs in Henan and Guangdong is about 800-900 per ton; the price of corncobs in Shandong is quite high, and the highest price is about 1700 Yuan per ton. In addition, the price of corncobs in Jiangxi, Guangxi, Hunan, Guizhou, Sichuan, Yunnan, Tianjin and other places is around 550-850 Yuan per ton (Figure 1-10).

Table 1-3. The total production of corncobs by provinces (municipalities and autonomous regions) in China

	Regional	Yield (10,000 t)	Proportion (%)			Regional	Yield (10,000 t)	Proportion (%)
0	All China	4588.25	100		16	Bubei	56.87	1.24
1	Heilongjiang	675.44	14.72		17	Guangxi	55.86	1.22
2	Jilin	582.90	12.70		18	Chongqing	54.20	1.18
3	Neimenggu	434.64	9.47		19	Jiangsu	45.44	0.99
4	Shandong	413.09	9.00		20	Ningxia	43.30	0.94
5	Henan	377.27	822		21	Hunan	38.85	0.85
6	Hebei	357.82	7.80		22	Tianjin	21.44	0.47
7	Liaoning	328.27	7.15		23	Guangdong	17.14	0.37
8	Shanxi	200.66	4.37		24	Beijing	15.79	0.34
9	Sichuan	160.10	3.49		25	Zhejiang	5.63	0.12
10	Yunnan	154.18	3.36		26	Fujian	4.05	0.09
11	Xinjiang	140.49	3.06		27	Qinghai	3.44	0.07
12	Shan’xi	123.21	2.69		28	Hainan	2.54	0.06
13	Gansu	120.02	2.62		29	Jiangxi	2.52	0.05
14	Anhui	89.46	1.95		30	Shanghai	0.53	0.01
15	Guizhou	62.58	1.36		31	Tibet	0.53	0.01

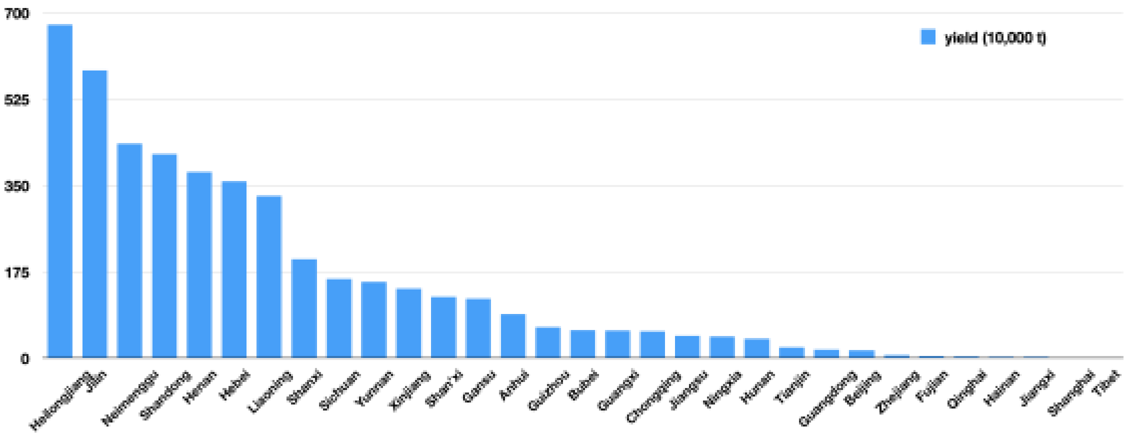


Figure 1-9. The annual yield of the corncob in different area of China

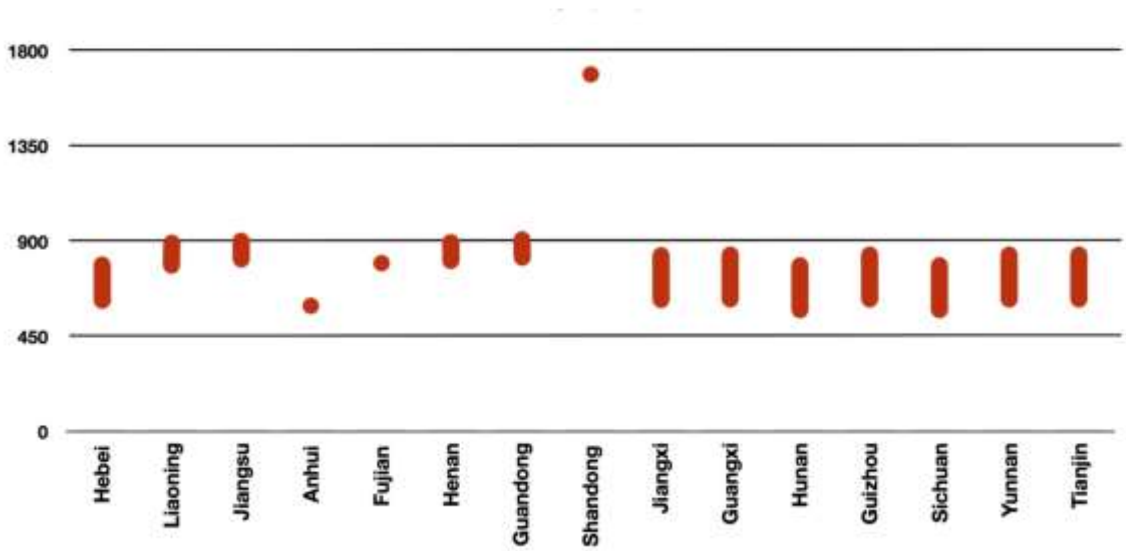


Figure 1-10. The general price of corncob in different area of China

1.4. Research purpose and significance

1.4.1. Research purposes

Traditional buildings are a kind of "special" existing buildings. At present, the goal of protecting and reusing historical buildings in my country is still at the level of protection and repair[13] lack of understanding of energy-saving renovation. The "Guidelines for the Repair and Construction of Modern and Modern Historic Buildings in Qingdao" pointed out that the goals and scope of the protection and repair of historical buildings in Qingdao include improving the function of buildings and improving the indoor comfort of buildings. Under the premise of protecting the architectural style from being damaged, building components should be properly optimized, building equipment should be updated, and the indoor thermal environment and the quality of life of users should be improved.

China usually divides the energy-saving renovation of historical buildings into the category of existing building renovation[14, 15], due to the particularity of historical buildings, conventional energy-saving renovation methods are damaged. If the energy-saving renovation of historical buildings is blindly required to meet the existing building energy-saving standards, one-sided pursuit of high thermal performance, and the use of measures such as replacing external windows, thickening thermal insulation layers, and adding thermal equipment will harm the historical and cultural value of the building. If you blindly focus on the age of the building and place too much emphasis on the historical value, it will affect the use of energy-saving measures, resulting in energy waste. The energy-saving renovation of historical buildings needs to be comprehensively implemented in combination with a variety of renovation technologies, and according to the current situation of different historical buildings, different renovation technologies are used to achieve the goal of improving thermal performance under the premise of protection and repair.

Because of the factors that affect the building energy consumption, such as its location, orientation, and body shape coefficient, the courtyard cannot be changed. Therefore, the thermal insulation performance of its envelope structure is very important to reduce energy consumption. Based on the current situation and repair work of Qingdao courtyards, this paper systematically analyzes the energy-saving optimization measures of the envelope structure that can be combined with the repairing technology of the courtyards. Combined with the analysis of the energy saving rate and economy, the purpose is to explore the energy-saving optimization measures that can meet the needs of most courtyard buildings. The required renovation measures provide a renovation idea for the protection and reuse of the courtyard.

The research in this thesis executes the study on sustainability embedded within the historical buildings. It discussed the possibilities and contributions of alternative recycling materials.

There are several purposes to be achieved in this research:
(1) To study the development status of Liyuan houses in Qingdao and identify indoor environmental problems.
(2) To explore the application and efficiency of different corncob recycle materials in envelope thermal performance improvement.
(3) To explore the ways and efficiency of indoor environment improvement in historical houses from the aspect of building envelopes.

1.4.2. Research significance

The courtyard building is a unique architectural form in Qingdao, the living memory of ordinary people in Qingdao, and has great historical protection value. However, due to the long-term construction and weak awareness of protection, the courtyard has problems such as poor preservation status, insufficient thermal performance and serious energy waste, which cannot meet the requirements of modern use. Therefore, this study discusses the appropriate energy-saving optimization measures for the courtyard enclosure structure.

In the protection and reuse of courtyard buildings, the repair of the building envelope is an indispensable link. At the same time, the implementation of energy-saving optimization measures can not only save energy and reduce energy consumption, but also improve the indoor thermal environment of the courtyard. Ensure user comfort. At the same time, it can make the courtyard building better play its value, give it a new life, awaken the urban memory of Qingdao, continue the historical context of Qingdao, and promote the protection and reuse of Qingdao's historical buildings. In addition, by summarizing the energy-saving optimization measures of Qingdao Liyuan, it can also provide a reference for the energy-saving optimization of Qingdao and other types of historical buildings across the country to a certain extent and improve the protection and reuse system of historical buildings.

(1) To provide data and information for the reuse of historical houses in the cold northern regions and help promote the development of the optimal design of houses.

Currently, the research on energy-saving and environmental improvement of the historical houses in China has some regional characteristics, and the quantification of primary data remains lacking. This study enriches and improves the data resources on the status of the envelope and the indoor and outdoor thermal environment through a large amount of data from surveys and provides first-hand information for constructing sustainable houses.

(2) Through the experiment of corncob integrated insulation material, exploring the methods and application of recycled material in the renovation of the envelope, expanding the application of corncob and reducing the pollution to the environment.
Corncob recycled building materials have the characteristics of being low carbon, energy-saving and sustainable. This study provides an economical and practical form of insulation and energy-saving in the renovation of the envelope. It expands the application of corncob, reduces air pollution, and can provide a reference role for applying corncob materials.

(3) Proposing a comprehensive reform plan for the energy-saving renovation and environmental improvement of the Liyuan external envelope in Qingdao will improve the indoor environment of the historical houses and promote green and sustainable development.

Under the background of global climate change and rapid urbanization, the deterioration of the human living environment and energy shortage has become a hot issue worldwide. At present, with the steady growth of social and economic development, the material living standard of people is improving, and the requirements of residents for the quality of life are also increasing. The historical residential buildings have a single form, serious aging of the envelope, poor insulation and heat preservation, and severe indoor and outdoor air pollution in the buildings, making it challenging to meet the requirements of the indoor living comfort for people. This study proposes a renovation plan for energy-saving renovation and environmental improvement. Envelope structure renovation will improve the thermal performance of the envelope, increase the indoor temperature, reduce heating energy consumption, lower carbon emissions, and improve the indoor air environment, thus promoting the green and sustainable development of traditional houses.

1.5. Research Structure

1.5.1. Research content

Strategies for energy-saving and environmental improvement are investigated concerning the low indoor temperature, high heating energy consumption, and poor indoor air quality in winter in Liyuan houses in Qingdao. The main research elements of this paper are as follows.

In chapter one, the current situation, problems, and opportunities for the development of Liyuan houses in China and Qingdao are reviewed, and the aims and framework of this study are also presented.

In chapter two, the discipline in Architecture heritage protection, the literature analysis of energy saving and energy-saving renovation of historic buildings are reviewed. It provides a theoretical basis for subsequent research.

In chapter three, the research methodology and simulation theory are introduced. The field survey methods for the status of Liyuan houses in coastal areas of Qingdao in this study include interviews, questionnaires, and actual measurements. Furthermore, simulate the effect of corncob materials on the thermal performance of ecological concrete. Finally, the principles of using the Ecotect Analysis software developed by the Autodesk Department of Energy to simulate and assess the thermal insulation and energy-saving efficiency of traditional Liyuan houses in Qingdao for envelope renovation are described.

In chapter four, through field measurements and questionnaire surveys of Liyuan houses in Qingdao, the status of the forms for the envelope, heating methods, and indoor thermal environment are investigated. Problems such as poor thermal performance of the envelope, outdated heating methods, low indoor temperature, and poor air quality are identified, which will provide first-hand data for later research.

In chapter five, experiments on the thermal conductivity of ecological concrete filled with corncob are introduced. They simulated the effect of corncob materials on the thermal performance of the ecological concrete through hot box method experiments. Then, a controlled experiment was conducted to find the lowest filling option for heat transfer, which will provide technical support for the energy-saving renovation of the building envelope.

In chapter six, the initial model of a typical Liyuan house in Qingdao is established using Ecotect software, with the climate and building envelope characteristics of the coastal area of Qingdao. Based on chapter five, corresponding energy-saving renovation technology measures are selected to simulate and test the thermal insulation and energy-saving efficiency of the house from three kinds of models: the original building; models that meet modern standards; models of the envelope using corncob as raw material. The energy-saving effect of different renovation options for various parts of the envelope was analyzed. Then the overall energy-saving efficiency of the renovation of the envelope was comprehensively analyzed.

In chapter seven, the whole summaries of each chapter and the future prospects were presented.

1.5.2. Research Flow

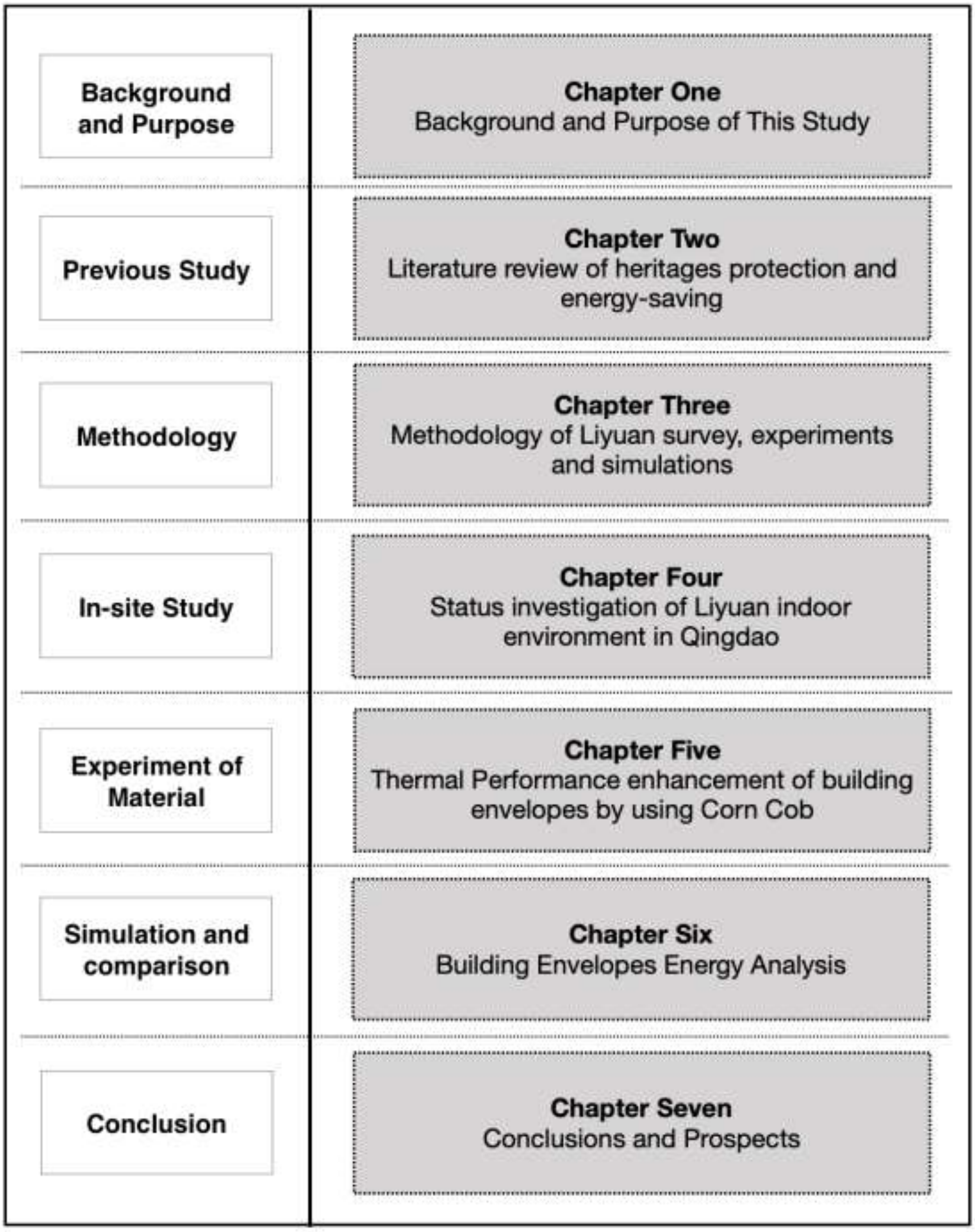


Figure 1-11.The chart of general research flow in each chapter

Reference

1. GISS Surface Temperature Analysis (GISTEMP v4). 2022 [cited 2022 March 18, 2022]; Available from: https://data.giss.nasa.gov/gistemp/.

2. D'agostino, D., P. Zangheri, and L. Castellazzi, Towards nearly zero energy buildings in Europe: A focus on retrofit in non-residential buildings. Energies, 2017. 10(1): p. 117.

3. Cao, X., X. Dai, and J. Liu, Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. Energy and buildings, 2016. 128: p. 198-213.

4. Agency, I.E., IEA World Energy Statistics and Balances. 2019.

5. Rao, P., Sustainable development. Vol. 1. 1999: Blackwell Publishers.

6. Nations, U., About the Sustainable Development Goals. 2020.

7. Hu, S., Y. Jiang, and D. Yan, China Building Energy Use and Carbon Emission Yearbook 2021: A Roadmap to Carbon Neutrality by 2060. 2022: Springer Nature.

8. National Bureau of Statistics. National Data-Energy Consumption [cited 2021 30 March]; Available from: https://data.stats.gov.cn/ easyquery.htm?cn=C01.

9. report, F. Energy Technology Perspectives. 2017; Available from: https://www.iea.org/reports/energy-technology-perspectives-2017.

10. Meggers, F., et al., Reduce CO_2 from buildings with technology to zero emissions. Sustainable Cities and Society, 2012. 2(1): p. 29-36.

11. Mazria, E., Resusitating a dying world, the 2010 imperative, a global emergency teach-in. Architecture, 2007. 2030.

12. Roodman, D.M., N.K. Lenssen, and J.A. Peterson, A building revolution: how ecology and health concerns are transforming construction. 1995: Worldwatch Institute Washington, DC.

13. ZUO, Y. and Y. GAO, A Study on the Methodology of Energy-saving Assessment for Preservation and Reuse of Historical Buildings. New Architecture, 2017.

14. Šekularac, N., et al., Restoration of a historic building in order to improve energy efficiency and energy saving—Case study—The dining room within the Žiča Monastery Property. Sustainability, 2020. 12(15): p. 6271.

15. Zhang, Y., J. Kang, and H. Jin, A review of green building development in China from the perspective of energy saving. Energies, 2018. 11(2): p. 334.

Chapter 2.

Literature review of heritages protection and energy-saving

2.1. Introduction

With the rapid development of urban construction and the further improvement of residents' living standards, people have put forward higher requirements for the indoor living environment. Wu Liangyong proposed that the core concern of the study of the habitat environment is the people; an appropriate habitat environment should meet the residential needs of residents as a prerequisite [1]. The environmental quality of houses is an essential prerequisite for ensuring a healthy life for dwelling residents. The main factors affecting the comfort of the living environment are light, thermal, ventilation, air quality, Etc. The indoor thermal environment is an essential component of this and directly affects the thermal comfort of the occupants. On the other hand, indoor air quality has a direct impact on the health of the occupants [2].Therefore, thermal comfort is considered the main parameter for building environment improvement studies. Energy-saving renovation measures in buildings can enhance indoor thermal comfort, an important measure to optimize the indoor environment and reduce building energy consumption [3].

A long time ago, some developed countries started research on the protection of historical buildings. There are some international laws and regulations. Although the specific provisions vary from country to country and from time to time, the core idea is similar, i.e., different renewal measures are proposed for different human and geographical conditions and economic statuses. China has also proposed many policies and regulations from the perspective of energy conservation, including the literature study. Specifically, in terms of new construction and renovation of traditional housing units, scholars have researched several aspects, such as improving the thermal environment of houses and the energy-saving renovation of buildings. In cold regions of China, the indoor thermal environment is essential due to the cold outdoor climate in winter. The research focus of researchers has changed to how to minimize building energy consumption and enhance the habitability of winter residences while ensuring a comfortable indoor thermal environment. Combining the research content , it reviews them in three aspects: the discipline in Architecture heritage protection; the literature analysis of energy saving; energy-saving renovation of historic buildings.

2.2 Energy saving standard

2.2.1 Development Status of worldwide building energy standards

The USA

Building energy efficiency in the United States is at the core of improving efficiency. Traditionally, there is no federal agency corresponding to building management in the United States, and the government's role in building energy efficiency is not significant. The main means are to formulate industry and product standards, develop and recommend new technologies, and the driving force of building energy efficiency comes from various private industries, associations, power companies and enterprises. Therefore, building energy efficiency relies on strong market forces. The energy policies issued by the government are mostly based on market transformation, so as to enable high-energy-efficiency technologies. It has been successfully promoted in the market, so the basic starting point of its energy saving is to promote energy-saving technologies and products and take building energy-saving as a new economic growth point.

From this basic starting point, U.S. building energy efficiency policies are mainly divided into two categories: one is to improve performance indicators and establish unified standards for the application of emerging technologies, and the other is to encourage the use and promotion of new technologies through economic and non-economic measures. Building energy efficiency standards in the United States are formulated in accordance with federal, government, and state goals.

Federal goals: ：

- " ZERH(Zero Energy Residential Houses) " , available in sale from 2020
- " ZEB(Zero Energy Buildings) " ,commercialized from 2025

Government Goals：

- All new government buildings are net zero energy buildings in 2030.

California Municipal Goals: ：

- All new buildings for new detached and apartment dwellings will reach ZNE(Zero Net Energy) in 2020 ；

- 50% of existing commercial buildings achieve net zero energy consumption，100% of new commercial buildings are net zero energy buildings

The US building energy-saving standards mainly focus on improving the efficiency of equipment and components, and mainly control the performance parameters of a single building component and equipment. The standard does not require too much energy consumption of the entire building[4, 5].

Germany

The development history of German building energy-saving regulations and standards revealed the changes in thoughts of building energy-saving. From the "Insulation of High-rise Buildings" in 1952, it noticed on the thermal resistance and heat transfer coefficient of the building envelope components from the initial stage, it also focused on the thermal resistance and heat transfer coefficient of the building envelope system, the average heat transfer coefficient, and then the specified terminal energy consumption for heating (annual heating terminal energy consumption per square meter of residential buildings in new buildings is less than 10L of oil), and till now ,the primary energy consumption limit for buildings nowadays. It reflected the variations in the concerns about energy consumption from focus on practice to on terminal consumption. Corresponding to the purpose of reducing terminal energy consumption, the building energy conservation policies are designed based on terminal energy consumption in Germany.

1) The 4 stages of development history of building energy saving standards

- Initial stage：Introducing building energy saving standard

The German regulations on the thermal insulation performance of building envelopes can date back to "High-rise Building Thermal Insulation" DIN4110 standard in 1938, which stipulates that the thermal resistance of external walls should not be less than 0.47W/ (m^2·K). Later, it was revised in 1952, 1960 and 1969 to introduce thermal insulation grades. In the DIN4108 standard of "Insulation of High-rise Buildings" issued in 1974, the minimum insulation requirements were raised to higher level, and the heat transfer coefficient of windows was limited to be no greater than 3.5W/ (m^2·K).

- The first stage：Controlling the building envelope, heat transfer coefficient and other parameters；

The Building Insulation Regulations in 1977 listed the thermal conductivity of each building element in detail. In 1981, Germany revised the DIN4108 standard again[6, 7], raising the minimum insulation requirements by one level on the basis of 1974. The second edition of "Building Insulation Regulations" in 1982 pushed forward higher requirements for the heat transfer coefficient of the envelope structure, such as the heat transfer coefficient of windows should not be higher than 3.1 W/(m^2·K), and the heat transfer coefficient value of external walls should not be higher than 0.6 W/(m^2·K).

- The second stage：Controlling the building energy consumption in every unit area；

The third edition of "Building Insulation Regulations" in 1994 directly lead the concept of total control (theoretical fuel consumption of new buildings is less than 10 liters per square meter per year) on the basis of further improving the requirements for the heat transfer coefficient of building envelopes. The "Building Thermal Insulation Regulations" no longer separately stipulates the limits of the outer wall, outer window, roof and other enclosure structural components for the heat transfer coefficient of new buildings but stipulates a comprehensive index - the average heat transfer coefficient, which is to adapt to the Flexibility in new building design. For the energy-saving renovation of existing buildings, the limit values for the outer walls, external windows, roofs and other enclosure structural components are specified. This is because the measures for energy-saving renovation are basically the same, and the respective limits are clearly specified, which is more conducive to practical operation.

- The third stage：Controlling the actual primary energy consumption of the building as a whole (Defining different fuel types)

In 2002, the Building Energy Efficiency Regulations replaced the Building Insulation Regulations, which proposed a 30% energy saving target and made important improvements in a number of areas: It is clearly stipulated that the evaluation of building energy effect is converted into primary energy demand, and the energy consumption limit that new buildings and existing buildings should reach in the future. Individual building components and equipment are then used as key criteria for judging energy efficiency and building energy consumption is expanded to include final energy consumption such as heating, hot water, ventilation and related auxiliary energy.

The primary energy demand is linearly related to the shape coefficient of the building, that is, the building with a large shape coefficient has a larger allowable primary energy demand. In 2004, the Building Energy Efficiency Regulations were revised, and instead of increasing the limit requirements, editorial and typographical revisions were made, and the applicable updated standards were noted.

- The Fourth Stage：Performance parameter in parallel with overall energy consumption limits.

In 2007, a new edition of the Energy Efficiency in Buildings Regulations (EnEV2007) was issued, mainly to comply with the European Union's building guidelines, which called for the widespread introduction of existing building energy certificate systems, as well as the addition of cooling energy consumption and lighting to the calculation method. There are two parameters of power consumption. For this reason, the summer energy consumption of residential buildings in EnEV2007 gets more attention.

In 2009, the latest version of the "Building Energy Conservation Regulations" EnEV2009 was formulated, and the relevant requirements were further improved, aiming to reduce the energy consumption of heating and hot water preparation in buildings by about 30%. The allowable annual primary energy demand of new buildings is reduced by an average of 30%, and the thermal insulation performance of the envelope structure is increased by an average of 15%; the energy efficiency level of related components in the renovation of the existing building envelope structure is increased by 30% (including facades, windows, roof, etc.), or retrofit at 1.4 times the energy-saving level of new buildings, and also involve the requirements for primary energy consumption and thermal insulation of the envelope structure[8, 9].

2） Development goals of German building energy efficiency standards:

- From 2021, new buildings will be implemented to achieve "nearly zero energy consumption buildings"；
- By 2050, all existing buildings will have become "near zero energy buildings”. The German building energy efficiency standards are not purely based on materials and individual technologies, but through a series of technical means to control the actual consumption of primary energy in buildings and achieve effective energy conservation.

Denmark

From the 1960s onwards, energy requirements for new buildings in Denmark became progressively stricter. In recent years, to promote the implementation of EU Directive 2002/91/EC in Denmark, the government has issued several standards, including current and future maximum building heat loads. Going a step further, the Danish Building Regulations also regulate the energy performance of exterior windows in new buildings and replacement of windows in existing buildings. The latest version of the standard plan calls for roof replacements, oil and gas boilers, heating retrofits, and more. The current version is the Danish Building Regulations 2010 (BR10). The Danish Building Regulations play a significant role in reducing energy consumption in new buildings. The previous version had greater flexibility in focusing on the total energy consumption of the building rather than the individual requirements of the building components. Development goals for buildings energy saving in Denmark: 50% reduction in greenhouse gas emissions by 2050

Japan

Japan's building energy conservation business is extended from industrial energy conservation, so the concept of building energy conservation is also extended from industry. The basic starting point of building energy conservation is still to improve efficiency, that is, to promote building energy conservation technology while improving building performance, such as residential buildings. The energy-saving standard "Guidelines for the Rational Utilization of Energy in the Design and Construction of Residential Buildings" stipulates the heat transfer coefficient of the envelope structure, while the standard for public buildings "The Standard for Rational Utilization of Energy for Users in Public Buildings" is the total cooling and heating load of the building throughout the year. Coefficients and equipment system energy use coefficients are limited, both of which are performance indicators for buildings and systems.

Development goals of building energy standards in Japan:

- More than 50% of new single-family homes in 2020 will be "net-zero energy"；
- There are technologies available to achieve "net-zero energy consumption" in public buildings in 2020；
- Reduce energy consumption per unit of GDP by 35% in 2030 compared to 2010；

2.2.2 Review of the Development of Building Energy Efficiency in China

Since the 1980s, there has begun to establish corresponding building energy conservation standards for civil buildings in China. which can be roughly divided into three stages：

Stage 1： In 1986, the Ministry of Construction issued the first civil building energy-saving design standard in China, namely "Civil Building Energy-saving Design Standard (Heating and Residential Buildings)" (JGJ26-86). The basic goal of this standard is to make the heating energy consumption in the local general use in 1980-1981 by adopting appropriate technical measures in the design of the building envelope and heating and heating system under the premise of ensuring the use function and indoor comfort. On the basis of the designed residential building heating energy consumption, reduce 30%. Later it was called first step energy saving (ie 30% energy saving).

Stage 2 :On December 7, 1995, the Ministry of Construction approved and promulgated the "Design Standard for Energy Conservation of Civil Buildings (Heating Residential Buildings)" JGJ26-95, which requires the heating energy consumption to be based on the local general design residential building heating energy consumption from 1980 to 1981. 50% lower. Later it was called the second step energy saving (ie 50% energy saving). Subsequently, "Technical Regulations for Energy-saving Retrofit of Existing Heating Residential Buildings" JGJ129-2000, "Design Standards for Energy-saving Residential Buildings in Hot Summer and Cold Winter Areas" JGJ134-2001, "Design Standards for Residential Buildings in Hot Summer and Warm Winter Areas" JGJ75-2003, "Energy-saving Design Standards for Public Buildings" GB50189-2005. During this period, the national standards "Code for Thermal Engineering Design of Civil Buildings" and "Standards for Building Climate Zoning" were also formulated.

Stage 3: In this stage, 30% energy saving must be achieved on the basis of the 50% energy saving in the second stage, that is, the goal of 65% energy saving is achieved. At present, many regions in our country have been promoting the goal of 65% energy saving in the third stage of building energy efficiency. Implemented on the 1st, it is stipulated that residential buildings in severe cold and cold areas need to achieve the goal of 65% energy saving. Due to climatic conditions, energy-saving effects of energy-saving technologies, calculation methods of energy-saving rates, and differences in economic development in different regions, areas with hot summers and cold winters and areas with hot summers and warm winters have not yet promoted the 65% energy-saving design standard on a large scale, only Chongqing, Shanghai and other places The 65% energy-saving design standard for residential buildings was promulgated, and its implementation time was January and October 2008, respectively. The newly revised "Design Standard for Energy Conservation of Residential Buildings in Hot Summer and Cold Winter Areas" (JGJ134-2010) and "Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Areas" (JG75-2012) still aim to save 50% of energy.

So far, the civil building energy-saving standard system in China has achieved remarkable results and has been extended to cover the energy-saving design of residential and public buildings in all climate zones across the country, from the energy-saving renovation of existing residential buildings in heating areas to all existing residential buildings and buildings. The energy-saving renovation of public buildings has expanded from the construction of external thermal insulation projects of buildings to the quality acceptance, testing, evaluation, energy consumption statistics, use and maintenance and operation management of building energy-saving projects, and has expanded from traditional energy conservation to solar energy, geothermal energy, and wind energy and utilization of renewable energy such as biomass. However, civil building energy conservation standard system in China mainly focuses on the improvement of the efficiency of energy-consuming equipment and does not pay too much attention to the goal of total building energy consumption control, which cannot be coordinated with the long-term control goal of total energy consumption.

2.3 Research on energy-saving renovation of old buildings

2.3.1 The discipline in Architecture heritage protection

Architecture is a comprehensive combination of multiple disciplines, which embodies the achievements in science & technology development and civilization evaluation. It turns out to be the long-existing crystallization of human history. The Architectural heritages can be read as historical evidence, just like written documents, which tell the story of past conditions and explain how society changes—the evidence presented by a surviving architecture for clues to the understanding of the buildings themselves. With more than 5000 years of recorded history, the architectural heritage in China is a unique wealth, an irreplaceable expression of the richness and diversity of the past. The buildings retained today, over time, acquire characteristics and special interests through their intrinsic quality, continued existence, and familiarity. The built heritage consists not only of outstanding artistic achievements but also of the everyday works of artisans. In a changing world, these architectural heritages have a cultural significance that we may recognize for the first time only when an individual building is demolished or threatened. As we enjoy this inheritance, we should ensure it is conserved to pass it on to our successors as another implementation of sustainability.

China's protection of modern historical buildings is relatively late. It was not until the 1980s that it entered the substantive building census. After several national meetings were held and various protection policies were issued, in 2002, the section on modern heritage was revised in the Cultural Relics Law. It legally confirmed the status of modern historical buildings. At the same time as theoretical research, the restoration of historical buildings has also gone through several stages: Before the introduction of various protection policies at the end of the 20th century, most of the projects carried out on modern historical buildings were for transformation and utilization, mainly including the reinforcement of building structures, internal and external eaves Re-decoration and re-division of inner space. Most of the projects in this period were renovation and construction. There was no concept of preservation of historical information: by the transition period of the 20th century and the 21st century, the idea of modern historical building protection gradually matured, and relevant issues were introduced in various places Protection policy, but in practical building restoration projects, the engineering technology of the previous period is still used, so the contradiction between the backwardness of restoration technology and the protection of building history and culture cannot be substantially resolved. Since the beginning of the 21st century, the protection theory of modern historic buildings has continuously matured and perfected. Correspondingly, with the development of science and technology, various new technologies developed for the restoration of historical buildings have also begun to be applied to subsequent projects.

It should note that the research on the restoration of outstanding modern Chinese historical buildings is still in the exploratory stage. This is not to say that there is a lack of modern Chinese building restoration theory or technology, but that there has been no perfect restoration principle combined with advanced restoration technology. That is to say, theory and practice are still in the running-in period and have not reached the optimal combination. There are roughly two reasons: there is no precise regulation on the historical value positioning of modern architecture. It is very different from traditional Chinese wooden architecture. There are few conventional construction techniques, and the historical information it carries is not extended. It is the product of the combination of traditional Chinese construction technology and foreign architectural culture. Modern historical buildings should be protected according to what principles the grade has not yet been clearly defined. The other is that the protection principles of modern historical buildings and the practical application of restoration techniques have not yet reached a perfect combination. The determination of the principles of the restoration of modern historic buildings and what kind of restoration techniques should be used under the guiding principles are modern history. There are very controversial issues in building restoration projects.

The research on historical buildings in European countries started earlier than other areas. Since the birth of archaeology in the 1840s, people have been exploring architectural heritage for more than a century, enriching and revising related cognitions. Finally, a reasonable and effective historical building protection system was established. Prof. Dr. Jukka Jokilehto, an expert on the protection of historical architecture in Finland, started from the macro perspective of the social and cultural background, using time and country as clue to investigate the history of the protection of historical architecture. The development of the restored modern ideals was formed in the 18th century along with the development of western historical thinking. It has been enriched and developed continuously in the debate and practice of the 19th and 20th centuries [10]. This book "A history of architectural conservation" has become a theoretical work that studies the concepts related to the history of architectural conservation.

From the "restoration fury" to the "anti-restoration movement" in the mid-19th century and the modern conservation movement: The evaluation of the value of historical buildings in the protection of historical buildings and modern protection theories and methods are based on the evolution of the theory of value. From style repair to critical repair; from traditional historical value to progressive value and time value; from protective repair to daily maintenance; from classic building protection to general building protection.

In 1931, the "Athens Charter" emphasized the importance of international cooperation and established an international documentation center to promote public education [11] Then there was the 1933 "Athens Charter" proposal for the preservation of monuments. In 1935, the Union of Pan American states issued the "Washington pact for the protection of artistic and scientific institutions and historic monuments", which proposed that "immovable monuments should be protected because they are part of the cultural heritage of mankind. This protection should be effective in times of peace or war"[12]; In 1959, the International Research Center for the Protection and Rehabilitation of Cultural Relics (ICCROM) was established. This is an international organization between governments that promotes the protection of cultural heritage in the world. The main thing is to protect cultural heritage through education and training, information exchange, investigation and research, technical cooperation, and public opinion dissemination. Then there was "Venice Charter" in 1964, 1972 "Convention Concerning the Protection of the World Cultural and Natural Heritage" and its "Implementation Guide", 1979 "The Contribution of Historic Preservation to Urban Revitalization"、"Weinberg, Preservation in American Towns and Cities"、"The conservation of European cities" , 1994 "The Nara Document on Authenticity" and other documents and conventions were issued. The perspective of historical building protection has become wider and wider, and international cooperation has also become closer.

In 1998, Paul Spencer Byard discussed the design methods and principles of the addition and renovation of historic buildings [13]. "Theory of Restoration" and "Definition of Restoration" discuss the basics and definitions of restoration. The Getty Conservation Institute's "Assessing the Values of Cultural Heritage" and Erica Avrami's Values and Heritage Conservation" discussed the connotation and realization of the value of architecture [14].

Table 2-1. Some international laws and regulations on the protection of historical buildings

Serial number	**Regulation name**	**Summary**
1	Scenic Spots Protection	For the first time, villages and small towns are clearly listed as objects of protection in the form of legislation
2	Venice Charter	The protection of cultural relics and historical sites includes the protection of a certain scale of urban or multi-village environment, spreading the focus of cultural relics protection from single cultural relics to important historical locations [15]
3	Charter of Machupicchu	To preserve and maintain the historical sites and monuments of the city, but also to inherit cultural traditions[16]
4	Chapter For the conservation of historic towns and urban area	The protection of historical cities and towns includes five aspects: cities, towns, historical centers or residential areas, natural environments and man-made environments[17].
5	Convention for the Protection of the World Cultural and Natural Heritage	Protect the material environment of the world cultural and natural protection heritage area, maintain its social function, and continue the spiritual tradition and cultural context[18]
6	Cultural Property Protection Law	Add " cultural property" as a new object of protection

The research on the protection of architecture heritages in China started relatively late and was influenced by the protection of historic buildings in the West. In the middle and late 1970s, developed areas in Asia first began to integrate the protection strategies of historic buildings into urban planning. Until the end of the 1980s, with the rise of history and architecture, research on the preservation of historical buildings began to advance gradually. China's protection of historical relics started with the "Antiquities Protection Law" promulgated by the Republic of China. Establish antiquities with historical and archaeological value as objects of protection. After the founding of the People’s Republic of China in 1961, the “Interim Regulations on the Protection and Management of Cultural Relics” was re-issued as a temporary regulation for the protection of historical cultural relics. At the same time, a key cultural relic’s protection system has been established, and 180 historical and cultural heritage sites have been listed as the first batch of national key cultural relic’s protection units.

In 1982, the "Law of the People's Republic of China on the Protection of Cultural Relics" was promulgated. When the new law was promulgated, 24 cities including Beijing, Nanjing, and Kaifeng were announced as the first batch of national historical and cultural cities. In 1986, the concept of "historical and cultural preservation areas" was first put forward, and 38 cities including Shanghai, Tianjin, and Wuhan were announced as the second batch of historical and cultural cities.

At present, China's legal system for the protection of historical buildings is still relatively weak. There are still many flaws and loopholes in the definition and protection of historical buildings, and it is impossible to include all historical buildings under protection. With the passage of time, a large number of historical buildings were forgotten by people and were completely destroyed in urban construction. Before the 1990s, almost no one in our country tried to practice the reuse of historical buildings. Since the mid-1990s, the trend of reuse of historical buildings in our country has increased year by year. There has been an upsurge in the development of historical districts in various places, and more and more practical cases of the protection and reuse of historical buildings have appeared. In recent years, Chinese academia has also significantly increased the related exploration and practice in the field of historical building protection. There are 1,247 academic journal papers and 629 dissertations on “historical building protection” collected on CNKI. 177 papers (Table 2-1, Table 2-2).

Table 2-2. Some Chinese laws and regulations on the protection of historical buildings

Serial number	Regulation name	Summary
1	The Cultural Relics Protection Law of the People's Republic of China	Historic buildings refer to buildings that are particularly rich in historical cultural relics and have revolutionary memorial significance or significant historical value. They can be reviewed by the people's government of a province, autonomous region or municipality directly under the Central Government and reported to the State Council for the record
2	The second batch of national historical and cultural cities list report notice	(1) Not only should we look at the history of the city, but we should also focus on whether there are relatively rich and well-preserved cultural relics and monuments with significant historical, scientific, and artistic value (2) As a historical and cultural city, the current pattern and style should retain historical characteristics and have certain blocks that represent the traditional style of the city
3	Notice of the State Council on Strengthening Protection of Cultural Heritage	(1) Material cultural heritage includes historical buildings and villages with special value (2) Cultural heritage is a non-renewable resource. Many historical buildings have been damaged to varying degrees in the environment of great economic development
4	Regulations on the Protection of Historical and Cultural Cities	It is clearly pointed out that the protection of historical buildings should follow scientific planning, strict protection principles, and maintain and continue its transmission pattern and historical features
5	Urban Purple Line Management Measures	The purple line refers to the country within and outside the historical block that has been publicly protected by the people's government at or above the county level through documents. The purple line of historical buildings includes a certain range of scenic areas in addition to the historical buildings themselves.
6	Urban and Rural Planning Law of the People's Republic of China	(1) The protection of historical and cultural villages is equivalent to that of historical and cultural cities, and they also comply with relevant laws and regulations (2) Both individuals and units enter the land use approval process only after obtaining the rural construction planning permit

2.3.2 Research on energy-saving renovation of traditional buildings

The thermal performance of the envelope is an essential factor in the energy consumption of a building[19].Countries with earlier research on energy-saving renovation of historical buildings are mostly concentrated in Europe, especially some countries with a large stock of historical buildings, including the United Kingdom, Denmark, the Czech Republic, Sweden, France, and Bulgaria. The renovation of historic buildings should balance historical and cultural preservation, indoor comfort and energy efficiency. In recent years, some governments have worked to identify general guidelines for reconciling the contradictions of energy-saving renovation of historic buildings, emphasizing that energy efficiency measures may damage historic buildings. In order to achieve the goal of reducing energy and carbon emissions, the European Building Performance Institute [20] clearly stated that, according to the characteristics of the European region, "for heritage buildings, small and moderate interventions can be carried out", "even if it is not a complete renovation, there is always some energy saving. Measures are available for historic buildings." As Livio de Santoli [21] pointed out, energy conservation measures should be seen as a tool to preserve the historic value of a building, rather than a process that might conflict with historic building conservation requirements.

Jurgis Zagorskas [22] and others discussed the heat transfer performance and water vapor penetration of brick wall insulation structure, and gave the method to choose the best thermal insulation scheme. Relative properties such as material cost, installation complexity, heat transfer coefficient, space loss when adding insulation, and hydrophobicity of insulation can be used as the basis for decision-making in the renovation of historic buildings. Hui Ben [23] pointed out that for historical buildings in London, changing user behavior may bring about better energy-saving effect, the impact of behavior change accounts for 62% to 86% of the total energy saving, and its energy saving far exceeds that of physical Improve the effect. Therefore, responding to changes in user behavior plays a key role in a comprehensive strategy for the renovation of historic residential buildings. Based on a typological approach, Viktória Sugár [24, 25] investigated the geometric characteristics of historic buildings in the urban area of Budapest, mainly including multi-storey apartment buildings. Investigating the energy demand and geometric characteristics of buildings and their relationship to architectural style shows that building heating demand can be estimated based on geometry and architectural style data. The authors also used simple data to estimate the energy saving potential of the 386 buildings in the study plot in Budapest. Calculations show that historic apartments have a high energy saving potential, with traditional solutions reaching near-zero energy consumption levels, and heating and domestic hot water energy can be reduced by 69% through upgrades.

In addition, some studies have shown that energy efficiency can also be greatly improved by optimizing the building envelope (replacement of doors, windows) and using sound heating, ventilation and air conditioning (HAVC) systems. Fabrizio Ascione [26]studied the renovation of Italian buildings in the fifteenth century as an example. Through field investigations on structural and energy consumption characteristics, using the methods of life cycle cost and sensitivity analysis, they discussed from a macroeconomic perspective of "Cost-optimized solution for the renovation of historic buildings". The analysis showed that a single measure of the envelope reduces energy demand compared to a retrofit of the HVAC system, and that the cost-optimal solution is to install low-e glass combined with roof insulation. Ghazi Wakili[27] tested and analyzed a 130-year-old brick building in Zurich, Switzerland, showing the use of high-performance thermal insulation materials to retrofit historic buildings. It is possible to add insulation to the inside of an existing façade without changing the overall appearance. Francesca Roberti [20] used the AHP analytic hierarchy process to analyze the compatibility between the renovation measures of historic buildings and protection requirements, and combined with the multi-objective optimization method to seek the best between protection compatibility, indoor thermal comfort and heating and cooling energy consumption requirements. The results of the study show that the preservation of historic buildings can be compatible with energy saving and thermal comfort requirements. Ljiljana Đukanovi´c [28] conducted research on the potential and limitations of energy regeneration in heritage buildings prior to the First World War. Taking the Belgrade house as an example, the improvement measures of only improving the windows and increasing the insulation layer of the envelope structure are proposed. The results show that although only improving the windows can reduce energy consumption, it can only increase the energy level by one level, which cannot meet the ideal requirements. It can be used in conjunction with natural thermal insulation materials or new internal thermal insulation materials. In 2014, Damyar S simulated with eQUEST energy simulation software and found that renovation upgrades to the roof, windows, external walls, balconies, floor edges, and ground floor slabs of a prototype building in Toronto resulted in energy savings of 0.8%, 9.4%, 27%, 2% and 2.2%, respectively[29]. Nicolae et al. have evaluated the common high-performance insulation materials available

[30, 31]. Chen Cellophane Jing et al. studied the performance of common external wall insulation materials: XPS, PU and other insulation panels, and the thickness of the insulation layer for optimal energy efficiency [3]. Mandilaras et al. developed new insulation and energy-saving materials such as vacuum insulation panels or PCM-based composite integrated walls in external walls, reducing the thermal conductivity of walls and heat loss [32, 33](Table 2-3).

Table 2-3. Different energy-saving design of building walls international

Authors (Year)	Country	Research materials	Core viewpoints
Nicolae, et al. (2015)	Romania	EPS, XPS, PUR	EPS is the best insulation, XPS is more durable than PUR, and EPS and XPS polystyrene are more flammable than PUR polyurethane.
Yassine (2017)	Morocco	PCM layer (epcm)	The optimum thickness of the PCM layer (epcm)is between 0.5 and 2 cm in the wall envelope; the optimum melting temperature of the PCM is 20°C.
Mandilaras, et al. (2014)	Greece	Vacuum Insulation Board	Incorporating vacuum-insulated panels into external walls reduces the thermal conductivity of the walls; the thermal resistance of vacuum-insulated panels is higher than that of traditional polystyrene panels, making them more conducive
Ravi, et al. (2019)	America	PCM and DIMS Integrated Wall	Phase change material PCM and Dynamic Insulation Material System DIMS integrated walls have a higher energy-saving potential than DIMS integrated walls only or PCM integrated walls only.PCM-DIMS integrated walls can reduce annual
Mohamad, et al. (2018)	French	Aerogel plaster with low radiation coating	When refurbishing old walls, aerogel plaster with a 0.5cm and 1cm low-e coating can reduce energy consumption by 21% and 30% respectively.
Sebastian Malz, et al. (2020)	Germany	Infrared reflective wall paint	Infrared reflective wall paint combined with historic brick masonry can reduce heat loss by 18%

In China, the energy-saving renovation of historical buildings mainly refers to the existing standards for energy-saving renovation of buildings. Chinese scholars are relatively lacking in research on energy-saving renovation of historical buildings and have not formed a complete evaluation system. In terms of case studies, the protective renovation of Wenyuan Building of Tongji University in Shanghai[34] is a pilot project of energy conservation in Shanghai. It is one of the earliest batches of Bauhaus-style buildings in my country and was included in the "World Architecture History", which has great architectural education and dissemination significance. It was built in 1953. The renovation was completed in 2007. As an excellent historical building in Shanghai, Wenyuan Building belongs to the three types of protected buildings, and the façade and the main frame structure are all protected parts. In the energy-saving design, the heat-insulating aluminum alloy Low-E insulating glass window and internal shading system are used, which can reduce heat radiation and achieve the purpose of thermal insulation and energy saving. Since the façade cannot be changed, Wenyuan Building adopts an internal thermal insulation system for the outer wall, using PUR, XPS and other materials to achieve the purpose of ecological energy saving while keeping the façade unchanged. In addition, a roof garden is set on the upper part of the roof of the central classroom to reduce the solar radiation heat of the roof and the heat transmitted through the roof through the absorption of solar energy by the vegetation.

Through these three measures, the energy saving rate of Wenyuan Building reached 17.1% after renovation. In terms of literature research, Du Xinrui [35] took the auditorium of Southeast University as the research object. He proposed a strategy for improving the thermal and humid environment of the relic buildings in Nanjing during the Republic of China under the premise of the protection of historical buildings. Active design, active strategy includes air conditioning system and seat ventilation air conditioning system, passive strategy includes opening top lighting windows in summer, and using natural ventilation to adjust the indoor heat and humidity environment. Architect Song Dexuan [36] selected 4 typical new-style linong houses in Tianjin, and conducted a field investigation on their envelope structure and layout. By changing the parameters of the envelope structure and the plane layout, the energy-saving differences of different renovation measures are simulated and analyzed. The research results show that the Tianjin Linong building can improve the indoor thermal environment by changing the building layout, replacing the form of external windows, and improving the thermal insulation performance of the roof. Jiabei[37] applied the Trumbo wall technology to the energy-saving renovation system for the exterior walls of modern historical buildings. He adopted a variety of design methods and measures to continue the original skin texture of the walls and found a balance between new technologies and old building protection. Zhu Yan [38] and others comprehensively considered building repair and energy-saving projects and adopted an integrated design method. The measures of energy-saving renovation of old houses are put forward by comprehensively applying the methods of water saving, material saving, energy saving, land saving, improving indoor environment and low-cost renovation. There are also some literatures that propose methods for establishing evaluation criteria for energy-saving renovation of historic buildings. Li Jinwen [39] investigated and tested 8 historical office buildings in Tianjin, and analyzed and summarized the differences between historical office buildings and ordinary office buildings in terms of body shape coefficient, envelope structure form and HVAC system. The reconstruction evaluation model was established by using AHP and TOPSIS multi-objective optimization method. The results show that the effect of energy-saving reconstruction of exterior windows is greater than that of wall and roof reconstruction, which provides a basis for energy-saving optimization of historical office buildings. Zuo Yan [40] and others believe that the establishment of the historical building energy efficiency evaluation index system should fully consider the differences in building type, construction time and region, protection level, and preservation status, and adopt a staged evaluation method to flexibly adjust the index system settings and weights. Wang Xu[41] took the 20th century heritage building envelope as the research object, put forward the grading standard and evaluation method of the retrofit degree of historical buildings, compared and analyzed the difference between the retrofit process of historical buildings and ordinary existing buildings, and carried out optimization, evaluation and analysis. Based on the energy-saving performance of different renovation measures, appropriate renovation strategies for historical buildings with different renovation degrees are obtained.

Qing Suan et al. studied the building envelope and found that external insulation of the building envelope was more helpful in reducing building energy consumption and reducing the magnitude of indoor temperature variation [42].Wei Ling et al. conducted an energy-saving optimization design of houses in severe cold areas by means of actual measurements and software simulations and found that constructing external walls with straw bricks can substantially save energy and reduce environmental pollution [43](Table2-4)

Table 2-4. Different energy-saving design of building walls in China

Authors (Year)	Research materials	Core viewpoints
Wenyuan Building (2007)	PUR, XPS and other materials	using PUR, XPS and other materials to achieve the purpose of ecological energy saving while keeping the façade unchanged
Li Jinwen (2017)	AHP and TOPSIS multi-objective optimization method	analyzed and summarized the differences between historical office buildings and ordinary office buildings in terms of body shape coefficient, envelope structure form and HVAC system. The reconstruction evaluation model was established by using AHP and TOPSIS multi-objective optimization method
Qing shan (2018)	Rigid polyurethane insulation board	The results show that rigid polyurethane insulation panels help reduce building energy consumption and reduce the magnitude of indoor temperature variation when they are used for external wall insulation compared to internal insulation.
Wei Ling, et al. (2015)	Grass tile eco wall	The annual energy consumption, CO_2 consumption and ecological footprint of eco-buildings are lower than conventional houses, 69.61%, 17.5t and 99.47%, respectively.
Jiang Mu (2019)	straw brick	Simulations with energy simulation software show that replacing the envelope of a traditional farmhouse with a new straw brick envelope can result in a 45.5% energy-savings.
Chen Dingjing, et al (2017)	XPS insulation board	When the thickness of the XPS insulation board is equal to 40mm, the highest energy-saving rate; plastic steel hollow glass windows can significantly improve the overall performance of the window, energy-saving rate of up to 50.78%.
Tan Yufei, et al (2016)	Solar wall system with glass transmissive collectors	A solar wall system with GTC was proposed for the poor thermal comfort caused by heating in rural areas of Northeast China, and the average indoor temperature increased from 12.12°C to 16.17-18.19°C.
Yawen He, et al. (2020)	3D-VtGW Wall	3D-VtGW buildings offer significant potential for energy-savings and improved thermal comfort. 3D-VtGW's integrated greening system significantly reduces external wall temperatures and over-wall heat fluxes through the combined effects of plant shading, evaporation and soil heat storage.

2.3.3 The literature analysis of energy saving

Now that we have realized the extensive implementation of energy-saving technologies, it is of great interest to provide a closer view and systematic understanding of sustainable solutions to improve building energy performance applied within existing buildings. Based on the literature study from pioneers' work, the methodology supported by bibliometric and statistical analysis on open access publication databases was proposed in this paper.

The review research mainly follows a three-step approach, including an initial definition among publication databases, refined keywords filtering within the selected databases, together with statistical and bibliometric analysis on the grouped papers to reach the final conclusion. The methodology here summarizes the existed research concerns and viewpoints on technical challenges and gaps, to explore the connection between sustainability goals and building energy performance improvements. It is expected to obtain a further exploration of energy-saving implementation in the energy efficiency and sustainable development for the existing buildings. This exhaustive literature study was performed to cover the major open-access academic publications through the following steps (Figure 2-1)

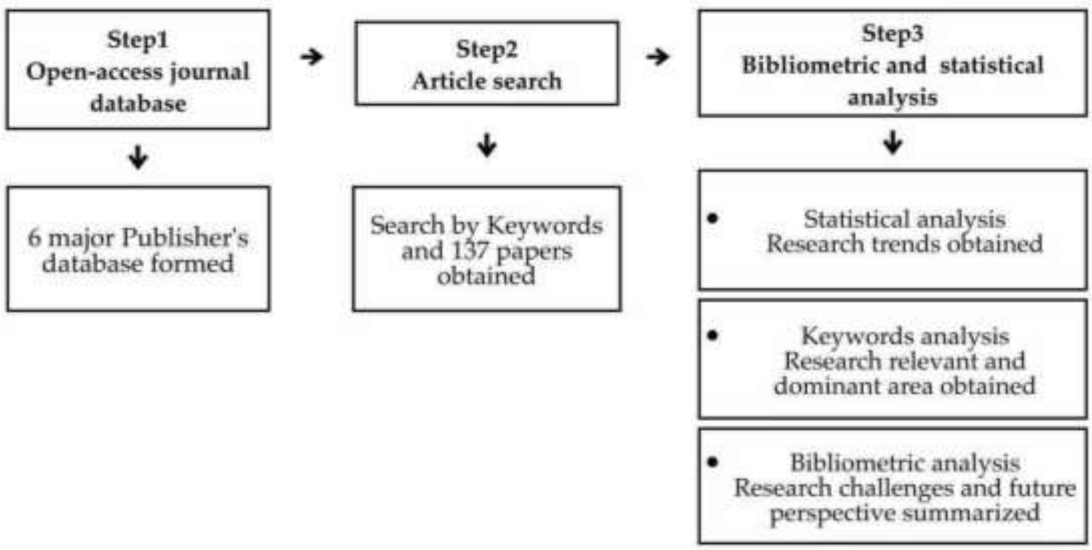


Figure 2-1. The general research flow illustrated for literature analysis

Different sections identified academic journal databases based on contributions to sustainability technologies. The databases contained most of the work within the past decade from 2006 to 2019, including various essential titles either on

(1) built environments and progress in generally integrated civil engineering, especially building issues.
(2) Civil Engineering Informatics applied in the construction sector.
(3) Life cycle consideration and building retrofitting and management stages.
(4) Building energy performance renovation and sustainable reconstruction with the energy concept. This initial selection of publications gave us six major open-access journal databases (as shown in Table 2-5).

Table 2-5. The journals selected by keyword filtering within the major journals' publisher databases[1].

Open Access Journals Publishers	Number of Journals Filtered	Number of papers Filtered
ELSEVIER	13	49
Springer	6	17
Wiley	2	26
Taylor &Francis (T&F)	15	32
American Society of Civil Engineers (ASCE)	2	7
MDPI	4	6
Total	42	137

[1] Journal publisher databases: www.elsevier.com; https://www.ebsco.com/; https://link.springer.com/ http://maint.onlinelibrary.wiley.com/; https://ascelibrary.org/; and https://www.mdpi.com/.

Limit the broad scope to the concerned energy-saving sections and narrow the bibliographical range applied in existing buildings. A keyword search was performed in the aforementioned academic journal publishers' databases with different keywords. The main keywords, including "building(information) modeling" "existing buildings" "energy retrofit" and "sustainability" were selected to further qualify the broad scope to the specific field of retrofitting or refurbishing existing buildings. The classification of the journal papers in the database is shown in Table 2-6

Table 2-6. The classification and quantity according to the scopes selected in the journal publishers' databases[1].

Scope	Journals （Publisher)	Number of Selected Papers
Built environment (number of journals: 9)	Architectural Engineering and Design Management (T&F)	3
	Archives of Computational Methods in Engineering (SPRINGER)	2
	Architectural Science Review (T&F)	4
	Journal of Architectural Engineering (ASCE)	5
	Journal of Building Engineering (ELSEVIER)	4
	KSCE Journal of Civil Engineering (Springer)	1
	Journal of Civil Engineering and Management (T&F)	2
	Science and Technology for the Built Environment (T&F)	1
	Frontiers of Architectural Research (ELSEVIER)	1
Civil Engineering Informatics (number of journals: 13)	Advanced Engineering Informatics (ELSEVIER)	2
	Automation in Construction (ELSEVIER)	11
	Advances in Engineering Software (ELSEVIER)	2
	Building and Environment (ELSEVIER)	6
	Building Simulation (SPRINGER)	12
	Computer-Aided Civil and Infrastructure Engineering (WILEY)	25
	Computer in Industry (ELSEVIER)	1
	International Review of Law, Computers & Technology (T&F)	1
	International Journal of Precision Engineering and Manufacturing (Springer)	1
	International Journal of Construction Management (T&F)	2
	Journal of Computing in Civil Engineering (ASCE)	2
	Buildings (MDPI)	1
	Energy Engineering (T&F)	2
LC Consideration and Building	Building Research & Information (T&F)	9
	International Journal of Strategic Property Management (T&F)	1

Retrofitting (number of journals: 8)	Intelligent Buildings International (T&F)	2
	Journal of Civil Structural Health Monitoring (Springer)	1
	Sustainable Cities and Society (ELSEVIER)	2
	Renewable and Sustainable Energy Reviews (ELSEVIER)	5
	International Journal of Environmental Research and Public Health (MDPI)	1
	IFAC-Papers Online (ELSEVIER)	1
Building Energy Performance (number of journals: 12)	Advances in Building Energy Research (T&F)	1
	Energy and Buildings (ELSEVIER)	7
	Journal of Cleaner Production (ELSEVIER)	4
	Environmental Progress & Sustainable Energy (WILEY)	1
	Strategic Planning for Energy and the Environment (T&F)	1
	Carbon Management (T&F)	1
	EURASIP Journal on Embedded Systems (Springer)	1
	Cogent Engineering (T&F)	1
	Energy Procedia (ELSEVIER)	1
	Sustainability (MDPI)	3
	energies (MDPI)	1
	HKIE Transactions+ IETE Technical Review (T&F)	2
Total		137

The statistical and bibliometric analysis, in the last step, is a further exploration of different concerns within the selected publication and papers. The analysis approach here depends mainly on the quantity statistics of keywords devoted to various research purposes from the previous classification. It intends to extract the variations of continuous development trends over time, the main research concerns and topic, and the interrelationship networks from all the categories and possible gaps.

The data analysis on the literature database revealed the recent implementation of energy in retrofit in existing buildings. The results and findings in the next section are expected to be a visual explication of current knowledge on sustainable ecology within the building energy field。

The emerging environmental threats associated with energy shortages and climate change have drawn attention from government sectors and construction-based professional bodies. They recognized the need for developing effective, sustainable building strategies and agreed to explore better technologies and reasonable energy source alternatives. It is reasonably necessary to create more intelligent, more effective methods implemented in the design, operation, retrofit, and maintenance aspects to make more intelligent and flexible buildings satisfy sustainable demand.

