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

«Evaluating Building Envelopes for Enhanced Energy Efficiency:

A Comprehensive Assessment Approach»

Assigned by: 2nd year student, group__III B-22m

specialty 192 Construction and Civil Engineering

(code and name of field of study, speciality)

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«11»_______06_______2024

Vinnytsia VNTU – 2024

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Vinnytsia National Technical University

(Full name of the higher education institution)

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Department of Construction, Urban Planning and Architecture

Education level Second (master's)

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Educational professional program Industrial and Civil engineering

APPROVED

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«11» 03 2024

TASK

FOR MASTER QUALIFICATION THESIS TO STUDENT

Yunsheng ZHAI

(full name)

1. Master's thesis topic Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach

Master's thesis supervisor Biks Y., PhD, Associate Prof. of CUPA Department,

(full name, academic degree, academic title)

approved by order of the higher educational institution from «13» 02 2024 No 16

2. Work submission deadline by a master's student June 1, 24

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

4. Content of the explanatory note (list of issues to be developed): Introduction, which should reflect the topic's relevance, purpose, scientific novelty, practical significance, tasks, object and research subject. The research part, consists of three sections: Chapter 1, in which scientific analysis of the state-of-the-art multicriteria analysis of building envelopes, attitudes, including single technology design and planning design and the near zero energy building technologies, formulation of the research scope, criteria, software, search for relevant scientific sources, techniques should be performed; Chapter 2, in which factors affecting the energy-efficient building performance. Comparative analysis of insulating technologies for different building elements, should be performed; Chapter 3 – Building energy-efficiency analysis of case study. Key factors, schemes and modelling results. AHP modelling and analysis. Chapter 4 – Economic outcomes and optimisation of proposed energy-saving building

envelope design. Total summary reflects the significant scientific and practical results of the resea

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

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

6. Consultants of thesis parts

Chapter	Surname, initials and position of consultant	Signature and date	
		Task issued	Task accepted
Introduction, Chapter 1	Biks Y., Associated prof. of CUPA Department	[signature]	[signature]
Chapter 2	Biks Y., Associated prof. of CUPA Department	[signature]	[signature]
Chapter 3	Biks Y., Associated prof. of CUPA Department	[signature]	[signature]
Chapter 4 Economic pa	Biks Y., Associated prof. of CUPA Department	[signature]	[signature]

7. Task issuance date 13.02.2024

CALENDAR SCHEDULE

No	The stage name of the Master's qualification thesis	Work stages terms	Note
1	Scientific analysis of the state-of-the-art multicriteria analysis of building envelopes, attitudes, including single technology design and planning design and the standard energy-saving technologies, formulation of the research scope, criteria, software, search for relevant scientific sources, techniques. Preparation of Chapter 1.		
2	Preparation for the research, choice of appropriate tools and criteria.		
3	Preparation for Chapter 2. Factors affecting the energy-efficient building performance. Comparative analysis of insulating technologies for different building elements.		
4	Preparation of Chapter 3. Building energy-efficiency analysis of case study. Key parameters, AHP modelling results.		
5	Preparation the Chapter 4. Economic optimisation of proposed energy-saving design of building envelope. Total summary.		
6	Prepublication editing and publication of Master's qualification thesis results. Approbation		
7	Plagiarism check		
8	Preliminary defence of the Master's qualification thesis		

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(Signature) (Ssurname and initials)

Master's thesis supervisor [signature] BIKS Y.
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ABSTRACT

UDC 621.3.088

ZHAI Yungsheng. Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach. Master's qualification thesis on speciality 192 - Construction and Civil Engineering, Educational professional program - Industrial and Civil Engineering. Vinnytsia: VNTU, 2024. 78 p.

In English language. Bibliographer: 43 titles; fig.: 14; tables 19.

The master's thesis focuses on evaluating the energy efficiency of the building envelope from the perspective of multiple indicators (including thermal performance), and aims to establish an adaptive evaluation system of the building envelope combined with adaptive evaluation indicators.

This paper focuses on the performance indicators that have a key impact on the actual performance of buildings. Centering on the comprehensive performance level of high-performance building envelope, a key issue that restricts the actual performance of low-energy public buildings, this paper uses methods such as model construction, simulation analysis and empirical research to construct and verify the level of adaptability evaluation system of high-performance building envelope. To solve the lack of an adaptability evaluation system for a high-performance building envelope.

Based on the investigation of domestic and foreign energy-saving standards, technical characteristics of building suitability evaluation, influencing factors and existing demonstration projects, this paper analyses the energy-saving suitability evaluation principles and evaluation standards of non-transparent envelope structures of near-zero energy buildings. According to the Chinese standard "General Code for Building Energy Efficiency and Renewable Energy Utilization", the thermal performance index design of envelope structure comprehensively expounds the relevant theories in the design stage of low-energy public buildings and identifies the key factors affecting the comprehensive performance level of low-energy public buildings design. The comparison of different buildings with the same wall structure in the climate zone, the data processing of architectural design information, makes the evaluation and analysis of architectural design more objective, has certain innovations in the specific use of research methods, and lays a certain foundation for related research. Therefore, the impact of the evaluation system and simulation data is analysed, and the important influencing factors of each index are analysed to build a scientific and effective adaptation evaluation system for this climate type.

Master thesis contains 33 sheets of graphics.

Keywords: Near-zero energy buildings; EnergyPlus analysis, Architectural design; Enclosure structure; Optimization design; Simulation analysis; AHP, Adaptability evaluation system.

CONTENT

INTRODUCTION

In recent years, mankind's long-term high-emission development pattern has led to frequent global climate problems. As an important part of the city, buildings occupy a considerable share, but their overall energy consumption performance is poor. As the skin of the building, the envelope plays a crucial role in the energy exchange process inside and outside the building. It provides insulation for the building and reduces heat transfer between indoor and outdoor environments. With increasing emphasis on reducing energy consumption and greenhouse gas emissions, the research on assessing building envelopes to improve their energy efficiency has become a cornerstone of sustainable building design and renovation, underscoring the significance of your work in this field.

A complete approach to evaluating a building envelope includes thoroughly examining all aspects of a building's design, construction, and operation. This includes assessing the building's thermal performance, air tightness, insulation and humidity management. When evaluating the effectiveness of building renovation schemes, the research perspective shifts from the near-zero energy consumption level of building technologies to the actual performance evaluation in practical applications, considering the four main parts of technology, adaptability, innovation and economy, as well as local building codes and climate conditions. For example, in the hot area, research has shown that incorporating phase change materials (PCM) into building enclosures can improve comfort and save energy use. In general, evaluating a building envelope for energy efficiency requires a comprehensive evaluation process that considers design characteristics, insulation, air tightness, thermal performance, and moisture management.

By applying building energy consumption modelling, thermal performance assessment and energy benchmarking technologies, retrofit solutions can be prioritized to achieve sustainable building design.

Topic actuality. The thesis's main emphasis is on objective evaluation of energy-efficiency performance, finding patterns for decreasing energy consumption in the predesign stage of the building energy efficiency design. This work is committed to playing an important role in analysing and evaluating building energy efficiency design at home and abroad and developing energy-efficient design tools based on a preliminary decision-making process based on the proposed AHP model in China.

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

The purpose and objectives of the study.

– To conduct software simulation tests on typical walls to evaluate the suitability of the same insulation materials used in the same climate zone. Through the Energyplus simulation analysis [28], we verified and analysed the main factors influencing the same wall under the same climate conditions and provided corresponding support for the energy-saving construction of the building envelope.

– To establish the suitability evaluation system of the enclosure structure.

– To clarify its influencing factors and determine the degree of influence of key factors on the performance of the enclosure structure, including insulation, fire resistance, construction convenience, heat conduction, connection safety and economic performance.

Based on the above comparison and demonstration project research results, the corresponding insulation materials are selected, and the suitability evaluation system is established by using the analytic Hierarchy process (AHP). The weights were calculated by AHP, the results were recorded in the input AHP judgment matrix, and the weight values of the total target layer were obtained by calculating the scheme layer, so as to determine the suitable envelope structure system for different climate zones, and provide ideas for the design of high-performance building envelope structure.

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

Publications. A thesis [50] was published on Youth in Science: Research, Problems, Prospects (MN-2024)

Zhai Y., Biks Y. "EVALUATING BUILDING ENVELOPES for ENHANCED ENERGY EFFICIENCY: A COMPREHENSIVE ASSESSMENT APPROACH". URL: https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21435 (Last accessed 06.13.2024).

Acknowledgements. This research was mainly conducted and completed under the guidance of scientific supervisor Yuriy BIKS, whose proposed concepts for envelopes energy-efficiency assessment were detailed and considered in the thesis.

1 THEORY AND CURRENT RESEARCH STATUS OF BUILDING ENVELOPE

1.1 Building envelope

The building envelope is an important aspect of architectural design as it separates the interior from the exterior and protects the occupants from various elements. Analysis of the building envelope requires an understanding of the physical and functional requirements of the envelope, including water control, air control, heat control, steam control and biological control [1]. The walls, floors and roofs that form the building envelope at the time of design must be designed and constructed in accordance with these codes.

The overall energy efficiency of the building also depends on the thermal performance of the shell. Depending on the type of building and the temperature zone, the walls, floor and roof must have some thermal resistance. For example, hot walls in climate zones must have the heat resistance of R-10ci[*1]. On the basis of practice method and design standard, the performance of building shell is studied[1]. This area of research has the potential to improve building shell performance, reduce energy consumption, and improve occupant productivity and comfort [2]. It covers the study of building science and how heat, air and moisture are transported through the walls of a building. This research can reduce energy consumption, increase occupant comfort and productivity, and improve the performance and longevity of buildings [3].

[*1] High R-value assemblies: Provide building enclosures that meet the heating and cooling performance requirements of passive houses (including the combined performance of the entire envelope; CI = continuous insulation.

The general design and function of the building is heavily dependent on the character and efficacy of its enclosed structure. Strengthening building shell performance, reducing energy consumption, and improving occupant comfort and productivity can be achieved through building shell performance research, building science, and physical technology of building shell performance.

In the design process of the building envelope, it is necessary to consider the impact of the building shell on the overall structure, as well as the behavioral changes of the materials used in the construction. This covers the volume change of the material and the deflection of the structural frame [4].

In order to correctly analyze the impact of the building envelope on the overall structure, the design of the building envelope must take into account the behavioral differences of the materials used [2]. The analysis includes understanding the physical and functional requirements of the envelope, the behavioral differences of the materials used, and the environmental factors that affect it. These factors must be considered when designing the building envelope to ensure the durability, performance and energy efficiency of the building.

For example, when determining the dimensions of vertically moving joints, the design team needs to consider the volume change of the material and the deflection of the structural frame. To accommodate vertical movement, structural engineers must also understand the behavior of the building envelope and help with the detailed design of curtain wall joints and horizontal sealants [2].

In order to ensure the durability and function of the building, the building envelope needs to be able to withstand various climatic conditions, including wind, temperature and humidity [5]. Researchers have solved the problem of developing a systematic, logical, and consistent framework for studying, analyzing, and designing building enclosures.

In addition to taking into account the necessary natural phenomena and functions, the shell must be designed to support, regulate and complete the building. In addition, as the shell of the building and its interior modified version of the local environment, the materials used in these structures must be able to handle the climate-related loads they do. Additional features of the shell, the surrounding structures, and the landscape all alter these microclimates.

1.2 Research progress at home and abroad

1.2.1 Foreign research progress

In recent years, developed countries have implemented policies related to near-zero energy buildings. For example, the European Union has launched the Building Energy Efficiency Directive [6], which clearly indicates that new buildings need to meet near-zero standards before the end of 2020. Although these countries have certain differences in the technical methods and definition models of near-zero energy buildings, However, from the current point of view, most countries in the world do not have exact goals for the development of near-zero energy buildings [7], but from the perspective of research directions, it can be roughly divided into the following types.

A) Research on high-performance building shell structure

High-performance building shell structure is an important part of sustainable building. In the structure in particular, the best factors for energy efficiency, thermal comfort and environmental sustainability are achieved. These structures act as the building's outer protective barrier, affecting its energy use, ventilation system, indoor air quality and overall performance. The advanced package prioritizes energy efficiency, thermal comfort and environmental sustainability known as HBES（Home and Building Electronic Systems）. These are specially designed structures that reduce heat loss and energy consumption and increase comfort [8].

HBES components include heat-resistant materials, highly insulated Windows, effective steam control and airflow management systems. Air and moisture barriers are key factors in ensuring tight air and moisture, preventing airflow leaks, managing moisture, and protecting the indoor environment [9]. Advanced materials and construction methods that promote penetration, such as sealants and tape, are used. The steam barrier controls the flow of water within the building, preventing condensation, mold growth and structural damage. Rain and weather barriers screen the building structure to prevent moisture intrusion, prevent water damage, and maintain the integrity of the envelope [10].

Table 1.1—Factors Affecting Building Envelope Energy Efficiency

Key Factors	Description
1. Thermal Bridging	When heat is transmitted through a material with a lower therm al resistance than the surrounding materials, a thermal bridge occ urs, resulting in energy loss. Minimizing thermal bridging is cruc ial for improving energy efficiency.
2. Air Tightness	Achieving sealing is the foundation for preventing airflow and ai r leakage, which can cause temperature fluctuations and energy waste. High-performance enclosure designs are used to minimize uncontrolled airflow.
3. HVAC System Design	The design of the heating, ventilation, and air conditioning (HV AC) system has a significant impact on the energy efficiency of a building. An efficient HVAC system that is well integrated w ith the building envelope can optimize energy efficiency.

Key Factors	Description
4. Smart Lighting Controls	An intelligent lighting control system can optimize energy efficie ncy by adjusting the lighting level according to occupancy, dayli ght availability, and other factors. These control systems can sig nificantly reduce energy consumption.
5. Daylighting Strategies	Using daylighting strategies such as skylights and high-side wind ows can reduce reliance on artificial lighting and optimize energ y efficiency.
6. Integration of New Ener gy-Efficient Technologies	Integrating phase-change materials and aerogels, among other ne w energy-saving technologies, can furtherenhance the energy effic iency of building envelopes.

HBES is a key component of sustainable buildings, characterized by the ability to optimize energy efficiency, thermal comfort and environmental sustainability [8]. By understanding key attributes, defining their composition, and addressing factors that affect energy efficiency, researchers and practitioners can advance knowledge of sustainable building practices and contribute to creating a greener, more efficient built environment.

B) Near zero energy building design research

At present, the design stage is the mainstream stage of near zero energy building research, and there are many scholars to study this. Through energy and daylight simulation, Thalfeldt et al. identified the best cost and highest possible design facade solution, including window performance, exterior wall insulation, window wall ratio, and exterior shading [10], resulting in cost-effective energy savings. Kang et al. developed an economically viable optimization method for life cycle costs (LCC), which was developed using default data (e.g., planned operation data), energy consumption prediction equations, and cost prediction equations to apply energy-saving techniques to the early design stages of buildings [11]. Hamdy et al. compared seven multi-objective evolutionary optimization algorithms to test their performance in solving design problems for near-zero energy buildings, resulting in more than 1,610 solutions. The study found that in order to stabilize the optimization results of building energy consumption model, at least 1400-1800 evaluations are needed [12].

Net-zero building containment is the key to achieving sustainable and energy efficient building design. These measures focus on optimizing the building envelope to minimize energy consumption while maintaining occupant comfort. Key parameters of energy efficiency evaluation of building envelope in net-zero building design [15]:

B.1) Insulation and thermal resistance: Proper insulation and thermal resistance within the building envelope is essential to minimize heat transfer, reduce energy consumption and improve overall energy efficiency.

B.2) Penetration: Achieving penetration of the building shell is essential to prevent wind penetration, air leakage and temperature fluctuations, helping to improve energy performance and occupant comfort.

B.3) Mitigating the thermal bridge: Solving the thermal bridge problem by avoiding heat transfer through materials with low insulation values is critical to optimizing energy efficiency and reducing heat loss.

B.4) Moisture management: Evaluate moisture control measures such as steam barriers and rain screens to prevent condensation, mold growth and structural damage, ensuring healthy indoor air quality and long-term durability.

C) Evaluation of near zero energy building

Evaluation research is a cognitive process of comparing and judging the value and merits of objects. Researchers sift information from the data and use scientific methods to process evaluation indicators to get results. The comprehensive evaluation of near zero energy public building design focuses on the comprehensive performance, performance, benefit and energy saving degree in the design stage. The core of evaluation is to use scientific and objective methods to measure the design performance level of buildings, including energy saving rate, green degree, technology application and economic benefits. This contributes to a comprehensive understanding of design developments and provides a basis for optimization and energy efficiency [16]. The comprehensive evaluation system focuses on energy saving, environmental protection, economic and social benefits. The weight of indicators is considered in the evaluation to ensure that the results are fair and accurate.

1.2.2 Domestic research status

China's research on "near-zero energy buildings" is relatively lagging behind, and relevant technical standards have also learned from European practices. In 2006, China and Germany established the German-Chinese Working Group on Promoting Energy Efficiency in Buildings. At this time, China began the pilot construction of passive low-energy buildings, and successfully built the "Hamburg House" with typical near-zero energy consumption properties in 2010 [17]. In 2015, China's "Passive Ultra-Low Energy Green Building Technical Guidelines (Trial)" was officially promulgated and implemented, clarifying the concept of green buildings. In 2016, China further promoted the preparation of engineering standards, and successfully started the preparation of the "Near Zero Energy Building Technical Standard" GBT 51350-2019. This means that China has officially entered the construction period of near-zero energy buildings. In September 2019, the "Near-zero Energy Building Technical Standard" GBT 51350-2019 standard [18] was officially implemented, which also means that

China's definition of near-zero energy buildings has been clear, specifically, it is to further reduce 60% to 75% on the basis of the existing energy conservation standards. It can be seen that China is moving toward the development goal of energy-saving buildings oriented by realizing near-zero energy consumption, and is in line with the development of international energy-saving buildings.

In recent years, a number of near-zero energy buildings or ultra-low energy building demonstration projects have been built. However, in the near zero energy building design research, the current domestic research focus is mainly the technical problems proposed and solved. For example, Gao Caifeng et al. took the Museum of Architectural Art as an example to systematically introduce the core design principles and methods of near-zero energy buildings [19]. They emphasize that near-zero energy buildings require a unique design approach compared to traditional buildings, with a focus on passive energy saving technologies. Chu Yingnan et al. emphasized the feasibility of integrating photovoltaic technology into near-zero energy consumption buildings, and conducted a preliminary exploration of its integrated design [20]. This further enriches the architectural character of these buildings and enhances the overall effect of these buildings. Using multi-objective optimization technology based on artificial intelligence, Yu Zhenyu et al. took typical high-rise residential buildings as an example to analyze the equilibrium solution of different climate regions and optimize the performance of near-zero energy consumption buildings [21]. Their findings provide a valuable reference for establishing design standards for parameters related to near-zero energy buildings.

In addition to the above scholars' research, many domestic scholars have conducted a comprehensive analysis of near-zero energy buildings in different environmental zones.

Huang Shuo [22] et al. established low-energy buildings in cold regions and conducted Energyplus simulation analysis to find that in the two models with heat transfer coefficients of 0.21W/ m2 ·K and 1.7W/ m2 ·K for external walls and Windows, and 0.36W/ m2 ·K and 1.9 W/ m2 ·K, heating energy consumption is significantly lower than that of ordinary buildings. Sunlight also gets relatively little heat.

Li Huxing, Zhang Ran and other scholars conducted a systematic analysis of the related energy consumption of a near-zero energy building in Shenyang as the object. The building applies advanced envelope insulation technology, making the heat transfer coefficient 0.1 W/㎡·K; the outer window glass uses Low-e technology, making the heat transfer coefficient 0.8 W/㎡·K; a water-repellent rock wool and PVT photovoltaic curtain wall facility is set in the southwest outer wall, generating electricity while recovering waste heat to realize full-range solar energy utilization. Combining phase change energy storage technology, energy is used more reasonably, and the results in saving the dynamic changes of the air conditioning system load and the main influencing factors have been achieved [23]. Compared with the same type of buildings, the near-zero energy building in winter heating only accounts for about 74% of the energy consumption level of conventional buildings, and the total annual savings are about 55.1%, of which the air conditioning system has huge potential for saving.

Feng Honggui and others conducted sensitivity analysis on the design parameters of the envelope structure of residential near-zero energy consumption buildings and constructed a model to evaluate the impact of these parameters on the design [24]. Wang

Weidong and others conducted a control design strategy focusing on the prominent consumption problem in tall office buildings, taking the Tianjin Eco-City Public Housing Show Center as a case study, to achieve the expected results of the consumption quota target [25].

1.2.3 Summary of research status at home and abroad

From the development history of nearly zero-energy buildings at home and abroad, nearly zero-energy buildings have developed rapidly in the past three decades. Western countries have been constantly updating the concepts in this field and have launched a series of policies and evaluation methods. In the design stage, Western countries have gone from designing the physical characteristics of buildings in the initial stage to emphasizing the important role of design in the life cycle, and then to focusing on the application of design technology. The design research has been constantly developing and updating. For the evaluation research in the design stage of nearly zero-energy buildings, scholars from the technical field have proposed various scientific and systematic methods to evaluate and verify the effectiveness of the methods proposed by researchers. These evaluations focus on evaluating and verifying the effectiveness of the methods proposed by researchers, with an evaluation level that is relatively narrow [26].

The theoretical research in the field of near-zero energy building is still relatively weak, which to some extent hinders the comprehensive development of evaluation research. As a fundamental component of evaluation research, theoretical findings can offer essential support for indicator selection and composition, thereby establishing a solid foundation for the design assessment of near-zero energy buildings. A systematic design approach plays a pivotal role in selecting appropriate design schemes for near-zero energy buildings. Chinese scholars have systematically described various design schemes and highlighted key challenges faced, such as the application of passive energy storage technology, which significantly impacts the energy-saving performance of near-zero energy buildings. Addressing this core issue is crucial for achieving successful implementation of near-zero energy buildings [27].

