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(Fullnameofhighereducationinstitution)
FacultyofConstruction, CivilandEnvironmentalEngineering
(Fullnameoftheinstitute, nameofthefaculty (department))
DepartmentofConstruction, UrbanPlanningandArchitecture
(Fullnameofthedepartment (subject, cyclecommittee))

MASTER'S THESIS

«Envelopesenergyefficiencyperformanceassessmentintermsoftheirdynamiccharacteristics»

Assigned by: 2nd year student, group__ IIB-22m
specialty 192 Construction and Civil Engineering
(code and name of field of study, speciality)

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«10» 06 2024

Vinnytsia VNTU – 2024

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Departmentof Construction, Urban Planning and Architecture
Educationlevel Second (master's)
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TASK

FOR MASTER QUALIFICATION THESIS TO STUDENT

DENG Xueqin
(full name)

1. Master's thesis topic «Envelopes energy efficiency performance assessment in terms of their dynamic characteristics»

Master's thesis supervisor BiksY., PhD, Associate Prof.ofCUPADepartment,
(full name, academic degree, academic title)

approved by order of the higher educational institution from February, "13th" 2024 No 16

2. Work submission deadline by a master's student June 13, 2024

3. Initial thesis data: Through the analysis of unsteady thermal characteristics by ISO 13786, building energy consumption for winter and summer season and revealing the major influencers for these periods is investigated. This paper aims to provide some scientific basis for the considering the calculation of dynamic thermal performance characteristics as key influencers for decision support process at predesign stage of construction for energy-savingoptimisation design; as well to suggest which practical experience obtained in mainland China and abroad was studied for the trend of building energy saving and mainly green building, and to predict and prospect and dynamics in this field.

4. Content of the explanatory note (list of issues to be developed): Introduction, which should reflect the research topic's relevance, purpose, scientific novelty, practical significance, tasks, object and subject of provided research. The research part consists of three sections: Chapter 1, in which scientific analysis of the state-of-the-art for dynamic performance parameters of building envelopes, attitudes, including domestic design and foreign design and the standard energy-saving technologies, formulation of the research scope, criteria, tools, search for relevant scientific sources, techniques should be performed; Chapter 2, in which factors affecting the energy efficiency for dynamic performance. Comparative thermal property analysis for different wall materials should be performed; Chapter 3 – Case study analysis of dynamic internal area heat capacity, decrement factor as dynamic characteristics for five multilayered wall assemblies according to the ISO 13786 Standardwith Excel-based analysis software. Meeting the Chinese climatic zones' thermal resistance compliance check for obtained modelling results, Chapter 4 – Economic outcomes impact calculation. Total summary reflects the significant scientific and practical results of the research.

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

Posters that reflect:1-5 - research background,topic, purpose and tasks of the work, scientific novelty, practical significance; 6-7 the wall assemblies typesfor analysis, parameters which should be considered in the energy-efficiency assessment of the designed construction; 8-12 – case study building parameters, model results and analysis of alternatives;13-20 – case study results of proposed evaluation in terms of economic benefits, payback period, research summary.

6. Consultantsofthesisparts

Chapter	Surname, initials and position of consultant	Signature and date	
		Task issued	Task accepted
Introduction, Chapter 1	Biks Y., Associate prof.ofCUPADepartment	[signature]	
Chapter 2	Biks Y., Associate prof.ofCUPADepartment	[signature]	
Chapter 3	Biks Y., Associate prof.ofCUPADepartment	[signature]	
Chapter 4 Economic part	Biks Y., Associate prof.ofCUPADepartment	[signature]	

7. Task issuance date 02/13/2024

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 for thermal performance analysis of building envelopes, domestic and abroad attitudes, including dynamic thermal performance characteristics, planning design and energy-saving technologies, formulation of the research scope, criteria, tool, 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 regarding winter and summer assembly behaviour. Comparative analysis of key influencers for different seasons.		
4	Preparation of Chapter 3. Building energy-efficiency analysis of case study. The basic process outline of the five most commonly used Chinese multilayered wall assemblies. Key factors, assembly cross-sections and modelling results.		
5	Preparation the Chapter 4. Economic outcomes calculus, payback period for "best" alternative of proposed multilayered assemblies of building envelope. Total summary.		
6	Prepublication editing and publication of Master's qualification thesis results. Approbation		
7	Plagiarism check		
8	Preliminary defence of the Master's qualification thesis		

Master student — Deng xueqin (Signature) — DENG X. (Surname and initials)

Master's thesis supervisor — [signature] (Signature) — BIKS Y. (Surname and initials)

ABSTRACT

UDC 621.3.088

DENG Xueqin. Envelopes energy efficiency performance assessment in terms of their dynamic characteristics. Master's qualification thesis on speciality 192 - Construction and Civil Engineering, Educational professional program - Industrial and Civil Engineering. Vinnytsia: VNTU, 2024.72 p.

In English language. Bibliographer: 19 titles; Figure: 25; tables 22.

Building energy consumption accounts for 30% of China's total social energy consumption, which is very serious for a country with low energy utilization levels and a lack of per capita medical resources. Building energy consumption has become the second largest energy consumption industry after industrial energy consumption. At the same time, with the advancement of the urbanisation process, the building area increases at a fantastic speed, so the proportion of building energy consumption will show a trend of increasing yearly. Therefore, the attention to building energy conservation is very significant in the current situation. This is related to alleviating the contradiction between energy supply and demand, the healthy and stable development of the construction industry and the sustainable development of the national economy. This paper mainly focuses on improving the indoor thermal environment of buildings to reduce the demand for artificial cold and heat sources. At the same time, it is under the condition of ensuring the quality of residential buildings to carry out relevant research. Through the analysis of climate characteristics, building energy consumption composition and building thermal process, the relationship between building energy saving and building energy consumption and related concepts is investigated. This paper aims to provide some scientific basis for the dynamic parameters, considering that MCDA analysis is going to be conducted through the multilayered wall thermal efficiency assessment. Introduction part through the main literature collection at home and abroad, combing the countries, the government and researchers for the building energy conservation measures, the research means and determine the research object and target, and summarises the main factors affecting the residential building energy consumption for wall thermal insulation to determine the subject to solve the problem and research methods and approaches. Chapter 1 analyzes the influencing factors, the standards, and the mathematical tools of the research. Chapter 2 analyzes the studies of target standards, material characteristics, data, tools, etc. Chapter three is the calculation of the dynamic unsteady-state thermal characteristics of multi-layer walls as internal area heat capacity and decrement factor under ISO 13786 as criteria for the energy efficiency assessment of multilayered wall assemblies. Chapter four is dedicated to the economic effect, payback period calculus, as well the shortcomings of the future research and development direction of this field.

Keywords: building energy conservation; green building; dynamic simulation analysis; energy consumption, MCDA analysis, multilayered wall assembly.

CONTENT

INTRODUCTION

Topic actuality. As the global energy crisis becomes increasingly severe, building energy consumption issues have become the focus of attention. As an important part of the building, the heat transfer characteristics of the building wall directly affect the energy consumption efficiency of the building and the comfort of the indoor environment. In modern architecture, in order to improve the thermal insulation performance of the building, multi-layer wall components have been widely used. These components are often composed of different materials and structural layers with complex heat transfer mechanisms. The dynamic thermal characteristics of multi-layer wall components refer to the dynamic changing characteristics of temperature distribution and heat flow transfer inside the wall under different times and environmental conditions. Understanding the dynamic thermal characteristics of multi-layer wall components is of great significance for optimizing building design, improving building energy efficiency, and reducing energy consumption. This thesis is dedicated to the comparison of the dynamic unsteady-state thermal characteristics of multi-layer walls as internal area heat capacity and decrement factor under ISO 13786 as criteria for the energy efficiency assessment of multilayered wall assemblies. As well to explore the impact of different materials and structures on the heat transfer performance of the wall, providing a scientific basis for architectural design and material selection. Through comparative analysis, we can determine the differences and advantages of different multi-layer wall components in terms of dynamic thermal characteristics and select the best solution.

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

The purpose and objectives of the study. The main goals of the research are:

- Provide the analysis of dynamic thermal performance key influencers in terms of winter and summer behaviour for multilayered wall assemblies;

- Research of most commonly used multilayered wall assemblies in Chinese construction sector;
- Numerical modelling of internal area heat capacity and decrement factor for different multilayered assembly walls, considering the mass of the wall and u-value in the multicriteria analysis;
- Climate zoning requirements' meeting check for all the compared alternatives;
- Providing the MCDA assessment of multilayered walls, choosing the "best" alternative, calculating the economic outcomes and the payback period.

The object of the study. The object of this study is a complex of thermophysical, physical, as well as economic indicators of wall assemblies.

The subject of the study. The subject of the study is a comprehensive assessment of the energy efficiency of multilayer envelope structures, taking into account their dynamic thermal performance parameters.

Research methods. Finding the dynamic characteristics of multilayer wall constructions was performed using the calculation package analytically described in [3] and implemented in the MS Excel program "Calculation-tool-Thermal-Mass-ISO-13786"[2]. MCDA analysis of multilayered wall assemblies comprehensive assessment was performed by standard mathematical formulae for providing the additive convolution.

