Vinnytsia National Technical University

(full name of higher education institution)

Faculty of Construction, Civil and Environmental Engineering

(full name of the institute, name of the faculty (department))

Department of Construction, Urban Planning and Architecture

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MASTER'S THESIS

«Ways of considering multi-criteria analysis for the design of energy-efficient envelopes. Case of Chinese construction practice»

Assigned by: 2nd year student, group IIIB-22m

Speciality 192 Construction and Civil Engineering

(Code and name of speciality)

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Faculty of_______Construction, Civil and Environmental Engineering________________
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APPROVED

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«__18_» __June______2025

T A S K

FOR MASTER QUALIFICATION THESIS TO STUDENT

____________________________XIANJIAN Yu
(full name)

1. Master's thesis topic_ Ways of considering multi-criteria analysis for the design of energy-efficient envelopes. Case of Chinese construction practice

Master's thesis supervisor Biks Y., PhD, Associated Prof. of CUPA Department,_________________
(full name, academic degree, academic title)

approved by order of the higher educational institution from «__»_______2025 No___

2. Work submission deadline by a master's student___13.06.2025_________________

3. Initial thesis data: Literature review upon the scientific direction. Research background. Building energy-saving Design. The modelling tool choice and parameters setup for comprehensive energy-efficient analysis of envelopes construction.

4. Content of the explanatory note (list of issues to be developed): Introduction, which should reflect the relevance of the topic, purpose, scientific novelty, practical significance, tasks, object and subject of research. The research part, consisting of three sections: Chapter 1, in which scientific

analysis of the state-of-the-art multicriteria analysis of building envelopes, attitudes, including single technology design and planning design and the standard energy-saving technologies, formulation of the research scope, criteria, software, search for relevant scientific sources, techniques should be performed; Chapter 2, in which factors affecting the energy-efficient building performance. Comparative analysis of insulating technologies for different building elements, should be performed; Chapter 3 – Building energy-efficiency analysis of case study. The basic process outline of the orthogonal test. Key factors, schemes and modelling results, Chapter 4 – Economic optimisation of proposed energy-saving design of building envelope. Total summary which reflects the signifi scientific and practical results of the research performed.

5. List of graphic material (with exact indication of mandatory drawings)

Posters that reflect: 1-3 — topic, purpose and tasks of the work, scientific novelty, practical significance; 4-5 — the criteria which should be considered in the energy-efficiency assessment of the designed construction; 7-11 – model results and analysis of several optimization schemes;12-13 – case study key parameters of proposed evaluation method by orthogonal test; 14 – Results of economic calculations; 15 – MQT Summary

6. Consultants of Master qualification thesis parts

Part	Surname, initials and position of consultant	Signature and date	
		Task issued	Task accepted
Introduction, Chapter 1	Yuriy BIKS, Associate Prof. of the CEUPA Department		
Chapter 2	Yuriy BIKS, Associate Prof. of the CEUPA Department		
Chapter 3	Yuriy BIKS, Associate Prof. of the CEUPA Department		
Chapter 4	Yuriy BIKS, Associate Prof. of the CEUPA Department		
Economic	Olena LYALIUK, Associate Prof. of the CEUPA Department		

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CALENDAR SCHEDULE

No	The stage name of the Master's qualification thesis	Work stages terms	Note
1	Scientific analysis of the state-of-the-art multicriteria analysis of building envelopes, attitudes, including single technology design and planning design and the standard energy-saving technologies, formulation of the research scope, criteria, software, search for relevant scientific sources, techniques. Preparation of Chapter 1.		
2	Preparation for the research, choice of appropriate tools and criteria.		
3	Preparation for Chapter 2. Factors affecting the energy-efficient building performance. Comparative analysis of insulating		

	technologies for different building elements.		
4	Preparation of Chapter 3. Building energy-efficiency analysis of case study. The basic process outline of the orthogonal test. Key factors, schemes and modelling results.		
5	Preparation the Chapter 4. Economic optimisation of proposed energy-saving design of building envelope. Total summary.		
6	Prepublication editing and publication of Master's qualification thesis results. Approbation		
7	Plagiarism check		
8	Preliminary defence of the Master's qualification thesis		

Master student ________Xianjian YU__
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ABSTRACT

UDC 621.3.088

Xianjian Yu. Ways of considering multi-criteria analysis for the design of energy-efficient envelopes. Case of Chinese construction practice. Master's qualification thesis on speciality 192 - Construction and Civil Engineering, Educational professional program - Industrial and Civil Engineering. Vinnytsia: VNTU, 2025. 77 p.

In English language. Bibliographer: 55 titles; fig.: 10; tables 22.

The Master’s thesis is devoted to the issue of assessing the energy efficiency of enclosing structures in terms of several indicators, including thermal, in the context of the life cycle of the building.

In the technical research section of this master's thesis, the main focus of modelling work using Tianzheng Energy Saving Software [55] is to attempt to summarise the main factors that affect the physical, mechanical, thermophysical, and economic indicators' potential of multi-layer envelope materials for complex evaluation. The resource database of the labour protection energy-saving software is used as a template to simulate the energy loss of walls, roofs, floors, and other enclosure structures. In the economic section, this article conducted numerical simulation analysis on nine types of multi-layer enclosure structures, including the unit building area cost, annual energy cost, and static life cycle cost of the multi-layer enclosure structure. This thesis elaborates on the critical points of energy-saving design for building envelope structures from the aspects of technology, economy, etc., and

uses China's Tianzheng Energy Saving Software [55] as the experimental object to analyse the optimal energy-saving design envelope structure through factor analysis method, ultimately obtaining the most effective and economical energy-saving way for people's reference. The research work of this thesis is conducive to the emergence of new cost concepts, reducing the life cycle investment cost to a certain extent, reducing the investment cost of enterprises in energy-saving buildings, and promoting the continuous expansion and promotion of energy-saving buildings. In addition, the research in this article is beneficial for enhancing the sustainability and practicality of energy-saving buildings, both in practice and on a theoretical basis

Master thesis contains 16 sheets of graphics.

Keywords: energy efficiency, multicriteria assessment, multilayer envelopes, life cycle cost.

CONTENT

INTRODUCTION

In recent years, scholars at China and abroad have focused on energy-saving envelopes, and there is more and more research in this field. It is still in the initial stage of research, and considering the life cycle cost of building, energy efficiency has become a crucial problem. This paper focuses on the life cycle, considering the practicality and economy of energy-saving buildings in an all-round way to strengthen energy-saving technology. Firstly, this paper analyses and summarises the current situation of energy-saving buildings at home and abroad in turn and introduces the definition and theory of building energy efficiency. Secondly, the technologies of energy-saving buildings are analysed respectively, including single technology design and planning design and the common energy-saving technologies in the current society are analysed, whether from the technical structure or the technical performance. Secondly, the energy-saving, buildings in this paper are analysed by Tianzheng energy-saving software [55], and the energy-saving rate and energy consumption rate of buildings are calculated respectively. The envelope structure is elaborated and accurately calculated by the orthogonal test method, and the annual energy-saving rate, load rate and calculation envelope structure are calculated. Finally, on the premise of using the orthogonal test method to design the envelope structure and technical skills, the best energy-saving scheme is selected from the whole scheme as the analysis case of this paper. At the same time, taking the practice of China as an example, the life cycle cost, initial cost and operating cost are calculated respectively, and the best scheme is selected from them, which is based on the general idea of energy-saving design. The research work of this paper can reduce the investment cost of life cycle and energy-saving buildings to a certain extent, which is conducive to improving the continuous expansion and promotion of energy-saving buildings and strengthening the sustainability and practicality of energy-saving buildings.

Theme actuality. To more objectively evaluate energy consumption alternatives for building energy efficiency design, it is not only necessary to evaluate the thermal and economic indicators of the enclosure structure, "Energy-saving materials should also be used in building envelopes, as permitted by laws and regulations, to achieve a more appropriate and cost-effective coexistence mode". This work is committed to playing an important role in the analysis and evaluation of building energy efficiency design at home and abroad, and also plays a key role in the development of energy efficiency design in China.

Connection of work with scientific programs, plans, and topics. This work was performed under the subject of scientific research of the Department of Construction, Urban Planning and Architecture of VNTU, speciality 192 "Construction and Civil Engineering".

The purpose and objectives of the study. The focus of this research lies in energy-saving design. First, an in-depth analysis of the development of architecture and related theoretical research at home and abroad is conducted. The original building energy conservation design has been transformed into a building envelope structure design. Specifically, it includes roof energy-saving design, exterior wall energy-saving design, floor energy-saving design, door and window energy-saving design, and shielding design. These designs' influencing factors and design elements are discussed and summarised respectively. Secondly, the comparative analysis method is used to strictly calculate, analyse, and compare the energy conservation systems in four specific aspects of the enclosure structure: doors and windows, exterior wall insulation, roof, and sunshade. To clarify the advantages and disadvantages of each component in the enclosure structure.

The practical significance of the results obtained. Detailed analysis and elaboration of an orthogonal test method, energy-saving building design, full life cycle cost, accurate calculation and simulation of building energy consumption, focusing on the relationship and impact of full life cycle cost on the original cost and operating cost of the building, and finding a balance between the two. The orthogonal test method is used to elaborate and accurately calculate the design of energy-saving buildings, calculate the energy-saving rate and load rate of the building throughout the year, and calculate the cooling load rate and heating load rate of the building's air conditioning and heating. The results of this work will have a good guiding significance for the future analysis of the envelope structure.

Publications.

Conference papers were published [56] and approved for publication [57] on this topic in the conference materials of the LII Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (Vinnytsia, VNTU 2023): Xianjian YU. Analysis of energy-saving design of building envelope// *Proceedings of LII Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (Vinnytsia, VNTU 2023)*. URL:

https://conferences.vntu.edu.ua/index.php/all-fbtegp/all-fbtegp-2023/paper/view/18115 (Last accessed 03.11.2023).

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2025 Conference. URL: http://www.iccrem.com/en/index.php (Last accessed 13.06.2025).

Acknowledgements. This research was mainly completed under the guidance of scientific supervisor Yuriy BIKS, whose proposed ideas of various advantages and disadvantages for concepts of envelopes energy-efficiency assessment were carefully analyzed in detail and considered in the thesis.

CHAPTER 1 CURRENT STATE-OF-THE-ART IN THE ENERGY EFFICIENCY ASSESSMENT APPROACHES IN THE CONSTRUCTION SECTOR

1.1 Research background and significance

Energy is one of the most important issues in the world. In all countries in the world, no matter European countries or Asian countries, the proportion of energy consumption is relatively high, especially in building energy consumption, which covers heating and air conditioning, construction and living energy consumption, accounting for more than 30%. According to relevant surveys, residential energy consumption is twice that of commercial energy consumption. According to the energy consumption in China, the total area of newly-built buildings in China in recent years has exceeded 2 billion square meters. Compared with developed countries in the United States, the total area of newly-built buildings in the United States is only 400-500 million square meters. " China is currently the country with the largest newly-added building area in the world, far larger than all newly-added building areas in other countries. As the real estate industry in China has been developing vigorously, it has become a pillar industry of China's economy. According to relevant statistics, the total construction area of urban and rural areas in China exceeds 46 billion square meters, of which 99% of buildings have high energy consumption.

Considering the life cycle, combining the practicality and sustainability of the building, this paper is conducive to the birth of a new concept of cost, to a certain extent, reducing the input cost of life cycle and reducing the input cost of enterprises to energy-saving buildings, which is conducive to improving the continuous expansion and promotion of energy-saving buildings. Therefore, the value of this paper is that it can bring benefits to the country from economic and social perspectives, so it has certain application value and practical value. First of all, the application of life cycle in energy-saving buildings is conducive to strengthening people's understanding and understanding of energy-saving buildings, and further promoting the expansion and expansion of energy-saving buildings. Secondly, from the economic point of view, according to the actual situation of the local construction industry, explore personalised solutions, and provide theoretical reference value and theoretical guidance for the large-scale development of energy-saving buildings in China in the future. In addition, the large-scale expansion of energy-saving buildings can improve people's living and living environment, reduce energy consumption, and on the other hand, help reduce air pollution and purify the air and environment.

Through the research of this paper, the practicality and sustainability of energy-saving buildings are discussed by combining practice with theory. To provide some reference value for the large-scale popularisation of energy-saving buildings in China in the future. Provide decision-making for domestic and foreign governments to launch energy-saving buildings.

1.2 Research status at home and abroad

1.2.1 Building energy-saving design

Energy-saving design of building planning

Due to population growth, the increase in indoor time, the increasing demand for building functions and indoor environment quality, and global climate change, the energy consumption of buildings has increased dramatically in the past decade. United States of America and the European Union, building energy use currently accounts for—more However, if the building is properly designed, constructed and operated, significant energy-saving effects can be achieved. Therefore, Building energy efficiency can be used for energy shortage, carbon emissions provide key solutions. And their serious threat to our living environment [1].

Building envelope parameters and geometric configuration can significantly affect building energy performance. However, it is not a simple task to determine the best tradeoff between different building shapes and envelope configurations to produce a design scheme close to the best in terms of its energy performance. Therefore, different methods have been adopted to optimise the parameters and geometric configuration of the building envelope to achieve better energy performance.

(2) Energy-saving design of a single building In 2015, Luo Chuanlian pointed out that quantitative analysis was used to explore the correlation between energy-saving and architectural form [3]. In 2014, Mo Xiaoya emphasised energy saving through a "temperature damping zone", including using high thermal insulation materials and expanding the heating area of buildings [4]. In 2014, Zhang Guohua advocated that the property of residence should determine the energy-saving effect of residence.

Architecture in the study of energy-saving design of building maintenance structure is mainly reflected in the following aspects:

Research on energy-saving design of building exterior wall

In 2015, Junli Yang(2015) proposed that the service life of the insulation layer is mainly affected by these factors, among which the material, thickness and cost of the insulation layer have a certain relationship with users [6]. In 2016, Xiao Juan and Lin Borong pointed out that excellent building insulation materials can not only meet the effect of environmental protection and energy saving, but also meet the requirements of thermal resistance, so they are widely used [7]. In 2016, Zhi Jiaqiang, Zhao Jing and Xin Yajuan advocated that when selecting thermal insulation materials, materials with good external thermal insulation effect should be chosen, because they can prolong the service life of thermal insulation materials and help prevent cracks on external walls [8]. In addition, Xi 'a Research Institute has developed a new wall material-insulation hollow block.

Research on the energy-saving design of building doors and windows

In 2014, Hadas Gabay put forward that the glass should be pasted with film, which not only can block the outside line, but also has the effect of heat insulation and heat preservation [10]. In 2014, Vahid Vakiloroaya, Bijan Samali and Kambizpushghadam clearly emphasised that glass and double-sided glass have good performance in heat insulation and heat preservation, and at the same time, the effect of the position and size of windows on building energy consumption was studied. It is pointed out that the ratio of windows to building area is 10%-12%, and the energy-saving effect is the best[11].

In 2016, Yu Xiaoping pointed out that doors and windows should pay attention to air tightness and heat preservation value in cold weather, and pay attention to the orientation of doors and windows, the ratio of windows to walls and other factors in the selection, to reduce energy consumption [l2]. In 2016, Li Kuishan and Zhang Xu pointed out that thermal protection measures should be taken for doors and windows in summer and thermal insulation measures should be ensured for doors and windows in winter [[13]. Whether you choose energy-saving doors and windows or ordinary doors and windows, you need to meet the following requirements:

1. You need to ensure the adequacy of indoor sunshine fully;
2. It needs to meet the function of thermal insulation, that is, heat protection measures should be taken for doors and windows in summer and thermal insulation measures should be ensured for doors and windows in winter;
3. It is necessary to satisfy the user's vision and ensure the indoor ventilation effect;
4. It is necessary to ensure the integrity and aesthetics of the building's appearance.

Research on energy-saving design of building roof

In the research process of building roof energy saving, the focus is on the roof structure and the performance of thermal insulation materials. In 2014, C.Y.Jim pointed out that it is necessary to study the energy saving of roof greening [14]. In 2015, Long Weiding and Ma Suzhen developed a silicon thin plate, which completely changed the traditional hollow precast slab and greatly improved the energy-saving utilisation rate of buildings.