At present, at home and abroad in the near zero energy building design stage discussion and verification of technical solutions have made some achievements, but still need to deepen. Although there have been some evaluation studies on near-zero energy building design, their evaluation scope is limited to the feasibility of technology or program, and the overall design level cannot be scientifically and effectively evaluated. Therefore, the lack of scientific and effective standards to support the building design scheme has led to a large difference in the overall actual performance of near-zero energy buildings. In order to realize reliable and comprehensive evaluation of near-zero energy buildings, it is very important to establish a perfect evaluation system.

Conclusion to the chapter 1

A) Summary: Through the investigation of domestic standards and relevant foreign energy-saving laws and other literature, the research status at home and abroad is analyzed, and the definition of near-zero energy building and the exploration process of reducing building energy consumption at home and abroad are understood. With the continuous increase of total energy consumption in China, the research on near-zero energy buildings is increasingly rich. Following the introduction of relevant energy-saving policies in European countries, China has summarized and released energy-saving standards successively. From energy-saving buildings to near-zero energy buildings, to zero-energy buildings and even to buildings with production capacity, domestic and foreign scholars have also conducted detailed studies on various factors affecting near-zero energy buildings. However, there is no comprehensive evaluation of the adaptability of high performance building envelope.

B) Research ideas of this paper:

First, in order to evaluate the suitability of the same insulation materials used in the same climate zone, we conducted software simulation tests on typical walls. Through the Energyplus simulation analysis [28], we verified and analyzed the main factors influencing the same wall under the same climate conditions, and provided corresponding support for the energy-saving construction of the building envelope.

Secondly, the suitability evaluation system of the enclosure structure is established. To this end, it is necessary to clarify its influencing factors and determine the degree of influence of key factors on the performance of the enclosure structure, including insulation, fire resistance, construction convenience, heat conduction, connection safety and economic performance. Based on the above comparison and demonstration project research results, the corresponding insulation materials are selected, and the suitability evaluation system is established by using the analytic Hierarchy process (AHP). The weights were calculated by yaahp, the results were recorded in the input analytic hierarchy process (AHP) judgment matrix, and the weight values of the total target layer were obtained by calculating the scheme layer, so as to determine the suitable envelope structure system for different climate zones, and provide ideas for the design of high-performance building envelope structure.

2 TYPICAL ENVELOPE STRUCTURE TEST

2.1 Typical enclosure structure

As mentioned earlier, studies can be conducted based on existing demonstration projects. The thermal insulation methods of building envelope in different climatic zones in China are different. According to the existing practices and data of energy-saving building envelope, the external wall thermal insulation materials in warm summer and warm winter areas are mainly lightweight mortar and thermal insulation mortar. However, when the technical system of building envelope structure is not mature, there is a gap between the actual thermal resistance and heat transfer performance of wall structure and the design expectation. Therefore, it is necessary to simulate the performance of the insulation system of the enclosure structure in some demonstration projects.

Take the "limit values of heat transfer coefficient and thermal inertia index for wall structures in residential buildings in different climatic zones" and "limit values of heat transfer coefficient and thermal inertia index for wall structures in public buildings in different climatic zones" from the "Construction Standard Design Drawings of National Building Code" 09J908-3 "Energy-saving Engineering Practices and Data for Building Envelope Insulation" [29].See Table 2.1 and Table 2.2.

Table 2.1 — Thermal conductivity coefficient and thermal inertness index limit of residential building wall in hot summer and warm winter area

<table>
<tr><td rowspan="2">Hot summer and warm winter</td><td rowspan="2">Outer wal</td><td>K≤2.0,D≥3.0
or K≤1.5,D≥3.0
或 K≤1.0,D≥2.5</td><td rowspan="2">The external wall heat transfer coefficient in the table is the average heat transfer coefficient including the structural thermal bridge K...</td></tr>
<tr><td>K≤0.7</td></tr>
</table>

zone			D is the thermal inertness index of the main part of the external wall. The limits of wall thermal conductivity and thermal inertia index of residential buildings in hot summer and warm winter areas are specified in standard documents such as JGJ75-2012. These limits are determined on the basis of a large number of measured data, simulation calculations and expert experience.

Table 2.2－Limits of heat conduction coefficient and thermal inertness index of public building wall in hot summer and warm winter area

Hot summer and warm winter	External walls (including non-transparent wall screens)	K≤1.5	The external wall heat transfer coefficient in the table is the average heat transfer coefficient including the structural thermal bridge K... The limits of wall thermal conductivity and thermal inertia index of residential buildings in hot summer and warm winter areas are specified in standard documents such as JGJ75-2012. These limits are determined on the basis of a large number of measured data, simulation calculations and expert experience.

In order to gain a deeper understanding of the effectiveness of building envelope energy-saving engineering, three or more typical demonstration projects in the summer hot and winter warm regions were selected for model simulation testing of the building envelope structure [30]. Among the main tested objects were the heat transfer coefficient of the exterior wall, the thermal performance of the enclosure structure, and the surface temperature of the thermal bridges.

The method of envelope structure of demonstration project is selected from National Building Standard Design Atlas 09J908-3 (Figure 2.1) :

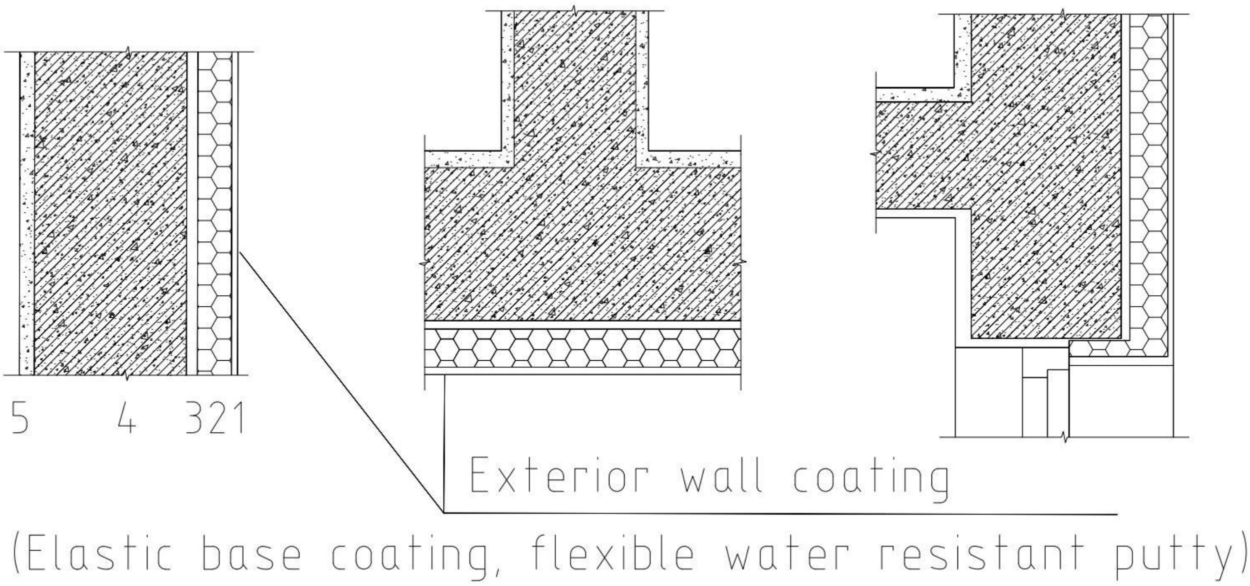


Figure 2.1 Typical enclosure structure with hot summer and warm winter

(1 - A layer of anti-cracking mortar composite alkali-resistant glass fiber mesh cloth is 5 thick (for the first layer, the thickness of anti-cracking mortar composite alkali-resistant glass fiber mesh cloth is 7 layers) : R = 0.005; D = 0.057;2 - EPS plate δ thickness: λc =0. 042; SC = 0.36;3 - Bonding layer;4 - Reinforced concrete wall 200 thick: r =0. 115; D = 1.98;5 - Plaster plaster mortar 7 thick: r =0.009; D = 0.085)

2.2 Typical Wall Structure and Analysis Method

2.1.1 The key influencing factors influence the selection

In the process of research, it is necessary to select the factors or indicators that have a greater impact on the energy saving of the wall part. However, the energy-saving effect of the wall is a complex issue, which is affected by many factors. These factors include: the thermal conductivity of wall materials determines its resistance to heat transfer [31]; Insulation thickness provides additional thermal resistance to reduce heat transfer through the wall; High surface reflectance can reduce the absorbed heat; Good penetration can prevent air penetration and reduce the resulting heat loss; Building orientation and design affect daylight and heat capture; The thermal insulation properties of Windows and doors exist as another heat transfer path; Shading facilities can reduce the heating effect of unnecessary solar radiation; The light color of the wall helps to reflect more and the remaining color is not absorbed to get more and send out for better results; The humidity in the wall will affect the material isolation effect; The overall penetration of the building includes all peripheral structures; Natural ventilation strategies effectively use natural wind for cooling; The internal layout and usage patterns of the building determine the demand and distribution; Maintenance and management to ensure long-term stable thermal insulation performance; Regional climatic conditions will affect architectural design and material selection. Building design standards guide energy efficient design and strictly enforce construction quality to ensure that design intent is achieved. By comprehensively considering these factors and taking corresponding measures, the energy efficiency of buildings can be significantly improved, the power consumption can be reduced, and the environmental conservation target can be achieved [27].

Because the research process uses different samples of the same area temperature and the same wall structure, the five factors of thermal conductivity, permeability, solar energy absorption coefficient, thickness and thermal reflectivity of the thermal insulation layer are selected to simulate and analyze their impact on the wall energy saving, which are referred to as thermal conductivity, permeability, solar energy absorption coefficient, thickness and thermal reflection in the following article.

2.1.2 Energyplus simulation analysis

Based on the above review, this paper uses EnergyPlus to simulate the thermal conductivity, permeability, solar absorption coefficient, insulation layer thickness and thermal reflectivity of different samples of the same wall structure in hot summer and warm winter areas to calculate the simulated power consumption. The control variable method is used to simulate a single coefficient floating.

2.1.3 Energyplus software introduction

EnergyPlus is an advanced building energy efficiency simulation software and is open source, which means it has an active developer community and ongoing technical support [32]. The open source nature of the software has also encouraged researchers and engineers worldwide to improve and extend it so that it can adapt to changing building technology and energy standards. It is widely used in performance analysis and design optimization of building energy systems. The software provides a detailed simulation environment that allows users to enter parameters such as the building's geometry, material properties, HVAC(Heating, Ventilation, and Air Conditioning) system configuration, and indoor and outdoor environmental conditions.

With these inputs, EnergyPlus uses physics-based calculations to model a building's energy use under specific climate conditions, including all aspects of heating, cooling, lighting and ventilation. The core advantage of the software is its high degree of flexibility and accuracy. It supports a wide range of building types and complex system configurations, and is able to handle simulation needs from simple residential to complex commercial and industrial buildings. EnergyPlus also has the capability of cross-season simulation to assess the energy performance of buildings in different seasons and different modes of operation.

2.1.4 Control variable method

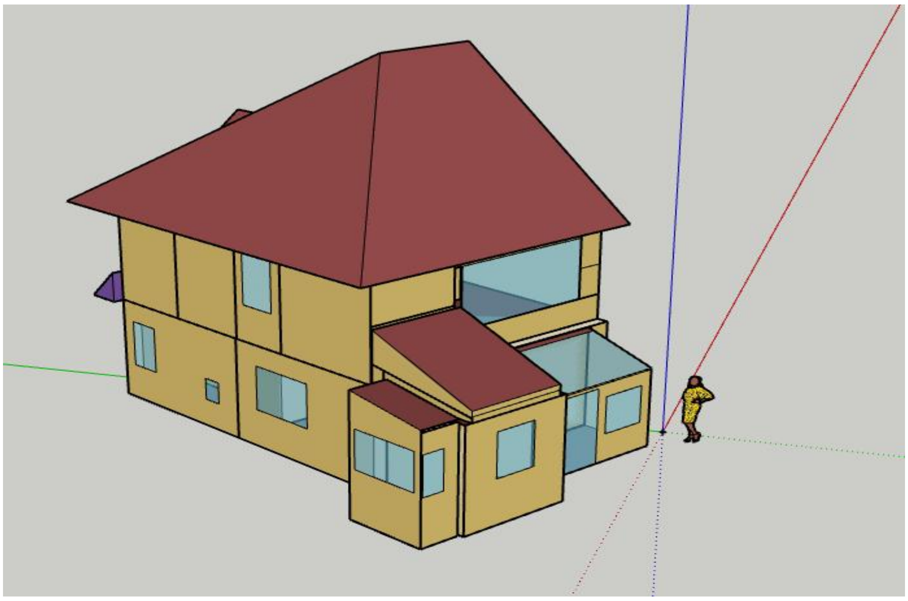
The control variable method is a scientific experiment design technique that determines the causal relationship between different variables by precisely controlling the experimental conditions. In this method, the researcher first identifies all the relevant variables in the experiment and divides them into independent, dependent, and control variables. An independent variable is one that the researcher intentionally changes to observe its effect. Dependent variables are outcomes that are expected to be affected by independent variables; The control variables are other variables that may affect the results except independent variables, and should be kept constant in the experiment to avoid interference [34].

Experiments are designed to ensure that all conditions are the same except for the independent variables, so that any observed changes in the dependent variables can be attributed to changes in the independent variables. Experiments typically involve the following steps: determining the research objective, identifying and classifying variables, controlling control variables, designing the experiment, conducting the experiment, collecting and analyzing data, repeating the experiment to ensure the reliability of the results, and interpreting the results.

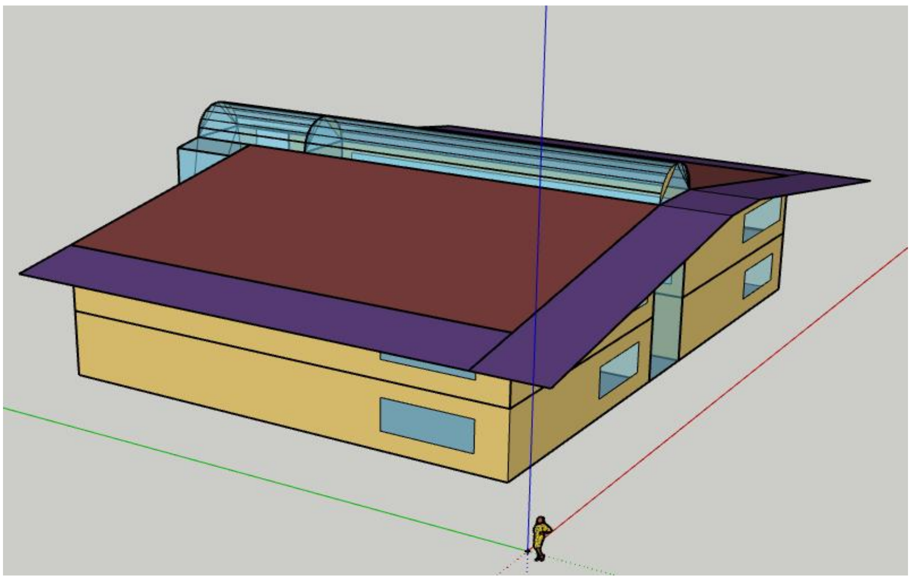
2.1.5 EnergyPlus simulation results and analysis were combined with control variable method

In order to analyze the technical evaluation index of the building envelope wall, the thermal conductivity, permeability, solar energy absorption coefficient, insulation layer thickness and thermal emissivity of the building energy-saving envelope wall were simulated and analyzed, and the basis was provided for the design and construction of the high-performance envelope structure.

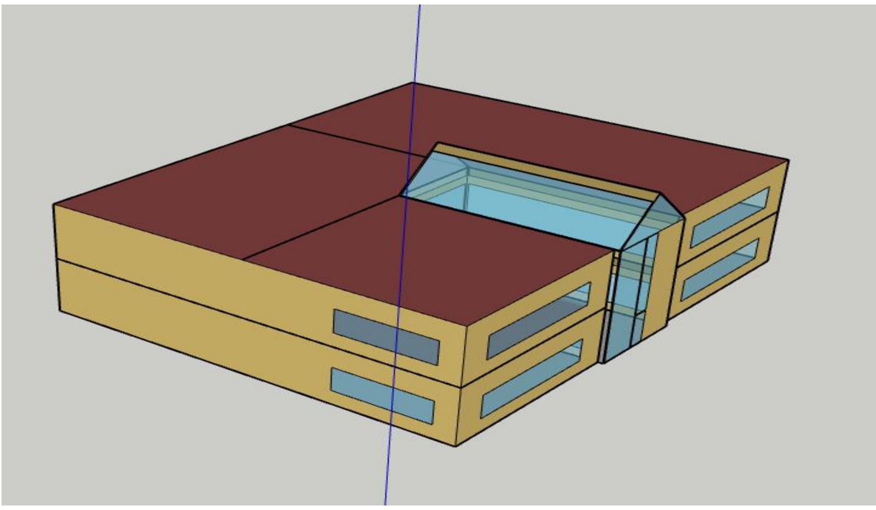
In the process of simulation analysis, three different model simulation data of A, B and C were carried out for the same structural wall under the same climate conditions in the same temperature region. The sample area of A was 101.25 ㎡, the sample area of B was 1036.16 ㎡, and the sample area of C was 850.88 ㎡, and the building samples were shown in FIG. 2.2.



a) Building Sample A



b) Building Sample B



c) Building Sample C

Figure 2.2 Building Sample

Each set of data lasts 8760 hours, and a total of 75 sets of cooling power consumption and heating power consumption data are collected. Since the simulated samples belong to the hot summer and warm winter region, heating energy consumption can only be generated in extreme weather, and the data statistical value is used to calculate cooling energy consumption, in which the median value is the usual coefficient of the insulation board on the market and the control variable method is used. The floating value of thermal conductivity is: 0.025, 0.030, 0.035, 0.040, 0.045, the unit is W/(m·k), the floating value of permeability coefficient is: 0.8, 0.9, 1.0, 1.1, 1.2, the unit is g/m^2h, the floating value of solar energy absorption absorption coefficient is: 0.4, 0.45, 0.50, 0.55, 0.60, the floating value of insulation layer thickness is: 0.005, 0.010, 0.015, 0.020, 0.025, the unit is m, and the floating value of thermal reflectivity is: 0.75, 0.80, 0.85, 0.90, and 0.95. The center is used as the common basic value. The energy consumption of the corresponding indicator is simulated and measured, as shown in Figure 2.3 to Figure 2.5.