Scientific novelty of the obtained results. Obtaining, as a result of calculations, the value of a comprehensive assessment of the buildings assemblies structures, taking into account their dynamic thermal performance influence factors, as well according the steady state parameter and their mass;

The practical significance of the results obtained. In this study, the multilayered assembly walls were investigated and analysed, as well the main thermal properties of envelope materials, such as wall and insulation systems commonly used in the Chinese construction sector were investigated. Based on the preliminary research outcomes, the key influencers for winter and summer wall assemblies behaviour of different walls are conducted, and the multilayered envelope was chosen based on MCDA analysis. Results let consider that not all the researched multilayered wall assemblies meet the thermal resistant requirements for Chinese climate zones. Finally, using the dynamic thermal performance simulation tool, comprehensively considering the comprehensive physical and dynamic thermal performance parameters for the selected envelope types were evaluated, and suggestions for the "best" alternative were put forward to achieve an efficient assessment of wall assembly.

Publications. A thesis [19] was published in the Proceedings of X International Scientific and Practical Conference Tokyo, June 13-15, 2024:

DENG Xueqin. Multilayered wall assemblies' dynamic thermal characteristics comparison. // Topical aspects of modern scientific research. Proceedings of the 10th International scientific and practical conference. CPN Publishing Group. Tokyo, Japan. 2024. Pp. 142-148. URL: https://sci-conf.com.ua/x-mizhnarodna-naukovo-praktichna-konferentsiya-topical-aspects-of-modern-scientific-research-13-15-06-2024-tokio-yaponiya-arhiv/. (Last accessed 06.13.2024).

Acknowledgements. This research was mainly completed under the guidance of scientific supervisor Yuriy BIKS, whose proposed ideas of MCDA comparison of several, most important dynamic parameters regarding the envelopes, along with the energy-efficiency assessment of most commonly used in China wall assemblies, which were comprehensively analysed in detail and considered in this Thesis.

1 CURRENT STATUS OF DYNAMIC THERMAL PROPERTIES OF DIFFERENT WALLS AT HOME AND ABROAD

1.1 Research background

1.1.1 Project source

In recent years, with the rapid development of national economy, the acceleration of urbanization and the rapid development of economy, the rapid growth of building area, residents of the indoor physical environment comfort requirements are also increasing, in order to keep the indoor physical environment comfort, residents generally choose in the form of the energy consumption to change the indoor environment, which makes our building energy consumption increased sharply. In the background of increasing energy consumption, the energy saving requirements of buildings have become a real demand. In the field of construction, building energy consumption is generally divided into: air conditioning energy consumption, equipment energy consumption, power supply energy consumption, transportation energy consumption, maintenance energy consumption, etc.

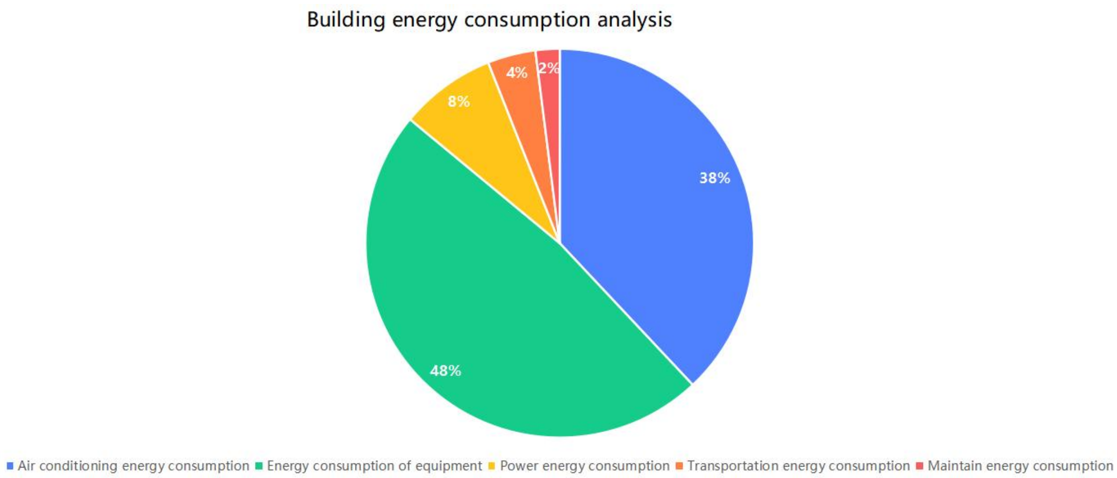


Figure 1.1 Building energy consumption analysis

The so-called construction energy consumption refers to the energy consumption caused by the production, transportation and installation of building materials during the construction process of the building; the operation energy consumption refers to the energy consumption when actually put into use after the completion of the building. While the global building energy consumption is growing rapidly, China's building energy consumption is also growing rapidly along with the urbanization process. From 2004 to 2018, China's construction energy consumption increased from about 400 million tce to 1.2 billion tce, with a growth rate of 200%, and its operating energy consumption increased from about 380 million tce to 1 billion tce, with a growth rate of 163%.

However, non-renewable resources are limited, such as the limited reserves of conventional energy sources such as coal, oil and natural gas, and excessive consumption will eventually deplete them. The use of conventional energy also has environmental problems such as air pollution, which is not conducive to environmental protection. Therefore, building energy conservation is an important part of achieving sustainable development. The construction industry is facing the great pressure of the upward pressure of building energy consumption, and it is urgent to find an implementation path of high energy efficiency to slow down the increase of energy consumption and energy saving.

At present, the research focus of many scholars is mainly focused on the development of air conditioning system and other measures, and there is very little research on achieving energy saving by optimizing the envelope structure. Secondly, the research focus of many scholars is often only on a specific impact factor, resulting in insufficient systematic and comprehensive analysis and lack of universal applicability.

1.1.2 Purpose and significance of the subject research

The purpose of the research is to effectively control the building energy consumption and guide the building energy saving design.

A) At present, there are many ways to control building energy consumption in our country. We have found some common methods, such as:

A.1) Design of building appearance and orientation: Make maximum use of natural light and natural ventilation through reasonable design of building appearance and orientation, and reduce reliance on lighting and air-conditioning systems.

A.2) Insulation and insulation design: Use efficient insulation materials and insulation structures to reduce heat transfer and loss. This includes insulation design for walls, roofs, floors and windows.

A.3) Efficient heating and air-conditioning systems: Choose heating and air-conditioning equipment with high energy efficiency and stable operation, rationally design the system layout, and optimize the energy consumption of heating and cooling.

A.4) Lighting system optimization: Use energy-saving lamps, such as LED lighting, and intelligent control systems to control the brightness and time of lighting to reduce energy consumption.

A.5) Water resource utilization and management: Use water-saving equipment and systems, such as low-flow shower heads, dual-flush toilets, etc., while recycling and reusing water resources.

A.6)Use renewable energy: Use renewable energy such as solar energy and wind energy to provide energy for the building through solar photovoltaic panels and wind power generation systems to reduce dependence on traditional energy.

A.7)Intelligent building management system: Utilize advanced building automation technology, such as intelligent control systems, sensors and data analysis, to monitor and control the energy consumption of the building in real time for refined management and optimization.

B.) Or building energy-saving design, you can take the following steps:

B.1) First, understand the energy consumption characteristics of the building: conduct a comprehensive analysis and evaluation of the energy usage of the building, and understand the energy consumption characteristics and bottlenecks of the building.

B.2) Secondly, set energy-saving goals: Based on the type, function and use needs of the building, set reasonable energy-saving goals, such as energy consumption reduction percentage, energy-saving standard compliance, etc.

B.3) Then, conduct energy consumption simulation and analysis: Use energy consumption simulation software to simulate and analyze the energy consumption of the building, evaluate the effects of various energy-saving design measures, and compare the energy consumption differences of different design solutions.

B.3) Propose energy-saving design suggestions: Based on the results of energy consumption simulation and analysis, put forward specific energy-saving design suggestions, including building appearance and orientation design, thermal insulation design, heating and air-conditioning system optimization, etc.

B.4)Combine with codes and standards: Consider local building energy conservation codes and standards to ensure that the design scheme meets relevant requirements and exceeds standard requirements as much as possible.

B.5)Regular monitoring and evaluation: After the building is completed, energy consumption monitoring and evaluation will be carried out regularly to check whether the actual energy consumption meets the design requirements, and at the same time make adjustments and improvements.

By comprehensively considering measures such as building exterior design, thermal insulation, energy-saving equipment and systems, renewable energy utilization, and intelligent building management, we can effectively guide building energy-saving design and minimize building energy consumption.

Scientific and reasonable building energy saving design is an important guarantee for building energy saving standards. At present, there are two basic and effective ways to achieve building energy conservation. One is to improve the thermal performance of the envelope structure in the design stage of the building scheme, and the other is to improve the operation efficiency of the equipment system in the operation stage of the building. The former is the basis of building energy consumption control and an important guarantee for the energy saving of the whole building.

The envelope refers to the building components that divide the indoor and outdoor space of the building and the space used inside the building. Improving the thermal performance of the envelope structure is designed to improve the effect of peak shifting and valley filling, and reduce the fluctuation of indoor air temperature. Taking an industrial plant as an example, in the early stage, the sealing of the building is mainly to separate the room from the outdoor, so the role of heat insulation is not taken into account when choosing materials. In summer, the intensity of direct sunlight is high. In order to reduce the temperature in the building, the air conditioning is often in an overload operation state, and the energy consumption of the air conditioning is high. In view of this situation, if the thermal insulation reflective coating is applied on the outer surface of the exterior wall of the factory building, most of the sunlight can be reflected, greatly reducing the running time of the air conditioning, and achieving the power saving rate of 15%.

