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

(full name of the department (subject, cycle committee))

MASTER'S THESIS

«The comprehensive assessment of building envelopes in the context of energy efficiency»

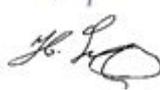Performed by: 2nd year student, group ШБ-22m

(Code and name of speciality)

Speciality 192 Construction and Civil Engineering

CHEN Peixian

(Surname and initials of student)

Supervisor: PhD, Associate Prof.

BIKS Yuriy

(Surname and initials)

Opponent: PhD, Prof.

KOTS Ivan

(Surname and initials)

Approved to be defended

Head of Department of Construction, Urban Planning and Architecture

PhD, Associate Prof. Vitaliy SHVETS

(First name and last name)

"18"_____ June_____ 2025

Vinnytsia VNTU – 2025

I

<p style="text-align:center">Vinnytsia National Technical University</p>
<p style="text-align:center">(Full name of the higher education institution)</p>
<p style="text-align:center">Faculty of Construction, Civil and Environmental Engineering_</p>
<p style="text-align:center">(Full name of the institute, name of the faculty)</p>
<p style="text-align:center">Department of Construction, Urban Planning And Architecture</p>

Education level_____Second (Master)_____

Studies direction 19___ Architecture and _ Construction _
<p style="text-align:center">(Code and name)</p>
<p style="text-align:center">Specialty 192 Civil Engineering and Construction</p>
<p style="text-align:center">(Code and name)</p>
<p style="text-align:center">Educational Program Industrial and Civil Engineering_</p>

<p style="text-align:right">APPROVED</p>
<p style="text-align:right">Head of Department CEUPA</p>

<p style="text-align:right">Shvets V.</p>
<p style="text-align:right">"18"_____ June____2025</p>

<p style="text-align:center">**TASK**</p>

<p style="text-align:center">**OF A MASTERS QUALIFICATION WORK**</p>

<p style="text-align:center">CHEN Peixian</p>
<p style="text-align:center">(FULL NAME)</p>

1. Master's qualification work's topic_« The comprehensive assessment of building envelopes in the context of energy efficiency»

Master's thesis supervisor Biks Yuriy, docent of the CEUPA Department,
<p style="text-align:center">(Surname, first name, patronymic, academic degree, academic title)</p>

approved by order of the higher educational institution from «__»___2025 No___

2. Deadline for submission of work by a master's student_____

3. Initial thesis data: This study focuses on the energy efficiency evaluation of building envelope structures, aiming to address the issue of high global building energy consumption. Combining with the research gap at home and abroad, it systematically explores the energy-saving mechanism, quantitative relationship, and economic feasibility of non transparent and transparent envelope structures, reveals the energy-saving impact mechanism of envelope structures, constructs a regional collaborative evaluation system, and ~~promotes the implementation of green building technology and policy optimization.~~

4. Content of the settlement and explanatory note (list of issues to be developed): The introduction should reflect the relevance of the topic, its purpose, scientific novelty, practical significance, research tasks, subjects, and main bodies. The research section consists of four chapters: Chapter 1,State of the art in envelope's energy efficiency. Chapter 2, Evaluation of the application effect of non-transparent enclosure structure. Using Design Builder software, taking the exterior walls of residential buildings in Hangzhou as the object, simulate the effects of different insulation thicknesses (20-140mm EPS), heating and air conditioning period parameters, and solar radiation, and verify them through full-scale experiments. Chapter 3, The relationship between transparent enclosure structure parameters and energy consumption quantification. Taking the doors and windows of commercial complexes in cold regions as the object, this study investigates the effects of heat transfer coefficient ($1.0\sim3.0W/m^2\cdot K$), shading coefficient ($0.25\sim0.85$), and air tightness ($1.5\sim13.5m^3/m^2\cdot h$) on energy consumption. Chapter 4, Economic impact assessment of energy-saving renovation of enclosure structure. Through quantitative analysis of heating and air

conditioning costs, maintenance expenses, and full lifecycle costs, demonstrate the economic feasibility of different renovation plans. Chapter 5, Conclusion and Prospect. Compare research questions, extract core conclusions from dimensions, and propose future research directions based on existing limitations.

5. List of graphic material (with exact indication of mandatory drawings): 1-3-Topic. Purpose and tasks of the work, novelty, practicality, significance. 4-6-Bionic architectural design status; 7-11-Development and practical application of bionic building facade theory to gain new ideas; 14-Economic calculation results: 15-Conclusion

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		

7. Issue date of the task_____15.01.2025_____

CALENDAR SCHEDULE

No	The name of the stages of the master's qualification work	The term of performance of work stages	Note
1	Analysis of the sustainable design principles, the challenges and problems it faces and the current development status in China. Preparation of Chapter 1.		
2	Preparation for the research objectives, tools and methodology.		
3	Chapter 2. Evaluation of the application effect of the non-transparent envelope structure.		
4	Chapter 3. Quantification relationship between parameters of transparent envelopes structure and energy consumption and evaluation of energy saving effect.		
5	Chapter 4. Economic impact assessment of energy-saving renovation of enclosure structure.		
	Chapter 5. Conclusion and outlook.		
6	Preparation for publication and publication of MQT results. Approbation of the work.		
7	Antiplagiarism check		
8	Preliminary defence of the Master's qualification thesis		

Graduate student   CHEN Peixian   CHEN Peixian

(Signature)   (Surname and

initials)

Master's qualification work supervisor_____   BIKS Yuriy

(signature)   (Surname and initials)

III

ABSTRACT

Chen Peixian. The comprehensive assessment of building envelopes in the context of energy efficiency, Master's qualification thesis in the speciality 192 - "Civil Engineering and Construction", Educational Project- "Industrial and Civil Engineering". VNTU, 2025. 128 p.

In English. Bibliography: 34 titles; fig. 43; tabl. 37.

The energy consumption of building envelope accounts for a significant proportion of the total energy consumption of buildings. The optimization of energy-saving technology is of key significance to reduce the operating cost of buildings and achieve the goal of "double carbon". At present, there are still gaps in the research on the quantitative relationship between the "anti energy saving" phenomenon of external wall insulation and the parameters of transparent enclosure structure in hot summer and cold winter areas at home and abroad, and there is a lack of systematic economic evaluation of energy-saving transformation. Taking the exterior walls of residential buildings (non transparent envelope) in hot summer and cold winter areas and the doors and windows of commercial complexes (transparent envelope) in cold areas as the objects, this study systematically explores the influence mechanism and economic feasibility of energy-saving effect of envelope structure by using design builder energy consumption simulation, full-scale model test and full life cycle economic analysis methods, and provides a technical and economic basis for the engineering application of energy-saving technology of envelope structure.

The master's qualification thesis contains 17 sheets of the graphic part.

Key words: transparent envelope structure; non-transparent envelope structure; energy-saving effect; evaluation

INTRODUCTION

Actuality of theme. The energy consumption caused by the building envelope accounts for a significant proportion of the building's total energy consumption, and its effective energy-saving properties are a crucial factor in ensuring the appropriate environment and comfort within the building. It is of great significance to study the energy-saving effects of the building envelope in reducing a building's energy consumption.

This paper examines the energy-saving effects of the building envelope from two perspectives: transparent and non-transparent envelopes. First to building envelope wall in the representative of the transparent structure, through Design Builder building energy consumption simulation software, represented by typical summer hot winter region in Hangzhou, in-depth analysis of the different thickness of external wall insulation, adopt warm air conditioning period set temperature, heating air conditioning period, energy mode single factors and multiple factors on the influence of residential building energy consumption. Based on the analysis of the action mechanism of solar radiation on building thermal environment, the numerical simulation calculation of building energy consumption under different solar radiation intensity, and the thermal insulation performance based on the internal, medium and external surface temperature, the indoor and external temperature difference and the external heat flow under different solar radiation intensity, providing the energy-efficiency design of buildings is of even greater significance.

Connection of work with scientific programs, plans, topics.

This work was conducted within the framework of scientific research at the Department of Construction, Urban Planning and Architecture of Vinnytsia National Technical University (VNTU), Research on Multi-Standard Design for the Sustainability of Modern Architecture. It aligns with the university's emphasis on addressing real-world engineering challenges under specialty 192 "Construction and Civil Engineering."

Purpose and tasks of the research

This paper takes the energy-saving effect of building envelope as the core research object, and aims to fill the existing research gap by systematically analyzing the energy-saving influencing factors, quantitative relationship and economic feasibility of non transparent envelope (residential building exterior wall in hot summer and cold winter areas) and transparent envelope (commercial complex doors and windows in cold areas), so as to provide technical and economic basis for building energy-saving design.

The following problems must be solved:

In the research of building energy-saving technology, as the key carrier of building energy consumption, the impact mechanism, quantitative relationship and economic feasibility of energy-saving effect of enclosure structure have been the core issues of academic and engineering circles. This study systematically analyzes the energy-saving characteristics of the exterior walls of residential buildings in hot summer and cold winter areas and the doors and windows of commercial complexes in cold areas. Combined with simulation test and economic evaluation, the following key issues are studied：

1. what factors affect the energy-saving effect of non-transparent enclosure (exterior wall)? How?

2. how does solar radiation affect the energy-saving effect of external thermal insulation?

3. what is the quantitative relationship between the design parameters of transparent enclosure (doors and windows) and energy consumption?

4. what is the economic feasibility of energy-saving reconstruction of envelope structure?

5. what are the defects and improvement directions of the existing envelope evaluation system?

Object of study

The research objects of this paper include: first, non transparent enclosure structure: taking the exterior walls of residential buildings in hot summer and cold winter areas as a typical representative, this paper focuses on the energy-saving effect of external

thermal insulation technology. Second, transparent enclosure: taking the doors and windows of commercial complex buildings in cold areas as the research object, the influence of door and window design parameters on building energy consumption is analyzed.

Methods of research

This research adopts the method of combining theoretical analysis, simulation and empirical research to systematically explore the energy-saving effect and economic impact of building envelope. The specific research methods are as follows:

Literature review and theoretical construction: combing the energy-saving evaluation systems of building envelope at home and abroad (such as BREEAM, LEED, gb50189-2015), analyzing the deficiencies of the existing standards in the adaptability of hot summer and cold winter areas, and constructing the theoretical framework of "non transparent transparent" envelope collaborative evaluation. Focus on the combination of heat transfer theory and the mechanism of solar radiation, clarify the theoretical basis of the "anti energy saving" phenomenon of external wall insulation, and lay a theoretical support for subsequent research.

Technical simulation and simulation verification: (1) energy consumption simulation tool: using design builder software (built-in energy plus engine), Taking Hangzhou, a hot summer and cold winter region, as a typical city, simulates the impact of different external wall external insulation thickness (20~140mm), door and window parameters (heat transfer coefficient $1.0\sim3.0w/㎡ \cdot K$, shading coefficient $0.25\sim0.85$) on building energy consumption. (2) quantification of key parameters: through simulation, the decreasing relationship between the thickness of external insulation and energy consumption of external walls (for example, the 120mm insulation layer can save 31.46% energy compared with 20mm), the sensitivity ranking of door and window parameters (shading coefficient>air tightness>heat transfer coefficient), and the influence mechanism of solar radiation on wall heat conduction are verified. (3) full scale test verification: carry out full-scale model test of external wall external insulation in Shida Environmental Laboratory of Baoye group, control parameters such as solar radiation intensity ($0\sim1000w/㎡$), temperature

and humidity, and measure data such as wall heat flux and internal and external surface temperature to verify the reliability of simulation results (energy saving rate error $\leqslant$ 5%).

Case demonstration and data validation: (1) residential building case: taking typical residential buildings in Hangzhou as the object, the energy consumption data under different insulation thickness and energy consumption mode (continuous/intermittent) are compared and analyzed to verify the impact of heating and air conditioning period division on energy saving effect (for example, the energy saving effect in winter is reduced by 23.5% due to the shortening of heating calculation period by 54 days). (2) commercial building case: select the commercial complex in cold areas, and quantitatively analyze the total energy consumption reduction (9.28%) and electricity cost savings (178500 yuan/1000 m2 per year) based on the door and window parameter optimization model (such as shading coefficient of 0.25 and air tightness of 1.5m ^{3}/m² h).

Comprehensive evaluation of economy and policy: (1) cost benefit analysis: establish a full life cycle cost model for energy-saving reconstruction of building envelope, calculate the payback period (within 3 years), net present value (310000 yuan/20 years) and maintenance cost reduction (86.7%) of different schemes, and form quantitative indicators of economic feasibility. (2) policy suitability assessment: according to the design standard for energy efficiency of residential buildings in hot summer and cold winter areas and other specifications, this paper analyzes the lack of existing indicators on dynamic factors (solar radiation and energy consumption mode), and puts forward policy suggestions to include the anti energy-saving critical temperature and intermittent energy consumption mode into the evaluation system, so as to provide the basis for the revision of regional energy-saving standards.

Scientific novelty of the obtained results

This study carries out from two aspects: transparent envelope structures and non transparent envelope structures. Through simulation analysis and experimental research, the influence of different design parameters on building energy consumption is explored, and corresponding energy-saving design strategies are

proposed. The innovation lies in:

Theoretical innovation: Building a "non-transparent transparent" collaborative evaluation model to break through the limitations of single structure evaluation. The inclusion of dynamic variables such as energy consumption mode (intermittent/continuous) and solar radiation intensity in the evaluation system has corrected the shortcomings of domestic and foreign standards (such as LEED and GB50189) in terms of regional climate adaptability.

Method innovation: Combining multi-scale simulation with experimental verification. By using Design Builder software to simulate the gradient of EPS insulation layer thickness (20-140mm), the energy-saving rate changes under different thicknesses were quantified (such as a 31.46% energy-saving effect of 120mm insulation layer compared to 20mm), and full-scale experimental verification was conducted to form a closed-loop research method of "simulation prediction experimental verification".

Application innovation: Establishing a full life cycle model that includes initial investment, maintenance costs, and energy savings, calculating a comprehensive renovation plan with a net present value of 310000 yuan over 20 years and an investment payback period of $\leqslant$ 3 years (such as a 2.78 year payback period for door and window shading optimization), providing a quantitative financial decision-making tool for enclosure structure renovation for the first time, breaking through the limitations of traditional technical research lacking economic feasibility analysis. Propose a regional adaptation strategy of prioritizing the increase of insulation thickness (120mm is recommended) for residential buildings and emphasizing shading of doors and windows (coefficient $\leqslant$ 0.43) for commercial buildings. Combined with government subsidies (such as 200 yuan/m²), the payback period can be shortened by 40% -60%, providing precise guidance for policy formulation and engineering promotion.

Practical significance of the obtained results

Supporting economic decisions for energy-saving renovation: Provide developers and property owners with clear financial feasibility data to accelerate the implementation of energy-saving technologies.

Promote the optimization of regional energy-saving policies: Suggest incorporating solar radiation intensity and intermittent energy consumption patterns into the "Energy Efficiency Design Standards for Residential Buildings in Hot Summer and Cold Winter Regions" to provide data support for regional standard revision and assist in the implementation of the "dual carbon" policy.

Promote sustainable development of the environment: The annual electricity cost for the renovation of residential building exterior walls is 5968 yuan per 100 square meters, which is equivalent to reducing carbon emissions by about 2.8 tons per year; Optimizing commercial building doors and windows can save 178500 yuan per 1000 square meters annually, equivalent to saving 210000 kilowatt hours of electricity and reducing carbon dioxide emissions by 168 tons, directly supporting China's 2030 carbon peak target.

Engineering practice and industrial driving: Provide technical pathways for green building certification in tropical regions (such as DBJ 46-064-2023) and promote the development of the green building market.

Comprehensive reflection of social and economic benefits: After energy-saving renovation of residential buildings, it can reduce the energy burden on residents and lower their living costs. Provide a cross structural systematic evaluation tool for the building energy efficiency industry, and promote the standardization of design, construction, and operation technology throughout the entire chain.

Personal contribution of the master's student

As the principal researcher, I propose a "non-transparent transparent" collaborative evaluation model for enclosure structures in hot summer and cold winter regions, integrating dynamic factors such as heat transfer coefficient, solar radiation, and energy consumption mode, filling the theoretical gap in regional energy-saving assessment. Simulate the impact of different insulation thicknesses (20-140mm EPS) and door and window parameters (heat transfer coefficient 1.0-$3.0W/㎡\cdot K$, shading

coefficient 0.25-0.85) on energy consumption through Design Builder, and establish a linear regression model Establish a full lifecycle cost model, calculate a comprehensive renovation plan with a net present value of 310000 yuan over 20 years and an investment payback period of $\leq$ 3 years, providing quantitative financial decision-making basis for energy-saving renovation.

Approbation of the results of the master's thesis

1.   The main results of this work were presented at the thesis [] in the electronic version on the website of VNTU in the international scientific and practical conference Research, Problems, Prospects (MN-2025). Thermal insulation of rural residential buildings in high-temperature-difference regions of northwest China / Chen Peixian, Guo Zhiyong, Wang Li// Abstracts of the report at the International scientific and practical Internet conference Youth in science: research, problems, prospects (MN-2025), (VNTU) – Electronic text data – 2025. URL:

https://conferences.vntu.edu.ua/index.php/mn/mn2025/paper/viewFile/25520/21086 (Last accessed 10.06.2025).

Publications []

1. Chen Peixian. A monitoring device for the insulation performance of building enclosure structures based on BIM technology: пат. CN216590759 U Китай; заявл. 2021-12-30; опубл. 2022-05-24. – CN216590759 U.

INTRODUCTION

The energy consumption caused by the building envelope accounts for a significant proportion of the building's total energy consumption, and its effective energy-saving properties are a crucial factor in ensuring the appropriate environment and comfort within the building. It is of great significance to study the energy-saving effects of the building envelope in reducing a building's energy consumption.

This paper examines the energy-saving effects of the building envelope from two perspectives: transparent and non-transparent envelopes. First to building envelope wall in the representative of the transparent structure, through Design Builder building energy consumption simulation software, represented by typical summer hot winter region in Hangzhou, in-depth analysis of the different thickness of external wall insulation, adopt warm air conditioning period set temperature, heating air conditioning period, energy mode single factors and multiple factors on the influence of residential building energy consumption. Based on the analysis of the action mechanism of solar radiation on building thermal environment, the numerical simulation calculation of building energy consumption under different solar radiation intensity, and the thermal insulation performance based on the internal, medium and external surface temperature, the indoor and external temperature difference and the external heat flow under different solar radiation intensity. It is found that the division of heating period and air conditioning period greatly impacts the energy saving effect of external wall insulation buildings. With the increase of the insulation thickness of the external wall (the decrease of the heat transfer coefficient), the energy consumption of the air conditioning period in summer and the winter heating period will decrease accordingly. The external wall of the building uses a specific thickness of external insulation, which has a good insulation effect, to achieve considerable building energy saving and consumption reduction.

In terms of transparent envelope, this paper selects doors and Windows as the representative of the transparent structure, analyses the relevant design parameters affecting the energy consumption of commercial complex, studies the influence of these parameters on building energy consumption, get the single parameter and

multiple regression model of the building energy saving effect from the perspective of sensitivity coefficient and energy saving rate, and evaluate the energy saving design strategy for cold commercial complex buildings according to the evaluation results. It is found that the design parameters such as heat transfer coefficient of doors and Windows, shading coefficient and air tightness of doors and Windows have a particular influence on the energy saving effect of doors and Windows. The influence of the three on their energy consumption is: shading coefficient of doors and Windows> air tightness of doors and Windows> heat transfer coefficient of doors and Windows. It can start from optimising the doors and Windows, the space position of the entrance, the space form, the entrance space envelope structure and improving the air tightness of the doors and Windows, to improve the energy saving efficiency of the transparent envelope structure, such as the doors and Windows.

Keywords: transparent envelope structure; non-transparent envelope structure; energy-saving effect; evaluation

CONTENTS

CHAPTER 1 STATE OF THE ART IN ENVELOPE'S ENERGY EFFICIENCY

1.1 Research background

With the acceleration of urbanisation year by year and the reorganisation of industrial structures, the construction industry in every region is expanding annually. As a result, the proportion of total energy consumption in building energy consumption is also rising steadily, and the work of building energy conservation has reached an urgent point. In the process of industrialisation, China's energy demand has a trend of blowout growth. According to the survey, the national building energy consumption accounts for more than 28% of the total social energy consumption. According to the development experience of developed countries, when the living standard is further improved, the proportion will increase to 40% in 2025. In 2009, the Chinese government promised to reduce national carbon emissions by 40-45 per cent in 2020 compared with 2005. China's energy conservation and emission reduction task is challenging, and the situation is still grim. To achieve it effectively, we need to reduce the domestic resource guarantee capacity and the impact of climate change.

With the gradual lack of non-renewable resources and the aggravation of the global environmental crisis year by year, the development of green buildings and the implementation of energy conservation and emission reduction have been set as a strategic national policy in China. And the construction industry, as a national industrial energy consumption, is significant; it must be regarded as a top priority. The energy conservation work of China's construction industry started in the 1980s, has been far behind the developed countries, and China's building energy conservation work mainly focuses on the northern area of the building heating, the focus is relatively single, unable to popularise the energy conservation work in all parts of the country. Building energy conservation is a significant project that benefits the government and the people. To accelerate the implementation of building energy conservation construction, we must first establish a scientific and practical evaluation system for building energy conservation effects, and accordingly evaluate the impact of building energy

conservation and put forward corresponding solutions, to promote the development of the building energy conservation industry.

1.2 Study purpose and significance

1.2.1 Study purpose

Residential building energy saving standards for the climate zone building envelope structure of walls and doors and Windows put forward precise energy saving requirements, however, the commercialisation of residential buildings makes developers and architects pay more and more attention to the personalisation of residential buildings, sometimes appear the designed building can not meet all the requirements of the building envelope energy requirements, at this point, determine the building does not meet the requirements of this standard is not scientific. To respect the architect's creative work, at the same time make the design can meet the requirements of the energy saving design standards, in hot summer and cold winter areas based on software simulation of air conditioning, heating energy consumption for the criterion, need to field simulation to target building to judge, calculation is troublesome, professional, software needs extra cost, still limited in application, the lack of an effective energy saving effect evaluation method to provide reference for dynamic simulation.

The lack of a building energy-saving market in China is one of the main obstacles to the marketisation of building energy-saving in China. Building energy consumption of energy saving system engineering of each link of participants, the degree of understanding is not the same, the public don't understanding of building energy consumption greatly affected the building energy conservation related policy and building energy saving service promotion, for those who do not have professional knowledge, energy saving effect evaluation more intuitive more reference value. The evaluation of energy saving effect helps the public to understand the current situation of energy consumption in their environment, primarily through such self-evaluation, they can know whether the existing buildings have energy saving potential, and what aspects

have room for improvement, to actively seek relevant improvement measures to achieve the effect of active energy saving. However, in calculating and evaluating building energy conservation, the envelope structure design remains the same in the same area. Due to the difference in the coefficient of building shape, some buildings meet the requirements of energy conservation, and some buildings do not. The current energy conservation evaluation index is complex to solve this contradiction.

Based on these problems, this paper, select the wall and other transparent structure and window transparent structure energy saving effect evaluation, for the hot summer area of residential building envelope energy conservation system evaluation method, the overall thermal performance as a system, can reflect the influence of the building energy consumption, not confined to the local thermal performance, and do not need simulation calculation, quick and straightforward calculation, can provide reference for dynamic simulation analysis, at the same time to improve the theoretical system of envelope structure through these discussions.

1.2.2 Study Significance

Currently, China's building energy consumption accounts for more than a quarter of the total energy consumption of the national economy. Most of the building's energy consumption is due to the severe loss of heat due to the poor insulation and air tightness of the exterior walls and windows of the building envelope. Maintaining a relatively comfortable living thermal environment comes at the cost of massive energy consumption. So, building energy conservation become an essential task in the energy saving policy, the State Council, the ministry of construction for building energy conservation issued a series of policies, regulations and technical procedures to promote the enterprise, such as various civil building energy saving management regulations and energy saving design standards, public building energy saving design standards, and hot summer and hot summer warm winter area residential building energy saving design standards, etc.

Residential building is the most basic environment for people to live. It is significant

to improve the living environment that cannot meet people's requirements. Although the energy-saving transformation work in China has been carried out for some time, and some achievements have been made, there is little research on the evaluation of the energy-saving transformation effect. Under the current situation of compulsory implementation of building energy conservation renovation in China, it is of theoretical and practical significance to study the evaluation of energy conservation renovation of existing residential buildings.

The theoretical significance is that the evaluation of the effect of building envelope structure can enrich and improve the theoretical content of building energy conservation in China, and provide new research directions and ideas; the establishment of the evaluation system enriches the current building energy conservation evaluation system from different perspectives.

The practical point is that, Through the evaluation of the energy saving transformation effect of the building envelope and its influencing factors, Establish the evaluation index system and the comprehensive evaluation model of the benefit of the existing residential buildings in northern heating areas, For the standardization of building energy conservation management, To improve the quantitative management level of energy conservation renovation of existing buildings and the quality of building energy conservation renovation projects, For the problems in the building energy saving renovation, Provide guidance for the future energy-saving renovation projects, To promote the smooth implementation of the building energy-saving renovation work in China, To improve the city's image, energy conservation and emission reduction, It is of great significance to meet people's increasing requirements of living comfort and health. In addition, under the policy and environment of energy conservation and emission reduction in China, further strengthening the research of building energy conservation transformation plays an important role in promoting the realization of the "fourteenth Five-Year" energy conservation and emission reduction target, which is conducive to promoting the economical development, clean development, safe development, the construction of a harmonious society, sustainable economic development and social

stability and unity.

1.3 Literature review

1.3.1 Status of foreign research

The foreign building energy saving evaluation is basically a sub-item of the sustainable development building evaluation. The evaluation results not only reflect the energy saving level of the building, but also usually include site selection, water resources utilization and pollutant discharge. At present, the main relatively mature are: the UK BREEAM evaluation system[1], LEED Green Building Evaluation System, USA[2]Green building evaluation tool GBTOOL[3], Comprehensive Environmental Assessment Method for Buildings in Japan (CASBEE)[4].

(1) The UK BREEAM Assessment system

The UK BREEAM system (UK Architecture Research Organization Environmental Assessment Law) has created the first green building "evidence", and provides practical guidance for the construction of green buildings, which has been widely praised. Since the BREEAM evaluation system was jointly developed by the British Architectural Research Organization (Building Research Establishment, BRE) and some private researchers in 1990, about 25% to 30% of new British public buildings have been evaluated through it, and have achieved good results and positive response. Countries around the world learn from the BREEAM evaluation system to build their own suitable building energy conservation evaluation system. To achieve the evaluation of the building, BREEAM has nine major evaluation projects: management 1 overall policy and procedures; health and comfortable indoor and outdoor environments; energy consumption and CO_2Emissions; transport-on site planning and transportation time CO_2Discharge; water consumption and leakage; raw material selection and role on the environment; land use of green land and brown land; regional ecological value of ecological area; air pollution (CO_2Except for) and water pollution[5]. Each project includes several sub-projects, specifically from three perspectives: building

performance, design and construction, management and operation, and the corresponding score is also specified. If the requirements are met, the corresponding score can be obtained. Later, the building performance score (BPS) can be obtained by adding the building performance scores of each sub-project, and the same method can also get the design and construction, management and operation scores. Calculate the sum of building performance (BPS) and design and construction or building performance (BPS) and management and operation points to get the total score of BREEAM grade of construction projects in different time areas. Finally, the environmental performance index (EPI) of the building is calculated from the conversion table and the BPS score, and the environmental performance of the building is expressed by the quantified score. With the above scores, the evaluation level of BREEAM can be divided into four grades: qualified, good, good and excellent, and the design and construction, management and operation have the specified minimum scores under each grade, so that the result level of the evaluation target can be determined[6].

(2) American LEED Green Building Evaluation system

The Green Building Evaluation System (Leadership in Energy & Environmental Design BuildingRating System), hereinafter referred to as LEED, was established and implemented by the Green Building Association of the United States. It is considered to be the most influential and perfect evaluation system among the various green building and building energy efficiency evaluation systems in the world. The concept of green building is constantly updated with the development of The Times. LEED green building evaluation system launched a new version 2.1 in 2003 to meet the needs of development, which is a revision and supplement to the previous versions. Initially, the evaluation object of LEED was only public buildings. Later, the green renovation standard LEED-EB for existing buildings and the green decoration standard LEED-CI for commercial buildings were successively introduced. Now the evaluation standard for residential buildings is under development. The evaluation scope of LEED includes office, commercial retail and service, hotel industry, research institutions, new commercial buildings, major renovation buildings, operation of existing buildings,

indoor parts of commercial buildings, residential buildings, regional development, etc.

The LEED evaluation system mainly evaluates buildings mainly from the five aspects of building energy saving and atmosphere, resources and materials, indoor air quality, sustainable building site and water resources utilization, and then judges its impact on the environment. These five aspects and multiple sub-items of each aspect constitute the basic framework of the evaluation system[7]. Each aspect of each item and are divided into purpose, requirements and related technical guidance of these three aspects, and the corresponding to different points, and then according to the requirements of the specific standards, finally comprehensive each aspect of the child points get the five aspects of comprehensive score, so you can be a comprehensive evaluation of the building. The evaluation results of the evaluation system are divided into five levels, including platinum, gold, silver, copper and certification, according to the score level, so as to distinguish the green level of the evaluated objects.