1.2.2 Building life cycle cost optimisation

GK.C.Ding calculated the energy-saving cost of an external wall insulation system based on the concept of life cycle cost and calculated the payback period of polystyrene board and asbestos insulation material [15].

In 2016, Omar Espinoza experimented with the roof construction. The data showed that compared with traditional roof construction, the investment in the new roof construction increased by 10%~14%, but the net present value of the operation was 20% lower [15].

In 2015, Jiangyi analysed and calculated the construction cost project, which mainly involved the progress, quality and cost of the project, and discussed in detail how to coordinate and manage the correlation among these three aspects [17]. In addition, some common methods in cost management can be roughly divided into responsibility cost method, engineering cost analysis method, deviation control method and earned value analysis method.

In 2018, Li Xiaojin and Wang Ding deeply analyzed and discussed the key points affecting project management, including control contents, control methods and control system factors. Considering the aspect of system engineering, listing some successful cases as the basis of research is conducive to optimising project costs and increasing economic and social benefits [18]. In 2016, Wei Wei listed Guangzhou, analysed and studied it through the bidding, construction, design, and final settlement stages, and managed and optimised the above contents [19]. In 2017, Lin Borong, Qin Youguo and Zhu Yingxin analysed the current situation and methods of the whole life cycle in China and thought that the investment of the whole life cycle cost could be controlled by the designers, constructors, competent departments and users [20].

1.3 Research directions

After the research background and literature review were carefully analysed and considered, the ways of current research have been proposed and formulated:

1. To analyse and compare the advantages and disadvantages of envelope structure, including energy-saving technology of doors and windows, external wall insulation technology, sunshade technology and roof energy-saving technology.
2. The research of current thesis should be performed through the orthogonal test, which aids detail considering the window type, floor heat transfer coefficient, external wall heat transfer coefficient, and roof heat transfer coefficient affect the following primary and secondary order, covering the cumulative total annual load, cumulative heating load and cumulative cooling load of air conditioning.
3. When optimising the envelope, it is necessary to optimise the energy-saving design and life-cycle cost and explore the balance points between future operating costs and initial construction costs.

CONCLUSIONS TO CHAPTER 1

Through this chapter's research, the main points are as follows:

1. Different enclosure structures have different advantages and disadvantages;
2. Preliminary determination of analysis methods should be considered to prepare for future research;
3. The calculation through analysis methods to draw further effective conclusions for the comprehensive choice making should be performed.

CHAPTER 2 ANALYSIS OF ENERGY-SAVING TECHNOLOGY OF BUILDING ENVELOPE

2.1 Building energy-saving planning and design

The purpose of building energy-saving planning and design is to reduce energy consumption, which could be obtained by architectural layout as well as by improvement of sunshine conditions.

2.1.1 Improvement of sunshine conditions

The improvement of sunshine depends on the rationality of the building layout. In this paper, residential buildings are listed. Due to the appearance difference between adjacent residential buildings, some shadows will appear due to the different architectural orientations. Therefore, it is necessary to obtain the sunshine status according to the layout of the houses [21-25].

2.1.2 Improve the wind environment

The northern part of China is easily affected by cold air, so it is necessary to take this factor into account in the planning process, avoid the northwest trend, and shield the cold air and the cold wind to the greatest extent.

Building shape

Building shape also has a certain impact on energy saving. Common influencing factors include landscape environment, design inspiration, construction technology and functional requirements. Whether from the height, width or length of the building, it affects the shape of the building [26].

In this paper, building energy efficiency is considered, assuming that the building volume is the same, it is necessary to reduce the gap between the building volume and the envelope area, to reduce the heat dissipation of the building. In this paper, the residential buildings in China have been investigated, and it is concluded that under the condition of the same building volume, assuming that the height of a residential building is 18m, there are five building shapes with different parameters, as shown in the following figure.

Building spacing

This paper needs to design the building according to the principle of energy saving, and factors such as building spacing and sunshine standards should be considered in the design process. The sunshine is determined by the distance between buildings. As shown in Figure 2.1.

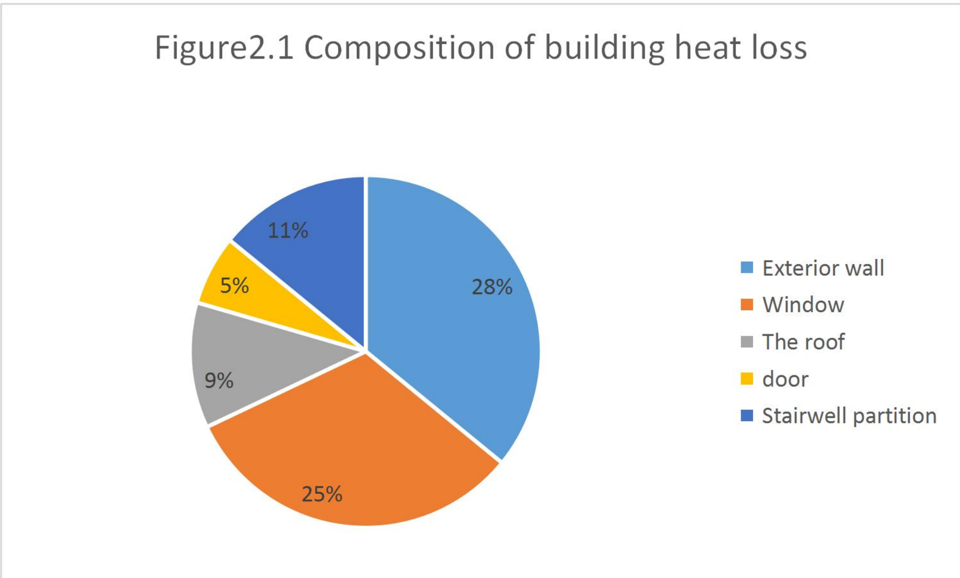


Figure 2.1 – Composition of building heat loss [27]

Architectural orientation

The standard of building orientation is to avoid direct sunlight in summer and get enough sunshine in winter [28-38].

2.2 Comparison of appropriate energy-saving technologies for building exterior protection components

2.2.1 Comparison of technical suitability of external wall thermal insulation system

Among the energy-saving technologies of external wall insulation, some insulation systems have been developed quite maturely, such as wall self-insulation, external wall internal insulation, external wall external insulation and external wall sandwich insulation. In this paper, the data of these four insulation technologies are analysed and compared respectively. The analysis results are shown in Table 2.1.

Table 2.1 – Comparison of wall insulation technologies

The main advantages	The main advantages	shortcomings
1	2	3
External wall internal protection temperature	1. The internal thermal insulation material is separated by the floor and the construction. Only within the scope of one floor, because the internal thermal insulation material is on the inside of the floor, there is no need to erect scaffolding during the construction process, and the construction can be carried out within the scope of one floor. Because of the fast construction speed of external wall internal insulation, it also has obvious advantages in construction progress. 2. Gypsum mortar and gypsum board can be used, and the requirements for material selection are not high, and the waterproof and weatherability of thermal insulation materials and decorative surfaces are not too high. It is convenient to take materials and reduce the cost. 3. The application range is wide, and the whole construction system and acceptance process are very mature.	1. Because the requirements of materials are not high, there are some problems in the upper structure and construction process led to cracking and weathering of many wall facades in the later period. 2. The thermal insulation efficiency of the thermal insulation layer is only 30% to 40% because the structural column, ring beam and floor will cause a thermal bridge effect, so the heat loss is relatively significant. 3. If the joint of the surface layer is lax and the air leaks, it is easy to dew on the insulation layer. 4. The effective indoor area is reduced. 5. The indoor temperature difference is obvious

Continuing Table 2.1

1	2	3
Exterior wall sandwich thermal insulation	1. The outer wall can protect the middle protection well. Temperature layer to avoid cracking and weathering. 2. Glass wool, rock wool and polystyrene can be used as materials, and the requirements for material selection are not high. 3. It can also be operated in winter, with low requirements for seasons and construction conditions. 4. The thermal insulation is better than that in the external wall, and the use function is acceptable.	1. The external wall with sandwich insulation is usually very Thick, which will reduce the actual indoor area. 2. There will also be a "thermal bridge" reaction, which will reduce the thermal insulation efficiency of the wall, and the thermal insulation efficiency will be 50%~75%. 3. Improper handling of joints of the insulation layer makes it easy to leak. 4. The seismic performance of the wall is not good.
External wall protection temperature	1. It can better protect the main structure of the building and increase the service life to a certain extent. 2. The thermal insulation layer has high efficiency, effectively avoiding thermal bridges, and the thermal insulation efficiency is as high as 85%~95%. 3. External thermal insulation of external walls can effectively prevent building facades from being affected by dampness. 4. The effective indoor area has not decreased. 5. Compared with other structures, it is more convenient for energy-saving transformation of existing buildings. 6. The room temperature is stable and the thermal comfort is good. 7. It can effectively avoid the damage of decoration to the insulation layer. 8. It is beneficial to improve the waterproofness and airtightness of the wall.	1. The use of on-site construction, the use of polymerisation There are strict requirements for cement mortar and construction quality, otherwise, the surface layer is easy to crack. 2. The construction weather and season are limited, so it is not easy to construct in the winter and rainy seasons. 3. If the joint of the precast slab is not handled properly, it is easy to cause leakage at the joint. 4. For high-rise buildings, a very solid insulation layer is needed, otherwise the suction force of the leeward side may suck off the insulation board. 5. After experiencing wind and rain erosion and temperature change, the bonding layer of the tile is easy to cause the wall to peel off, which increases the potential safety hazard.
Wall self-protection temperature	1. The envelope structure and thermal insulation are integrated, No additional thermal insulation materials are needed. 2. It can be used for a long time and has the same life as the building.	1. The wall is easy to open due to the material. Crack, low strength. 2. Short-leg shear walls are widely used in high-rise buildings, but filler walls are seldom used, so the self-insulation system does not play much role.

2.3.2 Comparison of Suitability of Energy-Saving Technologies for Doors and Windows

The special significance of doors and windows in building energy-saving design.

According to the composition table of wall heat loss, it can be reflected in the building envelope. Among the main components such as the roof, ground, wall and doors and windows, the door and windows have the most heat loss. Therefore, in the indoor thermal environment quality and the whole building energy saving, doors and windows are the most influential part. When heating in winter, the heat loss of single glass accounts for 30%~50% of the total indoor heating. However, in air-conditioning refrigeration in summer, the lost cooling capacity accounts for 20%~30% of the total refrigeration of air-conditioning. As can be seen from Table 2.2 below.

Table 2.2 – Heat Transfer Coefficient of Typical Envelope Parts in China at Present

Structural component name	Structural form	Heat transfer coefficient $k_{0,}$ [W/m×K]
external wall	Clay and shale solid brick 240mm	1.95
	Clay and shale solid brick 370mm	1.57
roofing	Concrete ventilated roof	1.45
exterior window	Single glass metal window	6.40
ground	soil	0.30
door	Metal door	6.40
	timber door	2.70

The heat transfer coefficient of doors and windows, that is, energy consumption accounts for about 30% of the total coefficient of the building envelope. It is more than

20 times the energy consumption of the ground, about 5 times that of the roof and 4 times that of the wall. To sum up, it is very important to enhance the thermal insulation performance of doors and windows in building energy conservation.

Comparison of suitable technologies for energy-saving doors and windows

PVC plastic doors and windows

PVC material is the abbreviation of PVC material. PVC material has the advantages of easy handling, high thermal insulation performance, heat insulation and flame retardancy. Compared with wooden doors and windows, the tensile strength and bending strength of PVC materials are much stronger. In terms of building doors and windows, the energy consumption of PVC profiles is 1:8.8 compared with aluminium of the same quality and 1:4.5 compared with steel.

Insulated broken bridge aluminium alloy doors and windows

Thermal insulation broken bridge aluminium alloy is a new material evolved from the original aluminium alloy profile, which can better improve thermal insulation performance. The original aluminium alloy profile has good thermal conductivity, so the relative heat energy loss is also relatively large. The broken bridge heat insulation aluminium alloy profile insulates the aluminium alloy and adds non-metallic materials such as polyamide and nylon spacers in the middle of the aluminium alloy to reduce the thermal conductivity, thus reducing the heat loss.

The advantages of aluminium alloy doors and windows with broken bridge insulation are good thermal insulation performance, low apparent density, strong stability, high plasticity and mechanical strength, good strength and fire resistance, high temperature and corrosion resistance and long service life. Finally, this material can be recycled and remelted after use, which has high advantages in energy saving and environmental protection.

Compared with the traditional aluminium alloy doors and windows, the broken bridge thermal insulation aluminium alloy doors and windows inherit the original air permeability resistance, rain water leakage resistance, wind pressure resistance and sound insulation performance, and also improve the thermal insulation performance of traditional aluminium alloy doors and windows.

Epoxy glass fibre reinforced plastic window

Epoxy glass fibre-reinforced plastic window belongs to a new generation of energy-saving door and window profiles. It has the advantages of energy saving, environmental protection, high strength and corrosion resistance, as well as high strength and no deformation. Epoxy resin glass fibre reinforced plastic is a new material composed of glass fibre and epoxy resin. Its advantages are light weight, small specific gravity, good insulation performance and cohesiveness.

High energy, high strength, high corrosion resistance, strong plasticity, good process performance and low shrinkage.

The heat transfer coefficient of epoxy glass fibre-reinforced plastic window is 1.4 ~ 1.8W/(m^2 K). Compared with the thermal insulation coefficient of 2.4 ~ 3.2 w/(m^2 K) of the broken bridge thermal insulation aluminium alloy window, the heat transfer coefficient of the broken bridge thermal insulation aluminium alloy window is about 0.3 w/(m^2 K) higher than that of the glass fibre reinforced plastic window under the same environmental conditions. Therefore, compared with the broken bridge insulated aluminium alloy window, the thermal insulation performance of FRP window is about 10% higher, and the thermal insulation performance is very good. The expansion coefficient of glass fibre-reinforced plastic windows and walls is the same, so in the installation process, polymer thermal insulation materials are usually used by multi-point filling, so the thermal insulation performance is very good.

2.3.3 Comparison of Suitability of Roof Energy-Saving Technology

As an important part of the building envelope, the roof also has a very important impact on the energy consumption of the building. The thermal insulation performance of a roof is related to the efficiency of building energy saving, and it also plays a great role in the living experience of upper-level residents. In the hot areas of China, the surface temperature of the building roof can even reach about 60-80 degrees Celsius in summer, which is 3-4 degrees Celsius higher than that of the lower floor of the building on average. Roof insulation system includes planting roof, ventilated roof, inverted roof, upright roof, inverted roof, water storage roof and sloping roof. See Table 2.3 for the technical performance comparison of these roofs.

Table 2.3 – Advantages and Disadvantages of Roof Insulation System

Technical type	Major advantage	Main disadvantages
1	2	3
Upright roof	1. The thickness of the insulation layer can be controlled independently according to the situation, without affecting the overall design. The running water after the insulation layer is finished on the roof. Find the slope problem.	1. The top layer is the waterproof layer, which can be easily damaged by wind and sun, causing it to age prematurely. 2. The roof slope is gentle, and the construction in the insulation layer. During or before the waterproof construction process, due to horizontal issues, it is challenging to drain the accumulated water. And affect the construction quality. 3. The waterproof layer is located at the top of the roof, directly connected to air contact, and exposed to sunlight and rain rot. Corrosion will significantly shorten the service life, and at the same time. Easy to crack and empty drum, resulting in quality problems. 4. Due to the strength comparison of insulation materials. Low, at the same time, poor bonding effect, easy to find. The flat layer is separated, resulting in an empty drum and an opening. Quality problems of some columns, such as cracks.