Energy saving efficiency of multiple energy saving measures	
Energy Savings Programme	Energy saving efficiency in industrial plants (%)
Partial shutdown of industrial equipment during periods of inactivity	12%
Optimisation of thermal conductivity of the envelope	4.40%
Turn on the plant-specific air conditioning	12.50%
Reduction of ultraviolet radiation	0.40%
Air conditioning set temperature increase	6.60%
Partial shutdown of industrial equipment during idle time + air-conditioning set temperature increase	19.30%
Optimisation of the heat transfer coefficient of the envelope + opening of plant-specific air conditioning	17.10%
Integration of five energy-saving options	36.30%

Figure 1.2-1 Energy saving efficiency of multiple energy saving measure

Energy saving efficiency is calculated according to the EN ISO 13786

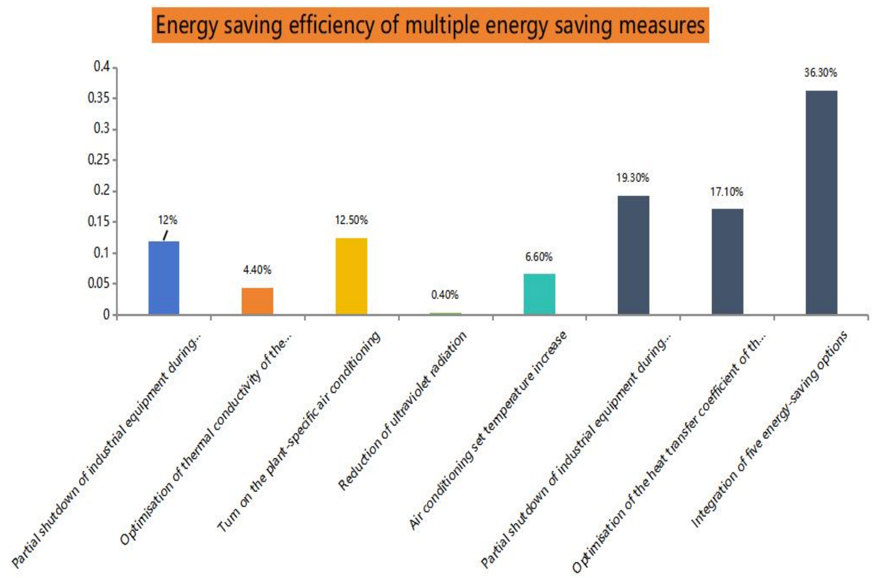


Figure 1.2-2 Energy saving efficiency of multiple energy saving measure

As an important part of the envelope structure, the thermal insulation performance and heat storage performance of the building wall play an important role in maintaining a stable indoor thermal environment and reducing the energy consumption of air conditioning operation. However, there are differences in the thermal insulation performance and heat storage performance of different walls. How to select the wall with the best performance and the maximum economy among many walls is the writing purpose of this paper.

In this paper, we will study the cavity wall insulation, straw wall insulation, steel frame-embedded AAC wall insulation, phase change heat storage wall, light wood structure wall, compare and analyze the thermal conductivity parameters of commonly used wall materials, and propose the dynamic thermal characteristics of industrial plant energy consumption. Based on the design of wall lining based on the dynamic thermal characteristics of energy consumption in the previous industrial plant, the value of different structural combination wall, internal heat capacity and attenuation factor are analyzed, and the scheme of high-quality wall is evaluated.

1.2 Status quo of relevant research at home and abroad

1.2.1 current situation of overseas research

Table 1.1—Several common wall overseas research status quo

Wall name	current situation of overseas research
Air cavity wall insulation	In the world, cavity wall insulation has been widely used and studied. Many countries and regions through regulations and standards require buildings to adopt cavity

	wall insulation technology to improve energy efficiency and reduce carbon emissions. For example, some developed countries in Europe, such as Germany, France and Sweden, have listed cavity wall insulation as one of the main building energy saving measures, and formulated relevant technical standards and guidance documents. In addition, some Asian countries such as Japan and South Korea have also accumulated rich experience in cavity wall insulation, and achieved significant energy saving effect. Advantages: energy saving
Straw wall insulation	Straw brick has been gradually loved by people because of its advantages of good heat insulation, good sound insulation performance, good fire and moisture proof effect, light and high strength, convenient raw material collection and low construction cost. At present, straw construction has been widely promoted and applied in the United States, Canada, France, Australia, Mongolia, Argentina and New Zealand. Technology integration and innovation: In addition to the traditional straw brick, straw concrete technology also has a certain development. By the end of the 19th century, Americans had made rectangular straw blocks as building materials for the walls. In the 1980s, Finnish institutes added plant fibers to concrete to increase the tensile resistance of the concrete. This plant fiber concrete has been proven to meet the standard of concrete structure design, so it has been popularized in the construction industry. The United States, Japan and other developed countries have already added crop straw and other raw materials to the light plate to make the straw board with light thermal insulation. This kind of plate has unique advantages in the construction of high-rise buildings, such as light quality, energy saving, green environmental protection. According to statistics, the use of all kinds of composite lightweight wall panels in the United States accounts for 46% of the building materials, and Japan accounts for 63%, which shows the wide application of straw wall insulation materials in developed countries. Advantages: 1．good heat insulation； 2．good sound insulation and sound insulation performance；

	3．good fire prevention and moisture-proof effect,； 4．light weight and high strength, and convenient raw material collection； 5．low construction cost.
Steel frame-embedded AAC wall insulation	Foreign for the influence of autoclaved aerated concrete material insulation performance such as moisture content, density, aggregate, drying process factors and affect the autoclaved aerated concrete wall thermal insulation material, finishing practice, thickness factors have related research, and put forward many for AAC material effective insulation performance calculation method, has made rich achievements. Advantages: insulation
Phase change heat storage wall	Phase change heat storage is a kind of high-tech energy storage technology based on phase change energy storage materials, which is mainly divided into thermochemical heat storage, sensible heat storage and phase change heat storage. Among them, the phase change heat storage technology has been widely studied and applied because of its advantages of constant temperature and large heat storage density. In the field of wall, phase change heat storage wall, as an effective means to solve the contradiction between time and space of energy supply, is also one of the important ways to improve the energy efficiency. The research and application of mobile heating abroad is much earlier than the domestic one. For example, the German company trans-heat tried out mobile heat storage at a demonstration site, storing heat from factory waste heat in phase change materials and then delivering it to a nearby office building. Although this application is not exactly the same as the phase change heat storage wall, but it shows the application of the phase change heat storage technology in foreign countries. Advantages: 1．constant temperature； 2．high heat storage density.
Light wooden structure wall body	In North America, about 85% of multi-story homes and 95% of low-rise homes have a light wood structure system. In addition, about 50% of low-rise commercial buildings and public buildings, such as restaurants, schools, churches, shops, and office buildings, etc. In California, for example, 99% of homes are built of light wood, and in Los Angeles, 96% of buildings. Advantages: 1．Light wood structure wall because of small section

	wood; 2．has good seismic performance, especially in the earthquake frequent areas; 3．The structure system is easy to build; 4．short construction period; 5．and easy to maintain and transform.

1.2.2 Status quo of domestic research

Table 1.2—Several common wall status quo of domestic research

Wall name	Status quo of domestic research
Air cavity wall insulation	In China, the cavity wall insulation technology has also been widely used and studied. With the rapid development of China's economy and the increase of energy consumption, energy conservation and emission reduction has become an important national strategy. As a high efficiency and energy saving technology, cavity wall insulation has also attracted wide attention. Many local governments and research institutions have promoted the application and development of cavity wall insulation technology in the field of construction through policy support and scientific research projects. At the same time, some universities and research institutions have also carried out a large number of experimental research and engineering case analysis, and accumulated rich practical experience. Advantages: 1．high efficiency and energy saving; 2．heat preservation; 3．effectively reduce the heat transmission ; 4．and energy consumption of buildings; 5．improve indoor comfort.
Straw wall insulation	China is rich in straw resources and wide in sources. Straw has the characteristics of light quality, thermal insulation, non-toxic and harmless. At present, the use of straw mainly has the following points: first, fuel energy. Is the rural firewood, can cook, heating, etc.; the second is feed fertilizer. The main consists of crop straw, wheat straw commonly used in domestic fertilizer; third, industrial raw materials. Take straw as the base material to produce straw wood-based panels and related composite materials; fourth, construction raw materials.

	With straw as raw material, using the current mature production process of particle board and fiberboard, has developed straw crushing board, straw high-density fiberboard, straw directional board, vegetation composite fiberboard, straw wall, straw packaging, straw fiber and plastic, cement, gypsum and other composite materials. However, at present, a large number of straw resources cannot be effectively used, which waste the resources, and seriously pollute the ecological environment. Straw as a building material, has the characteristics of heat insulation, light sound absorption. But it's not yet recognized by most people. In using quasi steady state method to test different density of straw light wall material thermal conductivity, calculate different composite wall thermal resistance, through the comparative analysis of thermal conductivity and thermal resistance value, study the wall insulation performance, promote the use of straw plate manufacturing light wall, thus waste, reduce excess straw pollution to the ecological environment. Advantages: 1．light quality; 2．thermal insulation; 3．non-toxic and harmless
Steel frame-embedded AAC wall insulation	Although the domestic research on the thermal insulation performance of autoclaved aerated concrete wall started late, the research efforts in recent years are gradually increasing. At present, there are more fruitful research results on the correlation between AAC material insulation parameters and porosity, water content, aperture size and other factors, a lot of insulation experiments and numerical analysis on the AAC block insulation wall and AAC block insulation wall, concrete structure and steel structure, and most of them are based on finite element simulation. Advantages: insulation
Phase change heat storage wall	As a new type of envelope structure, with its continuous application in engineering, new requirements for wall heat transfer simulation technology are put forward. Due to the variable property characteristics of the phase change materials (such as specific heat capacity, thermal conductivity, etc.), For an architect, When selecting phase change materials during the design phase of the building scheme, Only by comparison with a finite number of schemes, The number and value range of design variables are relatively narrow, Subject to certain restrictions,