The construction industry has been evolving to embrace sustainability. As a new trend of Information and Communication Technology applied in the AEC sector, Building Information Modeling technologies have been given more critical roles in building energy consumption. With its help, the built environment, sunshine, heating equipment, and even the embodied energy consumption and associated environmental impacts could be estimated [10]. However, it has been agreed upon that research on retrofitting buildings is still in the explorative stage, especially in the area of energy, because of the many complexities and challenges existing.

2.4. The situation research of material corncob

China attaches great importance to the development of circular economy, the core of which is the recycling of resources. The current ecological environment problems have attracted great attention worldwide, and the recycling of resources has important practical significance for protecting and improving the ecological environment, especially in the resource utilization of solid waste in agriculture and construction.

2.4.1 Research of Agricultural Solid Waste-corncob

Agricultural waste is a rich source of renewable energy, but with the development of science and technology, its utilization value is getting lower and lower, and it has gradually become one of the main pollution sources of the rural environment. In order to effectively alleviate this severe situation, it is necessary to make reasonable planning for agricultural waste resources, appropriately increase the comprehensive utilization rate of agricultural waste, and realize the recycling of waste resources, so as to turn agricultural waste from "waste" into "treasure". "[44-46]. As an important recyclable resource, corncob has not been used in high value in the process of agricultural development. It is usually treated by means of rural burning for heating, animal husbandry, and returning plow to fields, which not only pollutes the ecological environment, but also Caused a waste of natural resources[46, 47]. In addition, corncobs are uniform in texture, light in weight, have certain strength, thermal insulation, and sound absorption performance. They are a valuable secondary resource that urgently needs to be developed and utilized.

Research in China

Leading rural revitalization with green development, the comprehensive utilization of agricultural waste resources has become a hot spot in the industry[48]. In order to reduce environmental pollution in rural areas and improve the living environment in rural areas, China has focused on research on the comprehensive utilization of agricultural waste. China is a large agricultural country with abundant crop resources. However, China started relatively late in the resource utilization of agricultural solid waste, but it has developed rapidly and has achieved great results.

The resource utilization of corn waste in China mainly focuses on the application research of corn stalks. Corn stalks are hollow tubes inside and have a high thermal resistance value. When used as building materials, they can improve the insulation effect of buildings. Chen Limei[49-51] and others made use of the small thermal conductivity of corn stalks to prepare thermal insulation boards, and the biomass resources were fully utilized; Sun Jing et al. A new type of energy-saving and environmentally friendly concrete was developed. The test results showed that the incorporation of corn stalks reduced the thermal conductivity and apparent density of concrete, but greatly improved the thermal insulation performance of concrete.

Compared with sand and gravel resources, biomass resources have the characteristics of light weight, many pores, and high-water absorption. When used as building materials, they can reduce the dry density and compressive strength of concrete. Xu Jiahua [52] added corn stalk powder to autoclaved aerated concrete and conducted a systematic study on the performance of concrete blocks. The test results showed that the dry density of concrete blocks gradually decreased with the increase of corn stalks; Qian Kun [53] et al conducted the axial compressive strength test on the straw concrete test block, and the data analysis showed that the axial compressive strength of the concrete test block decreased with the increase of the amount of corn stalk, which is mainly The reason is that the strength of corn stalks is too different from that of cement, adding too much straw will reduce the mechanical properties of the overall block; Liu Wei studied the mechanical properties of clay ceramsite concrete mixed with corn stalks, and passed the test According to the data analysis, there is an obvious linear relationship between the amount of corn stalks added and the compressive strength of concrete. With the increase of the amount of corn stalks, the decrease of concrete compressive strength increases.

In recent years, with the promulgation of relevant national policies, a large number of wooden structures have risen, and the use of wood in construction has increased sharply, which has led to a significant reduction in China's forest resources. Qian Yongmei et al. [54] produced corn stalk recombined wood through the recombination process on the basis of retaining the original fiber structure of corn stalks. The compressive strength of corn stalk recombined wood was determined to be higher than GB/T50329-2012 " The highest compressive design strength of square timber and logs in the "Standards for Test Methods of Timber Structures", and it has certain elastic-plastic properties, it is a new type of wood substitute structural material.

China has made great progress in the research on the use of corn stalks as building materials, and the current research on the application of corncobs in building materials is basically in a blank state. Since both corn stalks and corncobs are biomass materials of the same plant and have certain similarities in material composition, the research on corn stalks in the field of building materials can provide a certain reference value for the application of corncobs.

There have been preliminary studies on the mechanical properties of corncobs in China. Zhao Wuyun conducted a study on the mechanical properties of corncobs after threshing. The test results showed that when the water content of corncobs itself decreased, the compressive cracking load and bending of corncobs were the smallest. The fracture load decreases accordingly, and the minimum fracture load of corncob compression and bending increases with the increase of corncob diameter; Li Xinping et al. studied the relationship between the compressive strength of corncobs and the moisture content of corncobs, and the test results It shows that the compressive strength is the highest when the moisture content of corncob is 25%. It can be seen that the water content of corncob has a great influence on the mechanical properties of concrete. In addition, stiffness refers to the ability of a material or structure to resist elastic deformation when it is stressed. The magnitude of the impact force and its change process when the corncob is impacted can be used as an important reference index for evaluating the stiffness of the corncob. Zhang Maojian [55] studied the influence of corncob diameter on the stiffness coefficient, and concluded that with the increase of corncob diameter, the corncob stiffness coefficient showed an upward trend.

Therefore, as the country vigorously advocates the application of environmentally friendly and energy-saving materials and improves the recycling of renewable resources, more and more universities and researchers are committed to the research on the reuse of biomass materials. Due to the abundant yield and low price of corncobs, the heat preservation effect is good, and it has gradually become one of the research hotspots of all parties.

International Research

For the application research on the use of agricultural waste as building materials, foreign countries started relatively early, and the application research on the use of corn stalks as building materials has achieved many results. For example, Orhan Aksoğan [56] studied the durability properties of concretes involving corn stalk, wheat straw and sunflower stalk ash along with barite and colemanite are investigated. Corn stalk, wheat straw and sunflower stalk ash are substituted in place of cement, while barite and colemanite are substituted in place of fine aggregate with different percentages. Concrete specimens were tested for compressive strength at 7, 28 and 180 days. Furthermore, abrasion and freeze–thaw tests were performed to investigate the physical and mechanical properties. 180-day sulfate resistance tests were applied in 5% sodium sulfate solution (Na2SO4) for investigating the chemical effect on concrete. Moreover, 12 × 12 × 2 cm mortar samples were produced to apply radiation shielding test. Am-241 gamma ray source was used for the radiation shielding test. The present study showed that the use of the abovementioned ashes improves many engineering properties of concrete. By filling the voids, the ashes produce a stronger concrete, which is further enhanced by colemanite and barite. Additionally, the additives improve the radiation shielding property of concrete.

The high energy consumption in buildings is a major contributor to climate change and atmospheric pollution in south cities of Chile. In this context, insulation materials are a key factor to reduce the energy demand during the operational stage of a building. These materials are however commonly fabricated from petrochemicals with high energy consumption, causing significant detrimental effects on the environment during the production and discarding stage. Due these reasons, insulation materials based on natural fibers waste appear as an excellent alternative, due to abundant availability in south regions of Chile, potential low cost, low energy consumption during the production stage and high bio-degradation rate at the end of life. Carlos Rojas [57] studied block type insulation based on wheat straw and corn husk residual fibers. Taguchi method was applied to investigate the effect on thermal conductivity and density of four control factors in three levels, namely fiber length, boiling time; NaOH concentration and blending time; in an L-9 orthogonal array. Furthermore, flexural and compressive stress were determined and compared with expanded polystyrene block insulation. The results show thermal conductivity values were between 0.046 and 0.047 $W/(m^2 \cdot K)$.. Flexural stress results were good compared to those of the standard expanded polystyrene type IX. Finally, optimum conditions of the process were determined to obtain a final block, which was morphologically analyzed using scanning electron microscopy, while the thermal behavior was studied by thermogravimetric analysis; Elsafi Mohamed Adam Elbashiry[58] studies light and green new environmentally friendly prefabricated building materials. On the basis of his research on lightweight composite materials for beetle's front wing, he found that straw cement-based building materials (especially brick wall structure) and beetle's front wing bionic structure are the perfect match point. A bionic model of beetle front wing based on straw cement was proposed. Taking straw bionic brick, a basic unit model of cement-based building materials, as an example, the physical sample was made, and its mechanics and heat transfer properties were investigated by experiments and finite element analysis. Then, two kinds of new light green prefabricated building materials, straw wall beetle board, were taken as the research object, and their mechanical and heat transfer properties were investigated by finite element analysis. The optimal structural parameters were obtained, and the influence mechanism of mechanical properties and heat transfer effect was explored; Koji Kito[59] introduced an environmentally friendly biodegradable board with corn stalk as raw material -- bio board. This paper introduces a kind of environmental protection biodegradable board with corn straw as raw material. Five kinds of manufacture technology of motherboard are put forward. In order to study the effect of pressure on the strength of biological plates, five kinds of pressure were applied during the forming process. The results show that it is successful to make board with corn straw under various experimental conditions; Muhammad Riaz Ahmad[60] and others studied a new type of bio-composite based on the mixture of magnesium phosphate cement , fly ash and corn stalk. The study determines the feasibility of using this composite as an insulation and structural material. Several concrete mixtures were formulated with different concentrations and two sizes of corn stalk to develop corn stalk magnesium phosphate cement concrete. The compressive strength, thermal conductivity, capillary water uptake and water absorption properties of all the bio-composites were investigated. The biomass composites thus prepared belong to the category of lightweight concrete.

The research on the engineering application of corn stalks abroad has been relatively extensive and the preparation technology has gradually matured, which has led some scholars and experts to gradually shift their focus to the application research of corncobs. For example, Solomon Oyebisi[61] conducted a systematic study on the activity index and durability of slag-based geopolymer concrete mixed with corncob ash, and the results showed that adding corncob ash can improve the concrete's compressive strength and sulfuric acid resistance to a certain extent Salt erosion performance, because the effect of corncob ash is the same as that of fiber, the addition of corncob ash can enhance the internal compactness of concrete, which leads to the improvement of its compressive strength and durability; In any building the indoor temperature relies on various elements of the building such as walls, roofs, windows, and doors. Major surface area of the wall is exposed to solar radiation, to reduce the heat gain through the wall the perfect insulation substances have to be chosen. Bhagirathi Rajwade[62] changed the chemical composition of fly ash bricks by using corncob ash with normal strength is a new dimension of bricks design, and large-scale purposes will enhance the development of the construction industry through cost savings. Corncob is the waste product obtained from maize or corn and it is the most important crop in the Chhattisgarh. The objective of the work is to manufacture fly ash bricks, with partial replacement of cement by corncob ash (CCA). The composition of fly ash bricks are fly ash, sand, and cement. In this work, CCA replaces the cement by 0, 10, 20 and 30%. Compressive strength, water absorption, and thermal conductivity test shows that replacement of cement with CCA in fly ash bricks gives the good results and fulfills the minimum requirement of common building brick; In line with Malaysia government environmental policy and encouraging of utilizing sustainable materials those from natural resources in order to reduce the detrimental effect of synthetic materials on the environment, Malaysian scholars A.C. Abdullah, C.C. Lee[63] used corncobs as raw materials to prepare bricks. The test results showed that corncob bricks had high water absorption rate and low flexural strength and compressive strength. This was mainly because corncobs had high Water absorption; a large amount of water is absorbed during the mixing process. With the extension of the curing period, the internal moisture is reversely exported to the concrete, which makes the concrete internal moisture too much, resulting in low flexural strength and compressive strength.

In summary, in the construction of new rural areas in China, a large number of energy-saving, environmentally friendly and low-cost wall materials are needed for the walls of rural residential enclosures. Corncobs are renewable resources, which are easy to obtain and energy-saving and environmentally friendly. Corncobs are used as concrete aggregates, the building cost will be greatly reduced. Corncob has a high value as a building material, but it has not been widely used at home and abroad at present. Whether it can be used as an environmentally friendly building material in the construction industry still needs to be studied in many aspects. Therefore, the application research of corncob as building material will have broad market prospects and significant economic and social benefits.

2.4.2 Current research on resource utilization of construction waste

Construction waste comes from construction and should be returned to construction. The use of construction waste as building materials has attracted much attention. With the acceleration of urbanization, demolition or reconstruction projects will generate a large amount of construction waste, and also bring about a serious shortage of building material resources. How to fully and efficiently utilize construction waste, especially the application of waste concrete, has become a hot topic of joint research in many countries [64].

Research in China

The limited nature of natural resources gradually does not correspond to the rapid development of the construction industry. The recycling of waste concrete can effectively reduce the consumption of natural resources. Recycled aggregate is an effective use of construction waste resources, which is both economical and environmentally friendly, and has significant benefits. Domestic research on recycled aggregates mainly focuses on the mechanical properties of recycled aggregates and recycled concrete.

The volume of aggregate accounts for about 70%-80% of the total concrete volume. Aggregate not only constitutes the skeleton of concrete, but also the properties of aggregate affect the performance of recycled concrete to a large extent. For the physical properties of recycled aggregates, many research results have been obtained. Yi Chao [65] studied the basic properties of recycled aggregates. After analysis, it was concluded that the water absorption and crushing index of recycled coarse aggregates should be higher. For natural coarse aggregate, it is mainly related to the fact that the recycled coarse aggregate particles have many edges and corners, the surface is rough, and the components contain hardened cement mortar; compared with natural river sand, the water absorption rate of recycled fine aggregate has increased by 16.8%. The surface of the recycled fine aggregate contains a large amount of fine powder, which significantly increases its water absorption performance. Yang Xiaoguang[66] studied the apparent density and elastic modulus of recycled aggregates, and concluded through the analysis of test data that the apparent density of recycled aggregates is related to the particle size of recycled aggregates. Attached cement mortar, its apparent density is lower than that of natural aggregate; the elastic modulus of recycled aggregate is also lower than that of natural aggregate. The reason for this difference is that the quality of recycled aggregate is not uniform, and the porosity is too large.

Recycled aggregates have poor performance and cannot be directly used in concrete. In order to improve the utilization of recycled aggregates and promote the development of recycled concrete, it is necessary to strengthen the recycled aggregates. Li Qiuyi[67] and others strengthened the quality of recycled fine aggregate, the particle size of the recycled fine aggregate after particle shaping was improved, the apparent density was slightly increased, and the water absorption rate was reduced; Guo Yuanxin et al[68] from the physical and the quality of recycled coarse aggregate is improved in chemical aspects. The study found that the 24h water absorption rate of recycled coarse aggregate after secondary particle shaping treatment is reduced by 2.5%, and the crushing index is reduced by 9%. The performance parameters are close to natural aggregate.; After chemical treatment of recycled coarse aggregate, its 24h water absorption rate decreased by 2.3%, and the crushing index decreased by 5%; It also improves the performance of recycled aggregate, so as to achieve the purpose of improving the performance of recycled aggregate concrete.

Under the trend of energy saving and environmental protection, the use of recycled aggregates to prepare recycled concrete has become the focus of researchers. Ji Feng et al. [69]studied the correlation between the water absorption rate of recycled aggregates and the strength of concrete. The strength of recycled concrete prepared from recycled aggregate decreases gradually with the increase of water absorption of recycled aggregate. Compressive strength is one of the main properties of concrete, and the replacement rate of recycled aggregate is an important factor affecting the compressive strength of concrete. Li Qiuyi et al. [[70]carried out experimental research on the working performance of recycled fine aggregate concrete. The test results proved that the higher the replacement rate of recycled fine aggregate, the more water consumption of recycled concrete mixture, and the lower the compressive strength; Chen Zongping [71] studied the effect of the replacement rate of recycled coarse aggregate on the mechanical properties of recycled concrete. After analysis, it was concluded that the compressive strength of recycled concrete showed an overall increasing trend with the increase of the replacement rate of recycled coarse aggregate. Due to the large difference in the quality of recycled aggregates and the complex interface structure, the shrinkage of concrete is relatively large. Sun Jiaying et al.[72]focused on the influence of the replacement rate of recycled fine aggregates on the shrinkage and cracking properties of concrete. The shrinkage of recycled concrete prepared by substituting natural sand for natural sand increased, and its crack resistance also decreased; Wang Yonghe [73] studied the performance of recycled concrete prepared under different replacement ratios of recycled coarse aggregate, and the test results proved that recycled concrete When the replacement rate of coarse aggregate changes, the impact on the early shrinkage of recycled concrete is not obvious, but it has a significant impact on the later shrinkage.

International Research

The treatment of construction waste started earlier in foreign countries, and the recovery and reuse efficiency of construction waste in developed countries can reach more than 95%, and a relatively complete resource utilization system has been formed. The United States implements low, medium and high three-level treatment methods for construction waste, and different levels of construction waste can play their greatest role as much as possible; Germany has a complete set of construction material waste treatment processes and technologies and has established large-scale construction materials in each state. The waste processing plant mainly applies construction waste to roads, and formulates corresponding technical specifications to guide the utilization of recycled concrete; Japan chooses to reduce the generation of construction waste from the source, and strictly controls every step to effectively reduce construction waste Yield, improve utilization efficiency [74-76].

In some western countries, the engineering application of construction waste recycling has achieved great results, and at the same time, the research work of the laboratory has also achieved more results. For example, Notre Dame University[77] studied the shrinkage properties of recycled concrete; H. P. S. Abdul Khalil et al.[78]studied the influence of recycled fine aggregate on the mechanical properties of recycled concrete hollow blocks under different substitution rates. The test results It shows that, under other conditions being the same, as the replacement rate of recycled fine aggregate increases, the compressive strength and flexural strength of recycled concrete hollow blocks gradually decrease; Rebeca Martínez-García et al. mainly studied the work performance change law of recycled concrete when the replacement rate of materials changes. The results show that it is technically feasible to use recycled aggregates to prepare self-compacting concrete, and the economic and social benefits are significant.

It can be seen that the development and application of waste in green ecological buildings are highly valued worldwide, and the comprehensive utilization of agricultural waste and construction waste is currently the most economical, ecological and effective way of waste utilization. The co-processing of agricultural waste and construction waste can turn waste resources into treasure, effectively alleviate the shortage of resources and energy, and can also reduce the pollution of solid waste to the environment, so as to realize the tripartite cooperation between environment, economy and society common long-term development.

2.5. Summary

This chapter introduced the current status of laws and registration on energy-saving and environmental improvement of traditional houses in different countries and times. Scholars have interpreted the theories and methods of building energy-saving and environmental improvement mainly from three perspectives: the discipline in Architecture heritage protection; the literature analysis of energy saving; energy-saving renovation of historic buildings. An objective and detailed analysis of the current research results on laws and registration reveals the importance attached to the protection of traditional buildings, but most of the existing studies are not yet generalizable.

In terms of residential thermal comfort and energy-saving research, this paper finds that the thermal comfort evaluation index system has been completed by combing thermal comfort evaluation indexes, residential thermal comfort evaluation research, and residential thermal comfort improvement research in the United States, the United Kingdom, Denmark, China, and other countries, but there are fewer research results on thermal comfort indexes in China, and innovative research, in theory, is, however, at the practical level, due to China's geographical location, the research on thermal comfort evaluation and improvement of residential houses in China is more extensive and comprehensive than in other countries. In this paper, we summarize the experiences of different countries through comparative studies and lay the foundation for the next step of environmental improvement of traditional houses.

In terms of the energy-saving design of traditional houses, the existing literature can be divided into several main areas: Built environment, Civil Engineering Informatics, Consideration, and Building Retrofitting, and Building Energy Performance. The existing residential energy-saving standards system has been basically completed, but there are still deficiencies in traditional areas. Due to the constraints of economic and technical conditions, which limit energy-saving, the energy-saving method for old houses needs to continue to be improved. The current building renovation mainly focuses on analyzing the single factor of the envelope structure, and the comparative analysis of the combination of each part of the envelope structure with each other is insufficient. In addition, research on energy-saving material exploration is needed.

Reference

1. Wu., L.Y., Introduction to Science of Human Settlements. Beijing: China Construction Industry Press, 2001.

2. Wargocki, P., et al. Ventilation and health in nonindustrial indoor environments. in Report from a European Multidisciplinary Scientific Consensus Meeting, Epidemiology. 2001.

3. Ge, J., et al., Energy-efficiency strategies of residential envelope in China's Hot Summer–Cold Winter Zone based on intermittent thermal regulation behaviour. Journal of Building Engineering, 2021. **44**: p. 103028.

4. Gowri, K., M. Halverson, and E. Richman, Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York. 2007, Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

5. Liu, B., M. Rosenberg, and R. Athalye. National Impact Of ANSI/ASHRAE/IES Standard 90.1-2016. in 2018 Building Performance Analysis Conference and SimBuild. 2018.

6. Dietrich, U., Room optimisation based on DIN 18599-4 (daylight), DIN 4108-2 (thermal comfort during summer) and simulations; Optimierung eines Raumes mithilfe von DIN 18599-4 (Tageslicht), DIN 4108-2 (sommerlicher Waermeschutz) und weiterfuehrenden Simulationen. Bauphysik, 2008. **30**.

7. Trogisch, A., EnEV 2002 and DIN 4108-Vol. 2"Thermal insulation in the summer season; EnEV 2002 und DIN 4108-Bl. 2"Sommerlicher Waermeschutz". Ki Luft-und Kältetechnik, 2002. **38**.

8. Haenel, K. and S. Brummack, Comparison of the heat insulation requirements for building envelopes between EnEV 2007 and EnEV 2009; Anforderungen an die Waermedaemmung der Gebaeudehuelle: ein Vergleich zwischen EnEV 2009 und EnEV 2007. Bauphysik, 2010. **32**.

9. Balkowski, M. and B. Dietrich, The German building energy conservation ordinance (Energieeinsparverordnung-EnEV 2007). Concept and application. ; Die Energieeinsparverordnung-EnEV 2007. Konzept und Anwendung. 2007.

10. Jokilehto, J., A history of architectural conservation. 2017: Routledge.

11. Corbusier, L. and A. Eardley, The athens charter. 1973: Grossman Publishers New York.

12. Hull, C., PROTECTION OF ARTISTIC AND SCIENTIFIC INSTITUTIONS AND HISTORIC MONUMENTS: TREATY BETWEEN THE UNITED STATES OF AMERICA AND THE OTHER AMERICAN REPUBLICS. Himalayan and Central Asian Studies, 2011. **15**(4): p. 79.

13. Byard, P.S., The architecture of additions: design and regulation. 1998: WW Norton & Company.

14. Avrami, E., Values and heritage conservation. Conservation: The Getty Conservation Institute Newsletter, 2000. **15**(2): p. 18-21.

15. Jokilehto, J., The context of the Venice Charter (1964). Conservation and management of archaeological sites, 1998. **2**(4): p. 229-233.

16. Sterental, S., The Charter Of Machu Picchu. The Fifth Column, 1982. **2**(2): p. 16-17.

17. Charter, W., Charter for the Conservation of Historic Towns and Urban Areas. Washington, DC: Adopted by ICOMOS General Assembly.(October 1987), 1987.

18. Room, I., Convention concerning the protection of the world cultural and natural heritage. 1972.

19. Jiang, Y., Current building energy consumption in China and effective energy efficiency measures. Hv&Ac, 2005. **35**(5): p. 30-40.

20. Roberti, F., et al., Energy retrofit and conservation of a historic building using multi-objective optimization and an analytic hierarchy process. Energy and Buildings, 2017. **138**: p. 1-10.

21. De Santoli, L., Guidelines on energy efficiency of cultural heritage. Energy and Buildings, 2015. **86**: p. 534-540.

22. Zagorskas, J., et al., Thermal insulation alternatives of historic brick buildings in Baltic Sea Region. Energy and buildings, 2014. **78**: p. 35-42.

23. Ben, H. and K. Steemers, Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London. Energy and Buildings, 2014. **80**: p. 120-130.

24. Sugár, V., et al., Architectural style in line with energy demand: Typology-based energy estimation of a downtown district. Energy and Buildings, 2018. **180**: p. 1-15.

25. Sugár, V., et al., Energy saving retrofit in a heritage district: The case of the Budapest. Journal of Building Engineering, 2020. **27**: p. 100982.

26. Ascione, F., et al., Design the refurbishment of historic buildings with the cost-optimal methodology: The case study of a XV century Italian building. Energy and Buildings, 2015. **99**: p. 162-176.

27. Wakili, K.G., et al., Efficiency verification of a combination of high performance and conventional insulation layers in retrofitting a 130-year old building. Energy and Buildings, 2014. **82**: p. 237-242.

28. Đukanović, L., A. Radivojević, and A. Rajčić, Potentials and limitations for energy refurbishment of multi-family residential buildings built in Belgrade before the World War One. Energy and buildings, 2016. **115**: p. 112-120.

29. Elmokadem, A., M. Shahda, and R. Elsawaf, Retrofit an Existing Building Envelope as a Tool to Improve the Energy Performance of Buildings. 2019.

30. Nicolae, B. and B. George-Vlad, Life cycle analysis in refurbishment of the buildings as intervention practices in energy saving. Energy and Buildings, 2015. **86**: p. 74-85.

31. Kharbouch, Y., A. Mimet, and M. El Ganaoui, A Simulation based-optimization method for energy efficiency of a multi-zone house integrated PCM. Energy Procedia, 2017. **139**: p. 450-455.

32. Mandilaras, I., et al., Thermal performance of a building envelope incorporating ETICS with vacuum insulation panels and EPS. Energy and Buildings, 2014. **85**: p. 654-665.

33. Kishore, R.A., et al., Enhancing building energy performance by effectively using phase change material and dynamic insulation in walls. Applied Energy, 2021. **283**: p. 116306.

34. Zhitie, Q., Energy-saving technology history of building of Tongji University College of Architecture and Urban Planning. Architecture Energy-saving 2014. **42**(2): p. 69-73.

35. Xinrui, D., Research on the improvement of thermal and humidity environment for the conservation and reuse of cultural relics on university campus in Nanjing-Taking the auditorium of southeast university as an example. 2019, Southeast University.

36. Dexuan, S., Research on energy-saving renovation strategies of new-style lilong residences in

Tianjin. Housing Science, 2019. **39**(12): p. 50-55.
37. Jiabei, A preliminary study on the application of the principle of Trumbo wall in the protection and renewal of the exterior wall of modern historical buildings. 2016, Beijing Jiaotong University.
38. Yan, Z., Research on the suitability of energy-saving renovation technology for historically protected buildings——Taking the protective renovation project of Luojia old house in Hangzhou as an example. Huazhong Architecture, 2014. **32**(10): p. 100-103.
39. Jinwen, L., Research on the evaluation model of energy-saving renovation of historic office buildings. 2017, Tianjin University.
40. ZUO, Y. and Y. GAO, A Study on the Methodology of Energy-saving Assessment for Preservation and Reuse of Historical Buildings. New Architecture, 2017.
41. Xu, W., Research on technology strategy of energy-saving renovation of century heritage building envelope. 2016, Beijing industry university.
42. Cui, Y., et al., Indoor temperature improvement and energy-saving renovations in rural houses of China’s cold region—A case study of shandong province. Energies, 2020. **13**(4): p. 870.
43. Jin, H. and W. Ling, External wall structure of green rural houses in Daqing, China, based on life cycle and ecological footprint theories. Frontiers of Architectural Research, 2015. **4**(3): p. 212-219.
44. Xiaoya, F. and C. Jie, Current situation and countermeasures of agro-ecological environment pollution. collection, 2019. **14**.
45. Teng Fei, L.J., Li Chuan-you, Li Zhen, ZHANG Li, Xiong Bo, Practice and exploration of resource utilization of agricultural waste. Agricultural machinery quality and supervision, 2020.
46. Lixin, W., Present situation and development prospect of comprehensive utilization of corn stover. Agricultural development and equipment, 2021.
47. Chen Shili, H.J., Hou Yuan, Research on Current situation of corncob recycling -- Based on analysis of Enactus Project of college students. 2019.
48. Xiao, S., Review and prospect of comprehensive utilization of agricultural waste. Outlook on Agriculture, 2020.
49. Chen, L.-m., Analysis of mechanical properties of corn straw insulation board. Journal of Jilin Agricultural University, 2021. **43**(4): p. 495-500.
50. Yiwei, M., Heat transfer performance analysis of corn stalk board. Journal of Jilin Agricultural University, 2019. **41**(4): p. 483-488.
51. Yang Xiufei, L.Q., Yang Huijuan, Yang Huijuan, ZOU Jun, GAO Wentao., The potential analysis of biomass as building thermal insulation material in China. Energy saving, 2012.
52. Jiahua, X., Study on production of autoclaved aerated concrete block with straw fiber and its performance. Guangdong Building Materials, 2019. **4**.
53. Kun, Q., Experimental study on mechanical properties of straw concrete block. Building energy efficiency, 2015. **43**(11): p. 48-52.
54. Yongmei, Q., Experimental study on compressive property parameters of novel corn straw composites. Industrial construction, 2019. **8**.

55. Zhang, Y., J. Kang, and H. Jin, A review of green building development in China from the perspective of energy saving. Energies, 2018. **11**(2): p. 334.
56. Aksoğan, O., H. Binici, and E. Ortlek, Durability of concrete made by partial replacement of fine aggregate by colemanite and barite and cement by ashes of corn stalk, wheat straw and sunflower stalk ashes. Construction and Building Materials, 2016. **106**: p. 253-263.
57. Rojas, C., et al., Thermal insulation materials based on agricultural residual wheat straw and corn husk biomass, for application in sustainable buildings. Sustainable Materials and Technologies, 2019. **20**: p. e00102.
58. ELBASHIRY, E.M.A., The Applied Foundational Research of Bionic Light Straw for Building, in International Institute for Urban System Engineering. 2019, Southeast University.
59. Wu, T., X. Wang, and K. Kito, Effects of pressures on the mechanical properties of corn straw bio-board. Engineering in agriculture, environment and food, 2015. **8**(3): p. 123-129.
60. Ahmad, M.R., et al., Development of a new bio-composite for building insulation and structural purpose using corn stalk and magnesium phosphate cement. Energy and buildings, 2018. **173**: p. 719-733.
61. Oyebisi, S., et al., Evaluation of reactivity indexes and durability properties of slag-based geopolymer concrete incorporating corncob ash. Construction and Building Materials, 2020. **258**: p. 119604.
62. Rajwade, B. and N. Netam, Investigation of effects of corncob ash in fly ash bricks. Materials Today: Proceedings, 2020. **28**: p. 2431-2434.
63. Abdullah, A. and C. Lee, Effect of treatments on properties of cement-fiber bricks utilizing rice husk, corncob and coconut Coir. Procedia engineering, 2017. **180**: p. 1266-1273.
64. Shouchang, D., Current situation analysis and research prospect of waste concrete recycling. concrete, 2006(11): p. 20-24.
65. chao, Y., Study on preparation of reclaimed aggregate concrete from construction waste. 2014, Guangzhou: Jinan University.
66. Xiaoguang, Y., Study on the basic properties of recycled aggregate. concrete, 2012(2): p. 66-68.
67. li, Q.-y., Study on quality standard and inspection method of recycled fine aggregate. Journal of Qingdao Technological University, 2005. **26**(6): p. 6-9.
68. Yuanxin, G., Study on quality improvement technology of recycled coarse aggregate. concrete, 2015(6): p. 134-138.
69. feng, J., Study on the correlation between water absorption and strength of reclaimed concrete. Journal of Yangtze River Scientific Research Institute, 2019. **36**(3): p. 139.
70. QIuyi, L., Experimental study on working and mechanical properties of recycled fine aggregate concrete. concrete, 2016(1): p. 131-136.
71. Zongping, C., Analysis of influence of recycled coarse aggregate content on mechanical properties of recycled concrete. Industrial construction, 2015(1): p. 130-135.
72. Chengcheng, C., Experimental study on plastic shrinkage cracking behavior of recycled fine aggregate concrete. concrete, 2012(3): p. 81-83.

73. Yonghe, W., Analysis of deformation behavior and influencing factors of recycled coarse aggregate concrete. Metallurgy and Materials, 2020.
74. Qiong, W., Present situation of comprehensive utilization of construction waste at home and abroad and domestic development suggestions. Fly ash, 2014(4): p. 19-21.
75. ChangJie, T., Analysis on the status quo of construction waste treatment and benefit of resource utilization. Green Technology, 2019.
76. Yongshan, Y., Current situation of construction waste recycling. Collection, 2018. **46**.
77. Yang, Z. and C. Tanimoto, Ancient Underground Opening and Preservation: Proceedings of the International Symposium on Scientific Problems and Long-term Preservation of Large-scale Ancient Underground Engineering (23-26 October 2015, Longyou, Zhejiang, China). 2015: CRC Press.
78. Yang, L. and S. Li, Analysis of the effect of substitution rate on the mechanical properties of recycled concrete hollow block. Advances in Materials Science and Engineering, 2019. **2019**.

Chapter 3.

Methodology of Liyuan survey, experiments and simulations

3.1. Introduction

The research process is divided into two stages and three levels. The first stage is research hypothesis and investigation. Through the preliminary investigation of the courtyard buildings in Qingdao City, Shandong Province, problems were found, and basic preparations were made for in-depth research. The second stage is the field investigation stage. Inspection of the courtyard buildings feels the living conditions of the residents and the indoor thermal environment, air quality of the existing residential buildings; and dimensional survey of the courtyard building sites helps making the sketch of building floors. Through interviews and questionnaires, a detailed investigation of the current housing situation and residents' living conditions was conducted to obtain first-hand information.

The research work is divided into three levels. The first layer is to investigate the overall pattern of the courtyard, that is, to understand the current situation of the courtyard, infrastructure, resources, economic level, customs, population composition, housing types, and energy consumption characteristics through interviews with local residents. The second tier is opinion polls, because there are fewer occupants. We used a questionnaire survey method based on face-to-face interviews. Considering the education level of residents and the accuracy of survey information, the survey method adopted face-to-face interview questionnaires. The third level is the combination of questionnaire analysis and field test, that is, selecting a typical courtyard house for household questionnaire survey, and conducting field inspection, indoor and outdoor temperature, relative humidity, indoor pollution gas, heat transfer coefficient test envelope and other rural houses parameter.

The three levels of research have different objectives, including the overall macro characteristics of the courtyard and the individual differences in the form of each block. At the same time, in-depth testing and research are carried out on typical cases. The survey data between the three levels can confirm and complement each other to improve the accuracy and reliability of the survey data.

The following analyses and activities were conducted in this research:

- On-site observation—the subject of preservation was determined on the basis of the analysis and evaluation of historic buildings.

- Taking one observed Liyuan building case study as a method of studying the case (as a whole) of the example of restoration and improvement of energy efficiency of the contemporary, enabled the realization of scientific knowledge.
- Designing and defining criteria for constructive protection based on the preliminary on-site investigation and choosing the type of work that needs to be undertaken in order to restore the building that has been continuously used for almost a century.
- Analyses of the building materials used in the construction of the historic building.
- Restoration of the building in accordance with the conservation requirements: retaining the authentic elements of the structure (facade walls, roof structure) as well as the authentic appearance of the building.
- Restoration of the contemporary building and retention its original appearance as much as possible, preserving the visual appearance of facade bricks walls and stone details, as well as majority of interior details, and meeting modern principles and requirements of building physics.
- Project preparation for the restoration of the contemporary building, along with checking the possibility of improving the already restored buildings by applying individual interventions scenarios in order to improve energy efficiency and energy saving.
- All interventions on the contemporary buildings, aimed at restoring and improving energy efficiency, are reversible processes and can be done in accordance with the conservation requirements.
- Analyses and evaluations of the achieved results by applying various proposed restoration scenarios for the purpose of energy refurbishment, along with normal use and preservation of the environment.

Here is going to introduce these methodologies in detail process map (Figure 3-1).

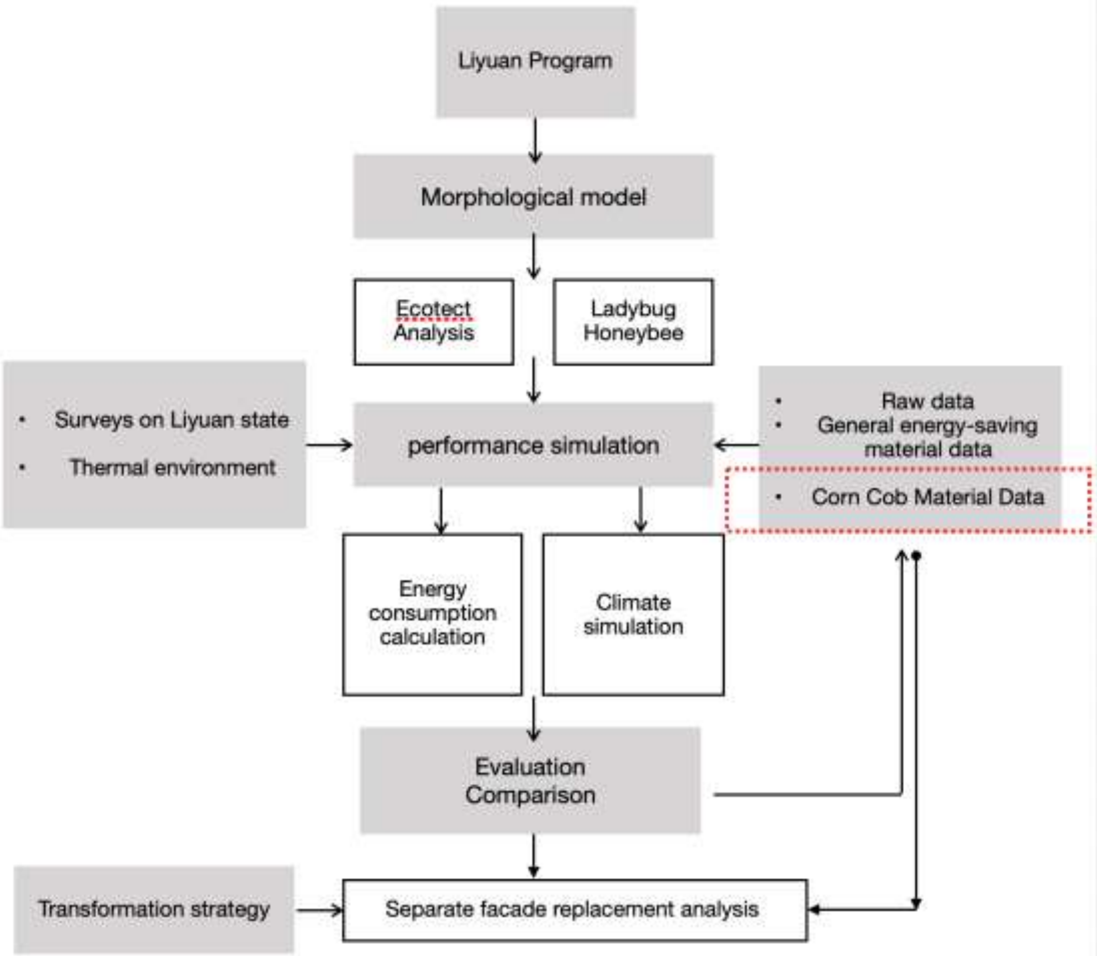


Figure 3-1. The process map of the research methodologies in detail

3.2. Surveys on Liyuan state

3.2.1. The questionnaire of the site

This thesis analyzes, tests, and investigates the houses in the courtyard through interviews, questionnaires, and field visits. The basic information about homes and residents is collected through interviews. Questionnaires are conducted to master the existing residents' lifestyles and living habits and to understand residents' subjective evaluations of indoor living conditions.

The main contents of the questionnaire include gender, age, family composition, family population, permanent resident population, etc. During the investigation of the residential district, there were plenty chances to contact with the local residents. Therefore, random interview is a good way during the progress of field investigation to find out the real living situation within the district, which can quickly reflect the most difficult, hot and focused issues from the voices of the residents.

Questionnaire survey is a research method to collect data by asking questions in writing. It is a standard data collection means of a social survey. It has the characteristics of a vast research scope, easy data statistics and quantitative analysis. Questionnaire design transforms the research purpose and research content into specific problems, making the research problems specific, organized, and operable to form a series of measurable variables or indicators. Each question in the questionnaire should contribute to the information to be selected or serve a specific purpose. The quality of questionnaire design directly affects the quality of collected data. The questionnaires can be divided from different angles, such as question answers, survey methods, questionnaire purposes, etc.

All the questions were designed to collect the users' attitudes and summarize the data towards the potential future possibility to retrofit the buildings. They were mainly divided into three parts. 1. Basic information of the habitants who are still living in the buildings and their family composition; 2. The current situation of the housing rooms inside the buildings, especially the kitchen part; 3. The potential demand for retrofitting and how their willingness to get better living comfort space. This survey questionnaire aims to get insight into the current living conditions within the Liyuan courtyard.
Discuss the existing residents' views on the current living conditions of courtyard buildings

and obtain their feedback on building reconstruction. This study conducted a questionnaire survey on all residents of the sampled buildings. The survey was conducted in the field, using face-to-face questions and recorded questionnaires, including a series of closed and open questions.

The method of interviewing here is only on-site investigation. Dozens of questions have been delivered out obtained with abundant response with facts suitable for dissemination to the masses. Regardless of whether the object of the interview is a natural phenomenon or a social phenomenon, this survey study here only pays attention to facts of value that are of concern to the sustainability development.
From the questionnaire, we could learn about the main structure of existing residents, family composition, income level, attitude towards building renovation, the ranking of issues concerned in the renovation process, and the importance of residents of different ages to different influencing factors of building renovation. This study also discusses the interactive relationship between some key points in the questionnaire data, so as to understand the necessity of architectural renovation from the perspective of social individuals.

In addition, the Engel coefficient is used to reflect the family income level. The Engel's coefficient used for data analysis as an economic criterion to discover the living conditions of the residents; Engel coefficient above 59% means Poor and depressed life; 50-59% means subsistence life; 40-50% means Moderately prosperous life; 30-40% means Abundance life; and less than 30% means luxurious life mode. Most of the existing residents belong to low-income groups, which means that there is little difference in the economic ability of building renovation when participating in the survey. Therefore, the basic influencing factors of inconsistent economic capacity are excluded. Therefore, the information fed back in this questionnaire has greater reference value for the consideration of social factors selected in the renovation research of ancient buildings.

3.2.2. The survey of the site

(1) Content of survey
Collect the functional layout and envelope structure of rural houses through field tests. Appendix B shows the some existing buildings in history with new purpose: Liyuan name, construction time, structural form, new functions, etc. The performance survey of houses

includes wall materials, wall thickness, insulation layer form, door and window materials, door and window air tightness, heating mode, etc. Moreover, detailed mapping of Liyuan buildings, drawing the floor plan, Liyuan houses plan and elevation.

(2) Survey instrument

The construction survey needs to carry out systematic surveys with professional instruments and tools on the layout of houses and the dimensions of doors and windows. The types, accuracy and contents of the main test instruments and the photographs of the instruments are listed in Table 3-1.

Table 3-1. The field survey instrument information form

Name	Equipment Information		
Tape Measure	Instrument model	DL9005B	
	Function	Measuring length	
	Accuracy	0.001m	
	Measuring range	0-5m	
	Resolution	0.001	
Laser rangefinder	Instrument model	MiLESEEY/X5	
	Function	Measuring length	
	Accuracy	±0.002m	
	Measuring range	0-40m	
	Resolution	0.001m	

Unmanned Aerial Vehicle	Uncrewed model	DJI Mavic 3	
	Function	Aerial photography	
	Pixel	2000W	
	Flight altitude	0-500m	
	Image transmission distance	0-8000m	

3.2.3. Thermal environment measurements

(1) Testing Subjects and programs

The thermal environment test includes indoor and outdoor air temperature, relative humidity, black ball temperature, etc.

- Outdoor environmental parameters

The main test content of outdoor environmental parameters is outdoor air temperature. For more accurate test results, the instrument should be prevented from being disturbed by other factors when setting the position of the measuring point. The temperature and humidity detector were placed at a distance of 1.5m from the ground to avoid the influence of direct sunlight and outdoor cold and heat sources. The sampling period was set to record once every 20 minutes.

- Indoor environment parameters

The main test content of indoor environmental parameters is indoor air temperature. According to the requirements of energy-saving testing standards, the measuring points should be kept at a certain distance from the envelope structure, while avoiding the direct influence of solar radiation, indoor light sources and heating facilities. Therefore, when arranging the measuring points in this study, the temperature and humidity detector was arranged at the intersection of the diagonal lines of the room, the distance from the ground was 1.5m, and the data was automatically recorded every 20min.

- Thermal performance of the envelope structure

The thermal performance of the envelope structure is one of the important factors affecting the building energy consumption. The actual measurement and software simulation help to understand the thermal performance of the Liyuan envelope structure in an all-round way. An infrared thermometer was used to record the temperature changes of the inner and outer surfaces of the enclosure. The sampling time was also recorded once every 20 minutes. During the test, the infrared thermometer was placed on the inner and outer sides of the enclosure to avoid interference from other heat sources.

(2) Testing plan and instruments

The thermal environment and air quality test is divided into three stages, including the preparation stage, test stage, and data processing stage. The preparation stage includes commissioning the instrument, preparing the level, dovetail clamp, and other test auxiliary supplies, and conducting a pretest. In the test preparation stage, field test aids have played a significant role in ensuring the smooth completion of the test. Now the field test aids, and their functions are listed in Table 3-2.

The main experimental instruments and their functions are introduced in detail in the section on test instruments. Table shows the accuracy and range of the measuring instruments used. These instruments are calibrated before each use, and their accuracy meets the requirements of relevant standards. In order to ensure good measurement accuracy, the measurement time of each parameter lasts for more than 20 minutes, and the measurement is repeated three times to ensure steady-state conditions. The measurement equipment was placed 1.5 m above the ground in the main room of each building.

Table 3-2. The accuracy and measuring range of measurement instruments

<table>
<tr><th>Name</th><th colspan="3">Equipment Information</th></tr>
<tr><td rowspan="5">JT2020 Multi-function measuring instrument</td><td>Instrument model</td><td>JT2020</td><td rowspan="5"></td></tr>
<tr><td>Tested parameters</td><td>black bulb and air temperature</td></tr>
<tr><td>Accuracy</td><td>±0.5°C</td></tr>
<tr><td>Measurement</td><td>-20°C ~85°C</td></tr>
<tr><td>Resolution</td><td>0.1°C</td></tr>
<tr><td rowspan="5">DECEMTMM 1520</td><td>Instrument model</td><td>Delixi</td><td rowspan="5"></td></tr>
<tr><td>Tested parameter</td><td>temperature</td></tr>
<tr><td>Accuracy</td><td>±0.2°C</td></tr>
<tr><td>Measurement</td><td>-40°C ~600°C</td></tr>
<tr><td>Resolution</td><td>0.1°C</td></tr>
</table>

(3) Testing Standards

China has formulated a series of test standards related to the indoor thermal environments. Field testing according to industry standards can ensure the standardization of measurement and the accuracy of results table 3-3.

Table 3-3. Relevant test standards for thermal environment and air quality

Standards	Regulations related to this study
Uniform standard for design of civil buildings (GB 50352-2019)	This Standard is formulated in order to make civil buildings conform to applicable, economical, green and beautiful building principles, meet the basic requirements of safety, health and environmental protection, and unify the general design requirements of all kinds of civil buildings

Standard of test methods for thermal environment of building (JGJ/T347-2014)	To standardize the testing method of indoor thermal environment of buildings, and provide testing basis for indoor thermal environment evaluation
standard for energy efficiency of residential buildings (JGJ/T 132-2009)	Detection requirements for indoor average temperature of buildings, thermal defects of peripheral protective structures and heat transfer coefficient of main parts of protective structures
Technical code for the retrofitting of public building on energy efficiency (JGJ 176-2009)	Promote building energy conservation, improve the energy efficiency of public buildings, reduce greenhouse gas emissions, and improve the indoor thermal environment.
Design standard for energy efficiency of residential buildings (DB 37/5026-2014)	This standard is formulated according to the climatic characteristics and actual situation of Shandong province, aiming at the development planning objectives of building energy conservation, improving energy utilization efficiency and thermal environment of residential buildings.
Code for thermal design of civil building (GB 50176-2016)	The thermal design of civil buildings shall be adapted to the local climate, ensure the basic indoor thermal environment requirements, conform to the national policy of energy conservation and emission reduction, and be applicable to the artificial design of new, expanded and rebuilt civil buildings.
Design standard for energy efficiency of residential buildings in severe cold and cold zones (JGJ 26-2018)	Improve the indoor thermal environment of residential buildings in cold and cold areas, improve energy utilization efficiency, adapt to the national requirements of clean heating, promote the building application of renewable energy, and further reduce building energy consumption. This standard is applicable to the energy-saving design of new, expanded and reconstructed residential buildings in cold and cold regions.

3.3. Experiment on the corncob material performance

3.3.1. Experiment devices

According to the requirements of relevant specifications, prepare two concrete heat-conducting plates of 300mm×300mm×30mm, which are cured for 28 days after demolding, and dried to constant weight, and conduct thermal conductivity test, as shown in Figure 3-2. Before testing the thermal conductivity of corncob-recycled aggregate composite ecological concrete, the density of the concrete thermal conductivity plate should be calculated. After the test instrument is turned on, the parameters should be set first. The temperature of the cold plate is set to 15 ℃, and the temperature of the hot plate is set to 35 ℃; The detection time is divided into two parts, the automatic detection time is 120min, and the estimation time is 30min. After installing the test piece, exit the setting; then observe the operation of the equipment. When the temperature of the cold and hot plate is displayed to drop to the set temperature, click Auto. After the automatic detection is completed, record the power and input the specified position to estimate the result. After the estimation is completed, record the thermal conductivity of the corncob-recycled aggregate composite ecological concrete heat-conducting plate. The thermal conductivity tester used in the test is shown in Figure 3-3.

Figure 3-2. The concrete heat conduction board after drying

Figure 3-3. The appearance thermal conductivity tester

3.3.2. Experiment principle

The basic principle for measuring the thermal conductivity of materials is the steady-state heat transfer through flat walls. The steady-state heat transfer process of the flat wall is shown in Figure 3-4. The process is divided into three parts during the whole thermal conductivity test: heat absorption from the inner surface of the flat wall, heat conduction from the flat wall material layer, and heat dissipation from the outer surface of the flat wall. Suppose there is a flat wall of a homogeneous material with a scale of length and width much greater than the thickness d of the wall (or the flat wall is enclosed with insulation) and assume that the indoor air temperature t_i is higher than the outdoor air temperature t_e, $t_i>t_e$. The temperatures on both sides of the wall are θ_i and θ_e, respectively, and $\theta_i>\theta_e$ in unit area, unit time through the wall of the heat conduction heat, which is known as heat flow intensity, usually expressed as q, and its value is:

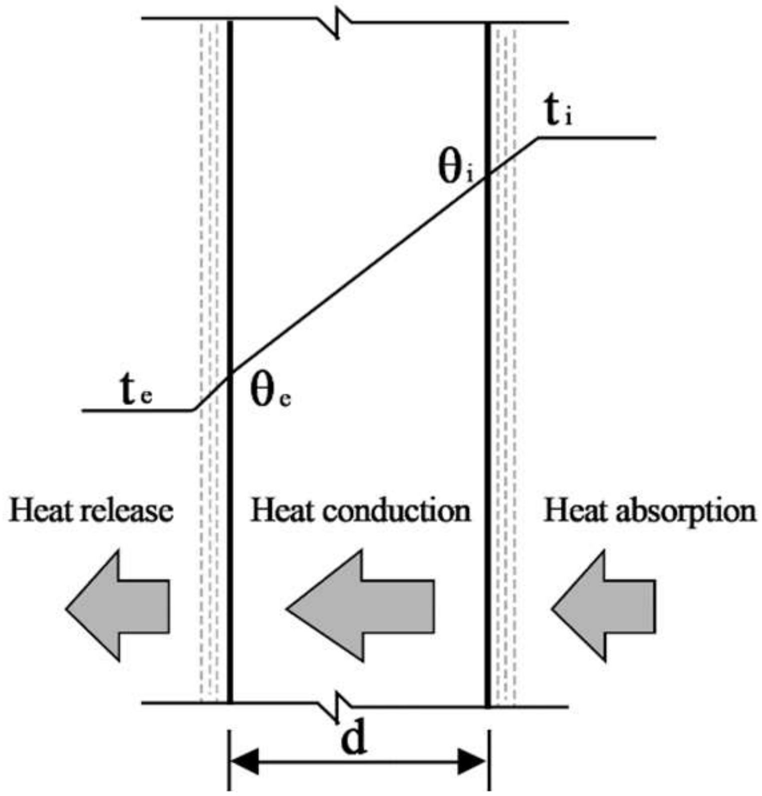


Figure 3-4: The experimental schematic diagram of heat transfer coefficient of materials

$$q = \lambda \frac{\theta_i - \theta_e}{d} \tag{3.1}$$

As can be seen from the equation above, the value of the thermal conductivity λ reflects the thermal conductivity of the wall material. It is numerically equal to when the temperature difference of the unit thickness of the material layer is 1K, the heat passes through the surface area of 1 m^2 in unit time. The value of the thermal conductivity λ of a material is directly related to the thermal conductivity of the heat transfer. Different materials or substances have a defined thermal conductivity, an essential thermo-physical parameter under certain conditions. Eq. (3.1) can also be written as:

$$q = \frac{\theta_i - \theta_e}{d/\lambda} = \frac{\theta_i - \theta_e}{R} \tag{3.2}$$

The above equation R is called the thermal resistance, and its unit is ($m^2 \cdot K/W$). Thermal resistance is the resistance encountered by the heat flow through the wall. It reflects the ability of the biscuit to resist the passage of heat flow. The more excellent the thermal resistance, with the same temperature difference, the less heat passes through the biscuit. To increase the thermal resistance, can increase the thickness of the flat wall d or choose a material with a small value of thermal conductivity λ.

Similarly, in the other two processes (heat absorption on the inner surface of the flat wall and heat dissipation on the outer surface of the flat wall), there is also a temperature difference and heat transfer. In summary, when the indoor temperature is higher than the outdoor temperature, the envelope passes through the three stages mentioned above to transfer heat to the outside. As the temperature only varies in the direction of the thickness of the envelope, which is commonly referred to as a one-dimensional temperature field, and as the temperature of all surfaces is in a steady state that does not vary with time, the heat transfer from all surfaces must be equal. Under the same indoor and outdoor temperature difference conditions, the greater the total thermal resistance R, the greater the total thermal resistance R of the flat wall, the less heat will be transferred through the flat wall, and the less heat is transferred through the wall. It can also be seen that the total thermal resistance of a flat wall represents the amount of resistance to heat transfer from one side of the flat wall to the other. The total thermal resistance and the total heat transfer coefficient of a flat wall are interrelated.

The physical meaning of the total heat transfer coefficient K of a flat wall is to indicate the total heat transfer capacity of the flat wall, which is numerically the amount of heat transferred through the unit area of the flat wall in a unit of time when the difference between the indoor and outdoor air temperatures is 1°C. Both the total thermal resistance R and the total heat transfer coefficient K are essential indicators of the thermal performance of a flat wall under stable heat transfer conditions.

3.4. Computational Modeling and Compared Analysis

The form of architecture is closely related to its geographical location and climate environment. In order to create a stable and comfortable built space environment, the traditional architecture has condensed a set of construction strategies and methods suitable for the local natural environment under the support of society, economy and culture through many years of inheritance and development, continuous inheritance and evolution through trial and error method, and formed a relatively fixed construction system In terms of structure form and material selection, correct answers and responses to the local climate and environment are achieved. Although this construction system is formed under certain historical background and technical constraints, the simple construction wisdom contained therein is undoubtedly the prototype theory guiding the construction activities. As the simple construction wisdom is handed down from generation to generation in the form of hand to mouth, it is the induction and summary of traditional experience, lacks scientific explanation and guidance, and is gradually disconnected from the contemporary context. It is in urgent need of scientific confirmation, inheritance and translation.

Therefore, through the prototype extraction of the buildings selected in Qingdao, the spatial elements are extracted and analyzed from the three dimensions of spatial combination, spatial interface, and spatial scale, so as to judge the climate efficiency of each space. Through modeling and software for quantitative analysis, through the control variable method for multiple data comparison and analysis, horizontal comparison of data through different software, combined with the above qualitative analysis, so as to make scientific research and judgment on the climate adaptability characteristics of the space prototype.

In order to conduct further qualitative and quantitative analysis on the morphology and building function, based on the research results and CAD drawings drawn in the previous chapter, the author uses Ecotect analysis and Ladybug and honeybee to digitally model and simulate buildings in the case studies. In terms of architectural form and function analysis, the digital model built by SketchUp software adopts the research method of quantitative and qualitative analysis to research and analyze the functional layout, room size, renovation plan, and iterative sustainability of the research sample. Afterward, through the establishment of the Ecotect model and ladybug and honeybee model the research samples were calculated and analyzed in terms of monthly energy consumption, hourly heat gain/loss, hourly temperature, passive component heat gain, and annual load.

- Simplify the imported information to improve the efficiency of follow-up work reasonably.
- Set the real units, styles and proportions to ensure the accuracy of the analysis.
- Perform scientific and reasonable classification and grouping work to reduce errors when building digital models.
- During the modeling process, attention should be paid to details such as the thickness of the wall, the position and size of doors and windows, to ensure the authenticity of the analysis. We cannot ignore any small components that have an impact on the analysis structure, such as functional or decorative components with shading and wind protection. It is necessary to truly reflect the materials used in the current construction.
- Use Ecotect analysis to simulate case A to obtain energy consumption data.
- Use Ladybug and honeybee to simulate case A to get energy consumption data.
- Compare the data between the two groups of software and compare the data. Obtain the material feasibility and the energy saving rate of energy consumption.

In order to quantitatively analyze the climate efficiency of the architectural space form and realize the goal of optimizing the microclimate environment of the space prototype by changing the relationship between the space elements, it is necessary to quantitatively analyze and study the composition parameters of the space microclimate (thermal environment, wind environment, light environment, etc.). The field measurement method can provide real and effective reference data for the qualitative analysis. However, due to the interference of many uncertain factors and the large number of variables controlling the spatial form, it is difficult to find a suitable model for comparative measurement, and it is impossible to study the climate efficiency of individual spatial elements, which limits the research. Therefore, to explore the effects of different spatial structures on microclimate, it is also necessary to establish a model and a control group according to the current situation through reasonable and effective simulation software and conduct quantitative analysis through comparative analysis.

Autodesk Ecotect analysis software is a comprehensive sustainable design and analysis tool, which includes widely used simulation and analysis functions to improve the performance of existing and new building designs. The software integrates the online energy efficiency, water consumption and carbon emission analysis functions with desktop tools and can visualize and simulate the building performance in the real environment. Users can use the powerful three-dimensional display function to conduct interactive analysis and simulate the impact of sunshine, shadow, emission, lighting and other factors on the environment [1]through multi-directional research, the accuracy of the software has been widely recognized by the industry. The simulation process is generally based on the introduction of meteorological data - the establishment of models - the establishment of grids - the simulation analysis - and the drawing of chart conclusions.

Ladybug is also an energy tool, a free and open source-built environment analysis plug-in for Grasshopper that helps designers in building environment design. The first step in the design process is weather data analysis; a comprehensive understanding of weather data will more likely to get high-performance design decisions. Ladybug can complete the analysis and display of various meteorological parameters, such as temperature, humidity, solar radiation, wind rose diagram, etc. At the same time, it can also display the analysis commonly used in passive buildings such as sun trajectory, sun shadow, sun time, etc. Ladybug imports standard Energy Plus Weather files (.EPW) in Grasshopper and provides a variety of 2D and 3D design-friendly interactive graphics to support the decision-making process in the initial stages of design. Honeybee connects Grasshopper's visual programming environment to four proven simulation engines (Energy Plus, Radiance, Daysim, Therm), especially by connecting with Open Studio, Radiance, Daysim for building energy consumption, thermal comfort, daylighting and lighting simulation. With the help of Radiance light environment analysis core and Energy Plus energy consumption analysis core, the calculation of cooling and heating load and dynamic energy consumption for 8760 hours a year is completed. At present, Honeybee supports 14 common forms of air conditioning systems, providing strong support for rapid assessment of building energy consumption levels in the planning stage. At the same time, Radiance and Energy Plus can be coupled to analyze the impact of various window control behaviors on building energy consumption.

3.4.1. Ecotect analysis modeling and thermal performance simulation

3.4.1.1. Ecotect analysis modeling

Preparation

SketchUp's modeling is based on the CAD graph drawn in the previous survey, but it needs to be processed to some extent. First, according to the needs of the analysis object, remove all unnecessary lines, layers and other related information. After the simplification is completed, export the CAD graphics. When exporting the graphics, the main building, internal walls, stairs, and balconies can be exported separately to improve the modeling efficiency of SketchUp. After the CAD drawing is ready, open the program in SketchUp and set the unit and style.

- *-Select the "Model Information" command in the "Menu Bar", in the dialog box that appears:*
- *-Select "Unit" and choose "Decimal" format.*
- *-Select the "Model Information" command in the "Menu Bar", in the dialog box that appears:*
- *-Select "Edit"> "Connection Settings" to deselect all options other than the connection.*

This operation is to ensure that the lines in the imported CAD drawings become thin lines for more accurate modeling. (This operation step can also be carried out after importing the CAD drawing, the effect is the same before and after the effect)

CAD files import

Select the "File" option, "Import" command in the menu; select the "Import DWG/DXF" option in its submenu. After that, the system will automatically pop up a dialog box, in the lower right corner of the dialog box there is an "option" click and a new dialog box will pop up, in this dialog box, select the "unit" as mm, (choose this unit to ensure import the ratio of SketchUp's model to the real building is kept 1:1, so that certain accuracy can be guaranteed during analysis.) Then the *.dwg diagram file is selected and the "import" command is executed. Then CAD drawings are automatically imported into SketchUp.