Continuing Table 2.3

1	2	3
Inverted roof	1. The insulation layer is above the waterproof layer, which can protect the waterproof layer well and is not easily affected by the environment, thus prolonging the service life. 2. The insulation layer on the surface can be more It can solve the problems of moisture prevention and effectively adjust the roof temperature. 3. Find the bond between the slope layer and the levelling layer The performance will be much higher, and at the same time, because looking for Slope strength is high, so it is not easy. There is a problem with the empty drum cracking.	1. If there is leakage in the waterproof layer, it is necessary to destroy the insulation layer before renovation and maintenance, and the renovation cost is relatively high. 3. There is no closed insulation layer surface or rainwater. It is easier to penetrate the insulation layer, thus reducing the insulation. Performance. 2. The insulation layer is easy to be damaged, which will lead to cracks in the protection layer, which will make the insulation layer and waterproof layer rain deposited in the gap. 4. The insulation layer is not easy to connect with mortar, resulting in the roof mortar easily falling off or cracking.
Ventilated roof	1. Thermal insulation under natural ventilation conditions. The ventilation effect is obvious and the heat dissipation is fast. 2. The structure is relatively simple and the construction is difficult. Low, can be used for flat roofs and sloping houses. Top. 3. There is not much need for special management, and the load increases.	1. Because of the rapid heat dissipation, it will come out in winter. Now because of the ventilation effect, the safety of the building is reduced temperature performance, which accelerates the decrease and increase of roof temperature. Add heating load. 2. The disadvantage of people going to the roof is that people will walk around. The service life of the overhead heat insulation board is shortened, and it is easily damaged. When the overhead insulation board is damaged, it also This will lead to accelerated damage to the waterproof layer, which needs to be approved. Regular maintenance can only be maintained, increasing costs. 3. The requirements for the natural environment are higher, in the natural wind. Insufficient areas can't play a better use role.

Continuing Table 2.3

1	2	3
Slope roof	1. The rainwater can be well discharged, The roof seepage is solved to the greatest extent. Leakage and other issues. 2. Beautify the image of buildings and cities. 3. The roof with the attic is as follows Effective thermal insulation performance can also be when the storage space is used.	1. There are certain requirements for materials. If the material is reversed too high light will be harmful to traffic safety nearby and the environment has an impact. 2. Large surface area, less space utilisation, no in the form, the investment in the structure is increased.
Planting roof	1. Can absorb or reflect off the big Part of the sunlight and heat. there can Effectively reduce the roof temperature. 2. Roof greening can improve greening. Area, beautify the environment, on the building week The surrounding climate plays a regulatory role. It can also purify the air and make people feel good. Pleasure. 3. The soil and plants on the roof also It can isolate a part of the noise.	1. The short life of planted roofs and roof soil and plants. Is shrunk in proportion to the degree of deterioration over time. 2. Roof load and waterproofing caused by plants planted on the roof Higher performance requirements, increasing costs. 3. Too thin an overburden layer leads to excessive water loss. Plants die, too thick will destroy the lower protection. Layer, quality problems.
Water storage roof	1. The water layer on the roof provides heat insulation. The function is a good water storage roof. Thermal insulation performance. 2. The aquifer is greatly reduced. Roof temperature, so that the waterproof layer does not be made because of high temperature or temperature difference. Deformation and cracking. 3. Water can make the roof material empty. Gas isolation, thus avoiding the oxidation of materials due to contact with air. And other problems, increasing the use of profiles life span. 4. Simple construction cost of water storage roof Low, at the same time, the structural requirements are not high required. 5. Plant plants and water in the water Biological farming can also increase the economy. Benefit, but also change the environment. Good action.	1. Water has the function of constant temperature and can be sucked during the day. Collect heat to reduce the roof temperature but at night It will release heat, but it will not cool down. 2. Increase the roof static load and prevent leakage. Water needs to strengthen the roof's waterproof measures. 3. Waste of water resources.

2.3.4 Comparison of Suitability of Shading System

In the process of application, shading methods usually coexist in various forms. Use different ways, to cooperate to make up for each other's shortcomings, to achieve a more comprehensive shading effect. The following analysis of various shading methods, to better match, give play to advantages, and achieve the purpose of environmental protection and energy saving.

External shading usually achieves the purpose of shading through external shading construction, reflecting sunlight and avoiding the interference of indoor heat balance. The internal sunshade is constructed indoors, but before the reflection is constructed in this way, the sunlight has already entered the room through the glass, and a part of heat energy consumption will still be increased in the process of back-and-forth reflection. Therefore, the efficiency of internal shading is lower than that of external shading according to the reflectivity of sunlight. In the part with a large window area, the effect of using external shading is obvious, especially in summer or in hot areas. Under the same environment, the use of an internal sunshade system can reduce the indoor temperature by 4-5 degrees Celsius, saving about 30%-40% of refrigeration energy consumption. The use of an external sunshade can reduce the indoor temperature of 7-8 degrees Celsius, saving energy consumption of air conditioning by about 40%-60%. Therefore, from the perspective of energy saving, the effect of external shading is better than that of indoor shading, and the maximum refrigeration power of air conditioning refrigeration energy consumption can be reduced by about 17%, and the refrigeration energy consumption can be reduced by about 83%-88%.

The advantage of an internal sunshade is that it has more material selectivity and a strong decorative effect. At the same time, it is more widely used because of its simple construction and easy operation and maintenance. Internal shading can also increase the privacy of people's lives, so internal shading cannot be completely replaced by external shading. In the process of architectural design and construction, we should fully consider the shading method. Combine the two to achieve better shading and energy-saving effect, and at the same time meet people's dual needs for use feeling and use function. Table 2.4 lists the actual shading coefficient caused by different shading methods and different materials.

Table 2.4 – Shading effects of different building shading methods

Types of building shading methods	Types of sunshade facilities	shading coefficient
Intermediate shading mode	common glass	0.76
	Double-layer ordinary glass	0.64
	Heat-reflecting glass	0.26
	endothermic glass	0.4
Internal shading mode	Dark green movable louvre	0.62
	White curtain	0.41
	White movable Venetian blinds	0.46
	White cotton and linen louver	0.3
External shading mode	Dark green small louver	0.13
	White louver (45 inclination)	0.14

CONCLUSIONS TO CHAPTER 2

This chapter primarily focuses on energy saving for analysis and discussion. First, the development and evolution of energy-saving building design were analysed and discussed; that is, energy-saving planning and design evolved into energy-saving design of maintenance structure, covering energy-saving of external walls, doors and windows, roof energy-saving, floor energy-saving technology and building sunshade system. Secondly, this paper makes a detailed comparison of the application of energy-saving products such as roof energy-saving technology, external wall insulation system technology, sunshade system technology, and door and window energy-saving technology, which lays the foundation for the following research.

CHAPTER 3 ENERGY CONSUMPTION ANALYSIS OF BUILDING ENERGY-SAVING DESIGN

3.1 Building Energy Efficiency Analysis

3.1.1 Project Overview

General situation of architecture

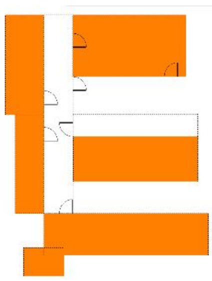
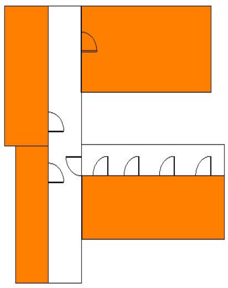
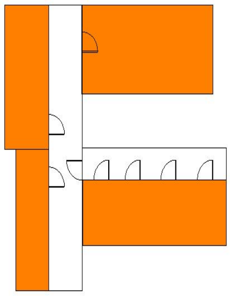
This project is a public building in Hexi, Nanjing, Jiangsu Province, China and a construction project of Fudan University in Shanghai. The newly-built science building in the project is located in the northeast of the campus, the material building of the project is located in the north of the campus, the research building is located in the west of the campus, and the landscape greening is concentrated in the south of the campus.

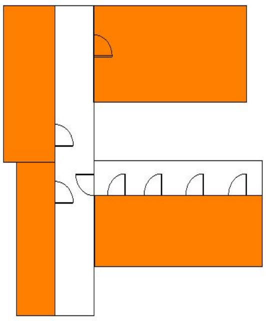
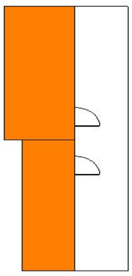
The fire-resistance rating of this building project is Grade II, and the seismic index is Grade 7. The building type belongs to public buildings and is divided into Grade II high-rise buildings. The safety factor of the building structure is Grade II, and the frame structure belongs to Class A The construction site of this building is relatively flat, with a total construction area of 24,380 square meters and a total area of 15,450 square meters, including 4,680 square meters underground and 19,700 square meters above ground. The greening rate of the environment reaches 32%, the building density is 18.5%, and the plot ratio is 1.27. This building has 7 floors, with a total height of about 22.700-27.100 meters.

The basic overview of the building model is shown in Table 3.1, and the standard floor plan is shown in Figure 3.1.

Table 3.1 – Project overview

building storey	5 floors above ground and 0 floors underground.	Building exterior area	5187.87m^2
building height	18.00m	Building volume (above ground)	18422.29m
covered area	5158.50m^2	shape coefficient of the building	0.28
North angle	115°	Building site	Jiangsu Nantong

		
1 standard layer	2 standard layers and	3 standard layers
Air-conditioned room area: 966.78m^2	air-conditioned room area: 795.79m^2	air-conditioned room area: 783.43m^2
Non-air-conditioned room area: 317.54m^2	Non-air-conditioned room area: 253.21m^2	Non-air-conditioned room area: 253.40m^2

	
Four standard floors	five standard floors.
Area of air-conditioned room: 571.08m^2	area of air-conditioned room: 379.76m^2
Non-air-conditioned room area: 227.25m^2	Non-air-conditioned room area: 74.68m^2

Design and selection of materials

The materials of the essential components of the building refer to the common practice in the Nantong area. In this model, 240-thick KP1 hollow bricks are used for the external wall, and the straight coiled material waterproof and thermal insulation flat roof and sloping roof are used for the roof. The external window is a single-frame Low-E hollow glass window with heat insulation aluminium alloy (6+12A+6). The names of materials used in this project, material density, thermal conductivity and thermal storage coefficient are shown in the table. See Table 3.2-3.7 for the specific structural forms of building components.

Table 3.2 Materials used in the model

Material name	Density [kg/m³]	Thermal conductivity [w/m*k]	Thermal storage coefficient
polymer mortar	1800.00	0.93	11.37
Plastic extruded board	30.00	0.030	0.54
cement mortar	1800.00	0.93	11.37
KP1 perforated brick	1400.00	0.58	7.92
mixed mortar	1700.00	0.87	10.75
reinforced concrete	2500.00	1.74	17.20
Cement anti-crack mortar	1800.00	0.93	11.37
Fine aggregate concrete	2300.00	1.51	15.36
Compacted clay 1	2000.00	1.16	12.99
Lime, cement, sand, mortar	1700.00	0.87	10.75
Energy-saving door (filled with mineral wool or glass wool, thickness>30mm		2.00	
Heat insulation aluminium alloy single frame Low-E hollow glass window (5+9A+5)		2.90	

Table 3.3 – Structure Table

Wall type	Wall thickness	Wall materials
Exterior wall type	240 thick KP1 hollow brick	KP1 perforated brick 240mm, cement mortar 20mm, adhesive 3mm, interface agent, extruded board 20mm, interface agent, polymer mortar 7mm, alkali resistant fibre breaking mesh cloth, polymer mortar 7mm, finishing layer
Roof type	Upright coiled material Waterproof and thermal insulation flat roofing Slope roof	Cement mortar 20mm, reinforced concrete 150mm, cement sand 20mm mortar extruded board 45mm, 20mm cement mortar, coiled material Waterproof layer, protective layer, Lime+cement+sand+mortar 20mm, reinforced concrete 120mm, cement mortar 20mm, extruded board 45mm, cement Mortar 20mm, coiled material waterproof layer, water strip, tile strip, ash tile
window	Heat cutoff aluminium alloy Hollow glass	Insulating glass (6Low-E+12A+6), bridge cutoff and thermal insulation aluminium alloy window Frame, heat transfer coefficient: 2.70W/(m² ·K)
Type of thermal bridge column	Thermal bridge column	KP1 perforated brick 240mm, cement mortar 20mm, adhesive 3mm, interfacial agent, extruded board 20mm, interfacial agent, polymer Mortar 7mm, alkali-resistant fibre-breaking mesh cloth, polymer mortar 7mm, Finish layer
Type of thermal bridge	Thermal bridge	KP1 perforated brick 240mm, cement mortar 20mm, adhesive 3mm, interfacial agent, extruded board 20mm, interfacial agent, polymer Mortar 7mm, alkali-resistant fibre-breaking mesh cloth, polymer mortar 7mm, Finish layer

3.1.2 Energy saving calculation results

Static indicators

See Table 3.4 below for the analysis and comparison of static indicators and specified indicators of the project.

Table 3.4 – Static Results

Static indicators of the project	Specified standards	Result
1	2	3
The shape coefficient is 0.28	For class B buildings, in areas with hot summers and cold winters, the shape coefficient should not be greater than 0.40	Meet the requirements
1	2	3
Vertical coiled material waterproof and thermal insulation flat roof (accessible) K=1 wind=0.65w/m² ·K	In hot summer and cold winter areas, K should be ≤0.70.	Meet the requirements
Flat roof with straight coiled material waterproof and thermal insulation (non -master) k = 1/ro = 0.66 w/m² ·K	In hot summer and cold winter areas, k should be ≤0.70.	Meet the requirements
Average thermal transmittancet of the outer wall k = 0.92 w/m² ·K	Hot summer and cold winter area, Class B building, K≤1.00.	Meet the requirements
Cantilever floor k = 1/ro = 0.91w/m² ·K	In hot summer and cold winter areas, k should be ≤1.00.	Meet the requirements
Slope roof k = 1/ro = 0.67 w/m² ·K	In hot summer and cold winter areas, K≤0.70.	Meet the requirements
The shading coefficient should be 0.48, the heat transfer coefficient should be 2.70, and the west window-wall ratio should be 0.39.	Average area ratio of window to wall: 0.3<Cm≤0.4, heat transfer coefficient K ≤3.00, shading coefficient ≤0.50.	Meet the requirements
The shading coefficient should be 0.45, the heat transfer coefficient. 2.70, and the east window-wall ratio is 0.20.	The shading coefficient is unlimited, and the heat transfer coefficient k should be ≤4.70, average area ratio of window to wall: Cm≤0.2,	Meet the requirements
The shading coefficient should be 0.62, the heat transfer coefficient should be 2.70, and the north window-wall ratio should be 0.33.	Average area ratio of window to wall: 0.3<Cm≤0.4, heat transfer coefficient K ≤3.00, shading coefficient ≤0.60.	Do not meet the requirements
The south window-wall ratio is 0.21, the heat transfer coefficient is 2.70, and the shading coefficient should be 0.47.	Average area ratio of window to wall: 0.2<Cm≤0.3, heat transfer coefficient K ≤3.50, shading coefficient ≤0.55.	Meet the requirements
The thermal resistance of the surrounding ground is r = Zr = 1. 119 m² ·K/w.	In hot summer and cold winter areas, the thermal resistance R0 should be ≥1.20.	Do not meet the requirements

Provisions on the Depth of Compilation of Construction Drawing Design Documents (Special Articles on Energy Saving) of Civil Building Engineering in Jiangsu Province (2009 edition) and Jiangsu Engineering Construction Standard-Energy Saving Design Standard for Public Buildings (DGJ32/J96-2010) stipulate that the shading coefficient of the back window of the building should be 0.60, while the north window coefficient of the above-mentioned building is 0.62, so it does not meet the specified requirements. The same ground thermal resistance is stipulated that R0 should be ≥1.20, and the above building is R = > R = 1.119 m² ·K/w, which also does not meet the requirements. Therefore, thermal trade-off calculation should be carried out as shown in Table 3.5-3.7

Table 3.5 – Thermal Parameters of Design Building

Retaining structure position		Design buildings		
external wall		0.92W/(m² ·K)		
roofing		0.67W/(m² ·K)		
Overhead floor		0.91		
External window (including transparent curtain wall)	orientation	Window-wall ratio	Heat transfer coefficient w/(m² ·K)	shading coefficient
	east	0.20	2.9	0.45
	west	0.39	2.90	0.48
	south	0.21	2.90	0.47
	north	0.33	2.90	0.84
skylight		--		--
ground		--		
Roof skylight area ratio		--		
The upper floor of the basement is not heated		--		
Unheated basement exterior wall				

Table 3.6 – Thermal parameters of reference buildings

Design building of enclosure structure
External wall 1.00 w/(m²·K) Roof 0.70 w/(m²·K) Overhead floor 1.00
The specific heat transfer coefficient w/(m²·K) shading coefficient of the external window (including transparent curtain wall) towards the window wall.
East 0.20 4.70
West 0.40 3.00 0.50
South 0.30 3.50 0.55
North 0.40 3.00 0.60
Skylight -
Ground 1.20
Roof skylight area ratio 0.20
No heating basement upper floor 1.20
No heating basement exterior wall 1.20

Table 3.7 – Comparison Table of Annual Energy Consumption of Design Building and Reference Building

Types of energy consumption	Design building unit surface Product energy consumption (kWh/m)	Reference building unit plane Product energy consumption (kWh/m)
Cumulative heating load	60.13	58.07
Cumulative cooling load of air conditioner	73.91	76.00
amount to	134.04	134.07

Through the thermal function analysis of the above table, the energy-saving rate of this building is 50.01%. The annual energy consumption of this building conforms to the civil building regulations of Jiangsu Province and the energy-saving regulations.