	And for the architect, Lack of complex expertise in related fields such as calculation and optimization algorithm of heat transfer wall, As a result, the architect cannot fully optimize the application effect of phase change materials under the actual climate conditions in a certain region, Unable to maximize the peak-shifting and valley-filling effect of the envelope, Only the envelope structure construction scheme with poor application effect can be selected. Advantages: insulation
Light wooden structure wall body	Light wood structure because of the use of small size specifications, wood has a small amount of wood, good heat preservation performance, easy modular design, factory processing and assembly construction characteristics, in recent years in China's residential and public construction have been applied. Through calculating the heat transfer value of the light wood structure wall, the calculated value of the temperature distribution within the wall and the heat transfer coefficient and the measured value; the average heat transfer coefficient of the light wood structure wall with different structures is tested by the method of heat box-heat flow meter, and compared with the theoretical calculated value; by selecting different insulation materials, the insulation performance, construction cost and construction advantage are analyzed, and the modular scheme of the thermal insulation wall board is designed for energy saving. Advantages: 1. energy-saving, 2. heat preservation

1.2.3 Summary of the literature review

To sum up, abroad for different wall dynamic thermal characteristics and envelope structure energy saving optimization of the main factors and affect the wall thermal insulation material type has carried out related research, domestic for different wall dynamic thermal characteristics and envelope structure energy saving optimization research started late, mainly including value, dynamic thermal characteristics, attenuation factor, internal area heat capacity parameters have related research. In general, abundant research has been carried out at home and abroad on the dynamic thermal characteristics of different walls and the energy saving optimization of envelope structures, which has promoted the promotion and application of different wall materials in the field of construction.

A).However, at home and abroad, the research on the dynamic thermal characteristics and energy saving optimization of different walls has the following shortcomings:

A.1)As room temperature overheating is affected by many factors, it is suggested to compare the basic dynamic characteristics of building materials. The international standard ISO 13786 [7] describes the dynamic thermal parameters of multi-layer wall / roof based on the sinusoidal change of temperature or heat flow rate and constant air temperature. These parameters indicate that the circulating heat flow rate is related to the change in the cycle temperature.

A.2)Five wall structures are studied and introduced: cavity wall insulation, straw wall insulation, steel frame-embedded AAC wall insulation, phase change heat storage wall, light wood structure wall. The u values of the five wall variants are very similar but differ from each other in size, material density and thermal conductivity.

1.3 The main research content of this article

The main influencing factors of summer behavior: internal area heat capacity κ 1 and attenuation factor f. The main influencing factors of winter behavior: steady-state thermal transmittance U and attenuation factor f.

Controlling building energy consumption is one of the important issues in current social development. The wall material of a building and its thermal properties have a significant impact on energy consumption. This study aims to analyze the thermal conductivity, heat flux density, plate thickness and temperature difference between the upper and lower surfaces in the quasi-steady state from a comprehensive perspective through experimental analysis and comprehensive research to determine the best wall material.

First, we will conduct experimental analysis to measure the thermal conductivity of different wall materials through experimental equipment. Thermal conductivity is an important indicator to measure the thermal conductivity of materials. It reflects the material's ability to conduct heat. We will select several representative wall materials to conduct experiments and compare their thermal conductivity differences. Through the analysis of experimental data, we can evaluate the thermal conductivity properties of different materials and provide a basis for subsequent wall optimization.

Secondly, we will comprehensively consider the nationwide meteorological data and building thermal zones to determine the wall optimization plan under the same environmental parameters. Climatic conditions and environmental factors in different regions have an important impact on building energy consumption. We will collect nationwide meteorological data and combine the test results with actual application scenarios based on the division of building thermal zones. By taking into account climatic conditions, environmental parameters and the thermal properties of the wall material, we can optimize the design of the wall for optimal energy control.

Finally, we will verify the evaluation system through practice, apply it to different wall materials, and obtain corresponding data. We will collect data on actual construction projects, including indicators on building energy consumption, indoor temperature, energy consumption, etc. By comparing the actual application effects of different wall materials, we evaluate their energy consumption control effects and economy. Through the establishment of a practical verification evaluation system, we can select the best wall materials and provide a scientific basis for building energy consumption control.

Conclusion to the chapter 1

The contribution of this study is to start from a comprehensive perspective, through experimental analysis and comprehensive research, combined with national meteorological data and building thermal zoning, to optimize the selection of wall materials to achieve control of building energy consumption. By expanding the research content, we will discuss in detail the material's thermal conductivity, heat flux density, plate thickness and the temperature difference between the upper and lower surfaces in the quasi-steady state, and combine it with practice to verify the evaluation system to provide reliable technical support and decision-making basis for the construction industry and contribute to energy conservation. contribute to emission reduction.

2 MATHEMATICAL INSTRUMENTS FOR INFLUENCING FACTORS, STANDARDS AND RESEARCH

2.1 Impact of building materials

High-temperature inertial materials can absorb heat during the day and release heat at night, thus reducing the impact of the temperature difference between day and night on the indoor temperature and reducing the dependence on the air-conditioning system. Moreover, materials with low thermal conductivity can effectively reduce heat transfer, maintain a stable indoor temperature, and improve energy efficiency. The evaluation of dynamic thermal characteristics is not only the key to the design of new buildings, but also crucial to the energy-saving renovation of existing buildings. In high temperatures, building materials may suffer severe thermal expansion, deformation and damage. The selection of materials has a significant influence on the dynamic thermal properties. Dynamic thermal characteristics refer to the response properties of the material to heat flow under specific conditions, including heat conduction, heat diffusion, etc. Here are five different walls studied:

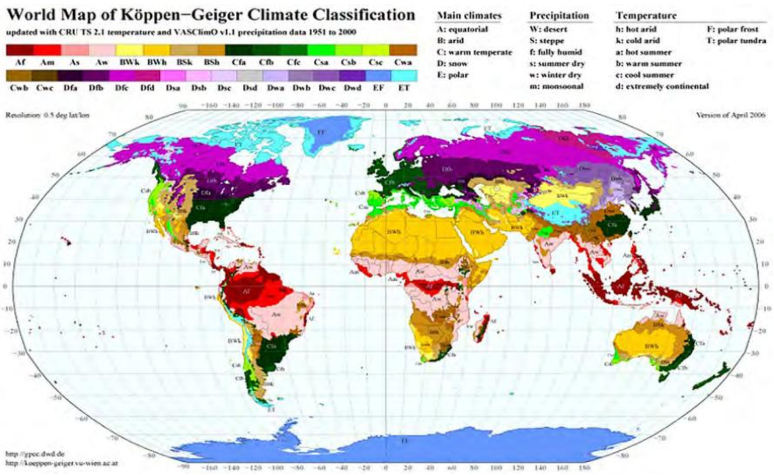


Figure 2.1 World climates, Köppen Geiger classification. M. Kottek, J. Grieser, C.

Beck, B. Rudolf, F. Rubel, World map of Köppen-Geiger climate classification, Meteoreol. Z., 15 (2006) 259 263

2.1.1 Space and cavity wall insulation

The main heat source of the wall is solar radiation. Because the radiation on the wall surface is a nonlinear equation about the wall surface temperature, if the wall surface temperature is the modeling as the unknown, the high degree coefficient matrix must be solved, and the calculation process is too complicated. Therefore, the general computational models are simplified at this point.

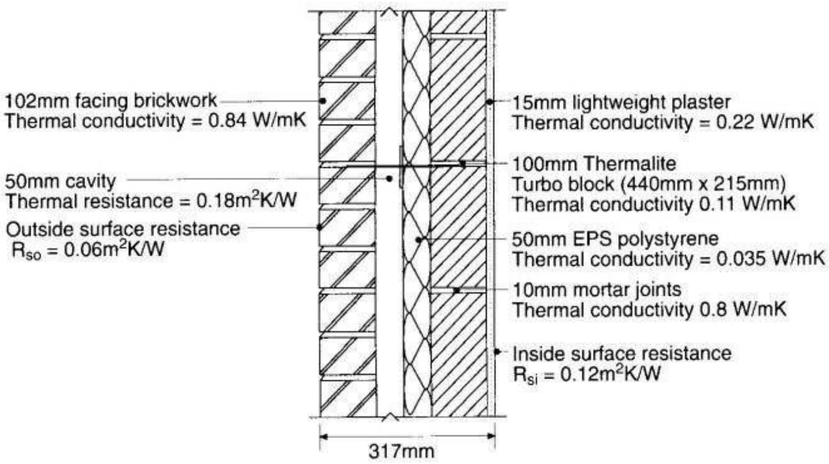


Figure 2.2 Air cavity wall insulation

The simplest method is to adopt the calculation theory of steady-state heat transfer.

Steady-state heat transfer refers to the process in which heat is transferred from one object or system to another at a stable rate under thermal equilibrium. Under steady-state heat transfer, the temperature distribution and heat flow in the system are constant and do not change with time.