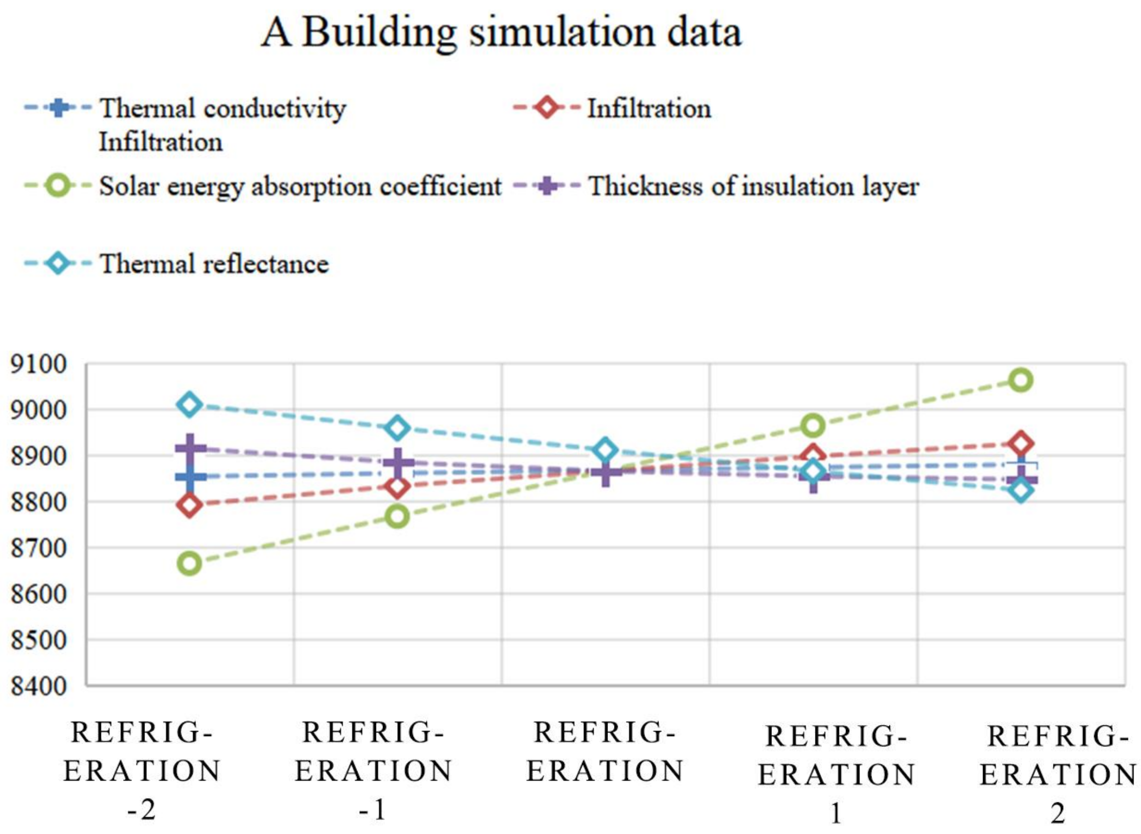


Figure 2.3 A Building simulation data

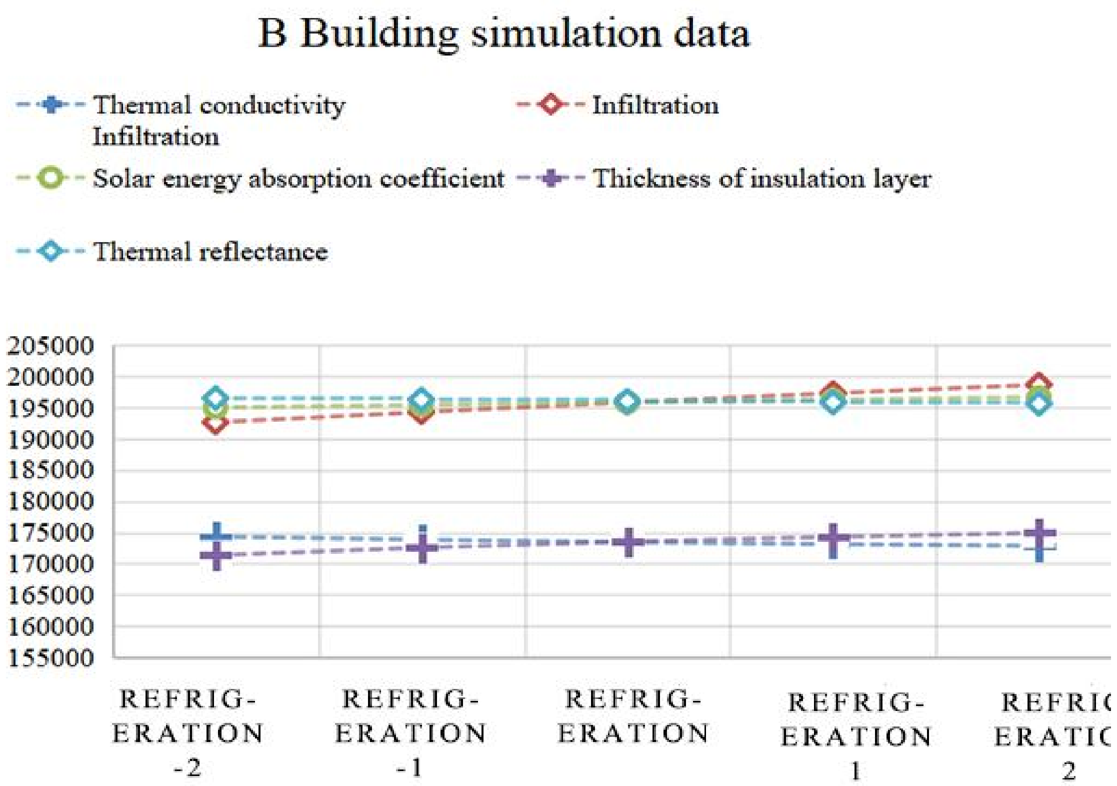


Figure 2.4 B Building simulation data

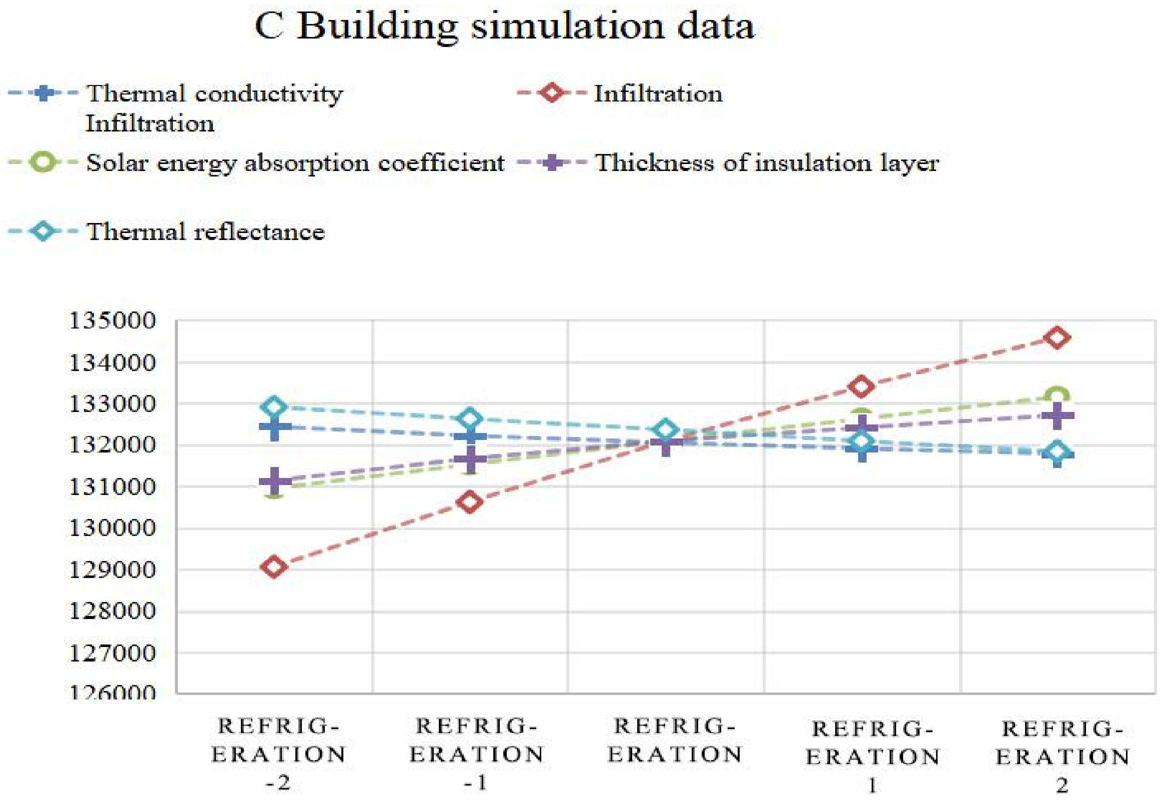


Figure 2.5 C Building simulation data

In the process of data sorting, the simulated energy consumption of buildings A, B and C is large, and the stacked data in the figure is not easy to analyze. In order to improve the comparability and visibility of the data, the original data is converted into floating percentage, which is positive and negative between 0% and 100% by calculating the fluctuation rate of energy consumption. The converted floating percentage data simplifies the comparison process. Data of different sizes or units can be directly compared, making it easier to reveal the relationship between the data.

The calculation of energy consumption fluctuation rate refers to the calculation of the percentage of energy consumption change in a certain period of time when the reference value (such as the average value or the energy consumption value in a specific period) is not fixed in the energy consumption data. The calculation formula of energy consumption fluctuation is as follows:

$$\text{Floating rate} = \frac{\text{Current energy consumption value} - \text{Baseline energy consumption value}}{\text{Baseline energy consumption value}} \times 100 \qquad (2\text{-}1)$$

The benchmark energy consumption value can be the energy consumption value of the previous period, the average value of a certain period, or any other reference value.

After the simulated data is substituted into Equation 2-1, the floating values of A, B, and C are shown in Figure 2.6 to Figure 2.8.

As can be seen from Figure 2-6, in the discounted graph of sample A data, energy consumption deviation of some indicators has a large fluctuation in the process of floating up and down the middle mean, and five key factors can be ranked according to the floating size of the numerical line. The greater the fluctuation, the greater the impact on energy saving, including thermal conductivity < permeability < thickness of insulation layer < thermal reflection coefficient < solar energy absorption coefficient.

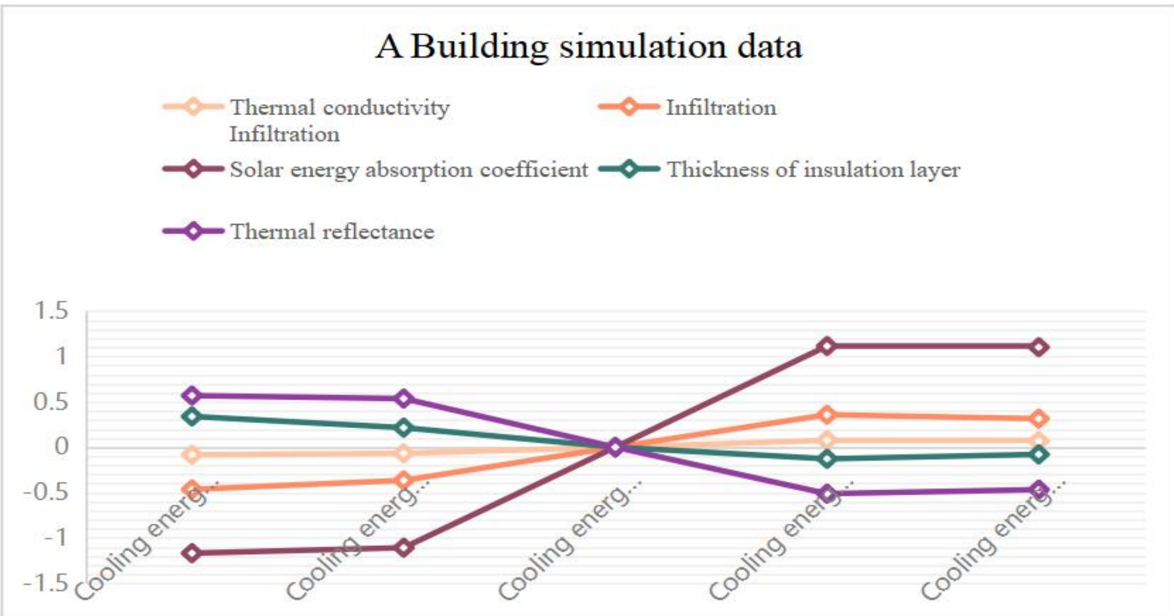


Figure 2.6 A Building simulation floating rate data

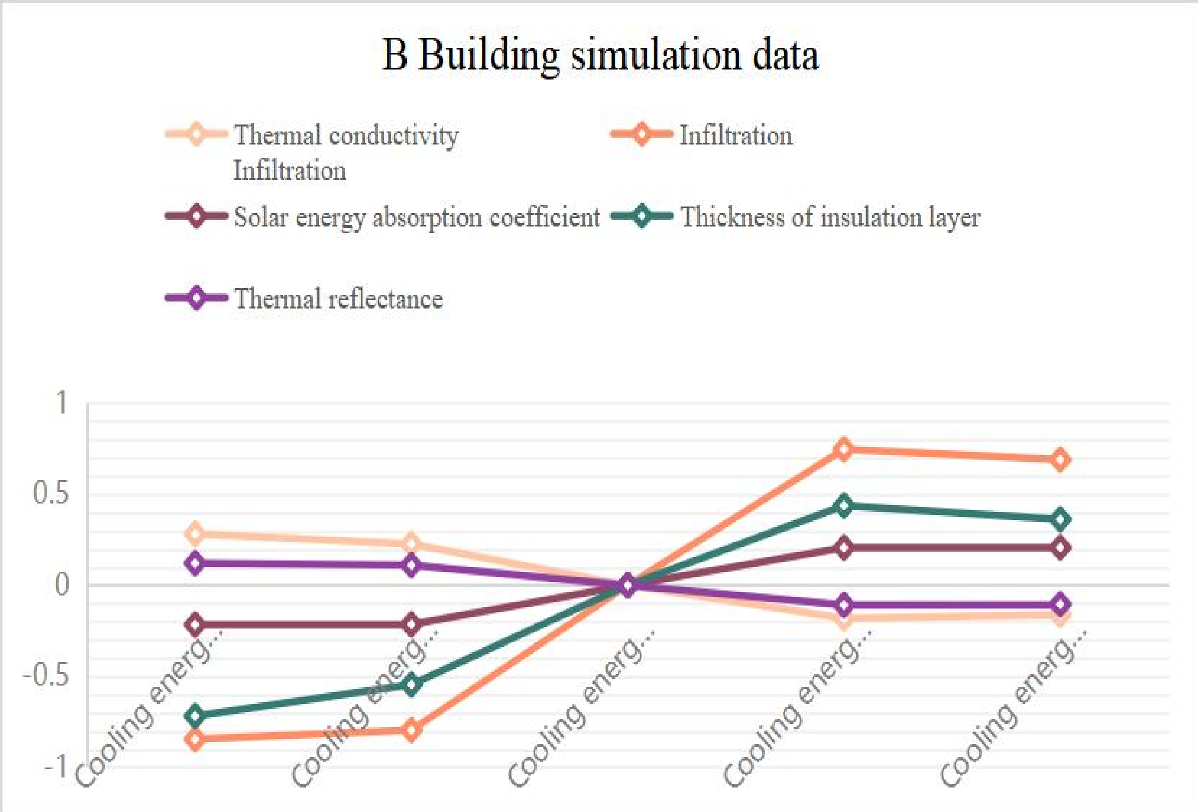


Figure 2.7 B Building simulation floating rate data

As can be seen from the data in Figure 2-7, in the process of floating up and down from the middle mean of sample B's data in the discount chart, some indicators have larger deviation and fluctuation, which is similar to that in Figure 6; however, the fluctuation of index energy consumption data is different, and it needs to be re-ranked. The greater the fluctuation, the greater the impact on energy saving. Where the thermal reflection coefficient < solar energy absorption coefficient < thermal conductivity coefficient < insulation layer thickness < penetration.

As can be seen from the data in Figure 2-8, in the process of floating up and down from the middle mean value in the discount chart of C sample data, some indicators have larger deviation fluctuation, but it is narrower than that in Figure 6 and 7. However, the curve fluctuation of indicator energy consumption data is different, and it needs to be re-ranked according to the floating size. The thermal conductivity < thermal reflectivity < insulation layer thickness < solar energy absorption coefficient < penetration.

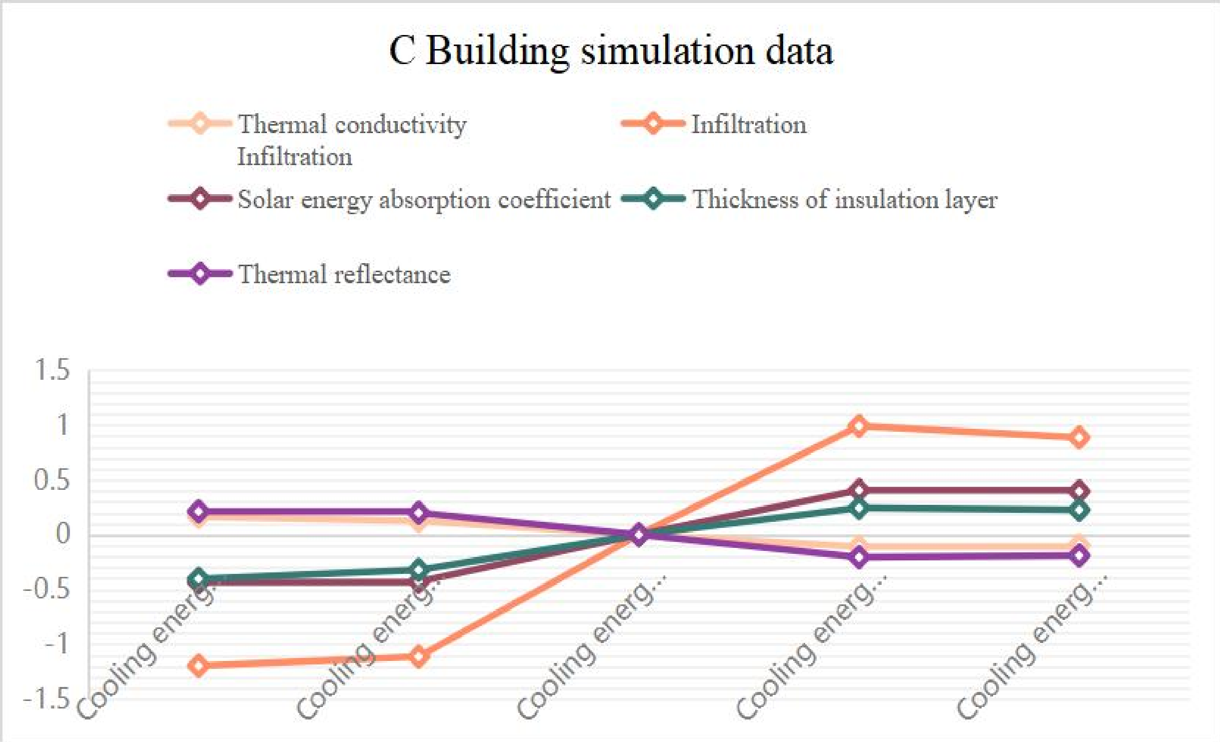


Figure 2.8 C Building simulation floating rate data

Conclusion to the Chapter 2

On the basis of the research in the first chapter, samples A, B and C in hot summer and warm winter areas are selected for simulation research. In this chapter, the key indicators of high-performance building envelope structure are sorted out through the introduction of typical envelope walls and data review, and the three model samples are simulated and analyzed by Energyplus software. Through the simulation of the main indexes of high-performance building envelope structure: thermal conductivity, penetration, solar energy absorption coefficient, insulation layer thickness, thermal emissivity, the following conclusions can be drawn:

A) From the Energyplus simulation data point of view, the five indicators from the original data or energy consumption floating rate statistics of the graph, a single indicator from the middle value floating up and down to produce a different energy consumption value, will not be a single with the index floating to save energy, it may also play the opposite role.

B) In the process of ranking indicators, the relative influence gravity is also obtained in the three groups of data fusion, thermal conductivity ≤ thermal reflection coefficient ≤ thermal insulation layer thickness ≤ permeability ≤ solar energy absorption coefficient. Due to the influence of other factors, it is also necessary to assign weights to them for AHP fuzzy evaluation.

C) From the data point of view, all the selected indicators will have a significant impact on the high-performance building envelope.

D) For the evaluation of samples with the same structure in the same climate region, other evaluation factors need to be added, and the main indicators cannot be viewed only.

3 ESTABLISHMENT OF ADAPTIVE EVALUATION SYSTEM OF HIGH PERFORMANCE BUILDING ENVELOPE

3.1 Establishment of evaluation system

For suitability technology, it needs to correspond to the actual conditions of the region, such as the local social, natural and economic environment, so that the corresponding system can have the best comprehensive benefits [34]. To this end, the evaluation system needs to meet the requirements of sustainable development. Through scientifically established evaluation standards and corresponding local experience and methods, adaptive evaluation should be carried out on the evaluation of high-performance building envelope structures. Among them, the evaluation index system can represent the suitability of evaluation objects to regional factors and enhance and expand the positive effects of appropriate technologies on local residential buildings. And the importance of each index is optimized. The purpose is to improve the adaptive evaluation level of energy conservation of building envelope structure, and to provide a basis for optimizing energy conservation transformation scheme and promoting energy conservation transformation of building envelope structure.

In addition, when establishing the evaluation index system, the following principles should be followed:

A) Adaptability principle

That is, the evaluation index can properly describe and measure the main key factors of the evaluation object, and it is not required to achieve 100% of all the characteristics of the performance evaluation object, but it should be able to describe the main characteristics and main information of the evaluation. In the complex object system, the evaluation index system based on the principle of comprehensiveness is generally stratified and classified.

B) Operability principle

The constructed index system should have certain operability, because the goal of the evaluation index is the provision of a certain aspect, it should reflect the essential attributes of the goal, and fully consider the quantification of the evaluation index and the difficulty of the data, so that the process can be operable.

C) The principle of predictability

The evaluation index system constructed can scientifically and effectively predict the basic trend of the future development of near-zero energy building design, so that the design system can be updated and improved on the basis of existing research, and relevant measures can be provided for government departments to formulate relevant policies [35].

D) Innovation principle

For the existing indicators, it is necessary to consider the comfort of human body, not to establish an evaluation system for seeking parameters, but to make sustainable improvements to the existing evaluation system with usability.

E) The principle of timeliness

The evaluation indicators and evaluation methods of adaptability evaluation are adjusted with the technical standards and specifications of near-zero energy consumption in various countries. In addition, the construction of the elements of the evaluation index system is determined on the basis of the current provisions of the relevant national norms. When there is a difference between the regional standard and the national standard for an evaluation index, the national standard should be considered.

F) Economic principles

Any evaluation system and the selection of building structural forms and materials are determined based on the economic environment, and all evaluation indicators are aimed at achieving energy savings while ensuring economic and cost effectiveness. This principle emphasizes that in the process of improving energy efficiency and reducing energy consumption, return on investment, cost-benefit analysis and long-term economic sustainability should be considered.

3.2 Selection of Evaluation Indicators

The evaluation system of energy-saving adaptability of high performance building envelope structure has its unique characteristics, and the evaluation index should be selected according to the architectural characteristics and regional characteristics. The key factors affecting the wall performance of the envelope structure mainly include thermal conductivity, permeability, solar energy absorption coefficient, thickness and thermal reflectivity, etc., while high-performance buildings have stricter requirements on the performance of the envelope structure than general buildings. Therefore, when analyzing the envelope structure of such buildings, it is necessary to create a corresponding difference evaluation system based on different climate environments. It provides an important reference for the design of near-zero energy building envelope.

Therefore, according to the thermal conductivity, permeability, solar energy absorption coefficient, thickness, thermal reflectance and economic performance of the wall of the enclosure structure, this chapter establishes the suitability evaluation system of the near-zero energy building envelope in hot summer and warm winter areas. At the same time, based on the reference of "Near zero Energy building Technical Standards" [36], "Near zero Energy Building Evaluation Standards" [37], foreign near zero energy building design standards and the existing green building design comprehensive evaluation system, etc., through the in-depth analysis of high-performance building envelope design research theory in chapter 1, evaluation indicators matching the research objectives of this paper are selected. For the construction of the evaluation index system, this paper divides the target criterion layer, namely the first-level index, into technical (B1), adaptability (B2), innovation (B3), economy (B4), and technical (B1), according to the order of the work in the design stage. The first-level index layer is subdivided into seven second-level index layers: exterior wall performance, roof performance, door and window performance, regional climate adaptability, active energy-saving innovation, market adaptability, construction cost; According to the properties of the envelope structure required by the regions with climate differences in hot summer and warm winter, the underlying influencing factors, that is, the third-level indicators, can be further derived based on the second-level indicators. The details of all indicators are shown in Figure 3-1 below.

3.3 Evaluation index content and description

According to the characteristics of high-performance building envelope structure and the results of previous evaluation studies in the green building design stage, four first-level indicators are analyzed, and the second-level indicator layer and the third-level indicator layer are derived respectively, so as to construct a comprehensive evaluation index system of near-zero energy public building design.