(3) A multinational green building evaluation tool, GBTOOL

Green building evaluation tool GBTOOL was proposed in 1996 by 14 countries such as Canada in the international cooperation action of green building Challenge. It is mostly used for the evaluation of school buildings, collective buildings, office buildings and other buildings. Based on the level of building technology and architectural cultural tradition of each participating country or region, through the development and application of the green building evaluation tool GBTOOL, we have developed an evaluation system suitable for each participating country or region, which is not directly oriented to the end user. In this way, the participating countries can strengthen the comparison and connection in green building practice and development, and promote the comprehensive and rapid growth of international green building.

The evaluation indicators of the green building evaluation tool GBTOOL include environmental sustainable development indicators, environmental load, resource consumption, indoor environmental quality, maintainability, economy, and operation management[8]. A combination of qualitative and quantitative analysis is applied to establish a multi-level weight system and output the results in the form of charts, with

hints to improve improvement. However, because different countries have different national conditions, the specific evaluation criteria, evaluation indicators and weight coefficients should be determined by each country according to their own actual situation.

(4) Comprehensive Environmental Assessment Method of Japan (CASBEE)

Building comprehensive environmental performance evaluation system (Comprehensive Assessment System for Building Environmental Efficiency, CASBEE) is made by Japan, it is the first formulated by Asian countries green building evaluation system, for our country and other Asian countries to establish based on their national conditions of building energy conservation evaluation system plays an important role, such as China's green Olympics building evaluation system is based on the product of CASBEE framework.

CASBEE The evaluation objects are divided into two types: "non-residential buildings" and "residential buildings". The evaluation contents include energy consumption (energy efficiency), resource reuse (resource efficiency), local environment (outdoor environment) and indoor environment (indoor environment), including 93 subcategories. In the evaluation process, CASBEE proposed the building environmental performance (Building Environmental Efficiency, BEE) as the evaluation standard for evaluating the green performance of buildings, and the formula is

$$BEE = Q / L, \qquad (1.1)$$

Where Q (Quality) refers to the environmental quality and performance of the building, which represents the improvement of the living comfort of the assessed object in the hypothetical enclosed space; L (Load) refers to the external environmental load of the building, which represents the negative impact of the assessed object on the environment in other public areas outside the hypothetical enclosed space. The imaginary enclosed space in CASBEE refers to the range of building environmental efficiency evaluation, which is a closed three-dimensional space system enclosed by the land boundary line and the highest point of the building. In the evaluation process, the two indicators of "environmental quality and performance of the building" and "external

environmental load of the building" are evaluated respectively. Finally, the ratio of these two indicators, namely BEE (Building Environmental Efficiency), is used to comprehensively reflect the green degree of the building, so that the evaluation results will be more objective and comprehensive. Through the above formula, it can be found that BEE is positively correlated with Q and negatively correlated with L, the larger the Q, the smaller the L, the larger the BEE, that is, the higher the green degree of the building. When conducting building evaluation using CASBEE, Q and L are first evaluated separately to obtain their respective scoring results, and then the BEE value of building environmental performance is obtained from the above formula[9].

To sum up, these evaluation systems have basically formulated quantitative scoring systems according to certain standards, and used quantitative indicators as evaluation objects as far as possible. For the indicators that are difficult to quantify, the method of grading is adopted to analyze and evaluate. Review abroad these green building evaluation system, their evaluation range is broad, involving each link of the building construction, standing in the macro point of view, for a specific energy-saving building or energy-saving technology scheme is not evaluate, and strong dependence on experts, high cost, evaluation index of regional, portability and poor shortcomings.

1.3.2 Status of domestic research

Building energy conservation is a major strategic issue for China's sustainable development, and it is also a technology policy that needs long-term development. Over the years, China's building energy conservation work has been hard to carry out, the use of the first urban after rural, first residential buildings after public buildings, first energy saving new after energy conservation reconstruction, first the north after the south method gradually promoted, to achieve the comprehensive development of China's building energy conservation work. With the continuous improvement of the national attention to building energy saving, a series of energy saving standards and norms have been continuously promulgated and implemented. In addition to the energy saving design of new buildings and the energy saving renovation of existing buildings, at the

same time, the detection and evaluation of China's building energy saving effect has also entered the research and development stage.

Since 1986, China has formulated relevant energy-saving design standards for residential buildings, put forward the requirement of 30% energy-saving standards, and revised the energy-saving standards in 1996, raising the energy-saving standards to 50%. In 2001 and 2003, the energy saving standard of 50% for residential buildings in hot summer and cold winter and hot summer and warm winter respectively. On July 1,2004, Beijing began to promulgate and implement the new standard "Energy Saving Design Standard for Residential Buildings", which once again raised the energy saving standard from the original 50% to 65%. The promulgation and implementation of this series of standards marks the continuous progress and development of the building energy conservation cause in China. Compared with foreign countries, in the field of building energy conservation, in addition to paying attention to the formulation of building energy conservation design norms and standards to meet the development needs of the society, and through the continuous efforts of many researchers, China's building energy conservation testing and evaluation research has also made great progress. In general, the evaluation indexes of building energy saving effect in China mainly include four types: specified index (Compulsory Index), performance index (Performance Index), comprehensive index and energy consumption index based on software simulation. The parameters of each energy consumption system of a building include the coefficient of building shape, shading coefficient, window-wall ratio and heat transfer coefficient of each part of the envelope, as well as the energy efficiency index of heating, air conditioning system and lighting system. Performance index (Performance Index) requires the building to meet the requirements of the overall comprehensive energy consumption, the building local thermal performance is not specific provisions, can be through a variety of technical measures and other means to achieve energy saving goal. The annual energy consumption evaluation based on the energy consumption simulation integrates the envelope structure, heating system and air conditioning system. And other building equipment and other factors affecting all aspects of the building energy

consumption to evaluate the building energy conservation, this method will be the accurate simulation of the whole building energy consumption into possible, its obvious deficiency is too strong professional, more difficult to calculate. The above four evaluation methods are all based on the building energy consumption from the perspective of the building itself, and consider less to the social and environmental external factors that affect the building energy consumption.

(1) Prescribed indicators

Prescriptive index (Compulsory Index) is mainly for the parameters of the energy consumption system of a minimum limit, such as building envelope (wall, roof, doors and Windows) of heat transfer coefficient or heat transfer resistance, shape coefficient, window ratio, glass shading, and heating, air conditioning, lighting equipment minimum energy efficiency index, meet all the parameters of the building, can be considered as low energy consumption state, as an energy-saving building[10].Many countries have adopted the specified indicators, such as Sweden, Denmark, Germany, the United States, Canada, Japan and Russia, all have regulations on the heat transfer coefficient of exterior walls, external Windows and roofs. The specified indicators are widely used in the evaluation of energy-saving buildings in China, especially when measuring whether the energy of residential buildings is energy efficient, the specified indexes such as heat transfer coefficient, building shape coefficient and window to wall ratio are often used.

Our country in 1986 issued the first building energy saving design standards, revised in 1995 the civil building energy saving design standard (heating residential building part) (JGJ 26-95), for northern cold climate characteristics, the heat consumption around the heating residential buildings and coal consumption index should not exceed the standard value, some provinces and cities also made the corresponding building energy saving design standards, technical provisions or detailed rules for the implementation. In hot summer and winter and hot summer and winter areas, residential buildings in cold winter energy conservation design standard (JG1 134-2001) [5] and hot summer and warm winter residential building energy conservation design standard (JGJ 75-2003)) should adopt dynamic method to calculate the envelope structure heat

transfer.

Nowadays, today's architectural design is increasingly diversified and personalized, and many buildings often cannot fully meet the requirements of these specified indicators. Therefore, because this sub-specified index is too specific, and each index is independent and lack of effective correlation, so it is impossible to conduct a comprehensive analysis of the energy consumption of each part of the building. In addition, because the various indicators are too rigid, the design freedom and creativity of architects are also limited to a certain extent.

(2) Performance indicators

The performance index is to only stipulate the total performance of the building envelope, that is, do not specify the local thermal performance of the building, allowing the designer to have a certain breakthrough in a certain link, so as to give the designer a large space to play freely. For example, the comprehensive heat transfer value OTTV (Overall Thermal Transfer Value), the surrounding annual load coefficient PAL (Perimeter Annual Load), envelope energy consumption (ENVLOAD) index, etc., these indicators meet the requirements of designers and equipment engineers and building energy saving standard control, but this index cannot reflect the influence of shape coefficient on the energy consumption of building envelope.

Effective heat transfer coefficient method is used in the calculation of energy saving heat consumption of heating residential buildings in cold areas of China. The effective heat transfer coefficient of the envelope is the net heat transfer per unit time under the unit air temperature difference on both sides of the envelope, including the heat transfer caused by the air temperature difference and the temperature loss caused by solar radiation. On the basis of OTTV index, Ren Jun et al. from Xi'an University of Architecture and Technology put forward the heat transfer index EHTV for the calculation and evaluation of energy saving design of residential buildings[11]. Different from OTTV index, EHTV will be converted to unit building area through the heat transfer of each envelope, and expand the application scope to five climate zones in China. At the same time, it also calculates the relationship between EHTV index and the

energy consumption of air conditioning and heating in China, which promotes the energy saving design of building envelope and the evaluation of building envelope in China.

(3) Comprehensive indicators

Comprehensive indicators are factors that comprehensively affect all aspects of energy consumption of building, including building envelope, air conditioning system, other building equipment, etc. Through the statistical data of building energy consumption, the actual energy consumption data of building (such as power consumption, coal consumption, etc.) is taken as the indicators to express the current situation of building energy consumption. In view of the climate conditions in hot summer and cold winter areas of hot summer and cold winter and high relative humidity throughout the year, Yu Jinghua proposed the EETP index to evaluate the overall thermal performance of the building envelope. This index regards the envelope structure as a whole system and evaluates the envelope structure on the whole [12]. Sun Lin established a comprehensive evaluation index system for energy saving technology of envelope structure in hot summer and cold winter areas, and gave a relatively simple evaluation and comparison method from three aspects of technical performance, economic benefit and social benefit [13].The system is also basically applicable to other climatic conditions, and has the widest range of physical performance indicators. In addition, the adaptability of construction technology and complete sets of technologies is also taken into account, which is especially important for new technologies, because many new technologies are very difficult in manufacturing, construction and other aspects, and are likely to affect the overall quality by failing to meet the requirements. This system also has some limitations. For example, the acoustic performance is not considered, and the evaluation of the economy is not comprehensive enough, and there is no single evaluation of the design, demolition, reuse and other costs.

The advantages of taking the actual annual energy consumption as the evaluation index are significant: the calculation (statistical) method is clear, which can widely reflect the comprehensive energy consumption performance of a building from all sides,

and can be easily transformed into economic indicators, which is directly related to the cost of building operation, and is easy to be accepted and used. However, China has not yet established the statistical system of building energy consumption, and the statistical system of building energy consumption is not perfect, and it does not consider the interrelated factors affecting building energy consumption. An absolute index given is not enough to reflect the energy saving potential of building envelope, and the evaluation is too general.

(4) Energy consumption index based on software simulation

The energy consumption index based on software simulation is an effective method for the efficiency evaluation of building energy consumption system and the consistency evaluation of building energy saving standard and specification, which provides greater flexibility for the overall energy saving design of buildings. On the basis of the simulation software (e. g. DOE-2, Energy Plus, etc.), according to the local climate conditions and indoor setting conditions, the energy consumption is simulated for the specific building and air conditioning system, and then the comprehensive energy consumption index of the whole building is evaluated. The representative one is ASHARE90.1l63l energy budget method ECB (Energy Cost Budget). According to the actual design of the building structure standard building, and then energy consumption simulation calculation software respectively calculate the annual energy consumption of the building DEC and standard building cost of SEC, when the calculation results meet the DECSEC or DEC / EC 1 is considered to meet the requirements, otherwise have to take certain energy saving measures, according to the design of the building design conditions, until the establishment. The purpose of the ECB approach is to make the final energy cost of the building no higher than in the case where the building meets all "normative" requirements. Because the standard building varies with the different design building, the annual energy consumption cost index SEC of the standard building is not a fixed value, so the energy cost budget method of this change index has the advantages of flexible and reasonable.

In addition, many researchers use the life cycle energy consumption to evaluate the

envelope performance. For example, Wang Songqing and Wang Jing used the method of life cycle energy consumption to evaluate the energy consumption of residential buildings in cold areas[14] [15]; Zhu He studied the characteristics and distribution of residential building energy consumption and environmental emission in each stage of the life cycle[16]; Yan Yan discussed the energy consumption of building life cycle in Zhejiang Province and established the basic database of each stage of building life cycle in Zhejiang Province[17]. Some scholars for the objective evaluation of energy consumption of building life cycle, the different kinds of energy consumption into a class of energy consumption, such as Zhou Shaoxiang track of energy supply, network distribution and the whole process of user terminal use, unified energy consumption into primary energy consumption to more objectively evaluate building energy consumption[18]; Jiang Yi suggested that the method of equivalent electricity should be adopted in the energy analysis, and that the equivalent electricity method can give the loss and circulation status of each link of energy transmission and conversion, and meet the requirements of energy statistical balance. At the same time, it can also make more scientific analysis and evaluation of various energy conversion methods and energy use methods [19].

The evaluation method of energy consumption index based on software simulation has made it possible to accurately simulate the energy consumption of the whole building and its building equipment. However, there are still some shortcomings in this index: (1) it can only be accurately simulated under the set ideal parameters, and can not reflect the energy consumption under the actual operation state of the building; (2) the calculation is troublesome, too professional, and the software needs additional costs, which is still limited in the application.

1.4 Main contents of the study

Based on energy conservation and emissions reduction, the urgent needs of zero energy consumption building, in view of the existing envelope research in the main problems, this paper will respectively from the building of the transparent and

transparent envelope structure, evaluation of related structure, discusses the theoretical requirements of various energy saving methods, finally hope to build a complete theoretical system of high performance building envelope structure. The main contents of the chapters of this paper are as follows:

The first chapter is the introduction. Firstly, the research background, research purpose and significance of the paper are introduced, and then the research status of domestic and foreign scholars and the necessity of this paper are briefly reviewed. By reviewing the existing research, we point out the places that need to be supplemented, and introduce the research content of this paper.

The second chapter is the application effect evaluation of the non-transparent envelope structure. The study subjects in this chapter are non-transparent envelopes. Start with a few concepts involved in the later discussion and the simulation and demonstration tools used. Then, typical wall materials are selected as the representative. Through Design Builder building energy consumption simulation software, represented as a typical city in hot summer and cold winter areas, the influence of the setting temperature of heating and air conditioning period, the division of heating and air conditioning period, energy use mode and multiple factors on the energy consumption of residential buildings is deeply analyzed. The application effect of the exterior wall as a non-transparent envelope structure is discussed through experiments.

The third chapter is the quantitative relationship between the transparent envelope structure parameters and energy consumption and the evaluation of energy saving effect. For the doors and Windows in the energy consumption of commercial complex related design parameters, study the influence of the parameters on building energy consumption, get the multiple regression model of single parameter and building energy consumption, and from the perspective of sensitivity coefficient and energy saving rate of different design parameters, and according to the evaluation results are suitable for cold area commercial complex building commercial area envelope of energy saving design strategy.

Chapter four is divided into two parts: conclusion and outlook. This chapter first

reviews the main research content of this paper and gives the main conclusions of this paper. Then we indicate the shortcomings of this paper and discuss possible directions for further research in the future.

CHAPTER 2 EVALUATION OF THE APPLICATION EFFECT OF THE NON-TRANSPARENT ENVELOPE STRUCTURE

Building energy conservation has become one of the important components of energy conservation and emission reduction in the whole society. The overall economy of hot summer and cold winter areas is relatively developed, and the form of building energy conservation is severe. It is extremely urgent to improve the insulation performance of building envelope, which is also one of the important technical measures to reduce consumption in this region. The importance of building exterior wall in building envelope is self-evident, occupying a large proportion of building energy consumption. Its thermal performance will directly affect the indoor thermal environment of the building and the comfort of households, thus affecting the level of building energy consumption. At present, the research on building exterior wall at home and abroad mainly focuses on the energy saving effect of different forms and optimal insulation thickness, but there are few basic theoretical research, the development of building energy saving technology suitable for regional climate characteristics is not sound enough; in addition, the correlation research of "anti-energy saving" phenomenon under the external wall insulation is less, and the boundary conditions are not clear enough, especially for the "anti-energy saving" characteristics of the typical climate characteristics of hot summer and cold winter in hot summer and cold winter.

In view of the above problems, this chapter takes a typical residential building in Hangzhou as an example. According to the typical climate characteristics of high temperature and hot summer and humid and cold winter in Zhejiang Province, Design Builder software is used to simulate the annual heating and air conditioning energy consumption and power saving rate of buildings with different external wall insulation thicknesses under the action of different factors. At the same time, the numerical simulation calculation of building energy consumption under different solar radiation intensity is conducted, and the heat conduction of building external wall is studied and analyzed. Combined with the experiment of the energy saving effect of the external insulation under different solar radiation intensity, the heat flow density from the

external wall of the external insulation wall to the interior and the annual energy consumption of the external insulation wall building is significantly reduced, and the conclusion that the external insulation of the external wall has a good energy saving effect is obtained.

2.1 Introduction to the building energy consumption simulation software

Correct analysis of building energy consumption has great practical significance and theoretical value for the rational use of energy, protecting the ecological environment and promoting the sustainable development of economy[20]. According to statistics, there are more than 100 kinds of building energy consumption simulation software in the world, such as BLAST, DOE 2, Energy Plus, ESPr, China DeST, etc[21]. These software are mainly used for the calculation and analysis of building cold and heat load, the evaluation of building thermal performance, the energy consumption analysis and auxiliary design of building equipment system, etc[22]. The accuracy of the calculation results of simulation software has always been a problem in the simulation field. A large number of scholars at home and abroad have done a lot of verification work on DOE 2, DeST and Energy Plus. Michael J.Witte, Drury B. And Crawley et al[23]. He has analyzed the simulation results of Energy Plus, D0E2, BLAST and ESP from three aspects of theoretical verification, comparative verification between procedures and experimental verification, so as to verify the authenticity and accuracy of Energy Plus simulation calculation. The DeST development team at Tsinghua University has also done a lot of DeST verification work[24]. The reliability of the numerical simulation results for real building is proved. Simge Andolsun and Charles.H.Culp from the "shoe box" model to the residential model[25], the simulation results between DOE 2 and Energy Plus are compared. And Cassie Waddell and Shruti Kaserekax in the treatment of solar heat and the impact on cooling load[26], eQuest, Energy Plus, IES and TRACE simulation software are used to compare the differences. From a lot of research work can be obtained: different software in different simulation conditions simulation results have certain differences. In fact, the difference in the

simulation results is not only influenced by the software itself, but also depends on the user's proficiency in the software operation. When different simulation software is used in real engineering and research, in order to get more correct simulation results, the user should be very skilled in the software to ensure the accuracy of the input parameters and the software calculation core.

In this chapter, Design Builder V4.5.0.073 (built-in computing engine Energy Plus V8.3) is used for numerical simulation calculation of building energy consumption. The time-dependent meteorological parameters used are typical meteorological annual data obtained by Tsinghua University, namely Chinese standard annual meteorological CSWD data[27].

2.1.1 Energy Plus

Energy Plus Is with the U. S. Department of Energy, Lawrence Berkeley National Laboratory (Lawrence Berkeley National Laboratory), University of Illinois (University of Illinois), U. S. Army Construction Engineering Laboratory (US Army Construction Engineering Research Laboratory)> Oklahoma State University (Oklahoma State University) Jointly developed by other units, Is a brand new software, It not only absorbs the advantages of the building energy consumption analysis software DOE-2 and BLAST, And with a lot of new features, It is considered a new generation of building energy consumption analysis software used to replace DOE-2[28].

Energy Plus, the reliability of itself has also been recognized by the industry, and the reliability of the software itself has withstood the test. After 15 years of development and innovation, Energy Plus has been widely used by many scholars at home and abroad in the field of building energy conservation research, with fruitful results. Kalua class [29], A computer simulation of typical Malawi by Energy Plus to optimize the envelope thermal design of free-running urban residential buildings in Malawi. Rojas, J, et al[30]. This paper compares the thermal performance results and Energy Plus simulation results of the two envelope structure systems of the wall and the roof of the whole concrete building, and finds that the simulation results are very close to the experimental data. Djuric class[31], On the basis of general optimization scheme and

Energy Plus simulation of indoor thermal environment comfort, the total cost including energy, insulation material cost and reflective material cost is optimized. Zhou Jingna[32], Taking Hefei city as an example, Energy Plus software was used to study the influence of the thickness of external wall insulation layer of a public building on the cumulative heat and cold load, peak heat and heat load and energy consumption of heating air conditioning system.

2.1.2 Design Builder

Design Builder Is the first integrated user graphical interface simulation software developed for the Energy Plus building energy consumption dynamic simulation engine[33]. The Energy Plus interface is cumbersome operation, poor user experience, low work efficiency and other problems are deepened. In 2006, ANSI / ASHRAE standard 140-2004 used a specific testing procedure for Design Builder Vl.2.0 (Built-in computing engine Energy Plus VI.3.0) In the building thermal environment and energy consumption simulation software of the applicable scope, and simulation ability and building environment control system were evaluated, evaluation and identification, Design Builder Vl.2.0 can be applied to the simulation of thermal environment and energy consumption of a large number of building types. Compared with the results of Energy Plus operation alone, the simulation and calculation results of Design Builder are very consistent[34].

2.2 Numerical analysis of the impact of external wall insulation thickness of residential buildings on building energy consumption

According to the "Energy Saving Design Standard for Residential Buildings in Hot Summer and Cold Winter Areas", EPS external wall insulation system is adopted for residential buildings, Thickness of 20mm, 40mm, 60mm, 80 nu, 100mm, 120mm, 140mm, The typical meteorological year of hot summer and cold winter in Hangzhou is taken as the outdoor simulated meteorological parameters, Simate the annual energy consumption under the corresponding influencing factors of the residential building through Design Builder, In order to analyze the influence of the external insulation

thickness of residential buildings on the energy consumption of heating and air conditioning under different influencing factors of energy saving standards in hot summer and cold winter areas, So as to evaluate the energy saving effect of indoor calculation temperature in different heating periods in hot summer and cold winter areas.

2.2.1 External insulation and energy saving effect of exterior walls of residential buildings under the energy saving standard in hot summer and cold winter areas

In this simulation, external insulation walls with different thicknesses (20mm, 40mm, 60mm, 80mm, 80 mm, 100mm, 120mm and 140mm) were used to simulate the energy consumption under the energy saving standard in hot summer and cold winter areas. The results are shown in Table 2.1.

Table 2.1- Energy Saving Effect of External Insulation Thickness of External Wall under Industry Standard

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m²•K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
	The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year	Energy consumption (kWh / m²)	22.28	18.71	17.15	16.28	15.69	15.27	14.96	14.71
	The power saving rate is (%)	/	16.2	23.03	26.93	29.59	31.46	32.85	33.98

It can be seen that in the simulation calculation under the industry standard, with the increase of the thickness of EPS insulation layer, the heat transfer coefficient of the external wall gradually decreases, which has better thermal performance. The energy consumption during air conditioning period, energy consumption during heating period

and annual energy consumption are reduced to varying degrees, and the energy saving effect of the building is more and more significant. When the thickness of EPS insulation layer increases from 0 to 120mm, compare from the air conditioning period: energy consumption from 8.84kWh / m^2Reduced to 7.58 kWh / m^2, The power saving rate increased from 9.16% to 14.25%; compared from the heating period: the energy consumption changed from 13.44 kWh / m^2 reduced to 7.13 kWh / m^2, Power saving rate increased from 32.14% to 46.95%; from the whole year: energy consumption from 22.28 kWh / m^2Reduced to 14.71 kWh / m^2, The power saving rate increased from 23.03% to 33.98%. Under the industry standard, with the increase of EPS insulation layer thickness, the heat transfer coefficient of the building exterior wall gradually decreases, the heat insulation performance of the wall gradually improves, and the energy saving effect gradually increases, but the rising trend is getting smaller and smaller; under the same insulation layer thickness, the power saving rate of the heating period is much higher than that of the air conditioning period.

2.2.2 External insulation and energy saving effect of external walls of residential buildings under the calculated temperature of different heating and air-conditioning periods

As can be seen from the above, the indoor calculation temperature during the heating and air conditioning period has a great impact on the heating energy consumption, air conditioning energy consumption and annual energy consumption in hot summer and cold winter areas. The calculated indoor temperature is as follows: indoor design temperature is 16℃, 17℃, 18℃, 19℃ and 20℃, and summer air conditioning is 24℃, 25℃, 26℃, 27℃ and 28℃. Under different external wall insulation layer thickness, the above indoor temperature is calculated respectively, and the simulation results are shown in Table 2.2-2.11.

Table 2.2 – Calculated temperature 16℃ Energy saving effect of external insulation thickness of external wall (Mode 1)

The EPS insulation layer thickness is mm	0	20	40	60	80	100	120	140
External wall heat transfer	1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26

	coefficient W/（m²K）								
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	9.49	7.00	6.05	5.49	5.12	4.86	4.67	4.54
	The power saving rate is (%)	/	26.24	36.25	42.15	46.05	48.79	50.79	52.16
complete year	Energy consumption (kWh / m²)	18.33	15.31	14.08	1337	12.89	12.55	12.3	12.13
	The power saving rate is (%)	/	16.47	23.19	27.06	29.68	31.53	32.90	33.82

Table 2.3 - Calculated temperature 17℃ Energy saving effect of external insulation thickness of external wall (Mode 2)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m²·K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	11.43	8.70	7.55	6.91	6.49	6.19	5.96	5.78
	The power saving rate is (%)	/	23.88	33.95	39.55	43.22	45.84	47.86	49.43
complete year	Energy consumption (kWh / m²)	20.27	17.01	15.58	14.79	14.26	13.88	13.59	13.36
	The power saving rate is (%)	/	16.08	23.14	27.04	29.65	31.52	32.96	34.09

Table 2.4 - Calculation Temperature in Heating Period 18 Energy Saving Effect of Building (Mode 3)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m²•K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
	The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year	Energy consumption (kWh / m²)	22.28	18.71	17.15	16.28	15.69	15.27	14.96	14.71
	The power saving rate is (%)	/	16.02	23.03	26.93	29.59	31.46	32.85	33.98

Table 2.5 - Calculated Temperature 19C (Mode 4)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m²·K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	15.51	12.15	10.74	9.94	9.42	9.05	8.76	8.54
	The power saving rate is (%)	/	21.66	30.75	35.91	39.26	41.65	43.52	44.94
complete year	Energy consumption (kWh / m²)	24.35	20.46	18.77	17.82	17.19	16.74	16.39	16.12
	The power saving rate is (%)	/	15.98	22.92	26.82	29.40	31.25	32.69	33.80

Table 2.6 - Calculated temperature of 20°C (Mode 5)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m² K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	17.64	13.96	12.41	11.54	10.96	10.56	10.24	10.00
	The power saving rate is (%)	/	20.86	29.65	34.58	37.87	40.14	41.95	43.31
complete year	Energy consumption (kWh / m²)	24.35	22.27	20.44	19.42	18.73	18.25	17.87	17.58
	The power saving rate is (%)	/	8.54	16.06	20.25	23.08	25.05	26.61	27.80

Table 2.7 – Calculation temperature during air conditioning period 24-C Energy saving effect of exterior wall insulation thickness (Mode 6)

The EPS insulation layer thickness is mm	0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m² K）	1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period — Energy consumption (kWh / m²)	11.74	10.81	10.36	10.10	9.93	9.80	9.71	9.63
Air conditioning period — The power saving rate is (%)	/	7.92	11.75	13.97	15.42	16.52	17.29	17.97
feudal estate warm designated time — Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
feudal estate warm designated time — The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year — Energy consumption (kWh / m²)	25.18	21.21	19.48	18.5	17.85	17.38	17.04	16.76
complete year — The power saving rate is (%)	/	15.77	22.64	26.53	29.11	30.98	32.33	33.44

Table 2.8 - Calculated Temperature of Air-conditioning Period 25- -Building Energy saving effect of external insulation thickness of exterior wall under C (Mode 7)

The EPS insulation layer thickness is mm	0	20	40	60	80	100	120	140
External wall heat transfer coefficientW/（m² K）	1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period — Energy consumption (kWh / m²)	10.27	9.54	9.18	8.97	8.84	8.73	8.66	8.59
Air conditioning period — The power saving rate is (%)	/	7.11	10.61	12.66	13.92	15.00	15.68	16.36
feudal estate warm designated time — Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
feudal estate warm designated time — The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year — Energy consumption (kWh / m²)	23.71	19.94	18.3	17.37	16.76	16.31	15.99	15.72
complete year — The power saving rate is (%)	/	15.90	22.82	26.74	29.31	31.21	32.56	33.70

Table 2.9 – Calculation Temperature of air conditioning period 26 Energy saving effect of exterior wall insulation thickness (Mode 8)

The EPS insulation layer	0	20	40	60	80	100	120	140

thickness is mm								
External wall heat transfer coefficient W/(m²K)	1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.84	8.31	8.03	7.88	7.77	7.69	7.63	7.58
	The power saving rate is (%)	/	6.00	9.16	10.86	12.10	13.00	13.69	14.25
feudal estate warm designated time	Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
	The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year	Energy consumption (kWh / m²)	22.28	18.71	17.15	16.28	15.69	15.27	14.96	14.71
	The power saving rate is (%)	/	16.02	23.03	26.93	29.59	31.46	32.85	33.98

Table 2.10 - Calculation temperature of air conditioning period 27 Building Energy saving effect of exterior wall insulation thickness (Mode 9)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m² K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	7.47	7.12	6.93	6.82	6.75	6.70	6.66	6.62
	The power saving rate is (%)	/	4.69	7.23	8.70	9.64	10.31	10.84	11.38
feudal estate warm designated time	Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
	The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year	Energy consumption (kWh / m²)	20.91	17.52	16.05	15.22	14.67	14.28	13.99	13.75
	The power saving rate is (%)	/	16.21	23.24	27.21	29.84	31.71	33.09	34.24

Table 2.11 - Calculated temperature of air conditioning 28. <2 Energy saving effect of building with external insulation thickness of lower exterior wall (mode 10)

The EPS insulation layer thickness is mm	0	20	40	60	80	100	120	140
External wall heat transfer	1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26

	coefficient W/(m² K)								
Air conditioning period	Energy consumption (kWh / m²)	6.19	6.00	5.89	5.83	5.78	5.75	5.73	5.71
	The power saving rate is (%)	/	3.17	4.85	5.82	6.62	7.11	7.43	7.75
feudal estate warm designated time	Energy consumption (kWh / m²)	13.44	10.40	9.12	8.40	7.92	7.58	7.33	7.13
	The power saving rate is (%)	/	22.62	32.14	37.5	41.07	43.60	45.46	46.95
complete year	Energy consumption (kWh / m²)	19.63	16.40	15.01	14.23	13.7	13.33	13.06	12.84
	The power saving rate is (%)	/	16.45	23.54	27.51	30.21	32.09	33.47	34.59

Under different indoor calculation temperature periods during the heating period, when the thickness of EPS insulation layer gradually increases, the power consumption of air conditioning refrigeration remains the same, the energy consumption during the heating period decreases, and the energy saving effect of the building is significantly improved, but the rising trend is gradually flat! For example, when the calculated temperature during the heating period is 20°C, the energy consumption during the heating period is reduced from 17.64 kWh / m² to 10.00 kWh / m², Power saving rate increased from 20.86% to 43.31%; annual power consumption increased from 24.35 kWh / m²Reduced to 17.58 kWh / m², The electricity saving rate increased from 8.54% to 27.80%.