3.2 Orthogonal test analysis of building energy-saving design

3.2.1 Basic procedures of orthogonal test design

Orthogonal experimental design is suitable for comprehensive experiments with many factors, which is a commonly used and relatively simple experimental method. The process of orthogonal experiments can be divided into two aspects: data processing and experimental design. The basic process of the orthogonal test is listed below.

1. First, determine the purpose of the test and relevant regulations or indicators.
2. Select the factors that need to be compared to measure.
3. Select the format of the orthogonal table and adjust it as needed.
4. Design and complete the test scheme, to get the result.
5. Finally, the experimental results are analysed and summarised.

3.2.2 Selection of factor level

Four aspects that significantly affect building energy consumption are selected from the chosen building model for calculation: floor heat transfer coefficient (D), roof heat transfer coefficient (C), window heat transfer coefficient (B), and exterior wall heat transfer coefficient (A). At the same time, four levels of these factors are selected for the orthogonal test. The following lists the factors and their respective levels, as well as the specific structural types of each factor as shown in Tables 3.8 and 3.9.

Table 3.8 – Values of Influencing Factors and Levels

level	Heat transfer coefficient of external wall a/(w/m²·K)	Heat transfer coefficient of window b/(w/m²·K)	Roof heat transfer coefficient c/(w/m²·K)	Count the floor heat transfer coefficient d/(w/m²·K)
1	0.95	4.70	0.770	1.790
2	1.090	4.00	0.80	1.390
3	0.960	3.30	1.210	1.860
4	1.010	3.50	0.860	1.470

Table 3.9 – Structure types corresponding to each value

	An exterior wall type	B window type	C roof type	D floor type
1	Clay porous brick and hollow brick wall 240 (moulded polystyrene board)	Plastic single-layer ordinary hollow glass window	Slope roof (polyurethane rigid foam plastic)	Cement mortar floor (rock wool, mineral wool)
2	Aerated concrete block	Aluminium alloy ordinary single flat frame double glass 6~12mm (push and pull)	Roofing (extruded polystyrene foam plastic board)	Overhead floor with natural ventilation at the bottom (extruded polystyrene board)
3	Sintered porous brick (expanded (extruded polystyrene board)	Ordinary hollow glass window with heat-insulating aluminium alloy single roof frame	Roofing (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)
4	Reinforced concrete wall (polyurethane plastic)	Aluminium alloy ordinary single-frame insulating glass 9~12mm (flat)	Flat roof (polyurethane rigid foam rigid foam waterproof overhead floor (rock wool, warm layer)	Mineral wool with natural ventilation at the bottom, glass wool board)

The structural composition of each part of the peripheral protection structure is usually the following types:

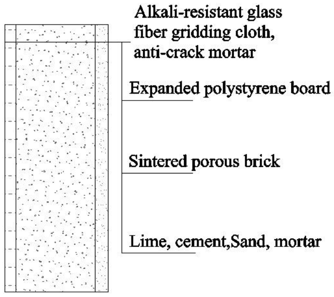
Aerated concrete block, reinforced concrete wall (polyurethane rigid foam), hollow brick wall 240 (moulded polystyrene board), clay porous brick, sintered porous brick (expanded polystyrene board), etc. are mostly used for external walls. See Table 3.10 for specific parameters.

The windows are made of aluminium alloy single-frame hollow glass 9~12mm (flat), aluminium alloy single-frame double glass 6~12mm (push-pull), aluminium alloy single-frame hollow glass window with thermal insulation and broken bridge and plastic steel single-frame hollow glass window 9~12mm, see Table 3.11

The roof is flat roof (extruded polystyrene foam plastic board), roof (extruded polystyrene board), sloping roof (polyurethane rigid foam plastic) and flat roof (polyurethane rigid foam waterproof insulation layer). See Table 3.12 for specific parameters.

The floors are mainly made of overhead floors with natural ventilation at the bottom (mineral wool, rock wool and glass wool board), overhead floors with natural ventilation at the bottom (extruded polystyrene board), cement mortar floors (rock wool and mineral wool) and overhead floors with natural ventilation at the bottom (polystyrene particle insulation mortar). See Table 3.13 for specific parameters.

Table 3.10 – Four Kinds of Exterior Wall Structures and Parameters

Exterior wall type	structural drawing	The material thickness of each layer	Thermal conductivity W/m² ·K	Thermal inertia index
1	2	3	4	5
Sintered porous brick (expanded polystyrene board EPS)		Layer 1: alkali-resistant glass fibre mesh cloth, anti-crack mortar, thickness of 4 mm. Layer 2: expanded polystyrene board with a thickness of 30mm Layer 3: sintered porous brick with a thickness of 240 mm. Layer 4: lime, cement, sand and mortar, with a thickness of 20mm.	0.960	3.830
Aerated concrete block		Layer 1: polymer mortar with a thickness of 20 mm. Layer 2: aerated, foamed	1.090	4.408

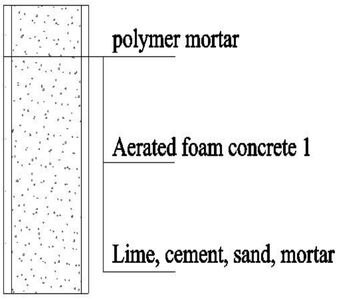
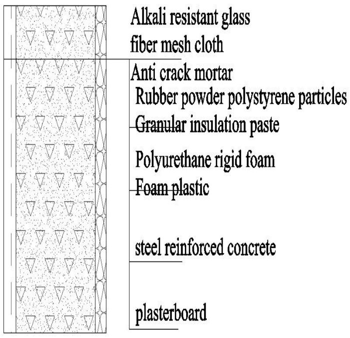
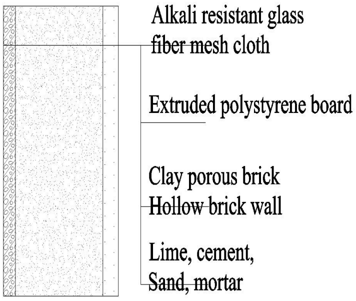
		concrete 1, with a thickness of 240mm, Layer 3: lime, cement, sand and mortar, with a thickness of 20mm.		
Reinforced concrete wall (rigid polyurethane foam)		Layer 1: alkali-resistant glass fibre mesh cloth, anti-crack mortar, thickness Smm. Layer 2: Rubber powder polystyrene particle thermal insulation slurry with a thickness of 10mm. Layer 3: Polyurethane rigid foam plastic 2, with a thickness of 20 mm. 4th floor: reinforced concrete, with a thickness of 200mm. 5th floor: gypsum board, with a thickness of 20 mm.	1.010	2.739
Clay porous brick and hollow brick wall 240 (XPS)		Layer 1: alkali-resistant glass fibre mesh cloth, anti-crack mortar, with a thickness of 5 mm. Layer 2: extruded polystyrene board with a thickness of 20mm Layer 3: clay perforated brick and hollow brick wall with a thickness of 240 mm. Layer 4: lime, cement, sand and mortar, with a thickness of 20 mm.	0.950	3.825

Table 3.11 – Structure and related parameters of four types of windows

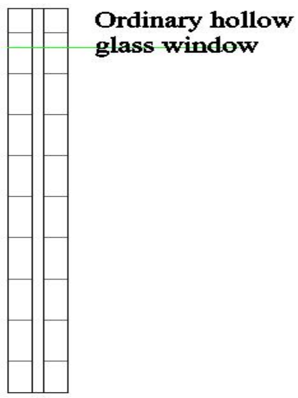
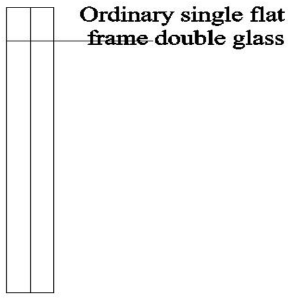
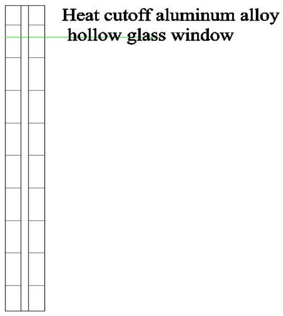
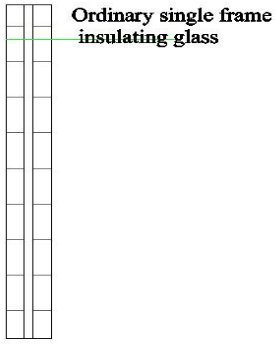
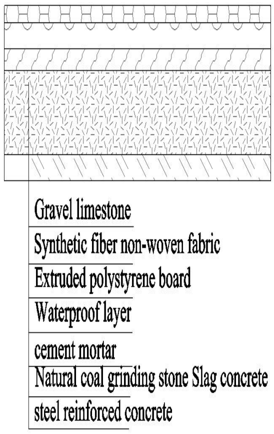
Window type	structural drawing	The material thickness of each layer	Thermal conductivity W/m² ·K	Thermal inertia index
Plastic single-layer ordinary hollow glass window		First layer: glass Second layer: air Third time: glass	4.70	8.60
Aluminium alloy ordinary single flat frame double glass 6~12mm (push-pull)		First layer: glass Second layer: glass	4.00	8.80
Heat cutoff aluminium alloy single roof frame ordinary hollow glass window		First layer: glass Second layer: air Third time: glass	3.30	8.69
Aluminium alloy ordinary single frame insulating glass 9~12mm (flush opening)		First layer: glass Second layer: air Third time: glass	3.50	9.25

Table 3.12 – Structure and Related Parameters of Four Types of Roofs

Roof structure map type	structural drawing	The material thickness of each layer	Thermal conductivity W/m² ·K	Thermal inertia index
Roofing (extruded polystyrene board)		Layer 1: Gravel, limestone, 40mm thick Layer 1: synthetic fibre non-woven fabric. Layer 3: extruded polystyrene board with a thickness of 20 mm. Layer 4: waterproof layer with a thickness of 10mm. Layer 5: cement mortar with a thickness of 20 mm. Layer 6: natural coal grindstone, slag concrete, with a thickness of 100mm. 7th floor: reinforced concrete, with a thickness of 120mm.	1.21	3.388

Continue Table 3.12

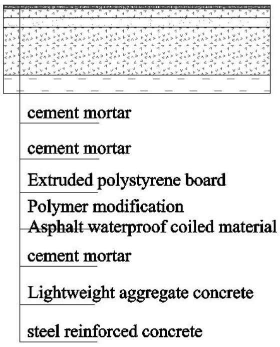
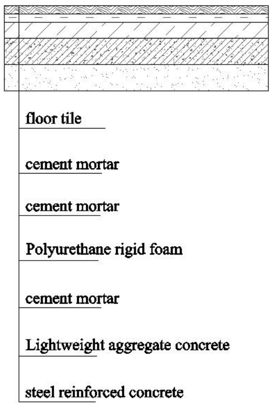
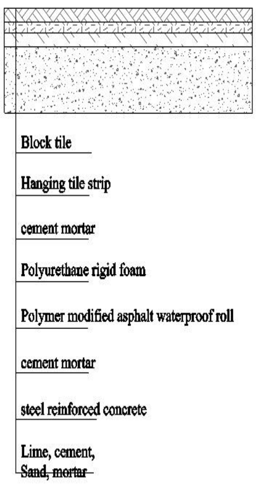
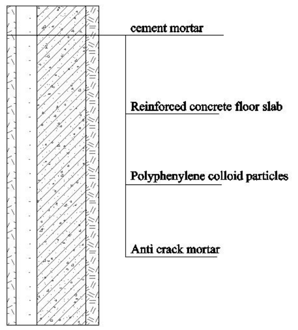
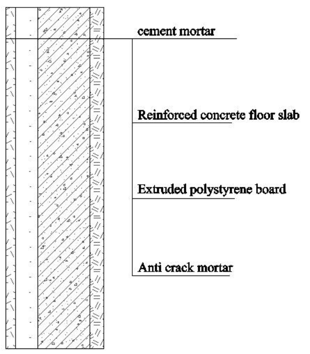
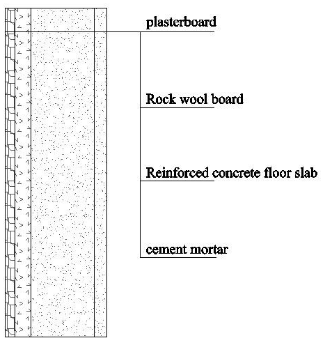
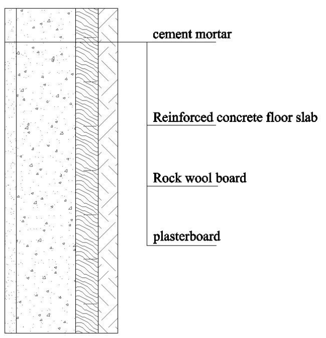
1	2	3	4	5
Flat roof (extruded polystyrene foam plastic board)		Layer 1: cement mortar, with a thickness of 5 mm. 2nd floor: cement mortar with a thickness of 20mm. Layer 3: extruded polystyrene board with a thickness of 35mm. Layer 4: polymer-modified asphalt waterproofing membrane with a thickness of 4 mm. Layer 5: cement mortar with a thickness of 20 mm. Layer 6: lightweight aggregate concrete, with a thickness of 80mm. 7th floor: reinforced concrete, with a thickness of 120mm.	0.78	2.966
Flat roof (polyurethane rigid foam waterproof insulation layer) 1		Floor 1: Floor tiles Layer 2: cement mortar with a thickness of 5 mm. Layer 3: cement mortar with a thickness of 15mm. Layer 4: Polyurethane rigid foam plastic with a thickness of 30 mm. Layer 5: cement mortar with a thickness of 20 mm. Layer 6: lightweight aggregate concrete, with a thickness of 80mm. 7th floor: reinforced concrete, with a thickness of 120mm.	0.86	2.256
Slope roof (polyurethane Ester rigid foam plastic) 1		Layer 1: Block Tile Layer 2: batten. Layer 3: cement mortar with a thickness of 20 mm. Layer 4: polyurethane rigid foam plastic, with a thickness of 35mm. Layer 5: polymer-modified asphalt waterproofing membrane with a thickness of 3 mm. Layer 6: cement mortar with a thickness of 15mm. 7th floor: reinforced concrete, with a thickness of 120mm. 8th floor: lime, cement, sand and mortar, with a thickness of 10mm.	0.770	2.198

Table 3.13 – Structure and Related Parameters of Four Types of Floors

Floor structure pattern		Thickness of each layer of material	Thermal conductivity W/m^2 ·K	Thermal inertia index
Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)		Layer 1: cement mortar with a thickness of 20mm. 2nd floor: reinforced concrete floor with a thickness of 120mm. Layer 3: colloidal phenol polystyrene particles with a thickness of 30 mm. Layer 4: anti-crack mortar with a thickness of 3 mm.	1.86	2.161
Overhead floor with natural ventilation at the bottom (extruded polystyrene board)		Layer 1: cement mortar with a thickness of 20mm Layer 2: reinforced concrete floor with a thickness of 120mm Layer 3: extruded polystyrene board with a thickness of 30mm Layer 4: anti-crack mortar with a thickness of 3 mm.	1.39	1.918
Overhead floor with natural ventilation at the bottom (mineral wool, rock wool and glass wool board)		Layer 1: gypsum board with a thickness of 10mm. Layer 2: rock wool board with a thickness of 35mm. 3rd floor: reinforced concrete floor with a thickness of 120mm. Layer 4: cement mortar with a thickness of 10mm.	1.47	2.123
Cement mortar floor (rock wool, mineral wool)		Layer 1: cement mortar with a thickness of 20mm. 2nd floor: reinforced concrete floor with a thickness of 120mm. Layer 3: rock wool board with a thickness of 35mm. Layer 4: gypsum board with a thickness of 10mm.	1.79	1.925

3.2.3 Determination of Orthogonal Test Table

This orthogonal experiment adopts a model of four factors and four levels. The table is established in L1o(45) mode, without considering the interaction of these factors, and an extra blank column is used to record the error data to measure this experiment. Each experimental scheme in the table corresponds to a row, which represents the horizontal combination of factors. The experimental scheme is sorted by numbers. At the same time, the blank column does not affect the experimental content. For example, in Experiment 1, the schemes are A1B2C3D4. This scheme represents an experiment in which the selected materials are an aerial floor with natural ventilation at the bottom (mineral wool, rock wool and glass wool board), aluminium alloy ordinary single-frame double glass 6~12mm (push and pull), flat roof (polyurethane rigid foam waterproof insulation layer) and sintered porous brick (expanded polystyrene board). The corresponding heat transfer coefficients are 1.470 W/m^2K for the floor, 4.00 W/m^2K for the window, 0.860 W/m^2K for the roof and 0.960 W/m^2K for the exterior wall. To sum up, this experiment needs 16 combined experiments, and finally, the experimental results are filled in the table. The results are divided into: the total annual cumulative load and energy-saving rate of the designed building, the cumulative heating load of the designed building, the cumulative cooling load of the air conditioner of the designed building, and so on.