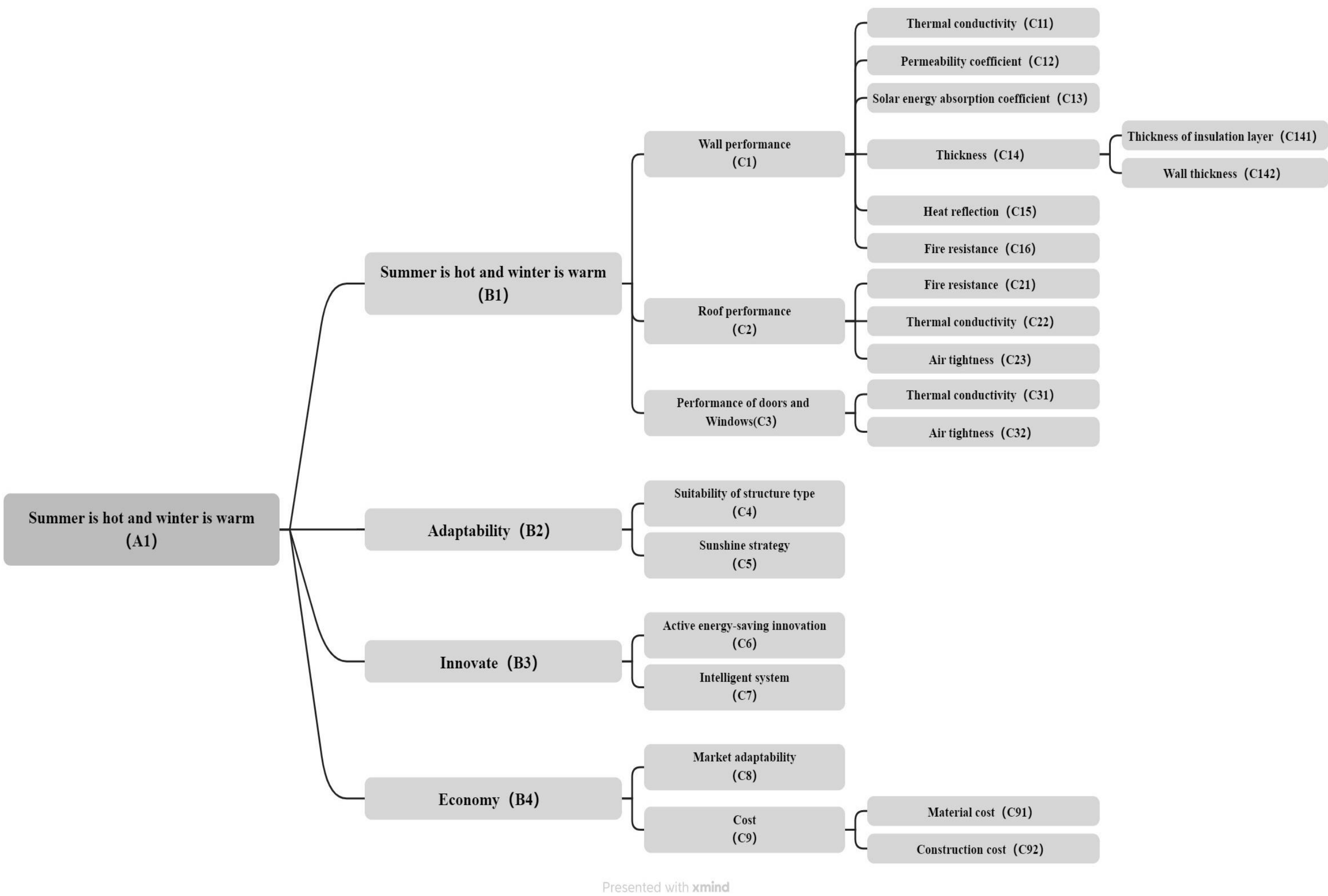


Figure 3.1 C Hierarchy diagram of suitability evaluation index of building envelope

3.3.1 Summer is hot and winter is warm（A1）

China is a country with very diverse geographical environment and climate types, from the cold northeast to the hot south, with significant differences in climate conditions in different regions [38]. Therefore, China needs to be classified according to the climate characteristics of different regions, and different architectural design and urban planning strategies are required in different climate regions to adapt to the local climate conditions and ensure the comfort of living and working environment.

Hot summer and warm winter areas are those that are very hot and humid in the summer and relatively warm and humid in the winter. This climate characteristic is common in subtropical climates, especially in parts of East Asia, such as the Jiangnan region of China, the southeastern United States, South America, and parts of Africa[39].

A) Technical

In the field of building energy efficiency, wall performance, roof performance, door and window performance need to ensure that the building meets the specific thermal performance requirements in the evaluation, evaluate the energy efficiency and energy saving potential of the building, analyze the impact of the building on the indoor and outdoor thermal environment, and ensure that the building design and construction comply with the relevant building codes and energy conservation standards.

A.1) Thermal conductivity: measures the ability of the material to transfer heat through the unit area and the unit temperature difference in a unit time, which is an important indicator to evaluate the thermal insulation performance of the material.

A.2) Permeability: Assessing the ability of a material to allow liquid or gas to pass through is of great significance for the waterproofing and airtightness of the building envelope.

A.3) Solar absorption coefficient: describes the proportion of solar radiation energy absorbed by the surface of a material and is crucial for assessing the thermal load and solar energy efficiency of a building.

A.4) Insulation layer thickness: directly related to the thermal insulation effect of buildings, is an important parameter in building energy saving design.

A.5) Thermal emissivity: Measures the ability of the material surface to radiate heat outward, affecting the thermal environment and energy consumption inside the building.

B) Adaptability

The adaptability of building energy conservation refers to the ability of building design, construction and operation to adapt to environmental changes, user needs and technological progress. This adaptability requires the building to operate efficiently, economically and comfortably under different climatic conditions, usage demands and energy supply.

Regional climate adaptability: The regional climate adaptability of building energy conservation refers to the ability of building design to realize energy saving and indoor environment optimization through efficient use of natural resources and adaptive technology by comprehensively considering the climate characteristics of a specific region [40].

C) Innovation

In the process of energy conservation evaluation, in addition to the evaluation of commonly used indicators, it is also necessary to draw closer to the cutting-edge research direction and technology of building energy utilization efficiency through advanced technical means and methods, so as to promote the development of the building industry in the direction of more energy conservation and environmental protection.

Intelligent system: The use of intelligent building management system to achieve real-time monitoring and optimal control of building energy use, improve energy efficiency.

D) Economy

The economy of building energy conservation refers to the various energy-saving measures and energy-saving technologies adopted in the process of building design and construction, which can not only reduce energy consumption, but also bring economic benefits by improving energy utilization efficiency and realize cost savings. By optimizing the energy system, using efficient equipment, improving the building envelope and other means, to achieve the dual goals of energy saving and emission reduction and economic benefits.

Material cost: New buildings and rebuilt buildings will involve energy-saving materials other than the materials of the building itself in the energy-saving process, and it is necessary to calculate whether it meets the project budget.

Construction cost: Construction cost is one of the key factors to evaluate the economic rationality of energy-saving measures. By comparing the additional cost of energy-saving measures with the long-term energy-saving benefits, the economic feasibility of the project can be judged [39].

3.4 Weight Analysis of Indicators Based on AHP Method

3.4.1Methods for Determining Weights

The assignment of index weights [41] is the key path for the construction of evaluation system model and directly affects the final evaluation result. Weight refers to the importance of a certain factor or indicator relative to related things. Different from ordinary proportions, it not only shows the ratio corresponding to the indicator, but more critically shows the importance and contribution degree of these factors relative to specific affairs. Therefore, in order to ensure the accuracy of comprehensive evaluation of near-zero energy consumption public building design, it is necessary to adopt a scientific and reasonable method to determine the weight of evaluation indicators.

There are several ways to determine the weights, each of which is suitable for different scenarios and needs. When calculating the full weight, it needs to be divided according to the difference of the original data, which can be commonly divided into subjective weighting method and objective weighting method.

Subjective weighting, as a weight calculation method, mainly relies on the experience and knowledge of the interviewee. In current practice, Delphi method and Analytic Hierarchy Process (AHP) are two main methods. Delphi method is mainly based on the experience and knowledge of experts, and carries out in-depth judgment and analysis of various indicators. After several rounds of anonymous scoring process, until a consensus conclusion is reached, the final assignment can be completed. The rule of hierarchical analysis is to compare various factors contained in the same level index based on their relative importance. After strict mathematical test and determination, the weight of each index is obtained. As a classical and scientific method, analytic hierarchy process (AHP) is often chosen as the main research means and is widely used in various evaluation systems.

Objective weighting method is a weight analysis method dominated by quantitative analysis, which mainly includes principal component analysis method and entropy weight method. By implementing linear transformation technology, principal component analysis method can reduce dimensionality of multiple variables, and then screen out key indicators for subsequent weight evaluation. The entropy weight rule focuses on the accurate quantitative weight analysis of each index according to the information characteristics of the sample itself, combined with the definition and characteristics of entropy. These two methods together constitute the core content of objective weighting method and provide strong support for scientific decision-making.

From the perspective of subjective empowerment, its current maturity is at a higher level. The significant advantage of this method is that experts can reasonably rank different weights based on specific decision problems and corresponding knowledge and experience, so as to ensure that there is no inconsistency between weight attributes and actual importance. In view of these advantages, this paper chooses Delphi method and analytic hierarchy process in the subjective weighting method in the weight analysis, in order to conduct a more accurate and scientific analysis of the evaluation system [42].

3.4.2 AHP

AHP analysis method, as a method to deal with multi-objective optimization problems, was first proposed by American operations research scientist T.L. Schaty in the 1970s. The core of this method is to decompose complex problems into multiple factors of different levels, and then calculate the weight coefficient of all evaluation factors to the overall goal based on human experience, judgment and comparison. This process not only reflects the scientificity and systematicness of AHP analysis, but also plays a key role in the decision-making process and provides important support for selecting the optimal scheme [43].

The basic steps of using analytic hierarchy process are as follows[44-46]:

(1) Construct the hierarchical analysis structure model, systematically disassemble the overall goal by layers, and divide it into multiple factors covering the target layer, criterion layer and scheme layer.

(2) Construct judgment matrix. According to the constructed hierarchical analysis structure model, the factors in the criterion layer and the scheme layer are compared and scored, and the scoring standard is set to 1 to 9 points. The higher the score is, the more important the former factor is compared with the latter factor. Through this scoring process, the judgment matrix is formed.

(3) Perform a consistency check. Since matrix calculation may not be completely transitive, it is necessary to carry out consistency test on the judgment matrix constructed in the preceding steps, in order to verify the consistency and rationality of its internal logic, and optimize and modify the matrix and evaluation system accordingly.

3.4.3 weight calculation

Delphi method is adopted in this paper to ensure the objectivity and scientificity of index weights. To this end, we adopted the form of multi-objective questionnaire to determine [47]. The main objects of this survey include energy-saving building designers, researchers and energy-saving building users, three major stakeholders.

In view of the fact that near-zero energy buildings are an emerging building type, we pay special attention to the relevant professional background and in-depth understanding of the field of architectural design when selecting the survey objects. The specific selection principles are as follows:

A) For energy-saving building designers, we selected professionals with rich experience and profound theoretical foundation in the field, the designers have at least five years of green building design experience and more than two years of near-zero energy building design experience, and participate in the design of at least one near-zero energy building in the form of design team. To ensure that they can provide accurate and valuable opinions and suggestions.

B) For researchers, we focus on selecting university teachers who have participated in the research of high-performance building envelope structures, mainly university researchers who have participated in design and research, and need to have more than 5 years of research experience in related fields.

C) For energy-saving building users, we focus on selecting users who have practical experience and have a certain understanding of the characteristics of near-zero energy buildings, so as to understand the advantages and disadvantages of near-zero energy buildings in actual use from the perspective of users. The users are divided into existing users and potential users. Due to the small number of buildings currently put into operation, the owners of near-zero energy buildings do not form a certain volume. However, in order to further enrich the survey data and expand the survey sample to include potential users of the building in the future, potential users must have a full and comprehensive understanding of near-zero energy buildings. The ratio of occupied users to potential users is controlled between 1:3 and 1:2.

According to the above strict selection principles, a total of 50 questionnaires were issued in this survey, which ensured the representativeness and professionalism of the survey objects and provided strong data support for the subsequent weight determination of indicators, including 20 energy-saving building designers, 20 researchers, and 10 energy-saving building users. Among them, a total of 32 reply questionnaires were recovered, of which 25 were valid reply questionnaires. See Figure 3.2 to Figure3.4 for the specific situation of the respondents.

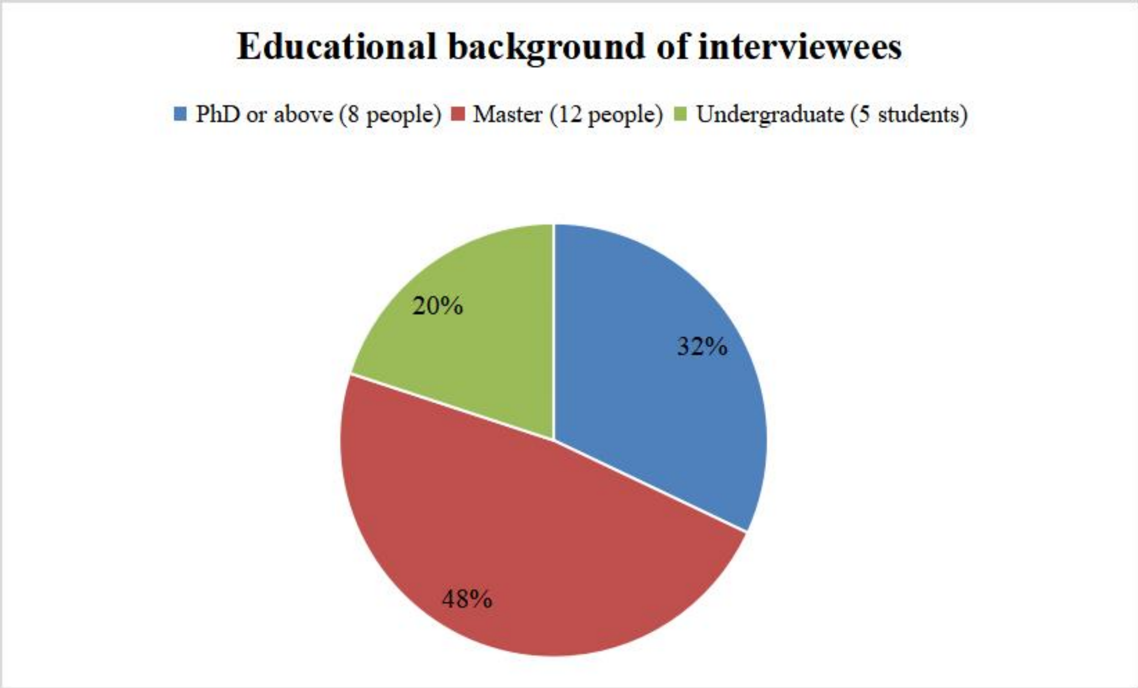


Figure 3.2 Educational background of the persons under investigation

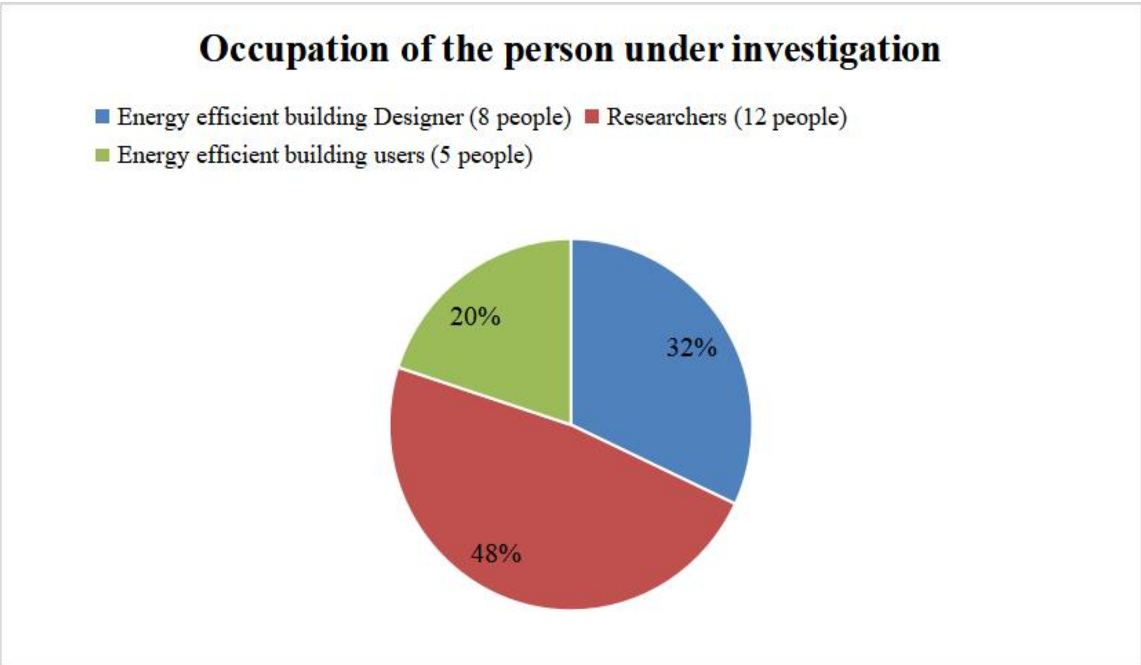


Figure 3.3 Occupation of the person under investigation

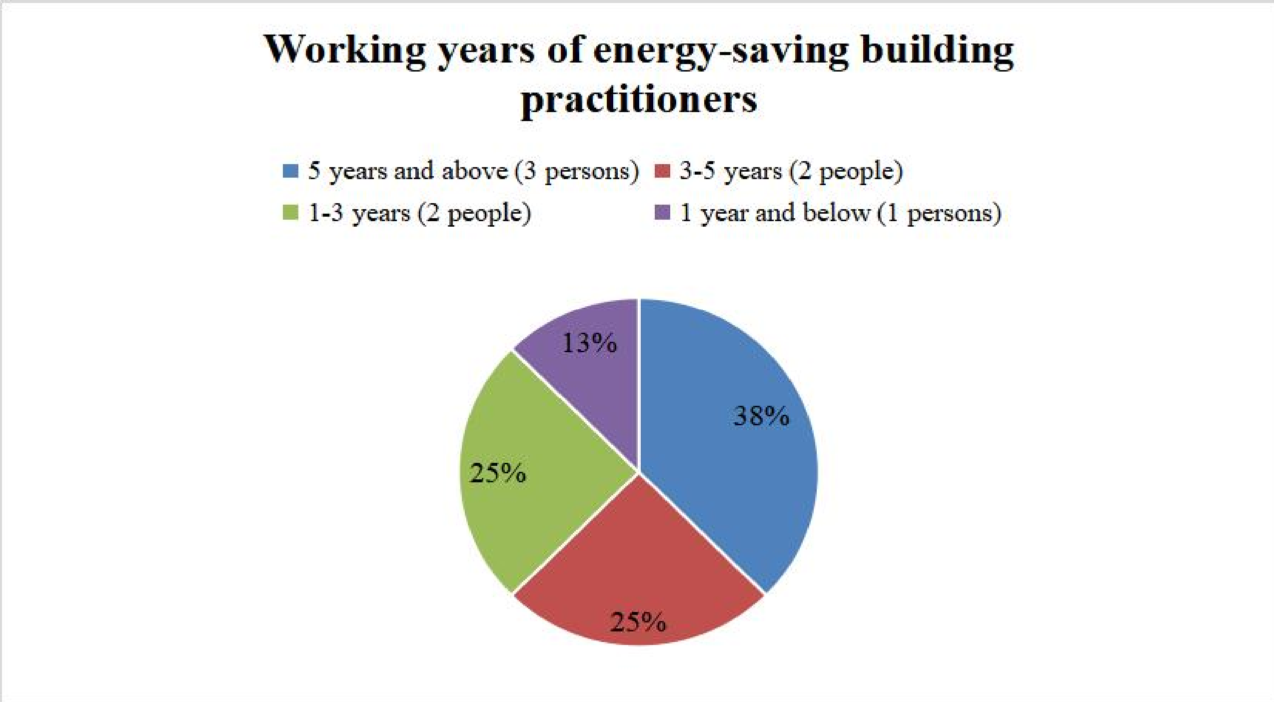


Figure 3.4 Working years of energy-saving building practitioners

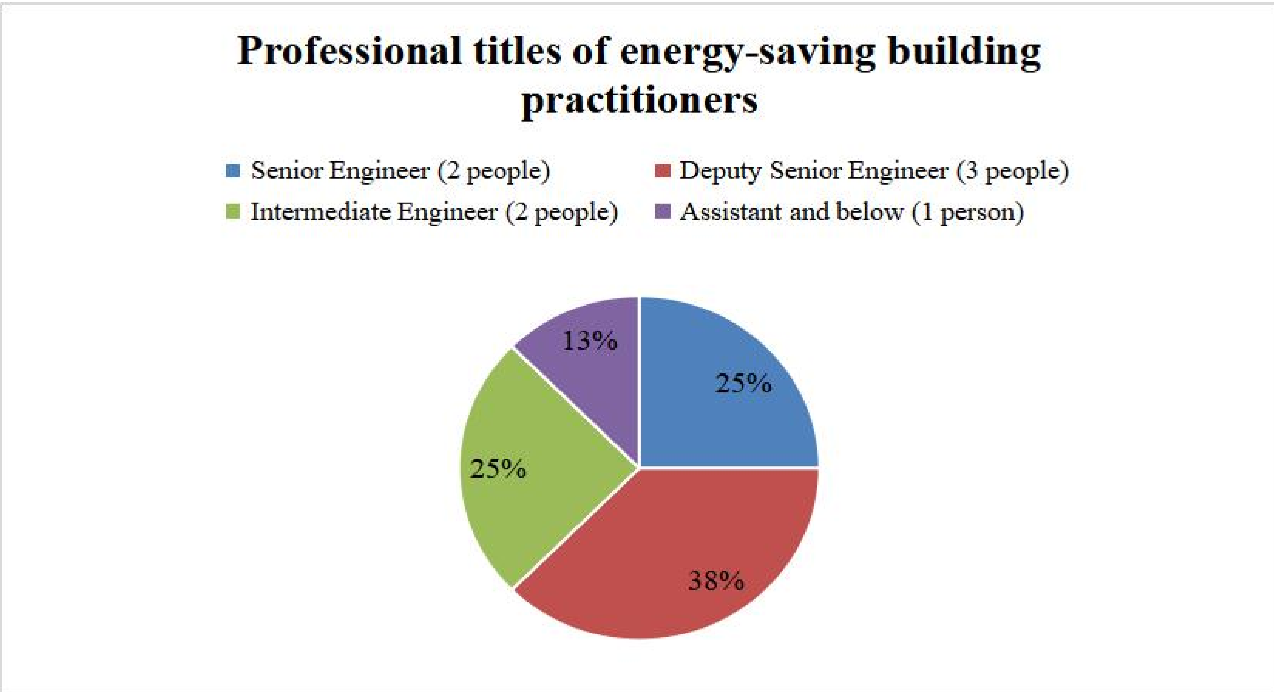


Figure 3.4 Professional titles of energy-saving building practitioners

In this process, the experts are required to assign the corresponding weight value to each level of indicators according to the structural levels and indicators of the suitability evaluation system of the enclosure structure. The purpose of this questionnaire was to determine the relative weights of the influencing factors of "Summer is hot and winter is warm (A1)". The questionnaire was designed according to the form of Analytic Hierarchy Process (AHP). This method is to compare the importance of influencing factors in pairwise at the same level. The measurement scale is divided into 9 grades, in which the values of 9, 7, 5, 3, 1 correspond to absolutely important, very important, somewhat important, slightly important, and equally important respectively. 8, 6, 4, and 2 indicate that the degree of importance is between the two adjacent grades. The ranking cell on the left indicates that the left column factors are more important than the right column factors, and the ranking cell on the right indicates that the right column factors are more important than the left column factors. Depending on your opinion, just click the corresponding cell. When clicked, the cell changes color to identify the judgment data for this pairwise comparison.