At the same time, different air conditioning period indoor calculation temperature, the change law is similar. For example, when the calculated temperature during the air conditioning period is 28°C degrees, the energy consumption during the air conditioning period ranges from 6.19 kWh / m²Reduced to 5.71 kWh / m², The power saving rate increased from 3.17% to 7.75%, and the annual power consumption increased from 19.63 kWh / m²Reduced to the 12.84kWh/m², The power saving rate increased from 16.45% to 34.58%.

The indoor temperature during heating and air conditioning period has a great influence on the evaluation of the energy saving effect of the insulation thickness of

external wall. With the decrease of indoor calculation temperature during heating period, the energy saving effect of external wall insulation thickness in winter, and it is true for indoor calculation temperature during air conditioning period. The value of critical temperature is ultimately attributed to the comprehensive consideration of three influencing factors: first, the energy use habits of local residents; second, the overall level and development trend of local building thermal performance; and third, the orientation of building energy conservation work. According to local conditions, reasonably adjust the temperature of the heating and air conditioning period, while fully considering the indoor thermal environment and human comfort needs, effectively improve the building energy saving effect, and make a correct evaluation of the energy saving effect of external wall insulation technology in hot summer and cold winter areas.

2.2.3 The external insulation and energy saving effect of external walls of residential buildings under different heating and air conditioning periods

As can be seen from the above, the division of air conditioning period during the heating period is also one of the important effects of heating energy consumption, air conditioning energy consumption and annual energy consumption in hot summer and cold winter areas. The simulation results of building energy consumption under different heating and air conditioning periods are shown in Table 2.1 and Table 2.12-2.13.

Table 2.12 – Energy saving effect of lower exterior wall insulation thickness of Standard North District of Zhejiang Province (Mode 11)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m² K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.92	8.39	8.11	7.95	7.85	7.77	7.71	7.66
	The power saving rate is (%)	/	6.32	9.08	10.87	12.00	12.89	13.57	14.13
feudal estate warm designated	Energy consumption (kWh / m²)	11.14	8.71	7.70	7.13	6.76	6.49	6.29	6.12

time	The power saving rate is (%)	/	21.81	30.88	36	39.32	41.74	43.54	45.06
complete year	Energy consumption (kWh / m²)	20.06	17.1	15.81	15.08	14.61	14.26	14	13.78
	The power saving rate is (%)	/	14.76	21.19	24.83	27.17	28.91	30.21	31.31

Table 2.13 – Energy saving efficiency of exterior wall insulation thickness under National HVAC Code (Mode 12)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m² K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.91	8.39	8.09	7.93	7.83	7.75	7.69	7.63
	The power saving rate is (%)	/	5.84	9.20	11.00	12.12	13.02	13.69	14.37
feudal estate warm designated time	Energy consumption (kWh / m²)	7.09	5.56	4.93	4.58	4.35	4.19	4.06	3.97
	The power saving rate is (%)	/	21.58	30.47	35.4%	38.65	40.90	42.74	44.01
complete year	Energy consumption (kWh / m²)	16.00	13.95	13.02	12.51	12.18	11.94	11.75	11.6
	The power saving rate is (%)	/	12.81	18.63	21.81	23.88	25.38	26.56	27.5

Compared with the energy saving design standard in hot summer and cold winter areas, the calculation period of heating is 27 days and 75 days, which is a large shortening; the calculation period of air conditioning is 1 day and 5 days, which is relatively small; for the energy consumption of warm air conditioning throughout the year, the energy saving effect of external insulation thickness is significantly reduced. It can be seen from the simulation results that the industry standard in hot summer and cold winter, the standard north district of Zhejiang Province, the national HVAC standard for heating and air conditioning calculation period, the energy consumption during the heating and air conditioning period decreases with the thickness of the EPS insulation layer, and the energy saving effect of the building is more and more

significant, but the trend tends to be flat!

In the process of simulation calculation, as the thickness of EPS insulation layer increases, the air conditioning period compares: the energy consumption ranges from 8.92kWh / m^{2}Reduced to 7.66kWh / m^2, Power saving rate increased from 6.32% to 14.13%; compare from the heating period: energy consumption from 11.14kWh/m^{2}Reduced to 6.12 kWh / m^2, Power saving rate increased from 21.81% to 45.06%; from the annual comparison: energy consumption from 20.06 kWh / m^{2}Reduced to 13.78 kWh / m^2, The power saving rate increased from 14.76% to 31.31%.

When using the national HVAC standard for heating and air conditioning calculation period, the energy consumption in the air conditioning period ranges from 8.91 kWh / m^{2}Reduced to 7.63 kWh / m^2, Power saving rate increased from 5.84% to 14.37%; the energy consumption during heating period increased from 7.09 kWh / m^{2}Reduced to 3.97 kWh / m^2, Power saving rate increased from 21.58% to 44.01%; annual energy consumption increased from 16.00 kWh / m^{2}Reduced to 11.60 kWh / m^2, The electricity saving rate increased from 12.81% to 27.5%.

According to the comparison of Zhejiang standard and the industry standard of hot summer and cold winter area, the calculation period is shortened by 27 days and 54 days respectively, and the winter energy saving effect of external wall insulation is weakened; but the air conditioning calculation period is basically similar, and the summer energy saving effect of natural external wall insulation is basically similar. For the annual building energy consumption, the building energy saving effect of external wall insulation is weakened with the shortening of the heating calculation period.

After adjusting the calculation period of heating and air conditioning period, the annual energy saving rate of external wall insulation technology and the insulation thickness of external wall decrease linearly. The larger the external insulation thickness of the external wall, the smaller the heat transfer coefficient, and the greater the annual energy saving rate. According to local conditions, combined with the actual climate characteristics and meteorological parameters, the heating calculation period and air

conditioning calculation period are more reasonably divided, so as to correctly evaluate the energy saving effect of external wall insulation technology in hot summer and cold winter areas.

2.2.4 External insulation and energy saving effect of exterior walls of residential buildings under different energy use modes

As can be seen from the above, energy use mode has a great impact on heating energy consumption, air conditioning energy consumption and annual energy consumption in hot summer and cold winter areas. The simulation results of different energy use modes under different external wall thickness are shown in Table 2.14.

Table 2.14 – Energy saving effect of external wall insulation thickness in intermittent energy use mode (Mode 13)

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m² K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	5.04	4.97	4.89	4.86	4.83	4.81	4.80	4.78
	The power saving rate is (%)	/	1.39	2.98	3.57	4.17	4.56	4.76	5.16
feudal estate warm designated time	Energy consumption (kWh / m²)	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption (kWh / m²)	12.54	10.9	10.1	9.65	9.34	9.12	8.96	8.81
	The power saving rate is (%)	/	13.08	19.46	23.05	25.52	27.27	28.55	29.74

In the intermittent energy mode, the heat flow direction of the wall is not as single as the continuous energy mode. In summer, there is outdoor flow to indoor and indoor flow to outdoor in winter. When the thickness of EPS insulation layer increases from 0 to 140mm, compare from the air conditioning period: energy consumption from 5.04 kWh / m²Reduced to 4.78 kWh / m², The power saving rate increased from 1.39% to 5.16%; compared from the heating period: energy consumption from 7.50 kWh / m²Reduced to 4.03 kWh / m², Power saving rate increased from 20.93% to 46.27%; from the whole year: energy consumption increased from 12.54kWh/m²Reduced to 8.81 kWh / m², The power saving rate increased from 13.08% to 29.74%. The energy consumption of air conditioning period, energy consumption of heating period and annual energy consumption decreased with the thickness of EPS insulation layer, and the energy saving effect of building is more and more significant.

Compared with the industry standard, the continuous energy use mode is adopted, and the energy use frequency in hot summer and cold winter areas is far less than that in northern heating areas, and is controlled by the subjective behavior of households. The

intermittent energy use is more consistent with the actual situation, and after the actual simulation calculation, the intermittent energy use mode should save electricity than under the continuous energy use mode. It can be seen that the energy use mode also has a certain impact on the evaluation of the energy saving effect of the external wall insulation technology.

2.2.5 External insulation and energy saving effect of exterior walls of residential buildings under the comprehensive action of multiple factors

The above analysis studied the different heating and air conditioning calculation period indoor temperature, heating and air conditioning period, different energy mode single factor effect on building energy saving effect, analyze the comprehensive energy saving effect of building exterior wall insulation, simulation conditions see table 2.15, simulation results are shown in table 2.162.20.

Table 2.15 – Simulation condition of multiple factors

operating mode	Multi-factor combination	remarks	
pattern 14	Mode 6 + Mode 13	The calculated temperature during air conditioning period is 24°C Intermittent energy use	The remaining conditions are determined according to the hot summer and cold winter area industry standard selection
pattern 15	Mode 7 + Mode 13	The calculated temperature during air conditioning period is 25°C Intermittent energy use	
pattern 16	Mode 8 + Mode 13	The calculated temperature during air conditioning period is 26°C Intermittent energy use	
pattern 17	Mode 9 + Mode 13	The calculated temperature during air conditioning period is 27°C Intermittent energy use	
pattern 18	Mode 10 + mode 13	The calculated temperature during air conditioning period is 28°C Intermittent energy use	

Table 2.16 – Energy saving effect of exterior wall thickness insulation and building under mode 14

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m² K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air	Energy	6.79	6.52	6.37	6.28	6.22	6.18	6.14	6.11

conditioning period	consumption (kWh / m²)								
	The power saving rate is (%)	/	3.98	6.19	7.51	8.39	8.98	9.57	10.01
feudal estate warm designated time	Energy consumption (kWh / m²)	7.50	5.92	5.21	4.79	4.47	4.31	4.16	4.03
	The power saving rate is (%)	/	21.07	30.53	36.13	40.4	42.53	44.53	46.27
complete year	Energy consumption (kWh / m²)	14.29	12.44	11.58	11.07	10.69	10.49	10.3	10.14
	The power saving rate is (%)	/	12.95	18.96	22.53	25.19	26.59	27.92	29.04

Table 2.17 - Energy saving effect of external wall insulation thickness of mode 15

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m²• K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	5.91	5.73	5.63	5.57	5.53	5.49	5.47	5.45
	The power saving rate is (%)	/	3.05	4.74	5.75	6.43	7.11	7.45	7.78
feudal estate warm designated time	Energy consumption (kWh / m²)	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption (kWh / m²)	13.41	11.66	10.84	10.36	10.04	9.8	9.63	9.48
	The power saving rate is (%)	/	13.05	19.16	22.74	25.13	26.92	28.19	29.31

Table 2.18 - Energy saving effect of exterior wall insulation thickness under mode 16

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m²• K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	5.04	4.97	4.89	4.86	4.83	4.81	4.80	4.78
	The power saving	/	1.39	2.98	3.57	4.17	4.56	4.76	5.16

	rate is (%)								
feudal estate warm designated time	Energy consumption (kWh / m^2)	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption (kWh / m^2)	12.54	10.9	10.1	9.65	9.34	9.12	8.96	8.81
	The power saving rate is (%)	/	13.08	19.46	23.05	25.52	27.27	28.55	29.74

Table 2.19 - Mode 17 Energy saving effect of external wall insulation thickness

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m^2• K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m^2)	4.22	4.21	4.19	4.18	4.17	4.17	4.16	4.15
	The power saving rate is (%)	/	0.24	0.71	0.95	1.18	1.18	1.42	1.66
feudal estate warm designated time	Energy consumption (kWh / m^2)	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption (kWh / m^2)	11.72	10.14	9.4	8.97	8.68	8.48	8.32	8.18
	The power saving rate is (%)	/	13.48	19.80	23.46	25.94	27.65	29.01	30.20

Table 2.20 - Energy saving effect of exterior wall insulation thickness under mode 18

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/（m^2• K）		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m^2)	3.46	3.52	3.53	3.54	3.55	3.55	3.56	3.56
	The power saving rate is (%)	/	-1.73	-1.98	-2.31	-2.60	-2.60	-2.89	-2.89
feudal estate warm designated time	Energy consumption (kWh / m^2)	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption (kWh / m^2)	10.96	9.45	8.74	8.33	8.06	7.86	7.72	7.59
	The power saving rate is (%)	/	13.78	20.26	24.00	26.46	28.28	29.56	30.75

When the calculated temperature in the air conditioning period is 24℃, 25℃, 26℃ and 27℃, the power consumption of heating remains unchanged (the heating temperature remains unchanged), the energy consumption in the air conditioning period decreases with the thickness of EPS insulation layer, and the building energy saving effect is more and more significant, but the trend area is flat! For example, when the calculated temperature of the air conditioning is 25℃, the energy consumption during the air conditioning period ranges from 5.91 kWh / m²Reduced to 5.45 kWh / m², The power saving rate increased from 3.05% to 7.78%, and the annual power consumption increased from 13.41 kWh / m²Reduced to 9.48 kWh / m²The power saving rate increased from 13.05% to 29.31%. When the calculated temperature in the air conditioning period is 24℃, 25℃, 26℃ and 27℃, the power consumption remains unchanged (heating temperature remains unchanged), the energy consumption in the air conditioning period decreases with the thickness of EPS insulation layer, and the building energy saving effect is more and more significant, but the trend area is flat! For example, when the calculated temperature of the air conditioning is 25℃, the energy consumption during the air conditioning period ranges from 5.91 kWh / m²Reduced to 5.45 kWh / m², The power saving rate increased from 3.05% to 7.78%, and the annual power consumption increased from 13.41 kWh / m²Reduced to 9.48 kWh / m², The power saving rate increased from 13.05% to 29.31%.

It is worth noting that when the calculated temperature in the air conditioning period is 28℃ and the power consumption remains unchanged (the heating temperature remains unchanged), the energy consumption in the air conditioning period increases with the thickness of EPS insulation layer! The external insulation technology of the external wall has lost the building energy saving effect and has the anti-energy saving effect. The energy consumption in the air conditioning period ranges from 3.46kWh / m²Increased to 3.56kWh / m², The energy saving rate decreased from-1.73% to-2.89%. As the heating energy consumption accounts for most of the annual energy consumption, the annual energy consumption of buildings shows energy saving, and the annual power consumption ranges from 10.96 kWh / m²Reduced to 7.59 kWh / m², The electricity

saving rate increased from 13.78% to 30.75%. When the thickness of EPS insulation layer is 20mm, 40mm, 60mm, 80mm, 80 mm> 100mm, 120mm and 140mm, the corresponding refrigeration energy consumption of air conditioning is arranged into Table 2.21- Table 2.27.

Table 2.21 – EPS, building energy saving effect of air conditioning temperature under 20mm of insulation layer

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m²)	6.52	5.73	4.97	4.21	3.52
The power saving rate is (%)	3.78	3.05	1.39	0.24	-1.73

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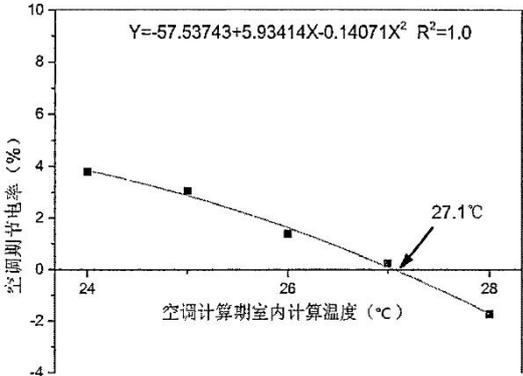
Figure 2.1 - EPS, energy saving effect of building calculated during air conditioning period under 20mm of insulation layer

Table 2.22 – EPS, building energy saving effect of air conditioning temperature under 40mm of insulation layer

Calculated temperature during the air-conditioning period.°C	24	25	26	27	28
Energy consumption (kWh / m²)	6.37	5.63	4.89	4.9	3.53
The power saving rate is (%)	6.19	4.74	2.98	0.71	-1.98
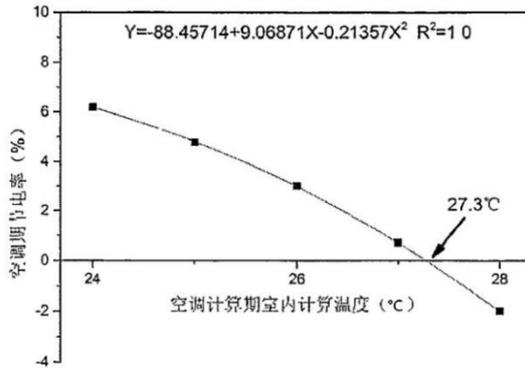
Figure 2.2 – EPS, energy saving effect of building calculated during air conditioning temperature under 40mm of insulation layer

Table 2.23 - EPS, energy saving effect of building calculated during air conditioning period under 60mm of insulation layer

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m^2)	6.28	5.57	4.86	4.18	3.54
The power saving rate is (%)	7.51	5.75	3.57	0.95	- 2.31
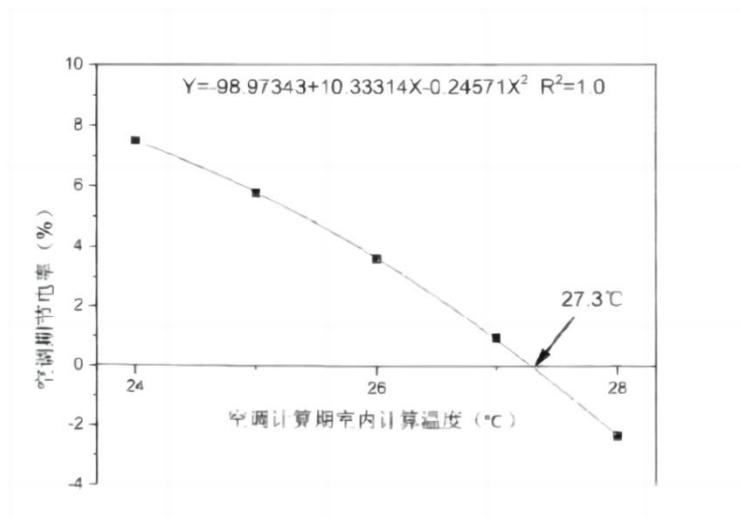
Figure 2.3 - EPS, Energy saving effect of building for calculating temperature during air conditioning period under 60mm of insulation layer

Table 2.24 - EPS, energy saving effect of building calculated during air conditioning period under 80mm of insulation layer

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m²)	6.22	5.53	4.83	4.17	3.55
The power saving rate is (%)	8.39	6.43	4.17	1.18	-2.6
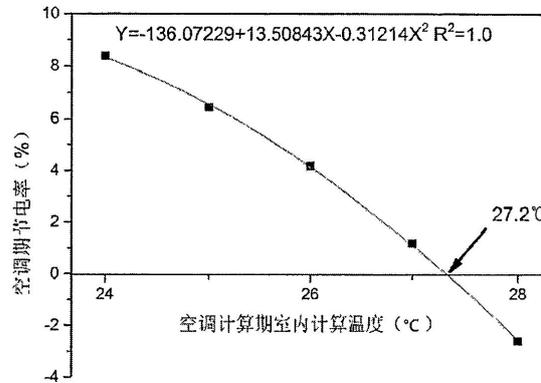
Figure 2.4 - Energy saving effect of building calculated during air conditioning period at 80mm of EPS insulation layer

Table 2.25 - EPS, building energy saving effect of air conditioning temperature under 100mm insulation layer

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m²)	6.18	5.49	4.81	4.17	3.55
The power saving rate is (%)	8.98	7.11	4.56	1.18	-2.6
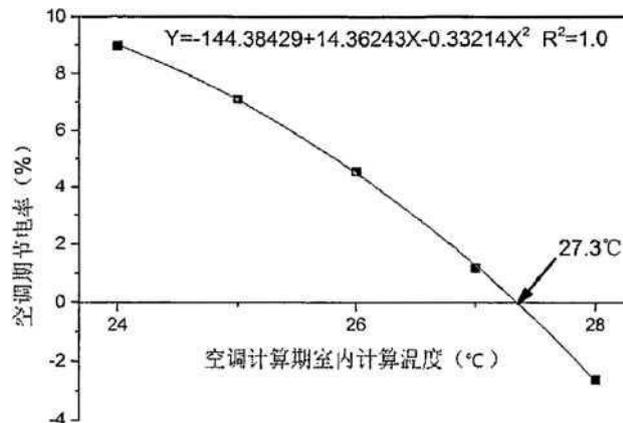
Figure 2.5 – EPS, building energy saving effect of temperature calculation during air conditioning period under 100mm of insulation layer

Table 2.26 – EPS, heat saving effect during air conditioning period at 120mm

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m2）	6.14	5.47	4.80	4.16	3.56
The power saving rate is (%)	9.57	7.45	4.76	1.42	-2.89
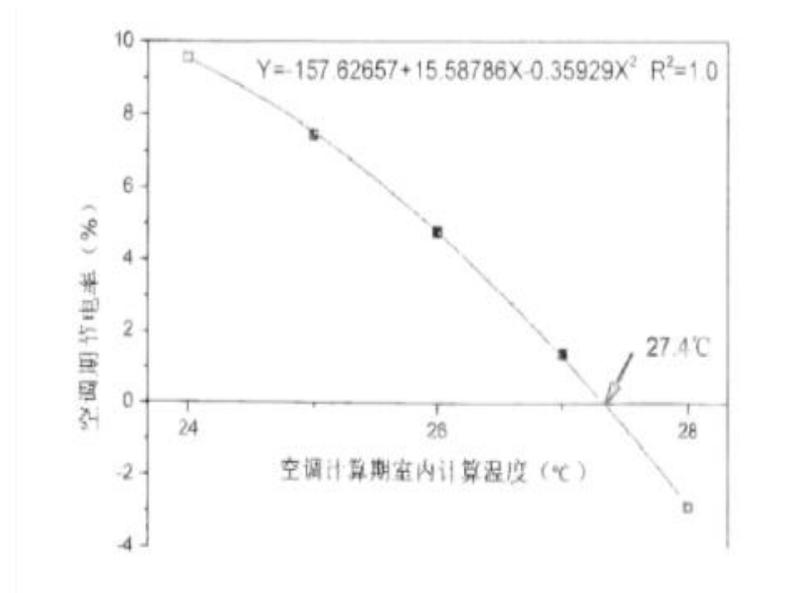
Figure 2.6 – EPS, air conditioning temperature under 120mm insulation layer

Table 2.27 - EPS, energy saving effect of temperature during air conditioning period under 140mm insulation layer

The calculated temperature during the air-conditioning period is °C	24	25	26	27	28
Energy consumption (kWh / m2)	6.11	5.45	4.78	4.15	3.56
The power saving rate is (%)	10.01	7.78	5.16	1.66	-2.89

空调期节电率 (%)

Y=-178.41257+17.31086X-0.39429X^2 R^2=1.0

27.3℃

空调计算期室内计算温度 (℃)
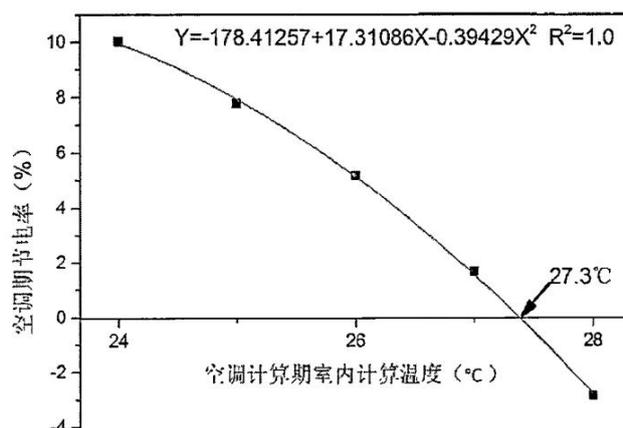
Figure 2.7 – EPS, air conditioning temperature under 140mm insulation layer

According to the above chart, the temperature is calculated in an anti-energy saving critical air conditioning period under the thickness of each insulation layer. Before this critical temperature, the building refrigeration in the corresponding insulation mode is energy saving. Once the critical temperature is exceeded, the building refrigeration in the corresponding insulation mode is anti-energy saving. It can be seen that the calculated temperature of the anti-energy saving critical air conditioning period corresponding to the thickness of the insulation layer of 20mm to 140mm external insulation layer hovered at 27.3℃, and the accurate correspondence between the two is as follows: the calculated temperature of the anti-energy saving critical air conditioning period corresponding to the EPS insulation thickness of 20mm to 140mm is 27.1℃, 27.3℃, 27.3℃, 27.2℃, 27.3℃, 27.4℃ and 27.3℃, respectively。The reasons are as follows:

When the whole space is energy used, the room temperature on the inner wall of the building is the same, so there is no heat transfer between the inner walls; however, when part of the space is energy used, the envelope of the energy room naturally has the outer wall and the inner wall, the boundary conditions of the two have changed, no longer like the whole space is consistent. At this time, the external wall carries out convection heat exchange through the external surface and the outdoor environment, while the internal wall carries out convection heat exchange through the internal and external surface and the indoor space.

The heat flow conduction of the wall is closely related to the wall temperature. When the building is used in full time, the wall heat flow conduction direction is generally one-way. In refrigeration in summer, the related temperature is indoor temperature <wall temperature <outdoor temperature distribution, natural heat flow from outdoor to indoor; in winter heating, just the opposite of summer, the related temperature is indoor temperature> wall temperature> outdoor temperature trend distribution, the heat flow is from indoor to outdoor. However, in the case of some time energy use, the wall temperature is in a complex unstable change process, and the direction of heat flow cannot be determined so simply.

In the summer refrigeration during the day, the heat flow direction of the wall is more complex, and it is no longer a single flow from outdoor to indoor, but to indoor and outdoor at the same time, because the temperature of the wall is higher than the external temperature and indoor temperature. If the external wall insulation technology is used, the wall heat flow to the external environment, that is, the heat can not be dissipated to the outdoor, to a large extent, this part of the heat will flow to the indoor, increasing the indoor air conditioning cooling load, thus anti-energy saving phenomenon! In the summer of refrigeration, the wall absorbs a certain amount of heat during the daytime due to its strong heat storage characteristics, and increases with the increase of the thickness of the insulation layer. In the same way, the temperature of the external wall is higher than the ambient temperature and indoor temperature. The heat flow of the wall no longer single flows from outdoor to indoor, and the heat flow is both indoor and outdoor.

In conclusion, with the increase of indoor calculation temperature during the heating period, the external insulation thickness has better energy saving effect on the anti-energy saving effect on the air conditioning period in summer. The indoor calculation temperature during the heating and air conditioning period has a great influence on the energy saving effect evaluation of the intermittent energy use mode. Around should adjust measures to local conditions, reasonable adjustment of heating, air conditioning period calculation temperature, at the same time to fully consider the

indoor thermal environment and human comfort requirements, of course, also should pay attention to the external wall insulation layer is not the thicker the better (the smaller the heat transfer coefficient, the better), this is conducive to the building energy saving effect, also conducive to correctly evaluate external wall insulation technology in hot summer cold winter area energy saving effect.