3.2.4 Calculation of Orthogonal Test Table

Determine the primary and secondary order of factors

The experimental results are different because of the different combinations of factors. Different experimental results will lead to different extreme ranges of various factors. The magnitude of extreme range values represents that the numerical values of factors will lead to changes in the experimental index values. The smaller the change, the smaller the influence of the level of proving factors on the experimental results. Conversely, the greater the change, the greater the proof influence. Therefore, the factor column with the largest range represents that the level of this factor has the greatest influence on the experimental results. Therefore, the cumulative heat load of heating in the whole year is influenced by the following factors: C roof heat transfer coefficient < D floor heat transfer coefficient < A exterior wall heat transfer coefficient < B window heat transfer coefficient. The order of cumulative cooling load factors of air conditioning is: d floor heat transfer coefficient < c roof heat transfer coefficient < an exterior wall heat transfer coefficient < b window heat transfer coefficient. For the cumulative total load of the whole year, the factors are arranged as follows: C roof heat transfer coefficient < D floor heat transfer coefficient ≤<A exterior wall heat transfer coefficient < B window heat transfer coefficient.

Determination of the optimal scheme

In the experimental range, the best combination of various factors is the best scheme.

The best scheme of heating cumulative heat load is the overhead floor with natural ventilation at the bottom (polystyrene particle insulation mortar) + single-frame ordinary hollow glass window with heat insulation aluminium alloy+flat roof (extruded polystyrene foam plastic board)+clay perforated brick and hollow brick wall 240 (moulded polystyrene board), which is A4B1C3D1 in the table.

The best scheme of air conditioning cumulative cooling load is cement mortar floor (rock wool, mineral wool) + plastic single-layer ordinary hollow glass window+flat roof (extruded polystyrene foam plastic board) + aerated concrete block, namely

A2B4C2D4 in the table.

There are two best schemes for the cumulative total load in the whole year, namely, the overhead floor with natural ventilation at the bottom (polystyrene particle insulation mortar)+single-frame ordinary hollow glass window with heat insulation aluminium alloy+flat roof (extruded polystyrene foam plastic board)+clay porous brick, namely A4B1C3D1 in the table; And the overhead floor with natural ventilation at the bottom (polystyrene particle insulation mortar)+single-frame ordinary hollow glass window with heat-insulating aluminium alloy + hollow brick wall 240 (moulded polystyrene board)+aerated concrete block, namely A4B1C3D4 in the table.

The most unfavourable scheme

In the experimental range, the worst combination of factors is the worst scheme.

The worst scheme of heating cumulative heat load is cement mortar floor (rock wool, mineral wool)+hot aluminium alloy single-frame ordinary hollow glass window+flat roof (polyurethane rigid foam waterproof insulation layer)+sintered porous brick (expanded polystyrene board), which is A2B4C4D4 in the table.

The worst scheme of air-conditioning cumulative cooling load is the overhead floor with natural ventilation at the bottom (mineral wool, rock wool and glass wool board)+plastic single-layer ordinary hollow glass window+flat roof (extruded polystyrene foam plastic board)+aerated concrete block, namely A1B1C3D3 in the table.

The worst scheme for the annual cumulative total load is the overhead floor with natural ventilation at the bottom (extruded polystyrene board)+plastic single-layer ordinary hollow glass window+sloping roof (polyurethane rigid foam plastic)+aerated concrete block, namely A2B4C4D2 in the table.

Figures 3.2~ 3.9 show the effects of the total annual cumulative load, the cumulative heating load and the cumulative cooling load of air conditioners on the changes of various factors and levels. As can be seen from the trend chart:

The cumulative heat load of heating increases with the increase of thermal conductivity of floors, windows and external walls, and the change range is very obvious. At the beginning of the increase of floor thermal conductivity, the cumulative heating load decreased and then increased with the gradual increase of thermal conductivity. When the thermal conductivity of windows and exterior walls increases, the cumulative heat load will also increase significantly. Therefore, it can be seen that the thermal conductivity of the floor is not completely proportional to the cumulative heating load, and a more suitable level should be sought to obtain a better scheme.

As for the change of cumulative cooling load of air conditioning, with the increase of thermal conductivity of floor, window and exterior wall, the cumulative load has not changed obviously.

Finally, according to the change chart of the cumulative total load in the whole year, the total load shows a downward trend at the beginning of the increase of the heat transfer coefficient of the floor and roof, and it shows an upward trend with the gradual increase of the heat transfer coefficient. With the increase in thermal conductivity of windows and external walls, the total load shows an obvious upward trend. Through the analysis of the data, the change in thermal conductivity of the roof has little effect on the cumulative total load of the whole year. The maximum variation range is 0.0475, the overall variation range is 137.085~137.1325, and the unit variation range is 0.594. The maximum variation ranges of doors, windows and exterior walls are 1.4 and 4.1075, while the unit variation ranges are 10 and 2.94. Therefore, we can see that doors, windows and external walls are the biggest factors affecting energy consumption in the maintenance structure.

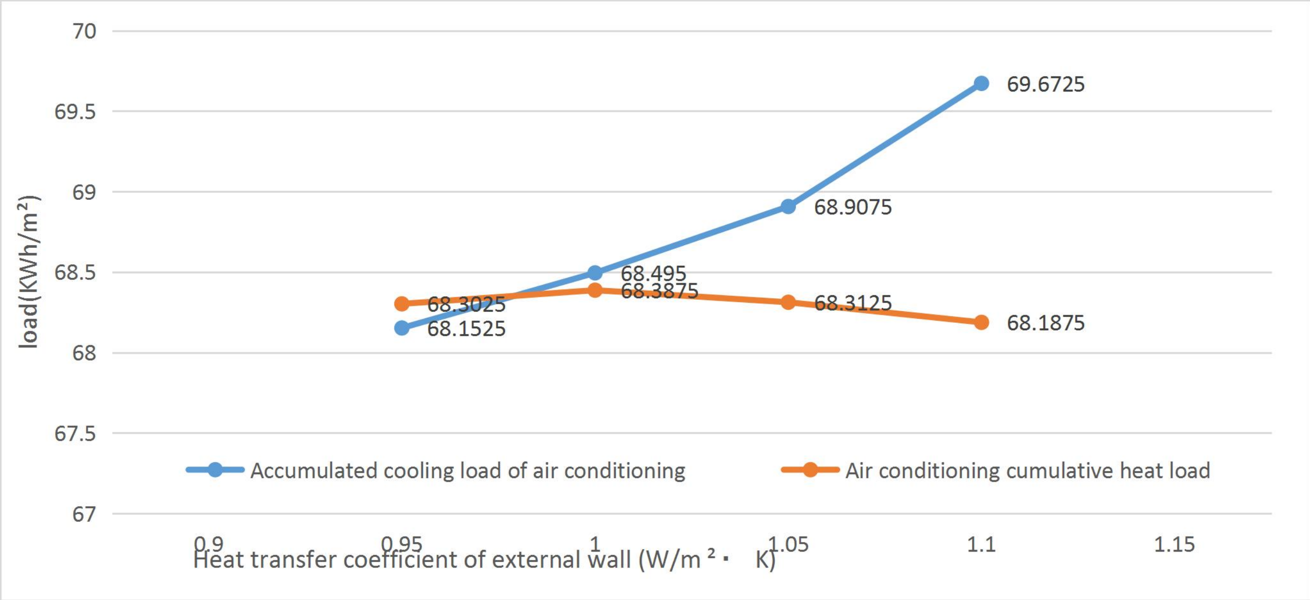


Figure 3.2 – Cumulative cooling and heating load changes with external wall heat transfer

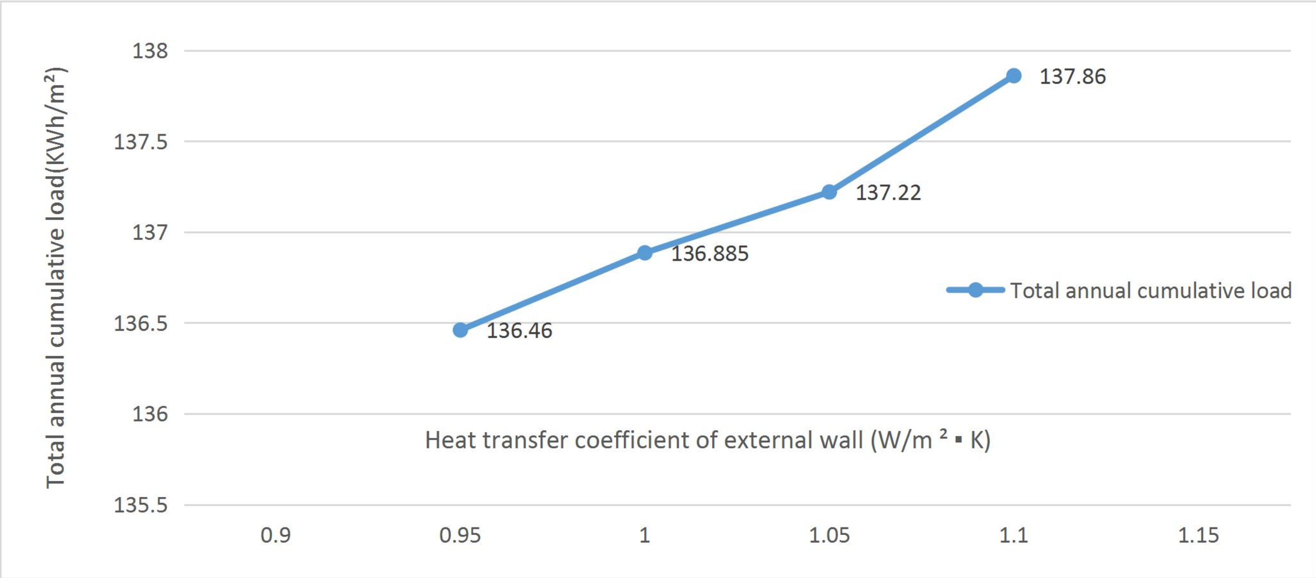


Figure 3.3 – Cumulative total load changes with heat transfer coefficient of external wall

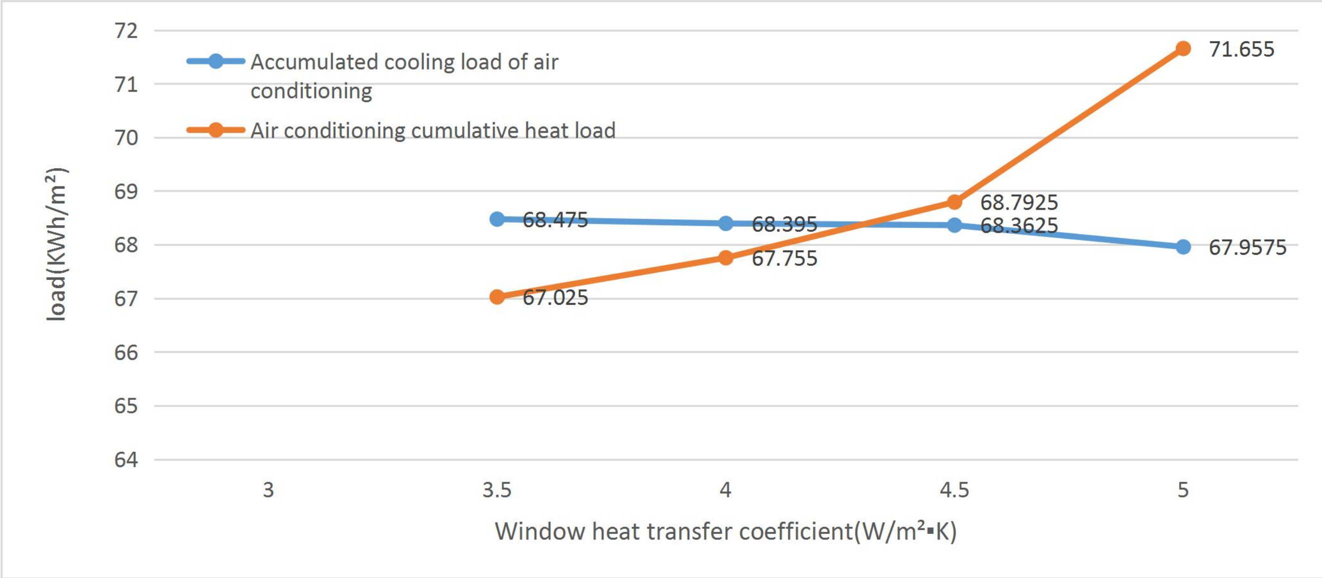


Figure 3.4 – Cumulative cooling and heating load changes with heat transfer in windows

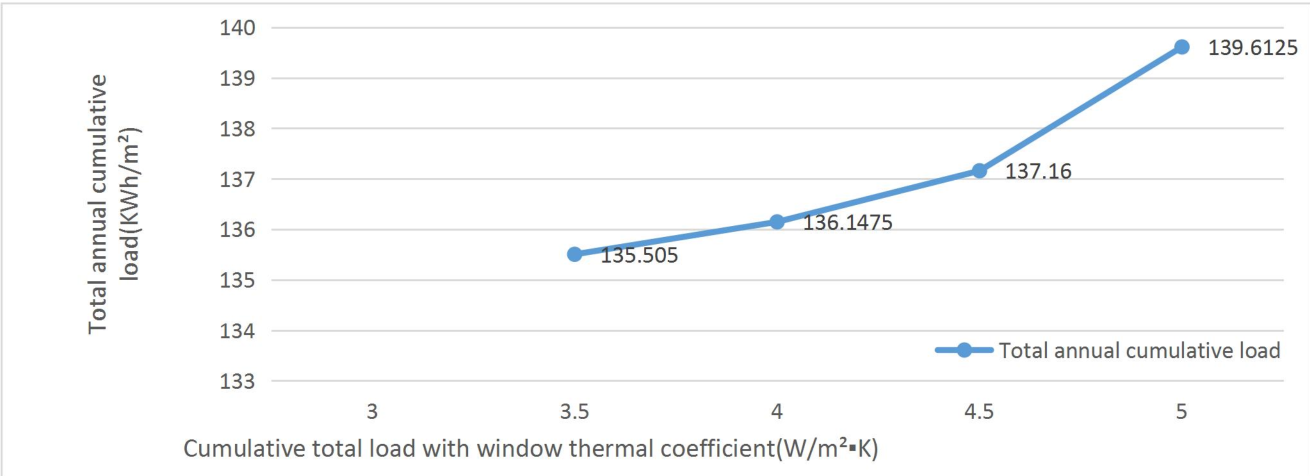


Figure 3.5 – Cumulative total load changes with heat transfer coefficient of an external wall.