The analytic Hierarchy Process (AHP) is used to calculate the weight of expert scores. Because yaahp software has the advantages of simple operation and more intuitive hierarchy model, this paper uses yaahp software to input expert scores into the judgment matrix and calculate the weight value of each level to the next level and the weight value of the scheme layer to the target layer. In order to make the weight of the final influencing factors more reliable and effective, The final aggregate judgment matrix is obtained by means of arithmetic average calculation. The final aggregate judgment matrix and the calculation results of index weights are shown in Figure 3-5. Table 3.1 to 3.5 lists the results.

Table 3.1－The weight of each level on the previous level

1. Summer is hot and winter is warm（A1） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：1.0000; λmax：4.0000							
Summer is hot and winter is warm（A1)	Summer is hot and winter is warm（B1）	Adaptability（B2）	Innovate（B3）	Economy（B4）	Wi		
Summer is hot and winter is warm（B1）	1	1	1	0.5	0.2		
Adaptability（B2）	1	1	1	0.5	0.2		
Innovate（B3）	1	1	1	0.5	0.2		
Economy（B4）	2	2	2	1	0.4		
2. Summer is hot and winter is warm（B1） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.2000; λmax：3.0000							
Summer is hot and winter is warm（B1）	Wall performance（C1）	Roof performance（C2）	Performance of doors and Windows (C3）	Wi			
Wall performance（C1）	1	1	1	0.3333			
Roof performance（C2）	1	1	1	0.3333			
Performance of doors and Windows (C3）	1	1	1	0.3333			
3. Adaptability（B2） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.2000; λmax：2.0000							
Adaptability（B2）	Suitability of structure type（C4）	Sunshine strategy（C5）	Wi				
Suitability of structure type（C4）	1	5	0.8333				
Sunshine strategy（C5）	0.2	1	0.1667				

4. Innovate（B3） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.2000; λmax：2.0000							
Innovate（B3）	Intelligent system（C7）	Active energy-saving innovation（C6）	Wi				
Intelligent system（C7）	1	1	0.5				
Active energy-saving innovation（C6）	1	1	0.5				
5. Economy（B4） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.4000; λmax：2.0000							
Economy（B4）	Cost（C9）	Market adaptability（C8）	Wi				
Cost（C9）	1	3	0.75				
Market adaptability（C8）	0.3333	1	0.25				
6. Wall performance（C1） Consistency ratio：0.0437; Weight for "Summer is hot and winter is warm（A1)"：0.0667; λmax：6.2756							
Wall performance（C1）	Thickness（C14）	Thermal conductivity（C11）	Permeability coefficient（C12）	Solar energy absorption coefficient（C13）	Heat reflection（C15）	Fire resistance（C16）	Wi
Thickness（C14）	1	1	1	1	1	2	0.1775
Thermal conductivity（C11）	1	1	2	2	2	2	0.2505
Permeability coefficient（C12）	1	0.5	1	0.5	2	1	0.1496
Solar energy absorption coefficient（C13）	1	0.5	2	1	1	1	0.1632
Heat reflection（C15）	1	0.5	0.5	1	1	2	0.1456

Fire resistance（C16）	0.5	0.5	1	1	0.5	1	0.1137

7. Roof performance（C2） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.0667; λmax：3.0000

Roof performance（C2）	Fire resistance（C21）	Thermal conductivity（C22）	Air tightness（C23）	Wi			
Fire resistance（C21）	1	0.3333	0.3333	0.1429			
Thermal conductivity（C22）	3	1	1	0.4286			
Air tightness（C23）	3	1	1	0.4286			

8. Performance of doors and Windows(C3） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.0667; λmax：2.0000

Performance of doors and Windows(C3）	Thermal conductivity（C31）	Air tightness（C32）	Wi				
Thermal conductivity（C31）	1	1	0.5				
Air tightness（C32）	1	1	0.5				

9. Cost（C9） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.4000; λmax：2.0000

Cost（C9）	Material cost（C91）	Construction cost（C92）	Wi				
Material cost（C91）	1	1	0.5				
Construction cost（C92）	1	1	0.5				

10. Thickness（C14） Consistency ratio：0.0000; Weight for "Summer is hot and winter is warm（A1)"：0.0118; λmax：2.0000

Thickness（C14）	Thickness of insulation layer（C141）	Wall thickness（C142）	Wi				
Thickness of insulation layer（C141）	1	1	0.5				
Wall thickness（C142）	1	1	0.5				

Table 3.2—The ranking weight of the first level index to the decision goal

Criterion layer element	Weight
Economy（B4）	0.4
Summer is hot and winter is warm（B1）	0.2
Innovate（B3）	0.2
Adaptability（B2）	0.2

Table 3.3—The ranking weight of the secondary index to the decision objective

Criterion layer element	Weight
Cost（C9）	0.4
Suitability of structure type（C4）	0.1667
Market adaptability（C8）	0.1
Intelligent system（C7）	0.1
Active energy-saving innovation（C6）	0.1
Wall performance（C1）	0.0667
Roof performance（C2）	0.0667
Performance of doors and Windows(C3）	0.0667
Sunshine strategy（C5）	0.0333

Table 3.4—The ranking weight of the three-level index to the decision goal

Criterion layer element	Weight
Material cost（C91）	0.15
Construction cost（C92）	0.15
Thermal conductivity（C31）	0.0333
Sunshine strategy（C5）	0.0333
Air tightness（C32）	0.0333
Thermal conductivity（C22）	0.0286
Air tightness（C23）	0.0286
Thermal conductivity（C11）	0.0167
Thickness（C14）	0.0118
Solar energy absorption coefficient（C13）	0.0109
Permeability coefficient（C12）	0.01
Heat reflection（C15）	0.0097
Fire resistance（C21）	0.0095
Fire resistance（C16）	0.0076

Table 3.5－The ranking weight of four levels of indicators on decision objectives

Criterion layer element	Weight
Wall thickness（C142）	0.0059
Thickness of insulation layer（C141）	0.0059

The adaptive evaluation system of high-performance building envelope was established through analytic hierarchy process (AHP). Delphi method was used to score each level, and then the analytic hierarchy Process (AHP) was used to carry out weight analysis. The weight calculation results (Table 3-2) could be obtained.

From the perspective of first-level indicators, the weight influence of Economy (B4) is much greater than that of other indicators. However, Summer is hot and winter is warm (B1), Innovate (B3), Adaptability (B2) are very important in the establishment of adaptability evaluation system of high-performance building envelope walls, followed by the consideration of technology, adaptability, innovation; From the perspective of secondary index, Cost (C9) is a prominent index that affects the comprehensive performance level of architectural design. In comparison, Wall performance (C1), Roof performance (C2), Performance of doors and Windows(C3), Sunshine The influence of strategy (C5) is not particularly obvious (Table 3-2), which is in line with the economy of the adaptability evaluation system of the near high-performance building envelope. Among the three indexes, Material cost (C91) and Construction cost (C92) have a great impact on the comprehensive performance level of the design (Table 3-4), and the two indexes almost account for 14.28% of the influence of the whole three indexes (Figure 3-4). By comparison, the influence of Fire resistance (C16), Heat reflection (C15) and ermeability coefficient (C12) was not significant. Fuzzy analysis can be carried out to verify the evaluation system when the indicators have weights.

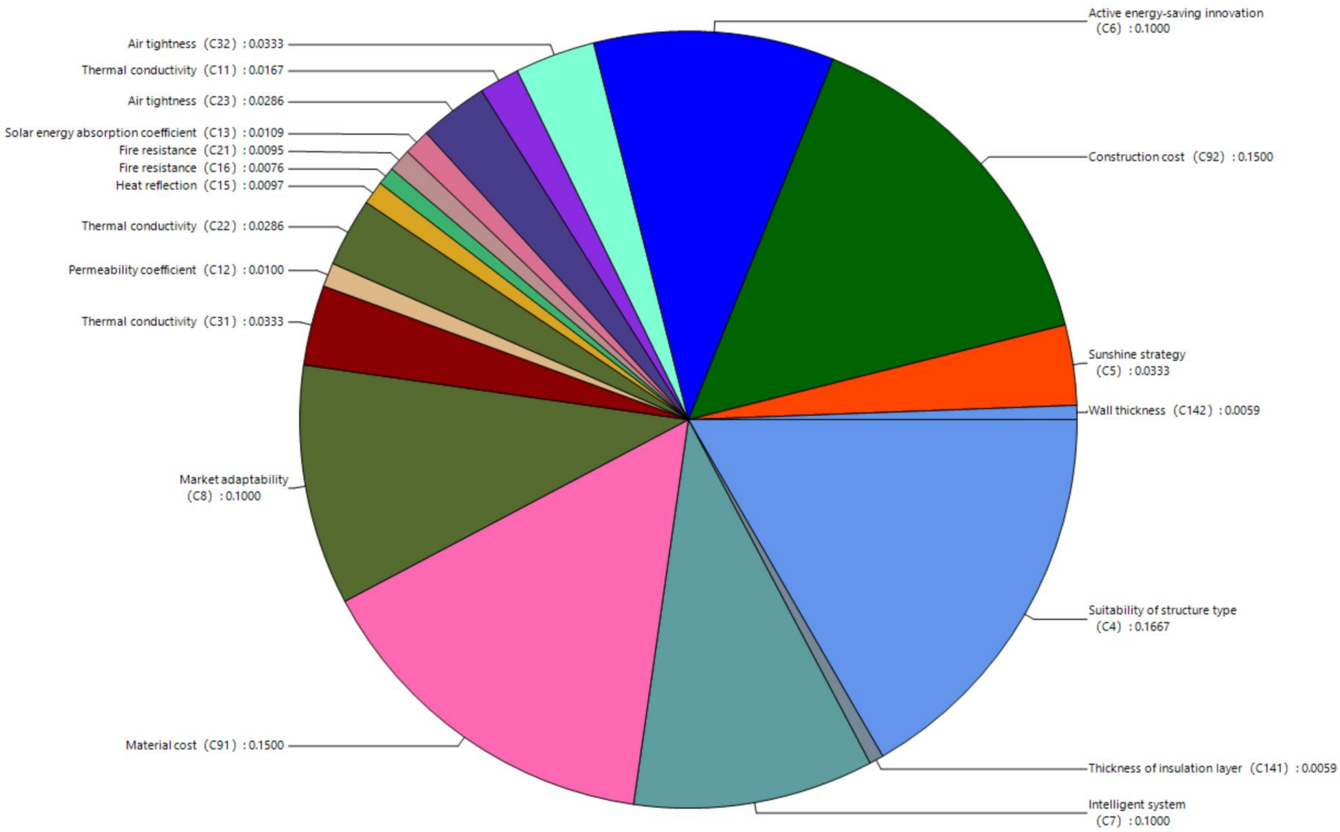


Figure 3.5 The three-level index criterion ranks the index weights

3.5 The evaluation system model based on fuzzy comprehensive evaluation method of AHP is constructed

3.5.1 The basic principle of fuzzy comprehensive evaluation method

Fuzzy comprehensive evaluation method, as a multi-attribute decision analysis technology, mainly relies on the relevant calculation principle of fuzzy mathematics, aiming to realize the organic combination of quantitative and qualitative factors, so as to greatly expand the information capacity of evaluation model. Based on the membership degree theory, this method skillfully transforms the originally difficult qualitative problem into a measurable quantitative problem, thus achieving a more comprehensive and accurate evaluation of the evaluation object [48].

In practical application, the evaluation object is often affected and restricted by many factors. These factors include both data indicators that can be quantified and qualitative factors that are difficult to quantify directly. In order to fully consider these factors, fuzzy comprehensive evaluation method came into being. It uses fuzzy mathematics to analyze the evaluation object at multiple levels and multiple dimensions, in order to reveal the internal relationship between each factor and the degree of influence on the evaluation result.

In the practical operation of fuzzy comprehensive evaluation method, all the factors of the evaluation object are optimized, and the optimal evaluation factor is expressed as 1. Then, according to the comparison between other sub-optimal evaluation factors and optimal evaluation factors, the corresponding evaluation value is obtained. These values reflect the importance and influence of each factor in the object of evaluation. In this way, we can get the unique evaluation value of each evaluation object, and these evaluation values will not be affected by the particularity of the evaluation object, which ensures the objectivity and fairness of the evaluation.

Because the fuzzy comprehensive evaluation method involves multiple evaluation objects and factors, it is necessary to sort the comprehensive evaluation results of all objects. By ranking the evaluation value of each evaluation object, we can clearly see the degree of the advantages and disadvantages of each object in the overall evaluation, and provide a strong basis for decision makers.

Fuzzy comprehensive evaluation method has wide applicability in practical application. Whether it is enterprise management, project management or policy evaluation, this method can be used for comprehensive evaluation. At the same time, with the continuous development and improvement of fuzzy mathematics theory, fuzzy comprehensive evaluation method will also play a greater role in the future, and provide strong support for the development of various fields.

As an effective multi-attribute decision analysis technique, fuzzy comprehensive evaluation method has obvious advantages and wide application prospects. By using the relevant principles and methods of fuzzy mathematics, we can realize the comprehensive and accurate evaluation of the evaluation object, and provide a strong basis and reference for the decision maker.

3.5.2 The basic steps of fuzzy comprehensive evaluation method

The principle of the Fuzzy Comprehensive evaluation (FCE) evaluation table of Yaahp software is based on the membership theory of fuzzy mathematics, transforming qualitative evaluation into quantitative evaluation, which is especially suitable for solving fuzzy problems that are difficult to quantify [49]. The process of creating and using the FCE evaluation form is closely integrated with the Analytic Hierarchy Process (AHP), and the following is how it works and how it works:

A) The weight vector is obtained according to the calculation results of AHP, and the evaluation questionnaire is created.

B) This time, the FCE evaluation questionnaire generated by combining Yaahp evaluation and AHP is used. The weights are sorted by AHP calculation results and directly used as weight vectors. Only the evaluation level needs to be specified.

C) In the software, the questionnaire is generated by the function button of "Create evaluation form" under the functional classification of "fuzzy comprehensive evaluation". Enter the necessary information, such as Sheet name, evaluation form title, description text, evaluation level, weight vector, etc., and ensure that the sum of the weight vectors is equal to 1.

D) After collecting the FCE questionnaire filled in by the experts, use the "Import" function of the software to import the questionnaire data. The fuzzy comprehensive evaluation data can be saved to a.fce file by using the "Save" button. The software will display the fuzzy comprehensive evaluation data viewing interface, showing the score of each evaluation object. View the evaluation results through the "Evaluation results" TAB and generate a fuzzy comprehensive evaluation report.

Conclusion to the chapter 3

This chapter analyzes the construction process of near-zero energy building design comprehensive evaluation model. At the beginning of the chapter, the steps of near-zero energy public building design comprehensive evaluation are proposed, and the evaluation process is systematically sorted out. Then the principle and process of AHP method are expounded, and the weight analysis of the comprehensive evaluation index of the near-zero energy public building design is carried out based on AHP method, and the weight results of all levels of indicators are obtained. Then, based on the weight results of AHP, a fuzzy comprehensive evaluation model is proposed. After a series of research steps and methodology discussions, the following conclusions are drawn in this chapter:

A) Weight allocation: Through the analytic hierarchy Process (AHP), this chapter determines the relative importance of each evaluation index, and assigns weights accordingly. This process improves the scientificity and objectivity of the evaluation system.

B) Integration of expert opinions: Using the expert scoring method (Delphi), this chapter integrates the valuable opinions from the experts in the field of construction to ensure the practicality and authority of the evaluation system.

C) Limitations and prospects: Although the evaluation system in this chapter has established an adaptive evaluation system for hot summer and warm winter areas with the support of the voting of theoretical experts and analysis methods, it needs to be analyzed in actual cases to verify the effectiveness and feasibility of the established evaluation system, and prove that this method can provide an accurate assessment of the adaptability of high-performance building envelope structures.

This chapter mainly constructs a comprehensive model based on AHP and fuzzy comprehensive evaluation, which provides a model basis for the verification of actual cases in the following chapter.

4 CONSTRUCTION OF EVALUATION SYSTEM MODEL BASED ON FUZZY COMPREHENSIVE EVALUATION METHOD

4.1 Basic Project Information

Located in Shenzhen, Guangdong Province, China, the project has a total floor area of 8,696.44 square meters and a building height of 23.02 meters, comprising seven floors. Prior to the renovation of the project, a comprehensive evaluation has been carried out through 3D laser point cloud modeling technology, thermal performance testing of the envelope structure and structural inspection. Subsequently, the core external structures such as the facade and the envelope were upgraded using the concept of climate biology design. In the renovation process, the project uses a number of green technologies. The whole building adopts the frame structure for transformation, and the outdoor parking space is transformed into grass brick parking space; Roads are paved with permeable bricks. In the renovation of the exterior facade, perforated aluminum plate is selected as the shading device to improve the shading performance of the building. In terms of thermal insulation, reasonable materials are used on the outer envelope structure to improve the thermal insulation effect. In terms of air conditioning system, the original split air conditioning system was replaced with an efficient multi-line system, and a fresh air system with 75% full heat recovery efficiency was added. At the same time, the outdoor unit is equipped with a spray system to achieve energy saving and efficient operation. In addition, the photovoltaic system has been set up to produce 30,000 kWh of electricity per year to make efficient use of renewable energy. In terms of intelligent monitoring, indoor air quality monitoring platform is introduced to monitor the concentration of pollutants such as formaldehyde in real time to ensure that indoor environmental quality meets standards; At the same time, BIM based 3D visual energy consumption monitoring platform fine management of various equipment energy consumption to achieve efficient use of energy.

In addition to the above transformation measures, energy-saving transformers, LED lighting, drip irrigation systems, water-saving sanitary appliances and KDM feedback elevators and other green technologies are used to comprehensively improve the energy-saving and water-saving performance of the building.

In the design of the project, the five elements of material saving, land saving, water saving and indoor environmental quality are fully considered, and the surrounding resources are fully utilized to optimize the allocation of resources.

Building overview: Table 4.1 describes the basic building overview.

Table 4.1－Case building basic overview table

Building name	Shenzhen Building Engineering Quality Supervision and Inspection Center Experimental Business Building Integrated Renovation Project
Project type	Public building
Geographic location	Shenzhen, China
Climatic environment	Temperate continental climate zone
Floor area	8 696 m2
Building height	Below 28 m
Number of floors	7
Building orientation	North-south

Structural system	Frame structure
Basic form	Full of raft foundations
Building life	30 years
Plot ratio	1.94
Ratio of green space	31%

4.2 Comprehensive evaluation

4.2.1 Collection of commentaries

A questionnaire of fuzzy Comprehensive Evaluation (FCE) evaluation form was established by Yaahp software, and the questionnaire was distributed to 15 experts in the field of near-zero energy buildings who had a deep understanding of the comprehensive renovation project design of the experimental business building of Shenzhen Construction Quality Supervision and Testing Center. After practical investigation, we successfully recovered 10 complete and effective questionnaires. Through the statistical analysis of the collected questionnaires, we calculated the average scores of each indicator and sorted them into the following table (as shown in Table 4.2), so as to better understand the overall performance of each indicator in the expert evaluation.