Model establishment

- **Wall**

Group the inner and outer walls of different floors and the walls of different thicknesses and use the rectangle command to make the walls of each group form a flat closed figure on the plane. Then use the plane push-pull tool to enter the corresponding height in the data box on the lower right side of the model building interface to push and pull the plane into a wall. In order to facilitate layer-by-layer analysis, the SketchUp model is modeled hierarchically and set into groups, and then the built-up layers are spliced up and down to form the main body of the building.

- **Windows**

The window not only has a great influence on the building form, but also is the focus of thermal performance analysis. Even if the position of the window in the wall is outside or inside, it will have a certain influence on the calculation and analysis of thermal performance. Therefore, the real window size and position are restored as much as possible during the modeling process.

- **Shading, windproof components, etc.**

Similar to the importance of windows, the shading and wind-proof components may seem inconspicuous, but the building form and thermal performance have a great influence and should be restored in the digital model as much as possible. For example, the firewalls protruding from the roof on the south and west sides of the sample are not only a vocabulary often found in courtyard buildings, but they also block the limited daylighting of the inner courtyard to a certain extent. There are also components such as the second-story outer corridor, stairs and decorative railings on the inner courtyard. This is not only a feature of Qingdao courtyard, an important traffic and communication space, but also has a huge impact on the lighting of the first floor of the inner courtyard. The author also restored and grouped the above components as detailed as possible during the modeling process.

- **Material Pasting**

Building materials and textures are an important part of the study of architectural forms. In order to intuitively experience the changes in architectural forms, from the base, exterior walls, roof, to the corridors, doors and windows, we strive to be consistent with the actual materials in terms of color, texture and proportion in order to restore the texture of liyuan buildings as much as possible.

The typical BIM software, like SketchUp, Ecotect, still require simplification of CAD drawings, and it is more simplification than SketchUp modeling. First of all, morphological information irrelevant to performance analysis can be eliminated. When simplifying the indoor environment, the mutual influence of different rooms in the analysis process should be fully considered. The walls that have no effect on the analysis results can be deleted, but all exterior walls, doors and windows, shading and windproof components, and partition walls of some key rooms must be retained. After simplification, save the CAD drawing as a DXF format file.

Weather zone setting in Qingdao, China

Click the "Set current time and\or location" option in the menu bar, and load weather file. Select the CHN_Qingdao_CTYWEPW.wea file in the Ecotect China Meteorological

Database, set the weather zone of the project to Qingdao, and set the date to the winter solstice.

Import DXF file

Select the "File" option in the menu, select the "Import" command, and select the "3D CAD Geometry" option in its submenu. After that, the system will automatically pop up a dialog box, in the upper left corner of the dialog box "DXF", and then import the previously prepared DXF file as a modeling base map to start modeling.

Model establishment

According to the imported plan drawings, use Ecotect modeling commands to build the sample's first-story wall, second-story wall, roof, second-story corridor, doors and windows, stairs, and firewalls between the surrounding buildings, etc. The size of the model, especially the size of doors and windows, must be accurate (Figure 3-5). What needs to be mentioned is that when constructing two-story corridors and some decorative components that have an impact on day lighting, it is considered that the complex shape of these components does not have much impact on the analysis of thermal performance. Therefore, in order to improve the efficiency of modeling and calculation, the above components have been simplified. At the same time, some steps and windowsill components that have no effect on the calculation have been deleted. In the process of model building, you need to set the element type of each component in the setting panel on the right. After the construction is complete, you can check whether each part of the model, such as walls, roofs, doors and windows, is successfully set to the corresponding element through the "by element type" option in the "select" option in the menu bar.

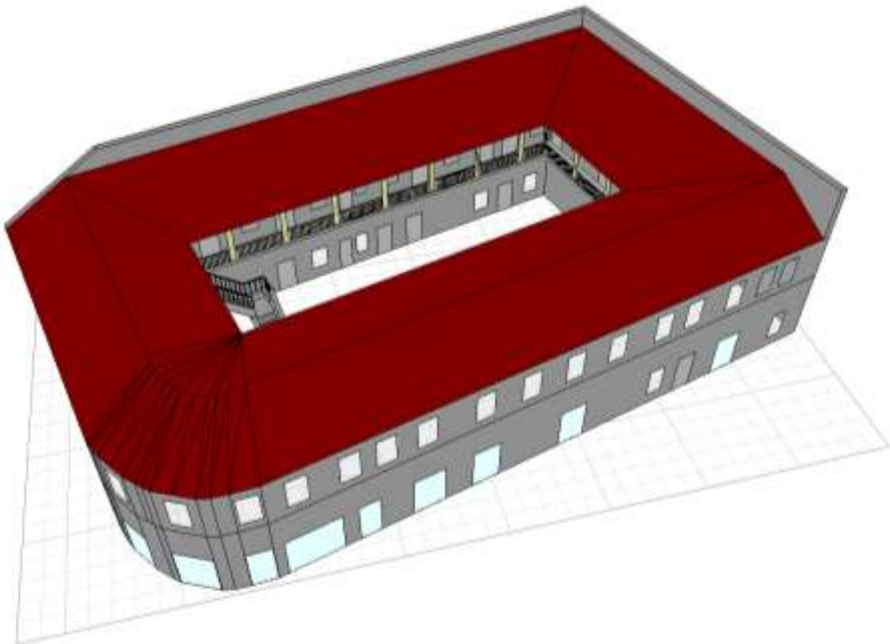


Figure 3-5. The model built in the Ecotect for the example building

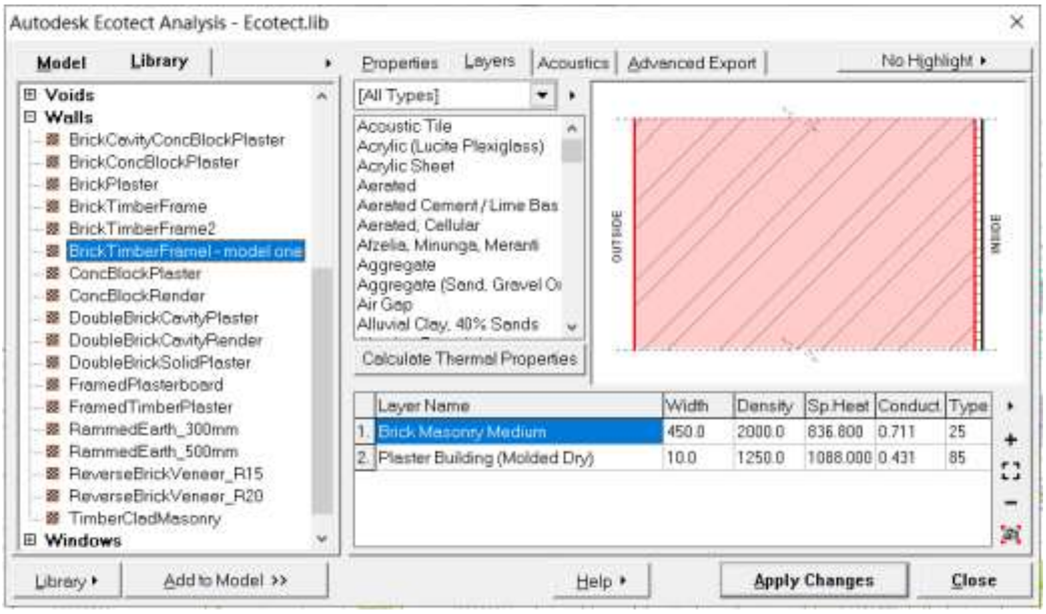
Material Assignment

Click "element library" on the toolbar to set the material. First select a material that is consistent or similar to the actual material, add the name suffix model_1, and then set the material parameters according to the actual building wall material. When setting layers, set the name, width, density, specific heat conducts any type of each layer according to the actual situation. After the setting is completed, the U-Value of the material can be calculated [*U-Value refers to under the condition of stable heat transfer, the air temperature difference on both sides of the enclosure is 1 degree (Kc), and 1 square meter can be passed within 1 hour. The heat transferred by the area; the unit is W/m²K*]（Figure 3-6-a,b）. After completing the creation of the material, click on the part of the model that needs to be assigned a material, and assign the material in the Material Assignments. The material setting of each component of the building is the key to completing this research. In order to fully compare the effects of different schemes on the thermal performance of the building, this study designed three different material schemes, named model_1, model_2, and model_3.

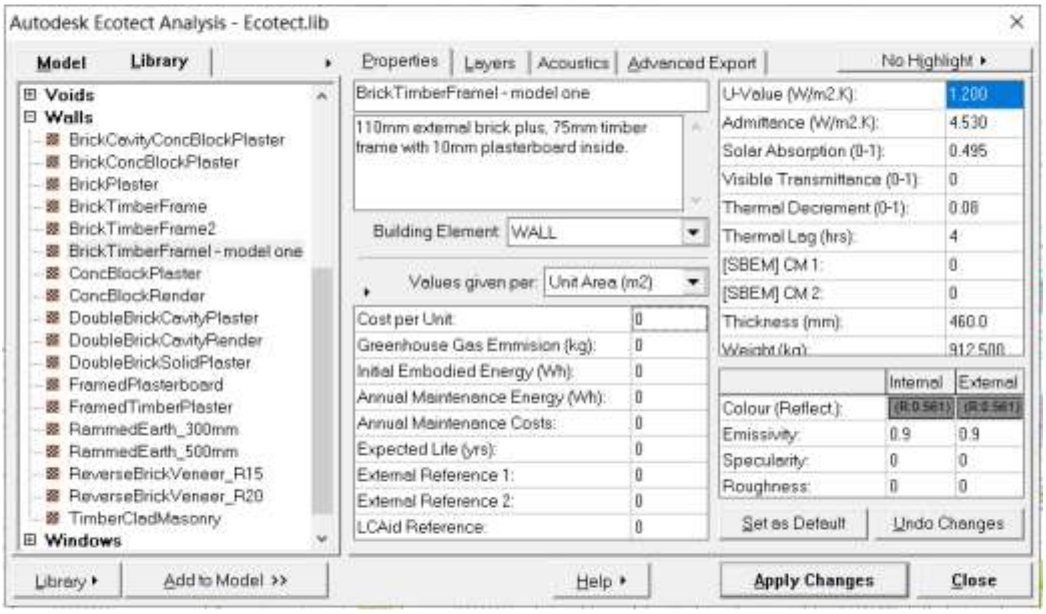
The area attributes mainly include the system type, number of people, equipment calorific value and activity (operation) schedule in the area. The main settings are in the area manager. The setting of regional attributes can be freely set according to the actual situation, and related content can also be set according to the "Design Standard for Energy Conservation of Public Buildings" (GB50189-2005)[2]. The data setting in this article is mainly based on the actual situation of the field survey.

General setting - Internal design conditions

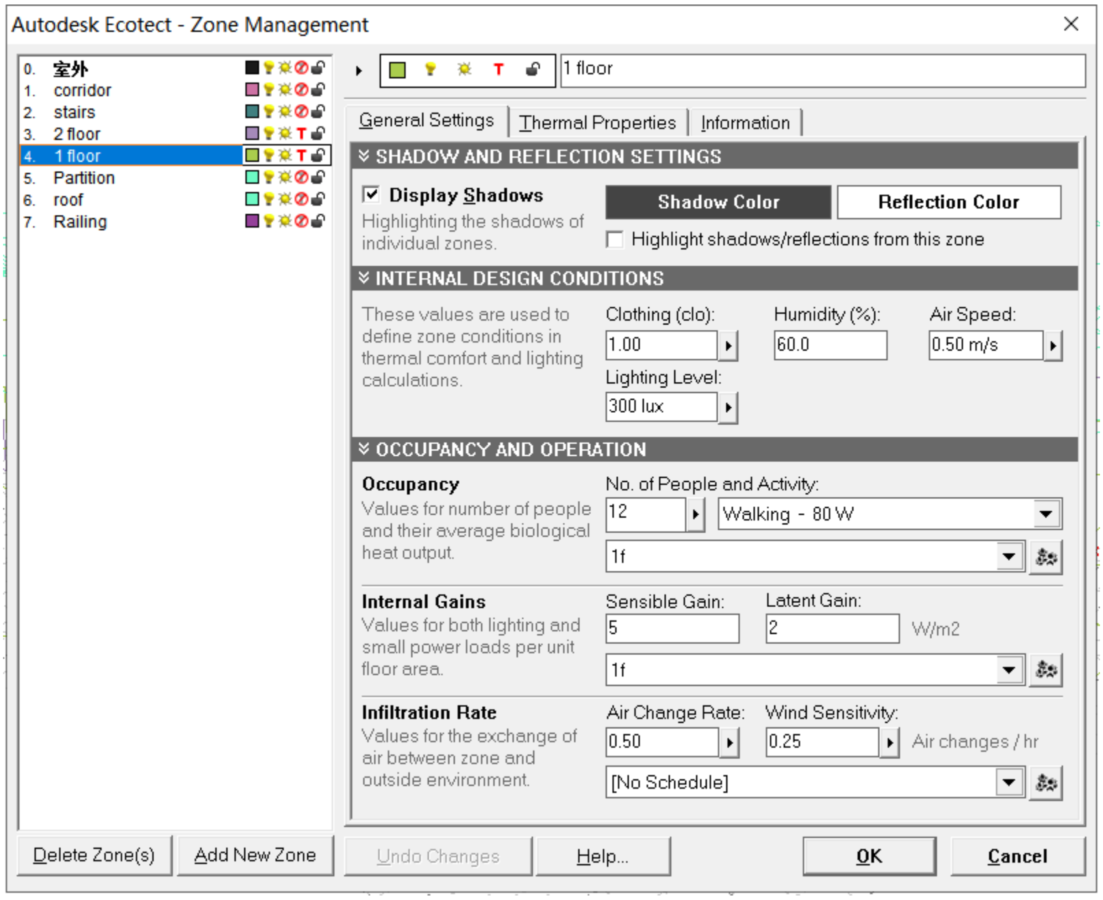
Open the "zone management" option on the right control panel to set some basic parameters (Figure 3-6,c). According to the on-site investigation and the use function of the building under study, in the "internal design conditions" option, set "clothing" to "light business suits", "humidity" to "60%", and "airspeed" to" 0.5", "lighting level" is set to "300lux".



a.basic material data settings



b. all component settings

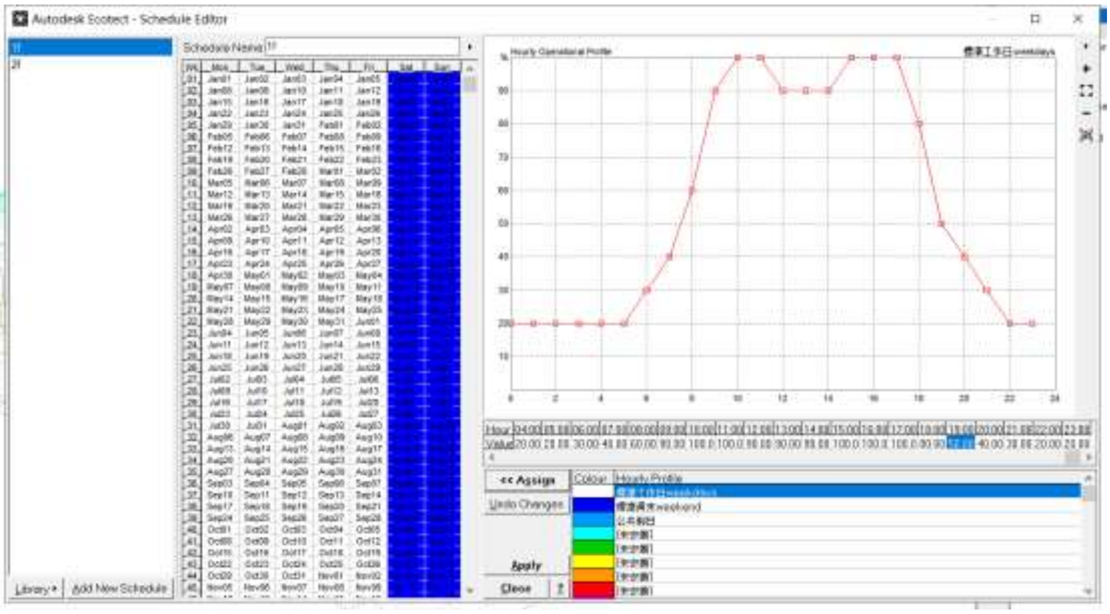


c. zone management

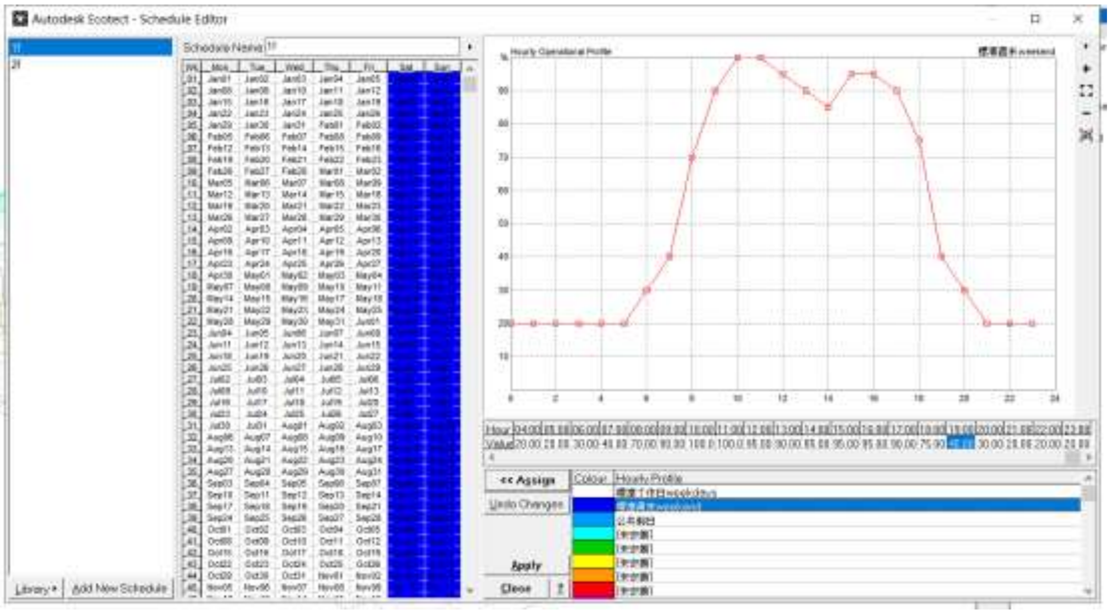
Figure 3-6. The settings in the Ecotect software for materials
(a.basic material data settings; b.all component settings; c. zone management settings)

General setting - Schedule editor

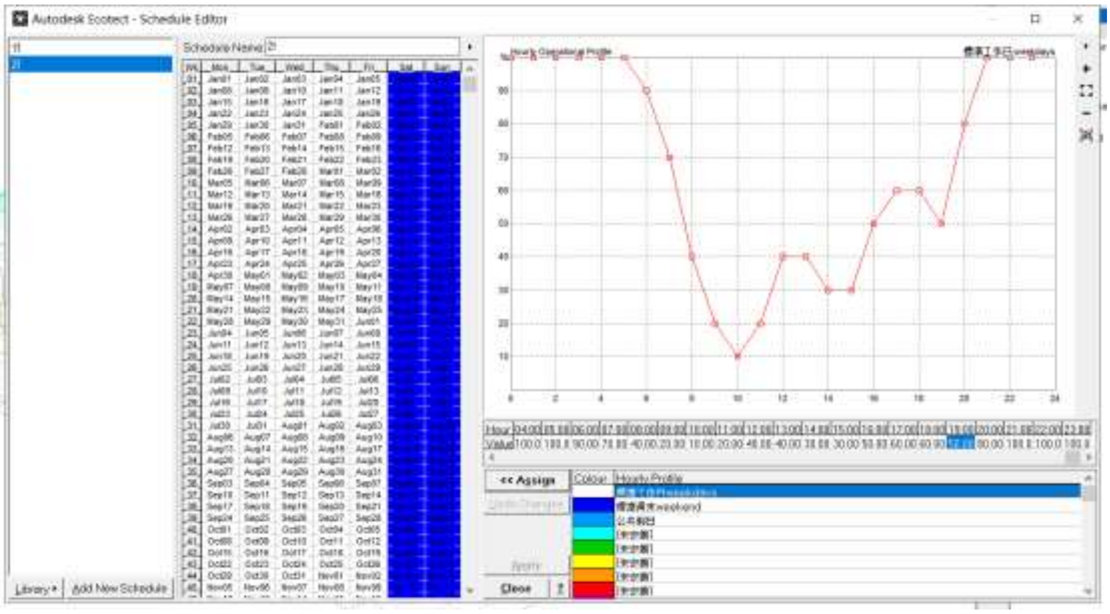
When setting "occupancy and operation", it needs to be set according to the usage of each functional area. The first-floor function of the building under study is mainly commercial and office, and the number of users is 12. Since the scale of operation is very small and the stay time of customers is extremely short, it is not considered; the second floor is mainly for residence, with 26 residents. Through the questionnaire survey, it is found that there are 2 permanent residents on the first floor, and the rest stay and leave according to the commuting time. The crowd activity schedule on the first floor is almost the same on weekdays and weekends; the 26 people on the second floor are all permanent residents. There is a certain difference in the crowd schedule on weekdays and weekends, which is mainly reflected in the large number of people leaving on weekdays due to work reasons. And the time is mainly concentrated in the morning. The number of travelers on weekends decreased significantly, and the travel time was mainly in the afternoon and evening. Based on the results of the appearance investigation, a timetable for crowd activities is drawn up, which is applied to the settings of "occupancy" and "internal gains". Finally, because the business functions of the first floor promote more people's activities, in the "activity" option of "occupancy", set the "activity" of the first floor to "walking-80w". The crowd activities on the second floor include "sleeping-40w", "resting-45w", "reading-55w", "cooking-95w", "cleaning-115w", etc. After analysis and weighing calculations, "70w" was selected as the biological heat output of the second-tier activity, and "sedentary-70w" was selected in this case. After observation, the frequency and amplitude of the activities of the first-tier crowd are indeed greater than those of the second-tier crowd. It can be seen that the calculation data of the biological heat output on the second floor is more reliable (Figure 3-7).



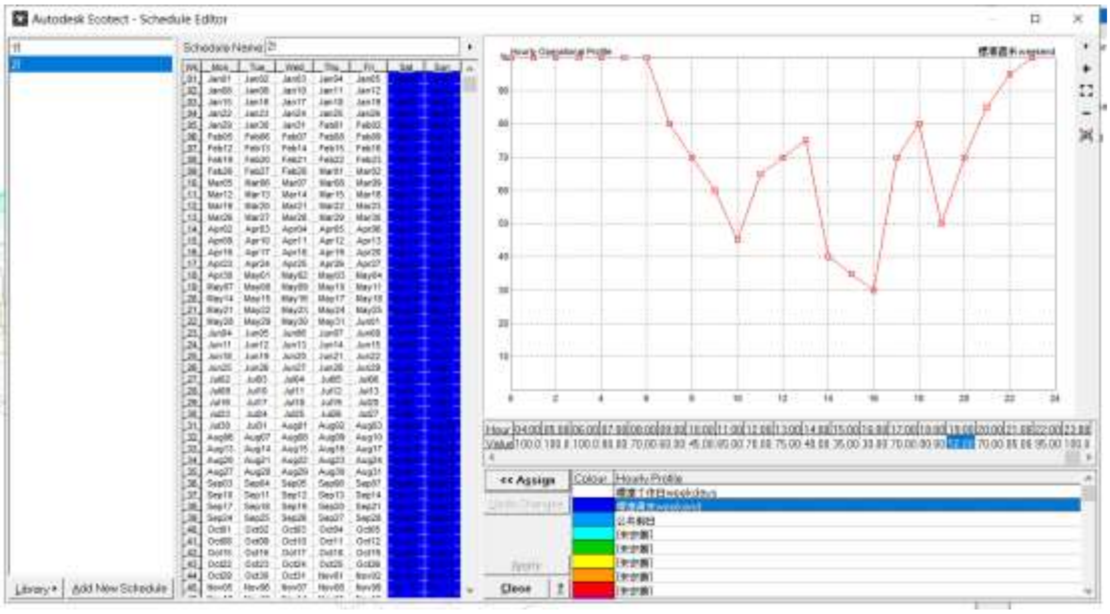
a. schedule-1st floor-weekdays



b. schedule-1st floor-weekends



c.schedule-2nd floor-weekdays



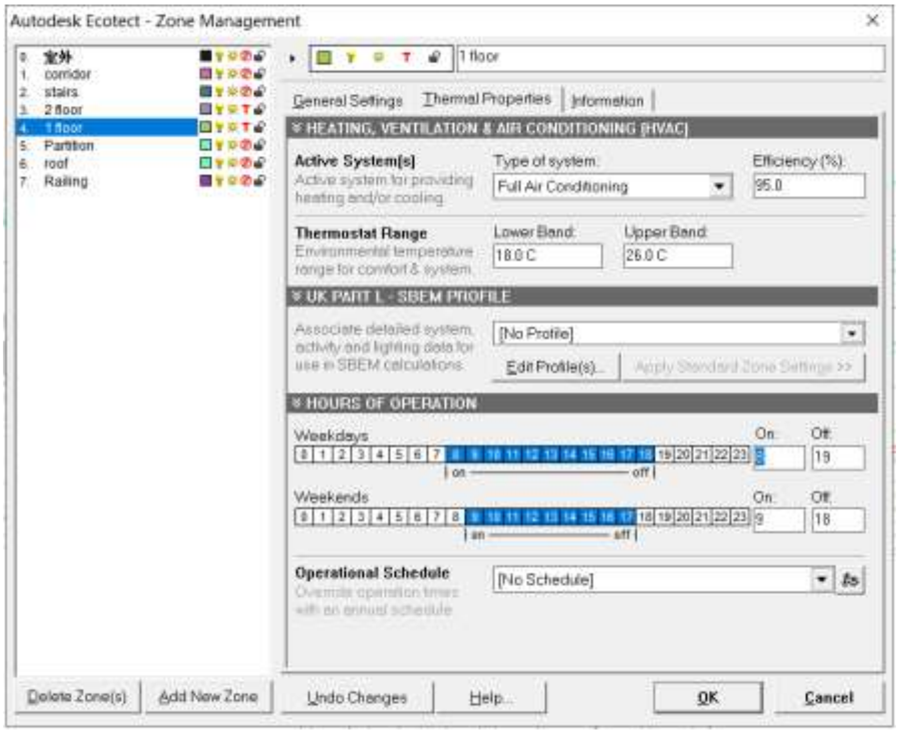
d. schedule-2nd floor-weekend

Figure 3-7. The time schedule settings for the 2 floors in weekdays and weekend based on the field investigation data

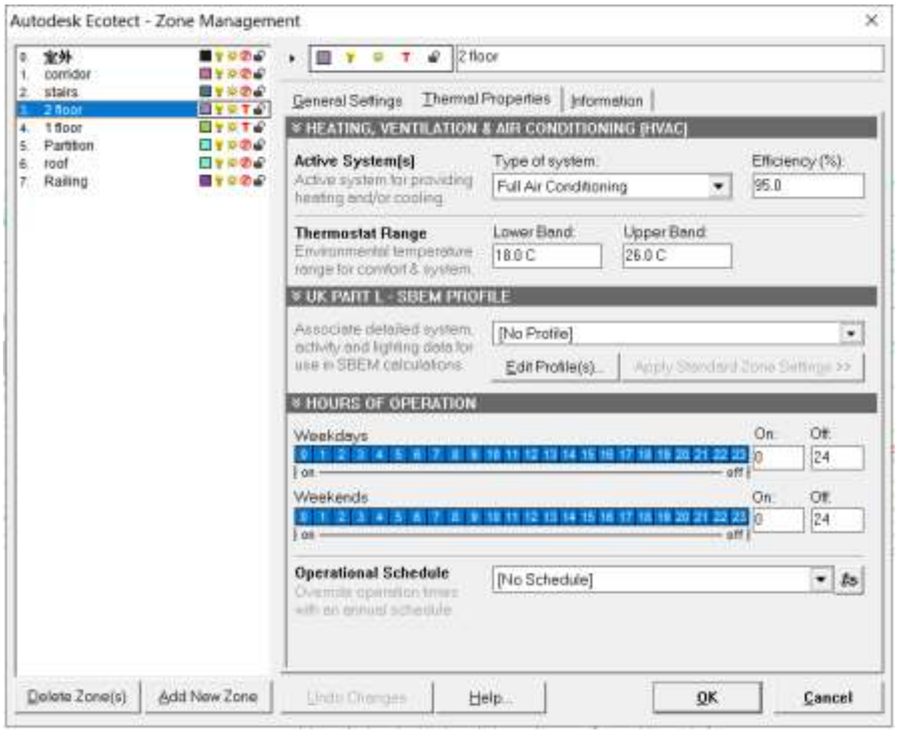
(a. schedule-1f-weekdays; b. schedule-1f-weekend; c. schedule-2f-weekdays; d. schedule-2f-weekend)

Thermal Properties

Since the research of the air-conditioning system is not the focus of this research, the parameter settings of each model can be consistent, so the parameters of this part are set as the ideal situation, in which it set "active system(s)" to "full air conditioning" and "thermostat range" to "18-26℃". According to the crowd activity schedules on the 1st and 2nd floors, set the "hours of operation" as shown in the figure (Figure 3-8). After the above parameters are set, the thermal performance analysis of the model can be performed.



a. thermal properties setting -1st floor



b. Thermal properties settings-2nd floor

Figure 3-8. The thermal condition settings in the Ecotect software
(a.Thermal properties settings -1st floor; b.Thermal properties settings-2nd floor)

3.4.1.2. Thermal performance simulation

Through the establishment of the above three models, it is not difficult to see that the effect of material changes on thermal performance is very significant. But what kind of changes will the above changes bring to the energy consumption of buildings, and to what extent? This requires further analysis and comparison. The author uses Ecotect Analysis to analyze and compare the building energy consumption of the three models. In a narrow sense, building energy consumption refers to the energy consumed to maintain the function of the building and the building's operation, including the energy consumption of lighting, heating, air conditioning, elevators, hot water supply, cooking, household appliances, and office equipment. Generally speaking, the largest proportion of energy consumption is the energy consumption of heating and air conditioning. Therefore, simulating and analyzing the energy consumption of air-conditioning is an index to evaluate the quality of building energy-saving design. Ecotect Analysis can simulate and analyze the monthly heating and air conditioning energy consumption and the annual heating/cooling maximum load of the building as a whole and each area. These data are presented in the form of histograms and data lists. It should be noted that Max Heating/ Cooling Load in the software is the category of power, and the unit is W; MONTHLY HEATING/COOLING LOADS is the category of energy and the unit is Wh.

(1) Basic concept

Thermal conductivity: refers to the heat flow through a homogeneous material per unit thickness and unit area under steady-state conditions and unit temperature difference. The symbol is, and the unit is W/ (m^2·K). The smaller number is the thermal coefficient, the weaker is the thermal conductivity of the material, which leads to better thermal insulation performance.

Heat transfer coefficient: It refers to the heat transfer through a unit area in a unit time when the air on both sides of the enclosure structure is a unit temperature difference under stable heat transfer conditions. The symbol is Km, and the unit is W/(m^2·K).

Heat storage coefficient means that when one side of a homogeneous material layer of sufficient thickness is subjected to harmonic heating, the surface temperature will fluctuate in the same cycle, and the ratio of the amplitude of the heat flow through the surface to the amplitude of the surface temperature. The symbol is S, and the unit is W/(m^2·K). The greater the heat storage coefficient values of the material, the better the thermal stability of the material.

Specific heat capacity: Refers to the amount of heat absorbed or released for 1kg of material to increase or decrease the temperature by 1℃.

Thermal diffusion coefficient: Also known as thermal diffusivity, it refers to the ratio of the thermal conductivity of a material to the product of its specific heat capacity and density, which characterizes the ability of an object to converge in temperature when it is heated or cooled. The larger the value is, the faster the temperature changes.

About the related concepts and calculations of thermal conductivity and thermal storage coefficient: To understand the thermal conductivity and thermal storage coefficient testing methods and principles. The concepts of several main physical parameters involved are explained as follows

(2) Calculation of coefficients:

The thermal conductivity and heat storage coefficient of recycled concrete plate specimens are tested using the "Technical Specification for Lightweight Aggregate Concrete" (JG. J51-2002)[3], which is the thermal pulse method, which is the test method for measuring the thermal conductivity. The test equipment is a heat storage coefficient tester (XRY-II). The equipment is based on the principle of non-steady-state heat conduction, heating the test material in a short time to change the temperature of the material, according to the characteristics of the change. By solving the thermal differential equation, the temperature conductivity, specific heat, thermal conductivity and heat storage coefficient of the test material can be calculated.

According to the principle of heat conduction, the differential equation of Thermal conduction is:

$$\frac{\partial t}{\partial \tau} = \alpha \frac{\partial^2 t}{\partial x^2} \tag{3.3}$$

Assume that the initial and boundary conditions are:

$$\tau = 0 \ , \ t = t_0 \tag{3.4}$$

Introduce excess temperature θ

$$\theta = t - t_\infty \tag{3.5}$$

Where t is the ambient temperature, the formula (3.3) is rewritten as

$$\frac{\partial \theta}{\partial \tau} = \alpha \frac{\partial^2 \theta}{\partial x^2} \tag{3.6}$$

After solving, a special solution of the one-dimensional non-steady-state thermal conductivity differential equation is obtained as:

$$\theta(x,\ \tau) = \frac{q\Delta\tau}{2cy\sqrt{\pi\alpha\tau}} e^{-\frac{x^2}{4\alpha\tau}} \quad (3.7)$$

q: Heat flux density, W/m^2

a: Thermal conductivity of the object, m^2/h

x: distance from the heat source, m

C: Specific heat capacity of the object, kJ/(kg*k).

y: the bulk density of the object, kg/m^3

$\Delta\tau$: Heating time of a heat pulse, h

At a certain time, the temperature of the test material rises as follows:

$$\theta'(x,\ \tau') = \int_0^{\tau'} \frac{q\Delta\tau}{2cy\sqrt{\pi\alpha\tau}} e^{-\frac{x^2}{4\alpha\tau}} d\tau. \quad (3.8)$$

Organize to get:

$$\theta'(x,\ \tau') = \frac{q\sqrt{\alpha\tau'}}{\lambda\sqrt{\pi}}\left[e^{-\frac{x^2}{4\alpha\tau}} - \frac{\sqrt{\pi}x}{2\sqrt{\alpha\tau'}} erfc\left(\frac{x}{2\sqrt{\alpha\tau'}}\right)\right] \quad (3.9)$$

If

$$B(y) = e^{-\frac{x^2}{4\alpha\tau}} - \frac{\sqrt{\pi}x}{2\sqrt{\alpha\tau'}} erfc\left(\frac{x}{2\sqrt{\alpha\tau'}}\right) = e^{-y^2} - \sqrt{\pi}y erfc\ (y) \quad (3.10)$$

And

$$y^2 = \frac{x^2}{4\alpha\tau} \quad (3.11)$$

So

$$\theta'(x,\ \tau') = \frac{q\sqrt{\alpha\tau'}}{\lambda\sqrt{\pi}} B(y) \quad (3.12)$$

$$erfc(y) = \frac{2}{\sqrt{\pi}}\int_y^{\infty} e^{-y^2} dy \quad (3.13)$$

Formula (3.13) is the Gaussian error complement function

Assuming 1 is the time when the heat source is turned off, at a certain time 2 after the heating is stopped, the excess temperature on the heat source surface (x=0) is

$$\theta_2(0,\tau_2) = \int_{\tau_2-\tau_1}^{\tau_2} \frac{q}{2cy\sqrt{\pi\alpha\tau}} d\tau = \frac{q\sqrt{\alpha}(\sqrt{\tau_2}-\sqrt{\tau_2-\tau_1})}{\lambda\sqrt{\pi}} \quad (3.14)$$

The thermal conductivity is

$$\lambda = \frac{q\sqrt{\alpha}(\sqrt{\tau_2}-\sqrt{\tau_2-\tau_1})}{\theta_2(0,\tau_2)\sqrt{\pi}} \quad (3.15)$$

The equation(3.15) is the calculation formula for measuring thermal conductivity by thermal pulse method.

Substituting formula (3.15) into formula (3.12), we get

$$B(y) = \frac{\theta'(x,\ \tau')(\sqrt{\tau_2}-\sqrt{\tau_2-\tau_1})}{\theta_2(0,\tau_2)\sqrt{\tau'}} \tag{3.16}$$

Calculate the value of B(y), "Technical Regulations for Lightweight Aggregate Concrete" (JGJ51-2002)[3] to obtain the value of y_2.

According to "Technical Regulations for Lightweight Aggregate Concrete" (JGJ51-2002)[3], the calculation formulas for thermal conductivity a, specific heat c and heat storage coefficient s are as follows:

$$\alpha = \frac{x^2}{4\tau' y^2} \tag{3.17}$$

$$c = \frac{\lambda}{ay} \tag{3.18}$$

$$s = 0.27\sqrt{\lambda c y} \tag{3.19}$$

Each group of test specimens is tested three times, when the relative error is less than 5%, the average value of the three tests is taken as the thermo-physical coefficient value of the group of specimens. The U-Value of the wall was successfully reduced to 0.23 W/㎡. k, to further improve the thermal performance of the building.

“Model_3” is another scenario model implemented with suggested modification by replacement of recycling construction materials [4] in envelope wall and further optimization in other building components. Together with Model_2, both renovation scenarios are going to improve the whole building energy saving goals to achieve the green building standard and even higher efficiency.

Monthly loads or discomfort: The monthly energy consumption analysis in Ecotect is very intuitive. The color in the histogram corresponds to the color of the area. It is very intuitive to see the energy consumption of each area and the proportion of the entire building. The comparison of monthly energy consumption can be seen.

Hourly heat gains or losses: This data contains hourly heat gains and losses related to building energy consumption, which are analyzed by simulation. It is possible to study the thermal insulation performance of the envelope structure, which can be combined with the passive component thermal analysis. It is also possible to understand the related thermal performance of the building from both the macroscopic and microscopic aspects.

Passive gains breakdown: This function is equivalent to counting the daily gains and losses of heat on the same graph and calculates the same content (including the gains and losses of heat conduction of the enclosure structure, the heat generated by the comprehensive temperature, the heat gained by direct solar radiation, and the cold wind Permeation gains and losses, internal personnel and equipment gains, and regional gains and losses).

3.4.2. Ladybug and honeybee modeling and thermal performance simulation

3.4.2.1. Ladybug and honeybee modeling

Build a parametric energy consumption model based on logical requirements. On the one hand, parameter modeling needs to be carried out according to formal logic; on the other hand, model data conversion is carried out according to the simulation logic of ladybug and honeybee. The whole process must follow Grasshopper's parametric modeling rules, rigorously define parameters and control logic, and organize forms and define data structures reasonably according to honeybee's specification requirements for energy consumption models. Specifically, in the process of establishing a parameterized geometric model, first, according to the determined formal control logic, appropriate variables are selected as control parameters to establish a parameter model. The process should follow the morphological evolution law of Grasshopper and carry out the evolution process from point and surface to volume. In the process of parametric modeling, it is also necessary to divide the geometric model into closed volumes, and group data in groups to ensure that the geometric model has a clear data structure.

Quantitatively qualify the model. Write a program to perform initial information definition and process data statistics and control the parameter changes of the geometric model through constants (such as a given building scale). Real-time output of conventional numerical information of the model (such as height, area, floor area ratio, etc.) provides basic operation data for energy consumption calculation. On the basis of establishing a parametric geometric model, it needs to be defined by a program and transformed into an energy consumption model that can be recognized by the software.

Define the program in Honeybee, call the calculation kernel, reorganize the calculation results of natural ventilation, natural lighting and solar energy production capacity, connect and import it into the corresponding data port, and participate in the energy consumption calculation process.

3.4.2.1. Thermal performance simulation

Construction of a design strategy based on energy-saving efficiency evaluation Before designing, it is necessary to analyze climate data, determine a reasonable passive design strategy, and provide design ideas for the general plan, building units and building details. Importing local meteorological data into the Ladybug tool can realize the quantitative rating of passive energy-saving design strategies and generate the ranking of energy-saving strategies suitable for local climatic conditions and the applicable time range of each strategy. The courtyard is located in a cold area, and the LADYBUG AND HONEYBEE tool gives the "Solar Heat Gain and Natural Ventilation" data. Among them, passive solar heat gain is suitable for a wide range of time, which can increase the indoor temperature and natural lighting time in winter and reduce the energy consumption of heating and lighting in winter; natural ventilation is suitable for use from June to August, which helps to reduce the cooling load of the house.

Energy-saving goal-oriented building forms are automatically generated by conventional methods. With the help of physical environment simulation software, through energy consumption calculation in scheme design, architects can find problems and improve schemes, and so on, to find the most energy-saving scheme. However, this process involves many morphological variables, such as plane shape, window-to-wall ratio, atrium shape, skylight shape, etc. The combination of these variables can form vastly different architectural shapes, resulting in an exponential increase in workload, and repeated simulation corrections will cost a lot of money time and manpower. On the other hand, this "simulation-optimization" cycle cannot achieve exhaustive optimization results, and there is a problem of only better but not the best, and it is difficult to obtain the best solution based on the energy saving goal in a relatively short period of time. In addition, the calculation models required by the natural lighting, ventilation and energy consumption simulation tools are different and cannot be directly compatible with the design model, so a lot of time is spent on repeated modeling, which reduces the efficiency of the scheme design and increases the performance calculation error.

The ladybug and honeybee tool can set the control logic to let the computer automatically complete the complex calculation and optimization process, and obtain the optimal result under the energy saving goal in a short time: transform the formal control goal of each design link into the parameters of the control form Based on the same parametric model, the ladybug and honeybee tool can couple natural lighting, ventilation, solar energy production and energy consumption simulation, etc., to improve the efficiency and accuracy of simulation optimization. According to the requirements of China's energy-saving design code, the calculation parameters are set, and the evolutionary algorithm module of Grasshopper is used as the solution method to realize the automatic optimization of building forms based on China's energy-saving goals, freeing architects from tedious simulation work. Focus on the design process itself and focus on formal innovations with the goal of saving energy (Figure 3-9).

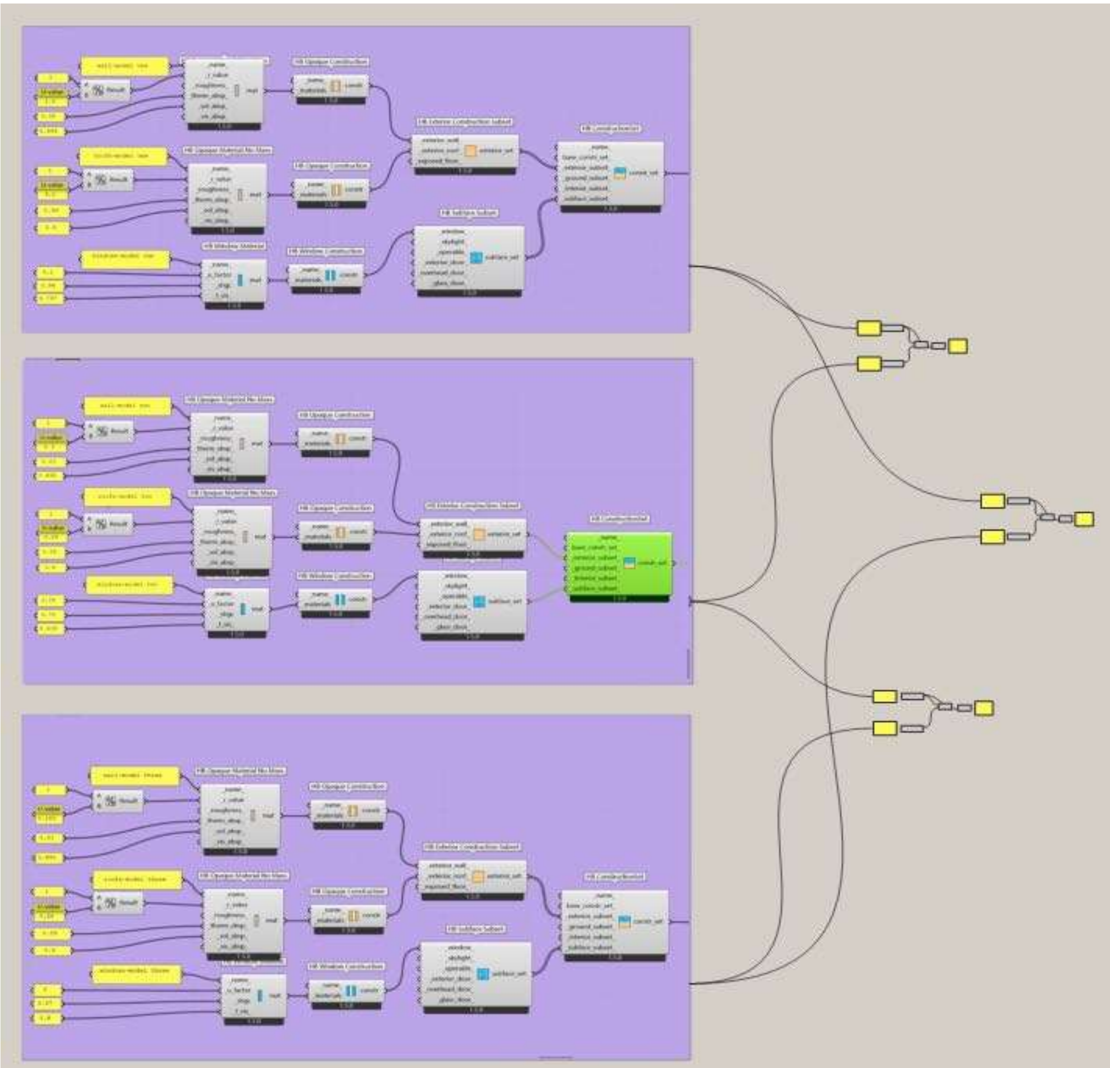


Figure 3-9. The canvas of the three models in Ladybug+Honeybee software

3.5. Summary

This chapter describes the methodology of field survey testing, thermal performance experiment of the envelope and numerical simulation of building a thermal environment of Liyuan houses in Qingdao. The main conclusions are as follows:

(1) The field survey methods include interviews, questionnaires, and field tests. Firstly, the questionnaire is designed through the pre-survey of traditional houses Liyuan in Qingdao, Shandong Province. The questionnaire is mainly structured and semi-structured, supplemented by open-ended. As local residents have been accustomed to the local climate, we have developed a separate questionnaire for local residents and volunteers. The survey method adopts a face-to-face interview questionnaire. Secondly, the field test and questionnaire survey are combined to test the indoor and outdoor temperature, relative humidity, envelope size, and other parameters.

(2) There are many ways to measure thermal conductivity, but they all have the same basic principles (flat-wall steady-state heat transfer method) and the same data processing process. A test study on the corncobs method combines the advantages of the most common methods, the guard hot box method, and the heat flow meter method, with lower requirements for experiments and accurate data results.

(3) Energy consumption simulations were performed with Ecotect analysis and ladybug+honeybee, respectively, using three different types of wall models to simulate the thermal environment and compare the data.

Reference

1. yi, Z.j.C., Research on indoor lighting analysis method of Green building based on BIM. Green architecture, 2016. (2016): 21-26.
2. China Architecture Publishing & Media Co., L., GB 50189-2005 "Design Standard for Energy Conservation of Public Buildings". 2005: China Architecture Publishing & Media Co.,Ltd.
3. China, M., Technical specification for lightweight aggregate concrete(JG. J51-2002). China Architecture& Building Press: Beijing, China, 2002.
4. Yongquan, H., W. Zheng, and L. Leji, Research on basic performance of recycled aggregate of construction waste. Recyclable Resources and Circular Economy, 2018. 5(11): p. 4.

Chapter 4.

Status investigation of Liyuan indoor environment in Qingdao

4.1. Introduction

People are now paying more and more attention to the quality of the living environment, especially the indoor thermal environment. The thermal comfort of traditional old buildings is lower than that of modern buildings. In the cold and severe cold regions of China, indoor heating is essential because the outdoor thermal environment is poor. However, these areas lack a formal central heating system, forcing residents to adopt a variety of adaptive heating methods and behaviors. Qingdao Liyuan was built earlier, and most of the enclosure structures have no thermal insulation structure and poor thermal insulation performance. Therefore, further research on the indoor thermal environment of traditional buildings in cold regions is of great significance to people living in rural areas.

Residential buildings in the cold regions of China requires heating for several months each year, leading to the consumption of a large quantity of solid fuel, which further results in poor air quality and a range of health problems [1-5] . The inefficient combustion of coal produces high emissions of various air pollutants, such as CO_2, PM2.5 and PM10, causing serious pollution in indoor air[5].

This study uses field measurements and questionnaires to understand the indoor quality of life of Liyuan buildings in winter. The questionnaire is used to identify the indoor quality of life and the living experience of residents, to test the indoor thermal environment, and to measure the thermal performance of the building envelope on-site. It is hoped that this study can provide a reference for improving the living environment of the courtyard buildings.

4.2. Investigated region and basic information

Qingdao is a city specifically designated in the state plan, a megacity, the economic center of Shandong Province, an important coastal city for resort and tourism, an important pilot zone for development of modern marine industry of China, an international shipping hub of Northeast Asia, economic corridor of New Eurasian Land Bridge of "the Belt and Road" and a pivot of marine cooperation strategy.

The city is located on the southeast coast of Shandong Peninsula, in the east of Jiao Dong Peninsula and frontal zone of China-Japan-South Korea free trade area. It borders on Yellow Sea, facing Korean Peninsula across the sea, adjacent to Yantai in the northeast, connected to Weifang in the west and neighboring Rizhao in the southwest. The world's longest sea bridge, the Jiao Zhou Bay Bridge, links the main urban area of Qingdao with Huangdao district, straddling the Jiaozhou Bay Sea areas. [5]. It has a total area of 11,282 km^2, administering 7 districts and managing 3 county-level cities. (Figure 4-1,4-2)

Figure 4-1. The location of Qingdao in the world map [Obtained via Google Earth]

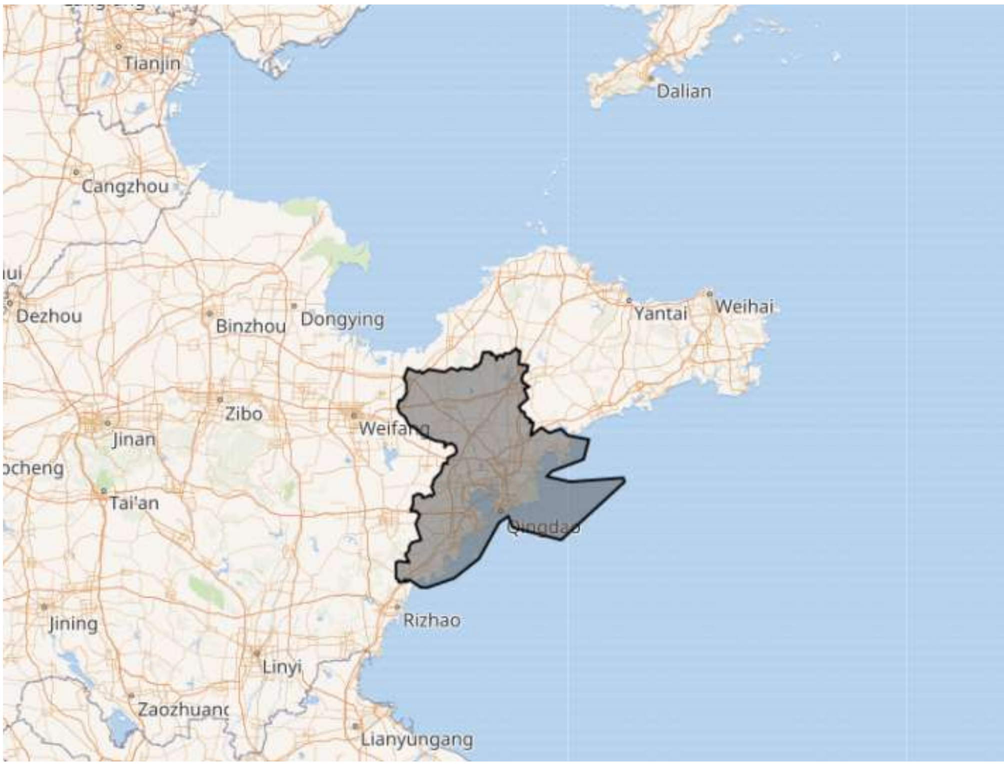


Figure 4-2. The location of Qingdao in the Shandong, China [Obtained via Google Earth]

The accelerating of urbanization in China also brought rapid population assembles in the major cities. Qingdao is one of the most developing cities in the past 10 years, which is an important economic center in Shandong Province on the eastern coastal area. According to statistics records in Qingdao Municipal Official webpage (Figure 4-3) [Accessed on 2020.04.12], the population of Qingdao was less than 400,000 in 1933 and 405 in 1949. The number surged to 7.0297 million from 6.55 million in 1999. In 2017, its total number of permanent residents was 9,290,500 and its total regional GDP was RMB 1,103,728,000,000 Yuan.

Qingdao is a major sea harbor city, naval base and new developed industrial center in eastern China. The city was occupied as colony 3 times during the World War periods because of its geographical predomination. The German colonial government occupied the city in 1897 as their military harbor and designed the first planning, which started the construction for its urban development. Therefore, there are still many distinctive German style buildings retained nowadays, which are well preserved as evidence keeping records of the Qingdao's history. The Liyuan houses are the main residential buildings first originated during this first urban construction period, which still exist as obvious architectural landmarks in the old town area of Qingdao.

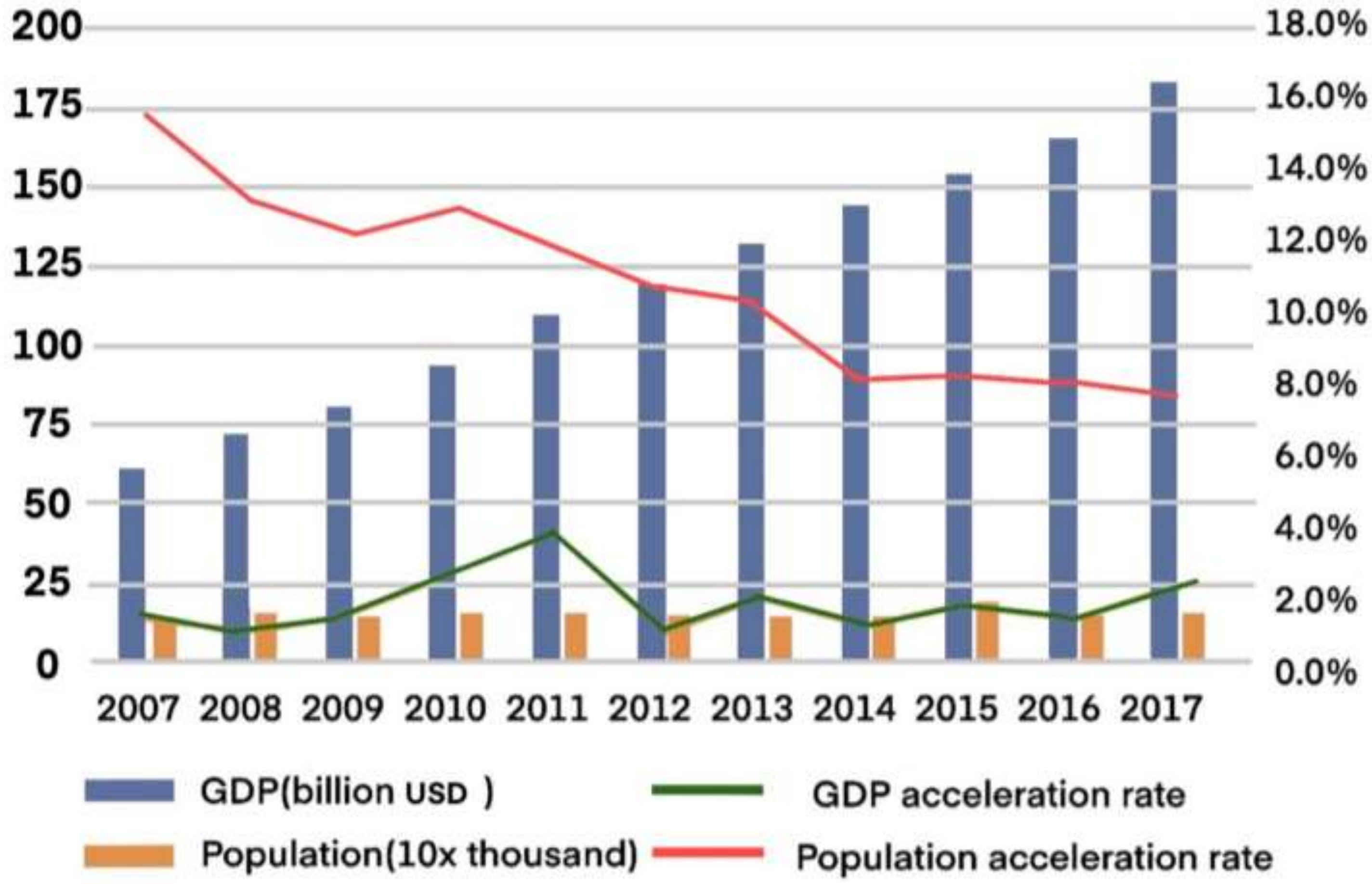


Figure 4-3. The variation tendency of GDP and Population in Qingdao from 2007 to 2017
(http://english.qingdao.gov.cn/n4248/n4267/n4271/160805124441766686.html) [Accessed on 2020.04.20]

As a representative architectural heritage of Qingdao, the Liyuan courtyard building is a valuable asset left to us by history. Liyuan courtyards mentioned in this article are referred to be the classical building style which origins from the 1900s and retain till today, containing the surrounding urban blocks serving functionally for the courtyards. The "blocks" here are defined as urban traffic spaces, including internal buildings and material spaces as well as social living spaces. The "Li" concept in the word "Liyuan" was originally referred to the commercial function, which means the shops outwards to the streets for business negotiation by merchants. The "Yuan" concept referred more specific to the living function, with larger scale than "Li". These two concepts were combined by government architectural department as the current definition of "Liyuan" courtyard only in 1999 [6-8]. The Liyuan courtyard buildings are considered as an important representative architectural type, it also represents a living form of middle-lower-level recognition in Qingdao at earlier period.

The general layout of the Liyuan courtyard consists two sections, the outer building looks like the rows of noisy street shops, while the inner part is filled with private corners of daily lives. A courtyard separates crowed public from quiet corners. When the construction of an open, modern, dynamic and fashionable international metropolis becomes Qingdao's mission, this old building style becomes the new starting point for the revival of the history of the city. Although neighborhoods are composed of houses, communities are more than just sticks and bricks. They include and are formed by people and social relationships, both within and across houses. This was as true in old times as it is today.

Sorted out the historical background according to time clues (Table 4-1), the main evolution procedures of Liyuan courtyards building were summarized. The very original Liyuan buildings were firstly generated during the German colonial period around the end of the 19th century; they were prepared for the local residents and workers settlement developed based upon the traditional Chinese courtyard-style buildings combined with western architectural style. There are many such kind of hybrid construction styles in the original urban planning showing the distinctive semi-colonial characteristics of the original Qingdao urban area. Liyuan building style was widely distributed around at that time and continuously inherited to be part of Qingdao's local culture.

Table 4-1. The historical background of liyuan courtyard building evolution

Time line	Government	Time Feature	Urban Area Feature	Main Habitant
1897-1914	German colonial period	Formation	The main areas for local natives	The native laboring workers
1914-1922	Japanese colonial period	Gradual expansion	Further expansion to the north from the German ruled area	The native and few Japanese settlements
1922-1937	Republic of China	Further Expansion	Additional expansion and supplement to the Japanese ruled area	The lower social class
1937-1945	China Anti-Japanese War	War disturbing	Limited development with supplement to the previous constructions	Native residents and some survived from the war
1945-1949	China Civil Liberation War	War disturbing	Repair works towards the damages from war	The native survived from the war
1949-1990	People's Republic of China	Stabilization & Saturation	Few expansions while the remaining buildings contain larger population	Native residents and outcomes
1990-2008		Deteriorative	Abandon and demolition of many buildings because changes in urban center	Old generation and temporary habitants with low income
2008-present		Expropriation & Protection	Partial repair to extend the life and ready for further retrofit	Few habitants with only temporary outcomes with low incomes

Before German's incursion, the region of Qingdao city had its original business, prosperous population, roads and docks in a good condition, commercial transportation industry kept in rapid development, numerous warehouses and gathered trading markets. The entire region was on a good fundamental background both in business and population. The domestic theoretical research on Liyuan courtyards in Qingdao can date back to the 1990s. In 1897, Germany invaded the region and began its 16 years of colonial domination of Qingdao. The German colonial government officially announced the first urban plan of Qingdao city in 1900 to establish 9 small areas, among them, the "Huiquan" and "Qingdao" are European areas; the other areas represented by "Dabao Island" were Chinese residential areas. Liyuan courtyard building, as a unique Chinese residential architectural style in Qingdao, is a special combination of local spirits of Qingdao and commercial residential chrematistics. From 1901, the Chinese district was further constructed, taking the "Xiaogang" harbor as the boundary, the basic construction of this part to the north was completed, while the construction in the southern part continued from 1902. From 1914 to 1922, the Japanese colonials followed the established and planned urban structure by Germany and expanded the urban construction. The Liyuan courtyard as an architectural style of commercial and residential integration became noticeable gradually within the Dabaodao and Zhongshan Road districts, without clear distinction between "Li" and "Yuan"[9-12].Later on, with the acceleration of the urban renovation construction process, buildings with newer styles started to fill up the area one after another. In the process of modern urbanization, Liyuan courtyards gradually decreased, damaged, and some were eventually demolished. With the urban modernization requirement and the general trend of traditional buildings protection, the Qingdao Municipal Government organized a general statistical survey of Qingdao Liyuan courtyards before 1980. It ended up with the number of nearly 800 courtyards still existed at that time. Due to the trend of economic reform and open up around the whole country, Qingdao's urbanization was accelerating even higher. Modern urban agglomerations and new districts are planned and constructed with a high speed never seen before. Because of the backwardness and seldom experience in the domestic concept of traditional architectural heritages protection, Liyuan courtyard ushered in a devastating blow at that time [13, 14].