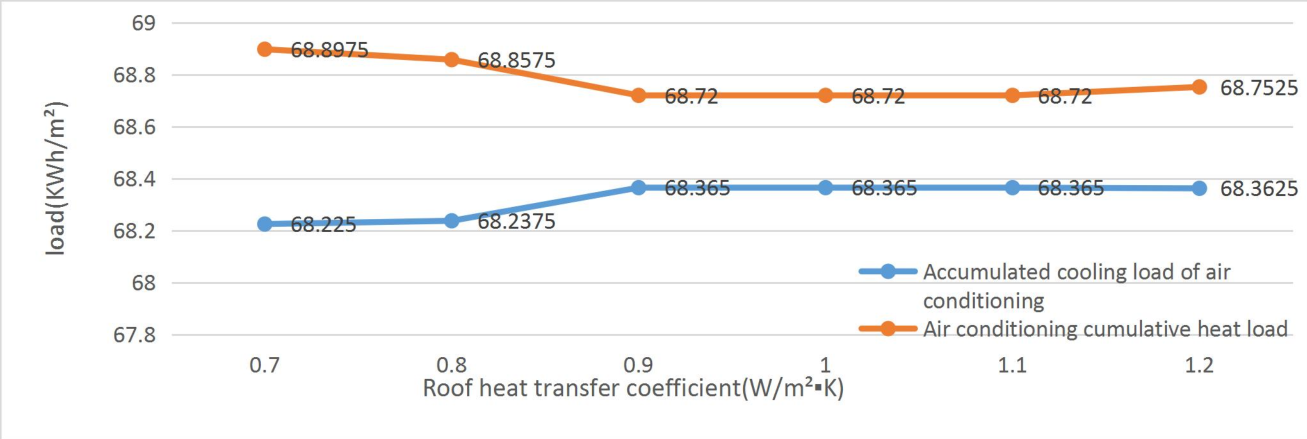


Figure 3.6 – Cumulative cooling and heating load changes with roof heat transfer

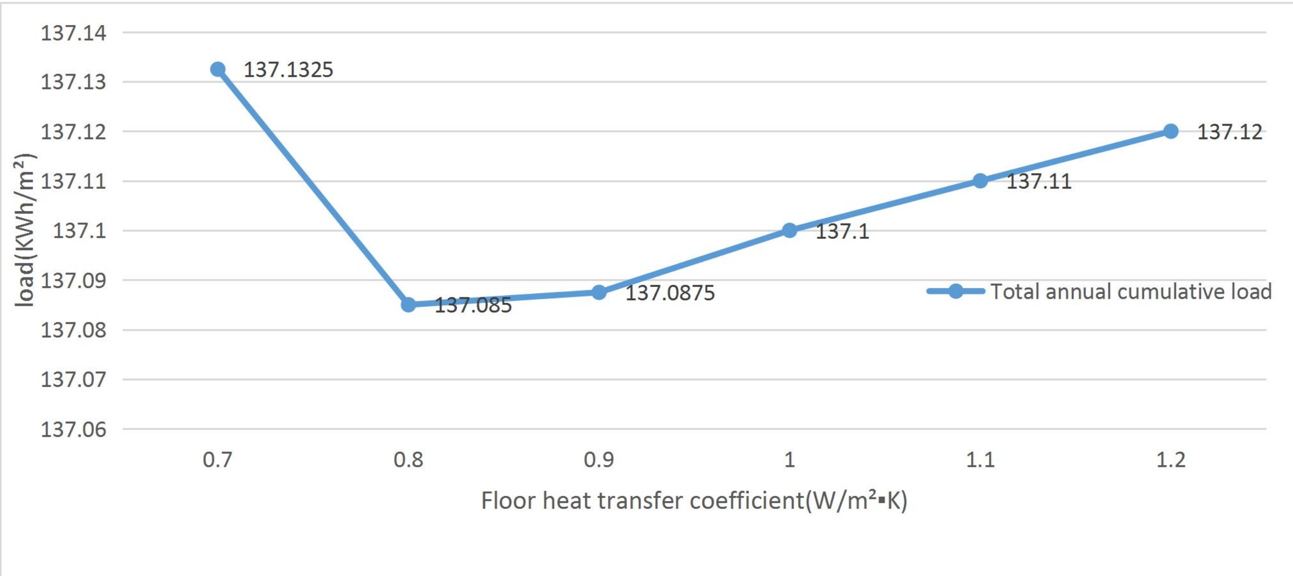


Figure 3.7 – Cumulative total load changes with heat transfer coefficient of roof

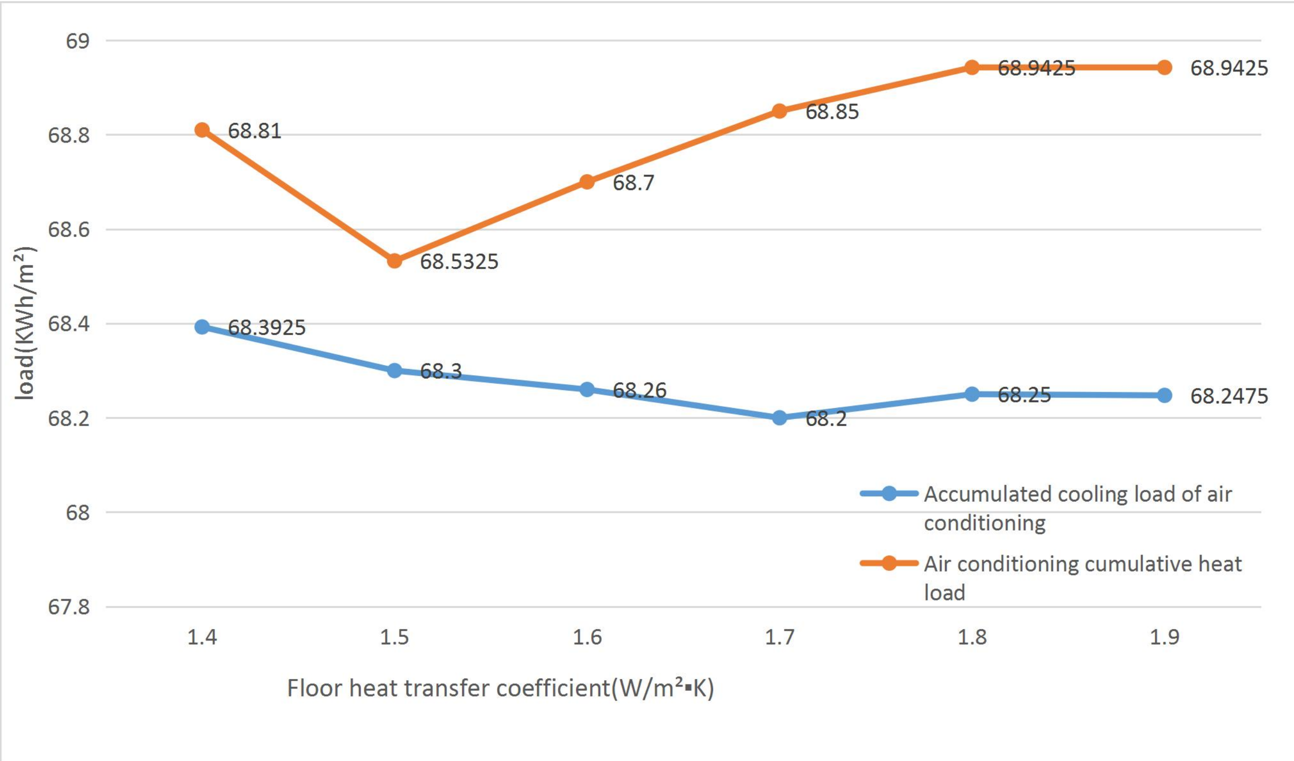


Figure 3.8 – Cumulative cooling and heating load changes with floor heat transfer.

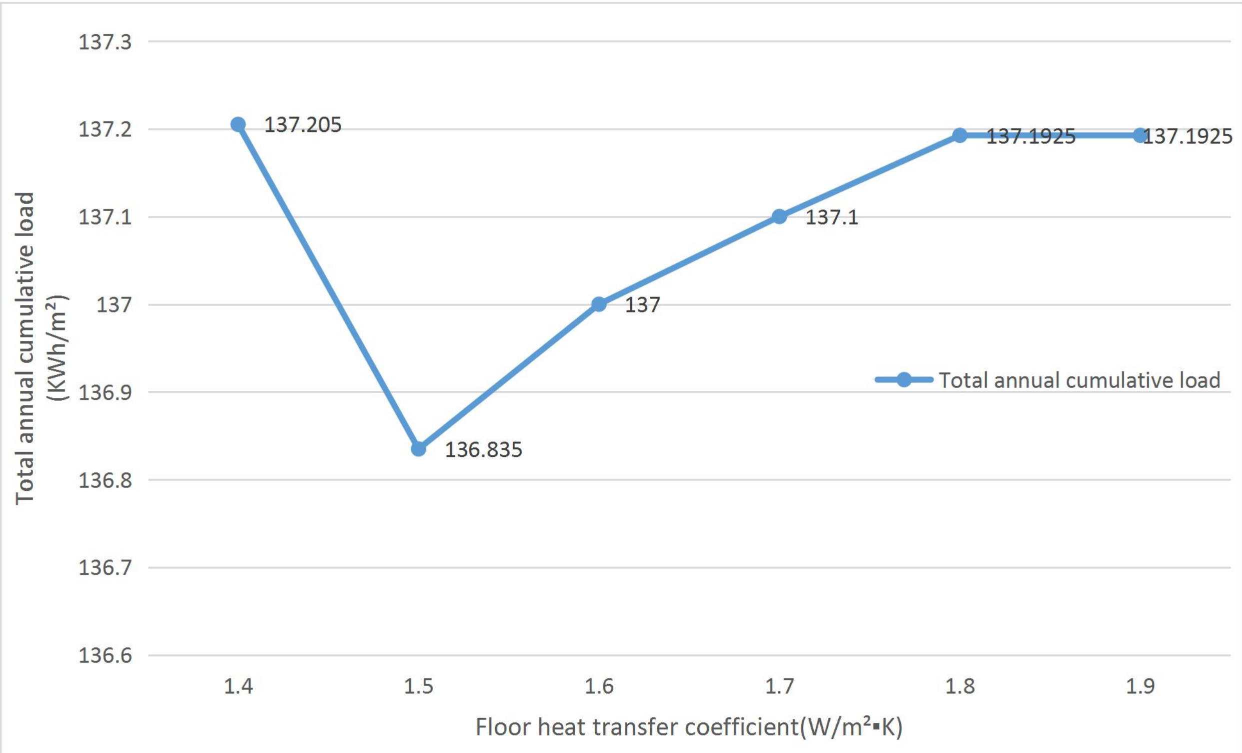


Figure 3.9 – Cumulative total load changes with heat transfer coefficient of the floor slab.

CONCLUSIONS TO CHAPTER 3

Through Tianzheng energy-saving software [55], the selected building model is studied in detail, the dynamic energy consumption is simulated, and the static indicators are analysed. It is concluded that the energy-saving rate of the maintenance structure combination initially adopted in the building is 50.01%. This index meets the requirements of local building codes. Through the analysis of four factors, such as floor heat transfer coefficient, window type, external wall heat transfer coefficient and roof heat transfer coefficient, four levels are selected from each factor for the orthogonal test. Through orthogonal table L16(45), we can see the cumulative heating load of the building, the cumulative cooling load of the air conditioner, the cumulative total load of the whole year and its energy-saving rate. Secondly, these test data are analysed, and finally, the cumulative heat load of heating, the cumulative cold load of air conditioning and the cumulative total load of the whole year are obtained, and the influence degree of various factors and horizontal combinations on them is obtained. Finally, the worst scheme and the best scheme of energy-saving design of envelope structure are given.

CHAPTER 4 ECONOMIC OPTIMISATION OF ENERGY-SAVING DESIGN OF BUILDING ENVELOPE

4.1 Economic analysis of enclosure structure and scheme selection

The public building in this paper covers an area of 5158.50m2, and the selected energy-saving standard reaches 50%. In the following tests, tests 1, 2, 3, 4, 10, 13, 14, 15 and 16 indicate that the elimination rate is within half, and tests 5, 6, 7, 8, 9, 11 and 12 indicate that the energy saving rate is over half. The verification basis of this experiment is based on the orthogonal design method, and the optimal scheme of this experiment is selected. In this paper, optimisation scheme 1 and optimisation scheme 2 are analysed and simulated respectively, which are completed by Tianzheng energy-saving software [55], and the total annual load of the optimisation scheme is accurately calculated. Table 4.1 reflects the summary of the optimal scheme and the energy saving rate exceeding 50%; Table 4.2 reflects the specific structure of the envelope.

Table 4.1 – Reserved Tests

Test number	A	B	D	Annual cumulative total load (kWh/m)	Energy saving rate
5	1	3	4	136.08	50.04%
6	2	1	1	136.05	50.05%
7	3	1	3	135.73	50.17%
8	4	3	2	135.78	50.15%
9	1	1	2	13	50.34%
11	3	3	1	136.11	50.03%
12	4	1	4	134.99	55.44%
Optimal scheme 1	4	1	1	134.26	50.71%
Optimal scheme 2	4	1	4	133.78	50.88%

Table 4.2 – Structural Forms of Components of Envelope Corresponding to Each Test

Test number	A	B	C	D	Annual cumulative total load (kWh/m)	Energy saving rate (%)
1	2	3	4	5	6	7
5	Sintered porous brick (expanded polystyrene board)	Aluminium alloy ordinary single-frame hollow Glass 9-12mm (flat)	Roofing (extruded polystyrene board)	Cement mortar floor (asbestos, mineral wool)	136.08	50.4
6	Aerated concrete block	Hollow ordinary glass aluminium alloy window with heat insulation and broken bridge	Flat roof (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	136.05	50.5
7	Reinforced concrete wall (rigid polyurethane foam)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roofing (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	135.73	50.17
8	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Pu aluminium hollow pu bo aluminium alloy Window 9-12mm (flat)	Roofing (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	135.78	50.15

Continue Table 4.2

1	2	3	4	5	6	7
9	Sintered porous brick (expansion Polystyrene board)	Thermal insulation broken bridge in glass aluminium alloy window	Slope roof (polyurethane hard Plastic foam)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	135.25	50.34
11	Reinforced concrete wall (rigid polyurethane foam)	Aluminium alloy ordinary single-frame hollow glass Glass 9-12mm (flat)	Slope roof (polyurethane rigid foam plastic)	Rice hollow floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	136.11	50.03
12	Clay porous brick and hollow brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow general glass aluminium alloy window	Flat roof (polyurethane rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	134.99	50.44
Preferred scheme 1	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roof polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	134.26	50.71
Preferred scheme 2	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow common glass aluminium alloy Golden window	Flat roof polyurethane (rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	133.78	50.88

4.2 Initialisation of construction costs

To show the cost difference caused by different combination schemes more clearly, different parts are separated and compared with each other, and the calculation unit is M. See Table 4.3. See Table 4.4 for the comparison of construction costs of different combination schemes.