Table 4.2—Design index expert score mean table

Criterion 1 layer	
Index item	Mean value
Summer is hot and winter is warm（B1）	3.939990633
Adaptability（B2）	3.5

Innovate（B3）	4
Criterion 2 layer	
Index item	Mean value
Wall performance（C1）	3.969971898
Roof performance（C2）	4
Performance of doors and Windows(C3）	3.85
Cost（C9）	3.8
Criterion 3 layer	
Index item	Mean value
Thickness（C14）	4
Criterion 4 layer	
Criterion 3 layer	Criterion 3 layer
Suitability of structure type（C4）	3.1
Sunshine strategy（C5）	3.9
Intelligent system（C7）	4
Active energy-saving innovation（C6）	4
Market adaptability（C8）	3
Permeability coefficient（C12）	4
Solar energy absorption coefficient（C13）	4
Heat reflection（C15）	3.8
Fire resistance（C16）	4
Thermal conductivity（C11）	4
Fire resistance（C21）	4
Thermal conductivity（C22）	4
Air tightness（C23）	4
Thermal conductivity（C31）	4
Air tightness（C32）	3.7
Material cost（C91）	3.6
Construction cost（C92）	4
Thickness of insulation layer（C141）	4
Wall thickness（C142）	4

The review set V consists of four grades, namely V={Excellent, good, Pass, Fail}. According to the set corresponding numerical relationship, excellent corresponds to 4 points, good corresponds to 3 points, qualified corresponds to 2 points, unqualified corresponds to 1 point, so the converted review set is V={4, 3, 2, 1}.

Table 4.3—Evaluation domain

Evaluation level	Value
Outstanding	4
Good	3
Up to standard	2
Below standard	1

4.2.2 Membership degree of comprehensive rating

In fuzzy comprehensive evaluation, we assign the quantification of the evaluation results to the pre-set grade category. In this process, membership is used as a mathematical expression to measure the membership of a particular result to a certain evaluation level, that is, the membership function value. This value is located in the closed range of 0 to 1 and is used to accurately characterize the degree of fit between the result and the grade. Then arrange it in the following table (Table 4.4).

Table 4.4—Membership degree of comprehensive rating

Evaluation level	Membership degree
Outstanding	0.7330
Good	0.2670
Up to standard	0.0000
Below standard	0.0000

For each evaluation level, a membership function is constructed, which defines the corresponding relationship between evaluation results and grades. Experts score each evaluation index according to their experience and knowledge, and these scores reflect their judgment that the results belong to a specific grade. In fuzzy comprehensive evaluation, The membership degree of several evaluation indicators is adopted and the maximum membership degree is Outstanding: 0.7330.

After the previous data analysis of the membership degree of the evaluation and other discussion domains, the mean table of the expert scores of the design indicators and the comprehensive rating, the results of the comprehensive evaluation can be obtained as follows: excellent. Detailed data are shown in Table 4.5.

Table 4.5—The result of comprehensive evaluation

Evaluation target	Comprehensive rating	Comprehensive score
Summer is hot and winter is warm（A1)	Outstanding	3.733

4.3 Conclusion and analysis suggestion

Through the comprehensive evaluation of the comprehensive renovation project of the Experimental business Building of Shenzhen Construction Engineering Quality Supervision and Testing Center, it can be concluded that the comprehensive fuzzy evaluation of the design of the building belongs to "excellent", and the results show that the actual performance of the design of the case building is relatively good. According to the analysis of the basic comprehensive design information of this building, it can be seen that this is a building in the near zero energy consumption design evaluation stage, and is an existing international demonstration building of green transformation. Its primary energy demand is 65.08 kWhpe/m2· year, and the data meets the requirements of economic and energy-saving buildings.

Based on the adaptive comprehensive evaluation, although the obtained results meet the requirements, there are still some problems in the evaluation process. First of all, the weight of the evaluation index and a series of other calculation results are based on the subjective scores of the surveyed objects. Although the value of the index has been optimized through scientific and effective methods, errors brought by subjective circumstances cannot be avoided, thus reducing the accuracy of the final evaluation results. Secondly, the index system is built for regional buildings in hot summer and warm winter areas, while the evaluation is another city in the same climate zone, and the regional adaptability and global indicators are not effective enough to fully reflect the comprehensive level of design, such as heating and cooling system and heating and cooling mode. Finally, through the study of adaptability evaluation, it is pointed out that the influencing factors that need to be paid attention to in the current design stage, such as the subordinate indicators of the control and monitoring system are the key indicators that affect the design performance of the near-high-performance building envelope, which need to be fully considered in the design stage and need to carry out reasonable design.

4.4 Reconstruction project and economic calculation

The case selected in this paper is the employee residential building of Agricultural Bank of China in Guangzhou. The building was built in 1996 with a service life of 50 years and has been in use for 28 years. The structure performance of the building is tested and evaluated. The structure performance of the building is good and meets the conditions of energy-saving renovation of the envelope structure. The building has a total of 4 floors, one ladder and two households. The construction area is 1169.7 2. The project is located in the due south direction. The specific design parameters of the building envelope were obtained through site investigation and relevant data reference, as shown in Table 4.6.

Table 4.6—Exterior wall construction

Name	Construction practice	Thickness（mm）	Thermal conductivity W/(m·K)
Painted stone wall sintered common brick exterior	1:1.5 cement stone surface, water brush exposed stone surface	10	1.0
	Plain cement slurry		
	1:3 Cement mortar skin cleaning	7	
	1:3 Cement mortar bottom cleaning	7	
	Sintered ordinary brick	240	
	Mixed mortar	20	

The thermal conductivity does not conform to 0.028-0.042W/(m·K) of the index thermal conductivity of the building envelope adaptation evaluation system in the hot summer and warm winter climate zone, and the first index B1 and the second index C1 in the evaluation system must meet all the three indexes to be qualified, so it is necessary to rebuild the original building.

4.4.1 Exterior wall reconstruction scheme

The typical structure with hot summer and warm winter is used for the transformation. The transformation scheme is shown in Table 4.7:

Table 4.7—Reconstruction scheme

	Outer wall	Exterior window
Reconstruction scheme	EPS thin plastered exterior wall insulation system	Ordinary hollow glass aluminum alloy sliding window + add window on the west wall

Molded polystyrene board (EPS) thin plastering system renovation scheme is to paste insulation board and finishing system on the outside wall of the building, the system is mainly composed of EPS board, adhesive, interface agent, plastering glue composite alkali resistant glass fiber mesh cloth protective layer and finishing layer. The thickness of the ordinary thin plaster reinforced protective layer should be controlled within 3~5mm, and the thickness of the reinforced thin plaster reinforced protective layer should be controlled within 5~7mm. The basic structure of the thin plaster reinforced protective layer is shown in Table 6.6. The thermal conductivity of XPS plate selected in this system is generally 0.028~0.035W/(m·K), the thickness should not be less than 3cm, and the combustion performance is not lower than B2.The reconstruction cost is shown in Table 4.8.

Table 4.8—Wall reconstruction cost

Serial number	Project name	Unit	Unit price (RMB)	Dosage（m^2）	Amount (RMB)	Thickness（m）	Loss coefficient
1	Bonded mortar	t	1400	0.005	7		
2	EPS board	m^3	540	0.055	29.7	0.06	1.1
3	Coating mortar	t	1500	0.006	9	0.05	
4	Fiberglass mesh cloth	m^2	2.5	1.3	3.25		1.3
5	Expanded nail	Each set	0.2	7	1.4		
6	Heat preservation labor cost	m^2			28		
Total insulation parts					78.35		
7	Flexible putty	t	1800	0.001	1.8		
8	Coating				12		
9	Paint finish labor cost	m^2			12		
The face is divided					25.8		
Total					104.15		

4.4.2 Exterior window reconstruction

The energy-saving transformation of the exterior window is mainly to reduce the heat loss of the exterior window by replacing the energy-saving glass, improving the thermal insulation performance of the window frame and strengthening the sealing measures of the exterior window.The cost is shown in Table 4.9.

Table 4.9—Window renovation cost

	Type	System construction	Price
Exterior window	Ordinary insulating glass	4+9A+4	130 RMB/m^2
	Aluminium alloy	Ordinary sliding window	115 RMB/m^2

4.4.3 Roof modification

The insulation layer of cement vermiculite insulation roof is usually 60 thick castin 1:10 cement vermiculite, because the insulation layer is castin, it is better combined with the roof base, so it is not suitable to remove it, so as not to cause damage to other structures of the roof. If the cement vermiculite insulation layer has appeared cracks, it should be repaired to prevent the roof from seepage phenomenon, such roofing and the 1980s without insulation roofing have the same problems, should be renovated.

Table 4.10—Roofing cost

Reconstruction type	Expense（RMB/m^2）					
	Screed course	Insulating layer	Waterproof course	Protective layer	Construction cost	total
Cement vermiculite insulation roof	17	38.9	25	21	34	108.9

4.4.4 Effect and economic benefit of energy saving transformation

Put the building into the Energyplus software to analyze the energy consumption before and after the renovation (Table 4.11) :

Table 4.11—Energy consumption before and after renovation

Before modification	After transformation
Annual building energy consumption 6564570 Wh	Annual building energy consumption 2675847 Wh

Through comparison, it is concluded that under the adaptability evaluation system of high-performance building envelope structure, the buildings that fail the evaluation have significant energy saving effect after reconstruction, and the annual savings after renovation are 3888723Wh. According to the average price of electricity in China of 1.23 RMB/KWh, the annual savings are 4,783.13 RMB by calculation. And the heat transfer coefficient of EPS material used after reconstruction is less than 0.035, which accords with the interval value of thermal conductivity of evaluation system.

Conclusion to the chapter 4

This chapter verifies the actual performance of the constructed comprehensive evaluation model in the case through the actual verification of the case, and reflects the specific actual situation of the case in the design comprehensive performance through the actual verification results of the case. Based on the weights of each index obtained by AHP method in the previous chapter, fuzzy comprehensive evaluation method is used to evaluate the comprehensive design performance of the case buildings. The evaluation result obtained is "excellent". Through the qualitative analysis of the evaluated case buildings, the feasibility and applicability of the constructed model are good and basically meet the satisfactory results of this study.

A) From the perspective of indicators. Some indicators need to be further optimized design, such as heating and cooling mode and heating and cooling system need to determine their weight value according to the climate region, while node design and each thermal bridge treatment index are key indicators affecting the actual comprehensive design level of high-performance building envelope structure, and need to be further optimized.

B) From the perspective of architectural cases. The mean value of each index obtained by fuzzy comprehensive evaluation is basically between excellent and good, indicating that most experts hold relatively unified opinions on the performance of this case building. The actual analysis of this building case also shows that the building is in the design evaluation stage of China Building Energy Efficiency Association, and the specific evaluation results have not yet been released. However, according to the standards of previous case buildings to be tested, the conditions of the building itself must meet the design standards of high-performance building envelope before it can be included in the evaluation system. Therefore, the official results of the evaluation of this building are as follows: Basically it will reach an ideal level, which also reflects from the side that the results of this study are basically a reasonable result.

C) The cost of EPS thin plastered external wall insulation system and ordinary hollow glass aluminum alloy sliding window is relatively low. The thermal conductivity of energy-saving materials can also reach the evaluation index value, and can achieve the expected energy-saving building energy consumption.According to the average price of electricity in China 1.23 RMB/KWh, the annual savings through calculation is 4783.13 RMB.

CONCLUSION

This paper first analyzes the research progress and standard overview of near-zero energy buildings at home and abroad, and analyzes the advantages and disadvantages of high-performance building envelope in practical application by simulating the thermal conductivity, permeability, solar energy absorption coefficient, insulation layer thickness and thermal emissivity of near-zero energy demonstration projects in different climate zones. At the same time, according to the software data simulation and data collection of different demonstration projects in the same climate area, the common thermal insulation system of outer protective structure in the hot summer and warm winter climate area is summarized. The control variable method was studied in the conventional value range of thermal insulation materials, and the relevant indicators of suitability evaluation of high-performance building envelope were analyzed. Then, by establishing the suitability evaluation system of the envelope structure in the hot summer and warm winter climate zone, the weight of the key factors affecting the performance of the envelope was calculated, and the following conclusions were drawn:

A) In the Energyplus simulation data analysis of the wall performance of the five indicators, in the original data or energy consumption floating rate statistics of the graph, a single indicator from the middle of the floating up and down to produce a different energy consumption value, will not be a single with the index float to save energy, it may also play the opposite role. However, as the data fluctuation exceeds the range of common energy consumption values, the energy consumption will suddenly increase.

B) In the process of index ranking, five fuzzy index rankings of wall performance are obtained, which are weighted for AHP fuzzy evaluation, and thermal conductivity >

thickness > thermal reflection coefficient > solar energy absorption coefficient > thermal emission are obtained. Since there are many factors affecting the envelope structure in the test climate zone, it will also be affected by other factors, after adding other adaptability evaluation factors, AHP fuzzy evaluation is carried out by assigning weight to it. Based on the main aspects of technology, adaptability, innovation, economy, etc., the second and third indexes are derived step by step, and a scientific evaluation index system of hot summer and warm winter is established. The index system thus constructed can reflect the comprehensive performance level of the high-performance envelope structure more comprehensively and adapt to the development situation.

C) The weight of the index reflects the adaptive performance level of the high-performance envelope structure, and the selection of a more scientific and quantitative calculation method can ensure the reliability of the results. In the process of determining the weight of the index by AHP, the paper collects and compares the questionnaires of the judgment matrix based on the three stakeholders of energy-saving building designers, researchers and energy-saving building users, and uses the rank average method to aggregate the final results of the judgment matrix, and the weight results obtained are satisfactory.

D) This paper conducts research from the perspective of evaluation, evaluates the comprehensive design performance level of near-zero energy consumption public buildings, and verifies the feasibility and effectiveness of the evaluation model by using concrete cases for demonstration. The analytic hierarchy process combined with fuzzy comprehensive evaluation is widely used, but it is rarely used in the evaluation of building envelope. In this paper, the classical reliable method is applied to a new field, and the application range of this method is expanded.

E) Under the adaptability evaluation system of high and new energy envelope structure, the evaluated buildings have significant energy saving effect after reconstruction, and the annual saving after renovation is 3888723Wh. According to the average electricity price of 1.23 RMB/KWh in China, the annual saving is 4783.13 RMB by calculation. And the heat transfer coefficient of EPS material used after reconstruction is less than 0.035, which accords with the interval value of thermal conductivity of evaluation system.

Through the research method combining theory and practice, from the establishment of index system, to the construction of comprehensive evaluation model, and finally the verification of actual cases, the adaptive evaluation system of high-performance building envelope has been formed. On the other hand, due to the author's knowledge level, there are still many shortcomings in this paper, which need to be further discussed.

A) Improve the index system. The evaluation index system only considers the building envelope structure, and does not fully consider the subsequent construction, operation and maintenance stage and other factors. In order to realize the comprehensive evaluation of energy-saving renovation scheme, energy-saving effect, construction difficulty, construction management scheme, resource saving and building operation and maintenance should be considered comprehensively, and follow-up evaluation should be carried out. Therefore, the evaluation index system of energy-saving renovation of building envelope needs to be further improved.

B) As the thermal insulation system used in hot summer and warm winter areas and mild areas is different from that in cold areas, cold areas, hot summer and cold winter areas, the subsequent research will focus on the thermal insulation system performance and energy-saving measures in hot summer and warm winter and mild areas, and a more comprehensive evaluation design and reference of the suitability of high-performance building outer protective structure.

C) Although the evaluation method used in this paper is a classical and reliable evaluation method, its scientific rigor is less than that of today's numerous scientific research methods. It is hoped that more scientific and effective methods can be used in the evaluation method in the future research, so as to make the evaluation results more reasonable and accurate.

REFERENCES

1. “BUILDING ENCLOSURE: NEW CONSTRUCTION.” Basis of Design, www. poahbod.org/building-enclosure-new-construction#building-enclosure-newconstruction.
2. angA，Bokel R，Dobbelstecn A V D，et a1．0ptimization ofthermal and daylight perf. oance ofschool buiIdings based on a mulli·objectiVe genetic algo rithm inthe coId climate of china[J]．Energy&Bu 订 dings，2017．139：37l一384．
3. ipek G D，0P01uk G Multiobjectlve Design optimization of Buildjng space Layout，E11ergy，and DayIjghting Perf’ormance[J]．JournaI ofComputing in CiViI Enginee“ng，2017，3l(5)：4 一 17
4. [4]https://buildingscience.com/documents/digests/bsd-018-the-building-enclosure_revised
5. Perepelitza, Mark . "Building Enclosure Performance Research— Applications in Professional Practice.".
6. Ma Suzhen, Long Weding, and Ma Hongquan." The EU Building Energy Efficiency Directive and its implementation in Europe." HVAC 36.8(2006):5.
7. Kirsten Engelund Thomsen.European national strategies to move towards very low energy buildings[EB/OL].2008[2013-06-01].
8. Yukihiro Nojiri, Kohei Sakai, etal. National Greenhouse Gas Inventory Report of JAPAN[C]. Japan: Ministry of the Environment, 2012:18-20.

9. "General requirements for Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS)." Part 1: General requirements (current) ".EN 50491-2014.2014.

10. JAPAN[C]. Japan: Ministry of the Environment, 2012:18-20.

11. Werner M.Seattle's Bullitt Center bills itself as world's greenest office building

12. [EB/OL].[2019-8-1].http://www.pbs.org/newshour/rundown/2013/04/seattes bullitt center opens today as woelds greenest office building.html.

13. Heinze M.Goal:zero enery building exemplary experience based on the solar estate Solarsiedlung Freiburg am Schlierberg[J].Journal of Green uilding,2009, 4(4):93-100.

14. Hamdy M, Anh-Tuan N, Hensen JLM. A performance comparison of multi-objective optimization algorithms for solving nearly-zero-energy-building design problems[J]. Energy and Buildings, 2016, 121: 57-71.

15. Suh HS, Kim DD. Energy performance assessment towards nearly zero energy community buildings in South Korea[J]. Sustainable Cities and Society. 2019, 44: 488-498.

16. Zhao Yanxiangwa." Evaluation Method and practical application of energy-saving design scheme for green buildings." Science and Technology Research 000.027(2014):434-434.

17. Wang Zhi-Yong, WANG Jun, LIU Chang-rong. Research status and development prospect of zero energy building technology [N]. Journal of Hunan University of Technology, 2017 (2) :8-14.

18. Near-zero Energy building Technical Standard GBT 51350-2019[S]. China Building and Construction Press.2019.

19. Gao Caifeng, Chen Mengyuan, Pan Yuliang et al. Design method of near-zero energy public buildings in cold climate region: A case study of a pavilion building [J]. Building Science, 2020, 36(04): 1-8+207.

20. Chu Yingnan, Song Ye-Hao, Sun Jingfen and others. Approach to integrated design of photovoltaic buildings with near-zero energy consumption [J]. Journal of Architecture, 2019(S2): 35-39.

21. Yu Zhenyu, Lu Fei, Zou Yu et al. Application of multi-objective optimization method based on simulation in Performance optimization design of near-zero energy buildings [J]. Building Science, 2019, 35(10): 8-15.

22. Huang Shuo. Research on Thermal characteristics and Heating System of Low-energy Buildings in cold Region [D]. Harbin Institute of Technology,2011.

23. Li Huixing, Zhang Ran, FENG Guohui et al. A comparative analysis of air conditioning energy consumption simulation between near-zero energy buildings and conventional buildings in cold regions [J]. Building Energy Conservation,2015 (6) :10-12.

24. Feng Guohui, Xu Xiaolong, WANG Yue et al. Sensitivity analysis of design parameters of near zero energy building envelope based on energy consumption [J]. Journal of Shenyang Jianzhu University (Natural Science Edition), 2018, 34(06): 1069-1077.

25. Wang Weidong, Xue Feng, Li Ting. Research on energy consumption distribution control strategy design for zero-energy buildings [J]. Building Science, 2015, 31(06): 168-172.

26. Liu Jian. Research on Comprehensive evaluation System of near-zero energy public building design.2021. Guangzhou University,MA thesis.

27. Pan Xiao. Design and performance analysis of solar semiconductor lighting system. Diss. Xiamen University.

28. Zheng Chengsheng." Exploration and analysis of the application of Energyplus in building energy consumption simulation." Urban Construction Theory Research: Electronic edition (2012).

29. China Building Standard Design and Research Institute. Building envelope energy-saving engineering practices and data. China Planning Publishing House, 2009.

30. Shen Renjun. Analysis and optimization of energy saving effect of office building envelope in different climate zones. Diss. Tianjin University, 2015.

31. Shen Yandi. Study on energy saving effect of external thermal insulation walls of residential buildings in hot summer and cold winter areas. Diss. Zhejiang University, 2017.

32. United Nations Development Programme. Bureau For Policy And Programme Support. EnergyPlus Guidelines : Planning for Improved Energy Access and Productive Uses of Energy. New York, N.Y., United Nations Development Programme, April, 2015.

33. Wang Shuguang." Control variable Method -- an important method to study and solve problems." Physics Teacher: High School Edition 23.7(2002):2.

34. Wang Yingmei. Suitability technology application analysis of traditional residential buildings in Northwest China. China Science and Technology Information, 2010 (18) : 54-55.

35. Shen Xinhua." Technical Design and implementation of public buildings under the goal of "Double carbon". China Metal Structures for Building 22.8(2023):136-138.

36. Li Hangxin, and Wang Shengwei." Feasibility study of zero-energy buildings in hot summer and warm winter areas and cold areas under the Technical Standard for Near-Zero-Energy Buildings." HVAC 52.1(2022):121-125.

37. "Evaluation Criteria for near-zero Energy Buildings ".T/CABEE 003-2019.2019.

38. Zhang Lu et al." Analysis of differences in the formation of winter fog days under different regional climatic conditions in China. Climatic and Environmental Research 024.005(2019):585-596."

39. Ministry of Construction of the People's Republic of China. Code for thermal design of civil buildings. China Planning Press, 1993.

40. Luo Yuan. Comprehensive Regionalization of regional climate change and climate adaptation evaluation.2019. Chengdu University of Information Technology,MA thesis.

41. Cheng Qiyue." Structural entropy weight method for determining the weights of evaluation indicators." Systems Engineering Theory and Practice 7(2010): 4.

42. Hu Xuan-nan, and Wang Wei-Ming." Comparative study on subjective and ob jective weighting methods." Inner Mongolia Statistics 1(2023):28-31.