In 1996, Torsten Warner, a German scholar provided a general survey research on the topic of analysis on development situation of Qingdao city during the colonial period occupied by Germany. He concluded a detailed statement of the significance of the Liyuan courtyards and their influence on this city[15, 16]. Lately, many domestic scholars carried out research on Liyuan courtyards in a comprehensive way or a certain aspect in manner with a combination of theory and practice. Summarized from literature records [17-20], the existing Liyuan courtyard buildings are mainly built between 1923 and 1953, with the most intensive time in 1923, 1930, 1933, 1936 and 1947. However, most of these theoretical studies which focus merely on the buildings with limited scope.

However, the courtyard currently has a bad living environment, and it is all-round worrying. The Liyuan buildings are unable to satisfy requirements for life. First of all, the living space inside the courtyard is small, and there is a lack of public supporting facilities. The sewage system is out of repair. The public toilets and public faucets can no longer meet people's daily needs. Secondly, many Liyuan buildings are now weather-stricken, and the aging phenomenon of all parts of the building is serious. Most buildings have peeled off the wall, and the wooden corridors and stairs in the courtyard collapsed and rotted. Some buildings even exposed it support structures, beams and columns were loose, leaving serious safety hazards.

The residents in these buildings are aging and complicated. The remaining residents are mostly elder generation with more than 60 years old. However, most existing liyuan buildings are in the old town area with a messy environment, where the community public facilities have completely lagged behind the development. In addition, a large number of housing leases to migrant workers after the residents have moved out, the composition of these groups is complex and difficult to manage:

Based on the previous background introduction and literature study, the contemporary buildings are always considered as symbols of cultural prosperity for certain time period. Some of them are also identified as the representative of history by their full characteristics. Similarly, the Liyuan buildings in Qingdao, taken as one classical architectural style, is a such kind of contemporary building with very typical local symbol and easier to intuitively reflect the unique characteristic spirit. It integrates the characteristics of the times with universal significance embodied not only in architectural features, but also large diversity in the individual building’s details. The research here started the assessment through some historical records study and field investigation to pick up some case study for the research purpose.

As the main residential form in the original time of urban development in Qingdao city, the Liyuan courtyard buildings have been existing together with this city along the history. Such architectural style also becomes the primary target in the overall urban renovation project for contemporary protection and restoration planning. As a matter of fact, every individual building is believed to have specific features, it is more convincing by collecting data from the on-site observation rather than reading text from historical documents. Therefore, comprehensive field investigations were conducted to get closer impression and collect more information on the real situation

In this study, two Liyuan courtyards with major size were selected within the mostly distributed area as mentioned in section 2. The locations of these buildings are illustrated in Figure 4-4. They are considered as the initial case studies to demonstrate the examples and advantages of how a historical heritage building form can retrieve its good old times. In this preliminary study, it is expected to get in close eyes on the current situation of the Liyuan courtyards and provide fundamental information for further analysis. Therefore, the random interviews during external and internal investigation and illustration after dimensional measurement are the two major manners in the process of field investigations.

(1). To identify the sustainability from the social scope, by subjective investigation and questionnaire assessment on the current living condition in some example buildings.
(2). To find out the gap between new living habits of people's daily lives and the long-lasting old buildings which may disturb the comfort as living environment.
(3). To analyze the attitudes from the present habitants toward the retrofit actions which express the social demands on satisfing their wish of modern living standard.

Figure 4-4. The distribution layout of the Liyuan courtyard in the old town of Qingdao city and the two case studies selected in this research [by Google Earth].

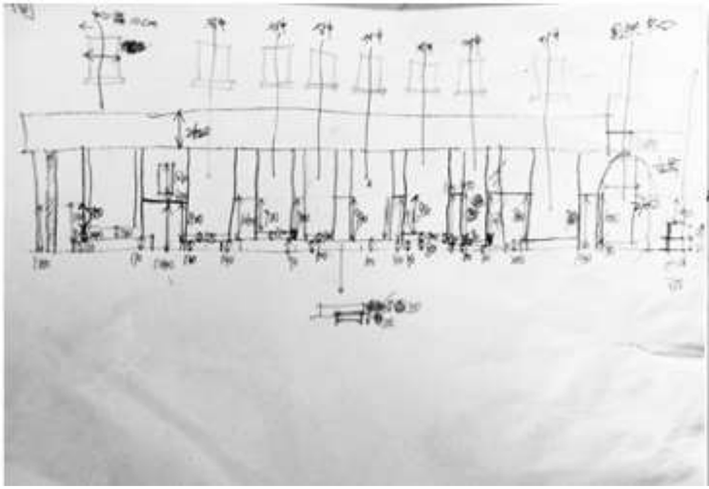
4.3. Dimensional measurement and architectural features analysis

The investigation here is going to collect more practical information and data both from the perspectives of architecture and human residents on site. Through these actions, the current situation of architectural form and the potentials for further retrofitting are going to be found out in details. The main methodology strategies implementation here included dimensional measurement, residents' feedback survey, data visualization and statistical analysis.

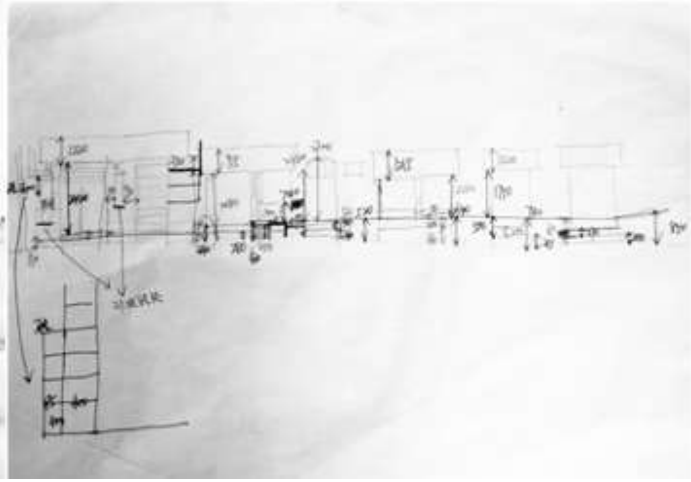
4.3.1. Dimensional Measurement and illustration of the buildings

In order to illustrate the structure and show up the inner design within these Liyuan residential buildings, this survey study conduct a digital drawing describing dimensional details within the buildings. Not only the dimensional information, but also the surrounding environment has been visualized to provide a brief look into the facts of these existing buildings experiences throughout a whole century. The survey aimed to measure and record the building districts in detail as much as possible for case studies. The data collection technique includes in-site investigation, mapping records, multiple-unit architectural surveying including freehand sketches, surveying, photography, etc. Sorting, instrument sketches, computer drawing with geographic information system (GIS) and some other internal work were performed in the following data treatment step to make visual sketch analysis for the buildings (Figure 4-5,4-6,4-7).

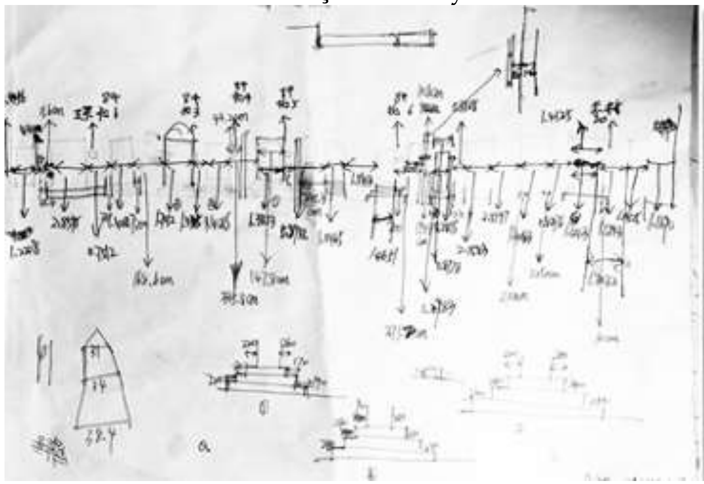
These courtyards normally take big land scale and consist of couple of smaller courtyards. Therefore, the case study in this research is sub-divided into two yards for deeper inspection to reflect the spirit of these miracle artificial artworks. Detailed survey investigation has been carried out including external observation, internal assessment, random interview, dimensional measurement and illustration analysis etc. The survey appended a large number of pictures, featured structures and other related contents, to a certain extent, filling up the vacancy for lack of data in observation and record in the field of protection of typical local traditional architectural heritage buildings for the urban planning and building refurbishment.



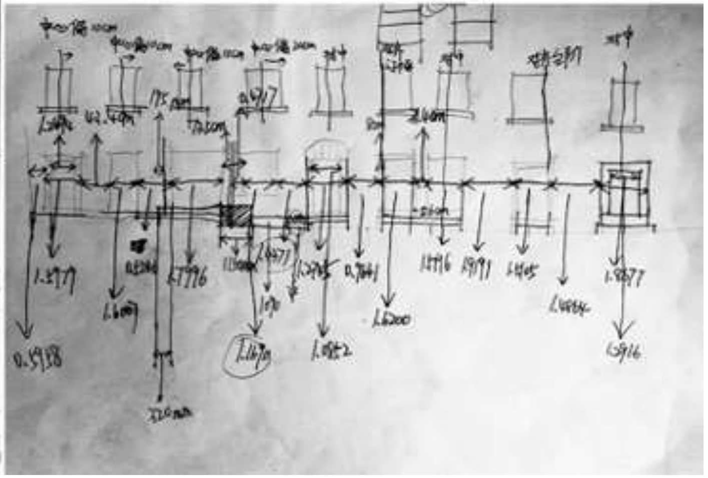
The southern Façade survey



The Initial survey on Northern Facade

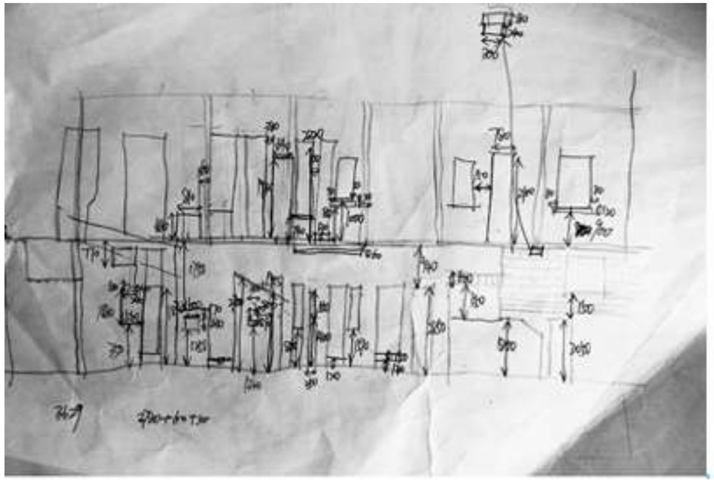


The western Façade survey

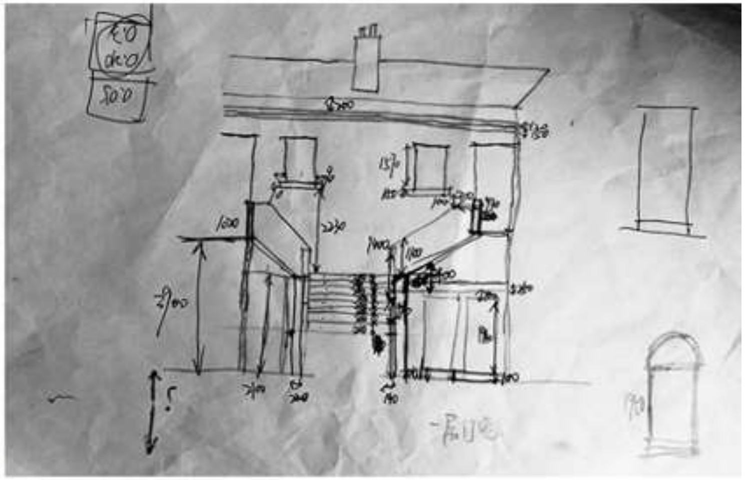


The initial measure of windows and doors in northern façade

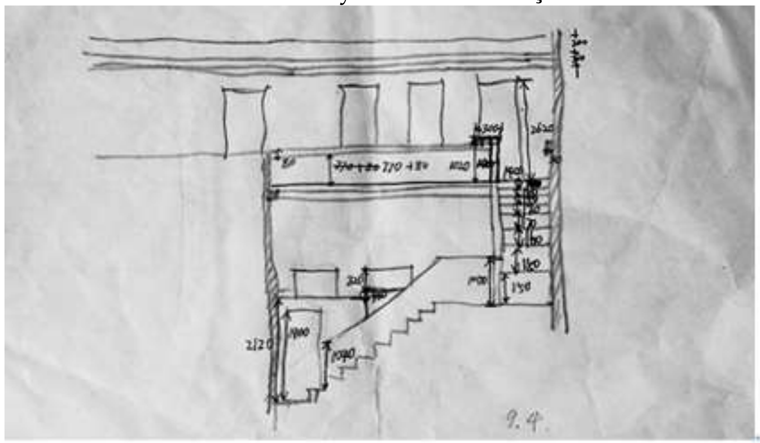
Figure 4-5. The hand drawing of outer Façade in the field investigation



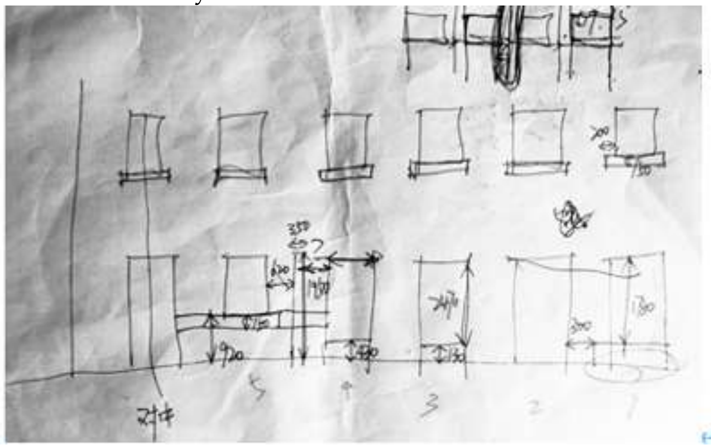
The survey on the inner façade



The survey on the inner southern facade

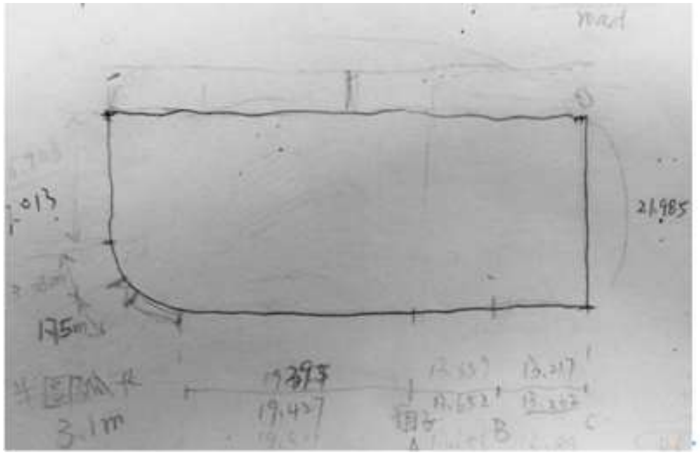


The inner details survey—steps

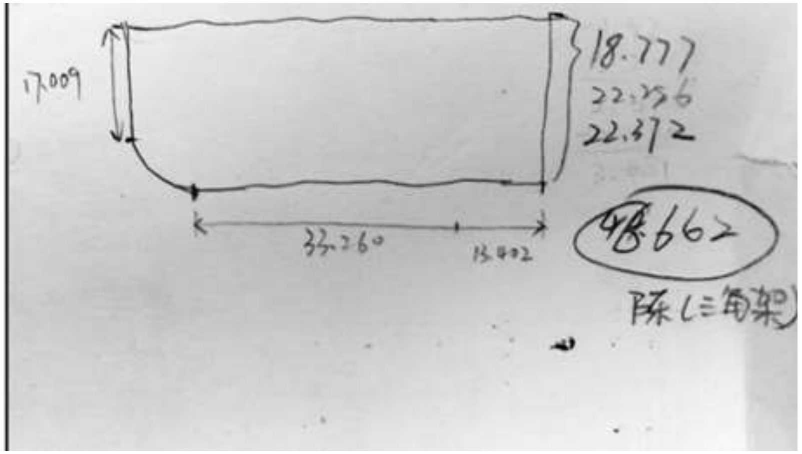


The inner details survey— windows

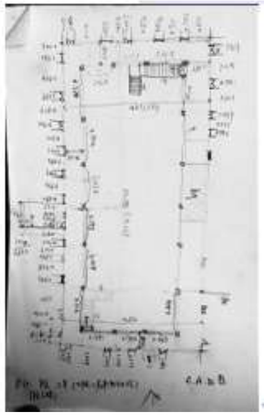
Figure 4-6. The hand drawing of inner Façade in the field investigation



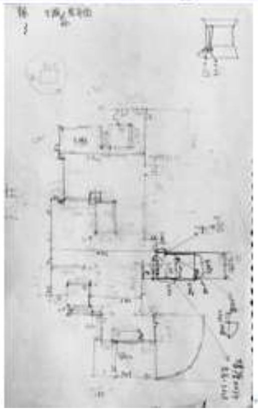
The initial survey of outline of the building scale



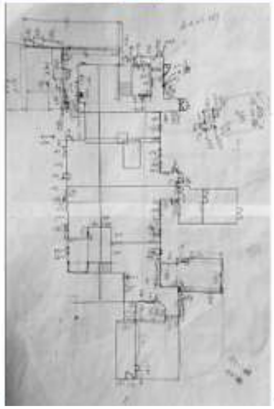
The confirm of the figures in the survey



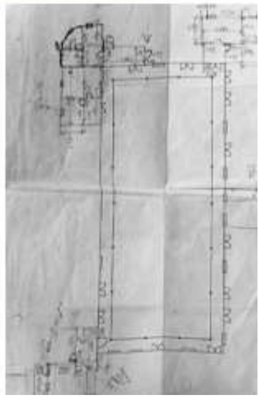
The outline of the inner yard



The outline of the 2nd floor



The Dimension record of 1st floor



The dimension record of 2nd floor

Figure 4-7. The hand drawing of the general layout of the building in field survey

There are two buildings selected for case study. The Liyuan courtyard in case study A (No. 84 Zhifu Road) has a very broad atrium yard which brought good lighting and ventilation. It also provided a nice place and good preconditions for residents to build extra rooms. While the building of the other sub-yards case B(No. 89 Yizhou Road) was built in 1931 next to the neighboring "Tian'an Li". The first floor was mostly used as shopping stores; meanwhile, the second floor was arranged as residential rooms. It has been taken back by municipal government of most rooms until recent years for unified management. The detailed layout of case A was shown in Figure 4-8.

4.3.2. Analysis of the layout of Case A

The 1st floor layout:

The detailed information of layout of the 1st floor in Case A has shown in Figure 4-9. There are many shopping stores on the first floor of this sub-yard. Some large rooms as the middle two rooms about 3-4 m^2 were separated by partitions in the middle, the front part is used as an external shop, the rear part is set as a rest room for the owner. There are also other large rooms arranged like the one shown in the left corner of the figure, one room is taken as meeting room while the other for living. Due to the oversailing platform on the second floor, the lighting condition is weakened for the habitants on the first floor who cannot benefit from the original advantage of the atrium as it should be. Thereby, most of the habitants on the first floor expanded their rooms as a small bedroom or a kitchen and bathroom space required good ventilation, showing their simple wisdom by making good use of the free space in the central atrium. The original atrium of this sub-yard was very wide and designed as a "Qing Gong" Iron Factory. When people started to live in, the empty courtyard was separated and surrounded with expanded annexes, walls, stairs and air defense facilities, which separated the open and privacy spaces as it looks like right now.

About 1800s, the toilet is taken as a place where nasty dirty things concentrated by common sense in China. Therefore, it was placed outside in the yard separated from living space in the household. With time flies, people changed their thoughts slowly and set up their own private toilets inside and enclosed the outdoor toilets with partition treatment which ensured its privacy and isolation from the living rooms (Figure 4-10).

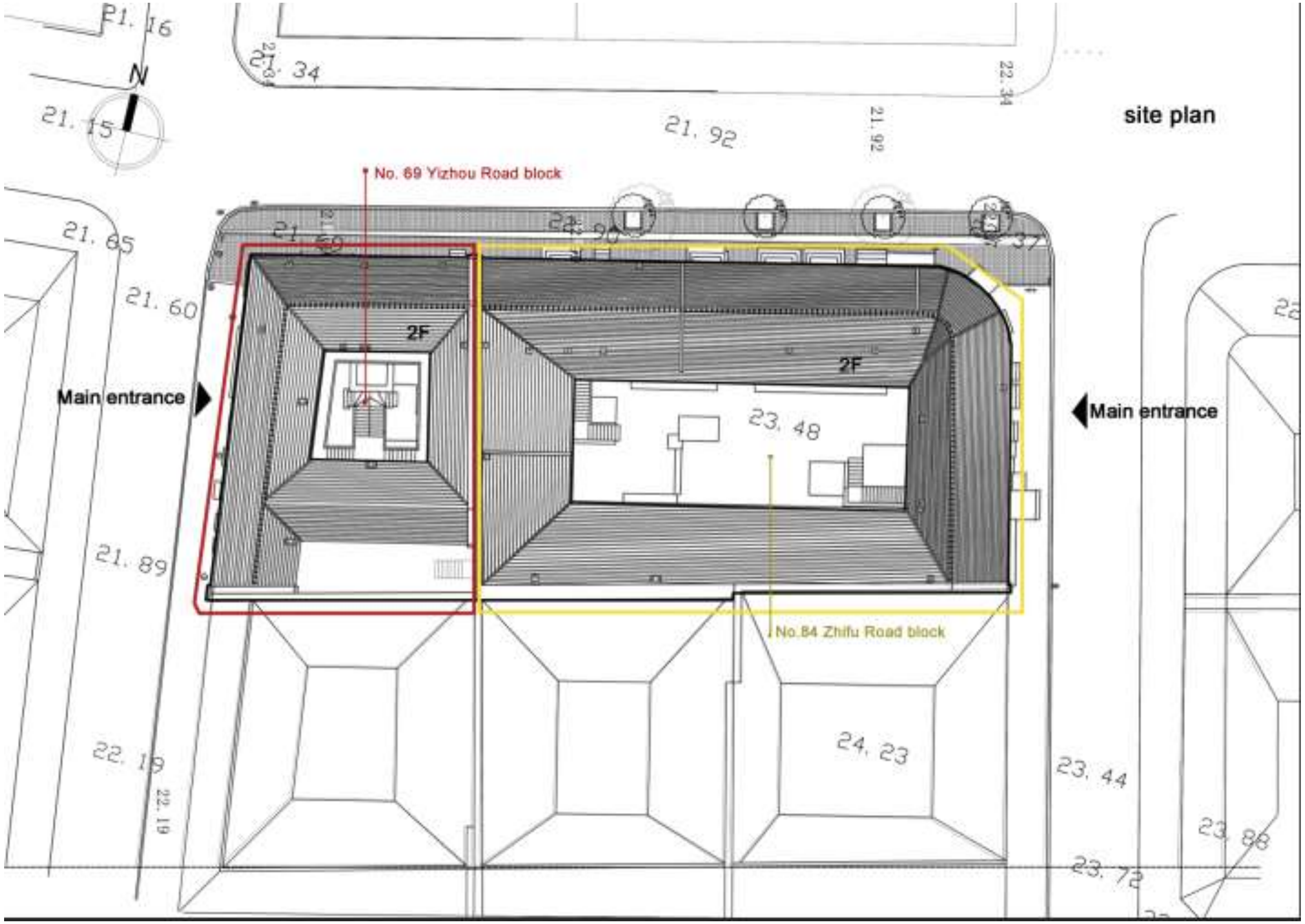


Figure 4-8. The layout of the Liyuan courtyard buildings of Case A

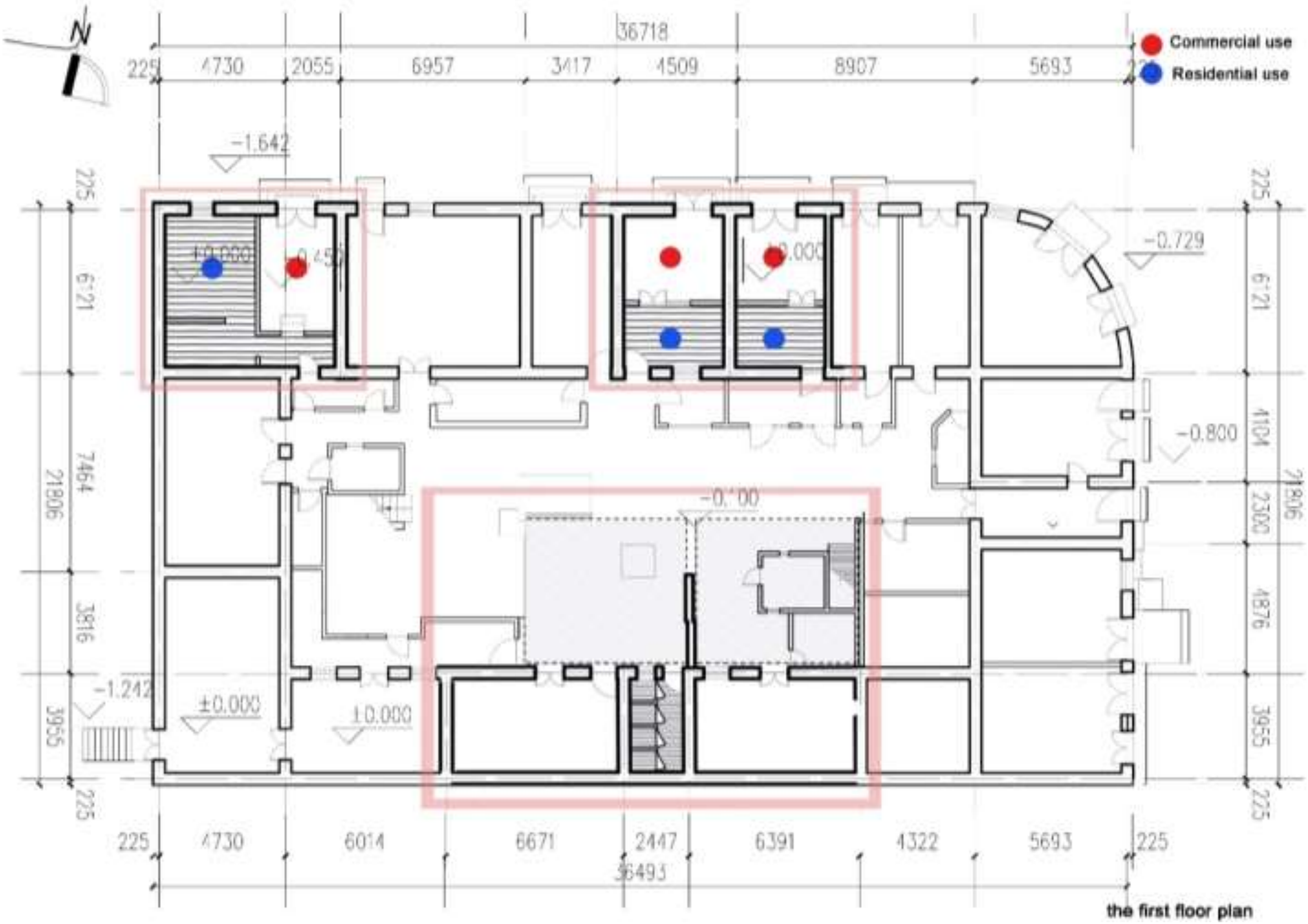


Figure 4-9. The analysis of the detailed layout on the first floor of Case A

Figure 4-10. The spatial arrangement in the central atrium including private extension and isolation of toilet

The 2nd floor layout:

From the detailed illustration from the data in the dimensional measurement (Figure 4-11), a majority of the partition walls within the building are 120mm-150mm thick. Obtained from the interview, the partition walls are mostly grass embryo ones, the hollow sound can be heard when tapped by hand; The external walls are mainly masonry ones, which are more or less 450mm together with the plaster, small disparity would be existed due to different attrition rate, a muffled voice could be heard once knocked on by fingers. Because of the limited space, some of the habitants occupied part of the public corridors as their kitchen, there is one family even enclosed the expanded part with door and windows.

The public toilet on this floor is no longer in use. Each household interviewed enclosed their own toilets with partition walls, although most of the small rooms don't have any external windows without good ventilation and lighting at all. Almost every habitant made his own suspended ceiling underneath the roof, which was commonly used as a small loft with the sloped roof on top of it.

4.3.3. Analysis of the layout of Case B

Building layouts on both floors：

The detailed layout of Case B is shown in Figure 4-12. The first floor of this sub-yard is opened up as shops along the street. The staircase is in the central of the inner circle, which is the only access between the 1st and 2nd floors. The protruding part next to the stairs is the kitchen belongs to one habitant. There is a public toilet on the first floor, whose gate is difficult to identify. It smells really bad once enter the yard, probably because of the unseen sewage pipes are installed just underneath the stairs.

The second floor of the building are all residential households, and the rooms on the south side have somehow good lighting and ventilation because there is a small lane next to the neighboring buildings. The original intention of the buildings Case B was only for residential functions, and the landlord who built the courtyard planned to lease them for profit.

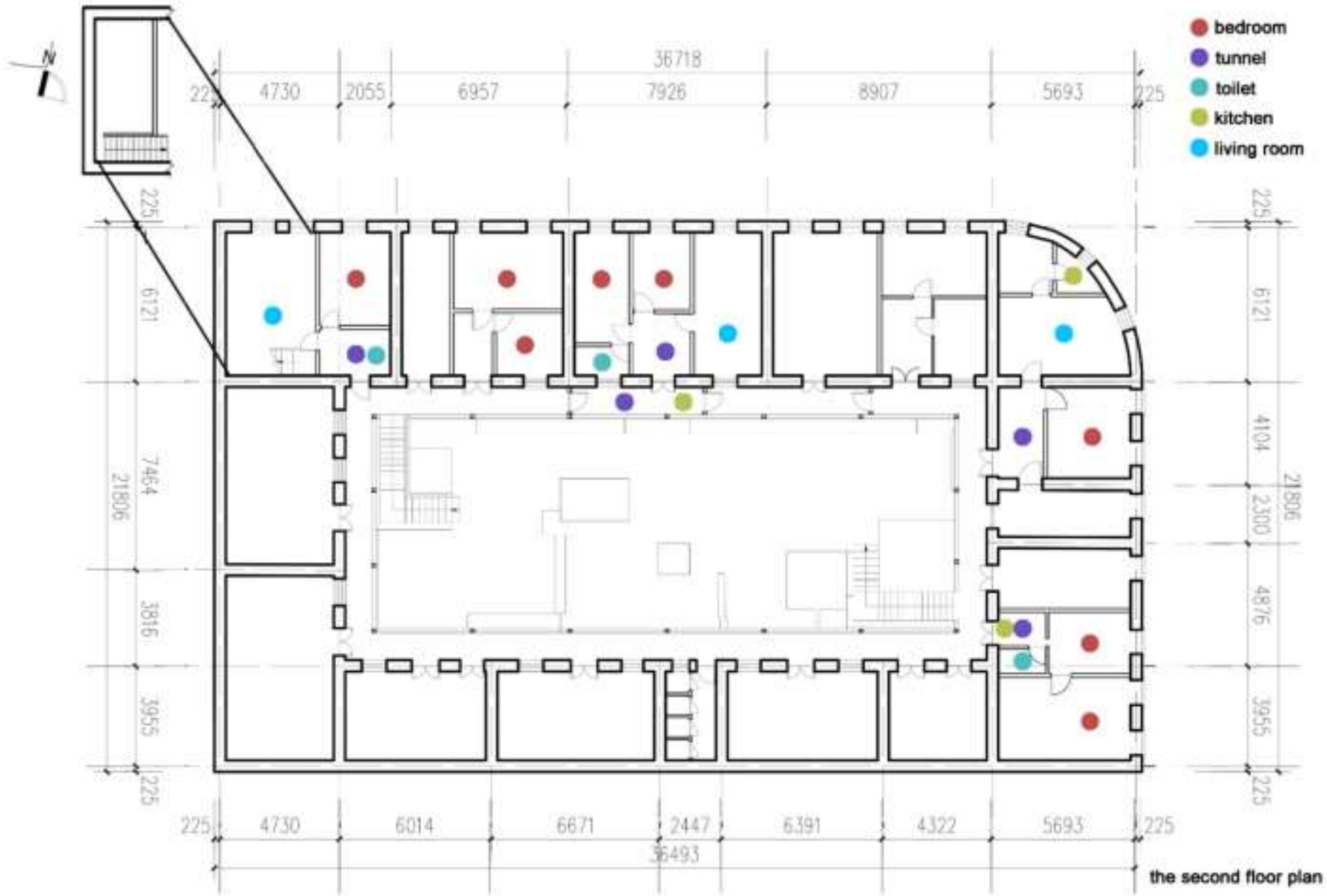
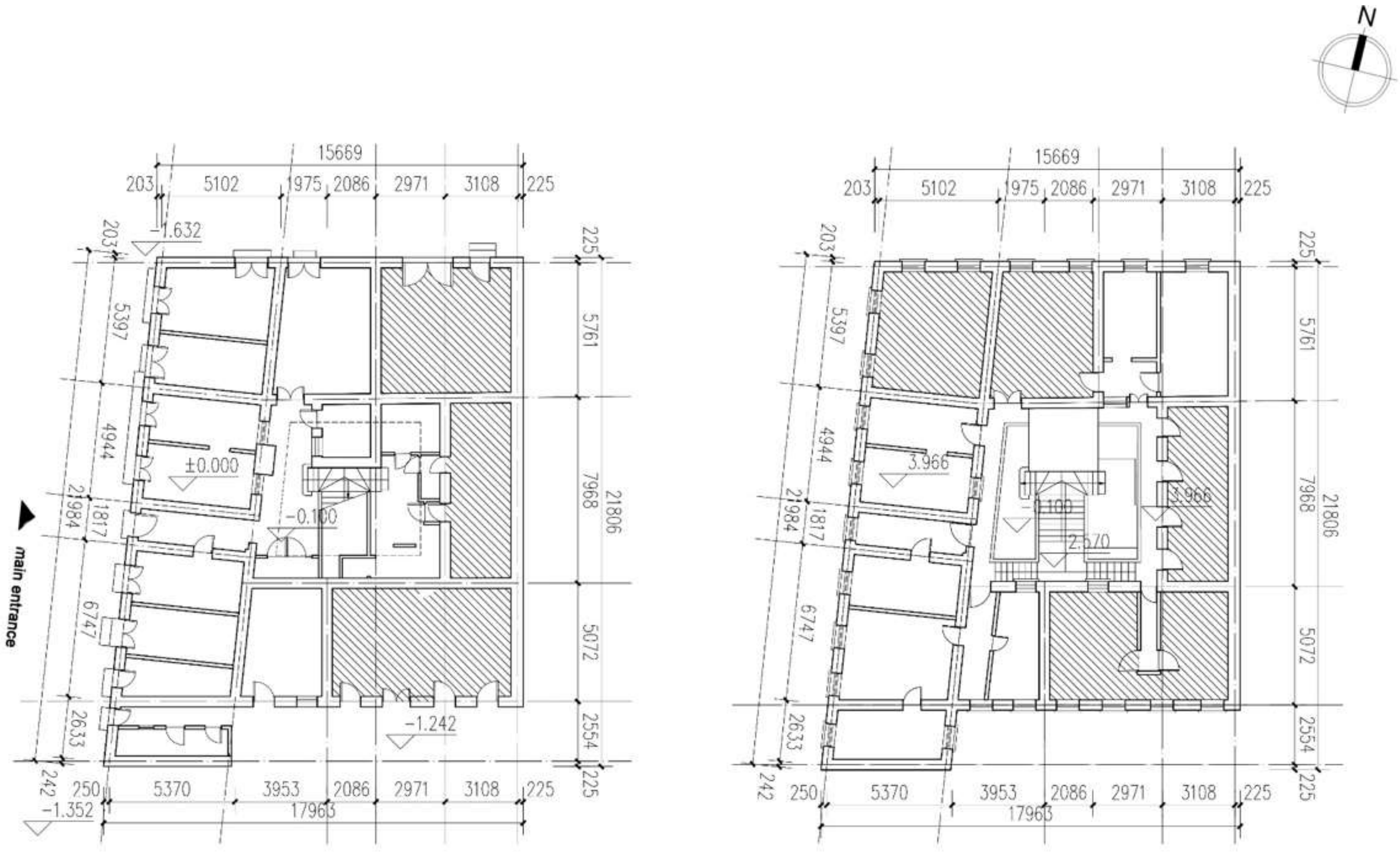


Figure 4-11. The detailed layout of the 2nd floor in Case A



The first floor plan

The second floor plan

Figure 4-12. The detailed layout of both floors in Case B

4.3.4. Building Facade analysis

The facades of the Liyuan courtyard in Case A adopt a three-stage composition method: 1) the lower part are mainly composed of wall bases and some structures, made by local granite materials; 2)the middle part are wall and windows, mostly composed of brick-wood structures, the original wooden staircase corridor and handrails internal have been replaced, while the external walls have been painted into yellow uniformly; 3)the upper part are the roof, cornices and drainage channels, mostly composed of double-sloped roof with gentle slope, and there are protrusions at the corners emphasizing its central position. There are gables at the junction with other courtyards, with red tiles on the hard mountain top (Figure 4-13).

Due to the commercial and residential features of the Liyuan courtyard building, the main entrance is not obvious, and there are great differences in image among all the courtyards. The main entrance to this courtyard is in the form of an arch coupon door with a width of 5 meters. It is simple and clean without much decoration, plays the role of the scenery very well. Connected by the view from eyes, the main space inside the courtyard can be caught in sight through the main gate once step in. This kind of small straight door is a relatively simple installation.

The drainage pipes can be observed from the external façade, because Qingdao is located in a rainy area with average precipitation of 435mm in summers, which require the consideration of drainage issues for the operation of the building. Most of the roofs in the Liyuan courtyard are double-slope structure with hard mountain tops, the courtyard is drained by rain with gutters and downpipes settled. Therefore, the rainwater pipes do not get through the household rooms, which is conducive to indoor beauty and reduce leakage happening. This design pattern follows the German architectural style, with a drainage channel installed under the eaves and connected to a thick iron drainage pipe (mostly made of PVC materials now). All of that made the Liyuan courtyard in Qingdao highlight the design features of "form follows function" from Western architectures.

Figure 4-13. The façade illustration of the building in Case A

4.3.5. Data visualization and statistical analysis

During the investigation of the residential district, there were plenty chances to contact with the local residents. Therefore, random interview is a good way during the progress of field investigation to find out the real living situation within the district, which can quickly reflect the most difficult, hot and focused issues from the voices of the residents. The method of interviewing here is only on-site investigation. Dozens of questions have been delivered out obtained with abundant response with facts suitable for dissemination to the masses. Regardless of whether the object of the interview is a natural phenomenon or a social phenomenon, this survey study here only pays attention to facts of value that are of concern to the sustainability development (Figure 4-15).

The Liyuan courtyard in case study A consistent of two sub-yards, which used to be a Japanese Iron blacksmith was completed in 1940.Thus, the fundamental functions of the buildings within this courtyard were factories, shops and residential rooms. Nowadays these buildings still exist as private residences only for living purpose. They are old two-story historical heritage buildings with traditional style, red tiles on top and half-timbered structure. From the document records and measurement in this survey, the Original land occurrence was 838.74 m^2, while the current is 968.23m^2; the original building area was 1695.91m^2, while the current is 1825.40m^2(increased by 129.49m^2 from the personal expansion by the habitants). In 1980s, the municipal government funded adaptive operation on protection and retrofit of the building, replaced the original wooden handrails and stairs with stone ones, the previous iron pillars with the current wooden material.

This random interview here obtained related facts about the situation of residents within this Liyuan courtyard building after 100 years operation. The answers collected from interviews gives a real state of the natural relationship between the long existing courtyard and generations of residents live in it. All of that was proved as a reference to find out the sustainability between solid architecture and social phenomenon (Appendix A).

The questionnaire survey part mainly focuses on the current building usage of residents and what defects may exist to improve the building conditions. From the initial evaluation of a set of questionnaires focusing on the composition of residents, income analysis and preliminary needs, to the transformation of all recipients in the case study.

Figure 4-14. The general situation inside Liyuan courtyard buildings in Case A

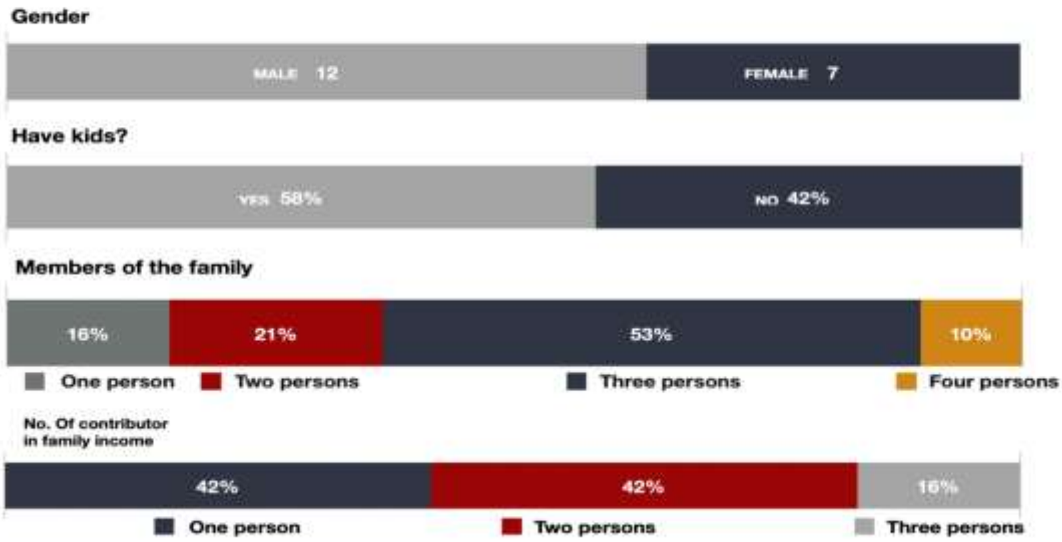


Figure 4-15. The statistical analysis of the basic information of recipients' families

Family consistent and incomes analysis

The first part of the question is mainly to study the basic family composition and family background of local residents. Since most of the households have moved out, there are 19 people in this questionnaire survey, of which 12 are males and 7 are females. The statistical analysis in Figure 4-15 shows the basic composition of the family, and more than half are three people composed of parents and children. The remaining one or two live with a number of temporary workers from other places or some old local residents.

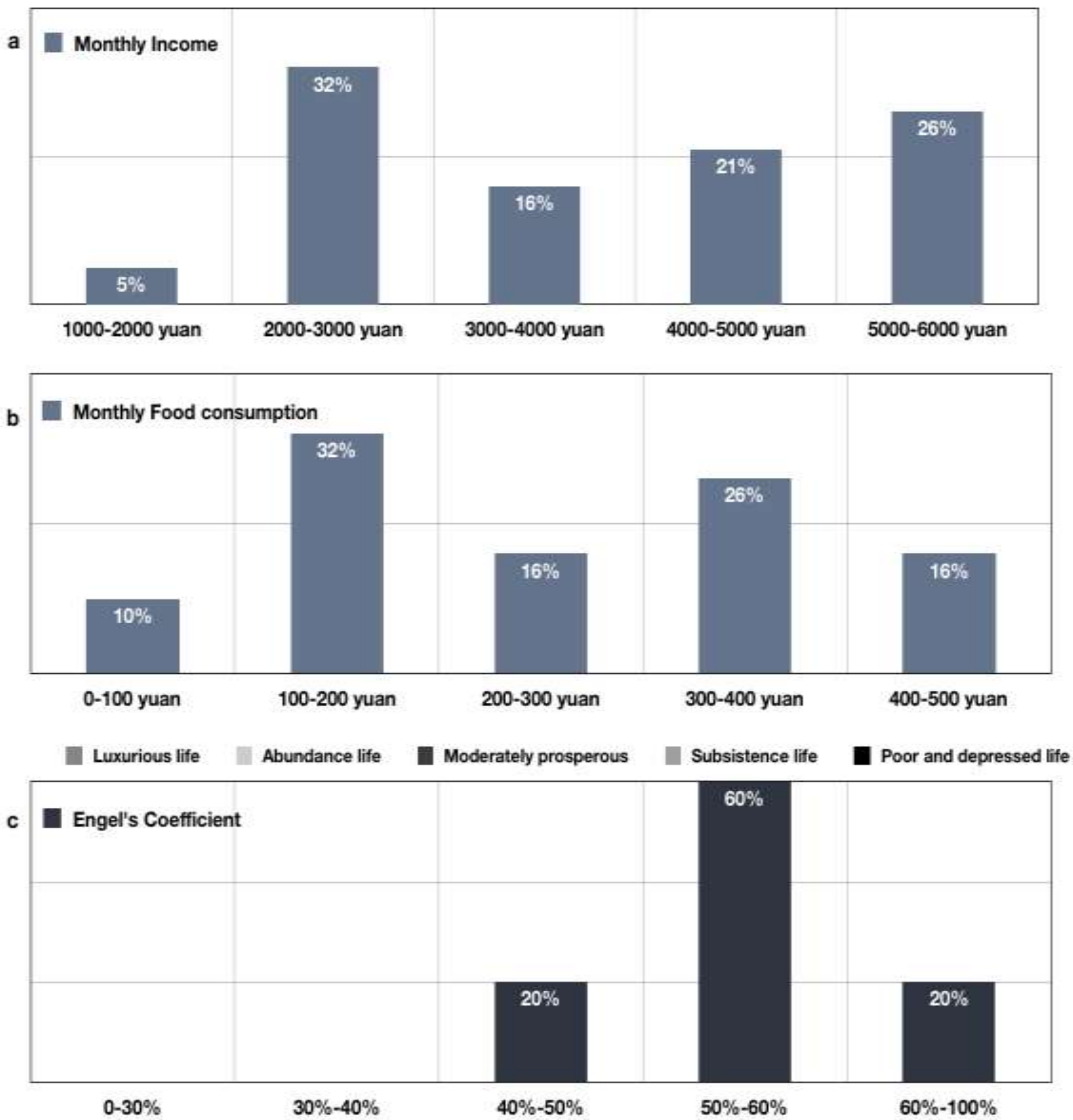


Figure 4-16. The economic analysis and Engel's coefficient evaluation based on questionnaire (a. The monthly income analysis; b. The monthly consumptions in food; c. The Engel's coefficient analysis result).

The figure above (Figure 4-16) shows the constituent analysis of the residents in the case study here. The Engel's coefficient used for data analysis as an economic criterion to discover the living conditions of the residents; Engel coefficient above 59% means Poor and depressed life; 50-59% means subsistence life; 40-50% means Moderately prosperous life; 30-40% means Abundance life; and less than 30% means luxurious life mode.

The Engel's coefficient analysis of data from questionnaire data in case study shows about 60% of the recipients belongs to the subsistence life model, while the other two portions took both 20% as moderately prosperous and poor and depressed life. The overall Engel's coefficient in China was 28.4% according to the statistical data in 2019. It concluded that the residents in this courtyard are mostly belonging to low-income groups, taking the hard life in the middle and bottom of society. It also explains economic contribution combined into deeper analysis on the family compositions. Most family's recipients have not more than 6000-yuan monthly income, and mainly concentrated in the range of 2000-3000 yuan and 4000-6000yuan. 84% of the recipient families have one or two persons who contribute to the total family income, very few families have more than 3 contributors. This is mostly because the families here are mainly temporary workers and the native families with more than 3 people are mostly elder ones who don't have capability to work any longer. There is no consideration of retrofit or moving out because they are not able to cover the cost in massive retrofit actions.

The spatial formation types of the kitchen area

From the analysis of answers to questionnaires and interviews, the most concerned partial retrofit is the kitchens. Based upon the kitchen spatial assessment results, it could be found that very limited areas arrangement in the original and current rooms plan layout. Figure 4-17 here shows the evaluation of the investigation results. From the original time, not all rooms were assigned with kitchen space, about 61% of the kitchen space is in good hygiene condition, but 54% are hardly to clean up. The rest 39% of kitchen space is in poor condition regardless easy to clean or not. After all, the highly concentrated potentials of building retrofit would be better from the kitchen areas.

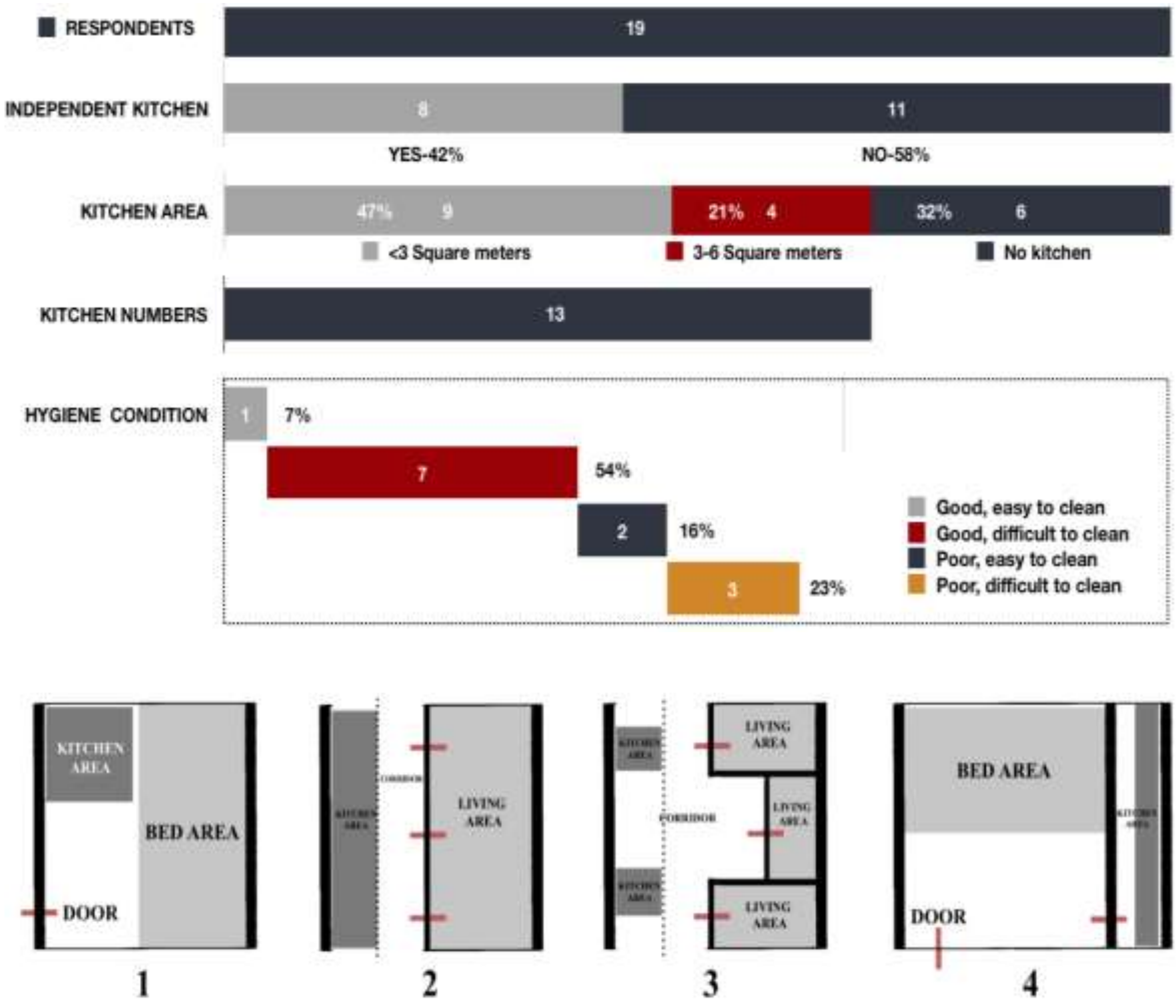


Figure 4-17. The spatial analysis in kitchen formations in Liyuan buildings

Family requirements for the renovation

Two tables with detailed data are present: It evaluates the factors that have influence on residents' choice when they decide to renovate their building. Table 4-2 shows the residents in different age attitude to the different aspects.

Table 4-2. The evaluation of the different feedbacks from habitants towards to retrofit

Question: How important do you consider the following issue when you decide on building renovation?

Requirements	Very important %	Rather important %	Less important %	Not important %	Mean	Std. Deviation	Rank
Cost	68.4	31.6	0	0	1.32	0.478	1
Health	47.4	42.1	5.3	5.3	1.68	0.82	2
Safety against theft	47.4	42.1	5.3	5.3	1.68	0.82	3
Fire protection	47.4	26.3	26.3	0	1.79	0.855	4
Cozy living	31.6	47.4	15.8	5.3	1.95	0.848	5
Short construction period	15.8	31.6	52.6	0	2.37	0.761	6
Surrounding environment	10.5	31.6	42.1	15.8	2.63	0.895	7
Maintenance	5.3	31.6	47.4	15.8	2.74	0.806	8
Durability	0	5.3	42.1	52.6	3.47	0.612	9
Aesthetic	10.5	5.3	10.5	73.7	3.47	1.02	10
Energy saving	0	5.3	31.6	63.2	3.58	0.607	11

1 Figures are rounded. Therefore, percentages within one row may not add up to 100.
2.The mean of all evaluations for one item (codes 1 to 4) reflect the feedbacks: the smaller of the average, the more important of the aspect with regard to the decision toward to certain building construction retrofitting.

Through analysis of the data, findings are shown as below:
(1) it is found that cost is the most important criteria for consideration when the users make decision.
(2) Health and cozy living are the second important classified criteria.
(3) Safety criteria is the 3rd influence factor, such as safety against thief, fire production, these are put on the top place of all the factors.
(4) Further issues are considered slightly less important, that aesthetic seems not that important as its place was left behind.
(5) Finally, the factor with smallest influence was energy savings. Because the users are mainly concerning on their stable living and seldom have the sense to consider about the energy issues behind the daily bills.

All of these findings show that users pay more attention on cost, security as their top influential factors in current living condition evaluation. While aesthetic, durability and energy saving prominent characteristics of the heritage Liyuan buildings are often put in unimportant standard for retrofitting the building. However, the most concerned factors of heritage buildings are often shown as these characteristics. Therefore, how to improve the building condition and how to let users to renew their knowledge of heritage buildings, especially improve their beliefs of Liyuan courtyard buildings is very important for the policy makers and interested stakeholders (Table 4-3).

Table 4-3 shows that people with different ages have different attitudes towards renovation. Due to different ages, different factors are considered. 1) People over 60 are more concerned about health, price and construction cycle. 2) People aged 40-60 are more concerned about the comfort and safety of living. 3) Young people begin to pay attention to aesthetics and energy saving on the premise of focusing on price and comfort.

Table 4-3. The analysis of attitudes in different aged habitants towards to retrofit

Age	Health	Safety against theft	Cozy living	Fire protection	Short construction period	Maintenance	Surrounding environment	Cost	Durability	Energy saving	Aesthetic
60+	1.25	1.75	2.25	2	1.75	2.5	3	1	3.25	3.75	4
40-60	1.43	1.29	1.57	1.43	2.57	2.43	2.71	1.43	3.29	3.71	4
25-40	1.6	2.2	2.4	1.6	2.6	2.8	2.4	1.4	3.8	3.4	3.2
-25	3	1.67	1.67	2.67	2.33	3.67	2.33	1.33	3.67	3.33	2

4.4. Thermal performance of Liyuan Yard envelope

4.4.1. Enclosure structure thermal performance

Qingdao Liyuan is load-bearing by brick walls, mainly relying on increasing the thickness of the wall to achieve building thermal insulation, generally with a wall thickness of 370-490 mm [50]. According to the measurement data of the 22 courtyards accessible in the survey, 14 have walls with a thickness of 370mm, 5 have walls with a thickness of 490mm, and 3 have walls with other thicknesses. The 370mm thick brick wall accounted for the largest proportion, accounting for 65% of the total number of surveys. The wall repair work of courtyard buildings can repair cracks, reduce water seepage, solve certain thermal defects, reduce the problem of high energy consumption caused by structural moisture, and improve the thermal insulation performance of external walls to a certain extent. After on-the-spot investigation and investigation, we learned that the current structure level and specific practices of the courtyard after the completion of the renovation are as follows (Table 4-4).

Table 4-4. The wall composition in Liyuan courtyard

<table>
<tr><th>Structure map</th><th>Tectonic Hierarchy</th><th>Construction practice</th><th>Thermal Conductivity W/（m·K）</th></tr>
<tr><td rowspan="4"></td><td rowspan="2">Modified layer</td><td>6mm 1:2.5 cement mortar Leveling</td><td rowspan="2">0.87</td></tr>
<tr><td>12mm 1:3 cement mortar Render</td></tr>
<tr><td>Clay brick wall</td><td>370 mm clay brick
Water embellishes leaching</td><td>0.79</td></tr>
<tr><td>Surface layer</td><td>1:0.5:3.5 cement mixed mortar</td><td>0.87</td></tr>
</table>

According to "Technical code for the retrofitting of public building on energy efficiency" JGJ 176-2009, when the outer walls of public buildings in cold areas cannot meet the requirement of non-condensation on the inner surface of "Code for thermal design of civil building" GB 50176-2016, Energy saving transformation should be carried out. To meet the requirement of non-condensation on the inner surface, it is necessary to meet the allowable temperature difference between the inner surface temperature of the wall and the indoor calculated temperature: $\Delta t_w \leq t_i - t_d$, the calculation formula is as follows:

$$\Delta t_w = t_i - \theta_{i \cdot w} \tag{4.1}$$

$$\theta_{i \cdot w} = t_i - \frac{R_i}{R_{0 \cdot w}}(t_i - t_e) \tag{4.2}$$

t_i-Indoor temperature

t_e-Outdoor temperature

$\theta_{i \cdot w}$-Internal wall surface temperature

R_i-Inner surface heat transfer resistance

$R_{0 \cdot w}$-wall heat transfer resistance

The indoor calculated temperature t_i in Qingdao area is set to 18℃, the outdoor calculated average temperature t_e is 2.1℃, the indoor air relative humidity is 60%, the density correction coefficient is 1.0, the temperature difference correction coefficient is 1.0, and the inner and outer surface heat transfer resistances are respectively 0.11 $m^2 \cdot k/W$, 0.04 $m^2 \cdot k/W$, the dew point temperature dt = 10.2℃. According to formula 4.1 and formula 4.2, the inner surface temperature of the wall with a thickness of 370mm is calculated to be $\theta_{i \cdot w}$=15.4℃, and the allowable temperature difference Δt_w=2.6℃≤$t_i - t_d$ =7.8℃, which meets the requirements. Therefore, in theory, no condensation will occur on the inner surface of the building envelope. According to "Design standard for energy efficiency of residential buildings" DB37/5026-2014, the limits of building heat transfer coefficient in cold regions are shown in Table 4-5. Due to the large heat transfer coefficient of masonry materials, although the wall is quite thick, the thermal insulation performance still cannot meet today's energy-saving standards. According to the calculation formula of the heat transfer coefficient of the enclosure structure, the heat transfer coefficient of the 370-490mm brick wall is about 1.296-1.527W/$m^2 \cdot$K. Whether it is used as a residential function or a public function after the renovation, the courtyard cannot reach the current standard requirement. Therefore, when the courtyard wall is repaired, although the external wall insulation measures will not be added, surface condensation will not occur, but the heat transfer coefficient of the wall is quite different from the current standard. Further energy-saving renovations are required.

Table 4-5. The average heat transfer coefficient of buildings in Shandong

Enclosure structure		Roof	Exterior wall	External window (window-wall ratio 0.2)
Heat transfer coefficient	Residential building	0.25	0.35	1.8
	Public buildings	0.45	0.50	2.7

4.4.2. Roof structure thermal performance

The courtyard has a red tile sloping roof. According to the investigation, the roofs of the courtyard buildings in Qingdao are mostly sloping roofs with wooden trusses, and the trusses are composed of upper chords, lower chords, roof truss central columns and sloping webs [21]. The triangular roof trusses are placed on the brick wall and the round or square purlins are placed on the roof trusses, and the purlins are covered with wooden lookout boards. The roof is covered with red terracotta tiles. When laid down, it is necessary to nail the hanging tile and the downstream strip to the lookout board. They are laid in sequence to ensure that the rainwater flows along the tiles (Table 4-6).