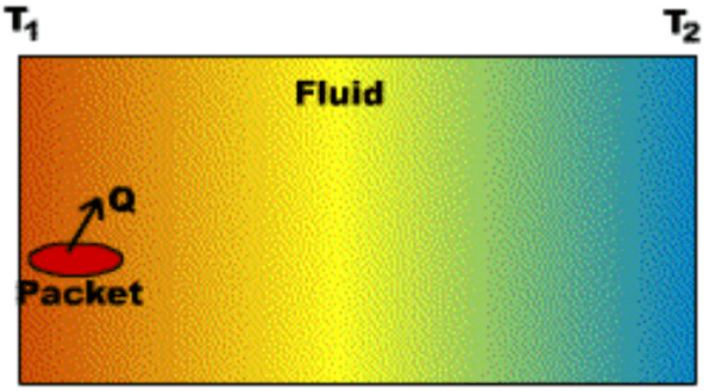


Figure 2.3 Heat exchange

A)Fields and applications, including but not limited to the following aspects:

A.1) Construction field: In buildings, steady-state heat transfer is widely used in heat conduction, insulation and air conditioning systems. For example, by studying the steady-state heat transfer characteristics of walls, the insulation design of buildings can be optimized and energy consumption reduced.

A.2) Industrial field: In industrial processes, steady-state heat transfer is used in heat exchangers, heating equipment and cooling systems. By studying the heat transfer performance of fluids or gases under steady-state heat transfer conditions, the efficiency and energy utilization of industrial production processes can be improved.

A.3) Environmental science field: In environmental science research, steady-state heat transfer is applied to the study of heat transfer in environmental systems such as the earth's atmosphere, oceans, soil, ice and snow. Analyzing the steady-state heat transfer properties of these systems can provide insights into the Earth system's energy balance and climate change.

A.4) Electronic field: In electronic equipment, steady-state heat transfer is used for heat dissipation and temperature management. By studying the heat conduction and heat dissipation performance of electronic devices in steady state, the stable operation of the equipment and extended service life can be ensured.

A.5) In summary, steady-state heat transfer plays an important role in many fields and applications. By studying and applying the principles and methods of steady-state heat transfer, energy utilization can be optimized, system efficiency improved, and problems related to heat conduction solved.

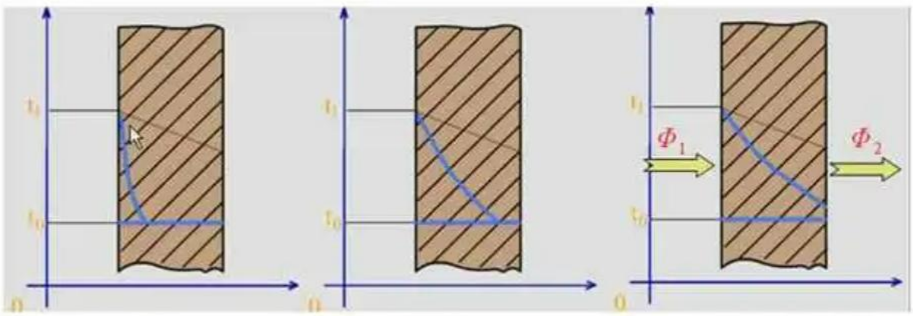


Figure 2.4　Store or release the energy

What is more important and complex in the model construction is the calculation problem of indoor mutual radiation. Based on the radiation theory of Hottel, the mutual radiation between the wall surfaces in the closed space is calculated, using the formula.

Can express the heat obtained from the wall surface. As one of the conductors of heat, when the temperature difference between the wall and the indoor air, the heat will be transmitted from the high temperature area to the low temperature area and heat exchange with the indoor air. The thermal balance relationship is as shown in the figure.

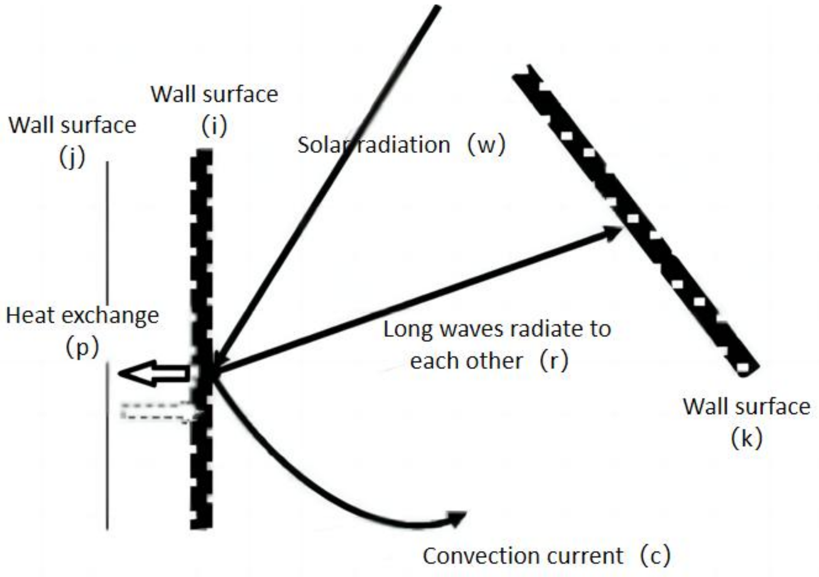


Figure 2.5 Thermal balance relationship

Joint air thermal balance equation, we can get the final system of equation form of internal dynamic temperature:

$$\begin{bmatrix} G+A\left(x_0-Z_1y_0\right) & -C \\ -C^T & D+H/\Delta \end{bmatrix} \begin{Bmatrix} \theta_{W,n} \\ \theta_{R,n} \end{Bmatrix} = \begin{Bmatrix} A\left(Z_2\sum_{j=0}^{n}\overline{y_j}\left\{\overline{\theta_{o,n-j}}\right\} - \sum_{j=1}^{n}x_j\left\{\theta_{W,n-j}\right\}\right) + \\ +Z_1\sum_{j=1}^{n}y_j\left\{\theta_{W,n-j}\right\} + \beta\left[\frac{a}{a'}\right]\Gamma\left\{S_{R,n}\right\} + A\left\{U_{W,n}\right\} \\ \left\{W_{R,n}\right\} + Hn_o\left\{\theta_{o,n}\right\} - H\left[s\left\{\theta_{R,n-1}\right\}/\Delta\right] \end{Bmatrix} \quad (2\text{-}1)$$

The scientific and technological achievements of energy saving optimization of dynamic thermal characteristics of cavity wall are mainly reflected in the following aspects: (by adopting the frequency domain finite difference method (FDFD) and CFD （F. Ascione, R.F. De Masi, F. de Rossi, S. Ruggiero, G.P. Vanoli, MATRIX, a multi activity test-room for evaluating the energy performances of “building/HVAC” systems in Mediterranean climate: Experimental set-up and CFD/BPS numerical modeling, Energy Build 126 (2016) 424–446, doi:10.1016/j.enbuild.2016.05. 044.）By numerical simulation and other methods, the theoretical heat transfer model and simplified dynamic heat grid model (RC model) of hollow block ventilation wall are established, and the accuracy of the model is verified through experiments. This provides a powerful tool for analyzing the thermal characteristics, energy saving potential and applicability of the wall.

Thermal performance improvement:

Compared with the ordinary wall body, the thermal performance of the hollow block ventilation wall has been significantly improved. The results show that when the air velocity in the cavity is 0, the heat flow density of the wall with different cavity thickness is lower than that of the ordinary wall within 24 hours. For example, the heat flow density of the wall with a cavity thickness of 80mm is 46% that of the ordinary wall, while the wall with a cavity thickness of 120mm is only 33% that of the ordinary wall.

The cavity design of hollow block has an important influence on the energy saving effect. By increasing the number of cavities perpendicular to the heat flow direction, the delay time and attenuation coefficient of the block can be effectively improved, and the total heat passing through the inner surface can be reduced. For example, by increasing the number of cavities from 3 to 5, the delay time can be increased from 3 hours to 4 hours, the decay coefficient increases from 6.67 to 13.89, and the total heat can be reduced from 8943 KJ / m2 to 5791 KJ / m^2.

Optimization of energy-saving effect:

Wall ventilation design, as a new energy saving technology, by introducing cold and hot external air into the wall (as shown in the figure), forming an air layer in the wall, playing the role of heat preservation and insulation, while reducing indoor humidity and improving human comfort. It is also shown that the wall insulation performance increases with the gas velocity of the cavity and the thickness of the cavity.

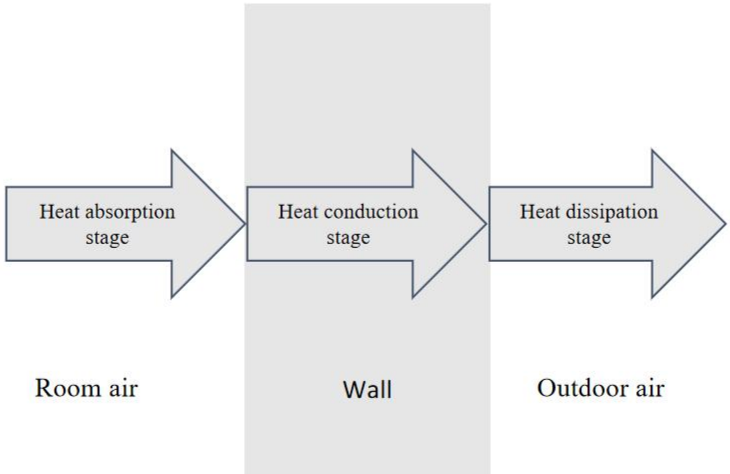


Figure 2.6 Schematic of heat transfer of the envelope

The cavity module composite wall technology not only improves the overall seismic performance of the house, but also because of its unique insulation performance, the winter room temperature in winter can improve 7-10 degrees, equivalent to 29CM thick composite wall to achieve the insulation effect of 350CM red brick wall. It can save 2 / 3 of the heating cost every year and reduce the use cost of households.