43. Saaty, Thomas L. , and L. G. Vargas . "Models, methods, concepts & appli cations of the analytic hierarchy process." International Series in Operations Research and Management Science (2012).

44. Xu Shubai. Principle of Analytic Hierarchy Process [M]. Tianjin: Tianjin Uni versity Press, 1988:82-88.

45. Xu Shubai. Principle of Analytic Hierarchy Process [M]. Tianjin: Tianjin Uni versity Press, 1988:82-88.

46. Zhu Hongtao, Liu Yong. Research on evaluation of digital library information service quality based on Analytic Hierarchy Process [J]. Information Scienc e, 2007(5):720-724. (in Chinese

47. Chen Wei, Fang Tingjian, and Jiang Xudong." Research and Application of Group Decision Making based on Delphi and AHP." Computer Engineering 29.5(2003):3.

48. Hong Chunhui, and Teng Yuemin." Application of fuzzy comprehensive evalu ation in bid evaluation decision." Journal of Jilin University of Civil Engine ering and Architecture 24.2(2007):4.

49. Li Wenbo, Zhang Hongyan, and Peng Chao." Regional evaluation of karst ground collapse hazard susceptibility based on AHP-FCE model." China Mining Industry 30.6(2021):5.

50. Zhai Y., Biks Y. "EVALUATING BUILDING ENVELOPES for ENHANCED ENERGY EFFICIENCY: A COMPREHENSIVE ASSESSMENT APPROACH". URL: https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21435 (Last accessed 06.13.2024).

APPENDIX A

The antiplagiarism check resul

ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Оцінка огороджувальних конструкцій будівель для підвищення енергоефективності: комплексний підхід

Тип роботи: Магістерська кваліфікаційна робота
(БДР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

Показники звіту подібності Unicheck

Оригінальність 82,1 % Схожість 17,9 %

Аналіз звіту подібності (відмітити потрібне):

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

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

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

Автор роботи ZHAI YUNSHENG (підпис) Чжай Юньшен (прізвище, ініціали)

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

Paper presentation

Architecture and civil engineering

Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach

Reporter: Zhai Yunsheng

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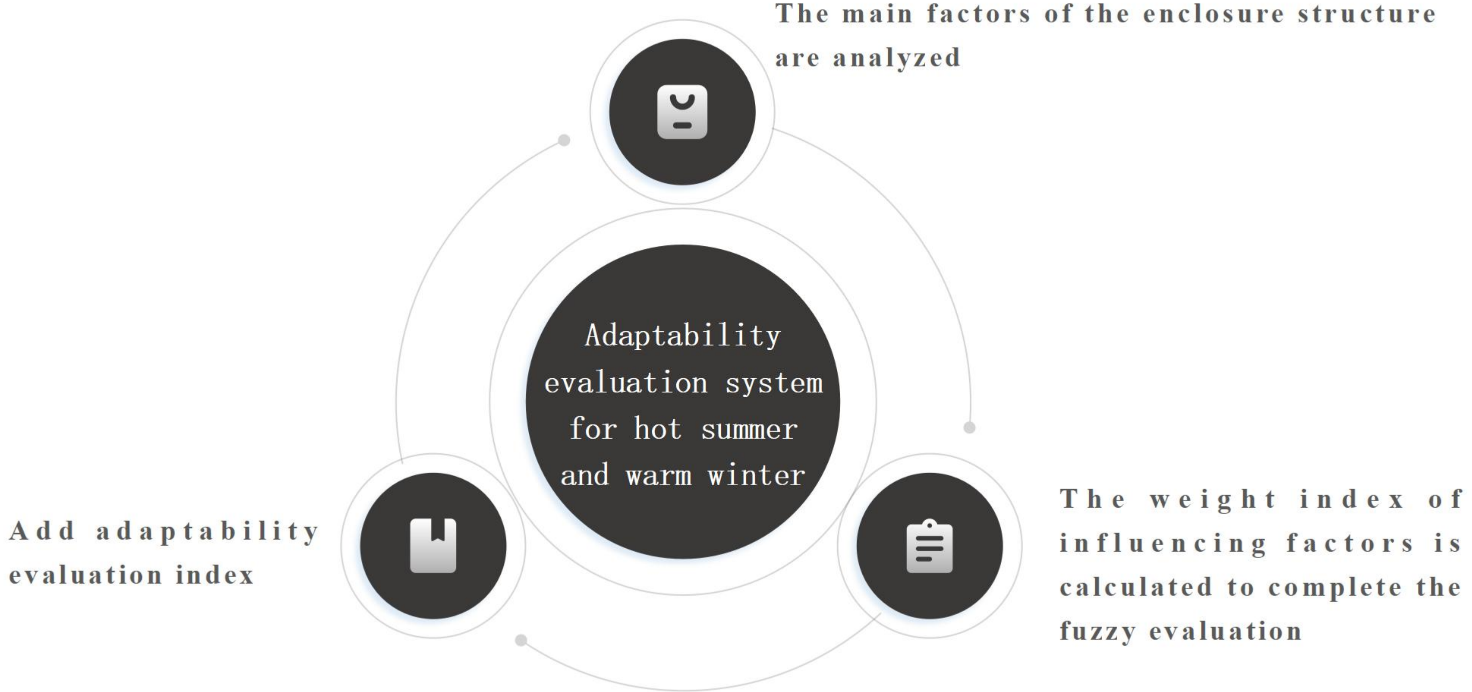
Biks Yuriy S.—PhD, Associate Professor, Department of Construction, Urban Economy and Architecture, Vinnytsia National Technical University, Vinnytsia, E-mail: biksyuriy@gmail.com

The purpose and objectives of the stud 1



2

Research theme	Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach
Research objectives and objectivestheme	Study whether the known factors can be used to evaluate the high performance envelope structure
Research object	Adaptive evaluation system of high performance building envelope structure in hot summer and warm winter area

Research task 3

- The research situation of energy-saving building is analyzed
- The evaluation system of building envelope is analyzed
- Determine the study climate area
- Find out the typical wall structure in common use, and determine the main influencing factors
- The thermal conductivity, permeability, solar absorption coefficient, thickness and thermal reflection of different buildings with the same structure in the same temperature zone were analyzed by EnergyPlus
- Since the evaluation system cannot be obtained, the adaptability evaluation system is obtained by adding other evaluation factors compared with other climates
- The evaluation system is endowed with weight indicators, and AHP analysis is carried out to obtain the proportion of influencing factors in the evaluation system and obtain the adaptive evaluation system
- The evaluation system was verified by the first near-zero building in China to ensure the usability of the evaluation system

Approbation of the results of the master's thesis 4

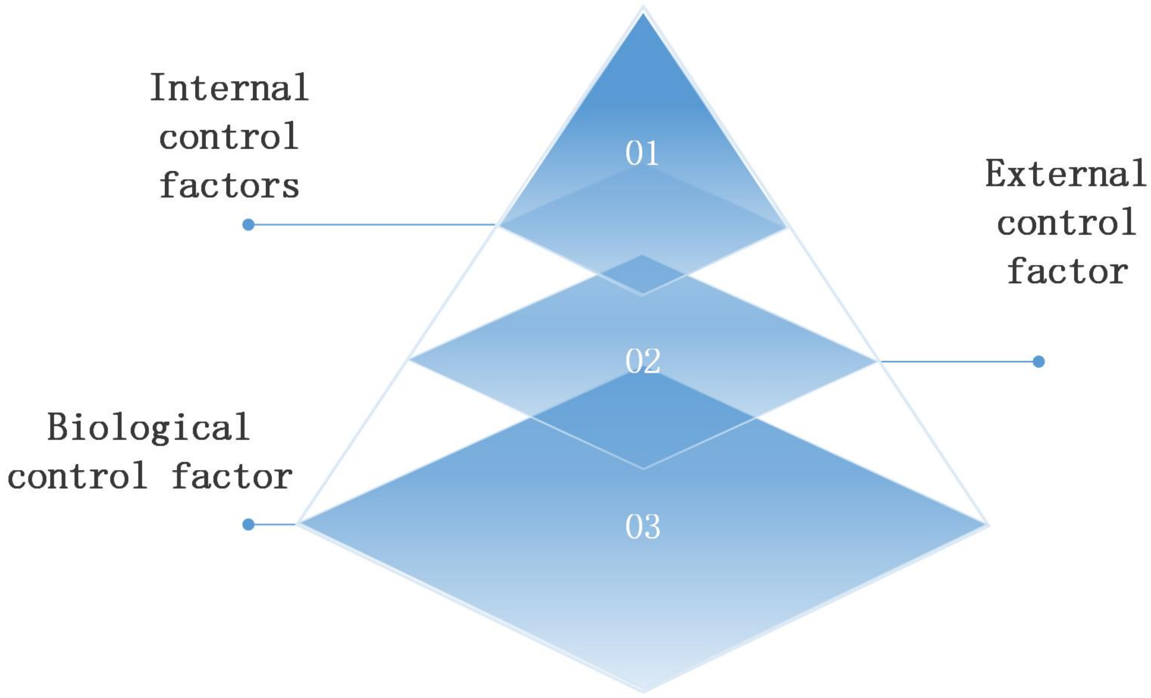
International Scientific and Practical Internet Conference:

VNTU CONFERENCES electronic scientific publications, Youth in Science: Research, Problems, Prospects (MN-2024)

[1] Biks, Yuriy, and Yunsheng Zhai. "EVALUATING BUILDING ENVELOPES for ENHANCED ENERGY EFFICIENCY: A COMPREHENSIVE ASSESSMENT APPROACH." Conferences.vntu.edu.ua, 22 May 2024, https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21435

Chapter 1 Theory and current research status of building 5

The building envelope is an important aspect of architectural design as it separates the interior from the exterior and protects the occupants from various elements.



Chapter 1 Theory and current research status of building 6

Most countries in the world do not have exact goals for the development of near-zero energy buildings, but they can be roughly divided into the following categories from the perspective of research directions.

1.Research on high-performance building shell structure

2.Near zero energy building design research

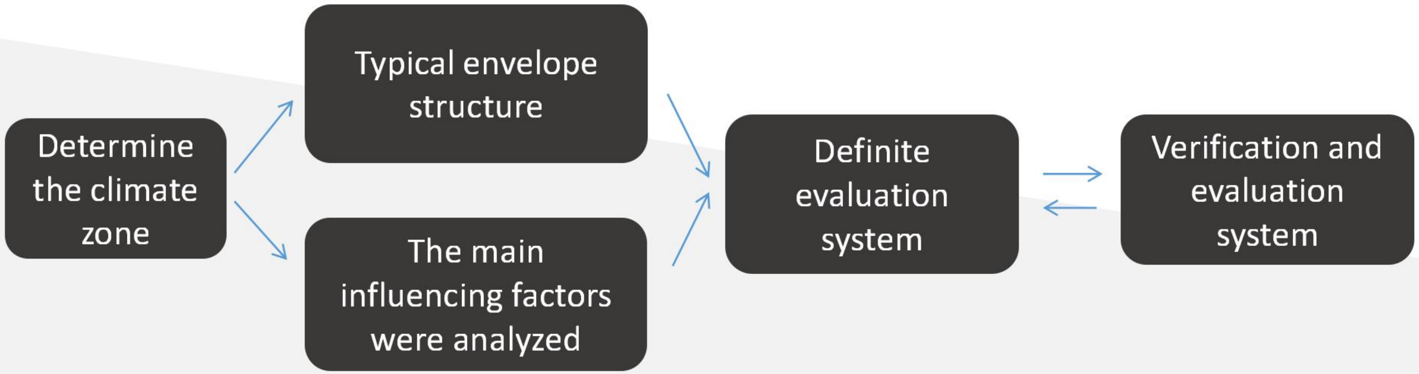
3.Evaluation of near zero energy building

Conclusion of this chapter 1 7

Conclusion:

Domestic and foreign scholars have also conducted detailed studies on various factors affecting near-zero energy buildings, but have not conducted comprehensive evaluation on the adaptability of high-performance building envelope.

The research idea of the paper:



Chapter 2 Typical envelope structure test envelope 8

The method of envelope structure of demonstration project is selected from National Building Standard Design Atlas 09J908-3 (Figure 2-1) :

1 - A layer of anti-cracking mortar composite alkali-resistant glass fiber mesh cloth is 5 thick : R = 0.005; D = 0.057

2-EPS plate δ thickness:

λc =0. 042; SC = 0.36

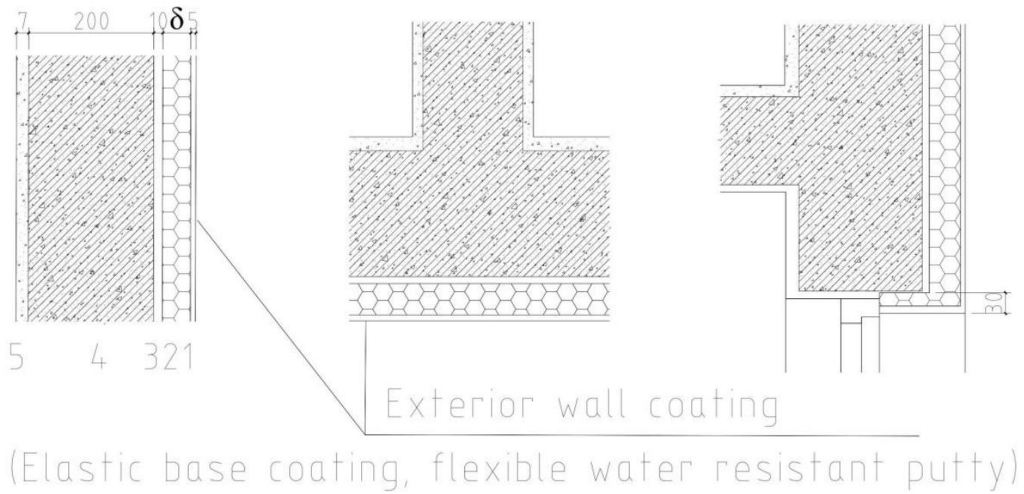
3- Bonding layer

4- Reinforced concrete wall 200 thick:

r =0. 115; D = 1.98

5- Plaster plaster mortar 7 thick:

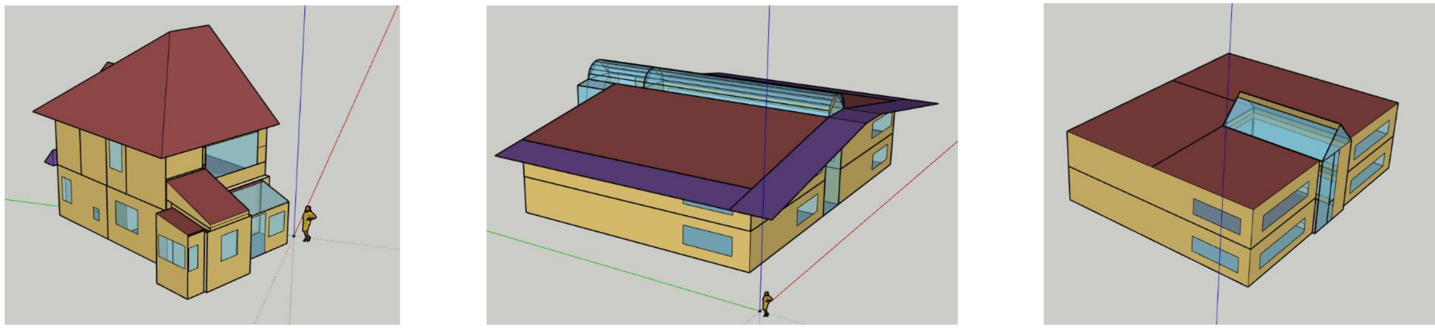
r =0.009; D = 0.085



Chapter 2 Typical envelope structure test envelope 9

The thermal conductivity, permeability, solar absorption coefficient, insulation layer thickness and thermal emissivity of different samples of the same wall structure in hot summer and warm winter areas were simulated by EnergyPlus to calculate the simulated power consumption.

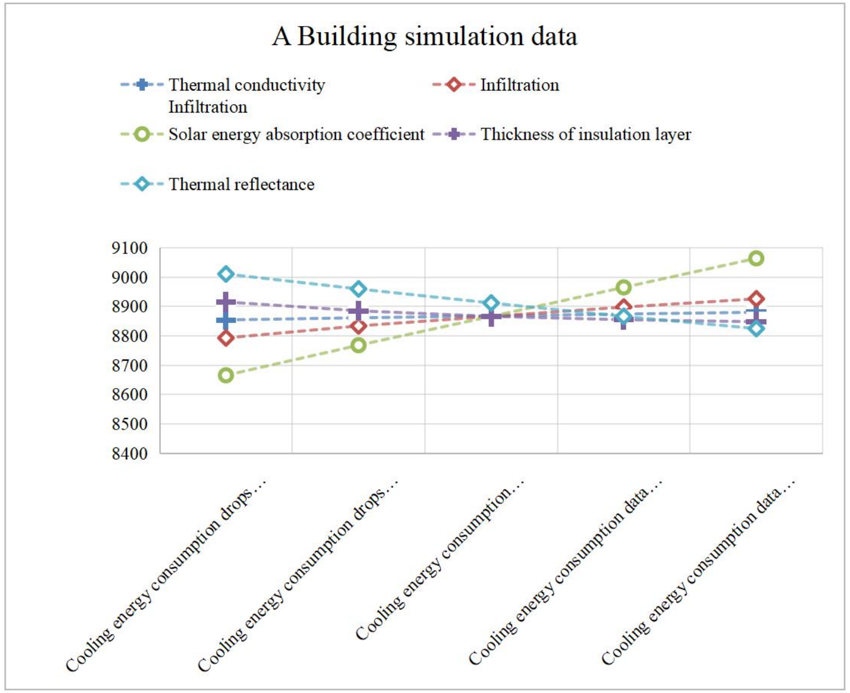
The control variable method is used to simulate a single coefficient floating.



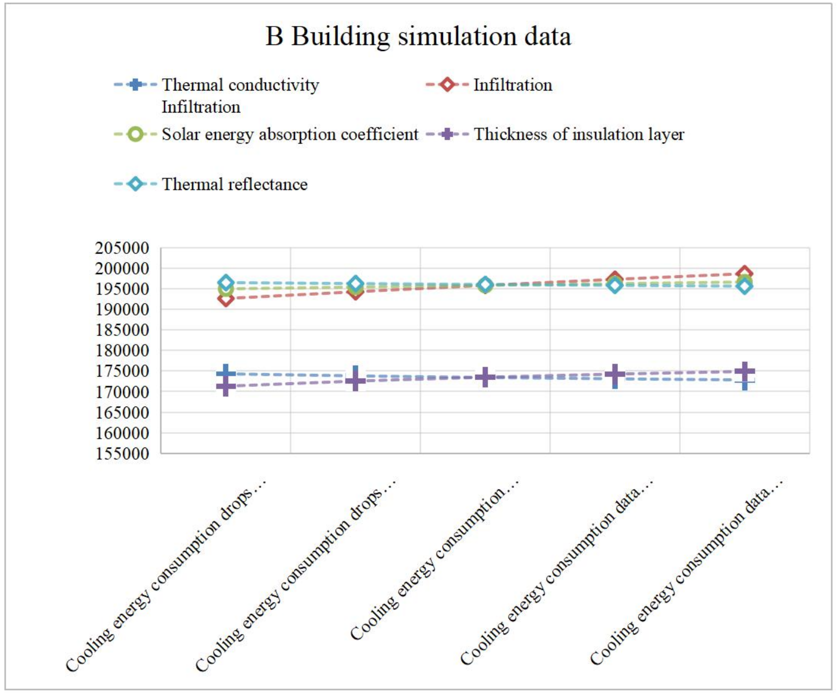
Building examples A, B, C

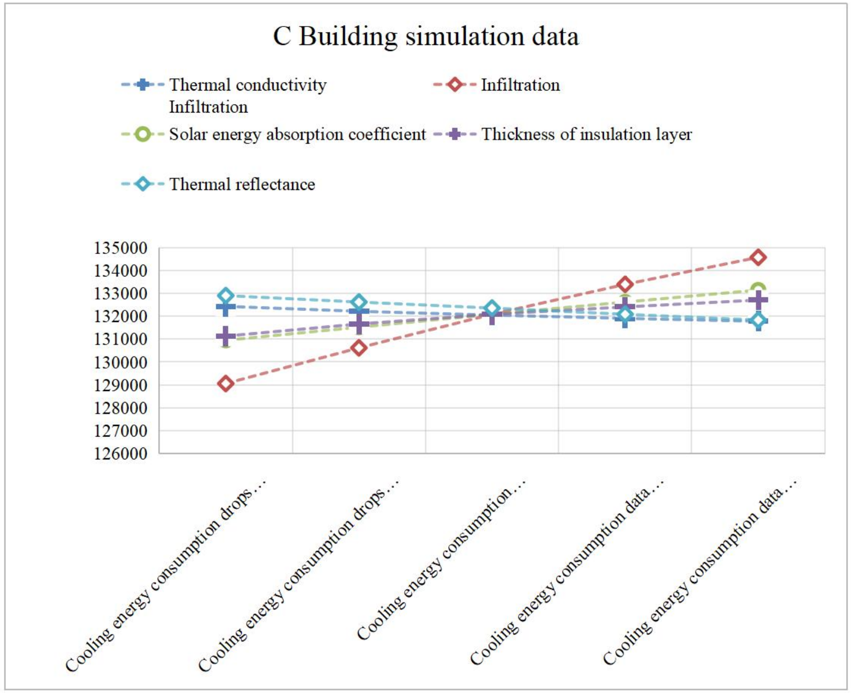
Chapter 2 Typical envelope structure test envelope 10

Since the simulated sample belongs to the hot summer and warm winter area, the data statistics are only carried out for refrigeration energy consumption, in which the median value is selected as the usual coefficient of the thermal insulation board on the market and the control variable method is used for floating test.