In short, on the basis of the above analysis, continue through Design Builder building energy consumption simulation software, the typical representative city hot winter area in Hangzhou a building deep step analysis, studied the industry under the condition of the standard of external wall insulation thickness on building energy saving effect, and analyzed the calculation of heating and air conditioning indoor temperature, heating and air conditioning period calculation period, using mode of single factors and multiple factors on the thickness of the building energy saving effect, the following conclusions:

Under the industry standard, the energy consumption of air conditioning in summer and winter heating period are decreasing with the external insulation thickness of external wall (heat transfer coefficient), that is, with the increase of external insulation thickness (the decrease of heat transfer coefficient), the energy consumption of air conditioning in summer and the energy consumption of winter heating period are reduced;

With the decrease of indoor calculation temperature during heating period, the effect of external wall insulation thickness during winter heating period; with the decrease of indoor calculation temperature during air conditioning period, the effect of external wall insulation thickness on energy saving during air conditioning period in summer. The indoor temperature calculation during the heating and air conditioning period has a great impact on the evaluation of the building energy saving effect of the external insulation thickness of the external wall;

The division of the heating period and the calculation period of the air conditioning period has a great influence on the energy saving effect of the external wall insulation building. The calculation period of heating and the calculation period of air conditioning are shortened by 27 days and 54 days respectively, and the building energy saving effect

of external wall insulation in winter is weakened; but the calculation period of air conditioning is basically similar, so the building energy saving effect of external wall insulation in summer is basically similar. For the annual building energy consumption, the building energy saving effect of external wall insulation is weakened with the shortening of the heating calculation period;

The energy use in hot summer and cold winter is completely different from that in northern China, and has the characteristics of intermittent room. After the actual simulation calculation, although the annual power saving rate in the intermittent energy mode is smaller than that in the continuous energy mode, but the total annual total energy consumption is far less than the continuous energy mode;

In the intermittent energy use mode, with the increase of indoor calculation temperature during the heating period, the effect of external wall insulation thickness is better and better in the winter, but the summer. In some thickness of the insulation layer, there is an anti-energy saving critical air conditioning period calculation temperature. Before this critical temperature, the building cooling in the corresponding insulation mode is energy saving. If a single exceeds the critical temperature, the corresponding insulation mode of the building cooling in the corresponding insulation mode is anti-energy saving! The indoor calculation temperature during the heating and air conditioning period has a great influence on the energy saving effect evaluation of the intermittent energy use mode. The EPS insulation thickness of 20mm to 140mm selected in this paper is increased by 20mm, and the corresponding calculated temperature of anti-energy saving critical air conditioning period is 27.1℃ and 27.3℃ respectively.27.3℃, 27.2℃, 27.3℃, 27.4℃ and 27.3℃.

2.3 Energy saving effect of external wall insulation buildings under different solar radiation

2.3.1 Simulation model

This chapter is based on the analysis of solar radiation on the indoor thermal environment and energy saving effect of buildings through the outer envelope (exterior

wall). The building model was simplified, and a small room with 2.5m depth, 3.0m depth and 2.8m clear height was selected. Only the outer wall has no inner wall. At the same time, in order to eliminate the test error caused by heat transfer on the ground and roof as much as possible, 60mm thick EPS insulation board was added to the floor of the simulation model and the roof. See Table 2.28 for the thermal parameters and structures of each envelope structure.

Table 2.28 – Structure and heat transfer coefficient of the envelope structure

exterior-protected construction	Main structure of the envelope structure (from inside to outside)	coefficient of heat transfer $W/(m^2 \cdot k)$
roofing	20mm cement sand'slurry + 120mm reinforced concrete + 20mm cement mortar leveling + 60mmEPS insulation board + 10mm cement mortar	0.366
baseboard	20mm, cement mortar + 120mm reinforced concrete + 60mmEPS insulation board + 10 mrn cement mortar	0.401
No insulation	10mm, cement mortar + 240mm porous brick wall + 10mm cement mortar	1.508
exterior window	10mm, cement mortar + 240mm porous brick wall + 30mmEPS insulation board 10mm, cement mortar	0.633
door	Double-layer hollow ordinary white glass, radiation transmittance (SHGC) is 0.7	2.8

2.3.2 Simulated boundary conditions

In this chapter, the simulated building is a typical city of hot summer and cold winter. According to the design standard of hot summer and cold winter energy, the design temperature of indoor heating in winter is 18K; the calculated temperature of air conditioning in summer is 26°C; the air ventilation times should be 1.0 / h; the heating and air conditioning equipment are household air source heat pump air conditioners, and the rated energy efficiency ratio during refrigeration should be 2.3, and the rated energy efficiency ratio should be 1.9; the average indoor heat intensity is 4.3W / m^2; Continuous energy use for 24 hours a day.

The energy saving effect of annual buildings is obtained on the basis of time by time, day by day and month by month, and has a close relationship between each other. To this, according to the hot summer and cold winter area energy saving design standard heating calculation period for the year 1 December solstice following February 28, air conditioning calculation period for the June 15 solstice on August 31, in the two

calculation period selected the high and low two typical radiation intensity of the sun, based on high and low two solar radiation typical conditions, building daily different energy mode of energy saving effect research analysis. According to the measured data of 270 ground meteorological stations (including air temperature, humidity, solar radiation, wind speed and direction, etc.) collected by the Meteorological Data Room of the Meteorological Information Center of China Meteorological Administration from 1971 to 2003 by Tsinghua University, Obobtained the typical meteorological year data of Hangzhou in 2002, Select the one-day hourly radiation intensity of the typical meteorological year air conditioning calculation period and heating calculation period, Organize the daily maximum radiation and average radiation in the corresponding calculation period, In order to select the typical radiation days of the air conditioning calculation period and the heating calculation period, The selection results are as follows: ① Heating calculation period: the typical solar day of high radiation intensity is December 24,2002, The typical solar day of low radiation intensity is February 6,2002; ② Air-conditioning calculation period: the typical solar day of high radiation intensity is July 28,2002, The typical solar day of low radiation intensity is July 11,2002.

2.3.3 Influence of solar radiation on the refrigeration effect of buildings

Under different typical solar radiation days, the surface temperature change of no insulation and external insulation under continuous cooling conditions in summer, and the energy use of small rooms are shown in Figure 2.9 Figure 2.12. Hangzhou in hot summer and cold winter, monthly average solar radiation in summer is similar, but from FIG. 2.9 and Figure 2.11, we can see that the single-day solar radiation in this area changes significantly. The average radiation intensity, highest radiation intensity and maximum radiation duration are far larger than the typical day of low solar radiation, and the difference is more than two times. And, whether in the high solar radiation typical day, or in low solar radiation typical day, room temperature temperature trend is closely associated with the fluctuation trend of the solar radiation, when the solar radiation gradually increase, outdoor temperature gradually rise, the solar radiation

intensity reached the peak, outdoor temperature also reached the highest value in this range.

On the typical day of high solar radiation, because of the continuous cooling temperature, the indoor temperature of the small room without insulation and external insulation is controlled at the cooling set temperature of 26℃. The internal surface temperature of the external insulation wall is always lower than that of the external insulation wall. The internal stress of the external insulation wall is small, and the energy consumption of the external insulation room is low, which reflects the energy saving effect of the external insulation wall, which is also reflected in Figure 2.10. During the 6:0015:00 period, as the solar radiation gradually increases from zero to the peak, the internal stress of both external walls is increasing, that is, the energy consumption of air conditioning is increasing. At the same time, the external surface temperature of the external insulation wall and the external surface wall temperature of the external insulation wall is first small and then large, and the gap is gradually increasing. The external surface temperature of the external insulation wall rises from 26.96℃ to 41.26℃, and the external surface temperature of the external insulation wall rises from only 27.67℃ to 37.82℃, which also reflects the effect of external thermal insulation. At 15:0019:00 period, as the solar radiation decreases from the peak to 0, the temperature of the external surface of the external insulation wall is greater than that of no insulation. This is because the external insulation wall hinders the diffusion of the internal heat of the external wall, while the internal heat of the external insulation wall is released, making the decrease of the external surface temperature slowly. In the period of no solar radiation from 19:00 to 6:00, the outdoor temperature is higher than that of the external wall, but it is lower than that of the external wall without insulation. This is also because the external insulation of the external wall hinders the heat transfer of the wall itself.
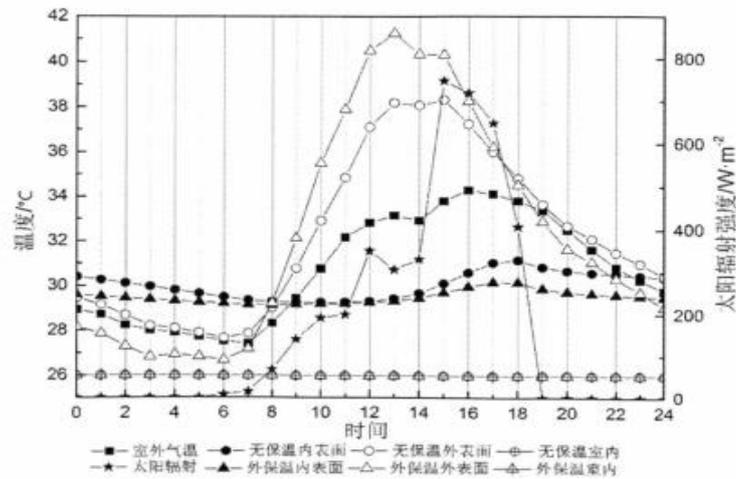
Figure 2.9 – External wall temperature change on a typical day of high solar radiation in summer
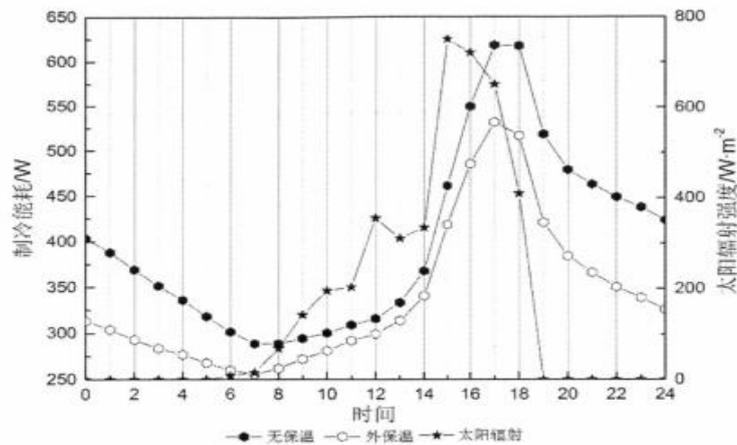
Figure 2.10 – Change of air conditioning refrigeration energy consumption of high solar radiation in summer

On low solar radiation days, the duration of solar radiation is 11:0019:00,5 hours less than high solar radiation days; outdoor temperatures are also lower than high solar radiation days. Because of the continuous refrigeration of the small room with external air conditioning, the indoor temperature is controlled at the set temperature of 26°C. No insulation of the small room air conditioning refrigeration energy consumption is 0, air conditioning does not work! This is because the outdoor temperature is low during the typical day of low solar radiation. When the small house passes the heat transfer of the wall itself, the temperature of the surface of the wall reaches the dynamic balance is lower than the set temperature of indoor air conditioning, so it does not need the

external air conditioning to assist refrigeration. As can also be seen from Figure 2.11, the internal surface temperature of the external insulation wall is always lower than that of the external insulation wall, and very close to the indoor air temperature, which is 26°C lower than the set temperature of the air conditioning.
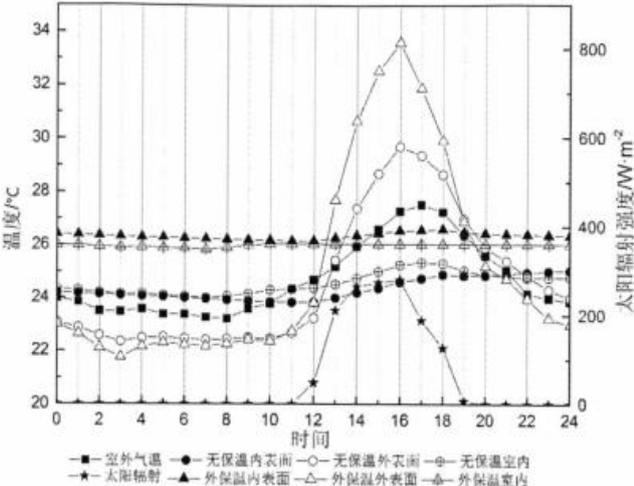
Figure 2.11 – Change of the internal surface temperature of the external insulation wall in summer

The small room without insulation does not need air conditioning refrigeration, and the external insulation wall has air conditioning refrigeration requirements, which is also reflected in Figure 2.12. During the 11:0016:00 period, as the solar radiation gradually increases from 0 to the peak, the internal stress of the external insulation wall is increasing, that is, the energy consumption of air conditioning is increasing. At the same time, the external surface temperature of the external insulation wall and the external surface temperature of the external insulation wall is first small and then large, and the gap is gradually increasing. The external surface temperature of the external insulation wall rises from 22.73°C± to 33.56°C, and the external surface temperature of the external insulation wall rises from only 22.66°C to 29.63°C, which also reflects the effect of external thermal insulation. At 16:00-19:00 time, as the solar radiation from peak to 0, external insulation external surface temperature drop than no insulation external surface temperature, this is because external insulation wall hindered external wall internal heat diffusion, and no heat insulation wall internal heat release, makes the

external surface temperature drop slowly. In the period of no solar radiation from 19:00 to 11:00, it can be seen that the external surface temperature of the external insulation wall is lower than that of the external insulation wall, and the temperature of both is lower than the air temperature, for the same reason as 16:00-19:00.

Figure 2.11 - External wall temperature change on typical days of low solar radiation in summer
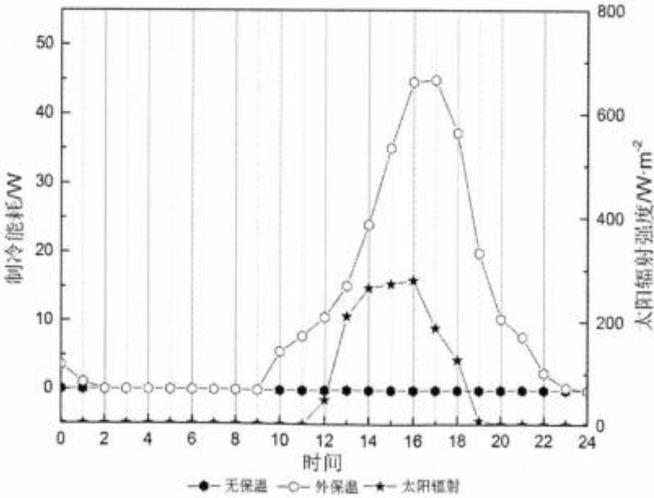
Figure 2.12 – Change of air-conditioning refrigeration energy consumption in typical days of low solar radiation in summer

2.3.4 Influence of solar radiation on the building heating effect

Under different typical solar radiation days, the surface temperature change in the south without insulation and outside insulation wall and the energy use in small rooms are shown in Figure 2.13 Figure 2.16. Hot summer and cold winter areas of Hangzhou winter monthly solar radiation, but from figure 2.13 and figure 2.15 know the region of daily solar radiation changes significantly, high solar radiation typical daily average radiation intensity, highest radiation intensity is far larger than low solar radiation, individual difference reached more than two times, but the solar radiation duration is shorter than low solar radiation. On the typical days of high and low solar radiation, the fluctuation trend of room temperature is closely related to the fluctuation trend of solar radiation. When the solar radiation gradually increases, the outdoor temperature

gradually rises correspondingly, and when the intensity of solar radiation reaches the peak, the outdoor temperature is also at this highest value in this range.

On the typical day of high solar radiation, the indoor temperature of the small room is controlled at the set temperature of 18℃. At 8:00-14:00 time, as the solar radiation from zero to peak, external insulation wall internal surface temperature has been higher than no insulation wall internal surface temperature, external insulation wall internal stress, external insulation small room air conditioning refrigeration energy consumption is low, embodies the energy saving effect of external insulation wall, it also reflected in figure 4.5. The internal stress of both external walls is decreasing, that is, the energy consumption of air conditioning is decreasing. At the same time, the external surface temperature of the external insulation wall and the external surface wall temperature of the external thermal insulation wall is small and then large, and the gap is gradually increasing. The external surface temperature of the external insulation wall rises from 4.29℃ to 48.66℃, and the internal temperature of the external insulation wall only rises from 7.93℃ to 37.24C, which also reflects the effect of external thermal insulation. At 14:0017:00, the internal surface temperature of the external insulation wall is higher than that of the external insulation wall, and the energy consumption of air conditioning in small rooms with external insulation is low. With the decrease of solar radiation from peak to 0, the temperature of the external surface of the external insulation wall drops more than that of no insulation. This is because the external insulation wall hinders the diffusion of the internal heat of the external wall, while the internal heat of the external insulation wall is released, making the temperature of the external surface drop slowly. During the period of no solar radiation at 17:006:00, the internal surface temperature of the external insulation wall is similar to that of the external wall without insulation; the outdoor temperature is lower than that of the external wall and higher than that of the external insulation wall. This is because the external wall insulation hinders the indoor heat transfer outward, and when the small room passes through the external wall heat transfer and outdoor environment, part of the air conditioning heating, energy consumption is used to maintain the temperature of the external surface of the external

wall, so that the total energy consumption of the small house in this period is higher than that of the small house with external wall insulation.
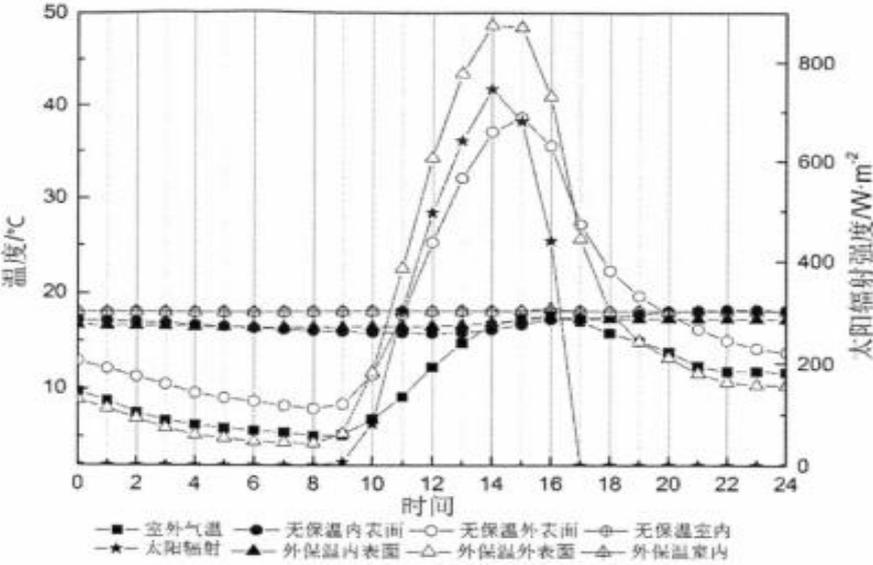
Figure 2.13 - Change of external wall temperature on a typical day of high solar radiation in winter
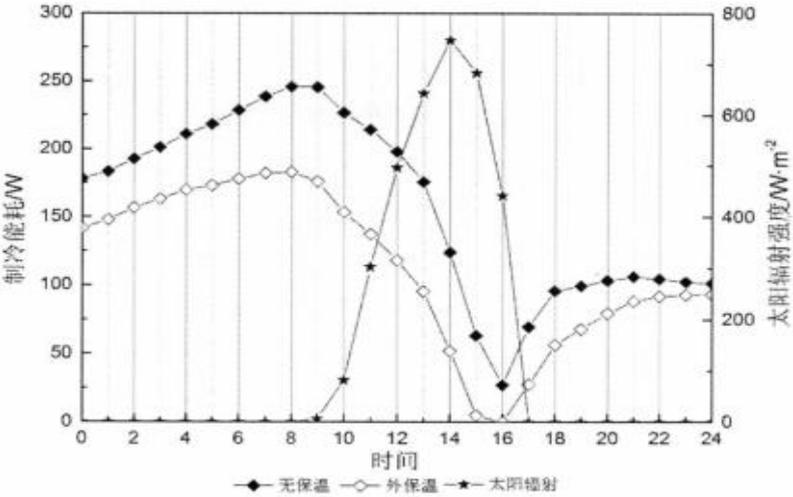
Figure 2.14 - Change of air conditioning with high solar radiation in winter

On a typical day of low solar radiation, the indoor temperature of the small room is controlled at the set temperature of the refrigeration of 18°C.

The internal surface temperature of the external insulation wall is always higher than that of the external insulation wall. The internal stress of the external insulation wall is

small, and the energy consumption of the air conditioning in the small room of external insulation is low, which reflects the energy-saving effect of the external insulation wall, which is also reflected in Figure 4.8. During the 8:0012:00 period, as the solar radiation gradually increases from zero to the peak, the internal stress of the external insulation wall is decreasing, that is, the energy consumption of air conditioning is decreasing. At the same time, the external surface temperature of the external thermal wall of the external thermal wall and the external surface temperature of the external thermal wall is small and then large, and the gap is gradually increasing. The external surface temperature of the external thermal wall rises from 2.53℃ to 8.7℃, and the external surface temperature of the external thermal wall rises from 3.79℃± to 7.28℃, which also reflects the effect of external heat insulation. At 12:0019:00 period, as the solar radiation decreases from the peak to 0, the temperature of the external surface of the external insulation wall is greater than that of no insulation. This is because the external insulation wall hinders the external diffusion of the external wall, while the internal heat of the external wall is released, making the temperature of the external surface decrease slowly. At 19:008:00 no solar radiation time, visible external insulation surface temperature is lower than no external insulation external surface temperature, because the external wall insulation hindered indoor heat transfer, and no insulation room through wall heat transfer and outdoor environment to achieve heat balance, part of the air conditioning heating energy consumption used to maintain the temperature of the external surface.
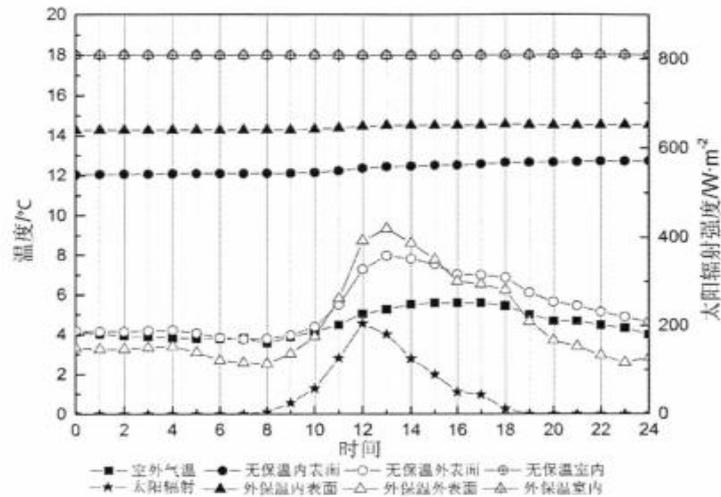
Figure 2.15 – Change of external wall temperature on low solar radiation days in winter
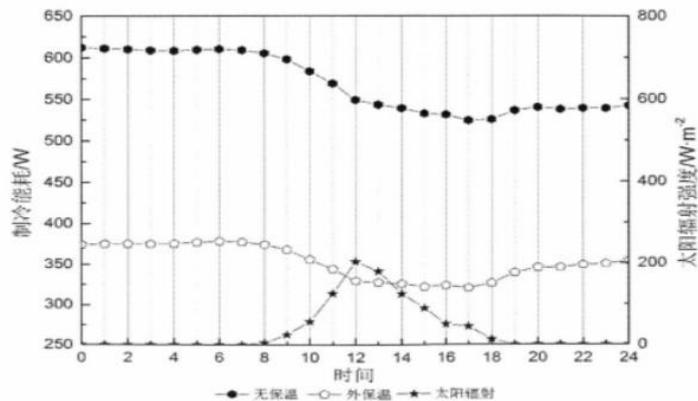
Figure 2.16 - Change of air conditioning refrigeration energy consumption of low solar radiation in winter

2.3.5 Summary

In this section, on the energy saving effect of different solar radiation in hot summer and cold winter, it is found that the solar radiation has great influence on the cold and thermal load of the external wall, which thus affects the building energy consumption in the typical days of high and low solar radiation in summer, but it is more energy consuming than the building without the insulation of low solar radiation in summer. In summer, the stronger the solar radiation, the higher the energy consumption of air conditioning; in winter, the stronger the solar radiation, the lower the heating energy

consumption.

2.4 Experimental study on the foot ruler of external wall insulation building based on solar radiation

This section will control the unique advantages of the main related climate simulation parameters through experiments, according to the current industry standards, test the insulation and energy saving effect of building external walls under different solar radiation intensity, and analyze the mechanism of the influence of solar radiation on building energy consumption through external walls.

2.4.1 Test and test preparation

2.4.1.1 Introduction to the laboratory

This experimental study was selected in the real environment laboratory of Baoyi Group Research Institute, namely the full foot all-weather Environmental laboratory. The real environment laboratory is imported from Japan and Germany with complete equipment: advanced heating unit, dehumidifier unit, air conditioning unit, sunshine equipment (Fig. 2.17), wind and rain equipment, ventilation equipment and general control system (Figure 2.18). The main climate parameters are controlled by adjusting the equipment, as follows: ① relative humidity control range: 2090%; ② air temperature control range: -3060°C; ③ rainfall control range: 110-300 mm; wind speed control range of ④ wind simulation device: 450m / s; ⑤ sunshine intensity control range: 0~1000W / m$^{2\circ}$
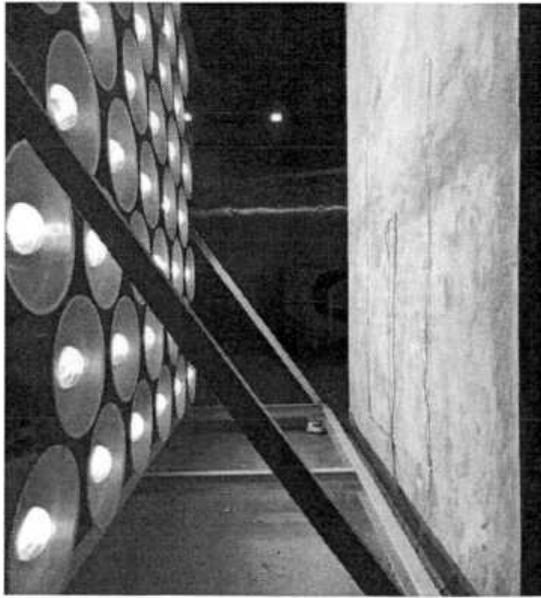
Figure 2.17- Sunshine equipment   Figure 2.18- The General Control System

Relying on this set of advanced equipment, through the control of the above climate parameters can simulate the all-weather weather in all regions of China outdoor climate, this test house built in the real environment laboratory, can be a comprehensive test of its thermal performance.

2.4.1.2 Test building information

The carrier of this test is a small house with 2.5m, 3.0m deep and clear height of 2.8m, directly built in the real laboratory. The relevant structural information is shown in Figure 2.19 Figure 2.24: ①0.78mx2.1m External wooden door; ② 1.39m wide xl.46m high flat open aluminum alloy window, double insulating glass structure of white glass + air layer + white glass; ③ 240 mm thick sintered solid brick wall with 10 mm thick cement mortar; ④ 4-hole prefabricated floor slab, single size of 500mmx3000mmx 120mm, double-sided 10 thick cement mortar; ⑤ lays 60mm thick extruded polystyrene board above the floor to eliminate the test error caused by ground heat transfer.