Table 4-6. The roof structure composition of Liyuan courtyard

Structure map	Tectonic Hierarchy Construction practice	Thermal Conductivity W/（m·K）
	15mm Thick clay tile	0.7
	20mm*30mm Hanging tile	
	25mm*12mm Water strip	
	20mm Thick wood lookout board	0.34
	Purlins	
	Roof truss	

The average heat transfer coefficient of the roof can be calculated according to the heat transfer coefficient of the flat wall part of the roof. According to the "Code for Thermal Engineering Design of Civil Buildings" GB 50176-2016, the calculation formula of the heat transfer coefficient is as follows:

$$K = \frac{1}{R_0} \tag{4.3}$$

$$R_0 = R_i + R_1 + R_2 + \cdots + R_n \tag{4.4}$$

$$R = \frac{\delta}{\lambda} \tag{4.5}$$

in:

K——The heat transfer coefficient of the flat wall of the envelope structure (W/(m²·k))

R_0——Enclosure heat transfer resistance (m²·k/W)

R_i、R_e——Internal and external surface heat transfer resistance (m²·k/W)

R_1、R_2、…、R_n——The thermal resistance of each material layer (m²·k/W)

δ ——Material layer thickness (m)

λ——Material thermal conductivity (W/(m·k))

The heat transfer resistance of the inner and outer surfaces of the roof is 0.11 m²·k/w and 0.04 m²·k/w. According to the roof structure diagram and formula, the total thermal resistance of the courtyard slope roof without thermal insulation measures R_0= 0.39 m²·k/w, the heat transfer coefficient K value is 2.53W / (m²·K), which is much higher than the limit of 0. 45W / (m²·K) for the roof heat transfer coefficient of public buildings in cold areas.

To sum up, when the courtyard roof is only repaired and no thermal insulation measures are added, the average heat transfer coefficient is large, and the thermal performance is poor. Improving the thermal insulation performance of the roof is beneficial to the improvement of the overall performance of the building. The roof repair of the courtyard is an essential process, so it is possible to carry out insulation works while repairing the roof to improve the overall performance of the roof.

4.4.3. Window structure thermal performance

The original window frames of the courtyard buildings are mostly wooden single-story windows, and after the 20th century, steel windows began to appear. Later, due to the damage of the original windows, the occupants replaced the windows by themselves, and replaced the original wooden windows with aluminum alloy windows. After the courtyard building renovation project was carried out, the courtyard windows were replaced with PVC plastic insulating glass windows. The original exterior windows of the courtyard and the windows replaced by residents themselves have a large heat transfer coefficient, which is far from the current standard and has poor thermal performance. Therefore, energy-saving optimization of exterior windows is an essential measure (Table 4-7).

Table 4-7. The windows structure composition of Liyuan courtyard

The window type	Whole window heat transfer coefficient
Single glass wooden window	5.0
Single glass steel window	6.7
Single glass aluminum alloy window	6.2
Ordinary aluminum alloy hollow glass Windows	3.7
PVC Plastic insulating glass window	2.7
PVC plastic Low-E Hollow glass window	2.0

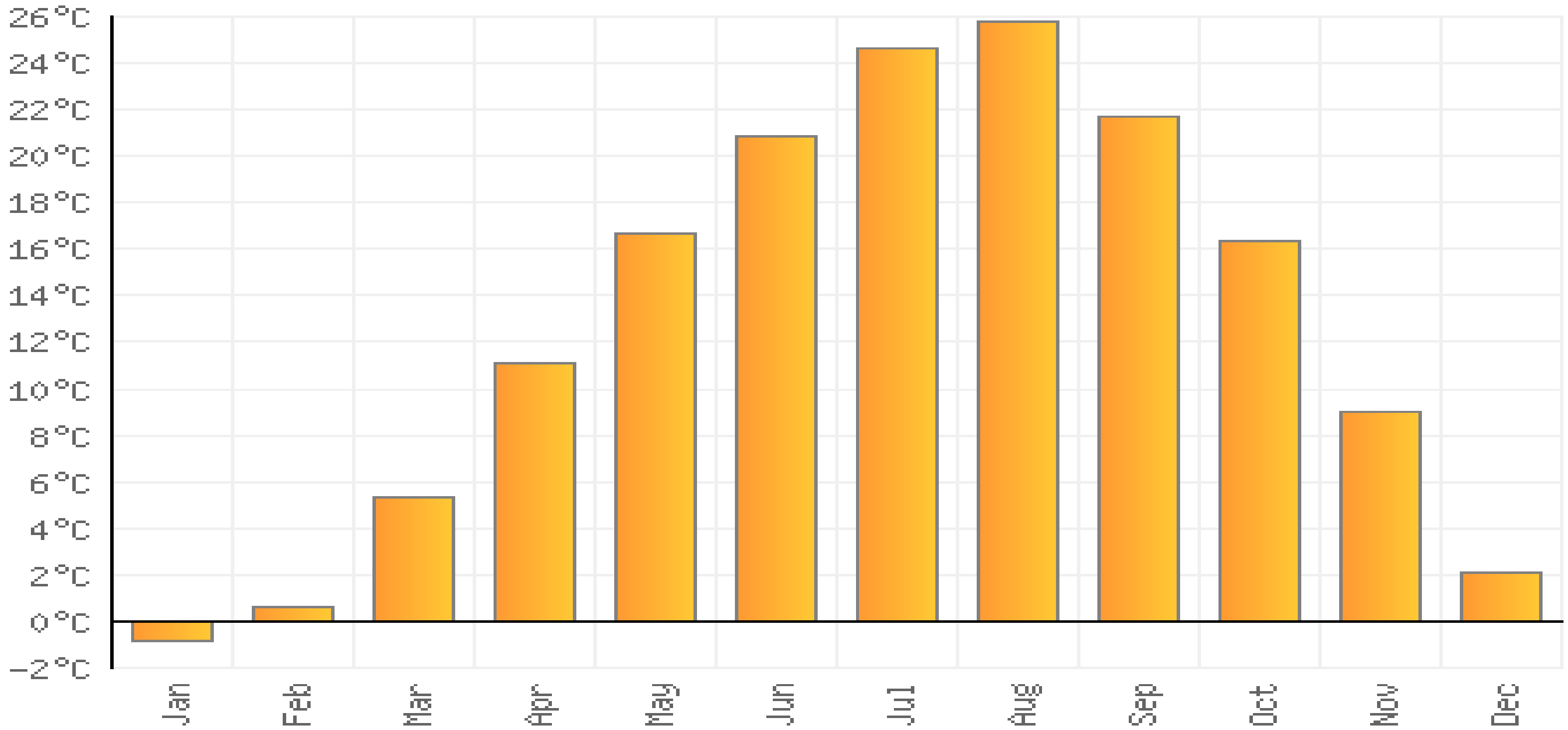
4.5. Thermal environment test and analysis of Qingdao Liyuan building

4.5.1 Site temperature measurement

The current status of Liyuan building protection is poor, and the safety hazards are serious. If people want to reuse, they must first carry out protection and repair work. In order to quantitatively compare and analyze the current status of the repair and transformation of the Liyuan buildings and understand whether further energy-saving optimization and transformation are needed, the main research object of this section is selected. Protect and repair the Liyuan buildings that can continue to be used. The test content includes the indoor air temperature and the inner and outer surface temperature of the enclosure structure. Through the thermal environment test and analysis of the courtyard, we can understand the current energy consumption of the courtyard and the problems existing in the renovation.

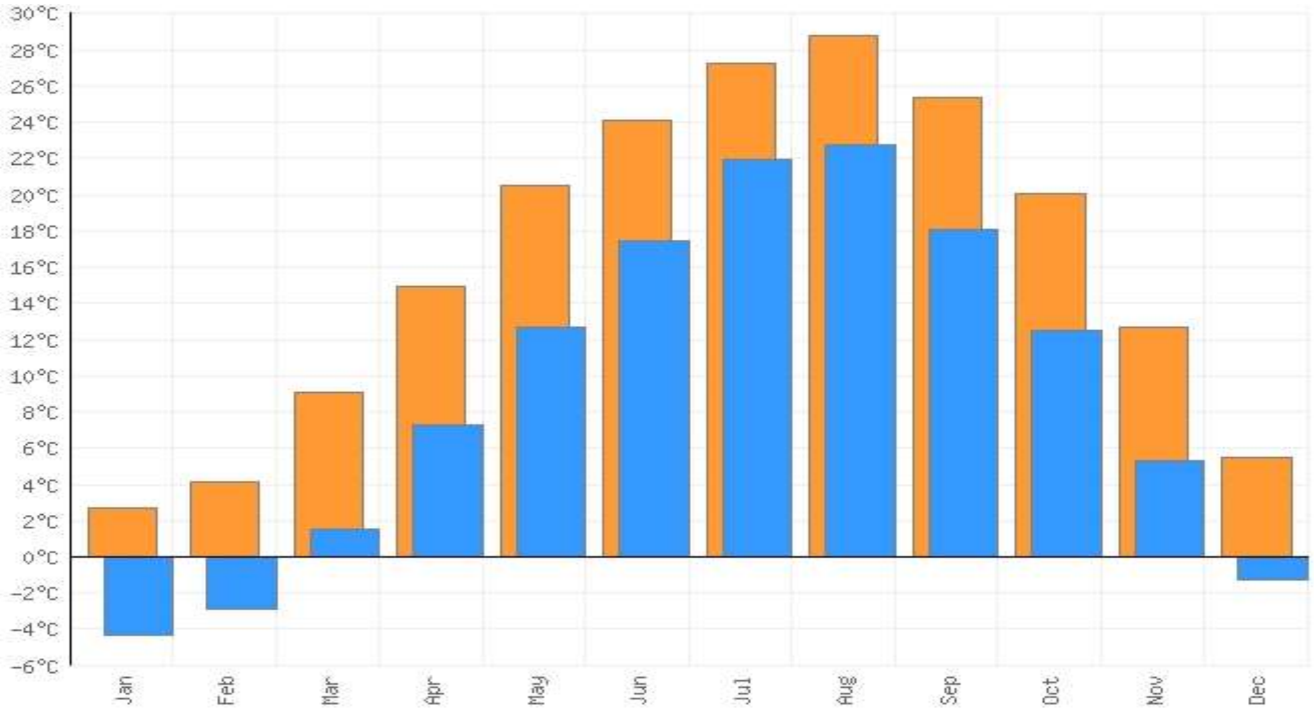
The warm season lasted 3.6 months, from June 10 to September 28, with daily average high temperatures exceeding 23°C. The hottest month of the year in Qingdao is August, with an average high temperature of 28.8°C and an average low temperature of 22.2°C. The cold season lasts for 3.2 months, from December 3 to March 9, with daily average high temperatures below 8°C. The coldest month of the year in Qingdao is January, with an average low temperature of -4.3°C and an average high temperature of 2.7°C (Figure 4-18).

According to the content of the research and the progress of the research paper, this field research is selected to be carried out in 2021-2022. According to the "Regulations on Heating Supply in Qingdao", the heating period in Qingdao is 141 days, and the heating period is from November 16 to April 5 of the following year. Combined with the climate characteristics of Qingdao, January 2022 is selected for heating of courtyard buildings. This time period is the most representative in reflecting the influence of climatic conditions in Qingdao on the heating energy consumption of courtyard buildings (Figure 4-19).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	2.5	3.9	8.9	14.8	20.3	24	27.1	28.7	25.2	19.9	12.5	5.3

Figure 4-18. The average monthly temperature in Qingdao



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min °C	-4.3	-2.9	1.5	7.3	12.7	17.5	22	22.8	18.1	12.5	5.4	-1.3
Max °C	2.7	4.1	9.1	15	20.5	24.2	27.3	28.8	25.4	20.1	12.7	5.5

Figure 4-19. The average max/min temperature in Qingdao

As mentioned before, there are 2 courtyards selected for the test, namely Case A (No. 84 Zhifu Road) and Case B(No. 89 Yizhou Road), both of which are well preserved, with similar conditions of use and repair techniques. Comparing the final test results, it is found that the two temperature trends are the same. As shown in the figure, this section selects one of them as an example to analyze the thermal environment test results of the courtyard (Figure 4-20).

The courtyard of Case A building is an enclosed building with a rectangular plan, a wall thickness of 370mm, a red tile sloping roof, and double layer insulating glass windows. Since few people use it now, there is no heating during the test, and the indoor doors and windows are tightly closed. A total of two measuring points is arranged indoors, two measuring points are arranged outdoors, and six measuring points are arranged in the enclosure structure.

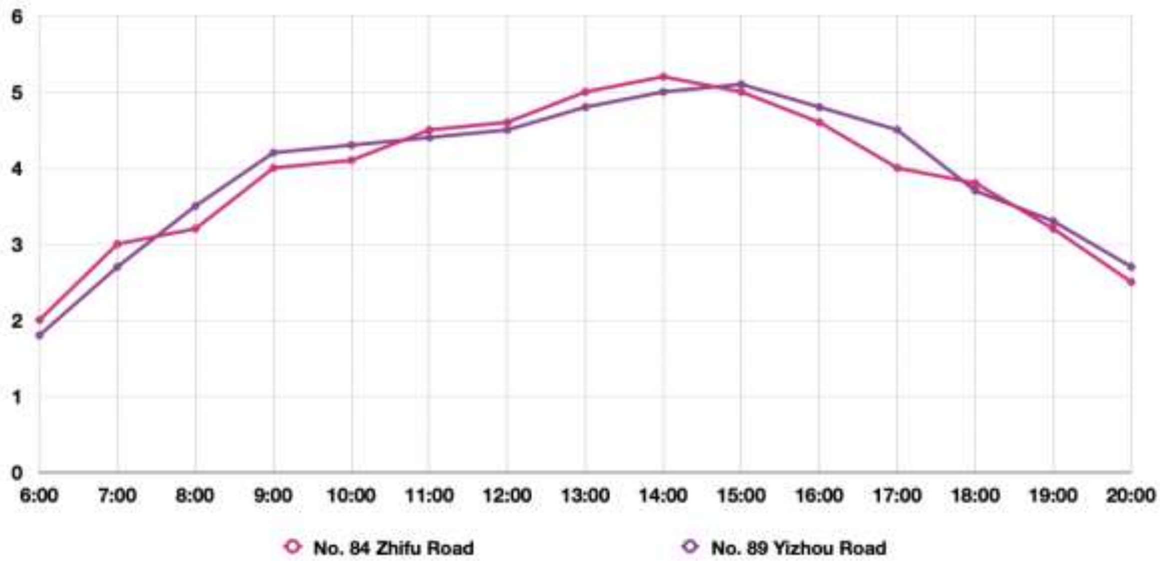


Figure 4-20. The comparison of indoor temperature change curves between two Liyuan courtyards

4.5.2 Air temperature analysis

It can be seen from the measured data that the temperature change curve of each measuring point of No. 84 Zhifu Road, in the case of no heating, the overall room temperature is lower than 5.5 ℃, the indoor temperature fluctuates due to the influence of the outdoor temperature, and the temperature at noon is higher, with cooler temperatures in the morning and evening. Since the doors and windows were closed during the test, the temperature fluctuations were not large, reflecting the good airtightness of the building. Comparing the temperature of the rooms on the first and second floors throughout the day, it can be seen that the indoor temperature of the rooms on the first floor is higher than that of the second floor, which is due to the fact that the rooms on the first floor have fewer windows and less heat loss. There are many windows on the second floor, and it is the top floor, which dissipates more heat through the windows and the roof.

The room temperature on the first floor was 5.2°C at the highest at 14:00, the lowest temperature was 2.5°C at 6:00, the average temperature throughout the day was 3.9°C, and the maximum temperature difference was 2.7°C; The highest temperature in the room on the second floor was 3.8°C at 13:00, the lowest temperature was 0.5 at 6:00, the average temperature throughout the day was 2.7°C, and the maximum temperature difference was 4.3°C. On the whole, the air tightness of the room is good, and the thermal stability of the rooms on the first and second floors is good. However, due to the insufficient thermal performance of the roof and the large window opening area on the second floor, the temperature of the rooms on the second floor is lower than that of the first floor (Figure 4-21).

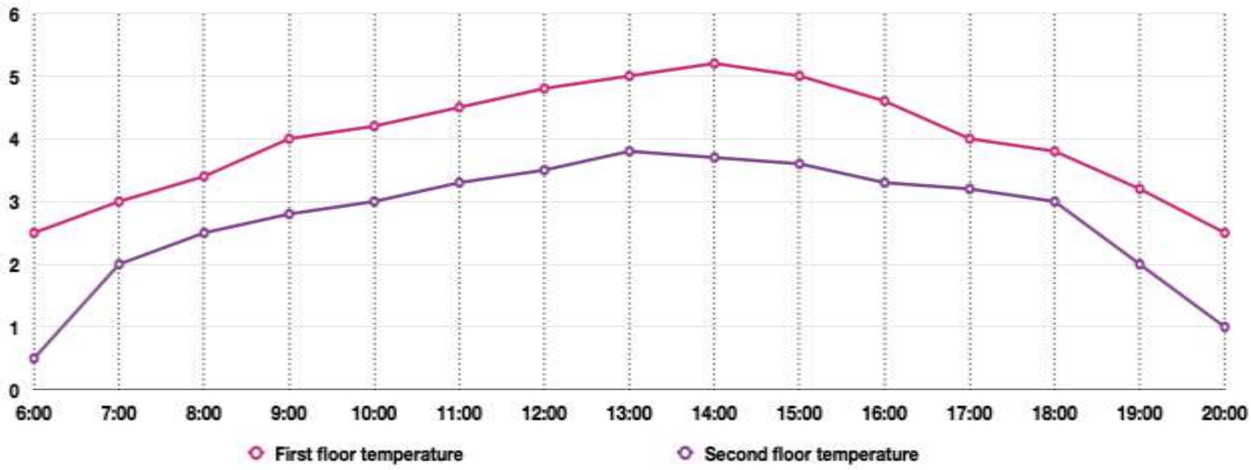


Figure 4-21. The temperature variation on two floors in Case A

4.5.3 Surface temperature analysis of envelope

When the surface temperature of the envelope is lower than the air temperature, the phenomenon of "cold radiation" - "radiation caused by cold walls to the body" will occur, which affects the indoor thermal environment and user comfort. In order to understand the difference between the surface temperature of the courtyard envelope and the indoor thermal environment, the surface temperature of the courtyard wall was tested.

Comparing the surface temperature of the outer wall, it can be seen that the wall with the highest average temperature is the south side wall, and the highest temperature appears at 13:00; The maximum temperature of the east outer wall appeared at 9:00, because the sun rose in the east and set in the west, and the east wall received more radiation in the morning, but the temperature was not very high; the maximum temperature of the west outer wall appeared at 15:00, because the measurement During this period, the wall is exposed to direct sunlight, so the surface temperature fluctuates violently. As the amount of solar radiation decreases, the temperature decreases. The exterior wall on the north side receives less solar radiation throughout the day, so the overall wall temperature is low, and the temperature fluctuation is small (Figure 4-22).

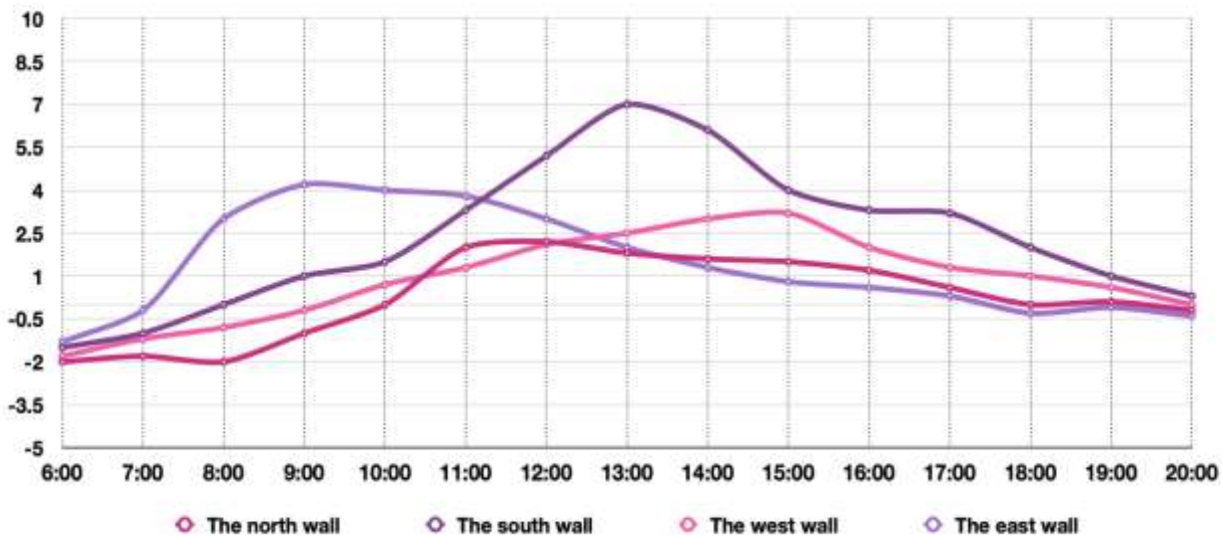


Figure 4-22. The temperature variation of outer walls in Case A

Comparing the surface temperature of the inner wall in all directions, it can be seen that the inner surface temperature of the south side wall is higher, because the outer surface of the south side wall absorbs more heat after receiving solar radiation, which affects the interior through the heat conduction of the wall material, thereby improving the internal temperature. However, due to the poor heat storage capacity of clay bricks, the inner surface temperature decreases after the solar radiation decreases, and the change is obvious; the inner wall temperature on the north side is less affected by solar radiation, and the air temperature is the most important factor. The temperature of the outer wall on the north side is low, the thermal insulation performance is poor, and the heat conduction effect makes the temperature of the inner wall lower (Figure 4-23).

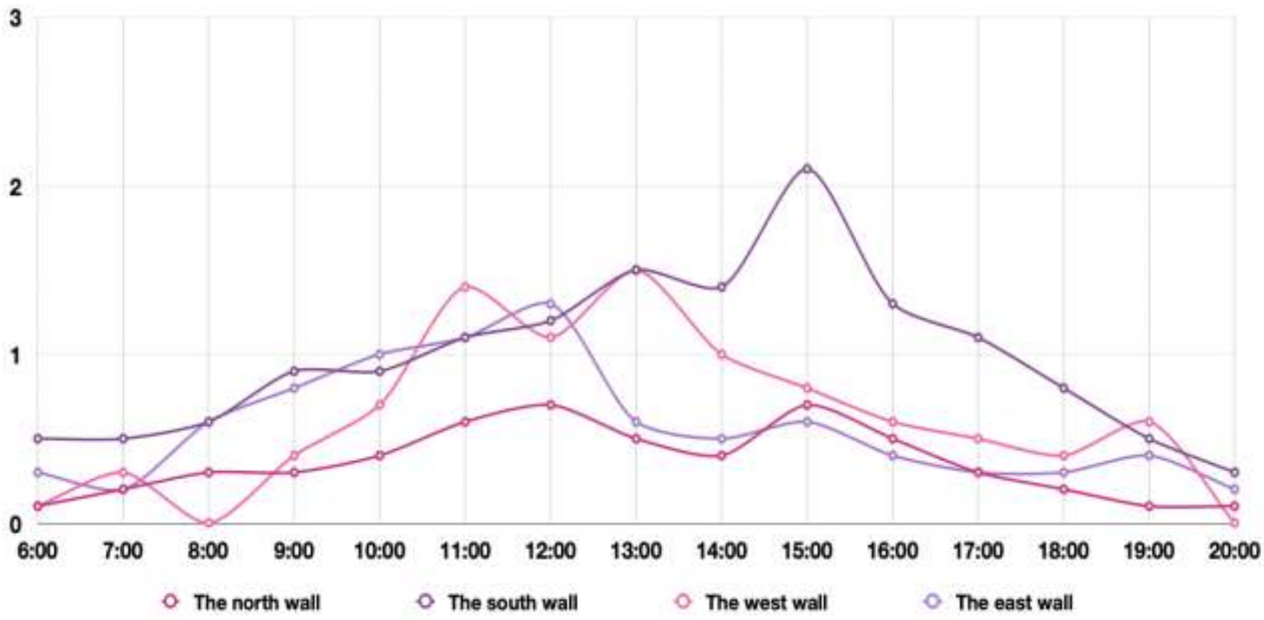


Figure 4-23. The temperature variation of inner walls in Case A

Based on the analysis of indoor and outdoor air temperature measurement and the surface temperature measurement data of the enclosure structure, it can be seen that due to the insufficient thermal performance, the wall is affected by the outdoor air temperature, so that the inner surface temperature of the courtyard wall is lower than the indoor air temperature, which has a certain impact on the indoor environment. Therefore, the thermal insulation performance of the wall should be improved to reduce the influence of the outdoor air temperature on the indoor temperature.

After the renovation of the courtyard building, the air tightness is improved, and the temperature change stability is good, but the overall room temperature is low and the comfort is poor; due to the insufficient thermal performance of the envelope structure, the inner surface temperature of the outer wall is lower than the indoor air temperature. Although solar radiation will affect the temperature, the duration is short and the effect is limited. Strengthening the thermal performance of the envelope structure can fundamentally solve the problem.

4.6 Summary

This chapter analyzes the historical development process and protection status of the courtyard buildings through literature review and field research and analyzes its existing problems.

1. After research, it is found that the building components of the courtyard are simple and the decorative elements are few, but the plane features are distinct, and the texture of the block combination is unique. It is a model of the combination of Chinese and Western architectural features and has protection value. The protection of the courtyard buildings is worrying, most of them are dilapidated and cannot meet the basic needs of use.

2. The early renovations focused on façade renovation and interior space regeneration. There were no other energy-saving measures other than replacing exterior windows and adding roof insulation for some buildings. Combined with the current situation of the courtyard enclosure structure and the repair project, the thermal performance of the courtyard enclosure structure is analyzed. The heat transfer coefficient is higher than the standard limit and needs to be optimized for energy saving.

3. Through the thermal environment test of the courtyard buildings that have been repaired, it is found that the air tightness of the courtyard after the repair is good, the indoor temperature changes smoothly, but the temperature is low and the comfort is poor, and due to the insufficient thermal performance of the envelope structure, As a result, the inner surface temperature of the outer wall is lower than the indoor air temperature, and attention should be paid to strengthening the thermal insulation performance of the envelope structure to fundamentally solve the problem.

Reference

1. Bonjour, S., et al., Solid fuel use for household cooking: country and regional estimates for 1980–2010. Environmental health perspectives, 2013. 121(7): p. 784-790.

2. Han, Y., et al., Influences of ambient air PM2. 5 concentration and meteorological condition on the indoor PM2. 5 concentrations in a residential apartment in Beijing using a new approach. Environmental Pollution, 2015. 205: p. 307-314.

3. Chen, Y., et al., Estimating household air pollution exposures and health impacts from space heating in rural China. Environment international, 2018. 119: p. 117-124.

4. Fan, G., et al., Indoor environmental conditions in urban and rural homes with older people during heating season: A case in cold region, China. Energy and Buildings, 2018. 167: p. 334-346.

5. Zhu, X., et al., Stacked use and transition trends of rural household energy in mainland China. Environmental science & technology, 2018. 53(1): p. 521-529.

6. Li, D. and F. Xu. Three forward leaps in Qingdao's urban development history: more discussion on the relationship between urban planning and urban development. in Urban Plan Forum. 2003.

7. LI, D. and Y. ZHOU, QINGDAO: ITS STATUS IN HISTORY AND IN THE EVOLUTION OF MODERN URBAN PLAN-NING [J]. City Planning Review, 2006. 4.

8. Zhang, M. and R. Rasiah, Qingdao. Cities, 2013. 31: p. 591-600.

9. Delin, L., Studies in modern Chinese architectural history. 2007: Tsinghua University Press.

10. Xu, F., The architectural heritage of modern China, Qingdao. 1992, Beijing : China architecture & building press.

11. Chunchi, Y., Qingdao Summary. 1922, The Commercial Press.

12. Dehan, S., Qingdao Culture Tour. 2012, ShangDong People's Publishing House.

13. Xu, F., The historical architecture in Qingdao (1891—1949). 2006, Qingdao: Qingdao Press.

14. Xi, C., The protection and reuse of Qingdao liyuan buildings. 2017, Suzhou Universtiy.

15. Warner, T., Deutsche Architektur in China: Architekturtransfer. 1994: Wiley-VCH.

16. Warner, T., Die Planung und Entwicklung der deutschen Stadtgründung Qingdao (Tsingtau) in China: Der Umgang mit dem Fremden. 1996: na.

17. Demgenski, P., Dabaodao: the planning, development, and transformation of a Chinese (German) neighbourhood. Planning Perspectives, 2019. 34(2): p. 311-333.

18. Demgenski, P., Living in the "Past": The Effects of a Growing Preservation Discourse in Contemporary Urban China, in China: A Historical Geography of the Urban. 2018, Springer. p. 225-249.

19. Shao, L. and H. Kanekiyo, Research into Liyuan Buildings, the Spatial Composition of Liyuan Blocks and Liyuan Residents' Lifestyles in Qingdao, China. Art and Design Review, 2013. 1(1): p. 6-9.

20. Liu, C., The Contemporary Development of Qingdao's Urban Space-The Perspective of Civil Society's Participation in Chinese Urban Planning. 2007.

21. Mingyou, W., Study for near mordern architecture protection and repair technology in Nanjing. 2017, Southeast University.

Appendix A

This appendix is an extra record containing details of interviews of different respondents

Respondent A（Age: 40；Profession: Painter (freelancer living on painting；Duration of residence: Since his birth)

Q: As you know, when was this courtyard built?

A: It was not authorized with a real estate certificate until the 1980s; I think it was completed around 1961 or 1962 (The later verification it was actually completed in 1940).

Q: What did this place used for when it was built as you know?

A: It was used as an iron blacksmith store. There was a manager room on the west side of the second floor, which was also called the accounting room at that time. The rooms on both sides were originally opened up as larger rooms for factory production. Then partitions walls made of grass and lime were added by next owners, which were very unreliable to be punched through by fists. It was then changed to be an iron plant, together with other surrounding workshops, which was recognized as the predecessor of "Qing gang" Iron factory. It was the most glorious time for this courtyard. During war time, bomb shelters were built in order to survive from air strike. Later on, it was changed as an Asian-American firm selling skin care products, and also a workshop producing thread rolls.

Q: Was there any repair occurred?

A: In the 1980s, there was some protection and renovation operation funded by the local government. The original wooden handrails and stairs were changed to stone ones during that procedure. The pillars used to be made of iron and wood was replaced by ordinary wood materials and sold for cash. There was also another renovation for the tiles, but it was only spray painting on and brought a lot of damage. It looked like new ones from outside, but the leakage of rainwater was even worse than before. During that time, the residents built their own tiles and added handrails of stairs with cement.

Respondent B (Age: 74; Profession：Engineer; Duration of residence: 50 years)

Q: How many years have you been lived in here? Why do you still live here?

A: I have already living here for 50 years; it was really bad experience to live here now. The space is too small, and the facilities are very poor, but it is not allowed by the economic ability to move out.

Q: How much is the area of your single-family?

A: They are normally 14-15 m^2 (maximum 20 m^2) for 2 to 3 people live in.

Q: How is the relationship between neighborhoods? Is there any security problem?

A: There are seldom group activities except for greetings when meet each other. The main gate to the entrance is basically unlocked, but the doors to the single households are all locked.

Q: How do you think the public facilities within the courtyard?

A: There are serious problem in the public facilities. Especially for sanitary and water use, all the neighborhoods share one public toilet on each floor, and only one water supply room available for daily use for all these two-stories buildings courtyard. Therefore, the fire protection is the top concerned issues, because it will be very hard to control if there is a fire disaster occurs.

Q: If the government would either demolish this place and refund with money or improve the infrastructure here to live on, which one will you prefer?

A: I would choose to accept the compensation with refund and move to a high elevated building for its inconvenience. But I wouldn't mind experiencing the life in the renovated courtyard.

Respondent C: Uncle Li

"Qingdao is located in the Jiaodong Peninsula, surrounded by blue sea and beautiful sky, the city looks fantastic with red tiles and green trees. As the symbol of the city, the Liyuan Courtyard with its red tile roofs stand for the unique residential style of the old time for the city. The early residents from migration, the characteristics of Chinese and foreign cohabitation, and the strong sense of excellence in business culture, mixing into a unique living pattern here..." Introduced by the respondent C

.

He continued: "This courtyard was originally a public bathhouse built by two capitalists. The terrace here was supposed to occupy the top floor, but it was then stopped due to insufficient funds. You can see there are different parts of floors made of wood and concrete, this is because the building was built as a bathhouse at that time. This wall over here is part of retrofit from a larger room, which was not a residential area. The rooms inside the house were intertwined. It turns out the typical old style of bathhouse, where you can get through it when you finished bathing here."

"There were all bathing pools from the first to the third floors on the western wing of the whole building. This was (at that time) the largest bathing house in Qingdao, and also the most formal one. It was fashion and advanced in that era, with baths, steaming well, soak, and massage services etc., while the other bathhouses are just simple ones. You can take a bath spending only five cents RMB. There is a story from elder generations, this bathroom ended from some artificial rumors. The story was about someone passed away when he was bathing here, nothing was found after his death but only hairs and clothes left. When this news spreads out, nobody never ever dares to come any more. This is why I said one rumor killed this bathhouse."

Respondent D: An old man

Q: Uncle, we saw there were some pillars with dragon patterns curved on the corridor, but some of them have gone, what happened to them?

A: It's probably due to wind and rain for a long time. With time flies, some of the decoration get loosen. There used to be someone came to repair it, however, who can keep that craft right now? Who will do it for you ...?

Q: Um, okay ... if so, what effect was the original wood between the dragon pattern and the pillars?

A: Just for beauty!

Q: Well, uncle, I can also see there is an additional layer only on the western top of the roof, but the other three sides are all sloped roofs. What was going on?

A: That place was originally a platform. This building was previously a three floors structure. This small additional house on this side was built by one habitant, while the other platforms are left as it used to be. People can get on it for personal purposes. When I was a kid, I usually play with friends on the top of it.

Respondent E: An old man

Q: This door looks very old, is it original as old as the courtyard?

A: Yes, they are all original ones. How good they are even now! They are all made of red lauan. The same of these walls, how strong they are! It seldom to see such strong walls anymore right now. If all these buildings will not be demolished...and cleaned up by government arrangement… it will regain the brightness again. Those structures are the coal reservoirs for the habitants within the courtyard, because we still burn coals for heating demand. If there were no such things installed, the corridors would have been very clear and spacious!

Q: We could also see many households have such hanging layers added?

A: Yes, it is kind of loft structure. There were normally seven or eight people in a family here, and the small children can sleep in it. Look at the small houses on that floor (Pointing at the expanded shed of 4 to 5 m^2), it was big enough for two or three young children to sleep inside.

Q: Well, it sounds a hard life at that time. I saw the wall skins have fallen off the roofs, is it made of wood?

A: Yes. In the past, all these old-style houses similar to Liyuan courtyard were made of wood. This is called gray beams with cement sloppy. The roofs are all supported by this kind of beams. These gray beams are laid out one by one. When they are nailed (by the tie-beam fixing), the beams will be plastered, and the hemp gray will be dressed on.

Q: Is it tightened by such kind of hemp rope?

A: Yes, hemp rope plastered, they can pull each other inside for support.

Q: Is that mean there is a horizontal and vertical boards layout at bottom, then another layer of hemp plaster on its top?

A: More or less, or, they are wrapped inside, the gray beams are wrapped within the boards.

Appendix B

This appendix is an extra table list containing details on reuse of existing old buildings in this area with new purpose.

No.	NAME	ADDRESS	BUILT	NEW FUNCTION
1.	Liu curtilage Old Site	Zhejiang Road No. 26	1897-1914	Void
2.	The Synod of the Svantocratic	Crossing of Qufu Road and Zhejiang Road	1899-1902	Shandong Academy
3.	St. Miel Catholic Church	Zhejiang Road No. 15	1932-1934	Church
4.	Qingdao International Club Old Site	Zhongshan Road No.1	1910-1911	Qingdao Science & Technology association
5.	Holy Heart Monastery	Zhejiang Road No.81	1901-1902	Shandong Academy of Sciences Ocean equipment
6.	Navy Hotel Old Site	Hubei Road No.17	1901 -1902	Apollo Temple Photography Company
7.	German Style Architecture	Zhongshan Road No.17	1897	Residential House
8.	German Police Department old Site	Hubei Road No.29	1904	Office Building for Qingdao Municipal Public Security Bureau
9.	Electric Affairs of Jiao-ao Commercial Port Old Site	Zhongshan Road No. 216	1909	Qingdao Electricity Power Supply Company
10.	Puji Hospital Old Site	Jiaozhou Road No. 1	1919	The Expert Office Building of Qingdao Municipal Hospital
11.	Shandong drama Old Site	Zhongshan Road No.97	1930	China Cinema
12.	Yijuhe Bank Old Site	Zhongshan Road No.82	1930s	China CITIC Bank Qingdao branch
13.	BC Qingdao Branch Old Site	Zhongshan Road No.93	1931	CCB Qingdao Shinan District Branch
14.	Shanzuo Bank Old Site	Zhongshan Road No. 64	1934	BOC, Qingdao Shinan district branch
15.	BOC Qingdao Branch Old Site	Zhongshan road No.62	1934	Office building ICBC district branch
16.	The Shanghai Commercial & Savings Bank Old Site	Zhongshan Road No.68	1934	BOC, Qingdao Shinan district branch
17.	The Continental Bank Old Site	Zhongshan Road No.70	1934	McDonald's Store
18.	ICBC Old Site	Henan Road No.13	1934	BOC Henan road

19.	Qingdao Bank Association Old Site	Henan Road No.15	1934	Provincial garment Company
20.	Golden City Bank Old Site	Henan Road No.17	1935	BQD Henan Road Branch

Note: The selection criteria of excellent heritage buildings in this form are the historical excellent buildings on Zhongshan Road and the ones within 200 meters from Zhongshan Road according to the author's field survey

* ICBC= Industrial and Commercial Bank of China; BQD= Bank of Qingdao; CCB=China Construction Bank;
BOC=Bank of China ; BC=Bank of Communications; CITIC =China CITIC Bank.

Chapter 5.

Thermal Performance enhancement of building envelopes by using Corncob

5.1. Introduction

With the exploration and extension of sustainable strategy attempted in China, the economic and agricultural development level has been improved continuously. However, in the process of fast growth, the balance between human activities and natural system has been broken; thus, the pressure on the ecological environment has gradually increased. In order to fix the balance between economic growth and environmental protection, the guiding policy of "concept of Eco civilization" has gradually gained popularity. Up to now, China has gained certain achievement in the Eco civilization construction. However, it is still confronting high pressure on the ecological environment.

Agriculture, as the primary industry in China, is significant to the development of the integral national economy. Since 2017, the Green production policy has promoted clean production in agriculture and focused on the management of outstanding agricultural environment problems. In 2018, it was proposed to lead rural revitalization with the concept of green development. In 2019, the policy of high-quality development in agriculture promoted the improvement of rural human settlements comprehensively. In 2020, steadily improve the rural living environment was taken as one of the national development goals.

As an opportunity of further optimization, taking advantage scientifically of the agricultural by-products, which has the features of abundant yield and flexible collection, and making use efficiently of biomass resources, can reduce the pollution to the living environment and promote the adaptation process of the living environment significantly. It could eventually achieve coordinated development of life, production and ecology

On the other hand, with the high speed in development of China's construction industry, the production of construction waste is also increasing. From preliminary statistics, the total amount of construction waste in China is about 2.1 billion to 2.8 billion tons, and the number is still increasing. The treatment of construction waste has become the major problem, which required reasonable solution urgently. With the continuous reduction of natural resources, it is especially important to improve the recycling efficiency of resources. In the outline of the 12th Five Year Plan for China's national economic and social development, it has been clearly proposed that "to accelerate the construction of a resource-saving production mode, to establish the concept of green development, and to realize improvement in Eco civilization."

5.2. The research background of the material

Construction waste comes from the demolished architecture and it should provide positive benefit to it. The use of construction waste as new building material has gained more attention recently. With the acceleration of urbanization, demolition and reconstruction projects generated a large amount of construction waste, which also accelerate the shortage of new construction resources. How to make full and efficient use of construction waste, especially the trials on making recycling concrete from waste, has become a concerned topic in many countries.

The limited natural resources cannot satisfy the fast development in the construction industry gradually. The recycling concrete from construction waste can reduce the consumption of natural resources significantly. The recycling aggregate is an effective utilization of construction waste, which is economical and environmentally friendly as positive solution to the environmental problem. Under the trend of energy saving and environmental protection, the use of recycling aggregate applied in recycling concrete has become the research concerns in architecture.

The comprehensive utilization of agricultural and construction waste is one of the most economical, ecological and effective methods. The co-processing of agricultural and construction waste can turn these recycling resources into valuable treasures, effectively alleviate the shortage of resources and energy, which can reduce the pollution of solid waste to the environment, but also achieve collective long-term development in environmental, economic and social benefits.

The Agricultural waste is an abundant renewable construction material source, which has no value without scientific treatment with technical methods. It has gradually become one of the potential pollutions to the rural environment. In order to effectively alleviate this severe situation, it is necessary to rationally plan agricultural waste resources, appropriately improve the comprehensive utilization rate of agricultural waste as the recycling and regeneration of waste resources, so as to turn agricultural waste into "treasure"[1, 2]. As an important recycling resource, corncob has not been used in high value in the process of agricultural development yet. It is usually disposed of by means of rural combustion for heating, animal husbandry and re-cultivation, which provide only pollution to the ecological environment together with a waste of natural resources [3, 4].

However, corncob has a uniform texture, light weight, certain strength, and good thermal performance as insulation. It is a precious secondary resource and requires further development and utilization urgently.

In the process of renovation construction in China, the envelope of residential enclosures requires a large amount of energy-saving, environmentally friendly and low-cost insulation materials. Corncob is one renewable resource solution, which is convenient to obtain, energy-saving and environmentally friendly. By using corncob as concrete aggregate, the building cost could be reduced greatly. Corncob has high value as a building material, but it has not been widely used at home and abroad. Whether it can be used as an environmentally friendly building material in the construction industry still needs to be certificated in many aspects. Therefore, the application of corncob as a building material will have great potential and significant economic and social benefits possibilities.

Therefore, this chapter makes experiment on fully utilization of the features of corncob, such as light weight, heat preservation and crack resistance, etc. At the same time, it co-disposes all-component recycling sand prepared from construction waste, and jointly prepares corncob-recycled aggregate composite ecological concrete, which develops a new technical solution of green ecological building concrete materials. It provided a solution to expand the high-end utilization of agricultural and recycling construction waste products. The research conclusion of this chapter will promote the coordinated development of rural economy and society, change the mode of rural economic development, and conform to the basic national policy of environmental protection and sustainable development in my country, and conform to the green ecological concept of harmonious coexistence between man and nature.

5.3. Description of corncob

5.3.1. Composition of materials

1) Coarse aggregate

In the experimental process of the research on the performance of corncob-recycled aggregate composite ecological concrete, the selected coarse aggregate is corncob in agricultural waste. When selecting raw materials, based on the principle of local materials, the corncob used in the experiment was provided by growers near Chengyang District, Qingdao. Considering that the corncob bone brings more impurities to the corncob during the mechanical threshing process, the corn leaves, corn silk, residual corn kernels and other magazines other than the corncob should be manually sorted and removed before the crushing treatment. The appearance and morphology of corncob before and after selection are shown in Figure 5-1(a) and Figure 5-1(b) respectively. It can be seen that many impurities attached to the surface of the corncob have been basically removed after the manual sorting treatment, which meets the requirements of the test before crushing.

In the test, the agricultural pulverizer (Figure 5-2) was used for crushing treatment on the raw material of corncob after the manual sorting. In the process of corncob crushing, the diameter of the screen inside the agricultural pulverizer has a great impact on the particle size of the formed corncob particles, so it needs to be screened after the crushing process. Considering the particularity of corncob and its use as a coarse aggregate for the preparation of ecological concrete, the crushed corncob particles were sieved through square-hole sieves with side lengths of 19mm, 9mm and 4.75mm in turn. The net is shown in Figure 5-3.

After sieving, corncob particles with different particle sizes were obtained, and their appearance and morphology were shown in Figure 5-4(a) and Figure 5-4(b), respectively. According to the different particle size range of corncob particles, in the experiment, the particle size range of 4.75mm-9mm is set as the small-diameter corncob particle, and the particle diameter of 9mm-19mm is set as the large-diameter corncob particle. According to the test needs and bulk density requirements, the mixing ratio of small-sized corncob particles and large-sized corncob particles is determined to be 1:1.5, and the mixed corncob particles are used for preparing corncob-recycled aggregate composite ecological concrete of coarse aggregate.

(a) Appearance before sorting (b) Appearance after sorting

Figure 5-1. The appearance and morphology of corncob

Figure 5-2. The appearance of agricultural crusher

Figure 5-3. The standard square hole sieve

(a)4.75mm-9mm (b) 9mm-19mm

Figure 5-4. The corncob particles with different particle size ranges

2) Fine aggregate

When the service life of some buildings is too long, the performance of recycled coarse aggregate is weakened, and the dismantled construction waste is no longer suitable for use as coarse aggregate for recycling; or the building itself cannot continue to build due to the quality of coarse aggregate. When the construction waste is completely crushed into fine aggregate due to construction requirements, the construction waste can be completely crushed into fine aggregate, which is called full-component recycled sand, which is the fine aggregate used in the test.

In the preparation process, the preparation process of full-component reclaimed sand can be subdivided into full-component simple crushing reclaimed sand and full-component particle shaping reclaimed sand. The main feature of the whole-component particle shaping reclaimed sand preparation process is that all the waste concrete blocks are used to prepare the reclaimed sand. That is, during the initial simple crushing, the natural coarse aggregate in the original waste concrete is no longer used to prepare the recycled coarse aggregate, but is all crushed into recycled sand. increase accordingly. However, the performance of full-component particle shaping regenerated sand is better than that of full-component simple crushing regenerated sand, and the economic cost increases less. Therefore, in the experiment, the regenerated sand with full-component particle shaping was finally selected as the fine aggregate for preparing corncob-recycled aggregate ecological concrete.

5.3.2. Preparation Methods of Aggregate

Coarse aggregate corncob is obtained by sorting, crushing and screening of corncob bones, and the waste concrete is crushed and reshaped to obtain full-component regenerated sand, which is used as the fine aggregate for this test; The water consumption, the two together constitute the water consumption of the concrete test, and the mixing ratio plan is designed with the mortar ratio and the volume content of the corncob as the influencing factors.

By exploring the relationship between the mass and volume of the corncob, the actual mixing quality of the corncob was determined; the basic performance (dry density and Thermal conductivity) and mechanical properties (cube compressive strength under different curing age conditions), and systematically explore the change law of its performance by analyzing the measured test results.

Based on the experimental research, using the method of combining data analysis and theoretical analysis, the co-processing of agricultural waste and construction waste is used to prepare corncob-recycled aggregate composite ecological concrete with significant environmental protection effect. The performance provides a certain theoretical basis for the later application and promotion of agricultural engineering.

The specific preparation process of the full-component particle shaping regenerated sand is as follows: firstly, the waste concrete blocks are simply crushed into 6-7mm particles by a jaw or hammer crusher, and then they are shaped by a particle shaping machine. Sand is called full-component particle shaping regenerated sand. Because the waste concrete contains about 50% of natural coarse aggregate, the full-component particle shaping reclaimed sand contains a large amount of reclaimed sand generated from natural coarse aggregate, which can effectively improve the firmness of the reclaimed sand. According to the relevant requirements in GB/T25176-2010 "Recycled Fine Aggregates for Concrete and Mortar", the main performance indicators of the regenerated sand with full-component particle shaping are tested.

1) Particle gradation

Comparing the regenerated sand with full-component particle shaping and natural sand prepared in the test, the particle gradation and fineness modulus are shown in Table 5-1. It can be seen that the regenerated sand used has a good gradation and is medium sand in Zone II.

Table 5-1. Comparison of particle gradation between full-component particle-shaping regenerated sand and natural sand

The types of sand		Full-component particle-shaping regenerated sand	Natural sand
Mesh size (mm)	4.75	0.3	0.0
	2.36	10.3	4.8
	1.18	27.0	14.8
	0.06	48.1	32.0
	0.03	70.4	69.7
	0.15	86.2	97.8
	Weight of screen residue	100	100
	Fineness modulus	2.4	2.2

2) Mud content (Micro powder content)

Generally, reclaimed sand is generated by crushing natural stones. The particles with a particle size of less than 75 μm in the sand are stone powder, while the particles with a particle size of less than 75 μm in the test concrete regenerated sand are mainly composed of cement stone powder, stone powder and soil. Therefore, the concrete is recycled. The content of particles with a particle size of less than 75 μm in the sand is defined as the content of fine powder. Table 5-2 shows the comparison of the mud content (micro powder content) between the regenerated sand with full-component particle shaping and the natural sand. It can be seen that the micro powder content of the full-component particle-shaping regenerated sand is higher than that of the natural sand, which is mainly related to the fact that the full-component particle-shaping regenerated sand contains a large amount of cement stone powder.

Table 5-2. Comparison of mud content/fine powder content between full-component particle-shaping regenerated sand and natural sand

The types of sand	Full-component particle-shaping regenerated sand	Natural sand
Mud content/ Micro powder content (%)	4.00	0.95

(3) Mud content

The mud content of the reclaimed sand can be understood as the cement stone chips attached to the surface of the reclaimed sand, washed with water, and scattered by hand. The specific test results are shown in Table 5-3. The test results show that the full-component particle shaped regenerated sand is relatively completely broken during the preparation process, and most of the cement stone chips attached to the natural sand or coarse aggregate in the original waste concrete are ground away and exist in the form of micro powder in the whole group. The regenerated sand is shaped into particles so that the mud content is close to that of natural sand.

Table 5-3. Comparison of mud lump content between full-component particle-shaping regenerated sand and natural sand

The types of sand	Full-component particle-shaping regenerated sand	Natural sand
Mud content (%)	2.2	1.4

(4) Solidity

In this test, the single-stage maximum crushing index is used to test the firmness of the reclaimed concrete. The larger the single-stage maximum crushing index is, the lower the firmness is. The specific test results are shown in Table 5-4. The results show that the full-component particle shaping reduces the single-stage maximum crushing index of the reclaimed sand to 14.0%, which is only 1.2% higher than that of the natural sand.

Table 5-4. Comparison of firmness of regenerated sand with full-component particle shaping and natural sand

The types of sand	Full-component particle-shaping regenerated sand	Natural sand
Solidity (%)	14.0	12.8

(5) Density

The density of sand includes bulk density, compact density, apparent density and porosity. The specific test results are shown in Table 5-5. The results show that the bulk density, compact density and apparent density of the regenerated sand with full-component particle shaping are on average 40kg/m^3 lower than those of the natural river sand and are close to the natural sand in terms of density performance.

Table 5-5. Comparison of density and porosity between full-component particle-shaping regenerated sand and natural sand

The types of sand	Full-component particle-shaping regenerated sand	Natural sand
Bulk density(kg/m^3)	1382	1454
Compact density(kg/ m^3)	1587	1555
Apparent density(kg/ m^3)	2518	2597
Porosity	37	40

(6) Water demand ratio and strength ratio of reclaimed rubber sand

In the test, reclaimed sand and standard sand were used to prepare reclaimed sand and standard sand that meet the fluidity requirements, respectively. The water demand ratio of reclaimed sand and the strength ratio of reclaimed sand measured in the experiment are shown in Table 5-6. The situation is shown in Fig. 5-5(a), Fig. 5-5(b) and Fig. 5-5(c) respectively.

Table 5-6.The water requirement ratio and strength ratio of full-component particle shaping regenerated sand

The types of sand	The water demand ratio	Strength ratio
Full-component particle-shaping regenerated sand	1.27	0.87

(a) Preparation of reclaimed mortar

(b) Measurement of fluidity of reclaimed mortar (c) Molding of reclaimed mortar

Figure 5-5. The test situation of reclaimed mortar

(7) Cementitious materials

The fast-hardening sulfoaluminate cement SAC42.5 is selected. The aliphatic super plasticizer produced by a building material company in Qingdao is used. Using ordinary tap water, in line with JGJ63-2006

5.3.3. Preparation methods of composite ecological concrete with corncob-recycled

In the test, a horizontal mixer was used to prepare a corncob-recycled aggregate composite ecological concrete mixture, as shown in Figure 5-6. The specific feeding sequence is:

(1) Add reclaimed sand and cement and mix well.

(2) Add water and water reducing agent for stirring, and the stirring time is controlled within the range of 10-15s.

(3) Add the mixed corncob particles, and after stirring for 2-3min, put the concrete mixture into the test mold.

(4) Use a vibrating table to vibrate, compact and smooth.

Figure 5-6.The concrete horizontal mixer

Because the corncob is light in texture, it will float up during the vibration process, so the vibration time should not be too long, and it is appropriate to control it within 3-5s in the test. In addition, after the ecological concrete is installed, in order to prevent its moisture from evaporating, it should be immediately covered with plastic wrap to lock the moisture, and marked for easy identification, as shown in Figure 5-7.

Figure 5-7. The concrete with formwork maintenance

5.4. Experiment for Basic Performance Properties

5.4.1. Experimental Mixing Proportion Design

(1) Determination of Corncob Quality

Add 50g, 60g, 70g, 80g, 90g, and 100g of mixed corncob particles to the standard mortar test (mortar ratio 1:3, water-binder ratio 0.5), stir evenly, and put them into a regular container, and then observe the change in the height of the mortar surface.

With the change in the number of mixed corncob particles, by actually measuring the height of the freshly mixed mortar in the regular container, the linear relationship between the mass and volume of the corncob is obtained. Based on the linear relationship of corncob mass-volume, the ratio of corncob to the total volume can be calculated, and then the ratio of corncob to cementitious material can be determined according to the different volume contents of corncob set in the experiment (defined as cob glue ratio), and finally, the quality of corncob used for preparing corncob-recycled aggregate composite ecological concrete can be calculated.

(2) Determination of test water consumption

The water consumption of the test should consider the water consumption of the mortar and the water consumption of the corncob, that is, the total water consumption = the water consumption of the mortar + the water consumption of the corncob.

(3) Determination of water consumption for mortar

In order to ensure that the concrete mixture has good working performance, the fluidity of the mortar is controlled to be 175-180mm, and the amount of aliphatic water reducing agent is 2% of the amount of the cementitious material. The results are shown in Table 5-7.

Table 5-7. Determination of water consumption for mortar

Cement sand ratio	Cement (kg/ m^3)	Sand (kg/ m^3)	Water-reducing admixture(kg/ m^3)	The amount of water (L)	Water to binder ratio
1:3	400	1200	8	174	0.434
1:3.5	400	1400	8	207	0.517
1:4	400	1600	8	227	0.567

(4) Determination of corncob water consumption

Due to the different harvesting time and storage environment of corncob, the water content of corncob itself is quite different. The water absorption test of corncob used in this experiment should be carried out in advance. During the test, take a certain mass of dry-weight mixed corncob particles and soak them in water, and measure the quality of the corncob at intervals of 10 minutes until the weight no longer increases, and record the quality of the corncob at this time. The water absorption rate of corncob is calculated according to formula (5.1):

$$\omega = \frac{M1-M}{M} * 100\% \tag{5.1}$$

in here：

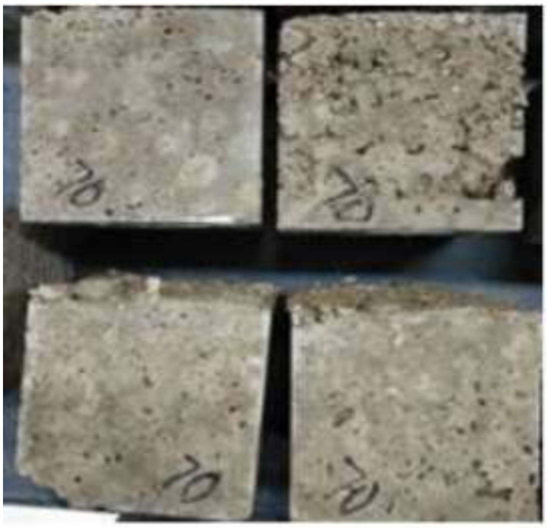
ω ——Corncob water absorption/%；

M1——The quality of corncob after water saturation/g

M ——The mass of corncob in dry weight state/g;

After calculation, the arithmetic mean of the three test results was taken as the water absorption rate of the corncob used in this test. Finally, the water absorption rate of the test corncob was measured to be 120%.

The porous organic fiber structure of corncob makes it highly absorbent, and too much moisture will not only reduce the strength of concrete, but also easily cause the concrete to crack later. In this experiment, fast-hardening sulfoaluminate cement was selected, which has a fast-setting speed, and the corncob takes a short time to absorb free water in the mixture, and it cannot reach water saturation in a short time, resulting in concrete bleeding. Taking the cement-sand ratio of 1:3 and the corncob volume content of 40% as an example, the experiment was carried out. First, the actual water consumption of the corncob was controlled to be 70%, 80%, 90% and 100% of the water absorption of the corncob, and the corncob was prepared in turn. The core-recycled aggregate composite ecological concrete cube compressive test block is used to optimize the optimal water demand of corncob by compressive strength. The test situation and results are shown in Figure 5-8 and Figure 5-9 respectively.



(a) 70%

(b) 80%

(c) 90%

(d) 100%

Figure 5-8. The concrete specimens prepared with different actual water consumption of corncob (a. 70%; b. 80%; c. 90%; d. 100%)

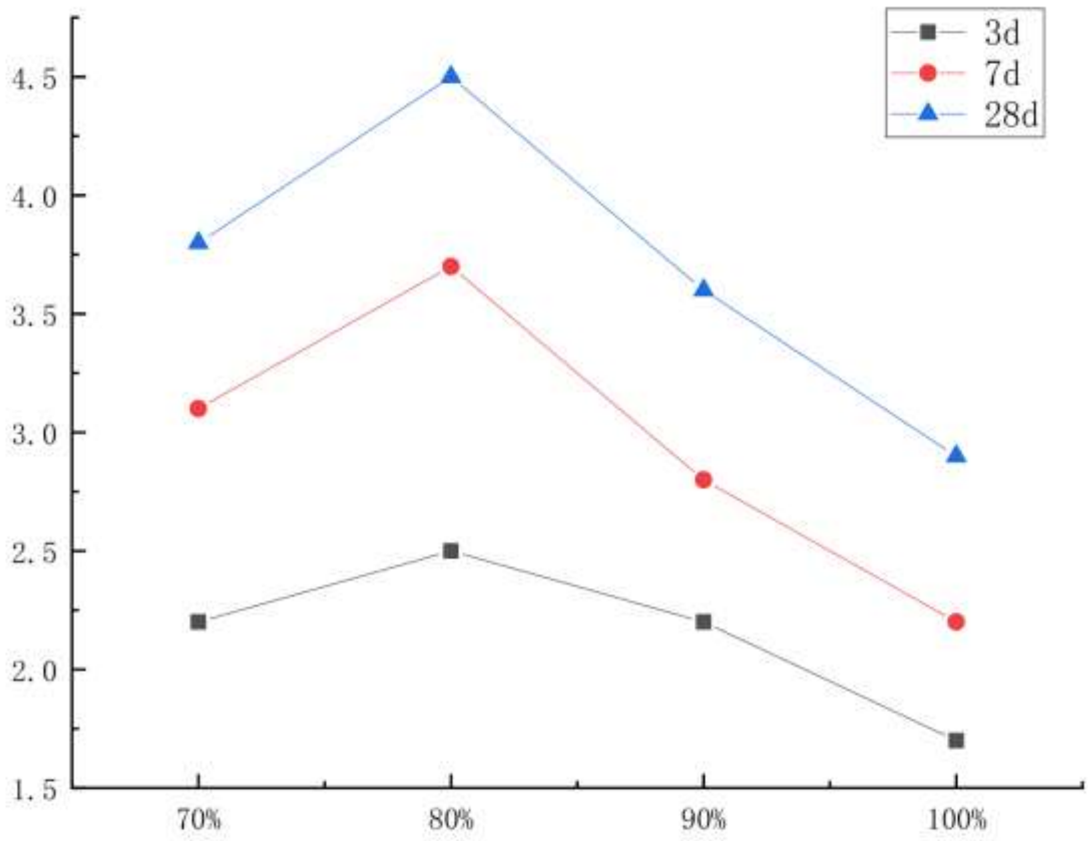


Figure 5-9. The compressive strength of concrete under different water consumption of corncob

5.4.2. Thermal conductivity change

In the test, the influence of two variable factors on the performance of corncob-recycled aggregate composite ecological concrete was mainly considered. The specific changes are as follows:

(1) Mortar ratio: take 1:3, 1:3.5 and 1:4 respectively.

(2) Corncob volume content: take 30%, 35%, 40%, 45% and 50% respectively.

Yang Xiufei[5] et al.conducted a repeatable experiment on thermal conductivity of 6 biomass materials in rural areas, including daylily stalk, sawdust, rice straw, rice husk, peanut husk and corn stalk. The thermal conductivity of biomass materials is between 0.0504W/(m·K) ~0.0790W/(m·K), and the thermal insulation is good, which provides a feasibility and theoretical basis for biomass materials as thermal insulation building materials. Generally speaking, the thermal insulation properties of materials mainly depend on the thermal resistance. The lower the thermal conductivity of building materials, the better the thermal insulation effect, and the thermal conductivity of different biomass materials varies. Corncob is a biomass resource with low thermal conductivity. As a building material, it can improve the thermal insulation performance of ecological concrete. The test results of thermal conductivity of corncob-recycled aggregate ecological concrete are shown in Table 5-8.