The attenuation coefficients and total heat mentioned in the description are calculated from specific thermal tests or simulations. These parameters are usually used to evaluate the thermal properties of the walls, especially in the analysis of the dynamic thermal properties.

Discount factor (f):

The attenuation coefficient is a parameter representing the decay rate of heat when passing through the material. In the analysis of wall thermal performance, it is usually related to the material thermal resistance, heat capacity and wall structure. The larger the attenuation coefficient, the faster the heat attenuation in the wall, the better the insulation performance of the wall.

The calculation of the attenuation coefficient may involve complex mathematical models and experimental data fitting. Generally speaking, it can be calculated by measuring the temperature changes on both sides of the wall, and the heat flow through the wall, and then using the appropriate mathematical model (such as the heat conduction equation).

In practical applications, the attenuation coefficient may be obtained through professional thermal testing equipment or software simulations. These tests typically involve applying a constant temperature or heat flow on one side of the wall and then monitoring the temperature response on the other side. By analyzing these data, the dynamic thermal properties of the wall, including the attenuation coefficient.

Total heat:

Total heat is the total heat transferred through the wall over a period of time. This parameter can be measured or calculated to evaluate the insulation performance of the wall. If the total heat is low, it means that the wall delivers less heat under the same conditions, and the thermal insulation performance is better.

The calculation of the total heat usually involves the integration of the heat flow through the wall. This can be measured directly by installing heat flow meters on both sides of the wall, or indirectly by measuring temperature changes and wall thermal parameters (e. g. thermal conductivity).

In the examples mentioned examples, when the number of cavities increases from 3 to 5, the total heat decreased from 8943 KJ / m2 to 5791 KJ / m^2. This reduction reflects the improvement of the thermal insulation performance of the wall by increasing the number of cavities. This improvement is due to the increase of the cavity that increases the thermal resistance of the wall and reduces the heat transfer.

It should be noted that the specific calculation methods of these parameters may vary by experimental conditions, test equipment, and mathematical models. Therefore, the standardized test methods and calculation procedures should be followed during the wall thermal performance analysis to ensure the accuracy and comparability of the results.

a.102mm facing brickwork thermal conductivity=0.84W/mk

b.50mm cavity Thermal resistance=0.18m^2k/w

c.outside surface resistance Rso=0.06m^2k/W

d.15mm ligtweight plaster Thermal conductivity=0.22W/m·k

e.100mm Thermalite Turbo block(440mm×215mm)Thermal conductivity 0.11w/mk

f.50mm EPS pdystyrene Thermal conductivity=0.035w/mk

g.10mm mortar joints Thermal conductivity 0.8w/mk

h.Inside surface resistance Rsi=0.12m^2k/w

2.1.2 Straw wall insulation

By adding low-density straw light lining to the inside of the existing wall, the thermal insulation performance of the wall is improved. The method is simple in construction and can effectively improve the thermal insulation performance of the wall. In the research, we mainly focus on the following aspects: wall density, bearing capacity, economy and environmental performance.

In the wall with low-density straw light lining, we will analyze the ratio of the mass of the lining material to the wall volume, to evaluate the lightweight performance of the wall. At the same time, we will also consider the load-bearing capacity of the wall, that is, the structural strength and stability of the wall after the addition of light lining. This will help to determine the reliability and safety of the wall in practical use. In addition, we will also evaluate the economic and environmental performance of the walls. By analyzing the wall construction cost and maintenance cost after adding low-density straw light lining, we can evaluate the economy of this method. At the same time, we will also consider the environmental impact of adding a light lining, such as the renewability and degradability of the material. Because the thermal conductivity of straw plate tends to be stable under temperature, humidity and other conditions, the thermal conductivity theories tested by the unsteady state and quasi-steady state test methods are the same. This test is a thermal simplified ideal test of the quasi-steady thermal conductivity. Steady-state thermal conductivity refers to the thermal conductivity process where the temperature field does not change with time, thus ensuring a stable heat flow. Thermal conductivity is calculated by testing the voltage, current, and contact area.

Thickness=36-45cm,

U=0.30-0.31w/(m2·k)

K1=38-41KJ（m2k）

Thickness=51cm,

U=1.6w/(m2·k）

K1=75KJ(m2·k)

F=0.08

The quasi-steady state method is used to test the thermal properties of straw insulation materials with different densities. By testing the thermal conductivity of the wall material, the thermal resistance is calculated, and the thermal insulation performance of the straw light wall with different density structure is compared and analyzed.

The thickness is the same, the thermal resistance and thermal conductivity are inversely proportional, the straw wall materials with different density have different thermal conductivity and thermal resistance, and with the increase of the density, the thermal conductivity increases and the thermal resistance decreases.

Because the thermal conductivity reflects the heat transfer ability of materials composed of certain structure, the greater the thermal conductivity, the worse the thermal insulation performance; the smaller the thermal conductivity, the better the thermal insulation performance, so the straw wall material with the same thickness decreases the thermal insulation performance with increasing density. Therefore, from the perspective of thermal engineering, the straw board used in the straw wall should be selected as the straw board with better thermal performance, that is, the low density.

2.1.3 Steel frame-embedded AAC wall insulation

The thermal insulation performance of steel frame-AAC peripheral protection system, and the simplified calculation method of external wall heat transfer coefficient considering the heat bridge effect of steel members is proposed. We will conduct an experimental study to evaluate the influence of steel members on the insulation performance of exterior wall and find the corresponding calculation method. Through the research, we will obtain the insulation performance data of steel frame-AAC peripheral protection system of prefabricated steel structure building, and provide feasible simplified calculation method to guide the design and construction in actual engineering.

AAC plate, a porous material, has low thermal conductivity in normal use conditions. If the water content of AAC plate is high due to insufficient maintenance conditions, its thermal conductivity will increase. The measured results show that the thermal conductivity is heterogeneous in different positions in larger AAC plates. In addition, the thermal parameters of steel, concrete and other materials are the standard recommended value, which is different from the true value, eventually leading to the error of wall temperature and heat transfer coefficient.

Effect of the AAC wall thickness

With the increase of AAC plate thickness, the width of the influence area on the two sides of the column and beam flange gradually increases, and the thermal bridge effect gradually increases. Among them, the maximum width of the column affected area is 31mm, the proportion of relative wall width is only 1.7%, the width and maximum value of the affected area on both sides of the beam flange are 90mm, and the proportion of relative wall height is 6.4%. With the increase of AAC plate thickness, the heat transfer coefficient of the wall is significantly reduced. Compared with the difference, the lowest increase is 1.7% and the highest increase is 9.2%, indicating that the greater the thickness of the AAC board, the better the insulation performance of the wall.

The wall has good thermal insulation properties and compressive strength. Thickness has a significant impact on a building's thermal performance and energy efficiency.

One of the effects of AAC wall thickness is thermal insulation performance. The thickness of the wall will directly affect the conduction of heat and the insulation effect. Thicker AAC walls can provide better insulation and reduce the transfer of heat between indoors and outdoors. This means that in winter, the wall can effectively retain indoor heat and reduce the heating load; in summer, the wall can effectively block the introduction of external heat and reduce the cooling load. Therefore, increasing the thickness of AAC walls can significantly improve the thermal insulation performance of the building and reduce energy consumption.

The impact of AAC wall thickness also involves sound and noise isolation. Thicker AAC walls can provide better sound insulation and reduce the transmission of indoor and outdoor noise. This is important for both residential and commercial buildings, providing a more comfortable and quiet indoor environment.

AAC wall thickness is also related to the compressive strength and structural stability of the wall. Increasing the thickness of the AAC wall can increase the wall's compression resistance and improve the structural strength and stability of the wall.

This is essential to withstand the impact of natural disasters such as earthquakes and wind, ensuring the safety and stability of the building.

Finally, the AAC wall thickness will also affect the use space and layout of the building. Thicker walls will take up more indoor space and may restrict the layout and use functions of the building. Therefore, when designing a building, it is necessary to consider the balance between wall thickness and use requirements.

In summary, AAC wall thickness has an important impact on the thermal performance, sound insulation effect, compressive strength and structural stability of the building. Proper selection of wall thickness can improve a building's energy efficiency, comfort and safety. In practical applications, it is necessary to comprehensively consider the design requirements of the building, environmental conditions and economic feasibility to find the most suitable AAC wall thickness.

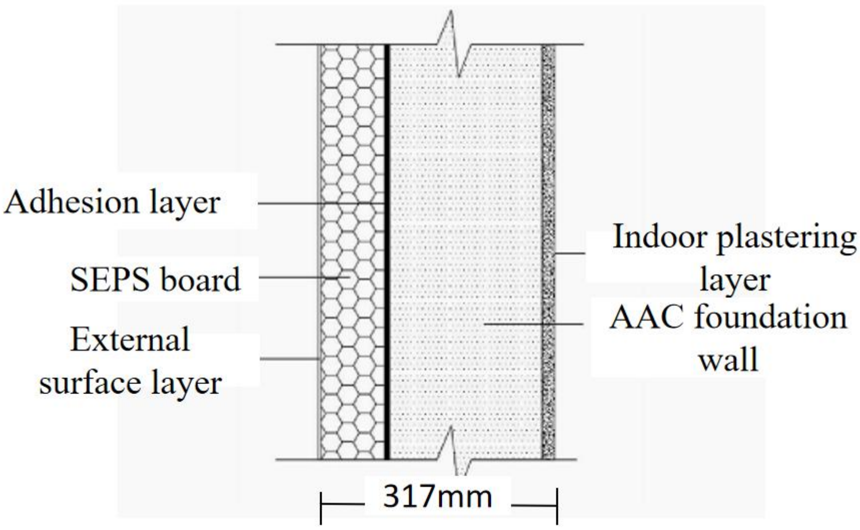


Figure 2.7 Schematic of heat transfer of the envelope

Effect of the AAC thermal conductivity

AAC is one of the main components of the wall, and its thermal conductivity determines the thermal resistance size of the AAC base wall, and then affects the thermal insulation performance of the wall. Taking the parameters of 200mm thick AAC wall, column width of 300mm, steel beam size HM200200812 (mm), column distance of 3.6m and height of 2.8m as examples, select four kinds of thermal conductivity of 0.11W / (m ℃), 0.14W), 0.14 W / (m ℃), 0.18W / (m ℃), and 0.22W / (m ℃) within the range of common AAC materials to calculate and analyze the influence of this parameter on the insulation performance of the wall.