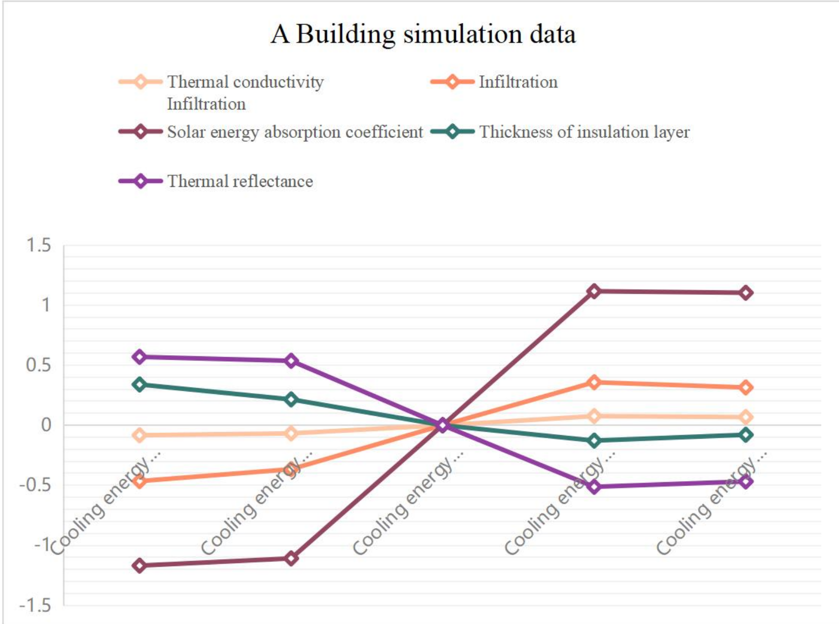
Chapter 2 Typical envelope structure test envelope 11



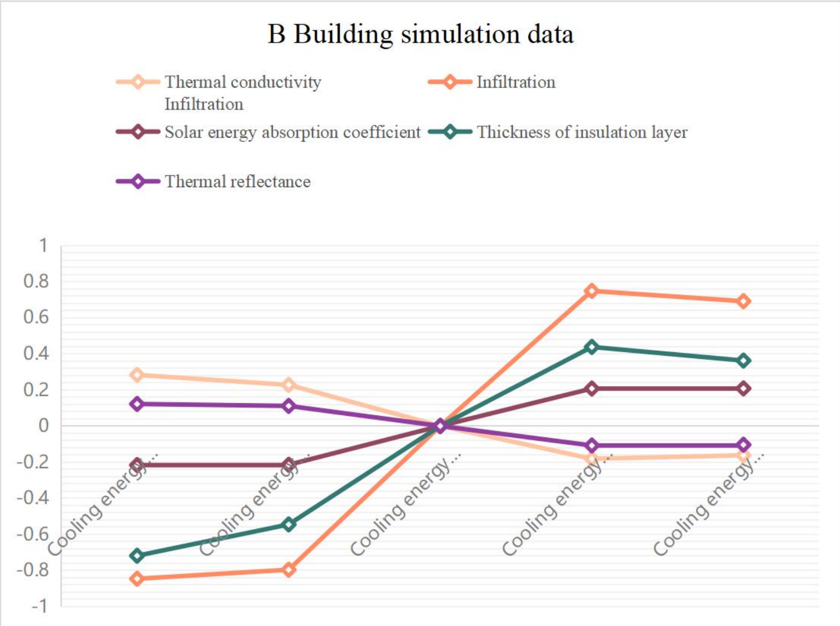


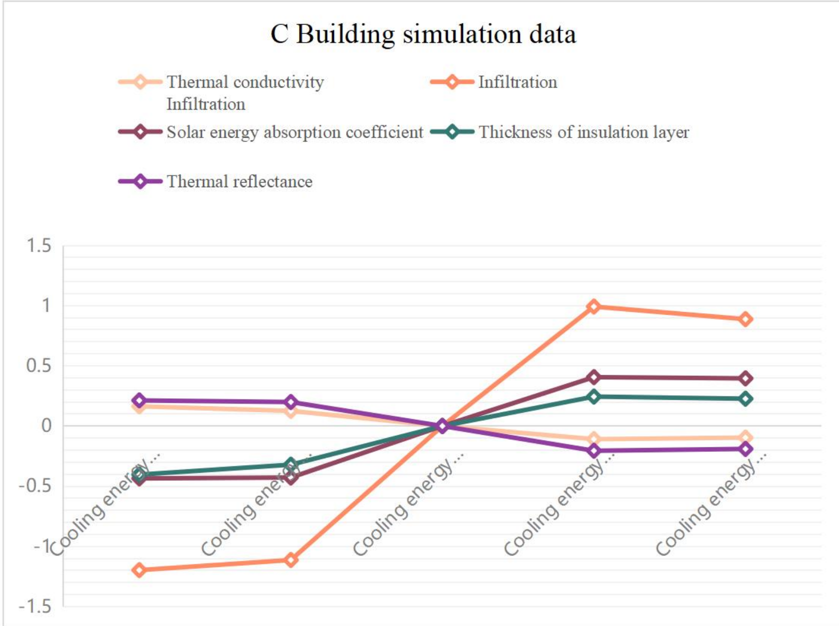
Chapter 2 Typical envelope structure test envelope 12

The simulated energy consumption of buildings A, B, and C is large, and the stacked data in the figure is not easy to analyze. The original data is converted into floating percentages, so that data of different scales or units can be directly compared.



Chapter 2 Typical envelope structure test envelope 13





Conclusion of this chapter 2 14

(1) From the perspective of Energyplus simulation data, a single indicator does not float with the index to save energy, and may have the opposite effect.

(2) Because it is also affected by other factors, no conclusion can be drawn directly, so it is necessary to assign weights to the selected coefficients for AHP analysis.

(3) All selected indicators will have an important impact on the high-performance building envelope.

(4) Other evaluation factors need to be added to the evaluation of samples with the same structure in the same climate region.

Chapter 3 Establishment of adaptive evaluation system of high performance building envelope 15

When establishing the evaluation index system, the following principles should be followed:

(1) Adaptability principle

(2) Operability principle

(3) The principle of predictability

(4) Innovation principle

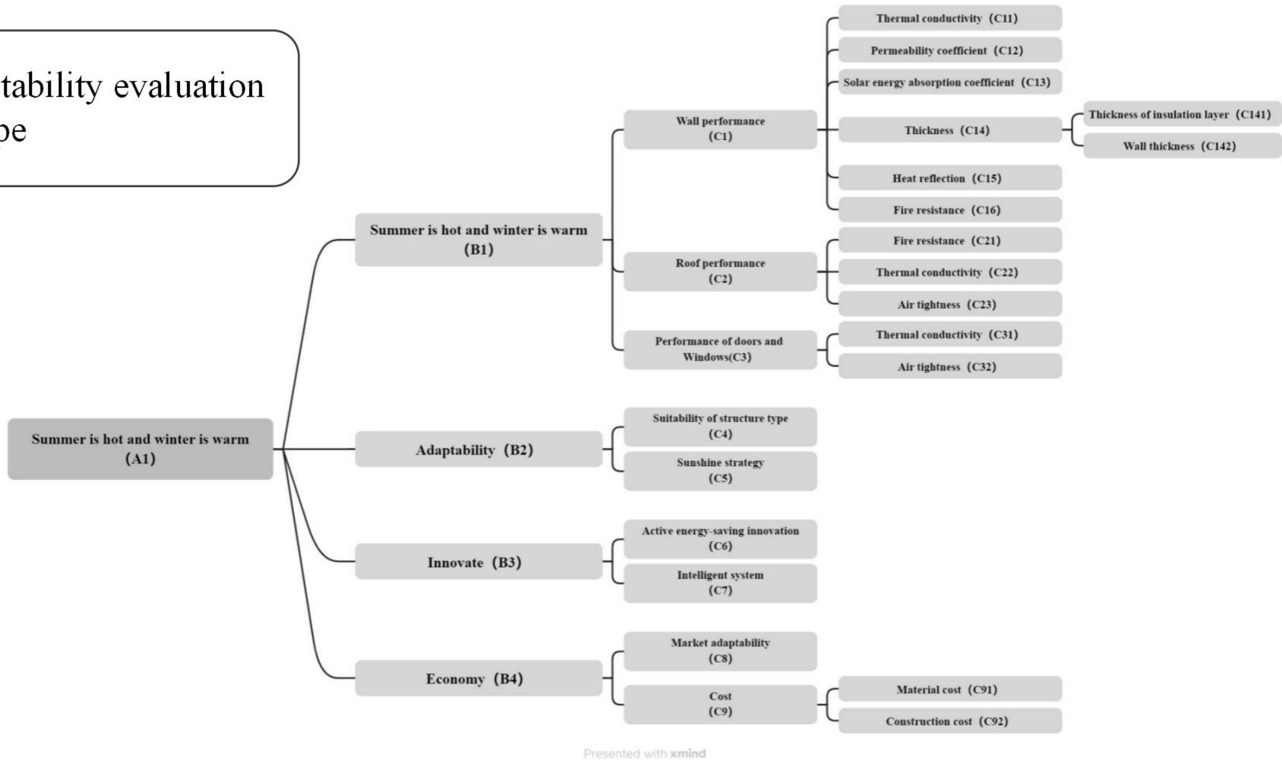
(5) The principle of timeliness

(6) Economic principles

Chapter 3 Establishment of adaptive evaluation system of high performance building envelope

16

Hierarchy diagram of suitability evaluation index of building envelope



Chapter 3 Establishment of adaptive evaluation system of high performance building envelope 17

In the process of weight analysis, Delphi method and analytic hierarchy process (AHP) are selected to analyze the evaluation system more accurately and scientifically.

The ranking weight of the first level index to the decision goal

Criterion layer element	Weight
Economy（B4）	0.4
Summer is hot and winter is warm（B1）	0.2
Innovate（B3）	0.2
Adaptability（B2）	0.2

The ranking weight of the secondary index to the decision objective

Criterion layer element	Weight
Cost（C9）	0.4
Suitability of structure type（C4）	0.1667
Market adaptability（C8）	0.1
Intelligent system（C7）	0.1
Active energy-saving innovation（C6）	0.1
Wall performance（C1）	0.0667
Roof performance（C2）	0.0667
Performance of doors and Windows(C3)	0.0667
Sunshine strategy（C5）	0.0333

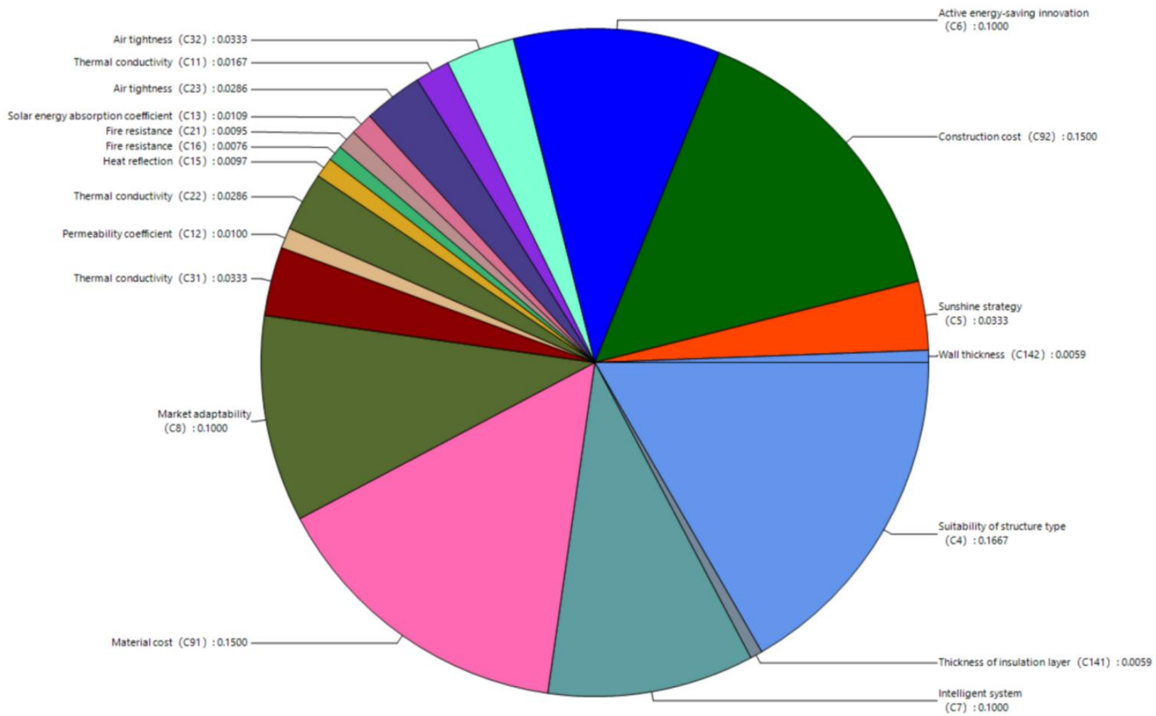
The ranking weight of the three-level index to the decision goal

	Weight
Material cost（C91）	0.15
Construction cost（C92）	0.15
Thermal conductivity（C31）	0.0333
Sunshine strategy（C5）	0.0333
Air tightness（C32）	0.0333
Thermal conductivity（C22）	0.0286
Air tightness（C23）	0.0286
Thermal conductivity（C11）	0.0167
Thickness（C14）	0.0118
Solar energy absorption coefficient（C13）	0.0109
Permeability coefficient（C12）	0.01
Heat reflection（C15）	0.0097
Fire resistance（C21）	0.0095
	0.0076

The ranking weight of four levels of indicators on decision objectives

Criterion layer element	Weight
Wall thickness（C142）	0.0059
Thickness of insulation layer（C141）	0.0059

Chapter 3 Establishment of adaptive evaluation system of high performance building envelope 18



The evaluation system model based on fuzzy comprehensive

Conclusion of this chapter 3 19

This chapter mainly constructs a comprehensive model based on AHP and fuzzy comprehensive evaluation.

(1) The weights of each evaluation index are determined through the analytic Hierarchy Process (AHP) and the expert scoring method (Delphi), which ensures the practicability and authority of the evaluation system.

(2) With the support of the voting of theoretical experts and analysis methods, the adaptability evaluation system of hot summer and warm winter areas was established.

Chapter 4 Construction of evaluation system model based on fuzzy comprehensive evaluation method 20

The new construction system is used to evaluate the existing buildings, and the adaptability evaluation system is verified.

Case building basic overview table

Building name	
Project type	Public building
Geographic location	Shenzhen, China
Climatic environment	Temperate continental climate zone
Floor area	8696 m2
Building height	Below 28 m
Number of floors	7
Building orientation	North-south
Structural system	Frame structure
Basic form	Full of raft foundations
Building life	30 years
Plot ratio	1.94
Ratio of green space	31%

The evaluation system model based on fuzzy comprehensive evaluation method of AHP is constructed.In the fuzzy comprehensive evaluation, the membership degree of multiple evaluation indicators is selected as Outstanding: 0.7330.

Membership degree of comprehensive rating

Evaluation level	Membership degree
Outstanding	0.7330
Good	0.2670
Up to standard	0.0000
Below standard	0.0000

Conclusion of this chapter 4 21

(1) From the perspective of indicators. Some indicators need to be further optimized design, such as heating and cooling mode, heating and cooling system need to determine their weight value according to the climate region.

(2) From the perspective of architectural cases. The official results of the evaluation of this building will basically reach an ideal level, which also reflects from the side that the results of this research are basically a reasonable result.

(3) Under the adaptability evaluation system of high and new energy envelope structure, the evaluated buildings have significant energy saving effect after reconstruction, and the annual saving after renovation is 3888723Wh. According to the average electricity price of 1.23 RMB/KWh in China, the annual saving is 4783.13 RMB by calculation. And the heat transfer coefficient of EPS material used after reconstruction is less than 0.035, which accords with the interval value of thermal conductivity of evaluation system.

Conclusion 22

This paper first analyzes the research progress and standard overview of near-zero energy buildings at home and abroad, and analyzes the advantages and disadvantages of high-performance building enclosures in practical applications by simulating the thermal conductivity, permeability, solar energy absorption coefficient, insulation layer thickness and thermal emissivity of near-zero energy demonstration projects in different climate zones. By establishing the suitability evaluation system of the enclosure structure in the hot summer and warm winter climate zone, the weight of the key factors affecting the performance of the enclosure structure is calculated, and the following conclusions are drawn:

Conclusion 23

(1) In the Energyplus simulation data analysis of the wall performance of the five indicators, in the original data or energy consumption floating rate statistics of the graph, a single indicator from the middle of the floating up and down to produce a different energy consumption value, will not be a single with the index float to save energy, it may also play the opposite role. However, as the data fluctuation exceeds the range of common energy consumption values, the energy consumption will suddenly increase.

(2) In the process of index ranking, five fuzzy index rankings of wall performance are obtained, which are weighted for AHP fuzzy evaluation, and thermal conductivity > thickness > thermal reflection coefficient > solar energy absorption coefficient > thermal emission are obtained. Since there are many factors affecting the envelope structure in the test climate zone, it will also be affected by other factors, after adding other adaptability evaluation factors, AHP fuzzy evaluation is carried out by assigning weight to it. Based on the main aspects of technology, adaptability, innovation, economy, etc., the second and third indexes are derived step by step, and a scientific evaluation index system of hot summer and warm winter is established.

Conclusion 24

(3) The index weight reflecting the adaptive performance level of the high-performance envelope structure, and the selection of a more scientific and quantitative calculation method can ensure the reliability of the results. In the process of determining the weight of the index by AHP, the paper collects and compares the questionnaires of the judgment matrix based on the three stakeholders of energy-saving building designers, researchers and energy-saving building users, and uses the rank average method to aggregate the final results of the judgment matrix, and the weight results obtained are satisfactory.

(4) From the perspective of evaluation, this paper evaluates the comprehensive design performance level of near-zero energy consumption public buildings, and verifies the feasibility and effectiveness of the evaluation model by using concrete cases for demonstration. The analytic hierarchy process combined with fuzzy comprehensive evaluation is widely used, but it is rarely used in the evaluation of building envelope. In this paper, the classical reliable method is applied to a new field, and the application range of this method is expanded.

Thank you, professors, for listening

Opponent's review of graduate student

ZHAI Yunsheng's Master's thesis

Master's thesis was performed according to the topic "Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach".

The Master's Qualification Thesis submitted for review was completed fully and within the deadline. The work corresponds to the approved topic and task. The subject is relevant and dedicated to the multi-criteria attitude for the design of energy-efficient envelopes.

It should be noted that the author carried out the thesis on this topic, and the research was dedicated to the multi-criteria assessment of the modelled building using one of the proposed techniques under specific parameters.

The material of the work is presented in a detailed and accessible form. The thesis consists of the following sections: analysis of the current state of theory and practice on the topic of the master's thesis; problems faced by Near Zero Energy Building; Optimization of construction process based on EnergyPlus simulation tool; Case Verification study; economic impact; and total conclusions.

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

In the first section of the thesis, a sufficiently detailed and qualitative review of the works of other authors with a close research direction is performed, emphasising the author's reasonable understanding of the chosen topic. The comparison of different buildings with the same wall structure in the climate zone, the data processing of architectural design information, makes the evaluation and analysis of architectural design more objective, has certain innovations in the specific use of research methods, and lays a certain foundation for related research.

This work is committed to playing an important role in analysing and evaluating building energy efficiency design at home and abroad and developing energy-efficient design tools based on a preliminary decision-making process based on the proposed AHP model in China.

In the fourth chapter, the economic part, the author provides a calculation of the probable implementation of the developed model.

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

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

The thesis's disadvantages include inaccuracies in the design of several tables and figures. Nevertheless, these shortcomings do not affect the positive impression of the work.

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

Opponent

Ph.D., Prof. Ivan KOTS

Supervisor's review for Master's thesis of

ZHAI Yunsheng

Master's thesis was performed according to the topic "Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach".

The Master's Qualification Thesis, submitted for review in a timely manner, demonstrates ZHAI Yunsheng's commitment to the approved topic. The chosen topic, 'Evaluating Building Envelopes for Enhanced Energy Efficiency: A Comprehensive Assessment Approach ', is not only relevant but also showcases a focused and multi-criteria approach to designing energy-efficient envelopes.

It's worth noting that ZHAI Yunsheng's thesis is centered around the evaluation of a modelled building. The author's choice to use the MCDA assessment method, specifically the Analytic Hierarchy Process, a widely recognized method in various technical fields, adds credibility to the research.

The work's material is presented in a manner that is both detailed and accessible. The thesis consists of the following sections: analysis of the current state of theory and practice performed on foreign and Chinese domestic practice case studies; energy-efficient tool for energy simulation EnergyPlus used for the optimization of construction; Case Verification study; economic impact; and total conclusions.

The first chapter of the thesis provides a comprehensive and qualitative review of the works of other authors with similar research interests, emphasizing the author's reasonable comprehension of the chosen topic. The comparison of different buildings with the same wall structure in the climate zone and the data processing of architectural design information make the valuable impact and analysis of architectural design more objective, have several innovations in the specific use of research methods, and lay a certain foundation for related research.

This presented thesis is performed and meets all the current requirements for analysing and evaluating building energy efficiency design and developing energy-efficient design tools based on a preliminary decision-making process, particularly based on the proposed AHP tool-based model.

In the fourth chapter, the economic part, the author calculates the probable implementation of the developed model on the case building.

The research results were praised at the international scientific and practical conference and in the report's abstracts. Executing the textual part of the explanatory note is mainly performed under the standards and in compliance with all requirements.

For the drawbacks of the thesis, the following could be considered:

– -several minor inaccuracies in the design of tables and figures.
– the economic calculations don't clearly reflect the previously obtained results.

Nevertheless, these minorly detected disadvantages do not affect the positive impression of the performed work.

The master's qualification thesis was performed reasonably, according to the task, and in compliance with all requirements. That's why, in my opinion, the work deserves a grade (A), and the author is awarded the qualification of "Master of Civil Engineering" in speciality 192 - "Construction and Civil Engineering."

Scientific supervisor
Ph.D., Associate Prof. Yuriy BIKS