Figure 2.19 - Overall photos of the experimental vector
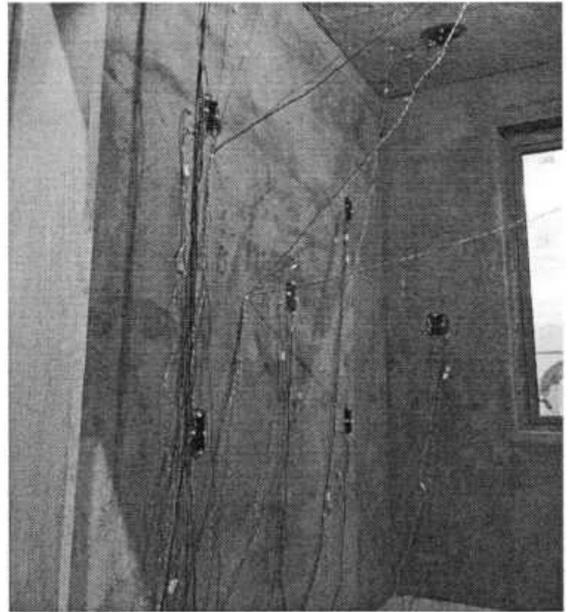
Figure 2.20 - Interior photograph
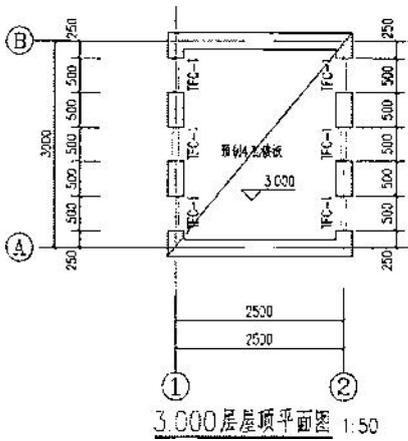
Figure 2.21 - The first floor plan
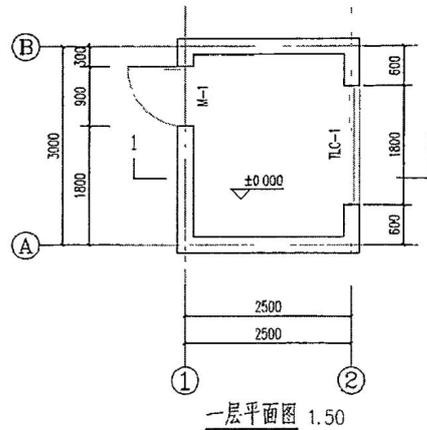
Figure 2.22 - Roof plan
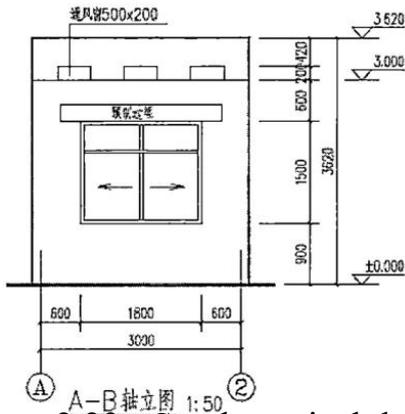
Figure 2.23 - South vertical drawing
3 South facade
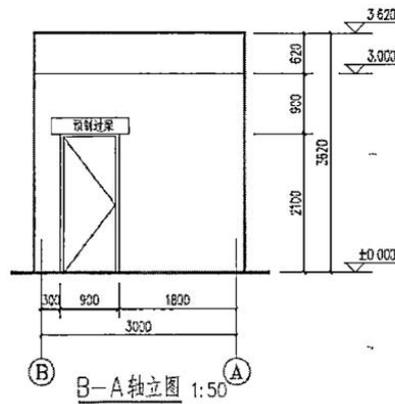
Figure 2.24 – North Elevation

2.4.1.3 Test and test system

(1) Test instrument

Record the relevant temperature, heat current density and radiation intensity by using the following instruments and sensors:

1 Jiantong Technology JTNT- -temperature and heat flow density dynamic data acquisition instrument, 0.1℃ measurement temperature resolution, 0.1 W / m^2 Measurement of heat flow accuracy;

12 Jiantong Technology JTCO 9 temperature sensor, ± 0.5℃ accuracy, temperature measurement range-20-100℃;

13 technology JTC08A heat flow sensor, 4% accuracy, heat flow measurement range 02000 W / m^2;

2 jiantong technology JTC03A radiation intensity sensor, 5% accuracy, 02000 W / m^2 Radiation intensity measurement range;

One multi-functional daily-mounted LR8400-21 dynamic data gathering instrument;

30 thermocouple temperature sensors, ± 0.5℃ accuracy, -200400℃: temperature measurement range;

1 daily PW3335 power meter, soil 0.15% accuracy;

13200W wall-mounted air conditioner.
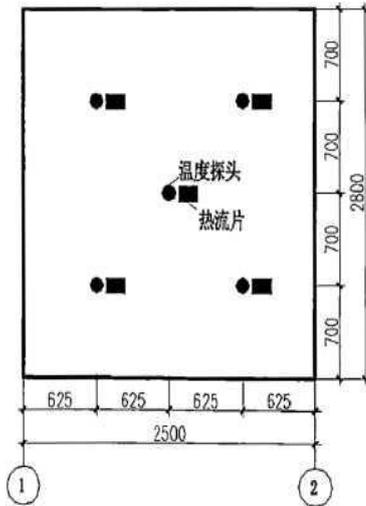
Figure 2.25 – Location layout of the east wall measuring points
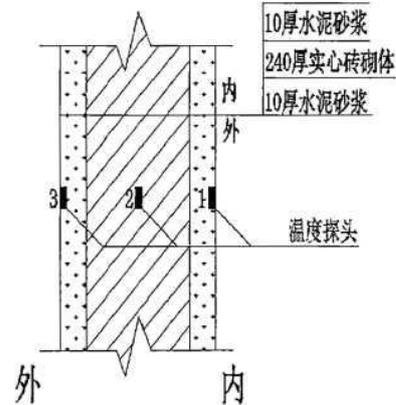
Figure 2.26 – Location diagram of wall temperature sensor

(2) Measurement point layout

As shown in Figure 2.25,5 measuring points are arranged on the east wall of the small house with 3 temperature sensors in the surface of the wall, the center of the wall, and the outer surface of the wall, as shown in Figure 2.26. Meanwhile, 1 heat flow sensor is attached on the inner surface of the east wall. In order to reduce the interference of solar radiation and air flow on the temperature probe of the wall surface and improve the accuracy of the wall temperature, the wall surface temperature sensors are specially buried at 1mm below the surface, that is, the surface is covered with 1mm thick cement mortar, as shown in Figure 2.27.

Figure 2.27 – Burdrawing of wall surface temperature probe

(3) Test principle

The equation of instantaneous heat current balance at steady state is as follows (2-1):

$$\emptyset_1 + \emptyset_2 + \emptyset_3 + \emptyset_4 + \emptyset_5 + \emptyset_6 = 0, \tag{2.1}$$

where $\emptyset_1$-The transient heat flow strength of the internal wall of the external wall flowing into the room, with the indoor heat as positive;

$\emptyset_2$-The transient heat flow strength of the ceiling inner wall flowing into the room, and the indoor heat is positive;

$\emptyset_3$-The transient heat flow strength of the interior wall of the door flowing into the room, with the indoor heat as positive;

$\emptyset_4$-The transient heat flow intensity of the interior wall of the window flowing into the room, with the indoor heat as positive;

$\emptyset_5$-Due to the transient heat flow intensity of indoor and outdoor air infiltration into the room, the indoor heat is positive;

$\emptyset_6$-The transient heat current intensity caused by indoor work during the air conditioning period is positive for indoor heat.

The thermal equilibrium equation at the steady state is as follows (Formula 2.2):

$$Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 = 0, \tag{2.2}$$

Where Q_1-the heat of the inner wall of the external wall flowing into the room per unit time, and the indoor heat is positive;

Q_2-the heat of the ceiling wall flows into the interior per unit time, and the indoor heat is positive;

Q_3-Heat from the inner wall of the door flows into the room per unit time, and the indoor heat is positive;

Q_4-per unit time, the heat of the window flows into the room, and the indoor heat is positive;

Q_5-Indoor heat permeated by indoor and outdoor air per unit time, and indoor heat is positive;

Q 6 The heat caused by air conditioning period within unit time, indoor heat is positive.

From equations 2-2 and 2-3, when the variable is only an integrated module of insulation decoration installed or not, the change of Ø 6 and Q 6 only depends on the change of Ø1 and Ø1 respectively. Thus, except for the assay Ø6 to directly calculate the consumption reduction ability of the thermal insulation decoration integration module, it can also be calculated by measuring the change of Ø1.

A heat flow sensor is set on the surface of the target wall to measure the heat exchange rate (heat flow strength) between the target wall and the room, and the consumption reduction rate of the external wall insulation module can be obtained. From the perspective of energy consumption, the power consumption of the air conditioner per unit time can be measured by the power meter.

2.4.2 Test working conditions and process

This experiment has 6 working conditions, including no radiation in summer, no radiation in summer, no strong radiation in summer, no radiation in winter, no radiation in winter and no strong radiation in winter. Table 2.29 specifies the outdoor temperature, outdoor relative humidity, solar radiation intensity and indoor control temperature values under the 6 working conditions.

Table 2.29 – Values of the parameters of each test condition

operating mode	Oat,℃	outside relative humidity,%	intensity of solar radiation, W/m^2	Indoor temperature control, ℃
There is no radiation in	35.5	80	0	25
Radiation in summer	35.5	80	175	25
Strong radiation in summer	35.5	80	350	25
There is no radiation in winter	0	75	0	18
Radiation in winter	0	75	175	18
Strong radiation in winter	0	75	350	18

2.4.2.1 Base group

Each test condition is continuous and uninterrupted, Without making any gap adjustment, The data recorder also keeps an uninterrupted recording, The recording

frequency is one once a minute, The test sequence is: no radiation condition in summer; Then there is the summer radiation working conditions; Back to the summer without the radiation condition, A duration of 12 hours, The purpose is to make the wall temperature field close to the steady state level under no radiation condition in summer; Finally, the summer strong radiation working conditions; After the summer working conditions have ended, Directly into the winter without radiation working conditions; Then came the winter radiation condition, Back to the no-radiation working condition in winter, alike, The purpose is to make the wall temperature field close to the steady state level under no radiation condition in winter; Finally, the strong radiation condition in winter. The standard of switching working condition is that the main related measurement parameters (external wall surface temperature, external wall thickness and center temperature, external wall surface temperature, external wall heat flow strength and air conditioner power) reach the steady state and continue above lh, and the next working condition is carried out after meeting the switching working condition.

2.4.2.2 Test group

After the experiment of the base group, the wall of the base group is constructed with the insulation decoration integrated board. The thermal system can be shown in Table 2.30, the construction photos are shown in Figure 2.282.30, and the experiment order and operation of the experiment group are consistent with those of the base group (the radiation conditions in winter are cancelled due to objective conditions, but there is no great impact on the test conclusion).

Table 2.30 - Thermal parameters of thermal insulation and decoration integrated board (fluorocarbon resin board series)

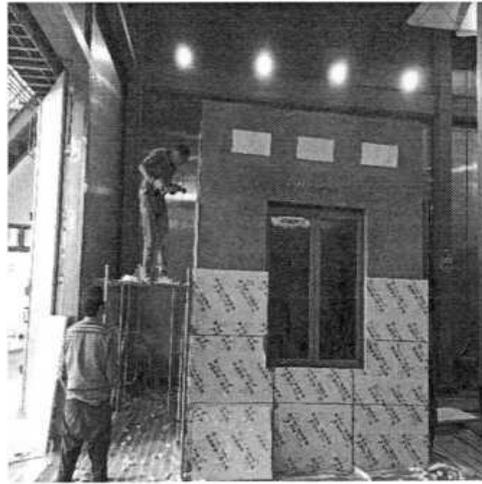| metric	Density, kg/m^3	Thermal conductivity,W/(mK)	Water resistance strength, MPa	Anti-bending load, N
parameter	15	0.024	0.19	1816

Figure 2.28 - Construction Drawing of Integrated Board

Figure 2.29 - Details of Construction Drawing

Figure 2.30 – Actual overall completion drawing

On the basis of the temperature probe on the inner, middle and outer surface of the external wall of the reference group, the temperature probe is also attached on the outer surface of the module after pasting the integrated insulation decoration module, so that the temperature gradient data can be obtained in the direction of wall thickness. The corresponding analysis of these temperature gradient data and the reference group can make a qualitative judgment, and the consumption reduction effect of the external wall insulation module can also be obtained. Although this analysis means is qualitative but not quantitative, it is more intuitive and persuasive, and can explain the principle of

consumption reduction of external wall insulation technology.

2.4.3 Test results and analysis

2.4.3.1 Comparison of summer working conditions

In the reference group and experimental group, the external wall heat flow density, external wall surface temperature, ambient temperature, external wall center temperature, external wall internal surface temperature and indoor temperature are shown in Figure 2.31 and 2.32.

(1) Comparison of ambient temperature and indoor temperature

According to Figure 2.31, the ambient temperature and indoor temperature of the reference group are dynamically stable at about 35.5℃ and 25℃ respectively, and from Figure 2.32, the ambient temperature and indoor temperature of the experimental group are dynamically stable at about 36℃ and 24℃ respectively. The outdoor temperature fluctuation of base group and experimental group is less than 0.5℃; due to the starting temperature and standby temperature of air conditioning, the indoor temperature has obvious regular fluctuation and the fluctuation range meets the requirements, less than 1.5℃. The ambient temperature and indoor temperature of the two groups are within a reasonable range, which can guarantee the comparison of the thermal performance difference between the reference group and the test group at the subsequent reach.
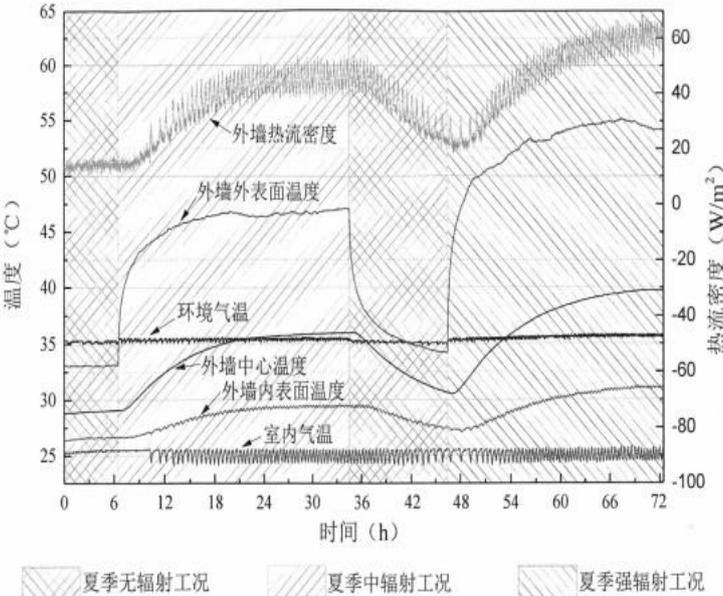
Figure 2.31 - Change of measured values of thermal parameters over time under each condition in summer
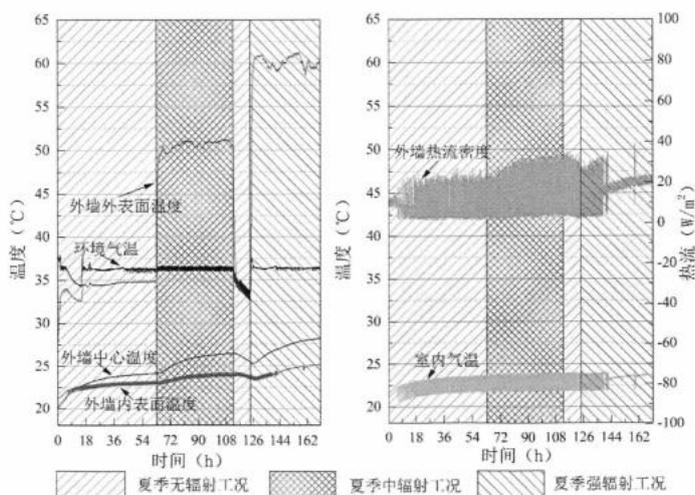

Figure 2.32 - Time change of measured thermal parameters under each condition in the test group in summer

(2) Comparison of the external surface, central temperature and internal surface temperature of the external wall

1) External surface temperature of the external wall

According to Figure 2.31, the duration of non-radiation condition in the base group is 06h27min, the external surface temperature of the external wall reaches the steady state at about 3h, and the steady state value is 33°C; the duration of moderate radiation condition in summer is 6h27 min~34h 30min, when the solar radiation intensity is changed from 0 W / m². Up to 175W / m²The external surface temperature rises rapidly immediately, and reaches the steady state at 24 h, the steady state value is 46.8°C; The duration of strong radiation condition in summer is 46 h 20 min 72 h 10 min, and the change trend is consistent with the moderate radiation condition in summer. The external surface temperature reaches the steady state at 66h, and the steady state value is 54.6°C.

According to Figure 2.32, the duration of no radiation condition in the test group is 058 h. The surface temperature of the external wall reaches the steady state at about 54h

than the base group, and the whole heat transfer process is more slow. The steady state value is 34.8℃, about 2℃ above the outdoor temperature error and the integrated insulation decoration, which is to reasonable range. The moderate radiation condition is 58h 110h in summer, when the solar radiation intensity is from 0 W / m²Up to 175 W / m2, the external surface temperature of the external wall responds immediately and rises rapidly, reaching the steady state at 108 h. The steady state value is 50.9℃; The duration of the strong radiation condition is 110h 166h, and the change trend is consistent with the moderate radiation condition in summer. The external surface temperature reaches the steady state at 162h, and the steady state value is 59.5℃.

2) Center temperature of the external wall

According to Figure 2.31, the duration of non-radiation condition in the base group is 06 h27min, the central temperature of the external wall reaches the steady state at about 3h 50 min, and the steady state value is 29℃; the duration of moderate radiation condition in summer is 6h 27 min 34 h 30 min, when the solar radiation intensity is changed from 0 W / m². Up to 175W / m², The central temperature of the external wall has hysteresis relative to the external surface, with a lag time of about 50 minutes and reaches the steady state at 24h50 min. The steady state value is 35.8℃. The duration of strong radiation condition in summer is 46h 20 min 72 h 10 min, and the change trend is consistent with the moderate radiation condition in summer. The central temperature reaches steady state at 66 h 50 min, and the steady state value is 39.7℃.

According to Figure 2.32, the duration of non-radiation condition in the test group in summer is 058 h, the central temperature of the external wall is about 55 h 40 min, and the time is longer than that of the base group, that is, the whole heat transfer process is more slow, the steady state value is 23.8℃, and its good heat insulation performance is fully reflected again; the duration of medium radiation condition in summer is 58 h 110 h, when the solar radiation intensity is changed from 0 W / m²Up to 175W / m², The central temperature of the external wall has hysteresis relative to the external surface temperature response. The lag time is about 100 minutes and reaches steady state at 109 h 40 min. The steady state value is 26.4C; the duration of strong radiation condition in

summer is 110 h-166 h, and the change trend is consistent with the moderate radiation condition in summer. The central temperature reaches steady state at 163 h 40min and the steady state value is 28.2°C.

3) Internal surface temperature of the external wall

According to Figure 2.31, the duration of non-radiation condition in summer is 06h27min, the internal surface temperature of the external wall reaches the steady state at about 4h 40min, and the steady state value is 26.6°C; the duration of moderate radiation condition in summer is 6h 27min 34h 30min, when the solar radiation intensity is changed from 0 W / m²Up to 175W / m²The internal surface temperature of the external wall has hysteresis relative to the external surface, with a lag time of about 100 minutes and reaches the steady state at 25 h 40 min, the steady state value is 29.4°C; the duration of strong radiation condition in summer is 46 h 20 min 72 h 10 min, the change trend is consistent with the moderate radiation condition in summer, the internal surface temperature reaches steady state at 67 h 40 min, and the steady state value is 31.1°C.

According to Figure 2.32, the duration of no radiation condition in the test group is 058 h, the internal surface temperature reaches the steady state at about 56 h 10 min, and the time is longer than that of the base group, that is, the whole heat transfer process is more slow and the steady state value is 22.8°C, which fully reflects good heat insulation performance; the duration of moderate radiation condition in summer is 58 h 110 h, when the solar radiation intensity is increased from 0 W / m2 to 175W / m²The internal surface temperature of the external wall has hysteresis relative to the external surface temperature response. The lag time is about 130 minutes and reaches the steady state at 110h 10 min, and the steady state value is 23.8°C. The duration of the strong radiation condition in summer is 110h 166 h, and the change trend is consistent with the moderate radiation condition in summer. The internal surface temperature reaches the steady state at 164 h 10 min, and the steady state value is 25.2°C.

In conclusion, the steady state value of external wall temperature field (including ambient temperature, external wall surface temperature, central temperature of external

plugging, external wall internal surface temperature and indoor temperature) under the reference group and test group is drawn into Fig. 2.33 and Figure 2.34. Whether benchmark group or test group, the test condition switch from no radiation to strong radiation, in the process, due to the increase of the radiation intensity, the temperature of the amplitude, through the wall heat transfer, and outer wall center, external wall internal surface temperature is gradually improved, namely the wall inside, temperature stress rose sharply, eventually lead to through external wall heat conduction into indoor heat rise, prompting air conditioning equipment for air conditioning refrigeration.

Comparative reference group: when the center temperature of the no radiation condition and the inner surface temperature of the test group decreased by 5.2℃ and 3.8℃ respectively; under the medium radiation condition in summer, the center temperature of the outer wall and the inner surface temperature decreased by 9.4℃, 5.6℃ respectively, the center temperature decreased by 11.5℃ and 5.9℃ respectively; with the increase of radiation intensity, the center temperature of the outer wall and the inner surface temperature decrease value increased, which fully verifies the good heat insulation performance of the outer wall insulation technology in summer.

(3) Comparison of external wall heat flow

According to Figure 2.31, the duration of the non-radiation working condition of the reference group in summer is 06h27min, and the heat flow of the external wall reaches the steady state at about 3h, and the steady state value is 14.1 W / m^2; The duration of the moderate radiation condition in summer is 6h27 min 34h 30min, when the solar radiation intensity varies from 0 W / m. Up to 175W / m^{2}The surface temperature of external wall heat flow responds immediately and reaches steady state at 24h, and the steady state value is 45.2W/m2; the duration of strong radiation condition in summer is 46 h 20 min 72 h 10 min. The change trend is consistent with the moderate radiation condition in summer. The internal surface temperature reaches steady state at 66h, and the steady state value is 61.2 W / m^2。

As shown in Figure 2.32, the duration of no radiation condition in the test group is 058h, and the heat flow of the external wall reaches the steady state at about 54h. The

time to reach the steady state is longer than that of the base group, that is, the whole heat transfer process is more slow, and the steady state value is 7.9W / m^2, Its good thermal insulation performance is fully reflected; the duration of moderate radiation condition in summer is 58 h 110h, when the solar radiation intensity is increased from 0 W / time to 175W / m^2, The external wall heat flow responded immediately and reached the steady state at 108h with a steady state value of 13.2W/m^2; The duration of the strong radiation condition in summer is 110h-166 h, and the change trend is consistent with that of the medium radiation condition in summer. The heat flow reaches the steady state at 162 h, and the steady state value is 22.1 W / m^2。

In conclusion, the steady state values of the three summer conditions of the reference group and the test group are drawn in Figure 2.33 and Figure 2.34. No matter the base group or the test group, in the process of switching the test condition from no radiation to strong radiation, due to the increase of radiation intensity, the heat flow density of the external wall also gradually increases, and the increased value is because of the increased solar radiation intensity. It can be seen that the greater the solar radiation intensity, the higher the temperature stability value of the external surface of the external wall, the more heat into the interior through the external wall, the greater the air conditioning load, and the higher the energy consumption.

Comparison reference group: under the no radiation condition in summer, the external wall heat flow of the test group decreased by 6.2W / m^2; In the summer medium radiation condition, the heat flow of the test group decreased by 32W / m^z; Under strong radiation condition in summer, the heat flow of the test group decreases by 39.1W/m2; with the increase of radiation intensity, the decrease value of heat flow of the external wall is greater, which shows the good heat insulation performance of external insulation technology in summer.
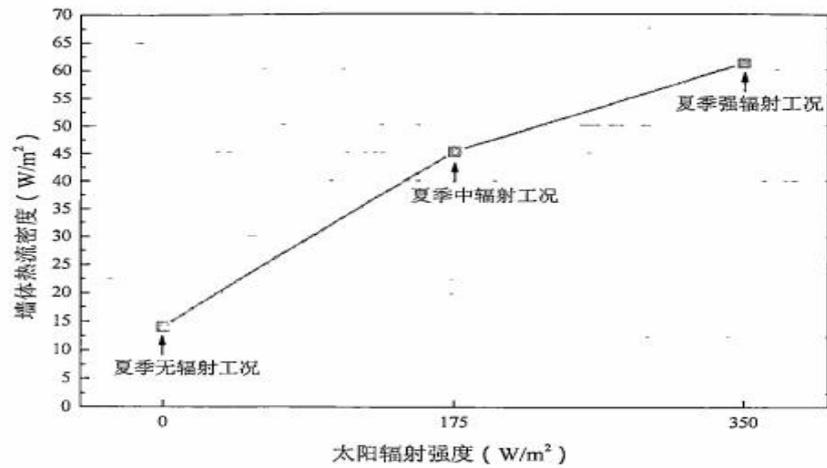
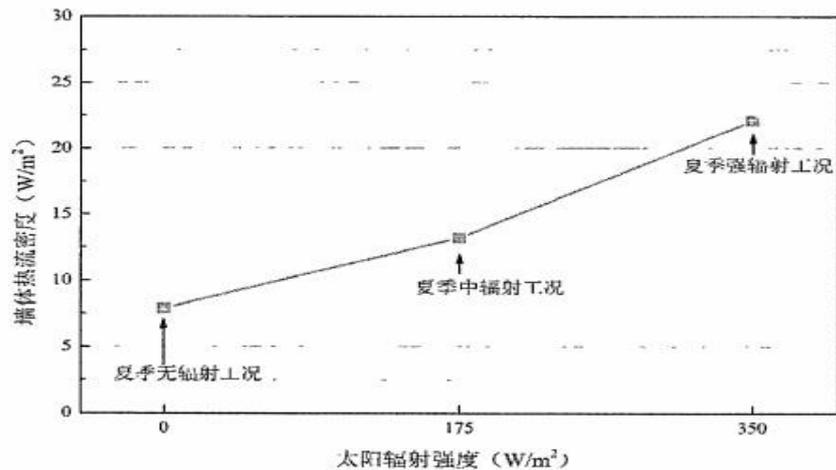Figure 2.33 - External wall heat flow steady-state value of the reference group in summer

Figure 2.34 - Steady-state value of external wall heat flow under each working condition in summer

(4) Energy consumption comparison

By reading the air conditioning power meter, get Figure 2.35. The energy consumption of air conditioning in the base group is 257 wh, 318 wh and 382 wh under strong radiation conditions in summer, 257 wh, 318 wh and 382 wh, while the corresponding energy consumption of the test group is 200 wh, 223 wh and 254wh, respectively, and the decrease of air conditioning energy consumption is more than 10%.
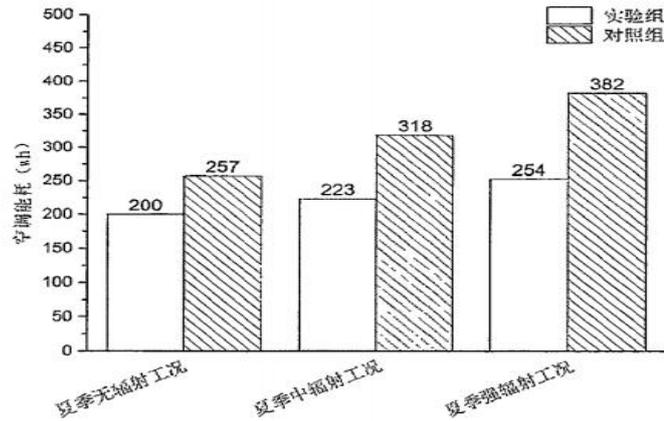
Figure 2.35 - Comparison of air conditioning energy consumption in summer working conditions between base group and test group

2.4.3.2 Comparison of winter working conditions

In the reference group and experimental group, the external wall heat flow density, external wall surface temperature, ambient temperature, external wall center temperature, external wall internal surface temperature and indoor temperature are shown in Figure 2.38 and 2.39.

(1) Comparison of ambient temperature and indoor temperature

According to Figure 2.36, the ambient temperature and indoor temperature of the reference group are dynamically stable at 0C and 18°C respectively, and from Figure 2.37, the ambient temperature and indoor temperature of the experimental group are dynamically stable at 0C and 18.5°C respectively. The outdoor temperature fluctuation range of the base group and the experimental group is less than 0,5°C; due to the starting temperature and standby temperature of the air conditioner, the indoor temperature fluctuates regularly, but the fluctuation range is less than 0.5. The ambient temperature and indoor temperature of the two at the steady state are within a reasonable range, which can guarantee the comparison of the thermal performance difference between the base group and the test group at the steady state.

Comparison of external surface, central temperature and temperature of inner surface
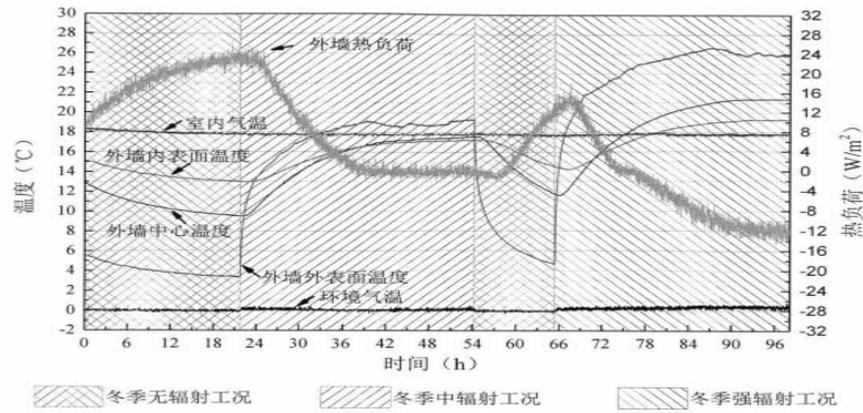
1) The exterior wall

Figure 2.36 - Change of measured values of thermal parameters with time under each working condition of the base group in winter
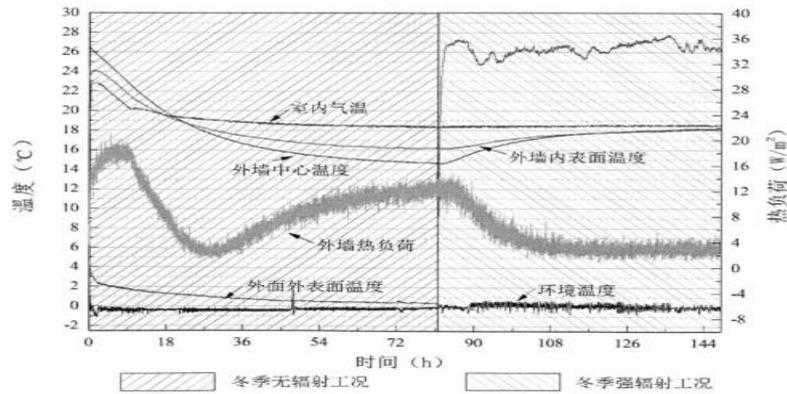

Figure 2.37 - Changes of measured thermal parameters over time under each winter condition in the experimental group

In Figure 2.36, the duration of non-radiation condition in the base group in winter is 021h45min, the external surface temperature reaches the steady state at about 21 h45 min, and the steady state value is 3.4C; the duration of moderate radiation condition in summer is 21 h 45 min 54 h, when the solar radiation intensity is from 0 W / m^2 Up to 175W / m^2 The external surface temperature responds immediately and rises rapidly, reaching the steady state at 51 h, the steady state value is 19.2°C; the duration of strong radiation condition in summer is 66 h 99 h, and the change trend is consistent with the moderate radiation condition in summer. The external surface temperature reaches the steady state at 96 h, and the steady state value is 25.9°C.