Table 5-8. The results of thermal conductivity test of corncob-recycled aggregate composite ecological concrete

Mortar ratio	Water reducing agent/kg/m^3	Corncob volume content/%	Water consumption/L	Coefficient of thermal conductivity W/(m·k)
1：3	6.4	30	210.9	0.2479
1：3	6.0	35	208.5	0.2392
1：3	5.6	40	205.5	0.2289
1：3	5.2	45	200.2	0.2177
1：3	4.8	50	193.5	0.2011
1：3.5	5.8	30	222.3	0.2421
1：3.5	5.4	35	215.6	0.2323
1：3.5	5.0	40	207.6	0.2184
1：3.5	4.6	45	198.4	0.2131
1：3.5	4.5	50	199.5	0.1857
1：4	5.2	30	220.7	0.2403
1：4	4.8	35	214.4	0.2151
1：4	4.6	40	215.6	0.2120
1：4	4.5	45	218.5	0.2109
1：4	4.3	50	218.3	0.1803

5.4.2.1. Influence of corncob volume content on thermal conductivity of ecological concrete

Corn stalks and corncob are by-products of the same plant. At present, the use of corn stalks as thermal insulation building materials has been studied, but corncob has not been widely used. In engineering, materials with thermal conductivity less than 0.23 W/(m·K) are called thermal insulation materials. The thermal conductivity of corncob is less than 0.23 W/(m·K), so it can be used in buildings to reduce the thermal conductivity of concrete, thereby improving Thermal insulation properties of concrete. Therefore, in this experiment, the influence law of the thermal conductivity of corncob-recycled aggregate ecological concrete was studied, and the results are shown in Figure 5-10.

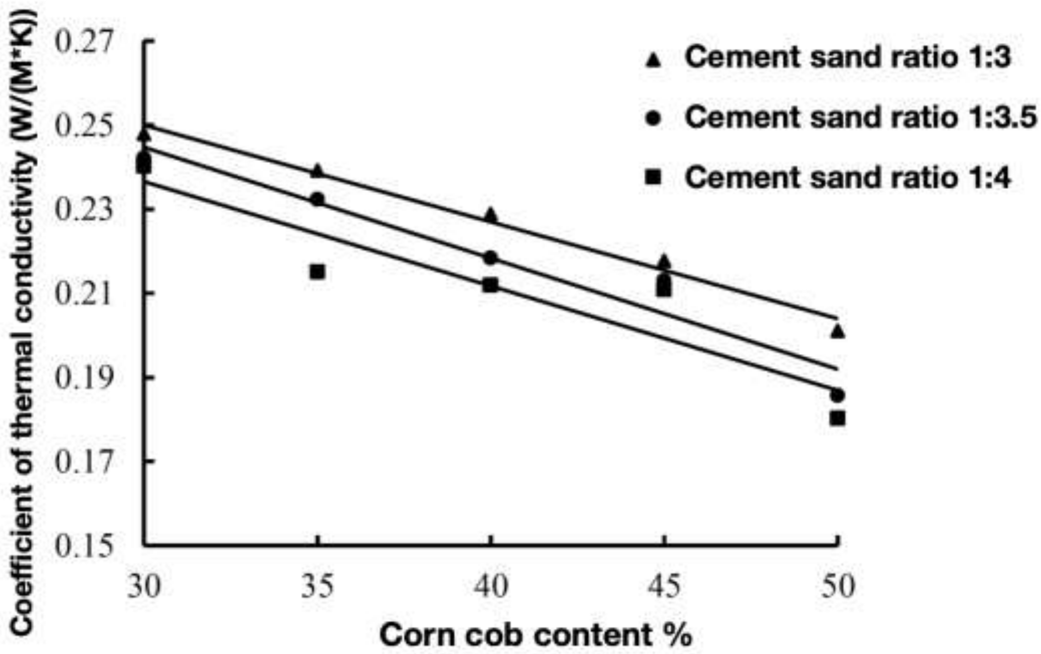


Figure 5-10. The thermal conductivity curve to the corncob volume content

As can be seen from Figure 5-10, under the conditions of different cement-sand ratios, with the increase of the volume content of corncob, the thermal conductivity of ecological concrete gradually decreases. This is because the thermal conductivity of ecological concrete depends on the pore structure of the concrete itself and the thermal conductivity of the air inside the concrete. Among common substances, air has the lowest thermal conductivity. When the volume content of the corncob is large, the independent pores in the ecological concrete structure increase, and the air content inside the concrete increases, so the thermal conductivity of the ecological concrete decreases, which can achieve the effects of heat insulation and heat loss prevention.

In addition, when the ratio of mortar to sand is 1:3, the thermal conductivity of eco-concrete is less discrete. When the volume content of corncob is 30%, the thermal insulation of ecological concrete is relatively weak, and the thermal conductivity of concrete is about 0.2479W/(m·K). When the corncob volume content increases to 50%, the thermal conductivity of the ecological concrete decreases to 0.2011W/(m·K), which means, for every 5% increase in the volume content of corncob, the thermal conductivity decreases by about 4.7%, and the decrease is relatively large. It can be seen that the corncob aggregate has a significant effect on the thermal conductivity of ecological concrete.

5.4.2.2. Influence of cement-sand ratio on thermal conductivity of ecological concrete

The thermal conductivity of concrete is inseparable from the constituent materials. In addition to recycled coarse aggregates, the influence of cementitious materials and recycled fine aggregates on the thermal conductivity of concrete cannot be ignored. The effect of different cement-sand ratios on the thermal conductivity of ecological concrete is shown in Figure 5-11.

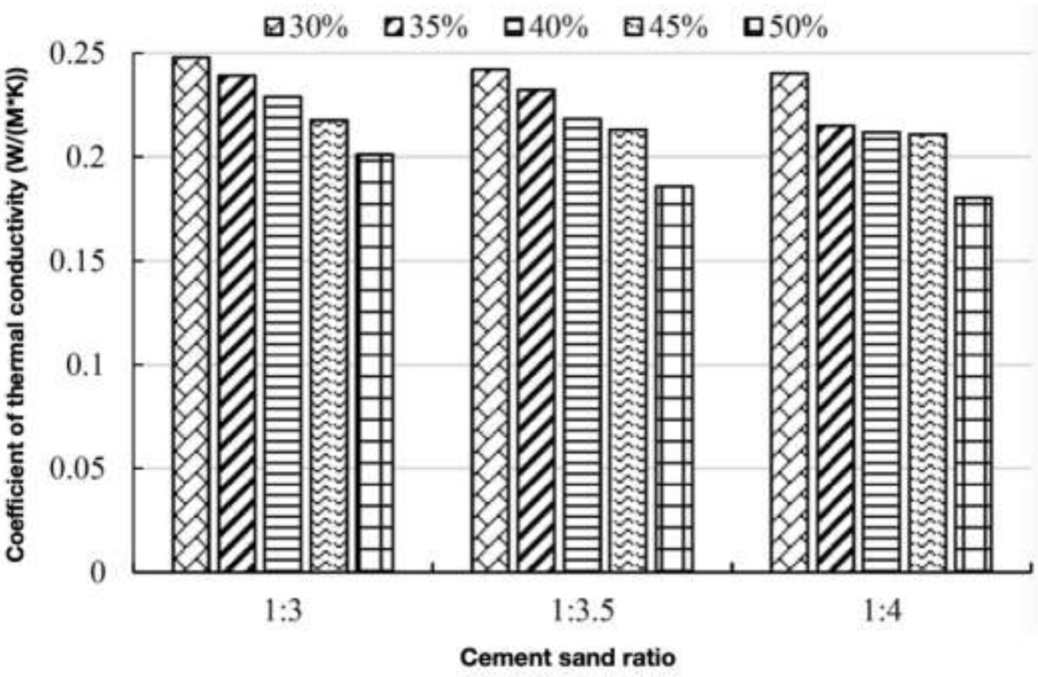


Figure 5-11. The relationship between the cement sand ratio and the thermal conductivity

The recycled fine aggregate produces cracks during the crushing process, which increases the internal porosity of the concrete, increases the water absorption rate, and increases the air content, resulting in a decrease in the thermal conductivity of the corncob-recycled aggregate ecological concrete. As can be seen from Figure5-11, with the increase of the proportion of recycled sand, the thermal conductivity of ecological concrete gradually decreases, but the highest is not more than 0.25W/(m·K), and the thermal insulation performance is better than that of ordinary concrete.

As can be seen from Figure 5-11, when the volume content of corncob is 30% and the ratio of mortar to sand is 1:3, the thermal conductivity of ecological concrete is 0.2479W/(m·K). The thermal conductivity of ecological concrete with a ratio of 1:4 is the best, and its thermal conductivity is 0.2403W/(m·K). When the content of recycled sand increases by 5%, the thermal conductivity of ecological concrete would slightly decrease by about 3.1%. The thermal conductivity of ecological concrete when the ratio of mortar to sand is 1:3.5 is close to the thermal conductivity of ecological concrete when the ratio of mortar to sand is 1:4. It can be seen that the effect of recycled fine aggregate on the thermal conductivity of ecological concrete is smaller than that of corncob on the thermal conductivity of ecological concrete.

In general, the thermal conductivity of corncob-recycled aggregate composite ecological concrete is between 0.1803 ~0.2479 W/(m·K) under the condition of different mortar ratio and corncob volume content. , which is very close to the classical thermal insulation material. This is expected to provide a basis for the research on the preparation of energy-saving thermal insulation wall panels.

5.5. Summary

This chapter systematically studies the influence of different cement-sand ratios and corncob volume content on the thermal conductivity of corncob-recycled aggregate composite ecological concrete, and draws the following conclusions:

(1) The corncob itself has high porosity, loose pores, and high-water absorption. With the increasing in the corncob content volume, the amount of water absorbed by the ecological concrete increases. In the dry state, the dry density of the ecological concrete varies with the ratio of mortar to sand. It gradually decreased with the increase of corncob volume content.

(2) Corncob is a lightweight, loose and porous fibrous material that retains a large amount of air in the pores of the corncob and is a biomass material with a small thermal conductivity. As the volume content of the corncob increases, the independent pores in the ecological concrete structure increase, and the air content inside the concrete increases, the thermal conductivity of the ecological concrete decreases, and the thermal insulation performance is better, which can achieve the effects of heat insulation and heat loss prevention. In the end, the corncob concrete material with the cement-sand ratio of 1:4, the water consumption of 218.3kg/m^3 and the volume content of corncob of 50% was selected, and its thermal conductivity was 0.18.

（3）The texture of corncob is uniform, but it is lightweight and porous, and its own compressive strength is low. With the increase of the volume content of corncob, the compressive strength of ecological concrete shows a downward trend; with the continuous reduction of the mortar ratio, the proportion of recycled sand increases, the content of cementitious materials in ecological concrete is reduced, the bonding force between aggregates is weakened, and the porosity is further increased due to insufficient aggregate wrapping, which makes the compressive strength of ecological concrete continue to decrease. Under the conditions of different mortar ratio and volume content, the 28-day compressive strength of ecological concrete is between 2.1 MPa and 5.4 MPa. Although it is lower than the compressive strength of ordinary concrete, it can still meet the requirements of masonry.

Reference

1. Fan Xiaoya, C.J., Present situation of agricultural ecological environment pollution and its treatment countermeasures. Green technology, 2019.
2. Teng Fei, L.J., Li Chuan-you, Li Zhen, ZHANG Li, Xiong Bo, Practice and exploration of resource utilization of agricultural waste. Agricultural machinery quality and supervision, 2020.
3. Lixin, W., Present situation and development prospect of comprehensive utilization of corn stover. Agricultural development and equipment, 2021.
4. Chen Shili, H.J., Hou Yuan, Research on Current situation of corncob recycling -- Based on analysis of Enactus Project of college students. 2019.
5. Yang Xiufei, L.Q., Yang Huijuan, Yang Huijuan, ZOU Jun, GAO Wentao., The potential analysis of biomass as building thermal insulation material in China. Energy saving, 2012.

Chapter 6.

Building Envelopes Energy Analysis

6.1. Introduction

Architecture is recognized as a comprehensive combination of multiple disciplines, which embodies the achievements in science & technology development and civilization evaluation. It turns out to be the long-existing crystallization of human history, e.g., the famous Egyptian pyramids, Chinese Forbidden City and Notre Dame de Paris. These heritage buildings have all become the symbols of the cultural prosperity because of their full characteristics of the representative times. Similarly, ordinary residential buildings styles have the same functions and easier to intuitively reflect local characteristics, they are easier to integrate the characteristics of the times with universal significance embodied in architectural features.

With the time flies, the innovation in technology has given birth to new possibilities of living; Meanwhile, it can also bring earth-shaking changes in the architectural building forms. The heritage residential houses in the city demonstrated inconsistent with the times in many aspects, which are also typical products of the old era. Under the rapid development of urban planning and construction, by discovering the inherent characteristics and adapt existing construction technologies in the heritage buildings, it has become an important research tendency in order to transform heritage buildings adaptive to the development in the new era continuously while maintaining its original characteristics.

The energy savings potential by retrofitting existing buildings is a milestone to meet the targets of a Low Carbon Economy. The construction industry has been evolving to embrace sustainability. This has highlighted the necessity to inspect sustainable performances throughout the post-construction building lifecycle. How to implement the retrofit of an existing building efficiently, furthermore, to evaluate the energy performance for low energy goals in environmental impacts is really the problem in the building sector. Considering specific active optional alternatives, it might be an active solution to those 100 years old buildings to overcome the energy hog problem. Deep assessments towards architectural heritages upgrades can be the great opportunities in which the users and residents could face the problem directly. Reasonable retrofit of existing buildings and keep the budget balance would be another option. As such, it relies more on the process, which can be adapted and optimized, than on the results.

The construction industry has been evolving to embrace sustainability. This has highlighted the necessity to inspect sustainable performances throughout the post-construction building lifecycle. How to implement the retrofit of an existing building efficiently, furthermore, to evaluate the energy performance for low energy goals in environmental impacts is really the problem in the whole building sector. Considering specific active optional alternatives, it might be an active solution to those 100 years old buildings to overcome the energy hog problem. Deep assessments towards architectural heritages upgrades can be the great opportunities in which the users and residents could face the problem directly. Reasonable retrofit of existing buildings and keep the budget balance would be another option. As such, it relies more on the process, which can be adapted and optimized, than on the results.

Sustainability analysis of building renovation can include many factors; the energy performance, material efficiency, environmental impact ,durability, affordability, and social benefit[1]. While the sustainability assessment of buildings and renovation should be based on a lifecycle analysis. Technical performance indicators are added to the environmental performance indicators in a sustainability assessment. Durability of renovation measures is one example of a technical performance indicator. Durability of a building envelope component depends on more factors such as constructional and material properties, maintenance and climate robustness. In a sustainability perspective, the economic performance should be evaluated as life cycle cost[2]. There are many methods described in the literature as decision making support tools for sustainability assessment. Quantitative multi-criteria models are the engineering approach for sustainability evaluation. Models with linear functions in the simulation tools on thermal comfort and environmental impact potential are used to evaluate renovation measures in the energy production and environmental impacts [3-8].

6.2. Basic data of Case Study A

6.2.1. House layout

The building Case A, measured in Chapter 4, was selected as the study object. This Liyuan house was chosen for the study because it has the largest proportion of all Liyuan houses in Qingdao in terms of age and heating method, as well as the poor insulation performance of the envelope of this rural house and the benefits of its renovation.

This Liyuan house was built in 1941 with an 回-shaped layout. The whole building area is 1036.2 m², and the entire area of the first floor is 518.1 m². When the building was initially built, it functioned as an iron factory, and many functional buildings were factories and warehouses (Figure 6-1).

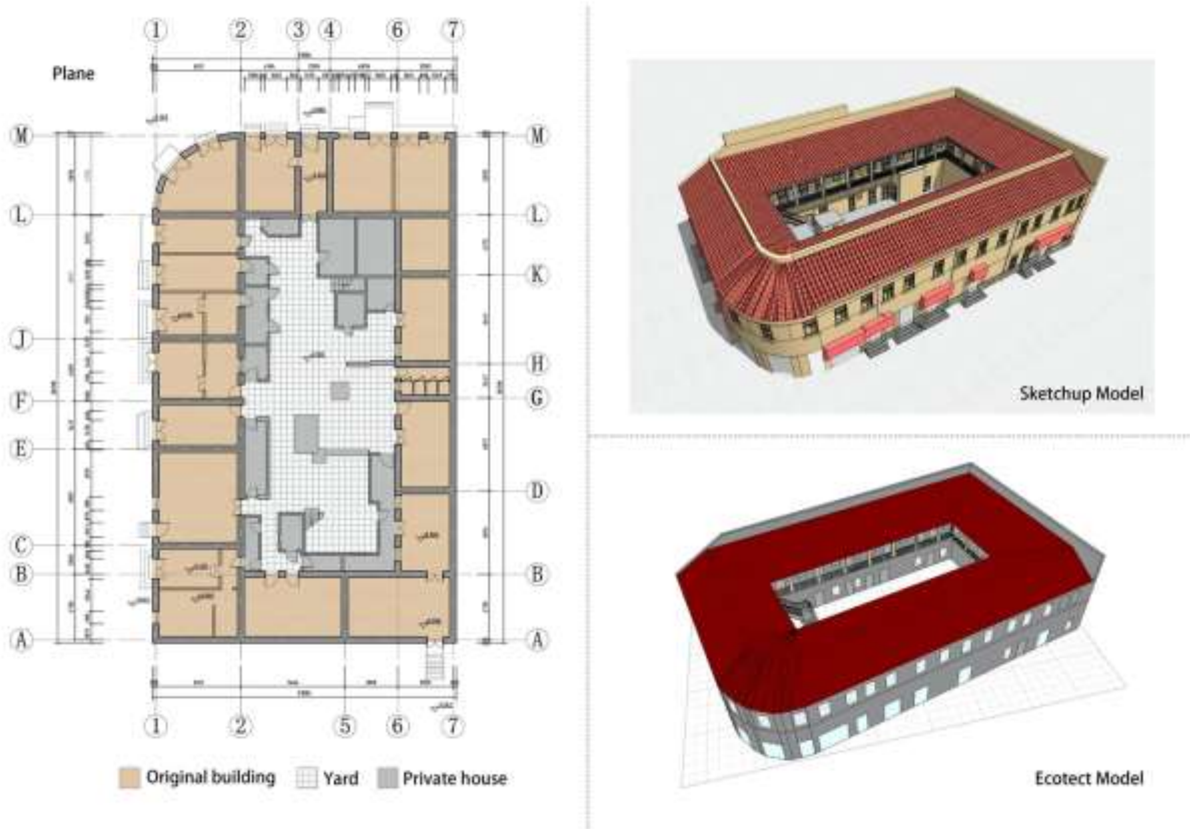


Figure 6-1. SketchUp model, simulation model, and plane of the Liyuan house in Qingdao

6.2.2. Liyuan house envelopes

The external envelope of this Liyuan house is very typical, with walls of mainly brick walls, red brick water walls, and some courtyard walls treated with cement brushing or artificial stone walls to increase the architectural artistic effect, wood window frames, cement floor, and heating by the furnace. The parameters of the envelope of this Liyuan house are shown in Figure 6-2.

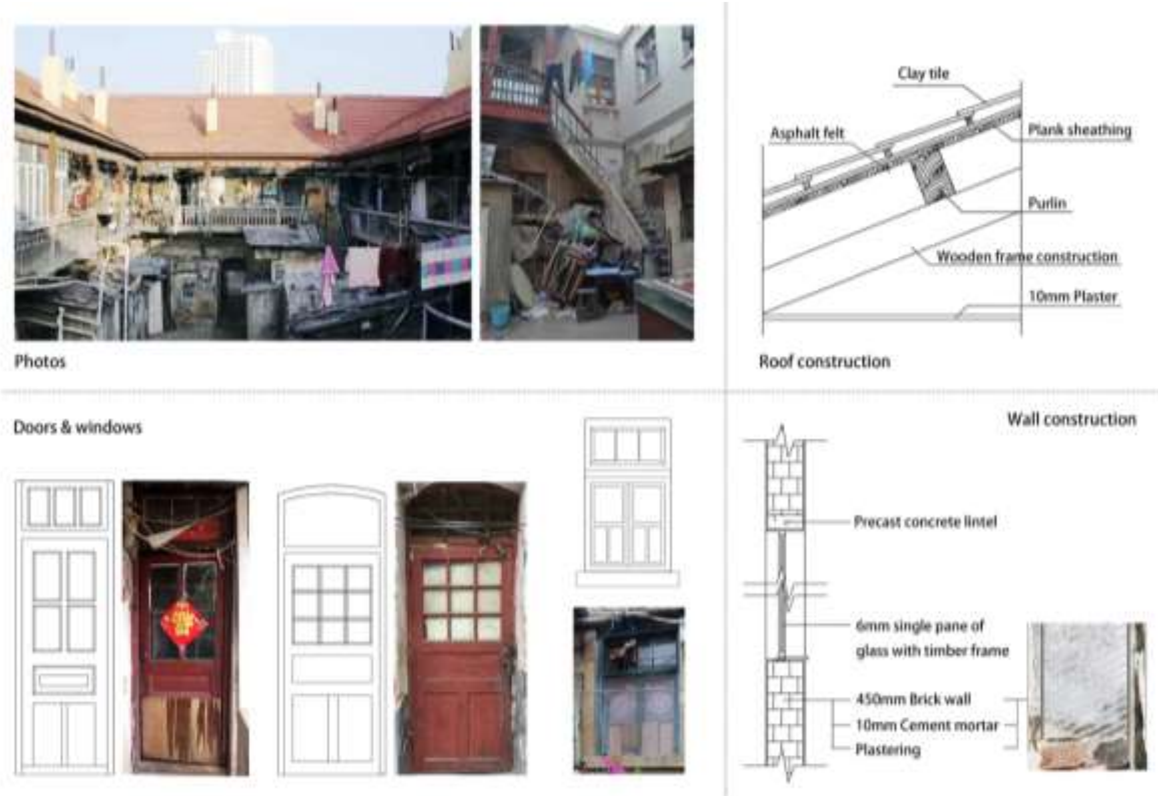


Figure 6-2. The Liyuan house residential enclosure structure

6.2.3. Indoor parameter setting

In building simulation, the indoor heat source usually refers to the energy allocated to the room by familiar internal heat sources such as personnel and lighting equipment, which largely determines the indoor temperature and thermal comfort for the user.

The Energy Conservation Design Standard for Residential Buildings in Severe Cold and Cold Areas (JGJ26-2018) [9]released in 2018 in China stipulates that the appropriate temperature for heating in severe cold and cold areas in winter should be taken as 18°C. However, relevant studies in recent years have shown that due to the layout of traditional houses, some extra rooms, such as kitchens, toilets, and other auxiliary rooms, are usually located in the courtyard, and residents often need to shuttle between the indoor living room and the extra rooms in the courtyard. In addition, residents often go in and out, and indoor living rooms and yards are generally dressed thicker in winter. So, if the interior design temperature is too high, residents will have to change their clothes frequently, which is not only inconvenient but also easy to make people feel cold [10]. When simulating the interior design temperature is designed to be 16°C [11]. In addition, the door and window permeability were set to 7.5 $m^3/(m^2 \cdot h)$, and the indoor wind speed was 0.01 m/s(Table 6-1,Table 6-2).

Table 6-1.The indoor air conditioning design parameters

Parameters	Value
Indoor Temperature	26℃ in summer
	18℃ in winter
Relative humidity	≤70 in summer
	≥30 in winter
Fresh Air Amount min.[m^3/(h person)]	30
Lighting Power Density(W/m^3)	9
Electric power density(W/m^2)	15
Average area occupied per person(m^2/person)	10

Table 6-2. The proportion of residential time arrangement

Run time	1	2	3	4	5	6	7	8	9	10	11	12
Working days	0	0	0	0	0	0	0	0	1	1	1	1
Run time	13	14	15	16	17	18	19	20	21	22	23	24
Working days	1	1	1	1	1	1	0.2	0.2	0.2	0	0	0

6.2.4. Local climate

Qingdao is located in the southeast of Shandong Province, China, on the edge of the Yellow

Sea. Qingdao has a temperate monsoon climate, hot in summer and cold in winter, with marine climate characteristics: slow warming in spring, few hot days in summer, slow cooling in autumn, low temperature in winter, humid air, moderate precipitation, and hot rainy season. Figure 6-3 shows the change in annual temperature, Figure 6-4 shows the annual wind environment in Qingdao. It shows that the south and southeast monsoon dominate in summer, and the north and northwest wind are prevalent in winter. Qingdao city is located north of the Tropic of Cancer, so the sunlight comes into the room from the south direction throughout the year. The solar altitude angle is higher in summer than in winter, and the solar altitude angle varies more markedly between winter and summer. These are the typical annual weather figures for Qingdao provided by the "Climate. One Building. Org" website and accurately represent the local weather conditions in Qingdao. Files in epw format recognized by the Energy Plus software are selected for subsequent simulation. (Figure 6-5)

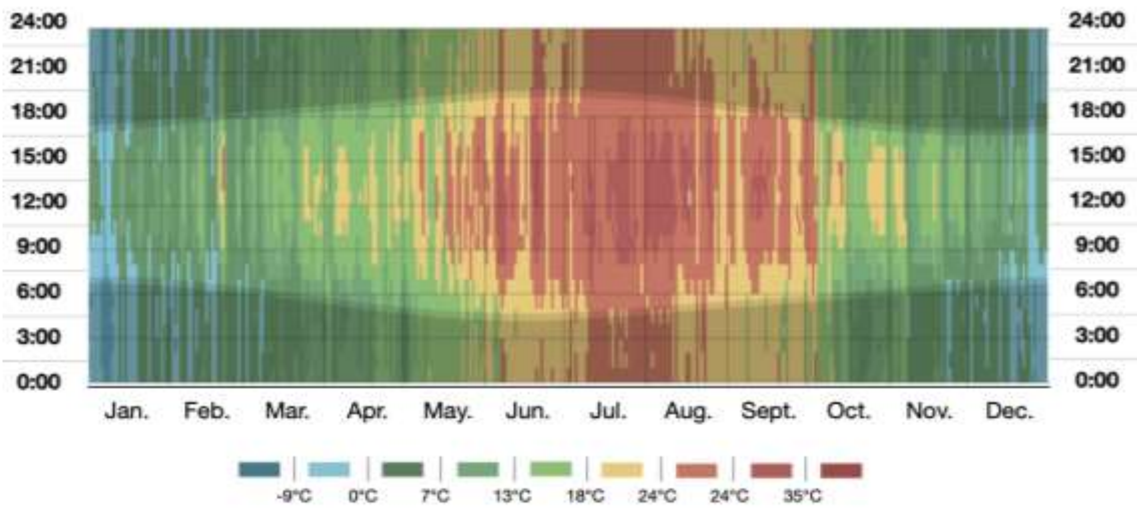
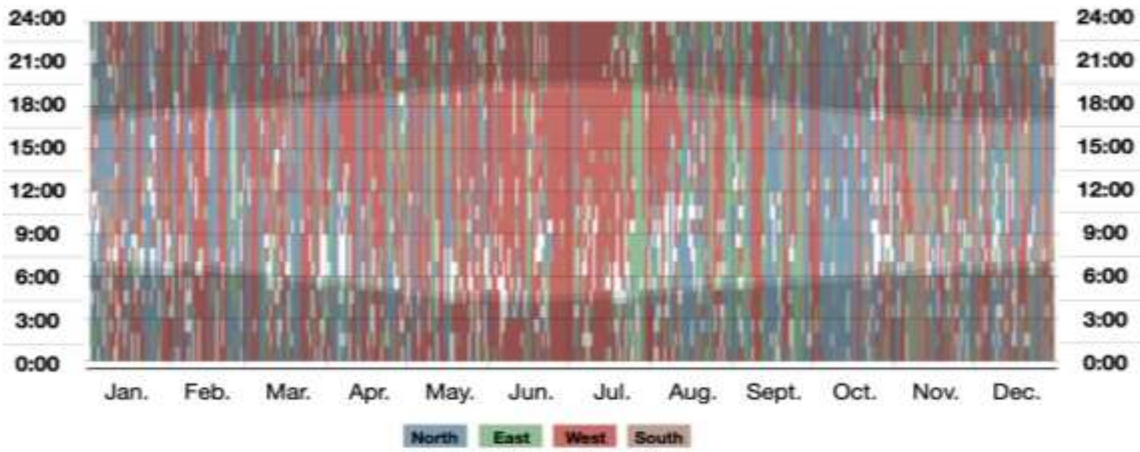
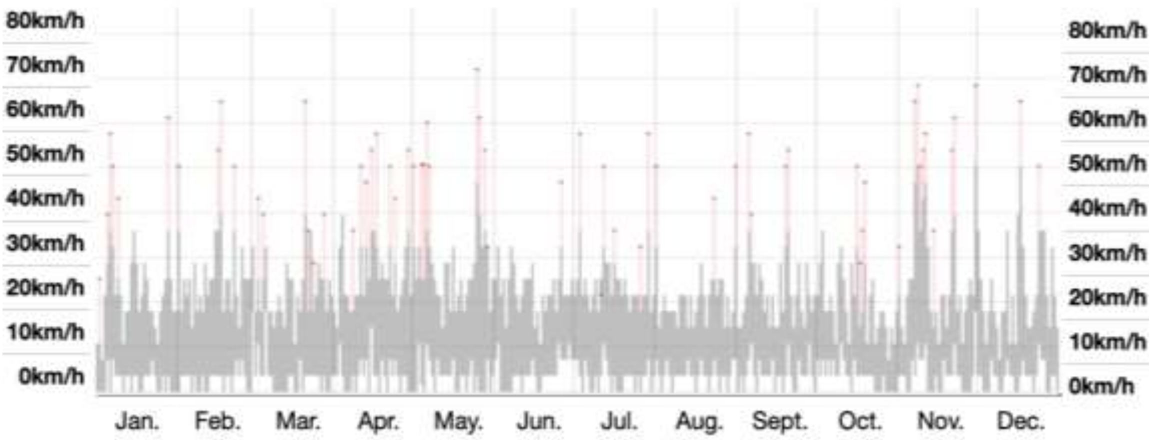


Figure 6-3.The annual temperature figure of Qingdao



a. The wind direction distribution in Qingdao



b. The wind speed in Qingdao

Figure 6-4. The wind environment attributes distribution of Qingdao

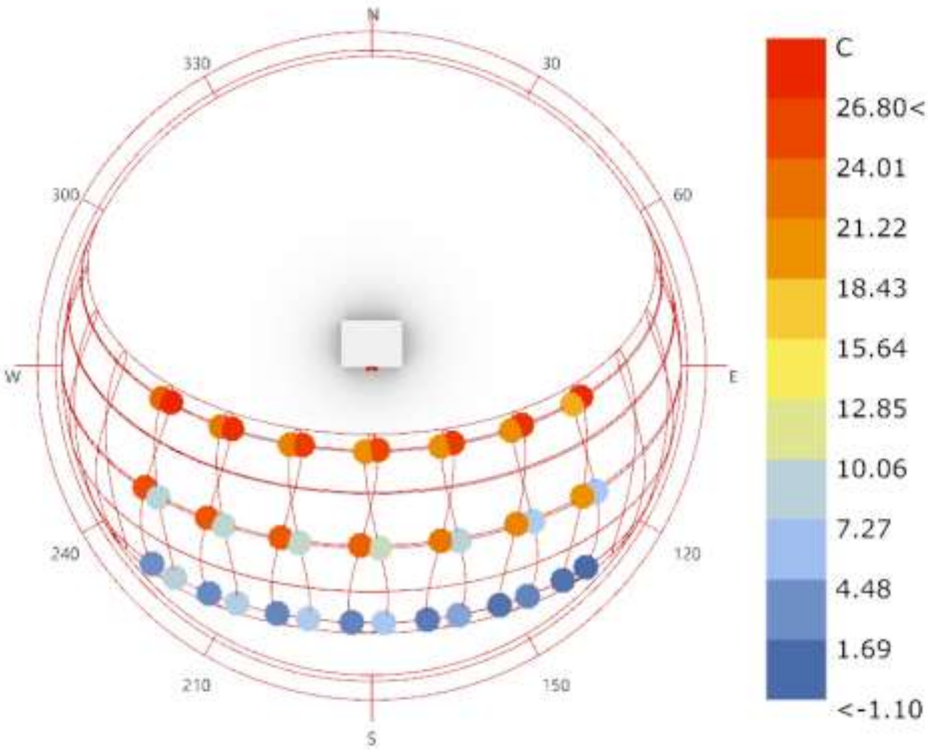


Figure 6.5. The annual sundial chart of Qingdao

6.3. Improvement strategies of house envelopes

In order to understand the change of building energy consumption before and after the repair of the courtyard building envelope, an energy consumption analysis model of building case A was established on the Rhino platform according to the building plan data. The building analysis model is shown in Figure 6-6

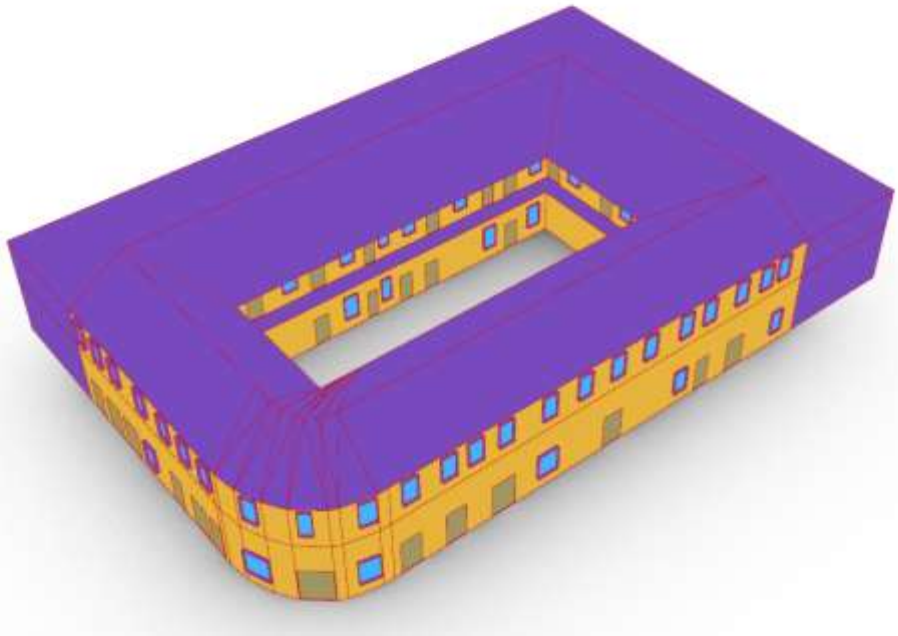


Figure 6-6. The building energy analysis model

In this section, selected Liyuan houses are individually renovated in walls, roofs, and windows in conjunction with the experimental materials chosen in the previous quarter. Their thermal and energy saving are approximated by calculating their heat transfer coefficients, K, to the extremes.

Three model parameters were set in the simulation test (Table 6-3, 6-4, 6-5). The original performance of the building labeled as “Model_1” is referred to the original built reference for the listed building, which induced the single glazed timber framed windows, wooden doors, old clay tile roofs, and brick timber framed walls; “Model_2” is one scenario with modification in accordance with conservation requirement standard implemented double glazed windows, exterior walls of insulation and renewal of roofs and doors to improve the thermal properties and physical behavior of the building to fulfill the conservation requirement. Although the various materials of model_2 have met the requirements of the specification, the author found that there is still possibility for further optimization. Therefore, by introducing an environment friendly material called "new concrete" in “Model_3”, which can replace the "brick masonry medium" in the original wall of the building with it.

6.3.1. Design of the Model_1

The material parameters of Model_1 are a reflection of the real status quo. The wall of the current building is mainly composed of a 300-450mm thick "brick masonry medium" and a 10mm thick "plaster building". According to calculations, the U-Value of the current wall is 1.2W/m^2·K, which is much higher than the standard 4.2.1 of "Shandong Energy-saving Design Standard for Residential Buildings" (DB37/5026-2014) K≤0.3W/(m^2·K) related requirements.

There are two types of doors in the current building: wooden doors (2.31W/m^2·K) and glass doors (5.356W/m^2·K). The wooden doors are mostly on the second floor and the glass doors are on the first floor. The "Shandong Province Residential Building Energy Efficiency Design Standard" (DB37/5026-2014)[12] stipulates that the U-Value of the outer door must be less than or equal to 3W/m^2·K. The air tightness needs to reach level 7, and only a small part of the doors of the current building meets the requirements of the code.

The windows of the current buildings are all single-sided ordinary glass windows with a U-Value of 5.1W/m^2·K, which does not meet the "Shandong Province Residential Building Energy Efficiency Design Standard" (DB37/5026-2014) K≤2.3W/(m^2·K) requirements. The roof of the current building is clay tiled roof, which is composed of clay tiles, air gap, and plaster. The U-Value is 3.1W/ m^2·K, which also does not meet the "Shandong Province Residential Building Energy Efficiency Design Standard" (DB37/5026-2014)[12] No. 4.2.1 The provisions of K≤0.3W/(m^2·K).

6.3.2. Design of the Model_2

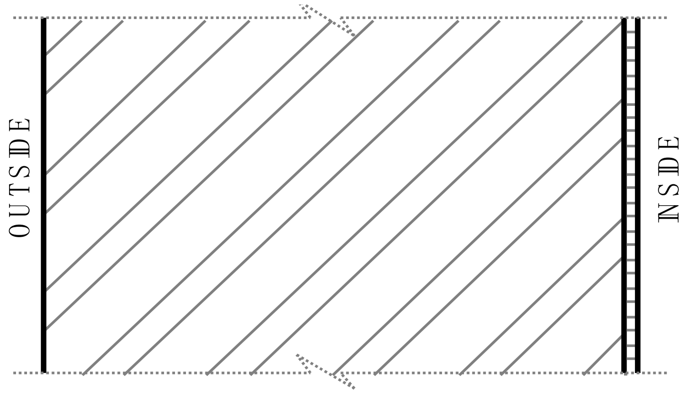
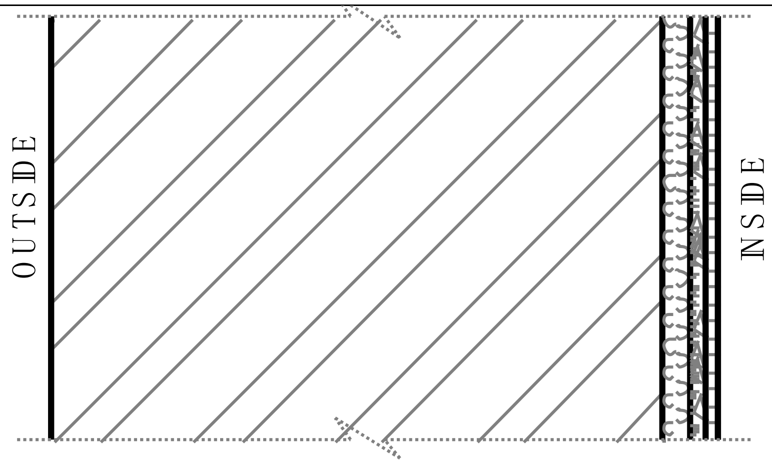
Based on the shortcomings exposed in the material analysis of Model_1, the author takes the requirements in the "Design Standard for Energy Efficiency of Residential Buildings in Shandong Province" (DB37/5026-2014)[12] as the bottom line. In Model_2, the materials of walls, roofs, doors and windows have been optimized or replaced. In the renovation of old buildings, wall replacement works are large, construction is difficult, and it will cause damage to the original style of the building. Therefore, in Model_2, the thermal performance of the wall is improved mainly by adding insulation materials to the original wall. Through analysis of actual historical building renovation cases, a 20mm thick polystyrene form (high density) and a 10mm thick cement plaster were finally added to the inner side of the original wall, which successfully reduced the U-Value of the wall to 0.3W/ $m^2 \cdot K$. In Model_1, most of the wooden doors meet the specification requirements. Therefore, in model_2, it is only necessary to replace all the glass doors with wooden doors. All windows are replaced with double glazed_lowE_timber frame, U-Value = 2.0 W/ $m^2 \cdot K$, and airtightness is level 7.Similar to the wall, the roof is filled with 10mm thick cement plaster and 30mm thick polystyrene form (high density) in the original air layer, and the U-Value is reduced to 0.26 W/ $m^2 \cdot K$. Through the above transformation, the U-Value of Model_2 meets the relevant regulations in the "Design Standard for Energy Efficiency of Residential Buildings in Shandong Province" (DB37/5026-2014)[12].

6.3.3. Design of the Model_3

Regarding the thermal performance research of building recycled concrete, the basic test materials required include ordinary Portland cement, fly ash, recycled coarse aggregate, sand, water, water reducing agent, and foaming agent. Among them, the source of recycled coarse aggregate is construction waste. After the initial treatment of crushing and decomposing, it is obtained by preliminary screening and sorting, and then through a series of process treatments such as two crushing treatments and re-screening and sorting. The construction waste is recycled in the recycled aggregates. The content of concrete aggregate is the largest, accounting for about 93.4%, the aggregate of broken bricks accounts for about 5.6%, and the content of impurities such as wood residue, glass, paper scraps, and plastics is less than 1%.

Recycled coarse aggregates are two kinds of single-grain grades of recycled coarse-aggregate, the single-grain grades are 5-8mm and 8-20mm respectively. Now those with a single grain size of 5-8mm are called short grain size recycled coarse aggregates, abbreviated as SRA (short grain size recycled coarse aggregate); those with a single grain size of 8-20mm are called long grain size recycled coarse aggregates. LRA (long grain size recycled coarse aggregate). In this construction recycled concrete, long-grain recycled coarse aggregate is used.

Table 6-3. The attribute table for the simulated wall

	Model_1
Model_1 Exterior wall	 450mm external brick 10mm plaster board Thickness :460mm
U (W/m²K)	1.2
Admittance (W / m² K)	4.53
Thermal Decrement (0-1)	0.08
Solar Absorption (0-1)	0.495
	Model_2
Model_2 Exterior wall	 450mm external brick 20mm Polystyrene Foam (High Density) 10mm Cement Plaster, 10mm plaster board Thickness :490mm
U (W/m²K)	0.3
Admittance (W / m² K)	2.00
Thermal Decrement (0-1)	0.03
Solar Absorption (0-1)	0.495

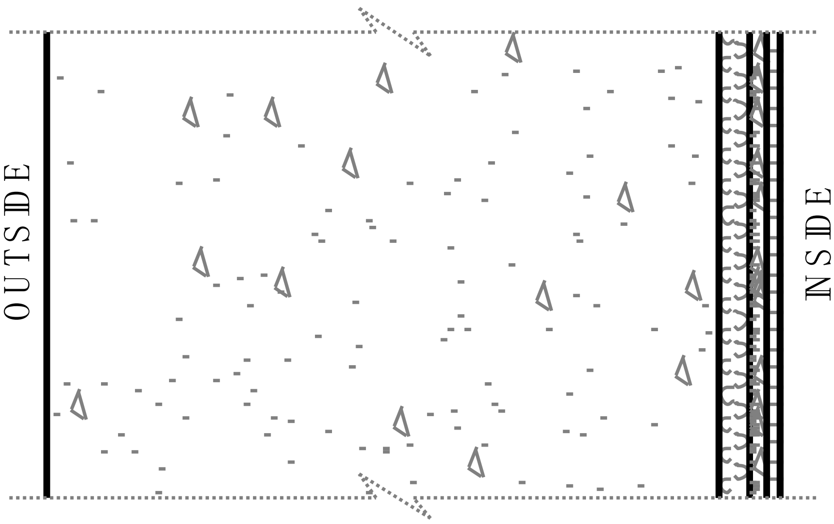
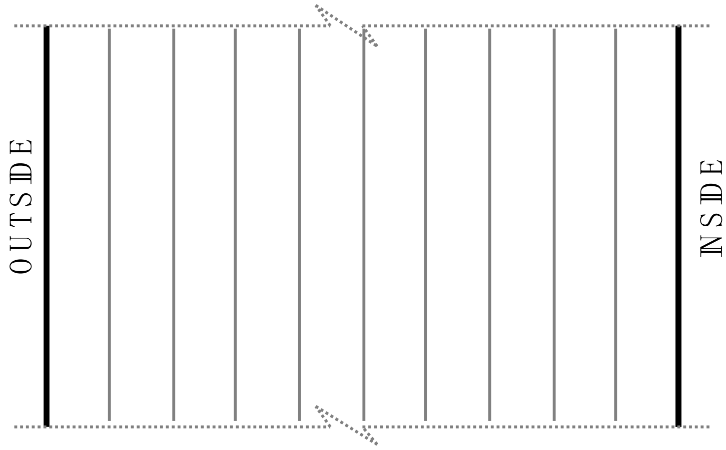
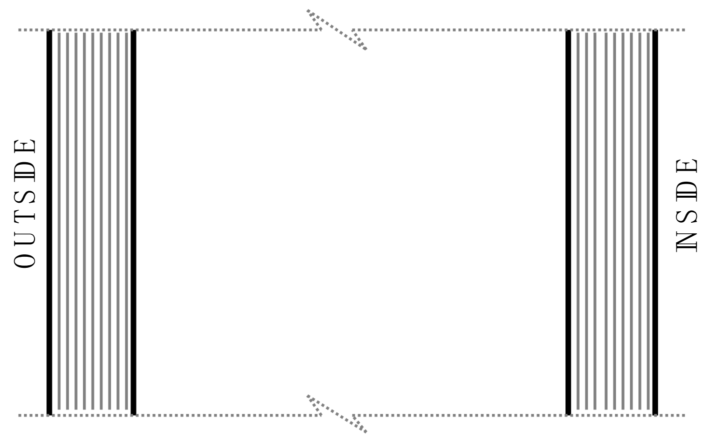
	Model_3
Model_3 Exterior wall	 450mm the wall modified with recycling material 20mm Polystyrene Foam (High Density) 10mm Cement Plaster, 10mm plaster board Thickness :490mm
U (W/m^2K)	0.18
Admittance ($W / m^2 K$)	2.01
Thermal Decrement (0-1)	0.01
Solar Absorption (0-1)	0.495

Table 6-4. The attribute table for the simulated window

	Model_1
Model_1 Exterior window	 6mm single pane of glass with timber frame Thickness :6mm
U (W/m^2K)	5.1
Admittance ($W / m^2 K$)	5.0
Solar Heat Gain Coeff	0.94
Visible Transmittance	0.737
Alt Solar Gain(Heavy wt)	0.47
Alt Solar Gain (Light wt)	0.64
	Model_2
Model_2 Exterior window	 6mm glass Standard 30mm air gap 6mm glass Standard Thickness :42mm
U (W/m^2K)	2.26
Admittance ($W / m^2 K$)	2.2

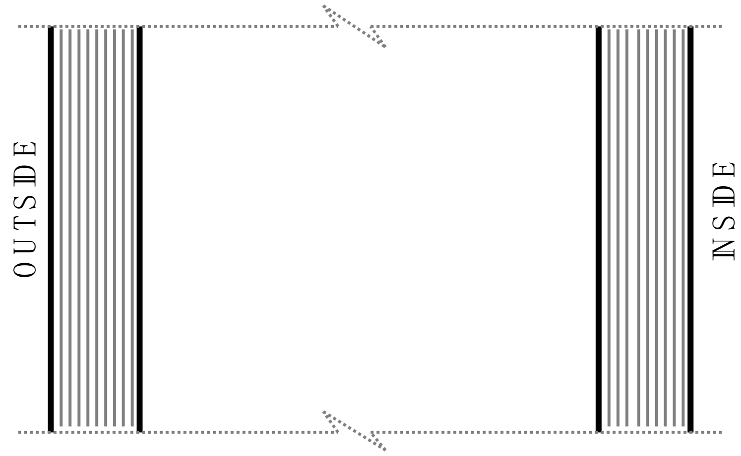
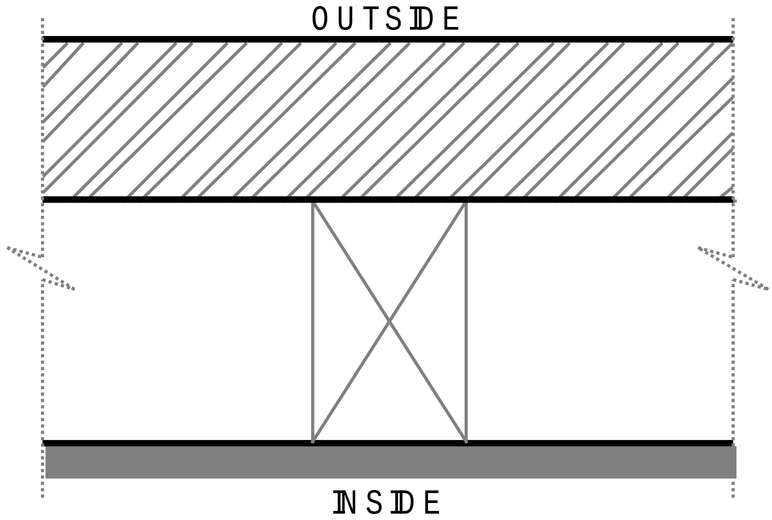
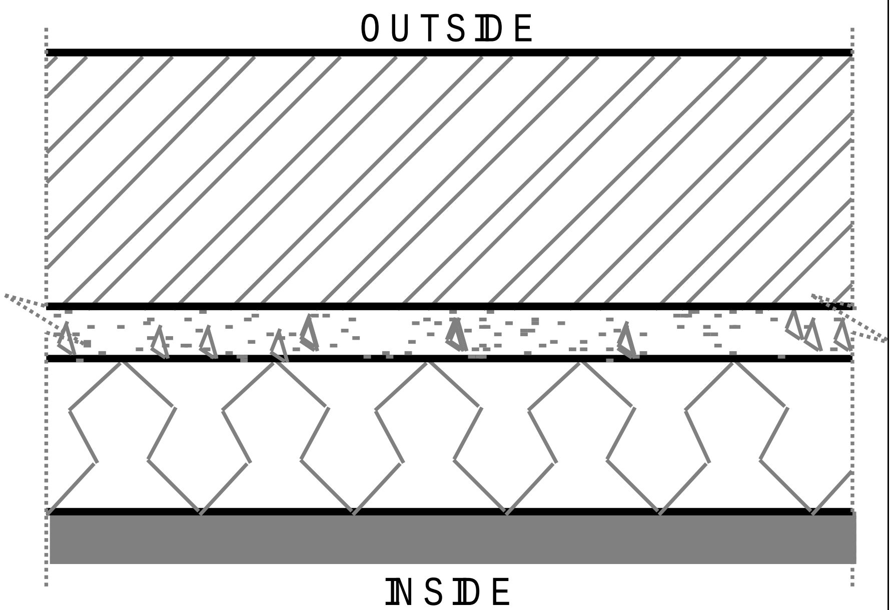
Solar Heat Gain Coeff	0.75
Visible Transmittance	0.639
Alt Solar Gain(Heavy wt)	0.21
Alt Solar Gain (Light wt)	0.29
	Model_3
Model_3 Exterior window	 6mm Advanced glass 30mm air gap 6mm Advanced glass Thickness :42mm
U (W/m^2K)	2.0
Admittance ($W / m^2 K$)	2.2
Solar Heat Gain Coeff	0.57
Visible Transmittance	0.4
Alt Solar Gain(Heavy wt)	0.21
Alt Solar Gain (Light wt)	0.29

Table 6-5. The attribute table for the simulated roof

	Model_1
Model_1 roof	 50mm Clay Tiles 75mm Air Gap 10mm Plaster Thickness :135mm (Thickness of structural layer is not included.)
U (W/m²K)	3.1
Admittance (W / m² K)	3.1
Thermal Decrement (0-1)	1
Solar Absorption(0-1)	0.6
	Model_2 / Model_3
Model_2 /Model_3 roof	 50mm Clay Tiles

	75mm Cement Plaster 30mm 20mm Polystyrene Foam (High Density) 10mm Plaster Thickness :135mm (Thickness of structural layer is not included.)
U (W/m^2K)	0.26
Admittance ($W / m^2 K$)	1.02
Thermal Decrement (0-1)	0.85
Solar Absorption(0-1)	0.6

6.4. Ecotect simulation: Comparative Analysis

Building energy consumption refers to the maintenance of building functions and the energy consumed during the operation of the building, including the energy consumption of lighting, heating, air conditioning, elevators, hot water supply, cooking, household appliances and office equipment. Generally speaking, the energy consumption that accounts for the largest proportion is the energy consumption of heating and air conditioning. Therefore, simulating and analyzing the energy consumption of mining air conditioners is an index to evaluate the quality of building energy-saving design. Ecotect Analysis simulates and analyzes the monthly heating and air conditioning energy consumption of the entire building and each area and the maximum annual heating/cooling load. These data are presented in the form of bar charts and data lists. It should be noted that Max Heating/Cooling Load in the software is the category of power, and the unit is W; MONTHLY HEATING/COOLING LOADS is the category of energy, and the unit is Wh.

Monthly loads or discomfort: Ecotect Analysist's monthly energy consumption analysis is very intuitive. The color of the bar graph corresponds to the color of the area, so that you can intuitively see the energy consumption of each area and the proportion of the entire building. The ratio of monthly energy consumption can also be seen.

Hourly heat gains or losses: This data contains hourly data on heat gains and losses related to building energy consumption. By analyzing these data through simulation, the thermal insulation performance of the envelope can be studied, combined with the heat gain analysis of passive components It is possible to understand the relevant thermal performance of the building from the macroscopic and microscopic aspects. In the hourly thermal analysis chart, it includes hourly HVAV Load, Conduction, So-Air, Direct Solar, Ventilation, Internal, 7 items such as Inter-zonal.

Passive gains breakdown: This function is equivalent to counting the daily gain and loss of heat on the same graph and calculates the same content (including the heat gain and loss of the thermal conductivity of the envelope, the heat generated by the integrated temperature, the heat gain by direct solar radiation, and the cold wind). It indicated the percentage of infiltration heat gain and loss, heat gain from internal personnel and equipment, heat gain and loss between areas).

Hourly heat gains or losses

The analysis of hourly heat gain and heat loss includes hourly data of heat gain and heat loss related to building energy consumption. Through simulation and analysis of these, the thermal insulation performance of maintenance structures can be studied. The data of Model_1, Model_2 and Model _3 is shown in Table 6-6, Table 6-7 and Table 6-8. It includes hourly heating and air conditioning load (HVAV LOAD), heat gain and loss from enclosure structure to heat (Conduction), heat generated by comprehensive temperature (Sol-Air), heat gained by direct radiation from the sun (Direct solar), heat gained and lost by cold air penetration (Ventilation), heat gained and lost by internal personnel and equipment (Internal), and the heat gained and lost between regions (Inter-zonal). The combination of conduction and sol-air becomes the heat gain and loss of the envelope, that is, the Fabric curve.

By comparison, it can be found that in the "Hourly Heat Gain and Loss" analysis, the curve of Model_2 is relatively flat, especially the curves of HVAC load, conduction and inter-zone. At the same time, the value of Model_2 is lower whether it is the monthly heating load or the monthly cooling load. Among them, the lowest point of the HVAC load curve has been reduced from close to 88kw to about 60kw. At the same time, whether it is monthly heating loads or monthly cooling loads, the value of model 2 is lower. Among them, the data of monthly heating loads in January has been reduced from more than 28kw to about 24kW, and the entire heating loads have been reduced from 72kW to 60kW, with the energy saving rate up to 16.44%. The total energy consumption of heating and cooling is reduced from 77kW/m^2 to 68kW/m^2, and the energy saving rate is 11.52%. This fully shows that the optimization of material u-value can effectively reduce the energy consumption of indoor heating and cooling in buildings, reduce indoor heat fluctuations, and improve comfort (Figure 6-7, 6-8).

Similar to the comparison of Model_1 and model_2, in the Hourly Heat Gain and Loss analysis, model_3 also has a flatter curve and a smaller number. The monthly heating loads and monthly cooling loads are also the lowest among the three models. The monthly heating loads in January were further reduced from 24700w in model 2 to about 24400w, which further increased the energy saving rate by 1.21%. Compared with model_2, the total energy consumption of cooling and heating is 1.24%, and the energy saving rate of heating is 2.75%. Combining the comparison data of model_1 and model_2, it can be seen that the size of the u-value of the material is proportional to the energy consumption of indoor heating and cooling in the building, that is to say, the lower the u-value of the building envelope, the less the building energy consumption., the better the thermal performance of the building, the better the comfort and energy saving effect. (Table 6-9).