Table 4.3 – Cost of Structural Forms Used in Components of Envelope

An exterior wall type	Sintered porous brick (expanded polystyrene board)	Aerated concrete block	Reinforced concrete wall (polyurethane hard foam Plastic)	Clay hollow brick wall 240 (moulded polystyrene board)
1	2	3	4	5
Unit price (￥/m)	131.51	144.15	170.5	122.97
Unit building area cost (￥/m)	94.45	103.53	122.45	88.32
B window type	Hollow glass aluminium alloy window with heat insulation and broken bridge	General aluminium hollow general glass aluminium alloy window 6~12mm (push-pull)	Ordinary aluminium hollow ordinary glass aluminium alloy window 9~12mm (flat)	Ordinary aluminium hollow ordinary glass aluminium alloy window 9~12mm
Unit cost (￥/m)	707.1	544.3	560.2	334.3
Unit building area cost (￥/m)	142.61	109.77	112.98	67.42
C roof type	Roofing (extruded polystyrene board)	Flat roof (extruded poly) Styrene foam plastic board)	Flat roof (polyurethane Rigid foam waterproof insulation layer)	Slope roof (polyurethane Ester rigid foam plastic)
Unit price (￥/m)	120.52	164.26	136.21	144.39

Continue Table 4.3

1	2	3	4	5
Unit building area cost (￥/ m)	18.44	25.13	20.84	22.09
D floor type	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	Overhead floor with natural ventilation at the bottom (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (glass wool board, rock wool And mineral wool)	Cement mortar floor (mineral wool and rock wool)
Unit price (￥ /m)	80.83	74.77	76.46	74.69
Unit building area cost (￥/ m)	72.44	69.43	68.52	66.94

Table 4.4 – Structural Forms of Components of Envelope Corresponding to Each Test

Test number	A	B	C	D	Unit construction area cost (￥/ m)
1	2	3	4	5	6
5	Sintered porous brick (expanded polystyrene board)	Aluminium alloy ordinary single-frame hollow Glass 9-12mm (flat)	Roofing (extruded polystyrene board)	Cement mortar floor (asbestos, mineral wool)	292.81
6	Aerated concrete block	Hollow ordinary glass aluminium alloy window with heat insulation and broken bridge	Flat roof (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	339.42

Continue Table 4.3

1	2	3	4	5	6
7	Reinforced concrete wall (rigid polyurethane foam)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roofing (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	352.02
8	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Pu aluminium hollow pu bo aluminium alloy Window 9-12mm (flat)	Roofing (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	291.58
9	Sintered porous brick (expansion Polystyrene board)	Thermal insulation broken bridge in glass aluminium alloy window	Slope roof (polyurethane hard Plastic foam)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	328.58
11	Reinforced concrete wall (rigid polyurethane foam)	Aluminium alloy ordinary single-frame hollow glass Glass 9-12mm (flat)	Slope roof (polyurethane rigid foam plastic)	Rice hollow floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	329.96
12	Clay porous brick and hollow brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow general glass aluminium alloy window	Flat roof (polyurethane rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	323
Preferred scheme 1	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roof polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	324.21
Preferred scheme 2	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow common glass aluminium alloy Golden window	Flat roof polyurethane (rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	318.71

4.3 Future operating costs

The following table shows the operating cost of the envelope as shown in Table 4.5

Table 4.5 – Structural Forms of Components of Envelope Corresponding to Each Test

Test number	A	B	C	D	Total cumulative load for the whole year (yuan/m)	Annual energy saving and cost saving (yuan/m)
5	Sintered porous brick (expanded polystyrene board)	Aluminium alloy ordinary single-frame hollow Glass 9-12mm (flat)	Roofing (extruded polystyrene board)	Cement mortar floor (asbestos, mineral wool)	136.08	117.99
11	Reinforced concrete wall (rigid polyurethane foam)	Aluminium alloy ordinary single-frame hollow glass Glass 9-12mm (flat)	Slope roof (polyurethane rigid foam plastic)	Rice hollow floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	136.11	118.01
12	Clay porous brick and hollow brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow general glass aluminium alloy window	Flat roof (polyurethane rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	134.99	117.04
Preferred scheme 1	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roof polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	134.26	116.40
Preferred scheme 2	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow common glass aluminium alloy Golden window	Flat roof polyurethane (rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	133.78	115.99

4.4 Life-cycle Cost and Best Scheme Selection

4.4.1 Parameter setting

Research period

The research period of architecture is mainly determined by two factors, one is the project construction period, and the other is the actual construction period. Each building has different characteristics, which determine the service period of the building. For example, the national reference period for office buildings is 50 years.

Discount rate

Discount rate = industry benchmark rate of return. At present, China has not yet formed a set of mature parameter standards for the discount rate, so it can only be calculated by using the combined model method, and the discount rate is obtained. In other words, the industry discount rate consists of the safe return rate I_f and the risk-return rate β (I_m -I_f), and the calculation formula is as follows :

$$I_c = I_f + \beta(I_m - I_f) \tag{4.1}$$

4.4.2 Determination of Life Cycle Cost Model

When considering the time value of capital: taking the industry benchmark discount rate i =12%, the annual energy cost is A yuan/m², the service life of the building is 50 years, and the initial construction cost of the energy-saving scheme for maintaining the structure is p yuan/m², then the dynamic life cycle cost of the building is:

$$LCCPv = P + A\frac{(1+12\%)^{50}-1}{12\%\times(1+12\%)^{50}} \tag{4.2}$$

$$LCCFv = P(1+12\%)^{50} + A\frac{(1+12\%)^{50}-1}{12\%} \tag{4.3}$$

$$LCCAv = A + P\frac{12\%\times(1+12\%)^{50}}{(1+12\%)^{50}-1} \tag{4.4}$$

Where

$LCCPv$-Present value of life cycle cost;

$LCCFv$-Future value of the whole life cycle;

$LCCAv$-Actual value of the whole life cycle;

P-The initial construction cost of the energy-saving scheme for maintenance structure;

A-Annual energy cost.

On the premise of ignoring the time value of funds, the static life cycle cost of buildings is calculated as $C=P+A\times50$.

4.4.3 Life Cycle Cost Calculation and Best Scheme Selection

See Table 4.6 for the calculation results of static life cycle cost (C) and dynamic life cycle cost ($LCCpv$, $LCCFv$, $LCCAv$) of the envelope energy-saving scheme.

Table 4.6 – Life Cycle Cost of Energy Saving Scheme for Envelope

Test number	A	B	C	D	Unit construction area cost (yuan/m²)	Annual energy cost (yuan/m²)	LCCpv (yuan/m²)	LCCFv (yuan/m²)	LCCAv (yuan/m²)	Static life cycle cost (c) (yuan/m²)
1	2	3	4	5	6	7	8	9	10	11
5	Sintered porous brick (expanded polystyrene board)	Aluminium alloy ordinary single-frame hollow Glass 9-12mm (flat)	Roofing (extruded polystyrene board)	Cement mortar floor (asbestos, mineral wool)	292.81	117.99	1272.66	367798.73	153.25	6192.31
6	Aerated concrete block	Hollow ordinary glass aluminium alloy window with heat insulation and broken bridge	Flat roof (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation	339.42	117.96	1319.02	3811.97.12	158.83	6237.42

				mortar)						

Continuing Table 4.6

1	2	3	4	5	6	7	8	9	10	11
7	Reinforced concrete wall (rigid polyurethane foam)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roofing (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	352.02	117.68	1329.29	384166.55	160.07	6236.02
8	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Pu aluminium hollow pu bo aluminium alloy Window 9-12mm (flat)	Roofing (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	291.58	117.72	1269.18	366792.37	152.83	6177.57
9	Reinforced concrete wall (rigid polyurethane foam)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roofing (extruded polystyrene board)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	352.02	117.68	1329.29	384166.55	160.07	6236.02
10	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Pu aluminium hollow pu bo aluminium alloy Window 9-12mm (flat)	Roofing (polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	291.58	117.72	1269.18	366792.37	152.83	6177.57
11	Sintered porous brick (expansion Polystyrene board)	Thermal insulation broken bridge in glass aluminium alloy window	Slope roof (polyurethane hard Plastic foam)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	328.58	117.26	1302.37	376384.34	156.83	6191.58

12	Reinforced concrete wall (rigid polyurethane foam)	Aluminium alloy ordinary single-frame hollow glass Glass 9-12mm (flat)	Slope roof (polyurethane rigid foam plastic)	Rice hollow floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	329.96	118.01	1309.97	378583.16	157.74	6230.46
13	Clay porous brick and hollow brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow general glass aluminium alloy window	Flat roof (polyurethane rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	323	117.04	1294.96	374243.71	155.93	6175
Preferred scheme 1	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow ordinary glass aluminium alloy window	Roof polyurethane rigid foam waterproof insulation layer)	Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)	324.21	116.40	1290.85	373057.40	155.44	6144.21
Preferred scheme 2	Clay porous brick, hollow Brick wall 240 (moulded polystyrene board)	Insulated broken bridge hollow common glass aluminium alloy Golden window	Flat roof polyurethane (rigid foam waterproof insulation layer)	Cement mortar floor (mineral wool and rock wool)	318.71	115.99	1281.95	370483.89	154.37	6118.21

It can be seen from Table 4.6 that the energy saving rate required by the state should be kept above 50%, so taking this as the precondition, in the comparison of time value, Experiment 8 is the combination with the best energy saving effect in the enclosure structure scheme, that is, clay perforated brick hollow brick wall 240+ aluminium alloy ordinary single-frame insulating glass 9~12mm (flat open)+flat roof+overhead floor. The cost of scheme 7 is the highest in the whole life cycle cost, that is, the enclosure structure adopts reinforced concrete wall+insulating aluminium alloy single-frame ordinary hollow glass window+roof+overhead floor. Through the analysis and calculation of LCC_{AV}, it is concluded that the lowest cost scheme of the selected building model costs 1,528,300 yuan per year, and the worst scheme costs 1,600,700 yuan per year, which can be reduced by 41,000 yuan.

From LCC_{AV}, this index is analysed in detail, and compared with the building area, the annual cost of the lowest cost scheme is 152.83 yuan, and the annual cost of the highest cost scheme is 160.07 yuan, which can be reduced by 37,347 yuan.

Ignoring the time value, Scheme 2 is the combination with the best energy-saving effect in the envelope scheme, that is, clay perforated brick+hollow brick wall 240+ insulating aluminium alloy single-frame ordinary hollow glass window+flat roof+cement mortar floor. Among them, the scheme with the most unsatisfactory effect is the single-frame ordinary hollow glass window with heat-insulating aluminium alloy+aerated concrete block+flat roof+overhead floor.

In this paper, the static life cycle cost is studied and analysed, and it can be found that on the premise that the energy saving rate fully meets the national requirements exceeds 50%, in the whole life cycle cost of this model, the worst cost of using the scheme can be reduced by 614,900 yuan compared with the best cost of the scheme.

CONCLUSIONS TO CHAPTER 4

In the previous article, based on the conclusion of the interactive test between the energy-saving design scheme of the envelope and the technical analysis of the energy-saving design, the scheme with the energy-saving rate of the envelope greater than 50% was selected. Finally, the scheme is calculated through the project cost. Finally, the initial construction cost of each scheme is obtained, including the whole life cycle version and future operating cost. After a series of research and comparisons, the most suitable scheme is obtained.

TOTAL SUMMARY

With the continuous development of China's economy and the continuous development of energy-saving resources, building energy conservation has become an increasingly important part of engineering projects. Due to people's prejudice and misunderstanding of building energy conservation, the development of energy-saving buildings is hindered to some extent. Therefore, the improvement and the optimisation of life cycle cost plays a significant role in energy-saving buildings. In this paper, the orthogonal test method and energy-saving strategy are combined to formulate a professional, systematic and comprehensive optimisation strategy. The detailed results of the study are as follows:

1. The orthogonal test method, energy-saving building design, life cycle cost, accurate implementation and simulation of building energy consumption are analysed and expounded in detail, with emphasis on the relationship and influence of life cycle cost on the original cost and operating cost of the building, to find the balance point between them.
3. The cumulative cooling load of air conditioning is analysed, and it is divided into floor heat transfer coefficient < roof heat transfer coefficient < external wall heat transfer coefficient < and window heat transfer coefficient according to different influence degrees.
4. The cumulative total load of the whole year is analysed, which is divided into roof heat transfer coefficient < floor heat transfer coefficient < external wall heat transfer coefficient < and window heat transfer coefficient according to the different influence degrees.
5. Aiming at the cumulative heating load, the best scheme is clay porous brick+hollow

brick wall 240+ hollow glass window+flat roof+overhead floor.

6. Aiming at the cumulative cooling load of air conditioning, the best scheme is an aerated concrete block+insulating glass+cement mortar floor roof.
7. According to the cumulative heating load, the worst scheme is aerated concrete block+plastic glass window+sloping roof+cement mortar floor.
8. According to the cumulative cooling load of air conditioning, the worst scheme is sintered perforated brick+hot aluminium alloy glass window+flat roof+overhead floor.
9. According to the cumulative total load of the whole year, the worst scheme is aerated concrete block+plastic glass window+sloping roof+overhead floor.
10. Taking the national standard of energy saving rate above 50% as the necessary condition and orthogonal experimental design combining building energy consumption simulation, technical analysis of energy-saving design and envelope scheme as the basic condition, if only time value is considered, then Experiment 8 is the best combination of energy-saving effect in envelope scheme, that is, clay perforated brick hollow brick wall 240+ aluminium alloy ordinary single-frame insulating glass 9~12mm (flat)+flat roof+overhead floor. The cost of scheme 7 is the highest in the whole life cycle cost,; thatis, the enclosure structure adopts reinforced concrete wall+insulating aluminium alloy single-frame ordinary hollow glass window+roof+overhead floor. After thoroughly aanalysingthe index of *LCCAv*, the lowest-cost scheme in this model costs 1,528,300 yuan per year, and the highest-cost scheme costs 1,600,700 yuan per year, which can be reduced by 41,000 yuan.
11. From the detailed analysis of this index, compared with the construction area, the annual cost of the lowest cost scheme is 152.83 yuan, and the annual cost of the highest cost scheme is 160.07 yuan, which can be reduced by 37,347 yuan.

12. Ignoring the time value, Scheme 2 is the combination with the best energy-saving effect in the envelope scheme, that is, clay perforated brick+hollow brick wall 240+ insulating aluminium alloy single-frame ordinary hollow glass window+flat roof+cement mortar floor. Among them, the worst scheme combination is the single-frame ordinary hollow glass window with heat-cut aluminium alloy+aerated concrete block+flat roof+overhead floor.
13. In this paper, the static life cycle cost is studied and analysed, and it can be found that on the premise that the energy saving rate fully meets the national requirements exceeds 50%, in the whole life cycle cost of this model, the worst cost of using the scheme can be reduced by 614,900 yuan compared with the best cost of the scheme.

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APPENDIX A ANTIPLAGIARISM CHECK REPORT

ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Способи врахування багатокритеріального аналізу для проектування енергоефективних огороджувальних конструкцій. Приклад китайської будівельної практики / Ways of considering multi-criteria analysis for the design of energy-efficient envelopes: A case study of Chinese construction practice

Тип роботи: Магістерська кваліфікаційна робота
(БКР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

Показники звіту подібності StrikePlagiarism

Оригінальність 97,91 % Схожість (КП1) 2,09 %

Аналіз звіту подібності (відмітити потрібне):

- [√] 1. Запозичення, виявлені у роботі, оформлені коректно і не містять ознак плагіату.
- [ ] 2. Виявлені у роботі запозичення не мають ознак плагіату, але їх надмірна кількість викликає сумніви щодо цінності роботи і відсутності самостійності її виконання автором. Роботу направити на розгляд експертної комісії кафедри.
- [ ] 3. Виявлені у роботі запозичення є недобросовісними і мають ознаки плагіату та/або в ній містяться навмисні спотворення тексту, що вказують на спроби приховування недобросовісних запозичень.

Особа, відповідальна за перевірку ________ (підпис) Блащук Н.В. (прізвище, ініціали)

Ознайомлені з повним звітом подібності, який був згенерований системою StrikePlagiarism щодо роботи.

Автор роботи Yu Xianjian (підпис) Юй Сяньцзянь / Yu Xianjian (прізвище, ініціали)

Керівник роботи ________ (підпис) Бікс Ю.С. (прізвище, ініціали)

Architecture and civil engineering

Ways of considering multi-criteria analysis for the design of energy-efficient envelopes. Case of Chinese construction practice

Reporter: Yu Xianjian

Yu Xianjian- -Master's student of Vinnytsia National Technical University ,Guangxi University, Nanning, China,E-mail:344348787@qq.com

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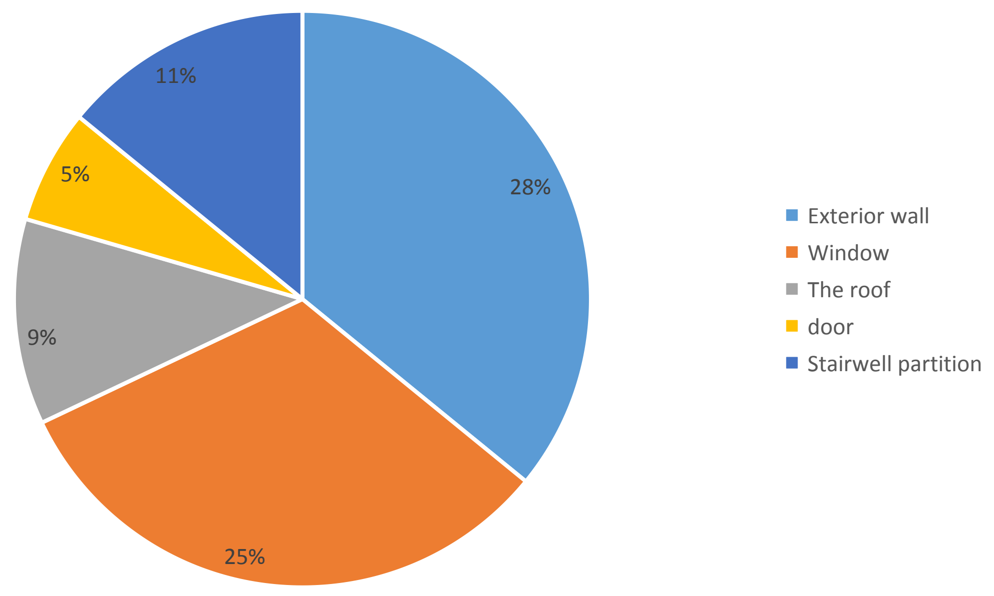
Research background

The research on energy-saving design is currently in its early stages, and how to incorporate lifecycle costs into building energy efficiency has become a key issue. This article will explore these issues from the perspective of building envelope structures

Figure2.1 Composition of building heat loss



The main content of the study

The main purpose of this study is to reduce the investment cost of life cycle and energy-saving buildings to a certain extent, improve the continuous expansion and promotion of energy-saving buildings, and enhance the sustainability and practicality of energy-saving buildings.