From Figure 2.37, due to some objective human factors in the middle of the test group in winter, the test experiment was interrupted during the working condition, and

the relevant parameters had corresponding fluctuations. However, given the obtained steady-state values of all parameters in winter without radiation conditions, this does not affect the quality of this experimental study. The duration of no radiation condition in summer is 081 h, the external surface temperature of the external wall reaches the steady state at about 80 h, and the time is longer than the base group, that is, the whole heat transfer process is more slow, its good insulation performance is fully reflected, the steady state value is 0.5℃; the duration of strong radiation condition in summer is 81 h 147 h, when the solar radiation intensity is changed from 0 W / m²Up to 350W / m², The external surface temperature immediately responded and rose rapidly, reaching the steady-state at 144 h with a steady-state value of 26.4℃ „

2) Center temperature of the external wall

According to Figure 2.36, the duration of non-radiation condition in the base group is 021 h45 min, the central temperature of the external wall reaches steady state at about 21 h 45 min, and the steady state value is 9.5℃; the duration of moderate radiation condition in summer is 21 h 45 min 54 h, when the solar radiation intensity is changed from 0 W / m²Up to 175W / m², The central temperature of the external wall has hysteresis relative to the external surface, with a lag time of about 40 minutes and reaches the steady state at 51 h 40min. The steady state value is 17.5℃. The duration of strong radiation condition in summer is 66h 99h, and the change trend is consistent with the moderate radiation condition in summer. The central temperature reaches at 96 h 40min, and the steady state value is 21.4℃.

According to Figure 2.37, the duration of non-radiation condition in the test group in summer is 081 h, the central temperature of the external wall reaches the steady state at about 80 h, and the time is longer than that of the base group, that is, the whole heat transfer process is more slow, the steady state value is 14.8℃, and its good insulation performance is fully reflected again; the duration of strong radiation condition in summer is 81 h 147h, when the solar radiation intensity is changed from 0 W / m²Up to 350W / m², The central temperature of the external wall has hysteresis relative to the temperature response of the external surface, with a lag time of about 90 minutes and

reaching the steady state at 145h 30 min with a steady state value of 18.2℃.

3) Internal surface temperature of the external wall

According to Figure 2.36, the duration of non-radiation condition of the reference group in summer is 021 h 45 min, the internal surface temperature reaches the steady state at about 21 h 45 min, and the steady state value is 13.1℃; the duration of moderate radiation condition in summer is 21 h45min 54h, when the solar radiation intensity is from 0 W / m²Up to $175W$ / m^2The internal surface temperature has hysteresis relative to the external surface, with the lag time of about 120 minutes and reaches the steady state at 53h. The steady state value is 17.2℃; The duration of strong radiation condition in summer is 66h 99h, and the change trend is consistent with the moderate radiation condition in summer. The inner surface temperature reaches steady state at 98 h and the steady state value is 19.3℃.

According to Figure 2.37, the duration of non-radiation condition in the test group in summer is 081 h, the internal surface temperature of the external wall reaches the steady state at about 80 h, and the time is longer than that of the base group, that is, the whole heat transfer process is more slow and the steady state value is 16.2℃, which fully reflects the good insulation performance; the duration of strong radiation condition in summer is 81h 147h, when the solar radiation intensity is changed from 0 W / m²Up to 350W / m², The temperature of the external internal surface has hysteresis relative to the external surface temperature response, with a lag time of about 130 minutes and reaching the steady state at 110 h 10 min with a steady state value of 18.1℃.

Whether base group or test group, the test condition from no radiation to strong radiation, due to the increase of the radiation intensity, the temperature of the external surface gradually increased a certain amplitude, through wall heat transfer, and wall center, external wall internal surface temperature also gradually improved, affect the indoor thermal environment.

Comparative reference group: under no radiation condition in winter, The center temperature of the outer wall and the inner surface temperature of the outer wall of the test group increased by 5.3℃ and 3.1℃ respectively; Under strong radiation conditions

in winter, The center temperature of the external wall and the temperature of the inner surface of the test group decreased by 32°C and 1.2°C respectively; As you can see, The comparison of the center temperature and inner surface temperature between the test group and the reference group is inconsistent, Because when there is no radiation in the winter months, The temperature of the exterior surface is much lower than the indoor temperature, External wall insulation hinders indoor to outdoor heat transfer, The temperature of the internal surface and the center of the external wall is higher than that of the reference group; When strongly radiation in winter, The external surface of the external wall has received strong radiation exposure, External surface temperature is higher than the indoor temperature, The presence of the external insulation layer, Hthe exterior facing indoor heat transfer, This leads to a lower inner surface and central temperature of the external wall than those of the reference group.

(3) Comparison of external wall heat flow

According to Figure 2.36, the duration of summer radiation-free condition in the reference group is 021 h 45 min, the heat flow of the external wall reaches the steady state at about 21 h, and the steady state value is 23.2 W / m^2; The duration of the moderate radiation condition in summer is 21 h 45 min 54 h, when the solar radiation intensity varies from 0 W / m2. Up to 175W / mz, The surface temperature of the external wall heat flow responded immediately and reached the steady-state at 51 h, with a steady-state value of 0.3W / m^2The outermost surface temperature, central temperature and inner surface temperature are very close to the indoor temperature, respectively 19.2°C, 17.5°C and 17.2°C, which makes the heat load of the external wall almost 0, thus the external wall heat is basically 0; the duration of the strong radiation condition in summer is 66h 99h, the change trend is consistent with the medium radiation condition in summer, the inner surface temperature reaches the steady state at 96 h, and the steady state value is-12.1W/m^2, When the solar radiation increases to 350 W / m^2, The steady state value of the external surface temperature of the external wall is further improved, reaching 25.9C, or even 7.9°C higher than the indoor temperature, the direction of the internal temperature stress of the wall is reversed, the direction of the

heat flow of the external wall becomes from the outdoor to the indoor, and the heat load of the external wall is negative.

As shown in Figure 2.37, the duration of the summer non-radiation condition in the test group is 081h, and the heat flow of the external wall reaches the steady state at about 80 h, and the time to reach the steady state is longer than that of the base group, that is, the whole heat transfer process is more slow and the steady state value is 12.1W/m^2, Its good insulation performance is fully reflected again; the duration of moderate radiation condition in summer is 81 h 147h, when the solar radiation intensity is from 0 W / m^2 up to 175W / m^2. The external wall heat flow responded immediately and reached the steady state at 145h, with a steady state value of 3.3W / m^2.

In conclusion, the steady-state values of the reference group and the test group in summer are plotted into Figure 2.38 and Figure 2.39. Whether, benchmark group or test group, the test condition from no radiation to strong radiation, due to the increase of radiation intensity, external wall surface temperature, wall internal temperature stress direction reversal, external wall heat flow direction from the outdoor to indoor, external wall heat load is negative, equivalent to external wall not adopt warm energy consumption, also share the heat load of his enclosure.

Comparison reference group: under the no radiation condition in summer, the heat flow of the test group decreased by 11.1 W / m^2; Under the strong radiation condition in summer, the external wall heat flow of the test group decreased by 15.4W/m^2; With the increase of radiation intensity, the decrease of heat flow of external wall is greater, which shows the good insulation performance of external wall insulation technology in winter.
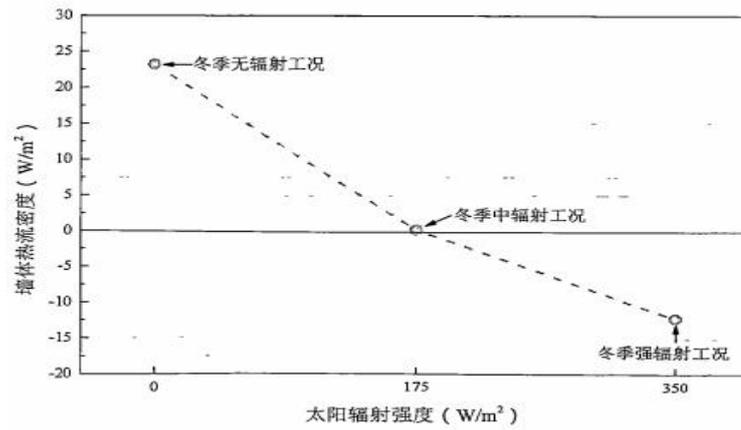
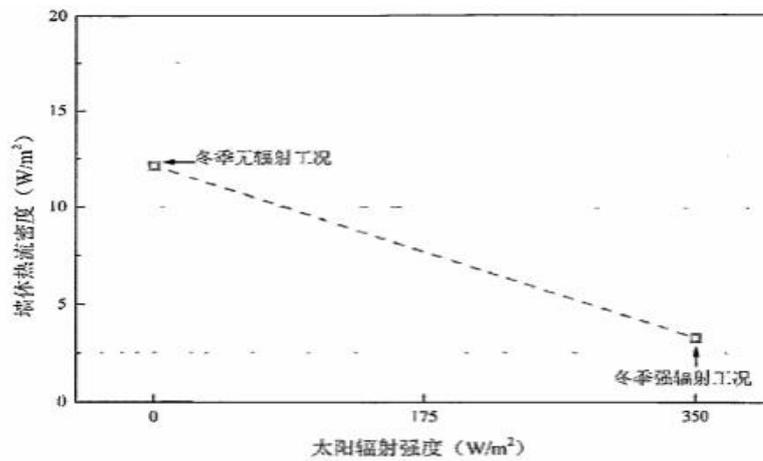Figure 2.38 - Steady-state value of external wall heat flow under various working conditions in winter

Figure 2.39 – Steady state value of external wall heat flow under all working conditions of the test group in winter

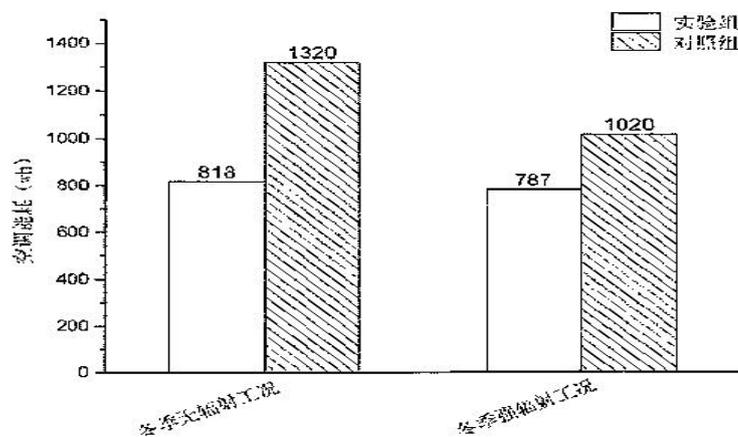(4) Energy consumption comparison

Figure 2.40 - Comparison of heating energy consumption in winter between base group and test group

By reading the air conditioning power meter, figure 2.44 is obtained. The energy consumption of air conditioning in the base group in winter, medium radiation conditions and strong radiation conditions in winter is 1320 wh, 1200 wh and 1020 wh respectively, while the corresponding air conditioning energy consumption in the test group is 818wh and 7874wh, respectively, and the amplitude of heating energy consumption is more than 10%.

2.4.4 Summary and discussion

In order to study the impact of external wall insulation technology based on solar radiation in hot summer and cold winter areas on building energy saving, this chapter carries out relevant experimental research by establishing a full ruler model in the real environment, taking ordinary solid sintering brick wall as the base group, and adding fluorocarbon resin insulation decoration integrated board wall as the experimental group. Through the adjustment of outdoor temperature, outdoor relative humidity, solar radiation intensity and indoor control temperature, there are no radiation in summer, no radiation in summer, strong radiation in summer, no radiation in winter and strong radiation in winter. The study results show that:

1. Comparmark group: without radiation condition in summer, The center temperature of the outer wall and the inner surface temperature of the outer wall of the test group decreased by 5.2℃ and 3.8℃ respectively; Under moderate radiation conditions in summer, The central temperature of the outer wall of the outer wall and the inner temperature of the test group decreased by 9.4℃ and 5.6℃ respectively; Under strong radiation conditions in summer, The center temperature of the outer wall and the inner surface temperature of the outer wall of the test group decreased by 11.5℃ and 5.9℃ respectively; Without radiation conditions in winter, The center temperature of the outer wall and the inner surface temperature of the outer wall of the test group increased by 5.3℃ and 3.1℃ respectively; Under strong radiation conditions in winter, The central temperature of the outer wall and the temperature of the outer wall surface of the test group decreased by 3.2℃ and 1.2℃ respectively.

2. Under no radiation condition in summer, the external wall heat flow of the test

group decreased by 6.2W / m^2; In the summer medium radiation condition, the heat flow of the test group decreased by 32W / m^2; Under the strong radiation condition in summer, the heat flow of the test group decreased by 39.1 W / m^2; In winter without radiation, the heat flow of the test group decreased by 11.1 W / m^2; Under the strong radiation condition in winter, the external wall heat flow of the test group decreased by 15.4W/m^2; With the increase of radiation intensity, the decrease of heat flow in the external wall is greater.

3. The energy consumption of the base group is 257 wh, 318 wh, 382 wh, 1320 wh, 1320 wh, 1200 wh in summer, no radiation in winter, and the corresponding energy consumption is 200wh, 223 wh, 254wh, 818 wh, 718 wh and 7874wh of the test group is more than 10% lower than that of the control group.

Solar radiation plays a very important role in the wall heat transfer process in both summer and winter. Solar radiation has a great impact on the cold and heat load of the external wall, and then affects the building energy consumption. In summer, the stronger the solar radiation, the higher the energy consumption of air conditioning; in winter, the stronger the solar radiation, the lower the heating energy consumption. With the same temperature difference between indoor and outdoor, the stronger the solar radiation in summer, the greater the demand for air conditioning, and the more in winter. When the external surface of the external wall is used with 4cm thickness of fluorocarbon resin board insulation decorative board, it is relatively no insulation ordinary wall, which has better thermal performance and building energy saving effect under different intensity of solar radiation.

2.5 Conclusions to Chapter 2

Through simulation and full-scale experiments using Design Builder, this chapter has thoroughly analyzed the effects of external wall insulation thickness, heating and air conditioning period parameters, and solar radiation on energy consumption. The gradient test data of EPS insulation layer from 20mm to 140mm, as well as the anti energy-saving critical temperature phenomenon under intermittent energy consumption

mode, provide quantitative basis for energy-saving design of non transparent enclosure structures. The following conclusions will summarize the mechanisms of key influencing factors and provide engineering application recommendations.

1. Critical value of insulation thickness: When the thickness of EPS insulation layer exceeds 120mm, the growth trend of energy saving rate significantly slows down (such as the energy saving rate during air conditioning period increasing from 13.69% to 14.25%), and there is an economic thickness optimization interval.

2. Anti energy saving mechanism: When the calculated temperature during the summer air conditioning period exceeds 27.3 ℃, the external insulation of the exterior wall may lead to an increase in cooling energy consumption (such as a 2.89% increase in air conditioning energy consumption when the 140mm insulation layer is at 28 ℃).

3. Impact of solar radiation: Under high solar radiation in summer, the external surface temperature of the insulated outer wall is 3.44 ℃ higher than that of the non insulated wall, but the internal surface temperature is 3.8 ℃ lower, indicating a significant insulation effect.

4. Energy consumption mode recommendation: Intermittent energy consumption mode has an annual energy consumption 29.74% lower than continuous mode, which is more in line with the energy consumption habits of residents in hot summer and cold winter areas.

CHAPTER 3 QUANTIFICATION RELATIONSHIP BETWEEN PARAMETERS OF TRANSPARENT ENVELOPE STRUCTURE AND ENERGY CONSUMPTION AND EVALUATION OF ENERGY SAVING EFFECT

This chapter will target the relevant design parameters of doors and Windows affecting the energy consumption of commercial complex, study the influence of these parameters on building energy consumption, obtain the multiple regression model of each single parameter and building energy consumption, and evaluate the energy saving effect of different design parameters from the perspective of sensitivity coefficient and energy saving rate, and propose the energy saving design strategy suitable for the commercial complex building in the cold area according to the evaluation results.

3.1 Energy-saving design parameters and energy consumption simulation of doors and Windows

3.1.1 Quantified relationship between doors and Windows and energy consumption

The energy saving effect of the doors and Windows outside the building is related to the window glass and frame. The heat and heat loss forms of Windows mainly include solar heat and heat exchange, and the corresponding evaluation parameters are shading coefficient and heat transfer coefficient, that is, the influence of glass and window frame on building energy consumption under the comprehensive effect of window frame. At the same time, due to the small opening area of the facade and the fixed form, the facade window wall ratio is small.

According to the characteristics of the exterior Windows of the commercial complex buildings in cold areas, the doors and Windows of the facade of this chapter respectively analyze the influence of the heat transfer coefficient of doors and Windows, the comprehensive shading coefficient of doors and the air tightness of the doors and Windows.

3.1.1.1 Heat transfer coefficient of doors and windows

The heat transfer coefficient of door and window is the common value of the heat transfer coefficient of door and window glass and the heat transfer coefficient of

window frame. According to the "Energy Saving Design Standards for Public Buildings" (GB 50189-2015) implemented by the Ministry of Housing and Urban-Rural Development on October 1,2015, according to the climate thermal zoning of buildings, the thermal performance of doors and Windows of public buildings should meet the relevant provisions of 3.3 and 3.4, as shown in Table 3.1 below.

Table 3.1 – Thermal performance limits of single facade exterior Windows of public buildings in cold areas in the Energy Saving Design Standard of Public Buildings (G B 50189-2015)

Enclosure structure parts		Body coefficient≤ 0.3		0.3 <body coefficient ≤0.5	
		coefficient of heat transfer K (W /m²·k)	The solar score is given, and the thermal coefficient is S H GC	Heat transfer coefficient K (m²·k)	The coefficient of heat S H GC
Window and wall area ratio of 0.2		≤3.0	-	≤3.0	-
Single facade exterior window (including transparent curtain wall)	0.2 <window-wall area ratio of 0.3	≤2.7	≤0.52	≤2.7	≤0.52
	0.3 <window-wall area ratio of 0.4	≤2.4	≤0.48	≤2.4	≤0.48
	0.4 <window-wall area ratio 0.5	≤2.2	≤0.43	≤2.2	≤0.43
	0.5 <window-wall area ratio 0.6	≤2.0	≤0.40	≤2.0	≤0.40
	0.6 <window-wall area ratio 0.7	≤1.9	≤0.35	≤1.9	≤0.35
	0.7 <window-wall area ratio 0.8	≤1.6	≤0.35	≤1.6	≤0.35
	Window and wall area ratio of 0.8	≤1.5	≤0.30	≤1.5	≤0.30

The reference value of 3W / m²K specified in the above table is the upper limit, and according to the range of 1.0-3.0 m ³ / (㎡ ·h), the threshold range is 1.0-3.0 m ³ / (㎡ ·h), and the step length is 0.2.

Through the selected building energy consumption simulation software Design Builder simulation, get other parameters unchanged, only the change of the total energy consumption, refrigeration energy consumption, heating energy consumption in the

following table, and calculate the standard model doors and Windows heat transfer coefficient is 2.6 W / ㎡·k when the working condition of energy saving rate, the calculation results in the following table (Table 3.2):

Table 3.2 – Heat transfer coefficient of doors and Windows, total energy consumption, sub-item energy consumption and energy saving rate

Heat transfer coefficient of doors and windows (W /㎡ ·k)	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
1	13785.31	1627.1	4480.97	0.47%	0.21%
1.2	13788.93	1628.73	4482.96	0.41%	0. 18%
1.4	13792.42	1630.33	4484.86	0.36%	0. 16%
1.6	13795.91	1631.94	4486.75	0.30%	0. 13%
1.8	13799.4	1633.54	4488.64	0.24%	0. 11%
2	13802.88	1635.15	4490.54	0. 19%	0.08%
2.2	13806.37	1636.75	4492.43	0. 13%	0.06%
2.4	13809.86	1638.35	4494.32	0.07%	0.03%
2.6	13814.31	1640.25	4496.89	0.00%	0.00%
2.8	13816.84	1641.56	4498.11	-0.04%	-0.02%
3	13819.65	1642.98	4499.52	-0.09%	-0.04%

It can be seen from the table, as the Windows of heat transfer coefficient, cold area large commercial complex total energy consumption, gradually reduce heating energy consumption, cooling, respectively, winter heating energy consumption than summer cooling energy consumption is faster, it shows that doors and Windows heat transfer performance, greatly reduce the winter indoor and outdoor temperature difference of heat loss, is conducive to the energy consumption of heating in winter. From the perspective of energy saving rate of the energy saving analysis, when the heat transfer coefficient of doors and Windows is within the threshold range of 1 ~3 W / ㎡ · k, the change range of heating and cooling energy saving rate is 0.09%~0.47%, and the change range of total energy saving rate is-0.04%~0.21%, that is, when the heat transfer

coefficient of doors and Windows is reduced, the building can always consume energy to achieve better energy saving purpose.

According to the data of the heat transfer coefficient of doors and Windows and the total energy consumption (Figure 3.1 of the building):
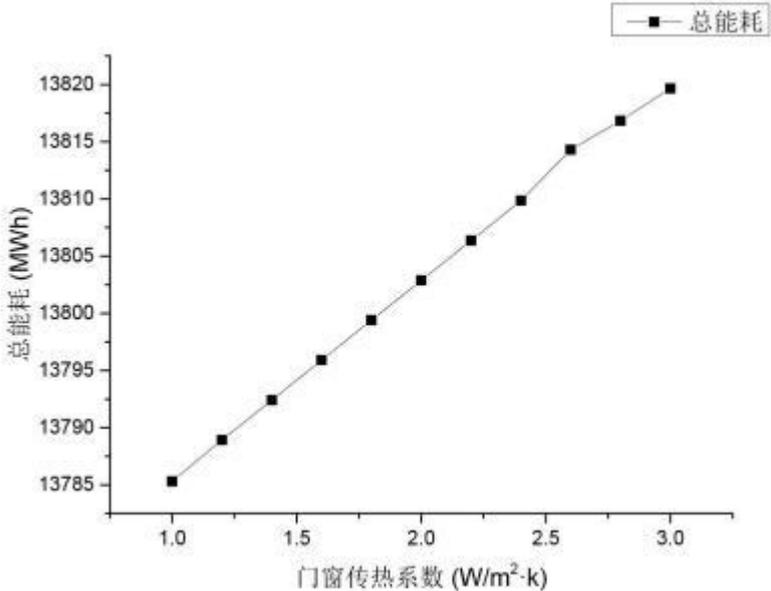

Figure 3.1- Scatter plot of the relationship between the heat transfer coefficient and the total energy consumption of doors and windows

Statistical analysis of the energy consumption simulation results can show that the heat transfer coefficient of doors and Windows and the total energy consumption are basically linear. As can be seen from the figure, the total energy consumption level of the standard model increases with the heat transfer coefficient of doors and Windows.

Therefore, the linear regression analysis of total energy consumption was conducted to form a mathematical model, and the linear formula of total energy consumption and heat transfer coefficient of doors and Windows in the commercial area of large commercial complexes in cold areas was obtained, in which the simulation was adjusted R^2 Was 0.9997, with an extremely high fit. The linear relation formed is:

$$y = 1.8427x + 5528.2$$

Where, the heat transfer coefficient of doors and Windows is the independent variable x, and the total energy consumption of the building is the dependent variable y (MWh).

According to the simulation analysis results, it can be seen that the function relationship between the total energy consumption and the heat transfer coefficient of doors and Windows in the commercial areas of large commercial complex buildings in cold areas is linear, but the total energy consumption of buildings increases with the increase of the heat transfer coefficient of doors and Windows. When the heat transfer coefficient of doors and windows is 1 W / ㎡ · k, the total energy consumption is the lowest, 13487.94 MWh, and the energy saving rate is 0.21%; when the heat transfer coefficient is 3W / ㎡ K, the total energy consumption is the lowest, 14568.59 MWh, the energy saving rate is-0.04%, when the heat transfer coefficient of doors and windows is 1 ~3 W / ㎡·k, the change range is-0.04%~0.21% for building doors and windows. The possible energy saving range of the thermal coefficient is 0.25%.

3.1.1.2 Comprehensive shading coefficient of doors and Windows

Solar radiation has a significant impact on the heating energy consumption of buildings. The use of appropriate shading technology can effectively reduce the heat transfer of doors and Windows, and control the increase of the cold load of buildings in summer. At the same time, more solar radiation in winter also has a great impact on the heating energy consumption of buildings. The shading coefficient of doors and Windows, that is, the comprehensive effect of the glass shading performance and the shading coefficient of the shading device, is studied. Its value is the product of the shading coefficient (SC) of the window itself and the shading coefficient (SD) of the device of the window, that is, the comprehensive shading coefficient of doors and Windows is studied here.

According to the energy saving design standard of public buildings (GB 50189-2015), the limit value of solar heat coefficient for opposite doors and Windows of cold climate area is 0.52 W / ㎡ K, and the shading coefficient is 0.59. Then, according to the types of doors and Windows summarized in the architectural drawings of 40 sets of commercial complexes in typical cold areas, the value range is appropriately expanded, that is, the threshold range is determined to be 0.25~0.85, and the step length is 0.1.

Through this paper selected the building energy consumption simulation software Design Builder simulation, get other parameters unchanged, only the doors and Windows comprehensive shading coefficient change the total energy consumption, refrigeration energy consumption, heating, at the same time calculated relative to the doors and Windows comprehensive shading coefficient is 0.52 when each condition of energy saving rate, 8 group calculation results in the Table 3.3.

Table 3.3 – Sunshade coefficient and total energy consumption, sub-item energy consumption and energy saving rate of doors and Windows

Doors and Windows comprehensive Sun shading coefficient s c	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
0.25	13634.96	1595	4361.85	2.94%	1.30%
0.35	13686.92	1617.11	4442.65	1.26%	0.92%
0.45	13756.04	1631.83	4475.64	0.48%	0.42%
0.59	13814.31	1640.25	4496.89	0.00%	0.00%
0.65	13894.29	1666.16	4585.29	-1.86%	-0.58%
0.75	13963.41	1682.5	4637.51	-2.98%	- 1.08%
0.85	14054.87	1696.18	4682.94	-3.94%	- 1.74%

It can be seen from the table above, as the door window shade coefficient decreases, block sunlight heat to the indoor radiation performance, the better, the total energy consumption and summer cooling energy consumption are gradually reduced, this is mainly because of the cold commercial complex door window shading performance enhancement, blocked the summer by the facade doors and Windows into indoor solar radiation, thus reducing the air conditioning cooling load produced by heat increment, shows that the doors and Windows shading performance improve the summer cooling energy consumption reduction effect is more significant. From the perspective of energy

saving rate of the energy consumption analysis, when the shading coefficient of doors and Windows is within the threshold range of 0.25~0.85, the change range of heating and cooling energy saving rate is-3.94%~2.94%, the change range of total energy saving rate is 1.74%~1.30%, that is, when the shading performance of doors and Windows is gradually enhanced, the building can always consume the year to achieve better energy saving purpose. Therefore, when setting the roof doors and Windows of commercial complex buildings, attention should be paid to the shading coefficient of doors and Windows combined with the internal and external shading system, so as to achieve the optimal value of the comprehensive shading coefficient. According to the data of doors and Windows, the scatter diagram of shading coefficient and total energy consumption of the building (Figure 3.2):
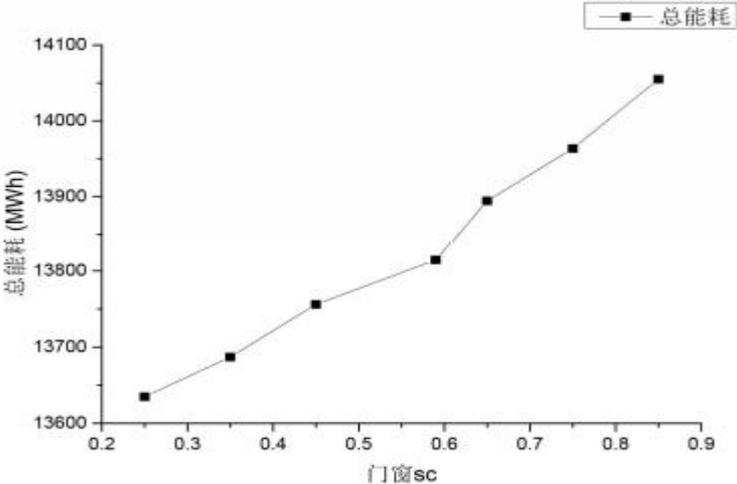

Figure 3.2 - Scatter plot of the relationship between shading coefficient and total energy consumption of doors and windows

Through statistical analysis of the energy consumption simulation results, we can see that the shading coefficient of doors and Windows and the total energy consumption are basically linear. As can be seen from the figure, the total energy consumption level of the standard model increases with the skylight shading coefficient.