As shown in Figure (A), the AAC thermal conductivity increased from 0.11W / (m ℃) to 0.22W / (m ℃), the AAC thermal resistance decreased and the relative thermal conductivity of the steel beam wing edge decreased, resulting in the minimum temperature of the inner surface and the lowest temperature of the wall increased by nearly 1℃, indicating that the high thermal conductivity AAC plate can effectively improve the internal surface temperature. As shown in Figure (b), with the increase of AAC thermal conductivity, the width of the affected area of the upper edge of the column and the beam gradually increases, while the influence width of the lower edge of the beam gradually decreases.

Among them, the maximum width of the column affected area is 18mm, the proportion of relative wall width is only 1.0%, the width and maximum value of the affected area on both sides of the beam flange is 67mm, and the proportion of relative wall height is 4.8%. As shown in Figure (c), with the increase of SEPS plate thickness, the heat transfer coefficient of the wall is significantly reduced. Compared with that, the heat transfer coefficient of the heat bridge wall is 4.8% and the highest increase is

12.1%, indicating that the greater the AAC thermal conductivity, the worse the insulation performance of the wall.

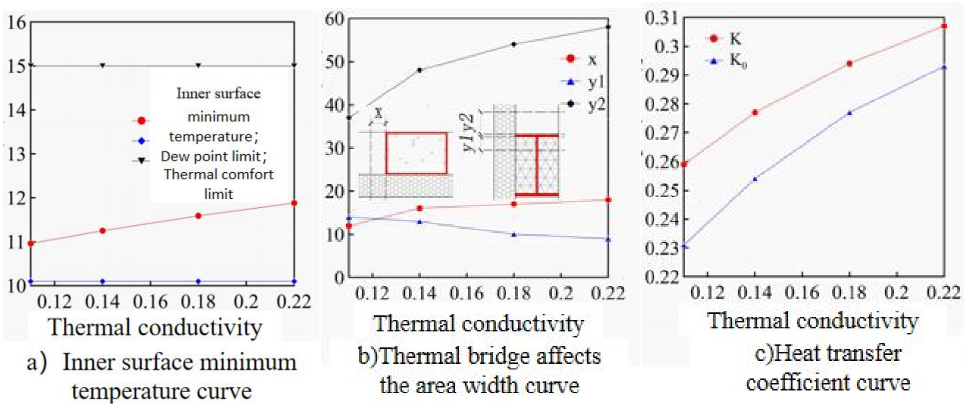


Figure 2.8 Phase change heat storage wall insulation

At the same time, the thermal conductivity of AAC walls also has an important impact on the thermal insulation performance and energy efficiency of the building.

The lower thermal conductivity means that AAC walls have better thermal insulation properties. The lower the thermal conductivity, the lower the wall's ability to conduct heat. This means that in winter, AAC walls can effectively retain indoor heat and reduce heating load; in summer, AAC walls can effectively block the inflow of external heat and reduce cooling load. Therefore, a lower thermal conductivity can significantly improve the thermal insulation performance of the building and reduce energy consumption.

The thermal conductivity of AAC walls also affects the surface temperature distribution of the wall and indoor thermal comfort. Lower thermal conductivity means that the wall surface temperature is closer to the indoor temperature, reducing the impact of the cold and heat bridge effect. This means that in winter, the wall surface temperature is higher, reducing the possibility of condensation and discomfort, and in summer, the wall surface temperature is lower, reducing thermal discomfort. Therefore, lower thermal conductivity can improve indoor thermal comfort.

The thermal conductivity of AAC walls also affects the energy efficiency of the building. Lower thermal conductivity means that the building can better maintain indoor temperature stability during heating and cooling processes, reducing energy consumption. By choosing AAC wall materials with lower thermal conductivity, the building's heat loss can be reduced and energy efficiency improved.

The thermal conductivity of AAC walls also affects the design and construction of the building. Lower thermal conductivity means that the wall requires less insulation material to meet thermal insulation requirements, reducing construction difficulty and cost. In addition, lower thermal conductivity can also expand the building's usable space, providing greater flexibility and design freedom.

Therefore, the thermal conductivity of AAC walls has an important impact on the building's thermal insulation performance, thermal comfort, energy efficiency and construction costs. By choosing AAC wall materials with lower thermal conductivity, the thermal insulation performance and energy efficiency of the building can be improved, contributing to the development of sustainable buildings. In practical applications, it is necessary to comprehensively consider the design requirements, environmental conditions and economic feasibility of the building to find the most suitable AAC wall material and thickness to meet the requirements for thermal insulation and energy saving.

2.1.4 Phase change heat storage wall

As a new type of envelope structure of phase change heat storage wall, new requirements for wall heat transfer simulation technology are put forward with its continuous application in engineering. Due to the variable property characteristics of phase change materials (such as specific heat capacity, thermal conductivity, etc.), the heat transfer calculation method of conventional wall is no longer suitable for the heat transfer calculation of phase change heat storage wall, and the nonlinear equation of variable property parameters needs to be used to describe the heat transfer process. In addition, common phase change materials have certain hysteresis phenomenon, and inorganic phase change materials are overcold phenomenon, which should be considered in the simulation process, so as to realize the accurate simulation of the heat transfer process of phase change heat storage wall, so as to provide support for the application effect evaluation of phase change materials.

At the same time, the thermal design of the phase change heat storage wall should adapt to the regional climate, and the phase change temperature, phase change latent heat, phase change material thickness and the corresponding insulation materials in different regions are not the same. For architects, in the architectural design stage when choosing phase change materials, only by the finite design, design variables and value of the range is narrow, limited, and for architects, the lack of phase change heat storage wall heat transfer calculation and optimization algorithm and other related fields of complex professional knowledge, causing the architect cannot fully optimize phase change materials in a certain area of actual climate application effect, cannot maximize the peak filling effect, can only choose the application effect of envelope structure construction scheme.

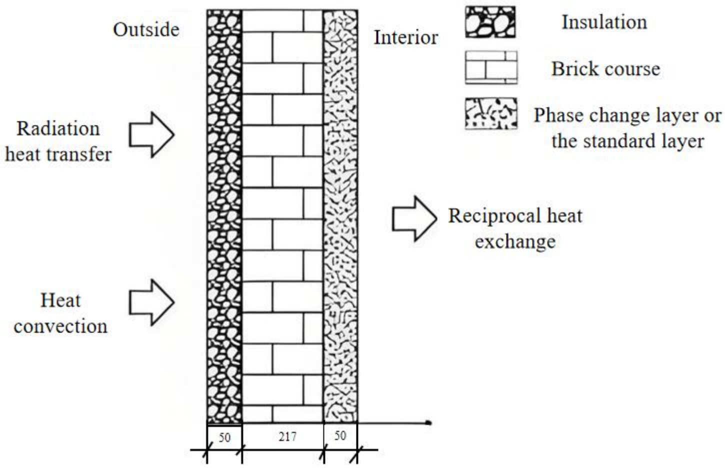


Figure 2.9 Phase change heat storage wall

In order to the application effect of phase change heat storage envelope under different actual climate conditions evaluation and optimization, based on the research background and existing problems, need to establish a can meet the requirements of the actual engineering design phase change heat storage wall heat transfer calculation model, and develop the relevant rapid calculation program, this is the work of this chapter.

Different from the dynamic heat transfer process of structure, the heat transfer of the variable property parameters (specific heat capacity, thermal conductivity, density, etc.), need to use the nonlinear equation of variable property parameters, and the existing domestic DeST energy consumption simulation software based on constant assumptions, it is difficult to heat transfer calculation and energy consumption simulation.

2.1.5 Light wooden structure wall

This paper analyzes from three aspects of insulation performance, construction cost and construction advantage, and makes energy saving design of wood structure insulation exterior wall board modular scheme. In relevant literature, the dimensional heat transfer theory is mainly used to study the insulation performance of light wood structure wall, and does not consider the influence of the heat transfer coefficient of the wall column on the insulation performance of the wall, and cannot accurately reflect the heat transfer characteristics of the heat bridge part of the wall column.

Therefore, this paper adopts the heat box-heat flow meter method to test the distribution of heat current density and temperature difference of different parts of the wall. According to the Code for Thermal Design of Civil Buildings (GB50176-2016), the thermal conductivity of wood is λ 0.17 / (mk) (vertical wood grain in the heat current direction), in order to further investigate the numerical model of the wall column on the wall. The calculation results show that: 1) when there is no external insulation, when the thermal conductivity of the wall column is λ 0.11W / (mk), the heat transfer coefficient of the wall column is ψ =0; when the thermal conductivity of the wall column is λ> 0.11W (mk), the heat transfer coefficient of the wall column is ψ =0.01W / (mk), the wall column should be considered, and the average heat transfer coefficient should be calculated according to the Code for Thermal Design of Civil Buildings.2) When there is external insulation, the thermal conductivity of the wall bone column is λ 0.17W / (mk), and the line heat transfer coefficient of the wall bone column is ψ =0, indicating that the external insulation can effectively reduce the heat transfer influence of the flythrough heat bridge.