Main content of the study

This article is divided into four chapters.

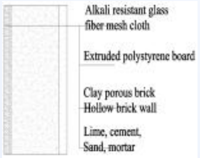
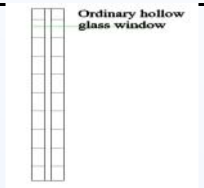
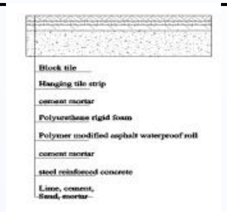
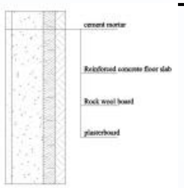
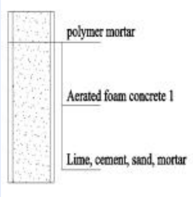
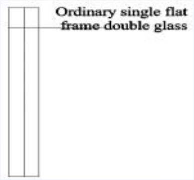
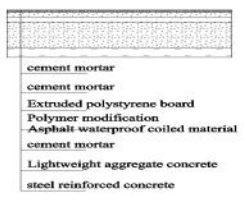
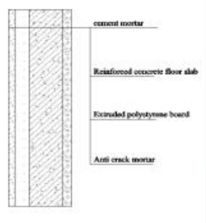
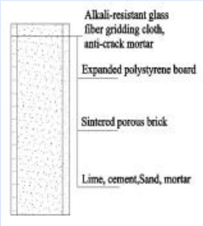
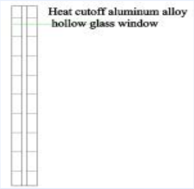
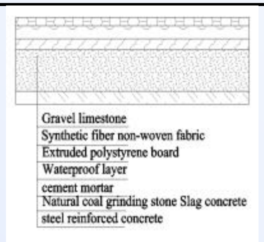
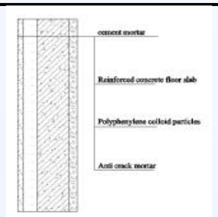
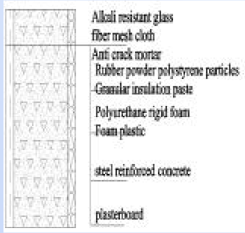
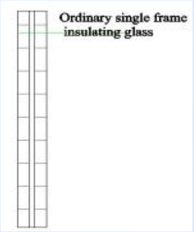
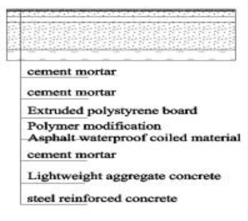
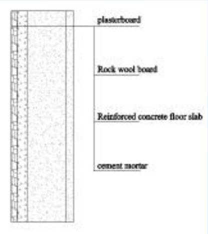
The first chapter mainly introduces the research status and development stages of energy-saving design of building envelope structures at home and abroad.

The second chapter mainly analyzes and discusses the development and evolution of energy-saving building design, that is, the evolution of energy-saving planning and design into maintenance structure energy-saving design, covering exterior wall energy-saving, door and window energy-saving, roof energy-saving, floor energy-saving technology, and building shading systems, in preparation for the establishment of a model in the next chapter.

The third chapter mainly Through the analysis of four factors of floor heat transfer coefficient, window type, external wall heat transfer coefficient and roof heat transfer coefficient of maintenance structure, four combinations of each factor are selected for orthogonal test.

Through the orthogonal table, it can be seen that the cumulative heating load, the cumulative cooling load of air conditioning, the cumulative total load throughout the year, and its energy saving rate of the building. Secondly, analyze these experimental data, and finally obtain the impact of various factors and level combinations on the cumulative heating load, the cumulative cooling load of air conditioning, and the cumulative total load of the year. Finally, the worst and best energy-saving design schemes for the enclosure structure are given.As shown in Table 1.1

Table 1.1:Orthogonal experimental table

	A exterior wall type	B window type	C roof type	D floor type
1	 Clay porous brick and hollow brick wall 240 (molded polystyrene board)	 Plastic single-layer ordinary hollow glass window	 Slope roof (polyurethane rigid foam plastic)	 Cement mortar floor (rock wool, mineral wool)
2	 Aerated concrete block	 Aluminum alloy ordinary single flat frame double glass 6~12mm (push and pull)	 Roofing (extruded polystyre ne foam plastic board)	 Overhead floor with natural ventilation at the bottom (extruded polystyrene board)
3	 Sintered porous brick (expanded (extruded expanded polystyrene board)	 Ordinary hollow glass window with heat-insulating aluminum alloy single roof frame	 Roofing (extruded polystyrene board)	 Overhead floor with natural ventilation at the bottom (polystyrene particle thermal insulation mortar)
4	 Reinforced concrete wall (polyurethane plastic)	 Aluminum alloy ordinary single-frame insulating glass 9~12mm (flat)	 Flat roof (polyurethane rigid foam rigid foam waterproof overhead floor (rock wool, warm layer)	 Mineral wool with natural ventilation at the bottom, glass wool board

The fourth chapter will select the scheme with the energy saving rate of the enclosure structure greater than 50%. Calculate through engineering cost. Finally, the initial construction cost of each scheme, including the entire lifecycle version and future operating costs, is obtained. After a series of studies and comparisons, the most suitable scheme is obtained. As shown in Table 1.2

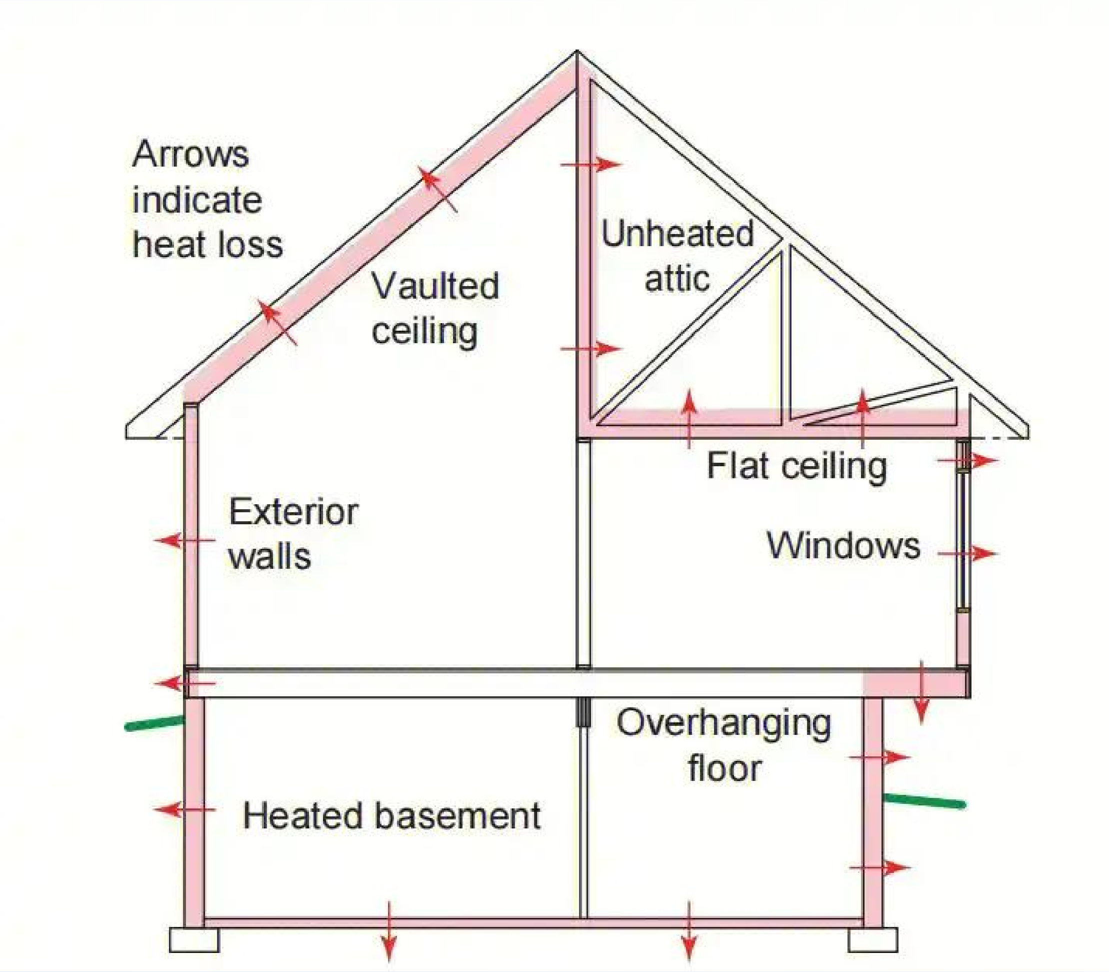
Table 1.2

Table 1.2 – Life Cycle Cost of Energy Saving Scheme for Envelope

Test number	AType of exterior wall	B Window type	C Roof type	DFloor type	Unit construction area cost (yuan/m²)	Annual energy cost (yuan/m²)	LCCpv (yuan/m²)	LCCFv (yuan/m²)	LCCAv (yuan/m²)	Static life cycle cost (c) (yuan/m²)
5	A3	B4	C3	D1	292.81	117.99	1272.66	367798.73	153.25	6192.31
6	A2	B3	C4	D3	339.42	117.96	1319.02	381197.12	158.83	6237.42
7	A4	B3	C3	D3	352.02	117.68	1329.29	384166.55	160.07	6236.02
8	A1	B4	C4	D3	291.58	117.72	1269.18	366792.37	152.83	6177.57
9	A3	B3	C1	D3	328.58	117.26	1302.37	376384.34	156.83	6191.58
11	A4	B4	C1	D3	329.96	118.01	1309.97	378583.16	157.74	6230.46
12	A1	B3	C4	D1	323	117.04	1294.96	374243.71	155.93	6175
Preferred scheme 1	A1	B3	C4	D3	324.21	116.40	1290.85	373057.40	155.44	6144.21
Preferred scheme 2	A1	B3	C4	D1	318.71	115.99	1281.95	370483.89	154.37	6118.21

Research surface

The influencing factors and design elements in energy-saving design of roofs, exterior walls, floor slabs, doors and windows were discussed and summarized. Using comparative analysis methods, rigorously calculate, analyze, and compare the energy-saving systems of the enclosure structure in four specific aspects: doors and windows, exterior wall insulation, roof, and shading. Thus, the advantages and disadvantages of each enclosure structure can be determined.



Research conclusion

Several sets of data have been obtained from this experiment, that is, based on the research and analysis of static life cycle costs in this article, it can be found that under the premise of fully meeting national requirements with an energy saving rate of more than 50%, in terms of total life cycle costs in this model, the cost of using the worst solution can be reduced by **614900** yuan compared to the cost of using the best solution

The significance of the study

Through the orthogonal test method, energy-saving building design, accurate calculation and simulation of the whole life cycle cost and building energy consumption, the relationship and impact of the whole life cycle cost on the historical cost and operating cost of the building are emphatically analyzed, and the balance between them is found. The orthogonal test method is used to accurately and accurately calculate the design of energy-saving buildings, calculate the energy saving rate and load rate of the building throughout the year, and calculate the cooling load rate and heat load rate of the building's air conditioning and heating.

Thank you all for listening

SUPERVISOR'S REVIEW

Master's thesis titled "Ways of Considering Multi-Criteria Analysis for the Design of Energy-Efficient Envelopes. Case of Chinese Construction Practice", completed by **Yu Xianjian**, represents a comprehensive and practically significant scientific research project that addresses the urgent problem of energy efficiency in building envelopes under modern sustainable construction requirements.

The thesis is structured coherently and includes four logically interconnected chapters, beginning with a well-developed literature review, followed by a thorough comparison of energy-saving technologies, modelling of energy performance using the orthogonal design method, and concluding with a solid economic evaluation. The author demonstrates proficiency in using modern simulation tools and analysing both thermal and economic performance of building elements through life-cycle cost analysis.

The scientific novelty of the research lies in the application of orthogonal testing methods to optimise multilayer building envelope configurations while considering four major thermal variables. The work also introduces a new combined approach for selecting envelope materials that balance thermal performance, economic feasibility, and energy-saving potential in Chinese climatic conditions.

The practical significance is supported by the use of real-life case modelling and the results of simulation experiments, which offer valuable design recommendations for sustainable buildings. The methodology can be adopted by engineers and decision-makers in urban planning and energy-efficient construction.

The author has demonstrated a high level of independence, analytical thinking, and commitment throughout the research. The thesis meets the requirements for a master's qualification work in the field of Construction and Civil Engineering, and is suitable for public defence. I recommend evaluating this thesis with a grade of A (Excellent) and the author, who will be awarded the qualification "Master of Civil Engineering" in the speciality 192 - "Construction and Civil Engineering".

I recommend the thesis for defence with a final evaluation of "excellent" (A),

Supervisor:
PhD, Assoc. Prof. Yuriy BIKS

OPPONENT'S REVIEW

OF GRADUATE STUDENT XIANJIAN YU MASTER'S THESIS

Master's Thesis was performed according to the topic "Ways of considering multi-criteria analysis for the design of energy-efficient envelopes. Case of Chinese construction practice".

The master's qualification thesis submitted for review was completed fully and within the deadline. The work corresponds to the approved topic and task. The subject is relevant and dedicated to the multi-criteria approach for designing energy-saving envelopes.

It should be noted that the author conducted the thesis under the topic, and the research focused on the multi-criteria assessment of the entire building using one of the proposed techniques under specific parameters.

The material of the work is presented in a detailed and accessible form. The thesis consists of the following sections: analysis of the current state of theory and practice on the topic of the master's thesis; problems faced by Green Construction, Optimization of construction process based on BIM and value engineering, Engineering Case Verification of China-Denmark Science Research and Education Center of Chinese Academy of Sciences, economic part, total conclusions.

At the beginning of the thesis, the author outlined in the introduction the relevance, purpose, task, object, and subject of the research related to the country's sustainable development, as well as its scientific novelty and practical significance.

In the first section of the thesis, a sufficiently detailed and qualitative review of the works of other authors with a close research direction is performed, emphasising the author's reasonable understanding of the chosen topic. In the second chapter, problems in green construction are considered. In the third section, the construction process based on BIM is optimised.

In the fourth chapter, the application of BIM technology and the value engineering method in green construction is presented in the example of the green demonstration project of the China-Danish Scientific and Educational Centre.

In the fifth chapter, the economic part, the author provides a technical and financial justification for using BIM software products to manage energy-saving and green construction projects.

The research results were reported at the international scientific and practical conference and written in the report's abstracts.

Execution of the textual part of the explanatory note was performed under the standards and in compliance with all requirements.

Disadvantages of the thesis include some inaccuracies in the formatting of the Thesis's explanatory note.

However, these shortcomings do not detract from the overall positive impression of the work.

The master's qualification work was performed reasonably, in accordance with the task, and complied with all requirements. The work deserves a grade (A), and its author is awarded the qualification "Master of Civil Engineering" in speciality 192 - "Construction and Civil Engineering".

Opponent

Ph.D., Associate Prof. Oleksander SPIVAK