Table 6-6. The specific simulated data of Model_1

HOUR	HVAC	FABRIC	SOLAR	VENT.	INTERN	ZONAL	(Wh)
0:00	-43277	-10651	0	-59256	5639	14626	
1:00	-44309	-10776	0	-61460	5639	14641	
2:00	-46255	-11160	0	-65823	5639	14694	
3:00	-47976	-11503	0	-69912	5639	14829	
4:00	-49551	-11789	0	-73444	5639	14837	
5:00	-49715	-12014	0	-73465	5639	14871	
6:00	-49536	-12211	0	-72604	6253	14696	
7:00	-48975	-12295	317	-70652	6503	14459	
8:00	-48003	-11831	912	-68374	7185	13973	
9:00	-46566	-10948	1464	-65652	8664	13208	
10:00	-88033	-10107	1482	-62684	9096	-25819	
11:00	-84892	-9795	1848	-60492	9278	-25730	
12:00	-82217	-9165	1908	-58294	8846	-25511	
13:00	-79894	-8774	2052	-56868	8846	-25150	
14:00	-59070	-8450	2045	-55680	8664	-5648	
15:00	-57879	-8289	1492	-54712	9278	-5648	
16:00	-59075	-8693	0	-54011	9278	-5648	
17:00	-59522	-10137	0	-53379	9642	-5648	
18:00	-59201	-10208	0	-52304	8959	-5648	
19:00	-20914	-10263	0	-50985	6753	33717	
20:00	-20681	-10316	0	-49876	5957	33883	
21:00	-19784	-10288	0	-48990	5889	34045	
22:00	-19106	-10289	0	-47702	5457	34212	
23:00	-38290	-10251	0	-47088	5639	14537	
TOTAL	-1222721	-250203	13520	-1433707	174021	164778	

Table 6-7. The specific simulated data of Model_2

HOUR	HVAC	FABRIC	SOLAR	VENT.	INTERN	ZONAL	(Wh)
0:00	-35084	-14308	0	-45436	5639	8535	

1:00	-35393	-14387	0	-45895	5639	8484	
2:00	-35771	-14558	0	-46344	5639	8465	
3:00	-36026	-14843	0	-46546	5639	8512	
4:00	-35972	-15043	0	-45974	5639	8485	
5:00	-36029	-15222	0	-45809	5639	8513	
6:00	-35896	-15392	0	-45206	6253	8385	
7:00	-35257	-15428	616	-43812	6503	8198	
8:00	-34435	-14969	1581	-42789	7185	7825	
9:00	-33499	-14202	2121	-41355	8664	7263	
10:00	-60933	-13494	2642	-39513	9096	-19664	
11:00	-57339	-12559	3177	-37650	9278	-19585	
12:00	-55076	-11602	3543	-36456	8846	-19408	
13:00	-51932	-10817	4504	-35328	8846	-19136	
14:00	-35990	-9926	4734	-33813	8664	-5648	
15:00	-35807	-9579	3287	-33145	9278	-5648	
16:00	-39760	-10239	0	-33150	9278	-5648	
17:00	-41867	-11994	0	-33866	9642	-5648	
18:00	-43394	-12408	0	-34298	8959	-5648	
19:00	-16958	-12898	0	-33807	6753	21669	
20:00	-17504	-13432	0	-34167	5957	21871	
21:00	-16911	-13538	0	-33987	5889	22014	
22:00	-16649	-13551	0	-33807	5457	22143	
23:00	-30272	-13643	0	-34167	5639	8508	
TOTAL	-873754	-318032	26205	-936320	174021	72837	

Table 6-8. The specific simulated data of Model_3

HOUR	HVAC	FABRIC	SOLAR	VENT.	INTERN	ZONAL	(Wh)
0:00	-28251	-8587	0	-45436	5639	5873	
1:00	-28534	-8614	0	-45895	5639	5811	
2:00	-28857	-8739	0	-46344	5639	5799	
3:00	-29036	-8942	0	-46546	5639	5861	
4:00	-28946	-9088	0	-45974	5639	5835	
5:00	-28946	-9188	0	-45809	5639	5867	
6:00	-28786	-9292	0	-45206	6253	5695	

7:00	-28495	-9310	190	-43812	6503	5478	
8:00	-28287	-9008	489	-42789	7185	5047	
9:00	-27763	-8470	656	-41355	8664	4380	
10:00	-54531	-7994	817	-39513	9096	-16936	
11:00	-51677	-7442	982	-37650	9278	-16845	
12:00	-50035	-6880	1095	-36456	8846	-16640	
13:00	-47826	-6418	1392	-35328	8846	-16318	
14:00	-35207	-5872	1463	-33813	8664	-5648	
15:00	-34181	-5682	1016	-33145	9278	-5648	
16:00	-35665	-6145	0	-33150	9278	-5648	
17:00	-37257	-7384	0	-33866	9642	-5648	
18:00	-38702	-7715	0	-34298	8959	-5648	
19:00	-13233	-7993	0	-33807	6753	16183	
20:00	-13627	-8176	0	-34167	5957	16399	
21:00	-13020	-8224	0	-33987	5889	16567	
22:00	-12749	-8182	0	-33807	5457	16718	
23:00	-23610	-8180	0	-34167	5639	5841	
TOTAL	-747221	-191525	8100	-936320	174021	32375	

Table 6-9. The energy saving data sheet

Simulation data	Heating	Cooling	Total
Model_1	72.409	5.472	77.881
Model_2	60.502	8.405	68.907
Model_3	58.838	9.212	68.05
Energy saving rate	**Heating**	**Cooling**	**Total**
Model_1&Model_2	16.44%	-53.60%	11.52%
Mode2_1&Model_3	2.75%	-9.60%	1.24%
Model_1&Model_3	18.74%	-68.35%	12.62%

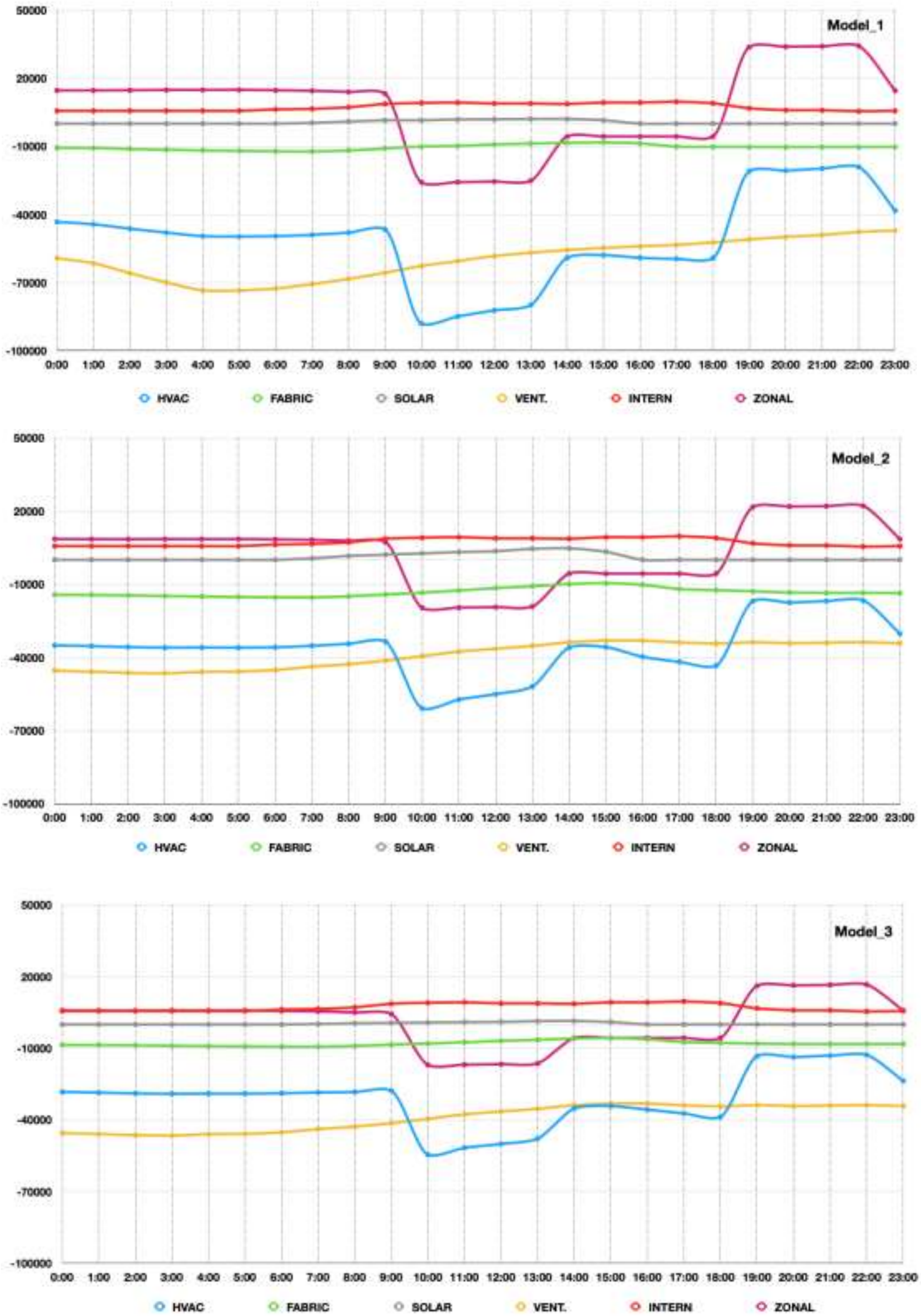


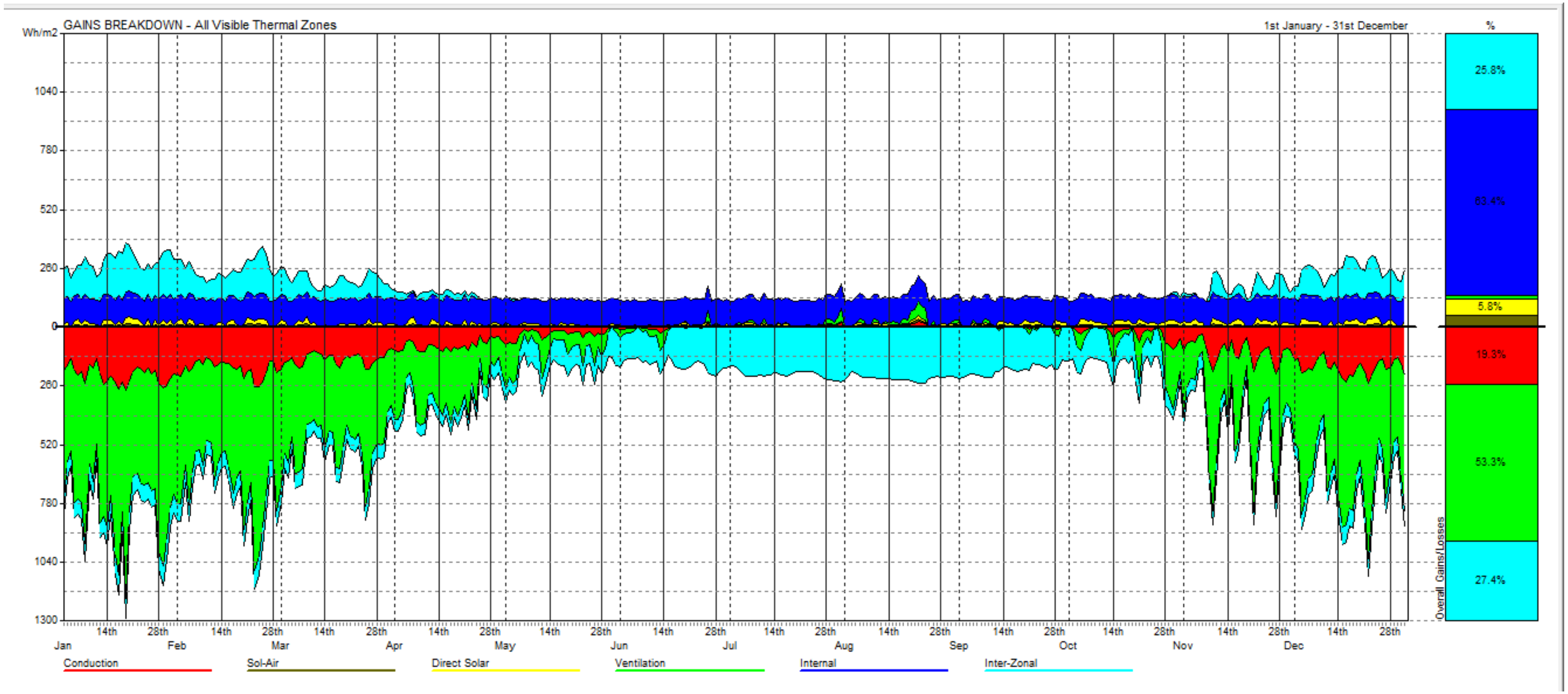
Figure 6-7. The hourly heat gains or losses result sheets of the three models

Figure 6-8. The monthly heating and cooling result sheets of the three models

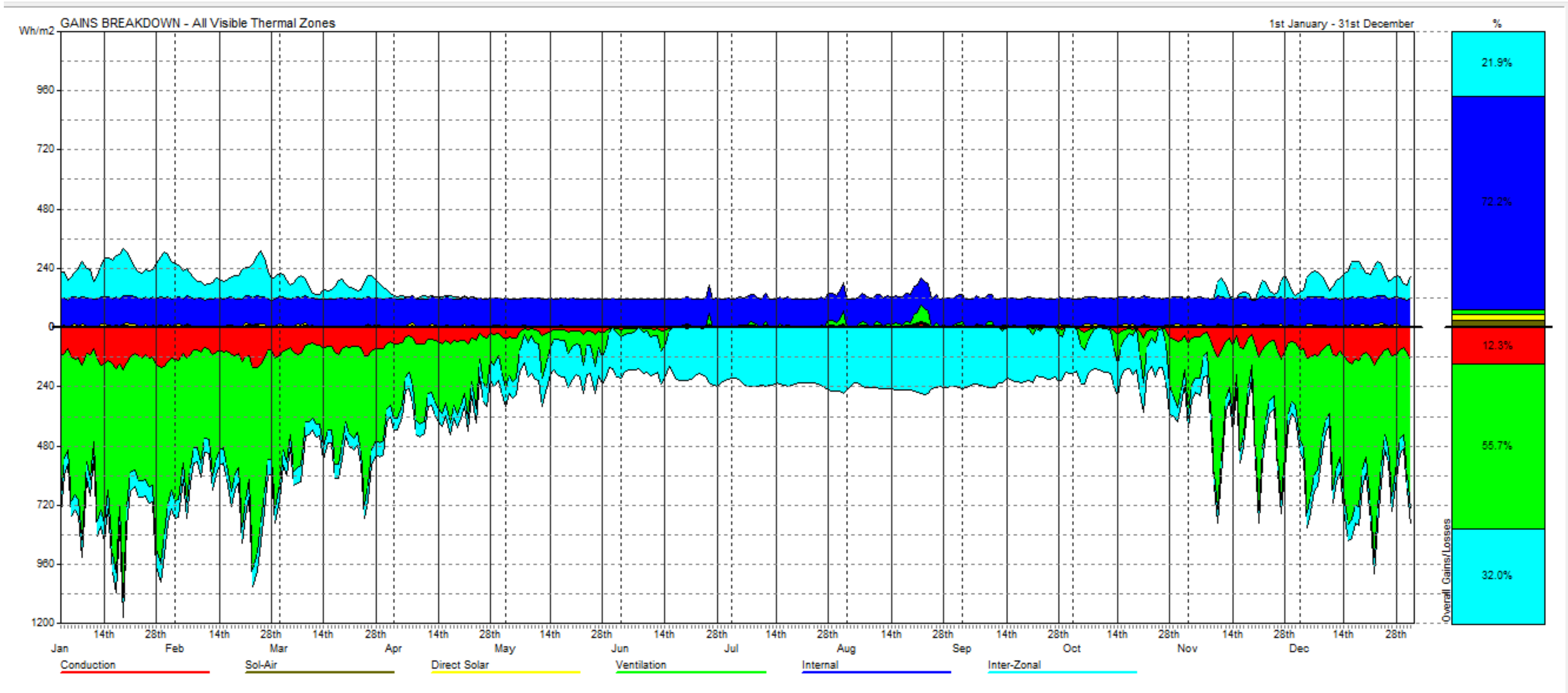
Passive gains breakdown

Through the data of "passive gains breakdown", it can be seen that the main energy consumption of buildings is mainly in three aspects: "Conduction, Ventilation and Inter-zonal". Comparing model one and model two, it can be seen that the total heat loss of model two has decreased significantly, from close to 1300Wh/㎡ to less than 1200Wh/㎡, and the energy saving rate is 7.69%. The proportion of conduction heat loss in the envelope also dropped significantly, from 19.3% to 12.3% of the total consumption. Improving the u-value of the building envelope and the air tightness of the doors and windows can effectively reduce the energy consumption of the building. At the same time, it is not difficult to find that Ventilation is the largest part of the heat loss of the building. On the one hand, it is caused by the poor air tightness of ordinary doors and windows, especially wooden doors, and many cold bridges. The courtyard not only increases the surface area of the building and improves the possibility of ventilation, but also makes the room generally small and the depth is too short. Once the airflow passes through, it will quickly take away the heat. In the case of the study, the maximum depth of the room is no more than 7 meters, and the heat is easily carried away (Figure 6-9).

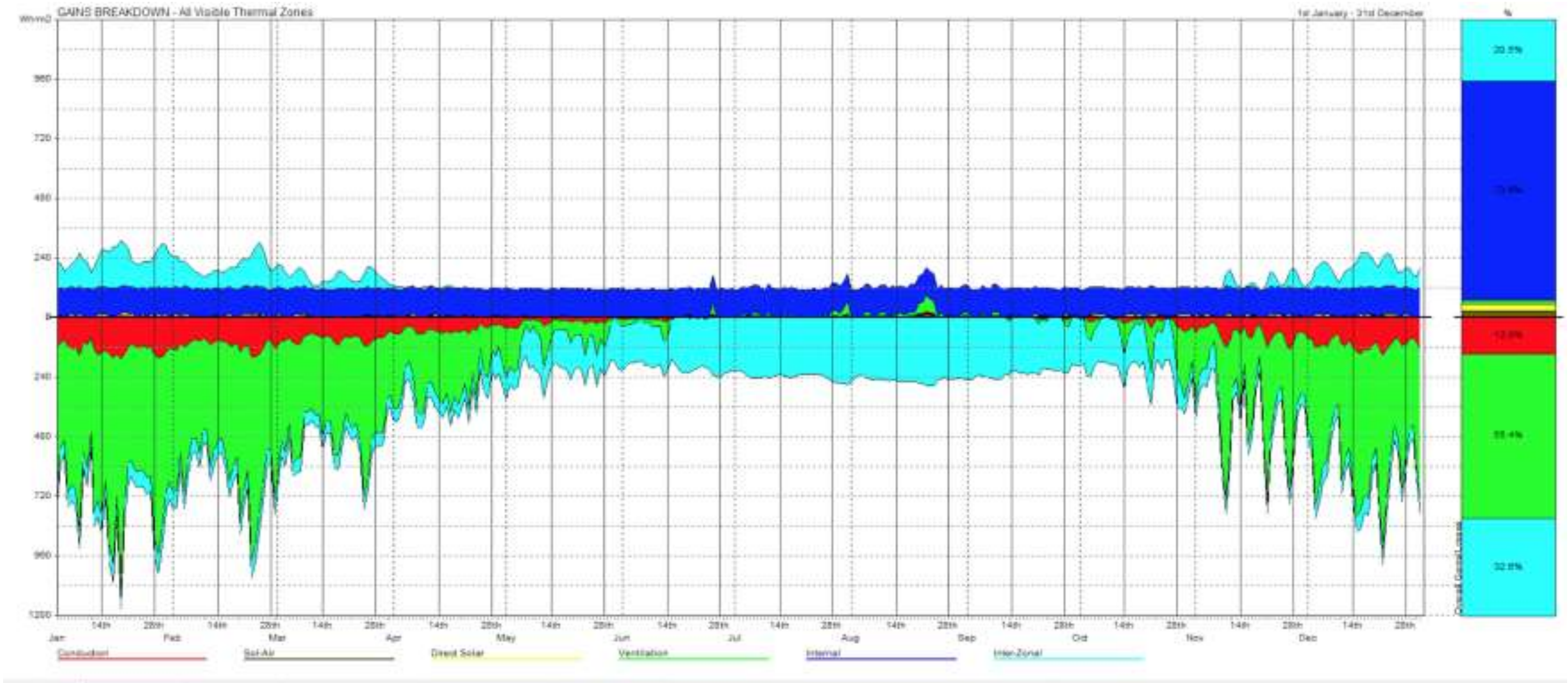
The data comparison results of Model_3 is also consistent with the comparison results of model one and model two. The total heat loss of Model three is further reduced on the basis of model two, in terms of conduction heat loss of the envelope, the total consumption drops from 19.3% to 12.0%.


GAINS BREAKDOWN - All Visible Thermal Zones
1st January - 31st December
Wh/m2
1040
780
520
260
0
260
520
780
1040
1300
14th
28th
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
%
25.8%
63.4%
5.8%
19.3%
53.3%
27.4%
Overall Gains/Losses
Conduction
Sol-Air
Direct Solar
Ventilation
Internal
Inter-Zonal

a. Model_1


GAINS BREAKDOWN - All Visible Thermal Zones
1st January - 31st December
Wh/m2
%
960
720
480
240
0
240
480
720
960
1200
14th
28th
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Conduction
Sol-Air
Direct Solar
Ventilation
Internal
Inter-Zonal
21.9%
72.2%
12.3%
55.7%
32.0%
Overall Gains/Losses

b. Model_2



c. Model_3

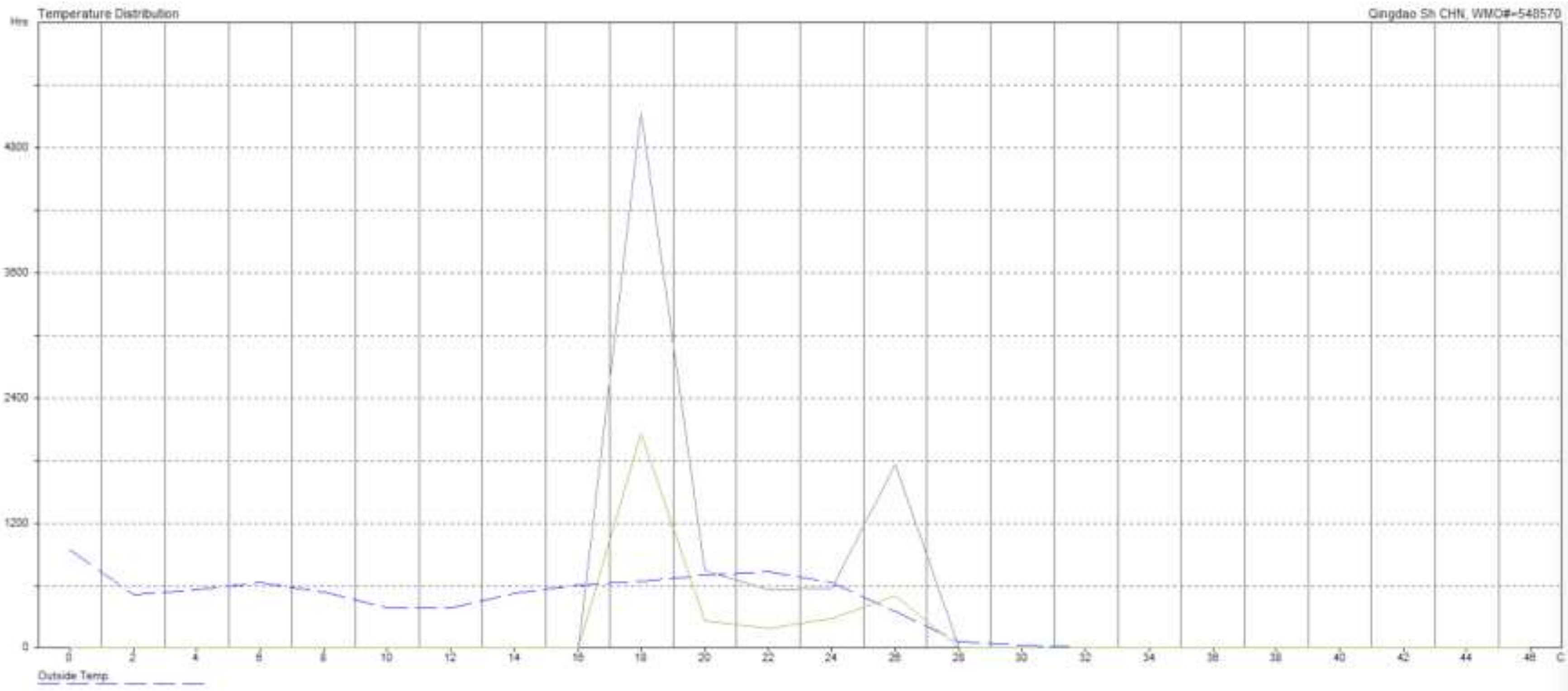
Figure 6-9. The passive gains breakdown result sheets of the three models

(a.Model_1; b.Model_2; c. Model_3)

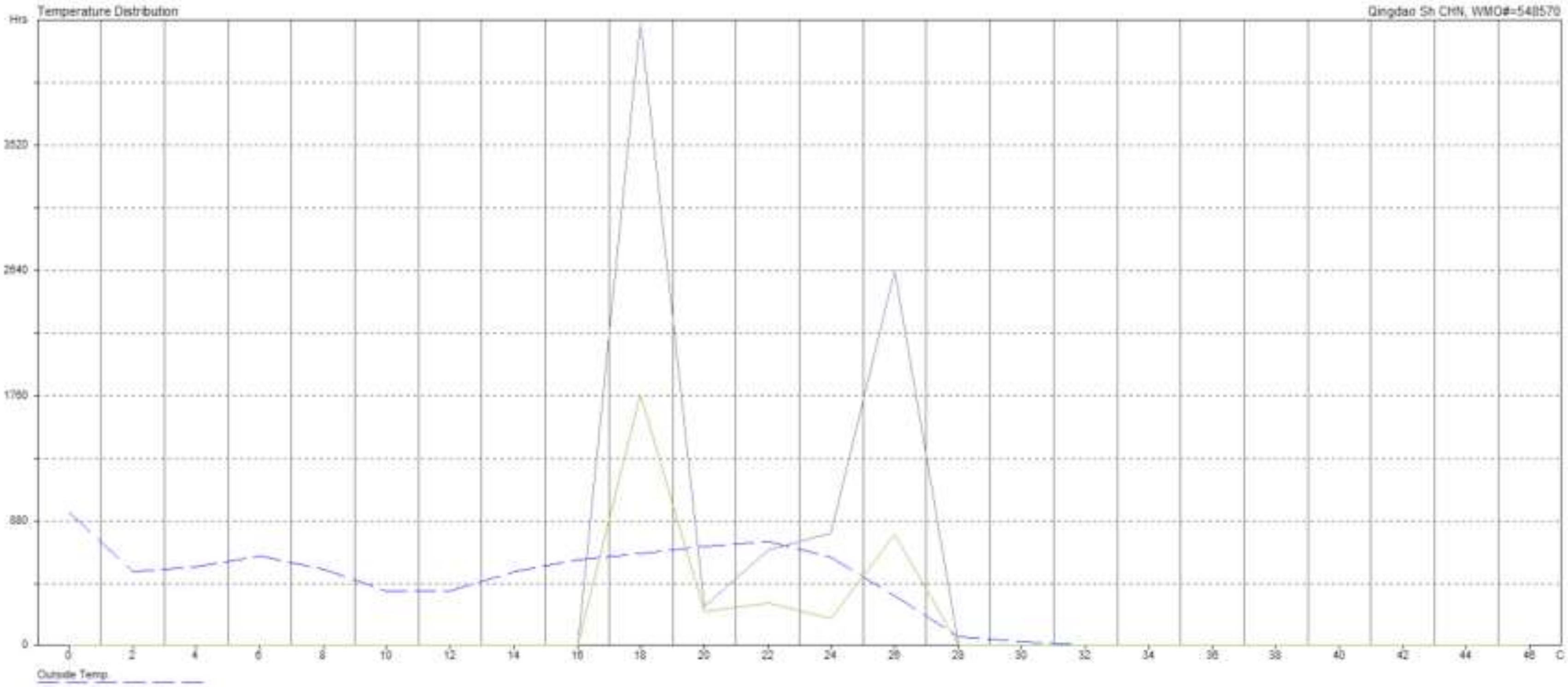
Temperature distribution

In the simulation, the indoor temperature is set to be kept between 16-28 degrees Celsius, but the results of the temperature distribution analysis show that there are differences in the temperature distribution of different test models within the 16-28 degrees Celsius range. In the comfort temperature range of 16-28 degrees, 22-26 is the relatively optimal indoor comfort temperature. The test results are real, compared to model_1, model_2 significantly increases the time in the range of 22-26 degrees Celsius. Model_1 keeps the indoor temperature at 22 degrees Celsius for about 373 hours, 24 degrees Celsius for about 425 hours, and 26 degrees Celsius for about 1130 hours. The indoor temperature of model_2 is about 490 hours at 22 degrees Celsius, about 491 hours at 24 degrees Celsius, and about 1710 hours at 26 degrees Celsius, an increase of 31.37%, 15.53% and 51.37% respectively. Renovations can improve the comfort of the indoor environment.

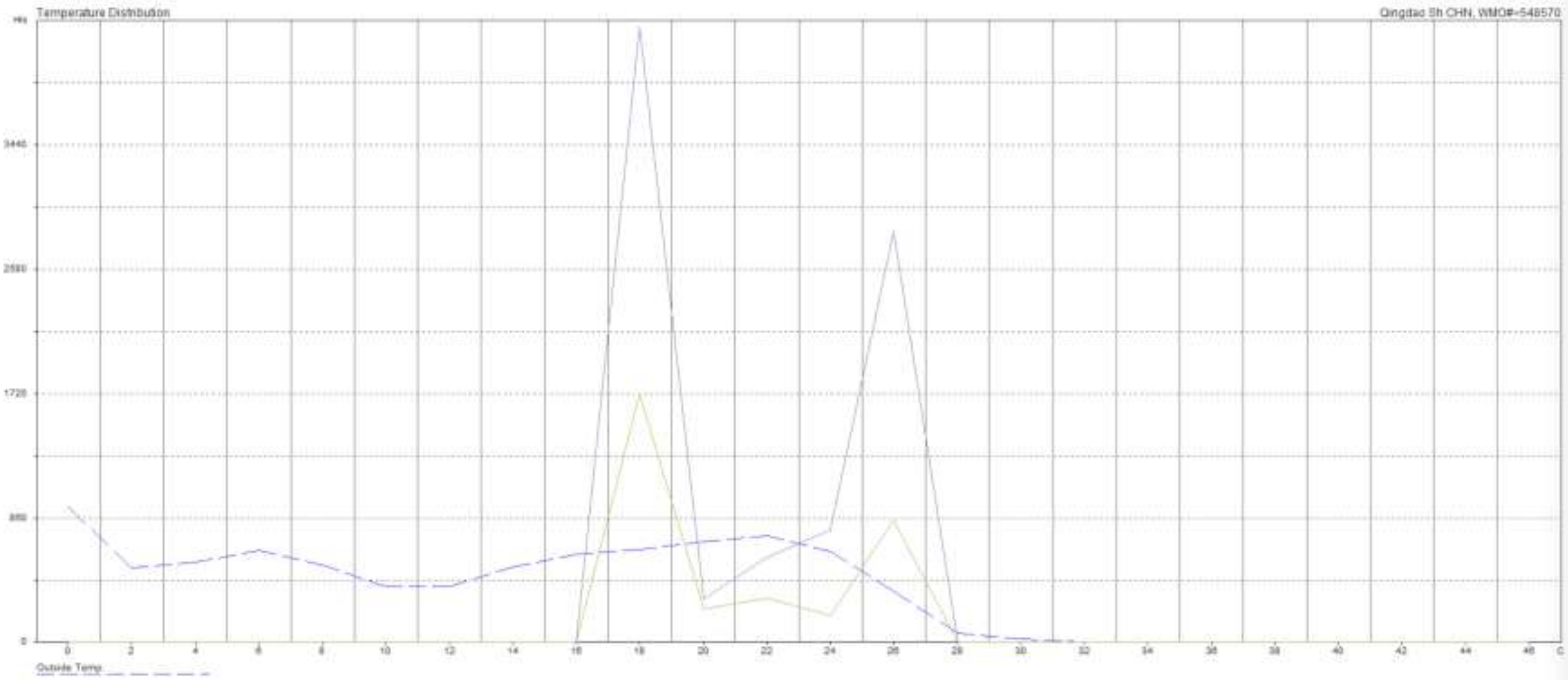
Based on Model_2, model_3 further increases the time in the range of 24-26 degrees Celsius. Model_3 maintains an indoor temperature of 26 degrees Celsius for about 1836 hours throughout the year, an increase of 62.48% over Model_1. At the same time, in the simulation of Model_1, the temperature of 18 degrees is about 3592.5 hours, while in Model_2 it is 3073 hours. In model_3, in the building simulation with corncob concrete as the wall, the time of the temperature of 18 degrees is reduced to 2992 hours, which shows that the change of the wall will change the uncomfortable feeling of the room. The wall of corncob material has a positive effect on the improvement of indoor comfort. This material further enhances the comfort of the interior environment. Through the analysis of the comfort temperature distribution of the three models, it can be seen that improving the thermal performance of the external structure of the building can not only reduce the energy consumption of the building, but also effectively improve the comfort inside the building(Table 6-10,Figure 6-10).


Temperature Distribution
Qingdao Sh CHN, WMO#=548570
Hrs
4800
3600
2400
1200
0
Outside Temp

a.model_1


Temperature Distribution
Qingdao Sh CHN, WMO#=548570
Hrs
3520
2640
1760
880
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
C
Outside Temp

b. model_2



b. model_3

Figure 6-10. The temperature distribution of the three models

(a.Model_1; b.Model_2; c. Model_3)

Table 6-10. The temperature distribution data sheet of three models

Model_1					
ANNUAL TEMPERATURE DISTRIBUTION			ANNUAL TEMPERATURE DISTRIBUTION		
1 floor			2 floor		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C			Comfort Band: 18.0 - 26.0 C		
In Comfort: 3285 Hrs (100.0%)			In Comfort: 8760 Hrs (100.0%)		
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0	0	0.00%	0	0	0.00%
2	0	0.00%	2	0	0.00%
4	0	0.00%	4	0	0.00%
6	0	0.00%	6	0	0.00%
8	0	0.00%	8	0	0.00%
10	0	0.00%	10	0	0.00%
12	0	0.00%	12	0	0.00%
14	0	0.00%	14	0	0.00%
16	0	0.00%	16	0	0.00%
18	2058	62.60%	18	5127	58.50%
20	260	7.90%	20	744	8.50%
22	186	5.70%	22	560	6.40%
24	279	8.50%	24	571	6.50%
26	502	15.30%	26	1758	20.10%
28	0	0.00%	28	0	0.00%
30	0	0.00%	30	0	0.00%
32	0	0.00%	32	0	0.00%
34	0	0.00%	34	0	0.00%
36	0	0.00%	36	0	0.00%
38	0	0.00%	38	0	0.00%
40	0	0.00%	40	0	0.00%
42	0	0.00%	42	0	0.00%
44	0	0.00%	44	0	0.00%
46	0	0.00%	46	0	0.00%
COMFORT	3285	100.00%	COMFORT	8760	100.00%

Model_2					
ANNUAL TEMPERATURE DISTRIBUTION			ANNUAL TEMPERATURE DISTRIBUTION		
1 floor			2 floor		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C			Comfort Band: 18.0 - 26.0 C		
In Comfort: 3285 Hrs (100.0%)			In Comfort: 8760 Hrs (100.0%)		
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0	0	0.00%	0	0	0.00%
2	0	0.00%	2	0	0.00%
4	0	0.00%	4	0	0.00%
6	0	0.00%	6	0	0.00%
8	0	0.00%	8	0	0.00%
10	0	0.00%	10	0	0.00%
12	0	0.00%	12	0	0.00%
14	0	0.00%	14	0	0.00%
16	0	0.00%	16	0	0.00%
18	1767	53.80%	18	4379	50.00%
20	238	7.20%	20	278	3.20%
22	304	9.30%	22	676	7.70%
24	190	5.80%	24	792	9.00%
26	786	23.90%	26	2635	30.10%
28	0	0.00%	28	0	0.00%
30	0	0.00%	30	0	0.00%
32	0	0.00%	32	0	0.00%
34	0	0.00%	34	0	0.00%
36	0	0.00%	36	0	0.00%
38	0	0.00%	38	0	0.00%
40	0	0.00%	40	0	0.00%
42	0	0.00%	42	0	0.00%
44	0	0.00%	44	0	0.00%
46	0	0.00%	46	0	0.00%
COMFORT	3285	100.00%	COMFORT	8760	100.00%

Model_3					
ANNUAL TEMPERATURE DISTRIBUTION			ANNUAL TEMPERATURE DISTRIBUTION		
1 floor			2 floor		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C			Comfort Band: 18.0 - 26.0 C		
In Comfort: 3285 Hrs (100.0%)			In Comfort: 8760 Hrs (100.0%)		
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0	0	0.00%	0	0	0.00%
2	0	0.00%	2	0	0.00%
4	0	0.00%	4	0	0.00%
6	0	0.00%	6	0	0.00%
8	0	0.00%	8	0	0.00%
10	0	0.00%	10	0	0.00%
12	0	0.00%	12	0	0.00%
14	0	0.00%	14	0	0.00%
16	0	0.00%	16	0	0.00%
18	1719	52.30%	18	4265	48.70%
20	231	7.00%	20	296	3.40%
22	304	9.30%	22	590	6.70%
24	186	5.70%	24	782	8.90%
26	845	25.70%	26	2827	32.30%
28	0	0.00%	28	0	0.00%
30	0	0.00%	30	0	0.00%
32	0	0.00%	32	0	0.00%
34	0	0.00%	34	0	0.00%
36	0	0.00%	36	0	0.00%
38	0	0.00%	38	0	0.00%
40	0	0.00%	40	0	0.00%
42	0	0.00%	42	0	0.00%
44	0	0.00%	44	0	0.00%
46	0	0.00%	46	0	0.00%
COMFORT	3285	100.00%	COMFORT	8760	100.00%

In fact, since the Qingdao courtyard was built in the last century, the current situation of these buildings is not optimistic. Most of them are facing the problems of aging building structure and wall cracking, and many wall blocks are severely weathered and corroded. Therefore, in the implementation process of a large number of renovation and renewal projects, the wall and roof materials are replaced on the basis of retaining the original structure as much as possible. It can be said that in the renovation and renewal of Qingdao courtyard, the most common way to renew the wall is to rebuild the masonry with blocks. The reconstruction of the wall provides a new possibility for the sustainable reconstruction of the building in the choice of building wall materials. This is also the reason why the author studied model_3 and researched new recycled concrete.

6.5. Ladybug and honeybee simulation: Comparative Analysis

In grasshopper, load the real data and all the information and parameters of the simulation to Model_1 and Model_2, respectively (Figure 6-11, Figure 6-12).

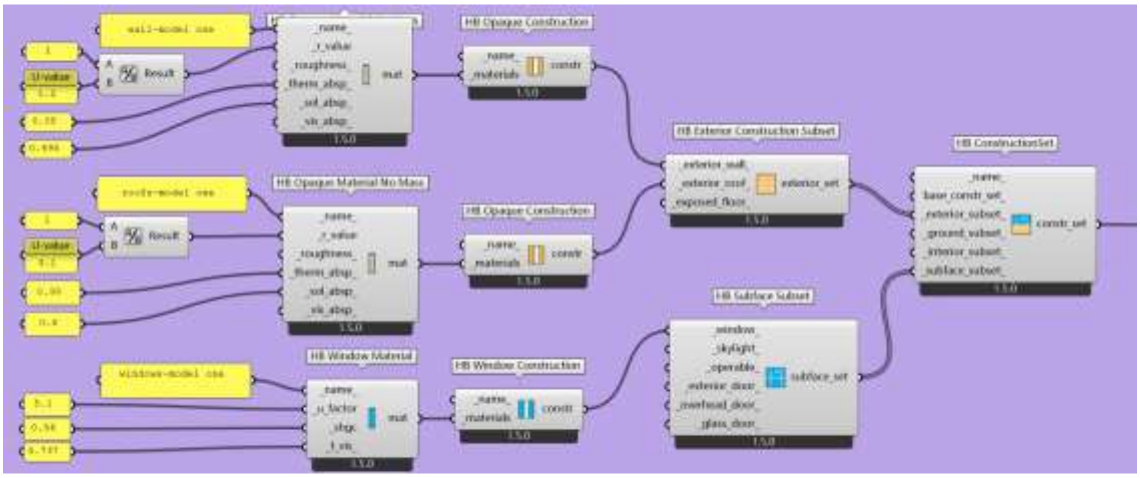


Figure 6-11. The simulation Settings of Model_1

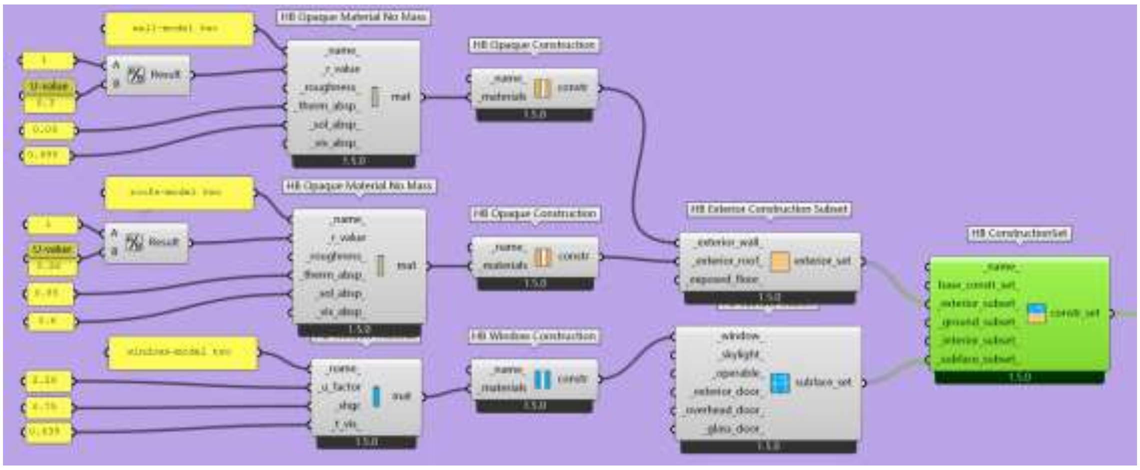


Figure 6-12. The simulation settings of Model_2

6.5.1. Comparative Analysis of Model_1 and Model_2

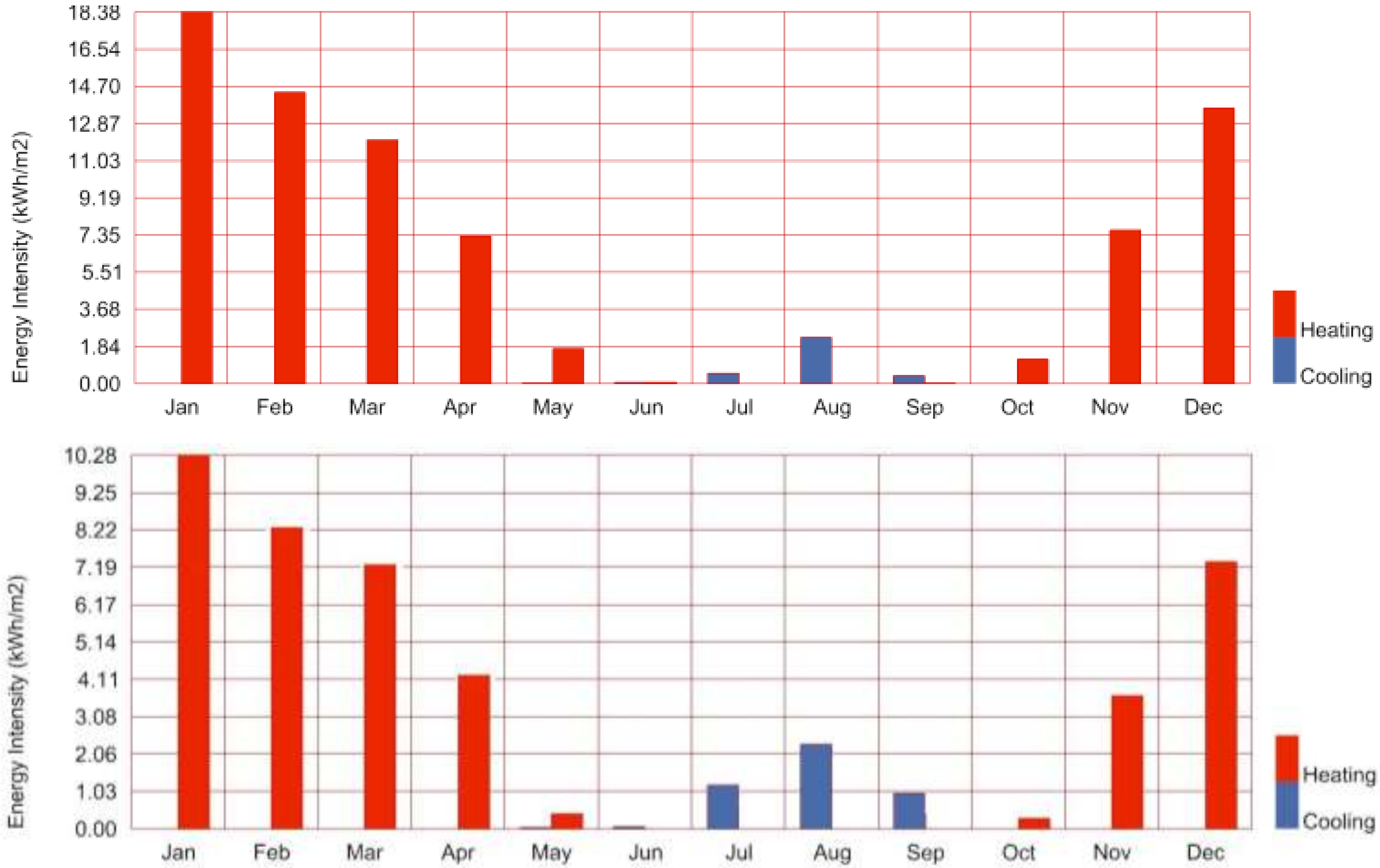
The energy consumption simulation results of model_1 before the repair and model_2 after the repair show that the cooling energy consumption per unit area of model_1 before the repair is 5.29 kwh/m2, the heating energy consumption per unit area is 72.35 kWh/m2, and the total energy consumption per unit area is 77.64 kWh /m2. In winter, the energy consumption of heating is large, and users need to consume a lot of energy to ensure indoor thermal comfort. After the renovation, the cooling energy consumption per unit area of model_2 was 7.56 kWh/m2, the heating energy consumption per unit area was 59.81 kWh/m2, a decrease of 17.32%, the total energy consumption per unit area was 67.37 kWh/m2, and the energy saving rate was 12.98% (Figure 6-13, 6-14, Table 6-11).

Table 6-11. The energy consumption contrast

Simulation data	Heating	Cooling	Total
Model_1	72.34762	5.290894	77.63851
Model_2	59.81053	7.559994	67.37053
Energy saving rate	Heating	Cooling	Total
Model_1&Model_2	17.32%	-42.91%	12.98%

The energy balance diagram of the courtyard building shows that the heat load is relatively high from November to March of the following year. After entering April, the outdoor air temperature rises, the heat load gradually decreases, and the cooling load gradually increases. The cooling load reaches the maximum value in August. Among them, the most heat is lost through the opaque envelope during the heating period in winter, followed by the heat loss caused by air infiltration and glass. The reasons are analyzed due to poor air tightness of the building and poor thermal performance of the envelope; cooling in summer Due to air infiltration, the indoor heat is too high, which increases the cooling load of the building.

After the repair, the total energy consumption of the model_2 building is reduced. Only the repair work can reduce the cooling and heating load of the building and achieve a certain energy saving effect. However, the repair work cannot significantly improve the thermal performance of the building envelope. The main reason for the high energy consumption is that the renovation of the courtyard should be combined with the energy-saving optimization measures of the enclosure structure to achieve the ideal energy-saving effect.



a. Model_1

b. Model_2

Figure 6-13. The energy comparison before and after renovation (a. Model_1 b.Model_2)

a. Model_1

b. Model_2

Figure 6-14. The energy balance before and after repair (a.Model_1 b.Model_2)

6.5.2. Comparative Analysis of Model_2 and Model_3

Model_3 is the result of using the wall optimization (Figure 6-15). The internal thermal insulation structure model with corncob as the wall material was established in the Rhino parametric design platform, and the heat transfer coefficient was corrected using the software. During the simulation, the indoor boundary temperature was set to 18°C, and the outdoor boundary temperature was the average outdoor temperature of 3.6°C during the heating period in Qingdao. Based on the model_2 model after the repair, the heat transfer coefficient of the corncob concrete wall is used, and other parameters are kept unchanged. The Energy plus software built in the Honeybee plug-in simulates the influence of different wall heat transfer coefficients on the energy consumption of the courtyard building, and finds energy saving rate.

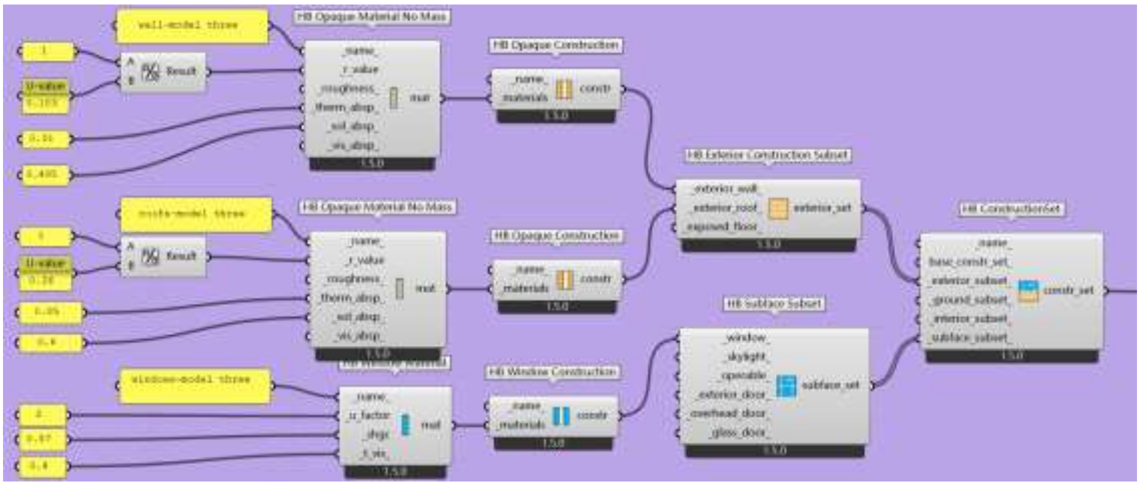


Figure 6-15. The simulation Settings of Model_3

The simulation results show that the cooling energy consumption per unit area of model_3 after changing the wall material is 8.26kWh/m2, the heating energy consumption per unit area is 58.59kWh/m2, and the total energy consumption per unit area is 66.86kWh/m2. Compared to the pre-renovation, the energy saving was 13.88%, and compared to the standard repair, the energy saving was 5.8% (Figure 6-16,6-17,Table 6-12).

Table 6-12. The energy consumption contrast of the three models

Simulation data	Heating	Cooling	Total
Model_1	72.34762	5.290894	77.63851
Model_2	59.81053	7.559994	67.37053
Model_3	58.58821	8.267142	66.85535
Energy saving rate			
Model_1&Model_2	17.32%	-42.91%	12.98%
Model_2&Model_3	2.06%	-9.40%	5.80%
Model_1&Model_3	19.02%	-56.14%	13.88%

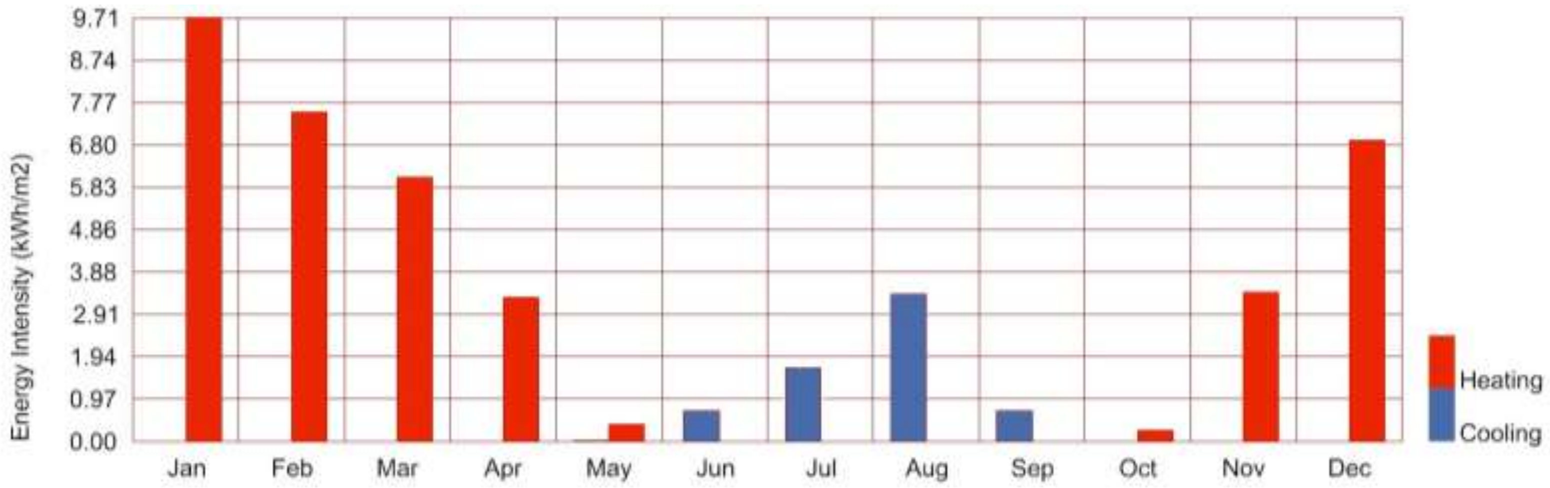


Figure 6-16. The energy consumption of Model_3

Figure 6-17. The energy balance analysis of Model_3

6.6. Comparison of two groups of data

Comparing the analysis data of the two software, it can be found that the energy consumption of heating and cooling is basically the same. The energy of model 1 under Ecotect analysis software is 72.409kW for heating, 5.472kW for cooling, 77.881kW for total energy consumption, and 77.881kW for honeybee. The consumption is 72.348kW for heating, 5.291kW for cooling, and the total amount is 77.639kW. The number of digits after the decimal point is omitted, and the data is the same.

In the software, due to the different classification of parameter settings, there will be slight differences. If in Ecotect, the door has different parameter settings, while in ladybug and honeybee software, the door parameters are default. The final simulation results of model_2 and model_3 is similar. The data is that the heating of model 2 is 60.502 kW and 59.810 kW, the cooling is 8.405 kW and 7.560 kW, the total amount is 68.907 kW and 67.371 kW, and the heating capacity of model 3 is 58.838 kW and 58.588 kW., Refrigeration 9.212 kW and 8.267 kW, the total is 68.05 kW and 66.855 kW, remove the decimal point to take an integer, the basic value is the same (Table 6-13).

For the energy saving of the entire simulated building, under the corncob concrete material in the Ecotect analysis software, the energy saving rate is 12.62%, and the energy saving rate of honeybee is 13.88%, as shown in the figure (Figure6-18), the trends are almost similar. So, the data can be trusted. The use of corncob material helps save energy.

Table 6-13. The data comparison table between the two software

	Heating	Cooling	Total
EA:Model_1	72.409	5.472	77.881
L:Model_1	72.348	5.291	77.639
EA:Model_2	60.502	8.405	68.907
L:Model_2	59.810	7.560	67.371
EA:Model_3	58.838	9.212	68.05
L:Model_3	58.588	8.267	66.855
Energy saving rate			
EA:Model_1&Model_2	16.44%	-53.60%	11.52%

L:Model_1&Model_2	17.32%	-42.91%	12.98%
EA:Model_2&Model_3	2.75%	-9.60%	1.24%
L:Model_2&Model_3	2.06%	-9.40%	5.80%
EA:Model_1&Model_3	18.74%	-68.35%	12.62%
L:Model_1&Model_3	19.02%	-56.14%	13.88%

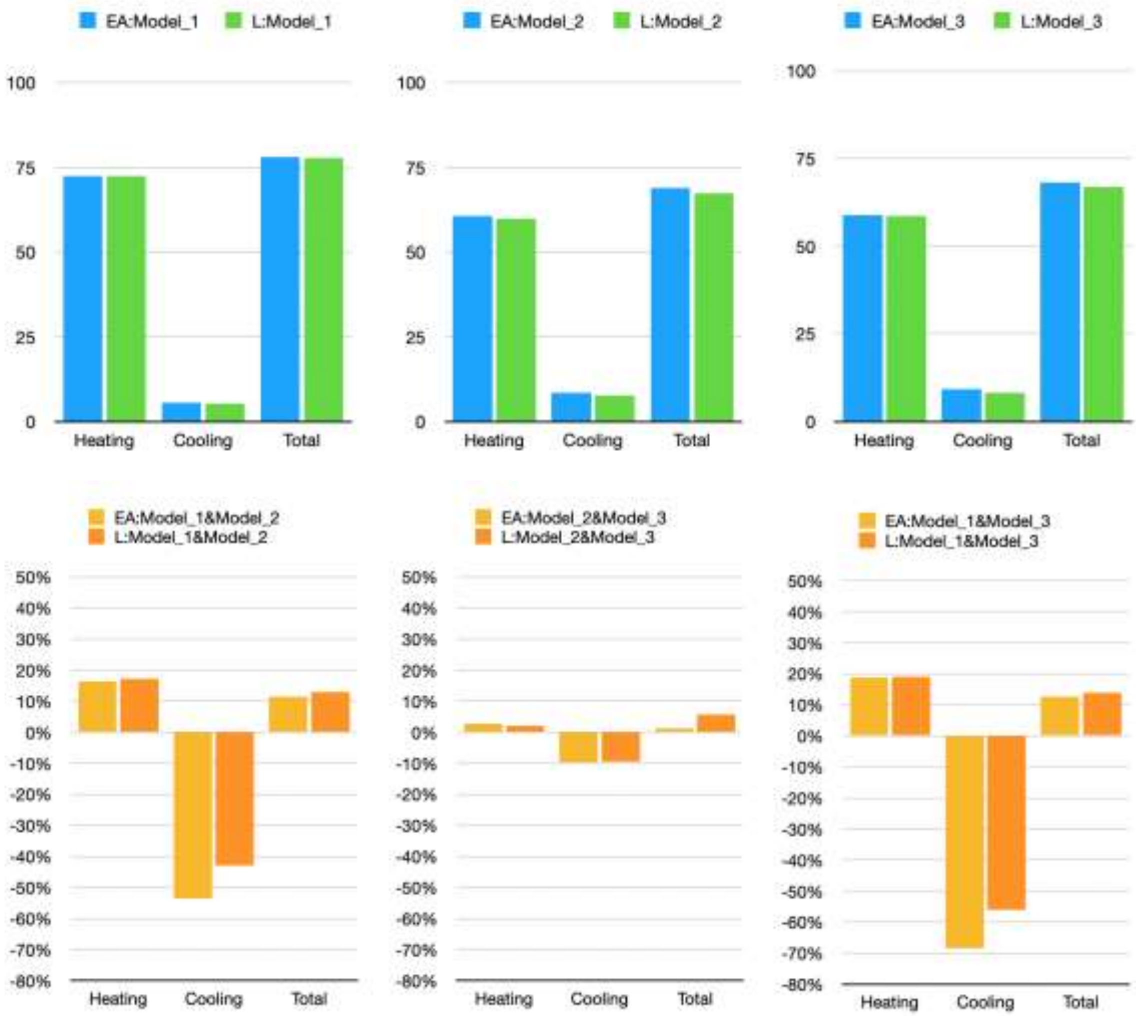
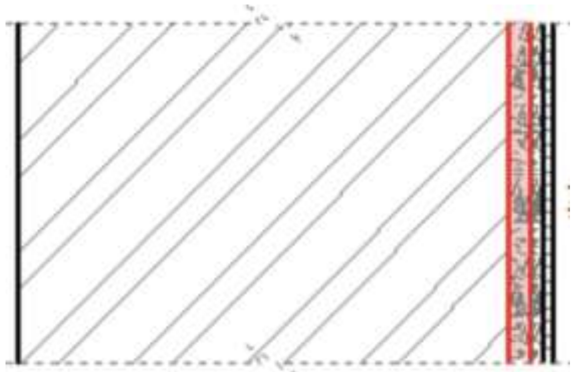


Figure 6-18. Comparison of data from Ecotect analysis and ladybug +honeybee software

6.7. Analysis of replacement insulation material

Set a certain thickness of corncob concrete outside the traditional wall envelope to conduct simulation experiments, which test the living comfort of the building and the variation of building energy consumption. Corncob concrete with a thickness of 20mm is set inside the plastering layer outside the traditional brick wall, and other parameters are consistent with Model_2 (as shown in the table 6-14). Setting the material configuration as model_4, it performed energy consumption simulation in the Ecotect analysis software; the results are listed as below:

Table 6-14. The data of new material as insulation layer in the wall

	Thickness	Density	Specific heat capacity	Thermal conductivity
Brick masonry medium	450	2000	836.8	0.711
Concrete corncob	20	1600	656.9	0.259
Cement plaster, sand	10	1860	840	0.720
Plaster building	10	1250	1088	0.431
Structural layer				

Monthly heating and cooling loads

The monthly energy consumption is simulated as follows: the maximum heating energy consumption is 91620 W at 10:00 on 18th January; the maximum cooling energy consumption Max Cooling is 16723 W at 13:00 on 21st August. For the whole year, the energy consumption of heating is 65.888kw, the energy consumption of cooling is 5.845kW, and the total energy consumption is71.732kW (figure6-19, table 6-15).

Model_1 is the original wall, Model_2 is a layer of insulation layer added, and Model_4 is the replacement of the insulation layer with corncob concrete material. After calculation, the heating energy consumption of Model_4 is 65.888 kW, the cooling energy is 5.845 kW, and the total energy is 71.732 kW. Compared with the simulated data of Model_1 and Model_2 (in table), it can be seen that the energy consumption of Model_4 is significantly higher than that of Model_1. It shows that corncob concrete has good thermal performance, and it can still greatly reduce indoor energy consumption even when it is only 20mm thick. However, compared with model 2, the energy-saving effect of Model_4 still has a certain gap, indicating that under the same thickness. The thermal performance of corncob concrete is not as good as that of high-density insulation board (Table 6-17).

Table 6-15. The temperature distribution data sheet of new model

MONTHLY HEATING/COOLING LOADS			
Max Heating: 91620 W at 10:00 on 18th January			
Max Cooling: 16723 W at 13:00 on 21st August			
	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
------------	---------	---------	----------
Jan	26069902	0	26069902
Feb	20007828	0	20007828
Mar	15961336	0	15961336
Apr	6924513	0	6924513
May	699055	0	699055
Jun	0	594855	594855
Jul	0	2967812	2967812
Aug	0	4013850	4013850
Sep	0	1507867	1507867
Oct	767120	0	767120
Nov	10826901	0	10826901
Dec	21154246	0	21154246
------------	---------	---------	----------
TOTAL	102410904	9084384	111495288
------------	---------	---------	----------
PER M?	65888	5845	71732
Floor Area:	1554.322 m^2		

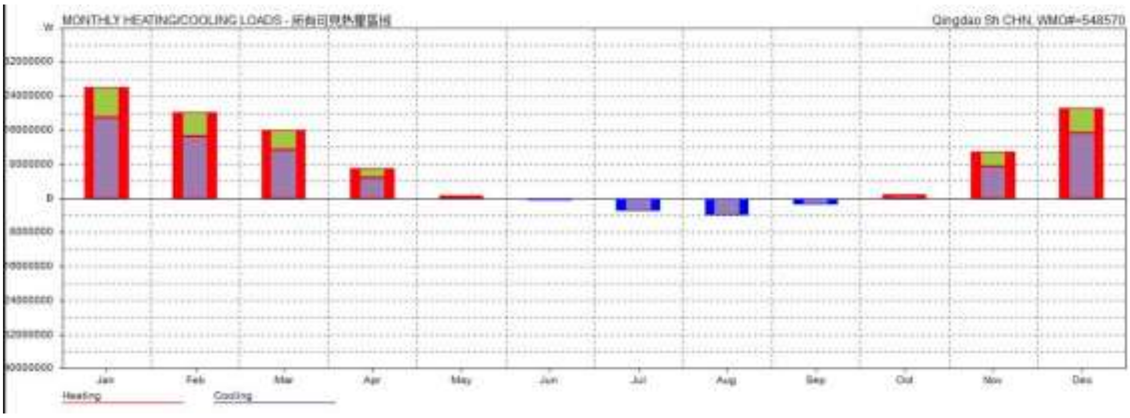


Figure 6-19. The monthly heating and cooling of the model_4

Passive gains breakdown

The loss of FABRIC gains is 11.5%, the loss of VENTILATION is 52.3%, the loss of inter-zonal is 36.2%, the energy gained is 58.8%, and the heat gain of internal personnel and equipment is 37.7% (Table 6-16, Figure 6-20).