Therefore, conduct linear regression analysis of total energy consumption, form a mathematical model, and obtain the linear formula of large total energy consumption and shading coefficient of doors and Windows in cold areas, which simulates the

adjustment R^2 Was 0.974, with an extremely high fit. The linear relation formed is:

$$y = 691.21x + 13445$$

The shading coefficient of doors and Windows is the independent variable x, and the total energy consumption of the building is the dependent variable y (MWh).

According to the simulation analysis results, it can be seen that the function relationship between the total energy consumption and the shading coefficient of doors and Windows in the commercial areas of large commercial complex buildings in cold areas is linear, and the total energy consumption of the building increases with the increase of the shading coefficient of doors and Windows. When the shading coefficient of doors and Windows is 0.25, the total energy consumption is the lowest when the shading performance is best, which is 13634.96 MWh, and the energy saving rate is 1.30%; i. e., when the shading coefficient of doors and Windows is 0.85, the total energy consumption is the highest, 14054.87 MWh, 1.74%, and the shading coefficient is 0.25~0.85, and the change range of energy saving rate is 1.74%~1.30%, that is, the shading system of building doors and the total energy saving range is 3.04%.

3.1.1.3 Air tightness of doors and Windows

According to Article 3.3.5 of the GB 50189-2015, the air tightness classification of the outer door and window of the building shall comply with the provisions of Article 4.1.2 of the National standard 100 and Testing Method of GB / T7106-2008. As the research object of this paper is large commercial complex commercial area buildings, it should meet the requirement that the "air tightness of the outer Windows of buildings below 10 floors should not be lower than grade 6". According to the air tightness classification of the skylight in the previous section, it is also applied to the air tightness classification of doors and Windows, so according to the values of 10Pa and 50Pa, it is the main indoor and outdoor pressure difference in cold area. The permeability value of grade 6 per unit area is 6.0~9.0 m ³ / (㎡ · h), and the value range is appropriately expanded, that is, the threshold range is 1.5~13.5 m³ / (㎡ · h), and the step length is 1.5.

Through the building full energy consumption simulation software Design Builder

selected in this paper, other parameters remain unchanged, and only the total energy consumption, refrigeration energy consumption and heating energy consumption when the air density per unit area of doors and Windows is studied in the Table 3.4

Table 3.4 – Classification index value of unit area and total energy consumption and sub-item energy consumption of doors and Windows

Index value of unit area classification m³/(m²·h)	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
1.5	13683.15	1598.62	4406.78	2. 15%	0.95%
3	13709.29	1606.93	4424.9	1.72%	0.76%
4.5	13736.12	1615.19	4442.7	1.29%	0.57%
6	13762.01	1623.45	4460.5	0.87%	0.38%
7.5	13788.95	1631.71	4478.3	0.44%	0. 18%
9	13814.31	1640.25	4496.9	0.00%	0.00%
10.5	13840.46	1648.24	4513.9	-0.41%	-0. 19%
12	13872.23	1656.5	4531.7	-0.83%	-0.42%
13.5	13890.45	1664.66	4548.96	- 1.25%	-0.55%

According to the data of each simulation result, the classification index value per unit area of doors and Windows and the total energy consumption of the building are made (Figure 33):
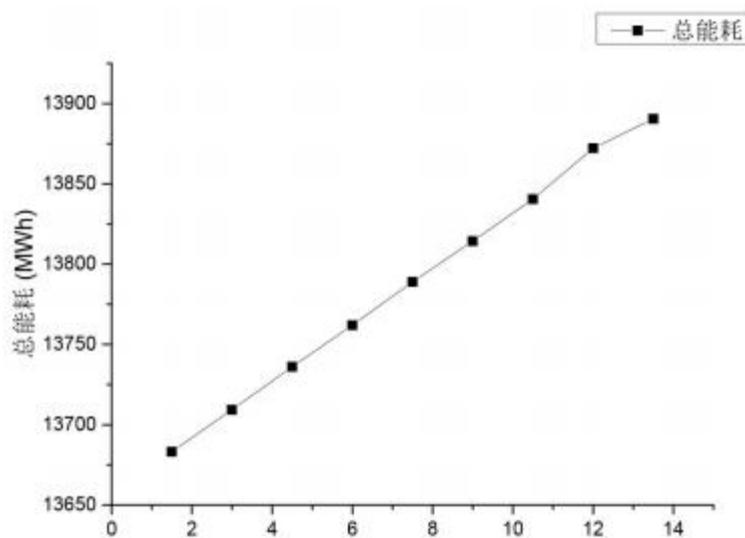

Figure 3.3 - Scatter plot of the relationship between unit area of air tightness and total energy consumption

Statistical analysis of the energy consumption simulation results can show that the

index value of unit area of doors and Windows and the total energy consumption basically show a linear relationship. It can be seen from the figure that the total energy consumption level of the standard model increases with the increase of the air density per unit area of doors and Windows.

Therefore, a linear regression analysis of the total energy consumption and a mathematical model obtains the linear formula of the total energy consumption and unit area of large commercial complexes in cold areas, where R is simulated and adjusted^{2}Was 0.998, with an extremely high fit. The linear relation formed is:

$$y = 17.292x + 13658$$

Among them, the index value of unit area of air tightness of doors and Windows is the independent variable x, and the total energy consumption of the building is the dependent variable y (MWh).

According to the simulation analysis results, it can be seen that the function relationship between the total energy consumption of commercial area of large commercial complex buildings in cold area of doors and Windows is linear, and the total energy consumption of buildings increases with the increase of the unit area index value of air tightness of doors and Windows. When the index value of air tightness per unit area of doors and Windows is 1.5 m ^{3} / (m² · h), the minimum total energy consumption of the seepage gap of doors and Windows is the lowest, For 13683.15 MWh, Energy-saving rate is 0.95%; When the index value of unit area of air tightness of doors and Windows is 13.5 m³ / (m² · h), the total energy consumption is the highest when the seepage gap of doors and Windows is maximum, For 13890.45 MWh, Energy-saving rate of-0.55%, That is, the index value of unit area of air tightness of doors and Windows is within the change range of 1.5 m³ / (m² · h)~13.5m³ / (m² · h), The change value of total energy consumption is 207.29 MWh (about 21 0,000 KWH), The variation in energy saving rate ranged from-0.55% to 0.95%, That is, the energy saving range of air tightness of building doors and Windows is 1.50%.

3.1.2 Sensitivity analysis of energy-saving design parameters of doors and windows

According to the above analysis, the heat transfer coefficient of doors and Windows, the comprehensive shading coefficient of doors and windows and the air tightness of doors and windows respectively play different roles in the impact of building energy consumption. The sensitivity analysis of the energy-saving design parameters of doors and Windows, get the influence of each factor on the change of energy consumption, and then guide the energy-saving design strategy of doors and Windows.

As shown in Table 3.5, the value range of the sensitivity values of different doors and Windows design parameters to the total energy consumption of commercial complex buildings in cold areas is arranged.

Table 3.5 - Sensitivity analysis of the total building energy consumption under different design parameters of doors and Windows

Design parameters for doors and windows	Sensitivity coefficient	
	least value	crest value
Heat transfer coefficient of doors and windows	0.0023	0.0041
Comprehensive shading coefficient of doors and Windows	0.017	0.039
Door and window air tightness	0.011	0.0126

From the range of sensitivity coefficient of the design parameters in the table, the influence of the three on energy consumption can be obtained as follows: comprehensive shading coefficient of doors and windows> air tightness of doors and Windows> heat transfer coefficient of doors and Windows

The above results show that the optimization design of shading coefficient and air tightness performance of doors and Windows in large commercial complex buildings in cold areas of China has great potential in building energy conservation.

3.1.3 Energy-saving technology strategy for doors and windows

3.1.3.1 Energy-saving technology at the first floor entrance

According to the investigation and analysis, the cold air penetration of the entrance at

the first floor of commercial complex buildings has a serious impact on the air temperature change in the entrance space area, which is the main problem of energy saving and insulation of doors and Windows. It is the key task of energy saving design of the entrance space to combine the energy saving factors of the doors and Windows of the commercial complex.

At present, in order to improve the thermal environment at the entrance in winter, large commercial complexes in cold areas usually set up a windshield curtain on the single side of the door bucket or add a windshield curtain on both sides of the door bucket, open the hot air curtain and add a temporary buffer space. However, the energy saving optimization design of the entrance space form and envelope from the design stage can achieve the long-term and efficient building energy saving goal.

(1) Space location design of the entrance

One is the entrance orientation setting, In the initial stages of the design, The determination of the entrance orientation should consider the influence of the dominant wind direction in winter, With mostly northerly and northwest winds in cold winter, The entrance design to avoid the dominant wind direction can minimize the cold air volume under the same other conditions, At the same time, choose the location of the larger solar radiation, To offset the heat loss caused by cold air penetration at the inlet; Second, the entrance should be set in the central part of the building, Try not to be located at the end of the building, This type of entrance space form has both sides of the facade in contact with the outdoor air, Easy to cause more heat loss in winter; Third, the entrance space door bucket setting is generally embedded, convex two forms, In the architectural design stage, in order to create the exaggerated artistic effect of the main surface, The entrance space will be designed in a convex form, And this form is often not conducive to building energy efficiency, Therefore, architects should comprehensively consider the artistic design effect and the overall building energy consumption in the early stage, Make a reasonable design scheme.

(2) Optimize the entrance space form

First, the entrance space plays an important role in the control of cold air penetration

and space temperature regulation. Meanwhile, the relative opening position of the double door has a significant impact on the change of the entrance wind speed. The wind speed greatly reduces the impact of the outdoor cold air and reduces the purpose of building energy saving.

(3) Optimization design of the entrance space envelope structure

First, due to the demand of commercial functions of commercial complex buildings in cold areas, The first floor envelope structure is often a large area of glass curtain wall, But the transparent envelope can absorb a lot of solar radiation and the cold air penetration caused by the gap between doors and Windows also has a great impact on the indoor thermal environment, Therefore, when the first floor facade is designed, The area ratio of the entrance space shall be controlled, On the premise of ensuring the visual transparency, visual beauty and indoor commercial physical environment to achieve the purpose of building energy saving; Second, according to the characteristics of frequent opening of the entrance door of the commercial complex and different cold air volume in each direction, Select the high-performance insulation material or increase the thickness of the insulation layer for the external wall of the entrance space area, Minimize the heat loss.

3.1.3.2 Improve the air tightness of doors and windows

In addition to improve the air tightness of doors and Windows, the main measures are as follows:

(1) Choose the window type reasonably to reduce unnecessary gaps. When designing the facade of doors and Windows, on the premise of meeting the ventilation requirements, minimize the opening fan. In addition, as far as possible do not use the window type, push the moving gap of the window is sealed by wool strip, but its effect is lower than the flat window.

(2) Improve the size of the profile and the accuracy of assembly, ensure the lap between the frame and the fan, the flat window is generally 6mm, and the four sides should be uniform.

(3) Increase the number of sealing channels and choose high-quality sealing rubber

strips. At present, the insulation window generally adopts multiple seals, and according to the different shapes of their profile sections, the design of different shapes of sealing strip.

3.2 Evaluation of energy saving effect of comprehensive energy saving design parameters of transparent envelope structure

The above energy consumption simulation experiment analyzes the cold area commercial complex transparent envelope is not, with energy saving design parameters in the case of independent variable single change of energy saving potential and variable relationship with energy consumption, including heat transfer Windows, Windows, Windows, air tightness, each single design parameters of energy saving rate in the Table 3.6.

Table 3.6 - Total energy saving rate of buildings under single variable design parameters of different envelopes

exterior-protected construction design value	doors and windows		
	coefficient of heat transfer	Shading coefficient	air tightness
Heating and refrigeration fractional energy saving	0.56%	6.88%	3.39%
Total energy saving rate	0.25%	3.04%	1.5%

As can be seen from the above table, the total energy saving rate of each parameter is small for the following two reasons: first, in the energy consumption composition of commercial complex, the proportion of lighting and other equipment is large, and the proportion of heating and cooling is small; second, the value range of design parameters is based on the existing standard, which is not large.

On this basis, all the energy saving design parameters of the envelope are integrated. According to the above regression equation, the optimal value group and the worst value group are taken to obtain the overall energy saving rate of the envelope:

When the performance of each envelope is optimal, the lowest total energy consumption is 12532.35 MWh, and the energy saving rate is 9.28%; when the worst performance, the highest is 16176.14 MWh and 17.1%, the change of the total energy

consumption is 364 3.79 MWh (about 3.64 million KWH), and the range of energy saving rate is-0. 17.1%~9.28%, that is, the overall energy consumption of the building envelope is 26.38%.

At the same time, the sensitivity coefficient of the energy saving design parameters of each envelope is summarized. By comparing the value range of the sensitivity coefficient, the influence degree of each factor on the change of energy consumption is obtained, and the priority degree of the energy saving technology of each envelope is summarized, so as to guide the energy saving design of commercial complex in cold areas. The range of sensitivity coefficient is shown below (Table 3.7):

Table 3.7 - Sensitivity analysis of total building energy consumption under different envelope design parameters

Design parameters of the envelope structure	The sensitivity coefficient value is taken	
	least value	crest value
Heat transfer coefficient of doors and windows	0.0023	0.0041
Comprehensive shading coefficient of doors and Windows	0.017	0.039
Door and window air tightness	0.011	0.0126

Based to the range of sensitivity coefficient, the influence of energy saving design parameters on energy consumption is as follows:

Comprehensive shading coefficient of doors and Windows> air tightness> heat transfer coefficient of doors and Windows

3.3 Summary

This section simulates the variable relationship between energy consumption in the doors and Windows. Through data analysis, the quantitative results of energy saving within the value range of design parameters are obtained: When the heat transfer coefficient of doors and Windows in the commercial area of large commercial complex buildings in the cold area is 1~3W / ㎡ · k, the quantitative relationship between the total energy consumption of the building is $y = 1.8427x + 5528.2$. The range of energy saving under the quantitative results is 0.25%, where the heat transfer coefficient of

doors and Windows is x (W / ㎡ · k), and the total energy consumption of the building is y (MWh).

The shading coefficient of doors and Windows is in the value range of 0.25~0.85, and the quantitative relationship between the total energy consumption of the building is y = 691.21x + 13445. The energy saving range under the quantitative results is 3.04%, where the shading coefficient of doors and Windows is x, and the total energy consumption of the building is y (MWh).

The unit area of air density classification index of doors and Windows is 1.5 ㎥ / (㎡ · h)~13.5m³ / (㎡ · h). Considering the cold air filling at the entrance of the first layer, the quantitative relationship between the total energy consumption of the building is y = 17.292x + 13658. The energy saving range under the quantitative results is 1.01%, in which the air tightness index of doors and Windows is x m³ / (㎡ · h), and the total energy consumption of the building is y (MWh). The sensitivity analysis of the design parameters of doors and Windows, we can get the influence of the three on energy consumption: shading coefficient of doors and Windows> air tightness of doors and Windows> heat transfer coefficient of doors and Windows.

Because the ratio mode of commercial complex facade is relatively fixed, the shading technology of facade doors and Windows, the optimization design of entrance space and improving the air tightness of doors and Windows are the main design strategies to realize the energy saving of doors and Windows.

3.4 Conclusions to Chapter 3

Based on the simulation of door and window parameters in commercial complexes in cold regions, this chapter has established a multiple regression model for heat transfer coefficient, shading coefficient, air tightness, and energy consumption. Sensitivity analysis revealed the dominant role of shading coefficient in energy consumption, and proposed specific strategies such as optimizing entrance space. The following conclusions will integrate the influence of parameters and energy-saving design thresholds to form a systematic optimization plan for transparent enclosure structures.

1. Parameter sensitivity ranking: door and window shading coefficient (energy-saving rate 3.04%)>air tightness (1.50%)>heat transfer coefficient (0.25%), optimization priority should be given to shading design.

2. Comprehensive energy-saving potential: When the heat transfer coefficient of doors and windows is 1.0W/(m^2 •K), the shading coefficient is 0.25, and the air tightness is 1.5m^3/(m^2 • h), the total energy consumption can be reduced by 9.28%, saving 3.64 million kWh of electricity annually.

3. Energy saving strategy at the entrance: The vertical turning of the double layered door can reduce the penetration of cold air by 40%, and combined with the use of a hot air curtain, it can further reduce heating energy consumption by 12%.

4. Design threshold recommendation: The shading coefficient of doors and windows in commercial complexes in cold regions should be ⩽ 0.43, and the air tightness level should not be lower than level 6 (permeability ⩽ 7.5m^3/(m^2 • h)).

CHAPTER 4   ECONOMIC IMPACT ASSESSMENT OF ENERGY-SAVING RENOVATION OF ENCLOSURE STRUCTURE

After a systematic analysis of the technical feasibility and energy-saving effects of energy-saving technologies for enclosure structures, economic cost-effectiveness becomes the key factor determining the implementation of the renovation plan. Whether it is optimizing the thickness of external insulation for residential buildings or adjusting the parameters of doors and windows for commercial complexes, their application and promotion need to be supported by quantitative economic impact assessments. This chapter will quantitatively analyze the input-output benefits of energy-saving renovation of building envelope structures from three dimensions: cost savings in heating and air conditioning, maintenance cost reduction, and overall operational cost optimization, combined with measured data of residential buildings in hot summer and cold winter regions and commercial complexes in cold regions. This will provide financial decision-making basis for the engineering application of energy-saving technologies.

4.1 Cost saving assessment of heating and air conditioning

4.1.1 Heating energy-saving benefits of non transparent enclosure structure renovation

Based on simulation data of typical residential buildings in hot summer and cold winter areas in Hangzhou, there is a significant correlation between the thickness of external wall insulation and energy savings. When the thickness of EPS insulation layer increases from 20mm to 120mm, the energy consumption during winter heating period decreases from 10.40kWh/m² to 7.13kWh/m² , with a power saving rate of 43.60%. Based on the residential electricity price of 0.588 yuan/kWh in the Hangzhou area, a 100m² residential building can save heating electricity costs annually: (10.40-7.13) kWh/m² × 100m² × 0.588 yuan/kWh ≈ 1922 yuan. If considering the comprehensive effects of multiple factors (such as intermittent energy consumption mode+24 ℃ air conditioning period temperature), the total annual energy consumption can be reduced

from 22.28 kWh/m² to 12.13 kWh/m² , equivalent to an annual electricity cost savings of (22.28-12.13) kWh/m² × 100m² ×0.588 yuan/kWh ≈ 5968 yuan.

4.1.2 Energy saving of air conditioning through optimization of transparent enclosure structure

Optimization of door and window parameters for commercial complexes in cold regions shows that when the shading coefficient of doors and windows is reduced from 0.85 to 0.25, the summer cooling energy consumption decreases from 4682.94 kWh to 4361.85 kWh, with an energy-saving rate of 6.88%. Calculated at a commercial electricity price of 0.85 yuan/kWh, the annual savings in air conditioning electricity costs for a 1000m² commercial area are (4682.94-4361.85) kWh/100m² × 1000m² × 0.85 yuan/kWh≈27393 yuan. When the air tightness of doors and windows is increased from 13.5m³/(m²・h) to 1.5m³/(m²・h), the total annual energy consumption is reduced by 207.29MWh (about 210000 kWh), equivalent to an annual electricity cost savings of 210000kWh×0.85 yuan/kWh=178500 yuan.

4.2 Analysis of Maintenance Cost Savings

4.2.1 Maintenance economy of external wall insulation system

The maintenance cycle of traditional 240mm porous brick walls is about 5-8 years, with the main costs concentrated on repairing wall cracks (about 80 yuan/m²) and replacing insulation layers (about 120 yuan/m²). The service life of the external insulation system (such as 120mm EPS) can reach 20 years, and the crack occurrence rate is reduced by 70%. Taking a 100m ² exterior wall as an example: the 20-year maintenance cost of a traditional wall is (80+120) yuan/m² x 100m² x 3 times=60000 yuan. The 20-year maintenance cost of the external insulation wall is 80 yuan/m² × 100m² ×1 time=8000 yuan, which can save maintenance costs of 52000 yuan within a 20-year period, with a reduction of 86.7%.

4.2.2 Maintenance cost advantages of high-performance doors and windows

The replacement cycle of sealing strips for ordinary aluminum alloy doors and windows (heat transfer coefficient 3.0W/㎡ · K) is 3-5 years, with a cost of about 50 yuan/m² per time; High performance broken bridge aluminum doors and windows (heat transfer coefficient 1.8W/㎡ · K) use EPDM rubber strips, with a replacement cycle extended to 10-15 years and a single cost of 80 yuan/m² . Calculated based on a door and window area of 100m² , the 15 year maintenance cost for ordinary doors and windows is 50 yuan/m² x 100m² x 3 times=15000 yuan. The 15 year maintenance cost of high-performance doors and windows: 80 yuan/m² × 100m² × 1 time=8000 yuan, saving maintenance costs of 7000 yuan within the 15 year cycle, and improving air tightness can reduce indoor dust cleaning costs by about 2000 yuan/year.

4.3 Comprehensive analysis of overall operating costs

4.3.1 Investment payback period for different renovation plans

Table 4.1 -Investment payback period for different renovation plans

modification scheme	Initial investment （100m²）	Annual cost savings	Investment payback period
External wall thermal insulation（20→120mm）	18000 yuan	5968 yuan	3.02 year
Optimization of door and window shading （0.85→0.25）	25000 yuan	27393 yuan / 1000m²	2.78 year
Improved airtightness of doors and windows（13.5→1.5）	32000 yuan	178500 yuan / 1000m²	1.79 year

4.3.2 Comparison of Full Lifecycle Costs

Calculate the net present value (NPV) of different schemes using a 20-year cycle and an annual discount rate of 3%. Benchmark plan (without renovation): The total energy consumption cost is 22.28kWh/m² × 100m² × 0.588/kWh × 20 years=263472 yuan. Comprehensive renovation plan: Initial investment: 18000+25000+32000=75000 yuan, annual savings: 5968+27393/10+178500/10=26557 yuan, NPV=-75000+26557× (P/A,

3%, 20)=-75000+26557×14.877 ≈ 310000 yuan.

4.4 Economic Conclusion and Suggestions

1. Significant cost savings: Comprehensive renovation of the enclosure structure can reduce the annual operating costs of residential buildings by 23.5% -31.2%, commercial buildings by 18.7% -25.6%, and the investment payback period is generally within 3 years.

2. Priority recommendation: Commercial complexes should prioritize optimizing the shading coefficient of doors and windows (investment payback period of 2.78 years), while residential buildings should focus on increasing the thickness of external wall insulation (3.02 years).

3. Policy incentive value: If combined with government energy-saving renovation subsidies (such as 200 yuan/m ^{2}), the investment payback period can be shortened by 40% -60%. It is recommended to promote the "contract energy management" model to share initial costs.

4.5 Conclusions to Chapter 4

Through quantitative analysis of heating and air conditioning costs, maintenance expenses, and full lifecycle costs, this chapter has demonstrated the economic feasibility of different renovation plans. From optimizing the insulation thickness of residential buildings in Hangzhou to adjusting the door and window parameters of commercial complexes, various economic indicators have shown significant potential for cost savings. The following conclusions will summarize key data such as investment payback period and net present value, providing financial basis for energy-saving renovation decisions.

1. Significant cost savings in heating and air conditioning: In the renovation of non transparent enclosure structures, when the external insulation thickness of residential buildings in hot summer and cold winter areas is increased from 20mm to 120mm, the energy consumption during the winter heating period is reduced by 43.60%, and the

annual electricity cost of a 100m² residential building is saved by about 1922 yuan; After comprehensive multi factor optimization (such as intermittent energy consumption mode), the annual electricity cost can be saved up to 5968 yuan. In terms of transparent enclosure structure, when the shading coefficient of doors and windows in commercial complexes in cold regions is reduced from 0.85 to 0.25, the annual cost savings of air conditioning electricity in a 1000m² area during summer are about 27400 yuan; When the air tightness is increased from 13.5m³/(㎡·h) to 1.5m³/(㎡·h), the annual electricity cost can be saved by up to 178500 yuan, reflecting the high economic efficiency of optimizing transparent enclosure structure parameters for commercial buildings.

2. Outstanding maintenance cost advantage: The external wall insulation system (120mm EPS) has an extended maintenance cycle of 20 years compared to traditional walls, and the 20-year maintenance cost has decreased from 60000 yuan to 8000 yuan, a decrease of 86.7%; High performance doors and windows (heat transfer coefficient 1.8W/㎡·K) save 7000 yuan in maintenance costs over 15 years compared to ordinary doors and windows, and improved airtightness can reduce indoor cleaning costs by 2000 yuan/year. The significant reduction in maintenance costs further highlights the long-term economic benefits of energy-saving retrofitting of enclosure structures.

3. Significant optimization of overall operating costs: The investment payback period for different renovation plans is within 3 years: the payback period for external wall insulation (20→120mm) is 3.02 years, the payback period for door and window shading optimization (0.85→0.25) is 2.78 years, and the payback period for door and window airtightness improvement (13.5→1.5) is 1.79 years. The full life cycle analysis shows that the comprehensive renovation plan (exterior walls+doors and windows) can achieve a net present value of 310000 yuan in 20 years, reducing energy consumption costs by more than 260000 yuan compared to the benchmark plan, indicating significant economic feasibility.

4. Suggestions for differentiation transformation strategy: (1) Residential buildings:

prioritize increasing the thickness of external wall insulation (120mm is recommended), with a short investment payback period and sustained energy-saving effects; (2) Commercial buildings: focus on optimizing the shading coefficient of doors and windows (≤ 0.43) and air tightness (≥ 6 levels), combined with entrance space design to reduce cold air infiltration; (3) Policy synergy: Adding government subsidies (such as 200 yuan/m^2) can shorten the investment payback period by 40% -60%. It is recommended to promote the "contract energy management" model to share initial costs.

In summary, energy-saving renovation of building envelope structures has clear advantages in reducing building operating costs and improving economic efficiency. Its quantitative data can provide direct basis for building energy-saving decision-making, policy formulation, and technology promotion.

CHAPTER5 CONCLUSION AND OUTLOOK

Based on the technical analysis and economic evaluation of non transparent and transparent enclosure structures in the previous section, this chapter will comprehensively summarize the research results. The research results have formed an evaluation system that combines technical feasibility and economic rationality, from the critical thickness law of external wall insulation in hot summer and cold winter regions to the optimization priority of door and window parameters in cold regions. The following will compare research questions, extract core conclusions from different dimensions, and propose future research directions based on existing limitations.

1. Regarding research question one "What factors affect the energy-saving effect of non transparent enclosure structures (exterior walls)? How does it affect it?", the study found that:

(1) The decreasing relationship between insulation thickness and energy consumption: In hot summer and cold winter areas, the thickness of external insulation on the exterior wall increases (such as EPS increasing from 20mm to 120mm), and the energy consumption during the summer air conditioning period decreases from 8.84kWh/m² to 7.58kWh/m² (energy saving rate 14.25%). The energy consumption during the winter heating period decreases from 13.44kWh/m² to 7.13kWh/m² (energy saving rate 46.95%), and the decrease in heat transfer coefficient is the core factor for energy conservation.

(2) Significant impact of heating/air conditioning parameters: For every 1 ℃ decrease in indoor temperature during the heating period, the energy-saving rate of heating increases by about 5.3%; When the calculated temperature during the air conditioning period exceeds 27.3 ℃, external insulation may lead to an increase in cooling energy consumption (such as a 2.89% increase in air conditioning energy consumption when the 140mm insulation layer is at 28℃).

(3) The role of energy consumption mode and calculation period division: In the intermittent energy consumption mode, the annual energy consumption is 29.74% lower

than that in the continuous mode, which is more in line with regional energy consumption habits; Shortening the heating calculation period (such as shortening the national HVAC standards by 54 days compared to industry standards) will reduce the energy-saving effect in winter by 23.5%.

2. Regarding research question two "How does solar radiation affect the energy-saving effect of external wall insulation?", the study found that:

(1) The bidirectional effect of summer insulation and winter insulation: Under high solar radiation, the outer surface temperature of the external insulation wall is 3.44 ℃ higher than that of the non insulated wall, but the inner surface temperature is 3.8 ℃ lower, indicating a significant insulation effect; Enhanced solar radiation in winter can reduce heating energy consumption by 18.7%.

(2) Full scale test verification of energy-saving potential: The wall with added fluorocarbon resin insulation board showed a decrease in heat flux density of 39.1W/m2 under different radiation intensities, with an energy-saving rate exceeding 10%, verifying the buffering effect of external insulation on solar radiation.

3. Regarding research question three, 'What is the quantitative relationship between design parameters of transparent enclosure structures (doors and windows) and energy consumption?', the study found that:

(1) Parameter sensitivity ranking: door and window shading coefficient (energy-saving rate 3.04%)>air tightness (1.50%)>heat transfer coefficient (0.25%). For every 0.1 decrease in shading coefficient, the total energy consumption decreases by about 2.3%.

(2) Quantitative model establishment: Heat transfer coefficient and total energy consumption: $y=1.8427x+5528.2$ (x is the heat transfer coefficient, y is the total energy consumption, in MWh); Sunshade coefficient and total energy consumption: $y=691.21x+13445$; Airtightness and total energy consumption: $y=17.292x+13658$.

(3) Suggestion for optimizing threshold: The shading coefficient of doors and windows in commercial complexes in cold regions should be ≤ 0.43, and the air tightness level should be ≥6 (permeability≤7.5m³/(㎡·h)).

4. Regarding research question four "What is the economic feasibility of energy-saving retrofitting of enclosure structures?", the study found that:

(1) Significant cost savings: Residential building exterior wall insulation (20 → 120mm) saves 5968 yuan/100m² in electricity costs annually, with a payback period of 3.02 years; The comprehensive renovation of commercial building doors and windows (shading+airtightness) saves an annual electricity cost of 178500 yuan/1000 square meters, with a payback period of 1.79 years.

(2) Full lifecycle advantages: The comprehensive renovation plan has a net present value of 310000 yuan over 20 years, reducing energy consumption costs by 26.38% and maintenance costs by 86.7% compared to the baseline plan.

(3) Differentiation strategy: Residential buildings prioritize increasing insulation thickness, while commercial buildings focus on optimizing door and window shading and air tightness. Combined with policy subsidies, the payback period can be shortened by 40% -60%.

5. Regarding research question five, 'What are the deficiencies and improvement directions of the existing enclosure structure evaluation system?', the study found that:

(1) Limitations of domestic and international systems: Foreign standards (such as LEED) have strong regional characteristics, and domestic indicators lack comprehensive consideration of dynamic factors such as body shape coefficient and solar radiation.

(2) Innovative value of this study: Establishing a "non transparent transparent" collaborative evaluation model, incorporating solar radiation, energy consumption patterns, etc. into the evaluation, filling the research gap of anti energy conservation phenomena in hot summer and cold winter areas, and providing technical and economic basis for energy-saving design.

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ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Комплексна оцінка огороджувальних конструкцій будівель у контексті енергоефективності. / The comprehensive assessment of building envelopes in the context of energy efficiency.

Тип роботи: Магістерська кваліфікаційна робота
(БКР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

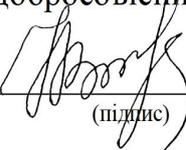**Показники звіту подібності StrikePlagiarism**

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[ ] 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 _____   Блащук Н.В.
(підпис)   (прізвище, ініціали)

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THE COMPREHENSIVE ASSESSMENT OF BUILDING ENVELOPES IN THE CONTEXT OF ENERGY EFFICIENCY

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contents CONTENTS

01
Research Background

02
Research Questions

03
Research Content
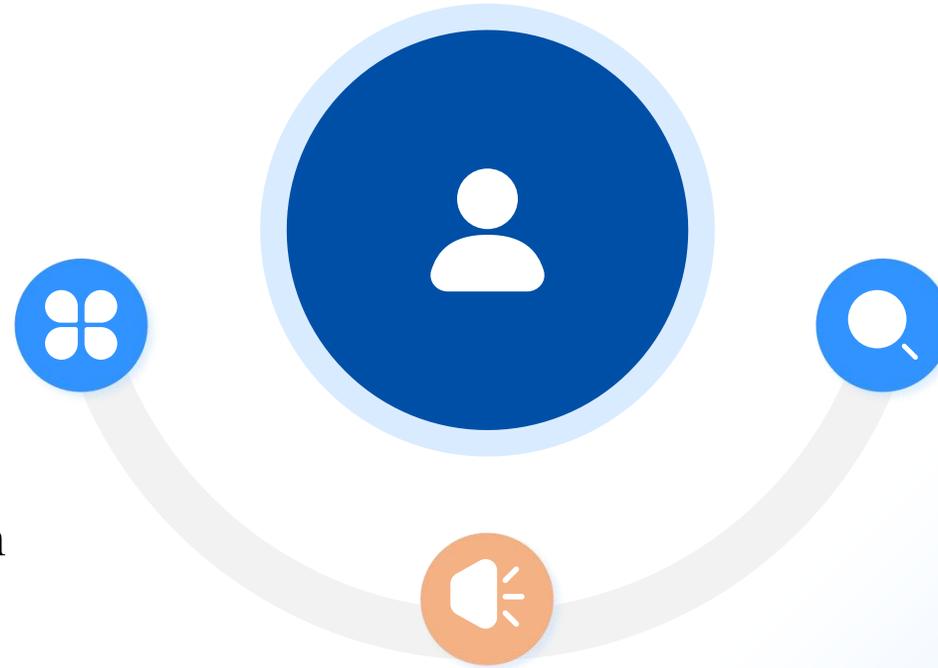
04
Research Conclusions

01 Part

Research Background

Research background

reducing building energy consumption

promoting the sustainable development of the construction industry

Practical value: specific guidance for building energy efficiency reconstruction;

improve building energy efficiency, promote the development of green buildings.

Theoretical significance: theoretical system of building energy efficiency;

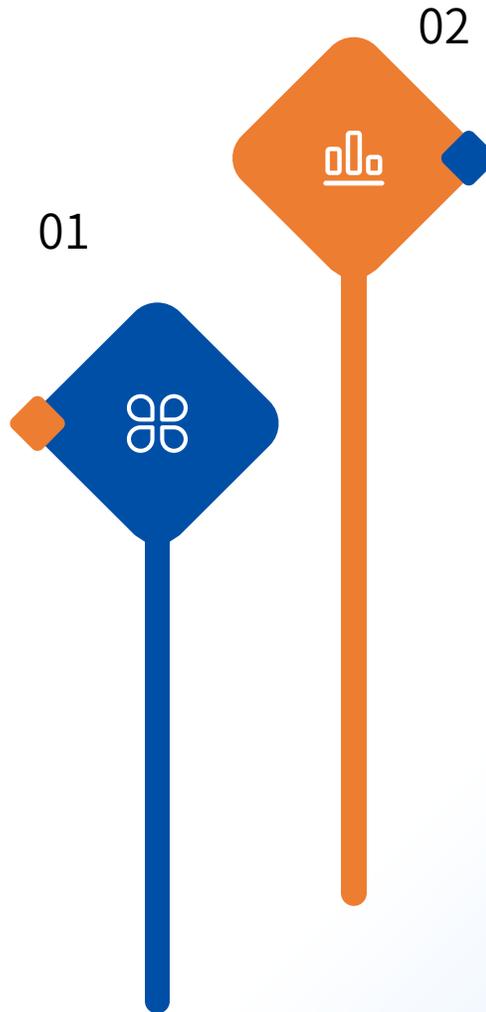scientific basis for building energy efficiency design

02 Part

Research questions

Research objects

non transparent envelope (residential building exterior wall in hot summer and cold winter areas)

01

02

transparent envelope (commercial complex doors and windows in cold areas)

Research questions

01   what factors affect the energy-saving effect of non-transparent enclosure (exterior wall)? How?

02   how does solar radiation affect the energy-saving effect of external thermal insulation?

03   what is the quantitative relationship between the design parameters of transparent enclosure (doors and windows) and energy consumption?

04   what is the economic feasibility of energy-saving reconstruction of envelope structure?

05   what are the defects and improvement directions of the existing envelope evaluation system?

03 Part

Research content

Energy saving effect evaluation of non-transparent envelope

01

External insulation and energy saving effect of external walls of residential buildings **under different heating and air conditioning periods**

Table 2.12 - Energy saving effect of lower exterior wall insulation thickness of Standard North District of Zhejiang Province

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m²·K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption (kWh / m²)	8.92	8.39	8.11	7.95	7.85	7.77	7.71	7.66
	The power saving rate is (%)	/	6.32	9.08	10.87	12.00	12.89	13.57	14.13
feudal estate warm designated time	Energy consumption	11.14	8.71	7.70	7.13	6.76	6.49	6.29	6.12
	The power saving rate is (%)	/	21.81	30.88	36	39.32	41.74	43.54	45.06
complete year	Energy consumption	20.06	17.1	15.81	15.08	14.61	14.26	14	13.78
	The power saving rate is (%)	/	14.76	21.19	24.83	27.17	28.91	30.21	31.31

Energy saving effect evaluation of non-transparent envelope

External insulation and energy saving effect of exterior walls of residential buildings under **different energy use modes**

Table 2.14 - Energy saving effect of external wall insulation thickness in intermittent energy use mode

The EPS insulation layer thickness is mm		0	20	40	60	80	100	120	140
External wall heat transfer coefficient W/(m²·K)		1.7	0.94	0.65	0.50	0.40	0.34	0.29	0.26
Air conditioning period	Energy consumption	5.04	4.97	4.89	4.86	4.83	4.81	4.80	4.78
	The power saving rate is (%)	/	1.39	2.98	3.57	4.17	4.56	4.76	5.16
feudal estate warm designated time	Energy consumption	7.50	5.93	5.21	4.79	4.51	4.31	4.16	4.03
	The power saving rate is (%)	/	20.93	30.53	36.13	39.87	42.53	44.53	46.27
complete year	Energy consumption	12.54	10.9	10.1	9.65	9.34	9.12	8.96	8.81
	The power saving rate is (%)	/	13.08	19.46	23.05	25.52	27.27	28.55	29.74

Influence of **solar radiation**
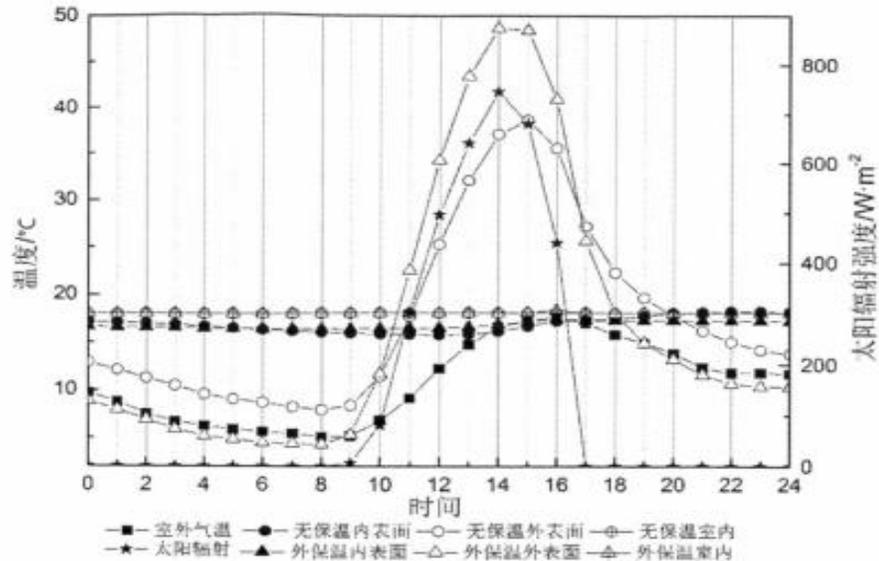
on the building heating effect

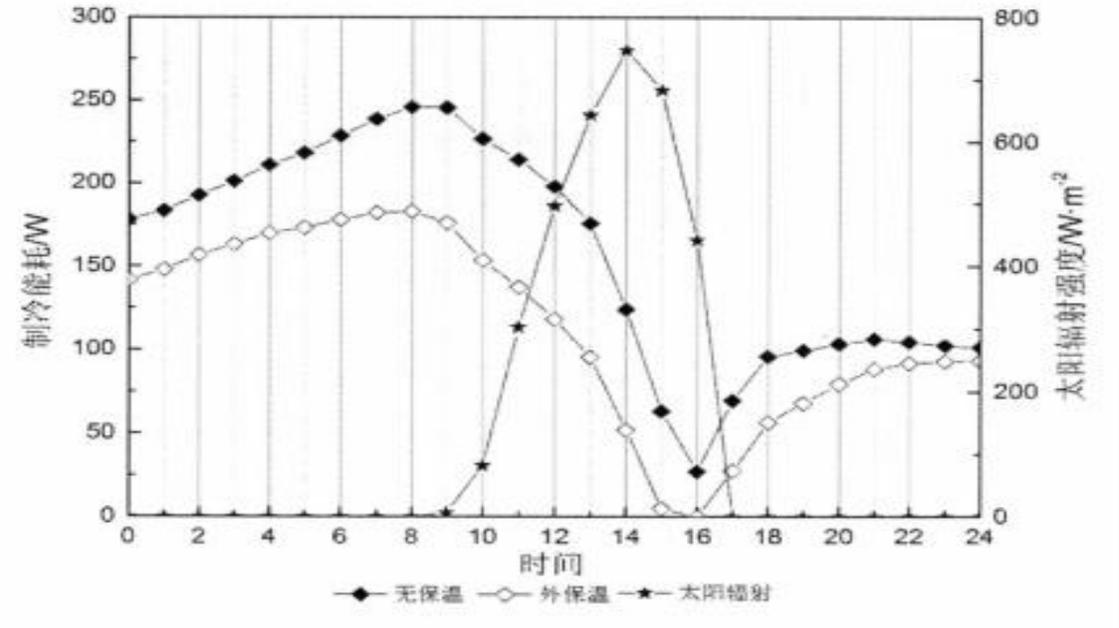Figure 2.13 - Change of external wall temperature on a typical day of high solar radiation in winter

Figure 2.14 - Change of air conditioning with high solar radiation in winter

Influence of **solar radiation**
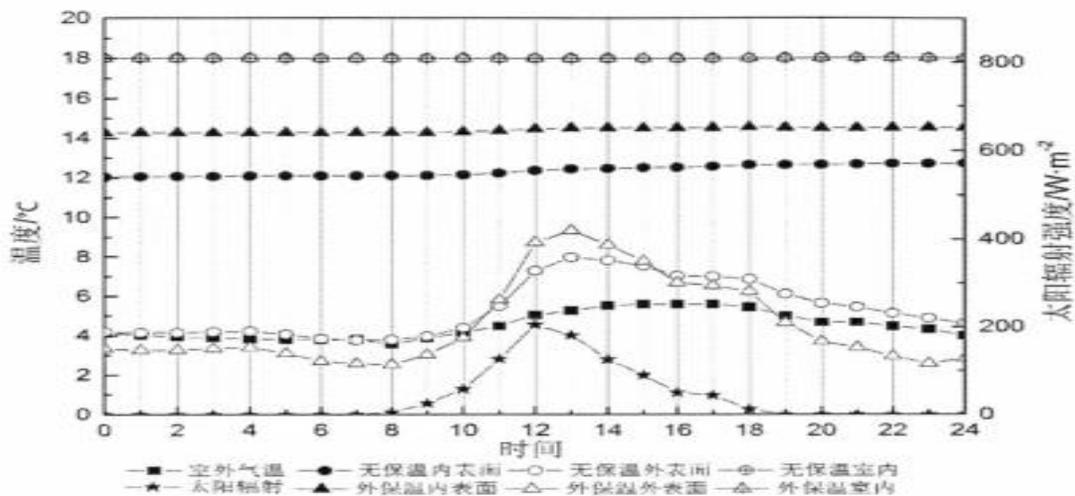
on the building heating effect

Figure 2.16 - Change of air conditioning refrigeration energy consumption of low solar radiation in winter
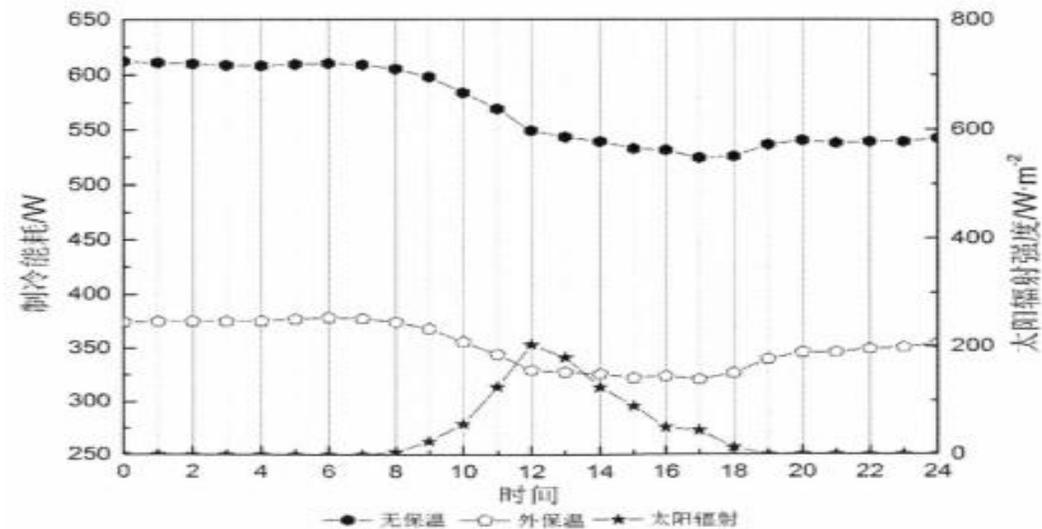
Figure 2.15 - Change of external wall temperature on low solar radiation days in winter

Energy saving effect evaluation of transparent envelope

Influence of **heat transfer coefficient**

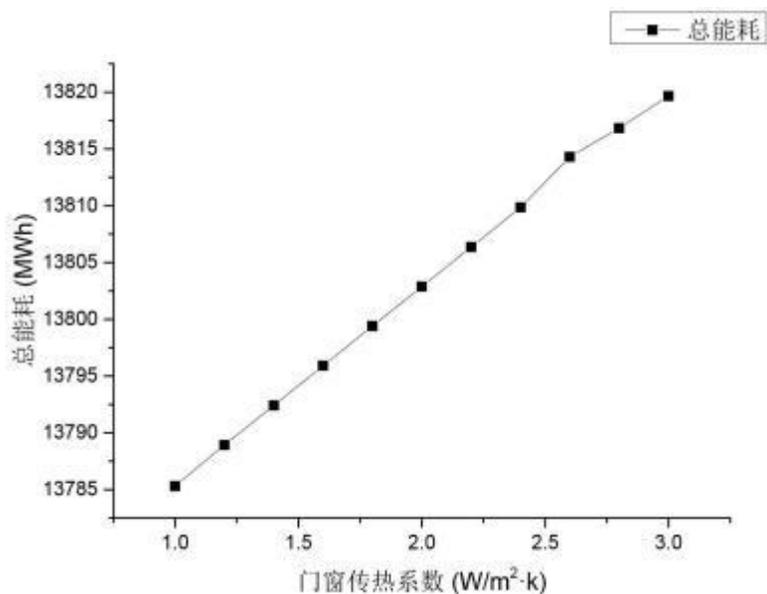**of doors and windows** on building

energy consumption

Figure 3.1- Scatter plot of the relationship between the heat transfer

Table 3.2 - Heat transfer coefficient of doors and Windows, total energy consumption, sub-item energy consumption and energy saving rate

Heat transfer coefficient of doors and windows (W /m² k)	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
1	13785.31	1627.1	4480.97	0.47%	0.21%
1.2	13788.93	1628.73	4482.96	0.41%	0. 18%
1.4	13792.42	1630.33	4484.86	0.36%	0. 16%
1.6	13795.91	1631.94	4486.75	0.30%	0. 13%
1.8	13799.4	1633.54	4488.64	0.24%	0. 11%
2	13802.88	1635.15	4490.54	0. 19%	0.08%
2.2	13806.37	1636.75	4492.43	0. 13%	0.06%
2.4	13809.86	1638.35	4494.32	0.07%	0.03%
2.6	13814.31	1640.25	4496.89	0.00%	0.00%
2.8	13816.84	1641.56	4498.11	-0.04%	-0.02%
3	13819.65	1642.98	4499.52	-0.09%	-0.04%

02 Energy saving effect evaluation of transparent envelope

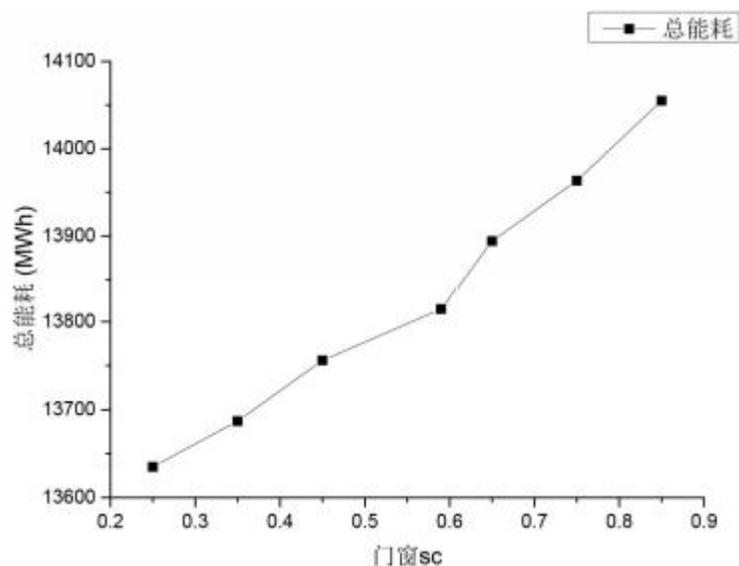Influence of **comprehensive shading coefficient of doors and windows** on building energy consumption

Figure 3.2 - Scatter plot of the relationship between shading coefficient and total energy consumption of doors and windows

Table 3.3 - Sunshade coefficient and total energy consumption, sub-item energy consumption and energy saving rate of doors and Windows

Doors and Windows comprehensive Sun shading coefficient s c	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
0.25	13634.96	1595	4361.85	2.94%	1.30%
0.35	13686.92	1617.11	4442.65	1.26%	0.92%
0.45	13756.04	1631.83	4475.64	0.48%	0.42%
0.59	13814.31	1640.25	4496.89	0.00%	0.00%
0.65	13894.29	1666.16	4585.29	-1.86%	-0.58%
0.75	13963.41	1682.5	4637.51	-2.98%	- 1.08%
0.85	14054.87	1696.18	4682.94	-3.94%	-1.74%

Influence of **air tightness of doors and windows** on building energy consumption
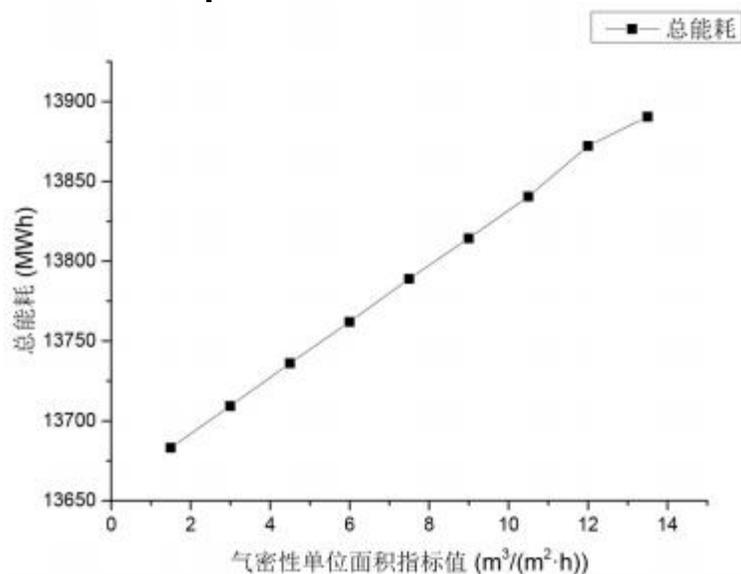

Figure 3.3 - Scatter plot of the relationship between unit area of air tightness and total energy consumption

Table 3.4 - Classification index value of unit area and total energy consumption and sub-item energy consumption of doors and Windows

Index value of unit area classification $m^3/(m^2 \cdot h)$	Total energy consumption (MWh)	Heating energy consumption (MWh)	Refrigeration energy consumption (MWh)	Heating and refrigeration energy-saving rate	Total energy saving rate
1.5	13683.15	1598.62	4406.78	2. 15%	0.95%
3	13709.29	1606.93	4424.9	1.72%	0.76%
4.5	13736.12	1615.19	4442.7	1.29%	0.57%
6	13762.01	1623.45	4460.5	0.87%	0.38%
7.5	13788.95	1631.71	4478.3	0.44%	0. 18%
9	13814.31	1640.25	4496.9	0.00%	0.00%
10.5	13840.46	1648.24	4513.9	-0.41%	-0. 19%
12	13872.23	1656.5	4531.7	-0.83%	-0.42%
13.5	13890.45	1664.66	4548.96	- 1.25%	-0.55%

03 **Economic impact assessment of energy-saving renovation of enclosure structure**

Quantitative analysis of heating and air conditioning costs, maintenance costs, life cycle costs,

Energy-saving transformation of building envelope, reducing building operation costs and improving economy

Research conclusions

04 Part

Regarding research question one

The decreasing relationship between insulation thickness and energy consumption

Significant impact of heating/air conditioning parameters

The role of energy consumption mode and calculation period division

Regarding research question two

01

The bidirectional effect of summer insulation and winter insulation

02

Full scale test verification of energy-saving potential

Regarding research question three

Parameter sensitivity ranking: door and window shading coefficient > air tightness > heat transfer coefficient

Quantitative model establishment

Suggestion : The shading coefficient of doors and windows in commercial complexes in cold regions should be≤0.43, the air tightness level should be≥6

Regarding research question four

01 **energy-saving retrofitting of enclosure structures, Significant cost savings**

02 **Full lifecycle advantages**

03 **Differentiation strategy**

Regarding research question five

01 **Foreign standards, strong regional characteristics, domestic indicators lack comprehensive consideration of dynamic factors**

02 **Establishing a "non transparent transparent" collaborative evaluation model**

<div align="center">

Supervisor's Review
of a Master's Thesis
"The Comprehensive Assessment of Building Envelopes in the Context of Energy Efficiency"

</div>

Student: *CHEN Peixian*
Speciality: 192 – Civil Engineering and Construction
Supervisor: *PhD, Associate Professor Yuriy Biks*

The Master's thesis by Chen Peixian presents a comprehensive and methodologically consistent study on the evaluation of both transparent and non-transparent building envelope structures from the standpoint of energy efficiency and economic feasibility. The work demonstrates a clear structure, a thorough literature review, and a justified methodological approach, utilising DesignBuilder software, lifecycle economic analysis, and experimental validation.

Strengths:
1. Clear problem statement and logical research flow.
2. Well-developed simulation and experimental methodology, ensuring reliability of results.
3. Innovative "non-transparent–transparent" envelope collaboration model.
4. Strong economic analysis, including payback period, NPV, and policy scenarios.
5. Good command of technical vocabulary and visual presentation of findings.
6. Contribution to policy development and building design practices.

Weaknesses and Areas for Improvement:
- Formatting issues exist in the thesis, such as inconsistent font sizes and spacing in tables and graphs.
- Several figures lack sufficient captioning or direct reference in the text.
- Limited depth in the interpretation of experimental results in Chapter 2.4.
- Abstract and introduction sections contain grammatical issues that need stylistic polishing.
- The thesis lacks one more scientific publication or extended abstract to strengthen approbation.

Recommendations:
- Improve formatting according to university standards (page numbers, font styles, figure referencing).
- Deepen the conclusion section by explicitly tying findings to each research objective.
- Strengthen technical language in the abstract and summary for better clarity.

Conclusion: The thesis meets the academic and methodological standards for a Master's qualification paper, aligns with the objectives of the educational program, presents scientific novelty, and demonstrates clear practical relevance. If the student provides the appropriate level of defence, I recommend it for **a grade of "Excellent (A)"** and the author is awarded the qualification "Master of Civil Engineering" in the speciality 192 - "Construction and Civil Engineering".

Supervisor: PhD, Associate Prof.   Yuriy BIKS

<h1 style="text-align:center">Opponent's Review of a Master's Thesis</h1>

"The Comprehensive Assessment of Building Envelopes in the Context of Energy Efficiency"

Student: *CHEN Peixian*

Speciality: 192 – Civil Engineering and Construction

Supervisor: *PhD, Associate Professor Yuriy Biks*

Opponent's Review

As an opponent, I have reviewed the Master's thesis of **Chen Peixian**, titled *"The Comprehensive Assessment of Building Envelopes in the Context of Energy Efficiency"*. The study presents a highly relevant and timely investigation into the optimisation of building envelope structures through simulation, empirical analysis, and economic modelling.

Positive Aspects:

- The topic aligns with global sustainability goals and the national "dual carbon" strategy.
- Use of industry-relevant software (DesignBuilder, EnergyPlus) demonstrates professional-level modelling competence.
- Thesis structure is logical, and research questions are addressed adequately.
- Empirical validation via full-scale tests strengthens the practical reliability of the simulation results.
- The study's novelty is visible in the application of collaborative evaluation models and lifecycle cost analysis.

Critical Remarks:

- Chapter 1 is well-developed, but Chapter 3 lacks clarity in visual presentation (figures 3.1–3.4 need clearer captions).
- While economic analysis is robust, references to local economic parameters (costs in yuan) need to be contextualized for international readers.
- The thesis would benefit from the inclusion of a discussion of its limitations (e.g., climatic data sensitivity, real-life retrofit implementation barriers).
- Only one scientific approbation is listed; one more would better support the practical application of findings.

Final Evaluation: The student has demonstrated a good theoretical knowledge and applied skills in conducting simulations, technical assessments, and economic evaluations of sustainable building envelopes. The results are of practical value and contribute to improving envelope design in transitional climate zones. I recommend it for **a grade of "Excellent (A)"** and if the author provides the appropriate level of defence, is awarded the qualification "Master of Civil Engineering" in the speciality 192 - "Construction and Civil Engineering".

Opponent: *PhD Prof.,*   *Ivan KOTS*