Table 6-16.The gains breakdown data sheet of new model

GAINS BREAKDOWN - All Visible Thermal Zones		
CATEGORY	LOSSES	GAINS
FABRIC	11.50%	0.20%
SOL-AIR	0.00%	2.10%
SOLAR	0.00%	0.40%
VENTILATION	52.30%	0.90%
INTERNAL	0.00%	37.70%
INTER-ZONAL	36.20%	58.80%

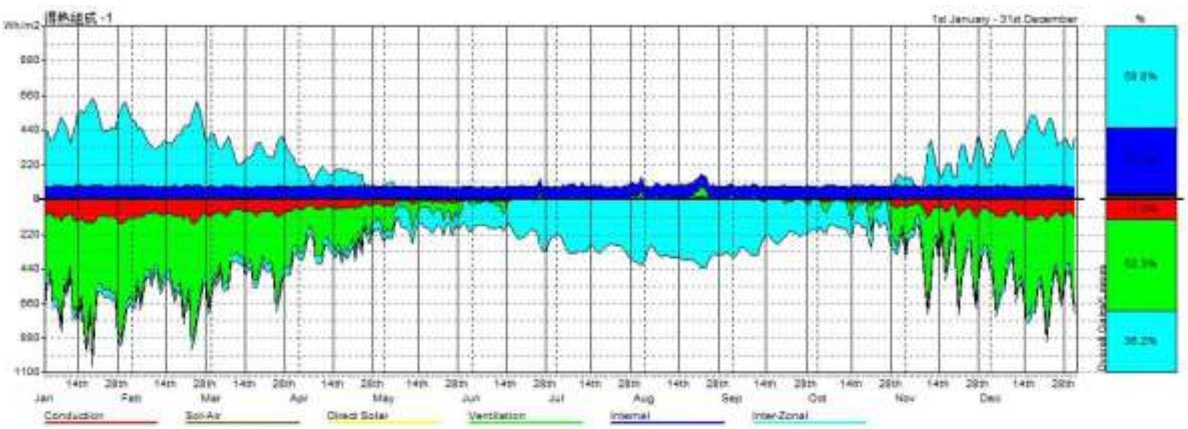


Figure 6-20. The passive gains breakdown of the model_4

Table 6-17. The data comparison table of three models

Simulation data	Heating	Cooling	Total
Model_1	72.409	5.472	77.881
Model_2	60.502	8.405	68.907
Model_4	65.888	5.845	71.732

The comfort temperature distribution

The data on the first floor of the comfort level in Model_4 is 1981 hours at 18 ℃, accounting for 60.3%, 308 hours at 20 ℃, accounting for 9.4%, and 287 hours at 24 ℃, accounting for 8.7%. 26 degrees is 535 hours, accounting for 16.3%; the data on the second floor is 18 ℃ 4879 hours, accounting for 55.7%, 20 ℃ is 691 hours, accounting for 7.9%, 22 ℃ is 650 hours, accounting for 7.4%, 24 ℃ is 548 hours, Accounted for 6.1%, 26 ℃ for 2002 hours, accounting for 22.9% (Figure6-21,Table 6-18).

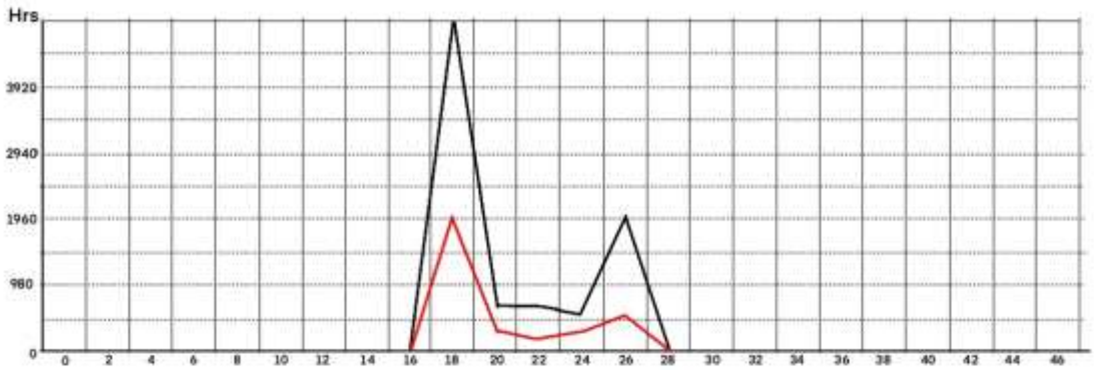


Figure 6-21. The annual comfort temperature distribution of model_4

Table 6-18. The temperature distribution of model_4

ANNUAL TEMPERATURE DISTRIBUTION						
Floor 1				Floor 2		
Operation: Weekdays 09-18, Weekends 09-18.				Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C						
TEMP.	HOURS	PERCENT		TEMP.	HOURS	PERCENT
0.0	0	0.00%		0.0	0	0.00%

2.0	0	0.00%		2.0	0	0.00%
4.0	0	0.00%		4.0	0	0.00%
6.0	0	0.00%		6.0	0	0.00%
8.0	0	0.00%		8.0	0	0.00%
10.0	0	0.00%		10.0	0	0.00%
12.0	0	0.00%		12.0	0	0.00%
14.0	0	0.00%		14.0	0	0.00%
16.0	0	0.00%		16.0	0	0.00%
18.0	1981	60.30%		18.0	4879	55.70%
20.0	308	9.40%		20.0	691	7.90%
22.0	174	5.30%		22.0	650	7.40%
24.0	287	8.70%		24.0	538	6.10%
26.0	535	16.30%		26.0	2002	22.90%
28.0	0	0.00%		28.0	0	0.00%
30.0	0	0.00%		30.0	0	0.00%
32.0	0	0.00%		32.0	0	0.00%
34.0	0	0.00%		34.0	0	0.00%
36.0	0	0.00%		36.0	0	0.00%
38.0	0	0.00%		38.0	0	0.00%
40.0	0	0.00%		40.0	0	0.00%
42.0	0	0.00%		42.0	0	0.00%
44.0	0	0.00%		44.0	0	0.00%
46.0	0	0.00%		46.0	0	0.00%
COMFORT	3285	100.00%		COMFORT	8760	100.00%

Combining the comfortable temperature distributions of Model_1, Model_2, and Model_4, it can be seen that the comfort temperature of Model_4 has no significant change from the results of Model_1 (Figure), and the occupancy hours of 26 ℃ on the 1st floor are reduced from the original 502 hours It rises to 535 hours, which is much less than 786 hours of model_2; similarly, in the simulated data of the second layer, the 26 ℃ of model_4 is 2002 hours, and the model_1 is 1758 hours, both of which are less than 2635 hours of model_2. This shows that although the corncob material can significantly improve the energy-saving effect of buildings, however, it is not great enough to improve the indoor thermal comfort. Compared with high-density insulation boards, the thermal performance is still far behind, and it does not meet the conditions for being an insulation material (Table 6-19 Figure 6-22,6-23).

Table 6-19. The comfort temperature analysis table of the three models

1Floor(hours)				2Floor(hours)		
Temperature	Model_4	Model_1	Model_2	Model_4	Model_1	Model_2
18degree	1981	2058	1767	4879	5127	4379
20degree	308	260	238	691	744	278
22degree	174	186	304	650	560	676
24degree	287	279	190	538	571	792
26degree	535	502	786	2002	1758	2635

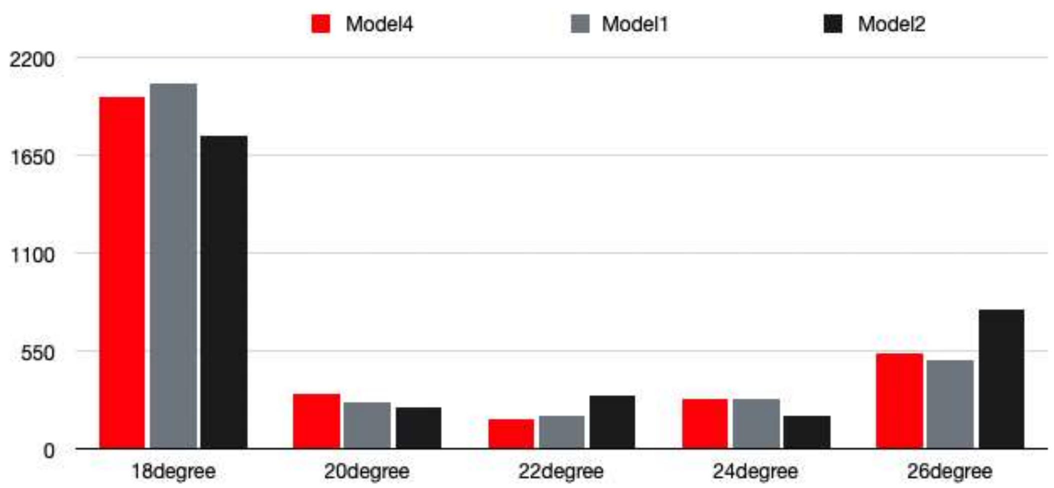


Figure 6-22. The comfort temperature distribution analysis on the first floor of Case A

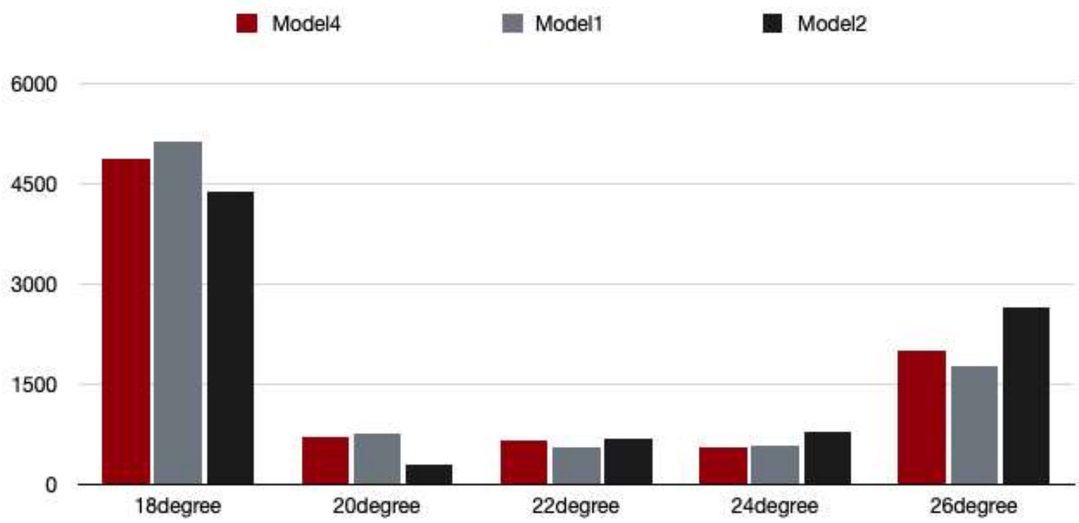


Figure 6-23. The comfort temperature distribution analysis on the second floor of Case A

6.8. Analysis of Retrofit Operation

Based upon the result of simulation in part 6.4, 6.5, 6.6, it is proved that the corncob recycled concrete can be used as an energy-saving material. During the renovation, especially considering the practical reason, replacing partial wall in each façade is considered as better renovation option. The energy consumption data could be obtained by simulating the replacement of partial wall. The east, south, west, and north facades of the case study building were replaced with corncob recycled concrete, and the energy consumption simulation of the replaced model was carried out, the final results were compared and analyzed.

- **Analysis of Monthly loads and discomfort：**

If the north facade is replaced with corncob recycled concrete, the monthly energy consumption is simulated as follows: the maximum heating energy consumption is 87916 W at 10:00 on 18th January; the maximum cooling energy consumption Max Cooling is 18393 W at 13:00 on 21st August. For the whole year, the energy consumption of heating is 60.289kw, the energy consumption of cooling is 8.522kW, and the total energy consumption is 68.811kW.

If the south facade is replaced with corncob recycled concrete, the monthly energy consumption is simulated as follows: the maximum heating energy consumption is 87870 W at 10:00 on 18th January; the maximum cooling energy consumption Max Cooling is 18427 W at 13:00 on 21st August. For the whole year, the energy consumption of heating is 60.197kw, the energy consumption of cooling is 8.569kW, and the total energy consumption is 68.766kW.

If the east facade is replaced with corncob recycled concrete, the monthly energy consumption is simulated as follows: the maximum heating energy consumption is 87970 W at 10:00 on 18th January; the maximum cooling energy consumption Max Cooling is 18363 W at 13:00 on 21st August. For the whole year, the energy consumption of heating is 60.388kw, the energy consumption of cooling is 8.465kW, and the total energy consumption is 68.853kW.

If the west facade is replaced with corncob recycled concrete, the monthly energy consumption is simulated as follows: the maximum heating energy consumption is 87938 W at 10:00 on 18th January; the maximum cooling energy consumption Max Cooling is 18377W at 13:00 on 21st August. For the whole year, the energy consumption of heating is 60.333kw, the energy consumption of cooling is 8.493kW, and the total energy consumption is 68.825kW.

(Figure 6-24,6-25,6-26,6-27; Table 6-20,6-21,6-22,6-23)

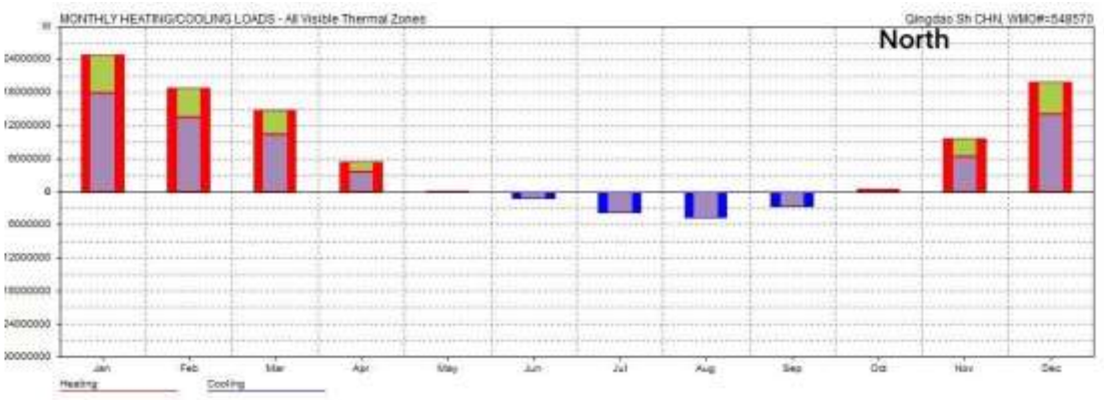


Figure 6-24. The monthly heating and cooling when changes NORTH facade

Table 6-20. The data of monthly heating and cooling loads when changes NORTH facade

MONTHLY HEATING/COOLING LOADS			
North			
Max Heating: 87916 W at 10:00 on 18th January			
Max Cooling: 18393 W at 13:00 on 21st August			
	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	24701242	0	24701242
Feb	18838994	0	18838994
Mar	14777605	0	14777605
Apr	5412224	0	5412224
May	173350	32806	206156
Jun	0	1412318	1412318
Jul	0	3960419	3960419
Aug	0	4854930	4854930
Sep	0	2866776	2866776
Oct	414363	118285	532649
Nov	9517582	0	9517582
Dec	19873784	0	19873784
TOTAL	93709144	13245534	106954680
PER M?	60289	8522	68811
Floor Area:	1554.322 m^2		

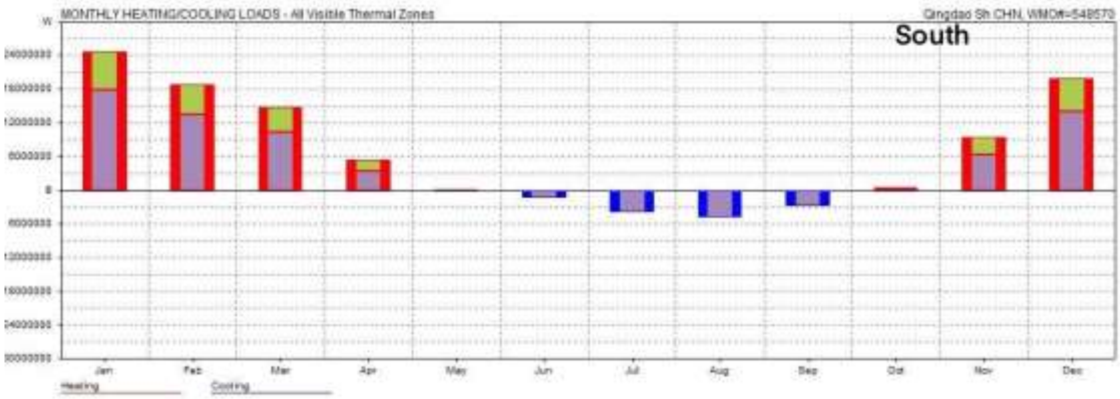


Figure 6-25. The monthly heating and cooling when changes SOUTH facade

Table 6-21. The data of monthly heating and cooling loads when changes SOUTH facade

MONTHLY HEATING/COOLING LOADS			
South			
Max Heating: 87870 W at 10:00 on 18th January			
Max Cooling: 18427 W at 13:00 on 21st August			
	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	24681768	0	24681768
Feb	18822382	0	18822382
Mar	14760737	0	14760737
Apr	5399695	0	5399695
May	172125	33495	205621
Jun	0	1420591	1420591
Jul	0	3974022	3974022
Aug	0	4868330	4868330
Sep	0	2887838	2887838
Oct	394816	135215	530032
Nov	9478610	0	9478610
Dec	19854752	0	19854752
TOTAL	93564888	13319491	106884376
PER M?	60197	8569	68766
Floor Area:	1554.322 m^2		

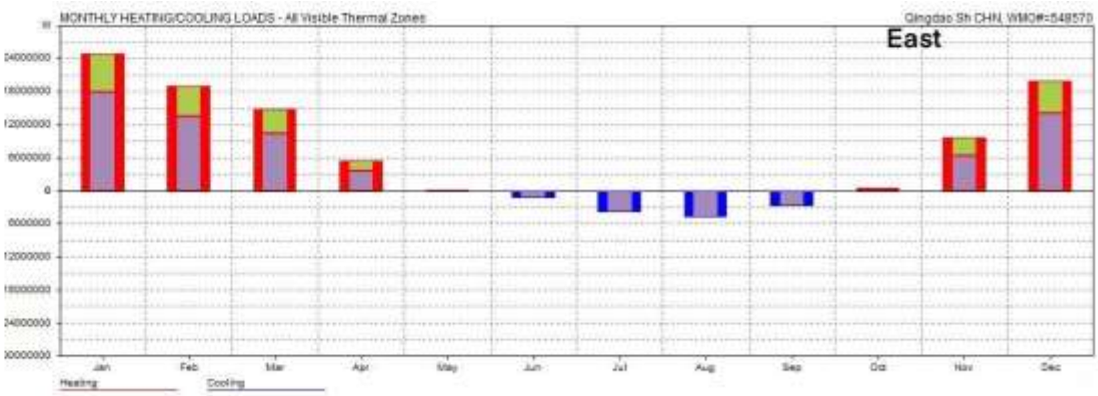


Figure 6-26.The monthly heating and cooling when change EAST facade

Table 6-22. The data of monthly heating and cooling loads when changes EAST façade

MONTHLY HEATING/COOLING LOADS			
East			
Max Heating: 87970 W at 10:00 on 18th January			
Max Cooling: 18363 W at 13:00 on 21st August			
	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	24721798	0	24721798
Feb	18857184	0	18857184
Mar	14797037	0	14797037
Apr	5440298	0	5440298
May	175359	31946	207305
Jun	0	1401717	1401717
Jul	0	3943084	3943084
Aug	0	4838356	4838356
Sep	0	2844649	2844649
Oct	440559	97441	538000
Nov	9537147	0	9537147
Dec	19893368	0	19893368
TOTAL	93862752	13157192	107019944
PER M?	60388	8465	68853
Floor Area:	1554.322 m^2		

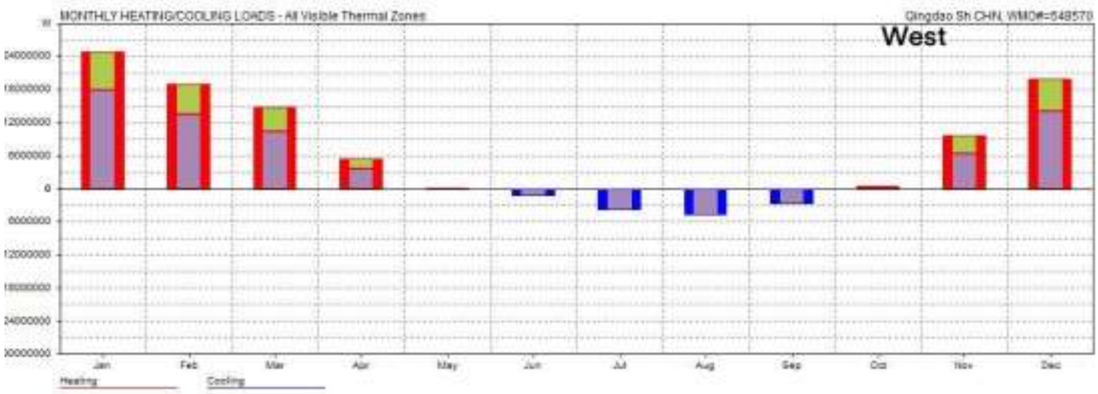


Figure 6-27. The monthly heating and cooling when changes WEST facade

Table 6-23. The data of monthly heating and cooling loads when changes WEST facade

MONTHLY HEATING/COOLING LOADS			
West			
Max Heating: 87938 W at 10:00 on 18th January			
Max Cooling: 18377W at 13:00 on 21st August			
	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	24708930	0	24708930
Feb	18846022	0	18846022
Mar	14785603	0	14785603
Apr	5422966	0	5422966
May	174180	32411	206590
Jun	0	1407782	1407782
Jul	0	3953156	3953156
Aug	0	4847995	4847995
Sep	0	2857519	2857519
Oct	434352	101229	535581
Nov	9523378	0	9523378
Dec	19880946	0	19880946
TOTAL	93776376	13200091	106976464
PER M?	60333	8493	68825
Floor Area:	1554.322 m^2		

If all the four facades are replaced with corncob concrete walls, the simulated energy consumption is heating59.631kW. The cooling is 8.867kW, and the total energy consumption is 68.496kW. Comparing the data with the simulation model 2 (6.4), it can be seen that the replacement of North, South, East, West facades can save 0.096kW, 0.141 kW, 0.054 kW, 0.082 kW, respectively. And if the facade is completely replaced, it can save 0.411kW, accounting for 23.36%, 34.31%, 13.14%, 19.95% of energy saving respectively (Table 6-24, Figure 6-28).

Table 6-24. The data comparison of monthly heating and cooling loads when changes the four facades

Wall replacement	Heating	Cooling	Total
North	60.289	8.522	68.811
South	60.197	8.569	68.766
East	60.388	8.465	68.853
West	60.333	8.493	68.825
Outside wall	59.631	8.867	68.496

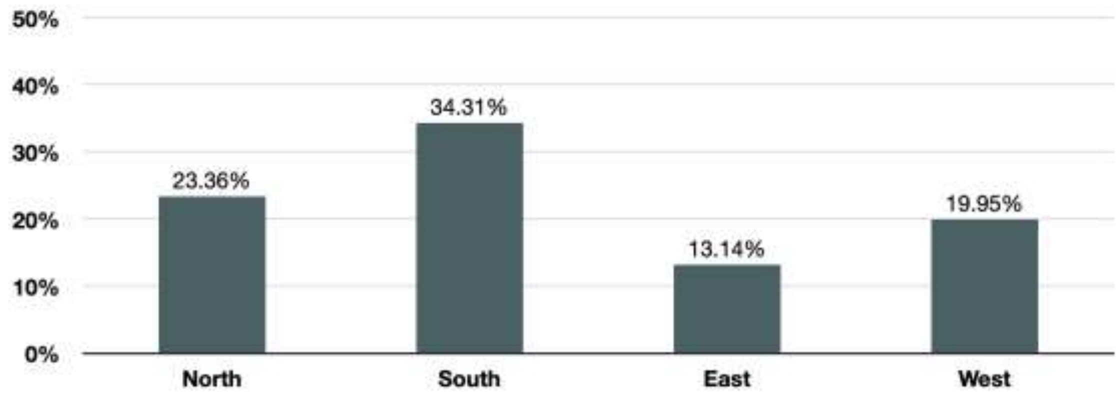
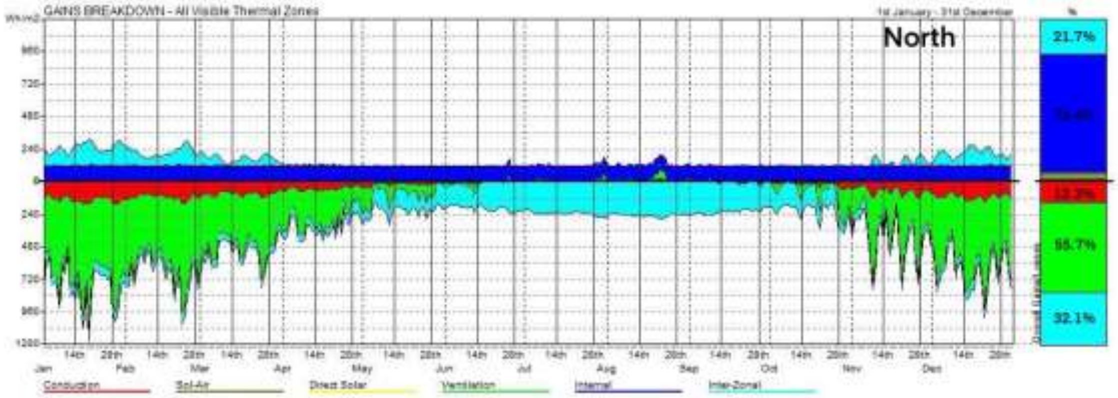


Figure 6-28. The comparative analysis of monthly heating and cooling when changes the four facades

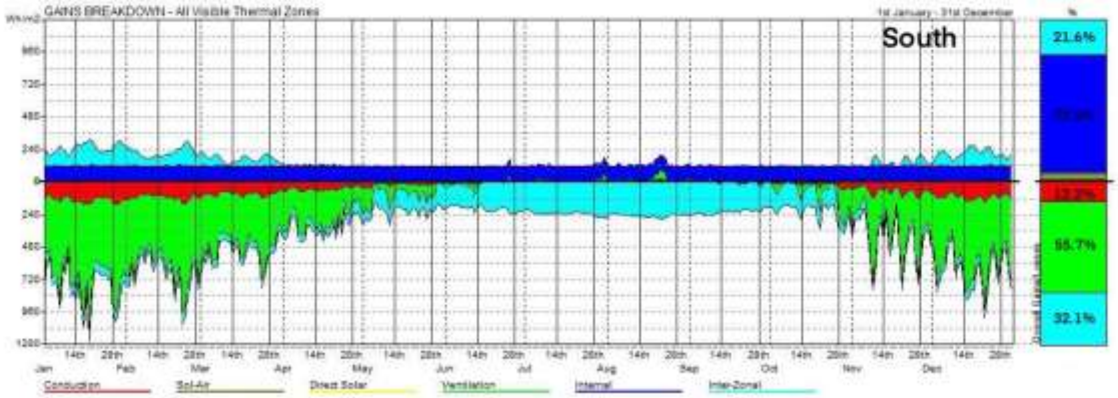
- **Passive gains breakdown**

If the north facade is replaced, the loss of FABRIC gains is 12.3%, the loss of VENTILATION is 55.7%, the loss of inter-zonal is 32.1%, the energy gained is 21.6%, and the heat gain of internal personnel and equipment is 72.5%. For the facade, if the south facade is replaced, the loss of FABRIC gains is 12.2%, and the energy loss of the envelope

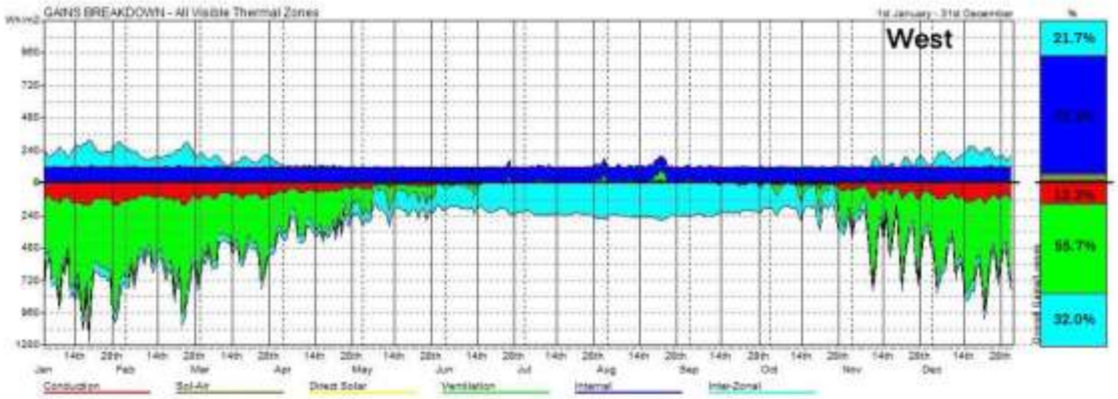
structure is reduced by 0.1%; if the east and west facades are replaced respectively, the result of Passive gains breakdown is the same, and the heat energy loss of the envelope structure Both are 12.3%, the loss of VENTILATION is 55.7%, the gain is 1.3%, the loss of inter-zonal is 32.0%, the energy gain is 21.7%, and the heat gain of internal personnel and equipment is 72.3%.
(Table 6-25, Figure 6-29)



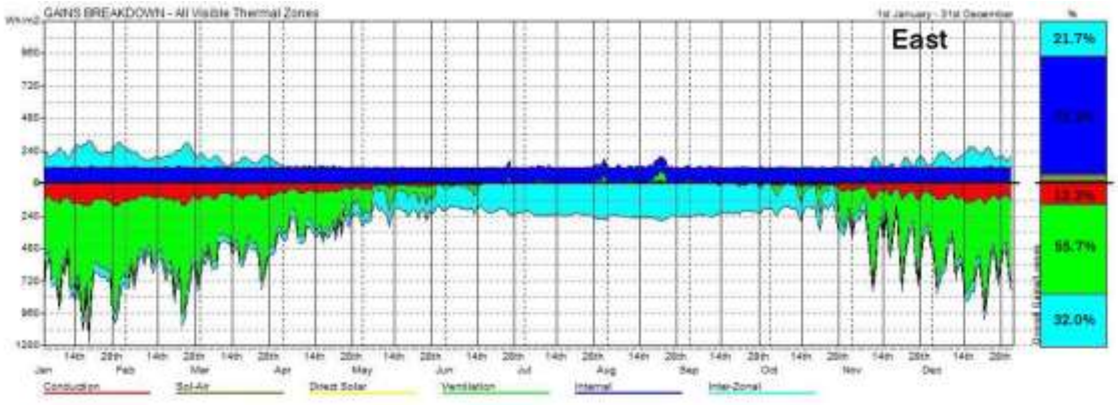
a.NORTH;



b.SOUTH



c.EAST



d.WEST

Figure 6-29. The passive gains breakdown analysis when changes each of four facades (a.NORTH; b.SOUTH; c.EAST; d.WEST.)

Table 6-25. The data comparison of passive gains breakdown when changes each of four facades

GAINS BREAKDOWN - All Visible Thermal Zones FROM: 1st January to 31st December					
North			**East**		
CATEGORY	LOSSES	GAINS	CATEGORY	LOSSES	GAINS
FABRIC	12.3%	0.3%	FABRIC	12.3%	0.3%
SOL-AIR	0.0%	2.2%	SOL-AIR	0.0%	2.2%
SOLAR	0.0%	2.1%	SOLAR	0.0%	2.1%
VENTILATION	55.7%	1.3%	VENTILATION	55.7%	1.3%
INTERNAL	0.0%	72.4%	INTERNAL	0.0%	72.3%
INTER-ZONAL	32.1%	21.7%	INTER-ZONAL	32.0%	21.7%
South			**West**		
CATEGORY	LOSSES	GAINS	CATEGORY	LOSSES	GAINS
FABRIC	12.2%	0.3%	FABRIC	12.3%	0.3%
SOL-AIR	0.0%	2.2%	SOL-AIR	0.0%	2.2%
SOLAR	0.0%	2.1%	SOLAR	0.0%	2.1%
VENTILATION	55.7%	1.3%	VENTILATION	55.7%	1.3%
INTERNAL	0.0%	72.5%	INTERNAL	0.0%	72.4%
INTER-ZONAL	32.1%	21.6%	INTER-ZONAL	32.0%	21.7%

- **Temperature distribution**

According to the comfortable temperature of Chinese buildings is 18-26 degrees, since most of the buildings are shops on the first floor and residential buildings on the second floor, when simulating the temperature, the time set on the first floor is 9 am on weekdays and rest days -18 points. Considering that there are a lot of old people living in the local area, when simulating the temperature comfort of the second floor, the temperature is set from

0:00 to 24:00 for a total of 24 hours.

When replacing the north wall, the first floor of the building is 110 hours at 18 degrees, accounting for 3.3%; 239 hours at 20 degrees, accounting for 7.3% of the total time; 304 hours at 22 degrees, accounting for 9.3% of the total time %, 24 degrees is 194 hours, accounting for 5.9% of the total time, 26 degrees is 268 hours, accounting for 8.2% of the total time. There are 1115 hours in the range of 18-26 degrees, and the comfortable time period accounts for 33.9% of the total time. The second-floor residential part of the building is 330 hours at 18 degrees, accounting for 3.8%; 283 hours at 20 degrees, accounting for 3.2% of the total time; 674 hours at 22 degrees, accounting for 7.7% of the total time, 24 degrees is 801 hours, accounting for 9.1% of the total time, 477 hours at 26 degrees, accounting for 5.4% of the total time. A total of 2565 hours in the range of 18-26 degrees, the comfortable time period accounted for 29.3% of the total time (Table 6-26, Figure 6-30).

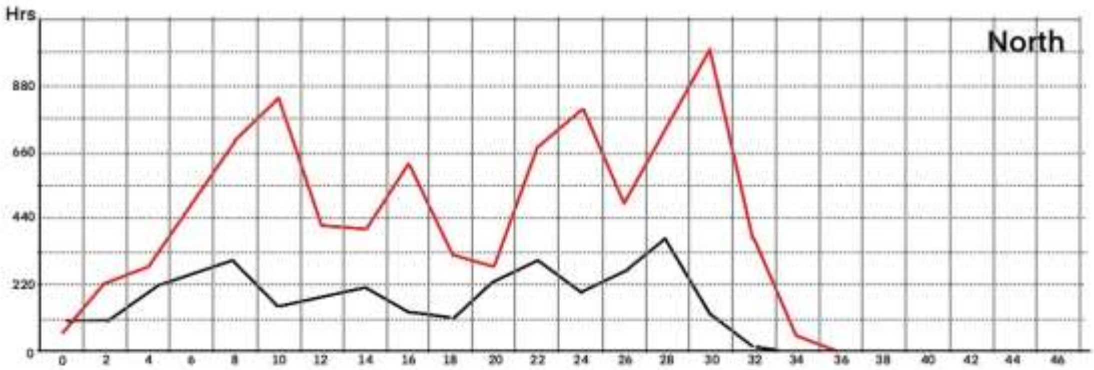


Figure 6-30. The comfort temperature distribution when changes NORTH facade

Table 6-26. The data of comfort temperature distribution when changes NORTH facade

ANNUAL TEMPERATURE DISTRIBUTION-North						
Floor 1				Floor 2		
Operation: Weekdays 09-18, Weekends 09-18.				Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C						
TEMP.	HOURS	PERCENT		TEMP.	HOURS	PERCENT
0.0	94	2.9%		0.0	50	0.6%
2.0	111	3.4%		2.0	219	2.5%
4.0	199	6.1%		4.0	288	3.3%

6.0	266	8.1%	6.0	492	5.6%
8.0	305	9.3%	8.0	678	7.7%
10.0	150	4.6%	10.0	852	9.7%
12.0	181	5.5%	12.0	417	4.8%
14.0	211	6.4%	14.0	405	4.6%
16.0	129	3.9%	16.0	612	7.0%
18.0	110	3.3%	18.0	330	3.8%
20.0	239	7.3%	20.0	283	3.2%
22.0	304	9.3%	22.0	674	7.7%
24.0	194	5.9%	24.0	801	9.1%
26.0	268	8.2%	26.0	477	5.4%
28.0	380	11.6%	28.0	733	8.4%
30.0	122	3.7%	30.0	1001	11.4%
32.0	22	0.7%	32.0	394	4.5%
34.0	0	0.0%	34.0	54	0.6%
36.0	0	0.0%	36.0	0	0.0%
38.0	0	0.0%	38.0	0	0.0%
40.0	0	0.0%	40.0	0	0.0%
42.0	0	0.0%	42.0	0	0.0%
44.0	0	0.0%	44.0	0	0.0%
46.0	0	0.0%	46.0	0	0.0%
COMFORT	1115	33.9%	COMFORT	2565	29.3%

When replacing the south wall, the first floor of the building is 108 hours at 18 degrees, accounting for 3.4%; 238 hours at 20 degrees, accounting for 7.2% of the total time; 307 hours at 22 degrees, accounting for 9.3% of the total time %, 24 degrees is 189 hours, accounting for 6.8% of the total time, 26 degrees is 269 hours, accounting for 8.2% of the total time. There are 1111 hours in the range of 18-26 degrees, and the comfortable time period accounts for 33.8% of the total time.

The second-floor residential part of the building is 332 hours at 18 degrees, accounting for 3.8%; 288 hours at 20 degrees, accounting for 3.2% of the total time; 665 hours at 22 degrees, accounting for 7.6% of the total time, 24 degrees is 797 hours, accounting for 9.1% of the total time, 477 hours at 26 degrees, accounting for 5.4% of the total time. A total of 2559 hours in the range of 18-26 degrees, the comfortable time period accounted for 29.2% of the total time. (Table 6-27, Figure 6-31)

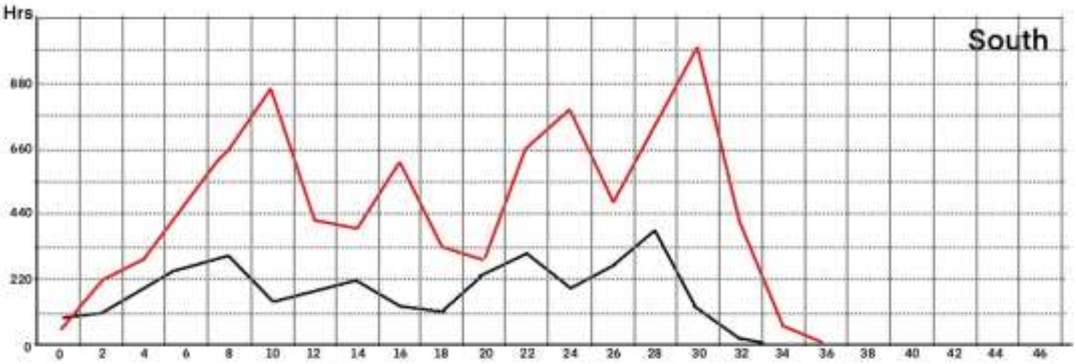


Figure 6-31.The comfort temperature distribution when changes SOUTH facade

Table 6-27. The data of comfort temperature distribution when changes SOUTH facade

ANNUAL TEMPERATURE DISTRIBUTION-South					
Floor 1			Floor 2		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C					
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0.0	93	2.8%	0.0	47	0.5%
2.0	111	3.4%	2.0	216	2.5%
4.0	197	6.0%	4.0	290	3.3%
6.0	268	8.2%	6.0	492	5.6%
8.0	305	9.3%	8.0	663	7.6%
10.0	149	4.5%	10.0	866	9.9%

12.0	177	5.4%	12.0	417	4.8%
14.0	217	6.6%	14.0	394	4.5%
16.0	128	3.9%	16.0	617	7.0%
18.0	108	3.3%	18.0	332	3.8%
20.0	238	7.2%	20.0	288	3.2%
22.0	307	9.3%	22.0	665	7.6%
24.0	189	5.8%	24.0	797	9.1%
26.0	269	8.2%	26.0	477	5.4%
28.0	385	11.7%	28.0	728	8.3%
30.0	121	3.7%	30.0	1008	11.5%
32.0	23	0.7%	32.0	404	4.6%
34.0	0	0.0%	34.0	59	0.7%
36.0	0	0.0%	36.0	0	0.0%
38.0	0	0.0%	38.0	0	0.0%
40.0	0	0.0%	40.0	0	0.0%
42.0	0	0.0%	42.0	0	0.0%
44.0	0	0.0%	44.0	0	0.0%
46.0	0	0.0%	46.0	0	0.0%
COMFORT	1111	33.8%	COMFORT	2559	29.2%

When replacing the east wall, the first floor of the building is 112 hours at 18 degrees, accounting for 3.4%; 236 hours at 20 degrees, accounting for 7.2% of the total time; 302 hours at 22 degrees, accounting for 9.2% of the total time %, 196 hours at 24 degrees, accounting for 6% of the total time, 267 hours at 26 degrees, accounting for 8.1% of the total time. There are 1113 hours in the range of 18-26 degrees, and the comfortable time period accounts for 33.9% of the total time.

The second-floor residential part of the building is 329 hours at 18 degrees, accounting for 3.8%; 281 hours at 20 degrees, accounting for 3.2% of the total time; 673 hours at 22 degrees, accounting for 7.7% of the total time, 24 degrees is 802 hours, accounting for 9.2% of the total time, 486 hours at 26 degrees, accounting for 5.5% of the total time. A total of 2571 hours in the range of 18-26 degrees, the comfortable time period accounted for 29.3% of the total time. (Table 6-28, Figure 6-32)

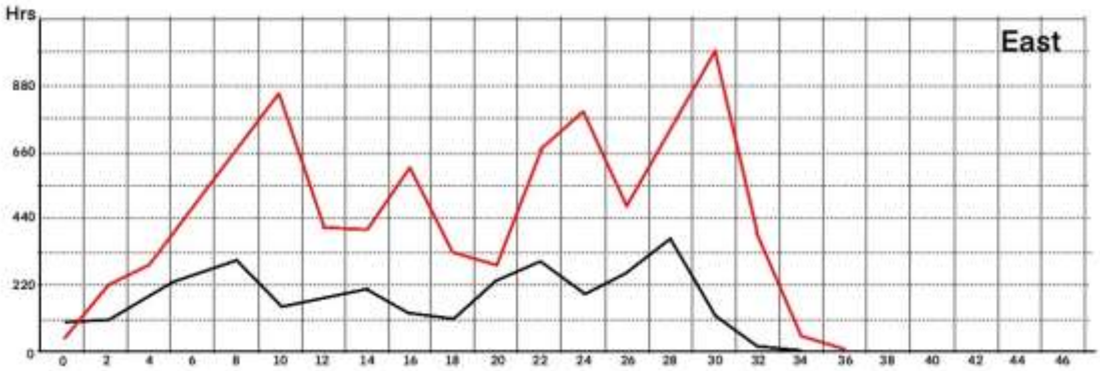


Figure 6-32. The comfort temperature distribution when changes EAST facade

Table 6-28. The data of comfort temperature distribution when changes EAST facade

ANNUAL TEMPERATURE DISTRIBUTION-East					
Floor 1			Floor 2		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C					
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0.0	97	3.0%	0.0	55	0.6%
2.0	108	3.3%	2.0	219	2.5%
4.0	204	6.2%	4.0	285	3.3%
6.0	265	8.1%	6.0	500	5.7%
8.0	302	9.2%	8.0	691	7.9%
10.0	150	4.6%	10.0	837	9.6%
12.0	180	5.5%	12.0	414	4.7%
14.0	213	6.5%	14.0	409	4.7%
16.0	131	4.0%	16.0	618	7.1%
18.0	112	3.4%	18.0	329	3.8%
20.0	236	7.2%	20.0	281	3.2%

22.0	302	9.2%	22.0	673	7.7%
24.0	196	6.0%	24.0	802	9.2%
26.0	267	8.1%	26.0	486	5.5%
28.0	378	11.5%	28.0	729	8.3%
30.0	124	3.8%	30.0	1006	11.5%
32.0	20	0.6%	32.0	375	4.3%
34.0	0	0.0%	34.0	51	0.6%
36.0	0	0.0%	36.0	0	0.0%
38.0	0	0.0%	38.0	0	0.0%
40.0	0	0.0%	40.0	0	0.0%
42.0	0	0.0%	42.0	0	0.0%
44.0	0	0.0%	44.0	0	0.0%
46.0	0	0.0%	46.0	0	0.0%
COMFORT	1113	33.9%	COMFORT	2571	29.3%

When replacing the west wall, the first floor of the building is 112 hours at 18 degrees, accounting for 3.4%; 237 hours at 20 degrees, accounting for 7.2% of the total time; 303 hours at 22 degrees, accounting for 9.2% of the total time %, 196 hours at 24 degrees, accounting for 6% of the total time, 268 hours at 26 degrees, accounting for 8.2% of the total time. There are 1116 hours in the range of 18-26 degrees, and the comfortable time period accounts for 34% of the total time.

The second-floor residential part of the building is 327 hours at 18 degrees, accounting for 3.7%; 280 hours at 20 degrees, accounting for 3.2% of the total time; 674 hours at 22 degrees, accounting for 7.7% of the total time, 24 degrees is 805 hours, accounting for 9.2% of the total time, 479 hours at 26 degrees, accounting for 5.5% of the total time. A total of 2565 hours in the range of 18-26 degrees, the comfortable time period accounted for 29.3% of the total time. (Table 6-29, Figure 6-33)

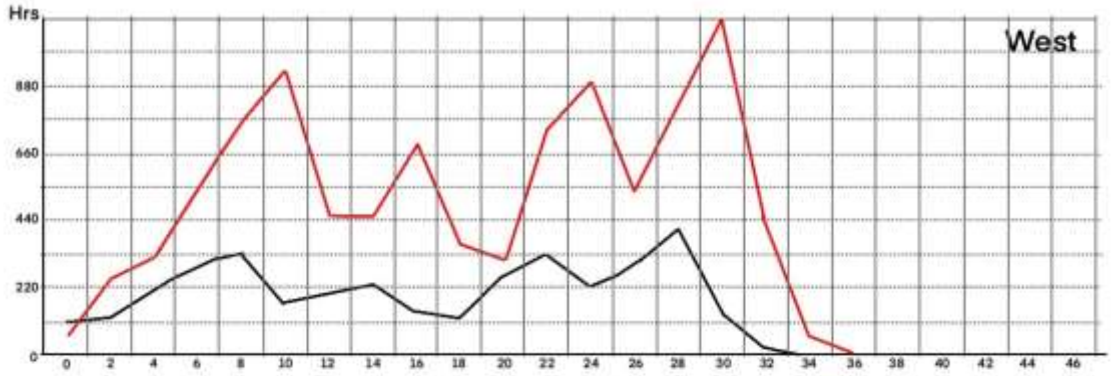


Figure 6-33. The comfort temperature distribution when changes WEST facade

Table 6-29. The data of comfort temperature distribution when changes WEST facade

ANNUAL TEMPERATURE DISTRIBUTION-West					
Floor 1			Floor 2		
Operation: Weekdays 09-18, Weekends 09-18.			Operation: Weekdays 00-24, Weekends 00-24.		
Comfort Band: 18.0 - 26.0 C					
TEMP.	HOURS	PERCENT	TEMP.	HOURS	PERCENT
0.0	95	2.9%	0.0	52	0.6%
2.0	110	3.3%	2.0	220	2.5%
4.0	201	6.1%	4.0	286	3.3%
6.0	267	8.1%	6.0	498	5.7%
8.0	302	9.2%	8.0	683	7.8%
10.0	151	4.6%	10.0	845	9.6%
12.0	180	5.5%	12.0	414	4.7%
14.0	211	6.4%	14.0	405	4.6%
16.0	130	4.0%	16.0	620	7.1%
18.0	112	3.4%	18.0	327	3.7%
20.0	237	7.2%	20.0	280	3.2%
22.0	303	9.2%	22.0	674	7.7%

24.0	196	6.0%		24.0	805	9.2%
26.0	268	8.2%		26.0	479	5.5%
28.0	378	11.5%		28.0	733	8.4%
30.0	123	3.7%		30.0	997	11.4%
32.0	21	0.6%		32.0	391	4.5%
34.0	0	0.0%		34.0	51	0.6%
36.0	0	0.0%		36.0	0	0.0%
38.0	0	0.0%		38.0	0	0.0%
40.0	0	0.0%		40.0	0	0.0%
42.0	0	0.0%		42.0	0	0.0%
44.0	0	0.0%		44.0	0	0.0%
46.0	0	0.0%		46.0	0	0.0%
COMFORT	1116	34.0%		COMFORT	2565	29.3%

Comparing the comfortable temperature range of the first floor after replacing each facade, it is better to replace the west facade on the first floor, and a total of 1113 hours of comfort time will be obtained; for the second floor to replace the east facade, 2571 hours will be obtained Hours of comfort time; combining the two floors, it is better to replace the east facade, and a total of 3684 hours of comfort time will be obtained（Figure 6-34）.

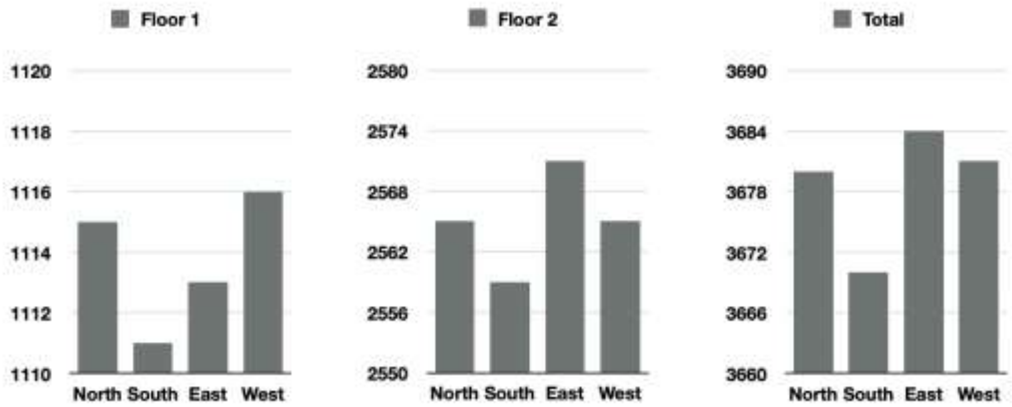


Figure 6-34. The data comparison analysis of comfort temperature distribution on two floors

6.9. Summary

6.9.1 Vertical Analysis

Vertically comparing model_1, model_2, and model_3 of Case-A the following conclusions can be found:

1. In the hourly heat gains or losses and passive gains breakdown, comparing the consumption of conduction and ventilation and the change in the ratio of the total energy consumption can be found: Through the changes to the wall materials, the energy consumption of the building in conduction has been significantly reduced. But in terms of ventilation, changing the performance of doors and windows has little effect on the heat loss caused by ventilation. Although the research has not thoroughly studied the causes and mechanisms of ventilation heat loss, this research can find improvements in the thermal performance of buildings. Compared with the energy loss of ventilation and heat dissipation, the loss caused by heat conduction is easier to control, and the modification method is simpler and has the possibility of facilities. This is also one of the factors in the study topic.

2. With the decrease of U value of building exterior walls, doors and windows and other components, the improvement of building thermal performance is very significant. In the Ecotect analysis, the annual energy consumption per unit area of Case-A is reduced from nearly 77.881kw/㎡ to less than 68.901kw/㎡, and the power saving rate exceeds 11%. The application of new materials, the energy saving rate exceeds 12%. In ladybug and honeybee software, the annual energy consumption per unit area of Case-A has been reduced from nearly 77.639kw/㎡ to less than 67.371/㎡, the power saving rate is over 12%, and the energy saving rate of new materials is over 13%. This fully shows that the potential of sustainable building renovation in energy saving and environmental protection is huge.

3. With the increase of the thickness of the insulation layer, the heat transfer coefficient of the wall continues to decrease, and the total energy consumption per unit area decreases. In winter, the heat dissipated from the interior through the wall is reduced, which reduces the heat load in winter and reduces the heating energy consumption; in summer, the cooling energy consumption per unit area increases slightly, but there is no severe heat in Qingdao in summer, and the high temperature time is short, so the cooling energy consumption is reduced. The effect is not obvious. In general, the reduction rate of heating energy consumption is much higher than the increase rate of cooling energy consumption, the total energy consumption per unit area is reduced, and the energy saving rate reaches 12%-13%.

6.9.2. Horizontal Analysis

Through the horizontal comparison of Ecotect analysis and Ladybug and honeybee, the simulated data after using the new corncob concrete material is compared with the original energy consumption, and the energy saving is 9.831kw and 10.784kw respectively. There will be differences, but the energy saving rates are 12.62% and 13.88% respectively. The data show that the use of corncob concrete helps to improve the energy consumption of the courtyard building, and different software data can prove this conclusion.

6.9.3. Replacement Analysis

The corncob concrete is partially replaced as an insulation material. The simulation results show that the thermal effect of this material is not obvious as an insulation material. On the other hand, it can reduce energy consumption as an energy-saving material if replacing the original bricks in the wall envelope. As a renovation project, the ultimate goal is to replace part of the wall to obtain the better living suitability and maximize total energy consumption saving impact. From the perspective of monthly loads and discomfort, the south facade has a greater influence on building energy consumption, and the energy saved by replacing the southern wall accounts for 34.31% in the total energy saving of all wall's replacement, which is the most beneficial for energy saving. Considering the comfort of human body, partial retrofit in the east wall can obtain longer comfort duration.

Reference

1. Mwasha, A., R.G. Williams, and J. Iwaro, Modeling the performance of residential building envelope: The role of sustainable energy performance indicators. Energy and buildings, 2011. 43(9): p. 2108-2117.
2. Risholt, B., B. Time, and A.G. Hestnes, Sustainability assessment of nearly zero energy renovation of dwellings based on energy, economy and home quality indicators. Energy and Buildings, 2013. 60: p. 217-224.
3. Asadi, E., et al., A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB. Building and Environment, 2012. 56: p. 370-378.
4. Chang, N.-B., Systems analysis for sustainable engineering: theory and applications. 2010: McGraw Hill Professional.
5. Diakaki, C., E. Grigoroudis, and D. Kolokotsa, Towards a multi-objective optimization approach for improving energy efficiency in buildings. Energy and buildings, 2008. 40(9): p. 1747-1754.
6. Anastaselos, D., E. Giama, and A.M. Papadopoulos, An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions. Energy and Buildings, 2009. 41(11): p. 1165-1171.
7. Juan, Y.-K., P. Gao, and J. Wang, A hybrid decision support system for sustainable office building renovation and energy performance improvement. Energy and buildings, 2010. 42(3): p. 290-297.
8. Allen, D.T. and D. Shonnard, Sustainable engineering: concepts, design, and case studies. 2012: Prentice Hall.
9. Housing, M.o. and U.-R.D.o.t.P.s.R.o. China, Design standard for energy efficiency of residential buildings in hot summer and cold winter zone. 2010, China Architecture and Building Press Beijing, China.
10. Wu, S., Study and evaluation of clustering algorithm for solubility and thermodynamic data of glycerol derivatives. Thermal Science, 2019. 23(5 Part A): p. 2867-2875.
11. Zhang., W., Study on the Rural House Heat Consumption in Cold Areas Study on the Rural House Heat Consumption in Cold Areas. 2012, Tianjin University.
12. DB37/5026-2014, Shandong Province Residential Building Energy Efficiency Design Standard [S]. 2015.

Chapter 7.

Conclusions and prospects

7.1. Conclusions

The energy-saving design of buildings effectively reduces heating energy consumption, improves indoor environmental problems in traditional houses, and plays an essential role in alleviating the increasingly severe environmental and energy problems. This study reviews the status of research on building energy-saving renovation and environmental improvement in various countries and summarizes their relevant research experiences. It also introduces the theories and methods of survey, experiment, and numerical simulation to provide a theoretical basis for energy-saving renovation and environmental improvement of residential houses. it also introduces corncob concrete material to provide new materials for the renovation of old buildings. This research is based on the coastal Liyuan houses in Qingdao, and the problems of Liyuan houses are identified through in-field investigation. Then, through experimental simulations, the application and efficiency of corncob materials in the thermal performance improvement of the envelope are explored. The renovation of old residential houses in terms of energy-saving and environmental improvement is proposed from envelope renovation. The conclusions of this study are as follows.

In chapter one, Background and Purpose of This Study, global climate change and energy shortage have become hot issues worldwide. According to statistics, building energy consumption accounts for 35% of global energy consumption, and carbon emissions account for 38% of global carbon emissions. They are the main factors limiting global climate and energy issues. In both China and Qingdao, the building area of old residential houses accounts for a large proportion, and traditional houses have high energy consumption and severe pollution in winter heating. In order to solve the above problems, solutions for energy-saving and environmental improvement of residential houses are proposed.

In chapter two, Literature Review of Energy-saving and Environmental Improvement. The current status of laws and registration on energy-saving and environmental improvement of traditional houses in different countries and times are introduced. Scholars have interpreted the theories and methods of building energy-saving and environmental improvement mainly from three perspectives: the discipline in Architecture heritage protection; the literature analysis of energy saving; energy-saving renovation of historic buildings. Comparing the research on energy-saving and environmental improvement of old residential houses in different countries and regions reveals that all countries have generally perfected their research in terms of theoretical research and evaluation systems.

In chapter three, Methodology of In-site Survey, Experiments, and Simulations, describes the methodology of field survey testing, thermal performance experiment of the envelope, and numerical simulation of building a thermal environment of old residential houses in Qingdao. The field survey methods include interviews, questionnaires, and field tests. Data on indoor and outdoor temperature, relative humidity, envelope dimensions, and other parameters were measured by these methods in a typical Liyuan of Qingdao, Shandong Province. In the experiment, using this method to test the thermal conductivity of corncob materials obtains accurate data, which has good results. This chapter also introduces the software and principles of Ecotect analysis and ladybugs simulation.

In chapter four, Status of Liyuan Houses and Indoor Environment in Qingdao, this present study surveyed the thermal performance of building envelope, indoor thermal environment, and air quality in the typical Liyuan area of Qingdao during the heating period. The results of the study are as follows. (1) The thermal performance of the envelope does not comply with the relevant standards. (2) The average indoor air temperature and black bulb temperature of the Liyuan buildings investigated were lower than the standard values of the indoor air temperatures during the heating period.

In chapter five, Thermal Performance Enhancement of Building Envelopes by Using corncob, different mortar ratios and different corncob contents was selected to carry out control experiments. Application of different material ratios and their effect on thermal performance improvement were tested. The experimental simulation results show that the ratio of mortar to sand is 1:4, the volume content of corncob is 50%, and the water consumption is 218.3kg/m^3, which has the best effect on thermal properties. Its heat transfer coefficient is 0.18W/K m.

In chapter six, The Energy-saving Improvement for The Liyuan Houses by Numerical Simulation, considering various factors such as temperature and heating energy consumption, suitable and reasonable energy-saving renovation technical measures are proposed for typical residential buildings. The Ecotect energy and ladybugs consumption simulation software was used to carry out univariate energy consumption simulations of the envelopes for Liyuan houses, three models were created as the final compared result. The energy saving rates of the final total energy consumption using new corncob materials are 12.62% and 13.88%, respectively. The results of the two software simulations were similar, and the use of the new material was beneficial in saving energy.

7.2. Prospects

This research focuses on the energy-saving renovation and environmental improvement of Liyuan houses in Qingdao, which is of great significance for the future development of energy-saving old residential houses in cold northern regions. Due to the limited space and time available for writing the thesis, there are still many aspects of the article that need to be studied in-depth and in detail, extrapolated and tested in practical engineering. The study of residential energy-saving has a certain complexity, so the research needs to be further improved and can be carried out in the future from the following aspects.

(1) Due to the extensive geographical area of the cold northern region and the fact that the actual research scope is limited to the Liyuan area of Qingdao, the number of sample houses is not comprehensive enough to reflect the whole situation of old residential houses in the cold region. In the future, we will consider further expanding the survey scope and adding new traditional old houses for research to enrich and update the primary data and improve the accuracy and scientific of the research results.

(2) This research focuses on comparing the renovated old Liyuan houses with the original houses through software simulation analysis. The results show that the renovated old houses show significant improvements in energy consumption. However, the renovated houses were only simulated by software data and were not applied in practice. In future work, it is hoped that the results of the theoretical research and analysis can be applied to practical projects, where their efficiency can be further verified, and the technology of energy efficiency in residential houses can then be promoted.

(3) This research has explored the possibilities of corncob materials for building insulation applications, expanding the uses of corncob materials. However, due to the complexity of corncob performance and production technology, it is hoped that future simulations of corncob material insulation performance can be further refined to investigate the relationship between corncob insulation efficiency and density and other elements, which will expand the application of corncob materials for building construction.

Acknowledgements

With completing my thesis just around the corner, I look back on my doctorate journey with a lot of emotion. I am very grateful to my supervisor, colleagues, classmates and family members who have provided me with so much help in my studies and life over the past three years. Without their support, guidance and assistance, this thesis would not have been completed.

First of all, I would like to express my sincere gratitude to my supervisor, Professor Bart Dewancker from Kitakyushu University, who gave me a lot of guidance and help in my thesis research. His vast academic knowledge and rigorous approach to science have influenced my research work all the time. Moreover, he also gave me a lot of encouragement and support in my daily life.

Secondly, I would like to express my deep gratitude to my Student Xiao Yufan, who assisted me greatly in the case study and made great effort in the field investigation and dimensional survey to help me get detailed information of the buildings.

Finally, I am very grateful to my family especially my wife. She provided academic discussion on the research. She encouraged me to overcome the hard time in publishing the SCI journal paper. She also brought our lovely son to the world in 2022. The whole family supports me to fight against the disease during covid-19 virus spreading.

Special thanks to all the love from the people mentioned above.