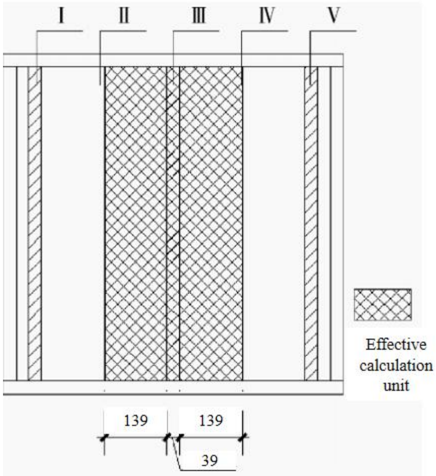


Figure 2.10 Light wooden structure wall

2.2 The shortcomings of these types of walls

Cavity wall insulation: Disadvantages include the cold bridge effect, proper insulation material selection and filling, higher construction and maintenance costs, and inevitable moisture problems. When selecting and designing cavity wall insulation structures, these shortcomings should be comprehensively considered, and appropriate measures should be taken to solve or mitigate these problems to achieve better insulation effects and durability.

Straw wall insulation: Disadvantages include moisture management, durability, fire resistance, and pest and mold issues. When using straw walls, you need to pay attention to these shortcomings and take corresponding measures to solve or alleviate these problems to ensure the reliability and durability of the wall. At the same time, it is also important to ensure that straw walls are constructed and maintained correctly.

Steel Frame - Inline AAC Wall Insulation: Disadvantages include construction complexity, higher cost, thermal conductivity, durability and design limitations. AAC walls have higher requirements for construction personnel. They need to have certain skills and experience, master the skills of wall installation and connection, and ensure the stability and structural strength of the wall. In addition, when performing caulking and surface treatment, attention needs to be paid to material selection and construction quality to ensure the beauty and durability of the wall. When selecting and adopting a steel frame embedded AAC wall insulation structure, these shortcomings need to be comprehensively considered, and corresponding measures must be taken to solve or mitigate these problems to achieve better insulation effects and durability. At the same time, pay attention to the quality of construction and maintenance.

Phase change thermal storage walls: Disadvantages include higher cost, increased volume and weight, difficulty in temperature control, and difficulty in maintenance. When selecting and adopting phase change thermal storage wall insulation structures, these shortcomings need to be considered comprehensively and their impact on building design, construction and maintenance needs to be evaluated. At the same time, ensuring the selection and use of high-quality phase change materials, as well as reasonable design and construction, can effectively alleviate these shortcomings and improve the insulation effect and durability of phase change thermal storage walls.

Lightweight timber walls: Disadvantages include poor durability and stability, poor fire resistance, sound transmission issues, and lower seismic resistance. When selecting and adopting lightweight wooden structure walls, these shortcomings need to be comprehensively considered, and corresponding measures must be taken to solve or mitigate these problems to improve the reliability and durability of the wall. At the same time, it is also very important to ensure the quality of construction and maintenance.

Conclusion to the chapter 2

By analyzing commonly used wall insulation, the dynamic thermal characteristics of different walls and energy-saving optimization of envelope structures, their advantages and disadvantages, the dynamic thermal characteristics of different walls, energy-saving optimization of envelope structures, and the impact of insulation thickness are proposed. The specific content is summarized as follows: the advantages and disadvantages of different wall surfaces are explained in detail, and the effects of thermal resistance and thermal conductivity are introduced. Through the contents of this chapter, we can better understand and understand that different wall materials may suffer severe thermal expansion, deformation, and damage due to different environments. Material selection has an important impact on dynamic thermal performance. Dynamic thermal properties refer to the response characteristics of materials to heat flow under specific conditions, including heat conduction, thermal diffusion, etc. Therefore, in order to further realize the research goal of dynamic performance simulation of multi-layer wall components, we are going to try to assemble different materials. Chapter 3 proposes a multi-layer assembly wall to further demonstrate the dynamic thermal performance of the wall.

3 MULTILAYERED WALL ASSEMBLIES' DYNAMIC THERMAL CHARACTERISTICS COMPARISON

By studying the previous common walls, we can draw some conclusions about wall combinations and propose some expanded ideas and methods to further improve the energy efficiency of buildings.

First, first of all, we can achieve more efficient building energy utilization through the combination of different wall materials. Common wall materials include concrete, bricks, stone, wood and so on. Each material has its specific heat conduction properties and heat capacity. By reasonable selection of the combination of wall materials, better heat insulation and heat storage effect can be achieved on the premise of meeting the structural requirements. For example, materials with high insulation properties, such as insulation panels or high-density bricks, can be used on the external walls to reduce heat conduction. The interior walls use materials with higher thermal capacity, such as concrete or stone, to increase the thermal storage capacity of the interior space. Such a wall combination can effectively reduce the energy consumption for winter heating and summer cooling.

Second, the energy efficiency performance of wall combinations can be extended by introducing phase change materials into the walls. Phase change materials are special materials that have the ability to absorb or release large amounts of heat when the temperature changes. Applying phase change materials to walls can regulate indoor temperatures and reduce building energy loads by absorbing and releasing heat. For example, phase change materials inside the wall can absorb solar heat during the day and release it at night to regulate indoor temperature. This wall combination can reduce reliance on traditional energy to a certain extent and improve the energy efficiency of the building.

In addition, the thermal insulation properties of the wall can be further improved by adding a thermal insulation layer or insulation layer to the wall. Thermal insulation layer or thermal insulation layer can reduce heat conduction and improve the thermal insulation effect of the wall. Common insulation materials include foam plastic, rock wool, fiberglass, etc. By applying these insulation materials to the interior or exterior of walls, heat transfer can be effectively reduced and the building's energy efficiency improved. Additionally, consider adding a ventilation layer or air layer to the wall to improve insulation and indoor air quality.

Finally, advanced building technologies and materials, such as wearable solar panels, light-to-heat conversion systems, etc., can be borrowed to extend the energy efficiency performance of wall combinations. Wearable solar panels can convert solar energy into electricity and supply it to the building's energy system. Photothermal conversion systems can use solar energy to generate heat for heating and hot water. Applying these technologies and materials to walls can further improve the building's energy self-sufficiency and energy efficiency.

In short, by studying the previous common walls, we can draw some conclusions about wall combinations and propose some expanded ideas and methods to further improve the energy efficiency of buildings. By rationally selecting the combination of wall materials, introducing phase change materials, adding thermal insulation layers or insulation layers, and drawing on advanced construction technologies and materials, more efficient building energy utilization can be achieved and contribute to sustainable development. These expanded ideas and methods need to comprehensively consider the structural requirements, material properties and practical application conditions of the building to ensure that feasible and sustainable solutions can be achieved. Next, we combine five different wall materials for study.

3.1 Concept of the research

The current subchapter is dedicated to calculating and further analysing the dynamic unsteady-state characteristics of internal area heat capacity and decrement factor under ISO 13786 as criteria for the energy efficiency assessment of multilayered wall assemblies. According to the proposed characteristics, a dynamic simulation Excel-based calculator [2] was used to compare the abovementioned characteristics for the three most commonly used types of wall assemblies in the Chinese construction sector.

Building energy efficiency is one of the key goals of the construction industry in the pursuit of sustainable development, energy conservation and emission reduction. To achieve this goal, traditional energy efficiency assessment methods are no longer sufficient, as they usually only consider heat conduction under steady-state conditions, ignoring the heat capacity of materials in dynamically changing environments. However, in actual use, the temperature and humidity inside a building will change over time, so considering dynamic thermal characteristics is crucial to accurately assess a building's energy efficiency.

Internal area heat capacity is an important parameter describing the energy required by building materials and components to store and release heat. It reflects the thermal stability and thermal responsiveness of the material. Traditional energy efficiency evaluation methods often only focus on the heat conduction performance of materials, while ignoring the heat capacity of materials in dynamic environments. However, the temperature and humidity inside the building will change with the changes in the external environment, causing the thermal conductivity characteristics of the building materials to be affected. Therefore, consideration of internal area heat capacity is one of the key factors in assessing building energy efficiency.

By incorporating internal area heat capacity into energy efficiency assessment criteria, the energy efficiency performance of building materials and components under different environmental conditions can be more accurately assessed. This can help designers make better choices of materials and components for more efficient building performance. In addition, considering dynamic thermal characteristics can also guide the optimal design of buildings, such as utilizing technologies such as thermal energy storage and heat recovery, to maximize energy efficiency.

However, incorporating internal area heat capacity into energy efficiency assessment criteria also presents some challenges. First, accurately measuring and modeling the thermal capacity of building materials and components is a complex task that requires consideration of multiple factors, such as the material ' s thermal conductivity, density, and specific heat capacity. Secondly, the study of dynamic thermal characteristics requires a large amount of experimental data and simulation analysis to obtain the thermal response characteristics of buildings under different environmental conditions. Therefore, establishing a comprehensive and accurate energy efficiency assessment model requires multidisciplinary cooperation and comprehensive research.

The attenuation factor is an important parameter for evaluating the energy efficiency of multilayer wall assemblies under dynamically unsteady conditions. In construction, the thermal conductivity properties of building materials are generally considered to be stable and fixed. However, in actual use, the temperature and humidity inside the building will change dynamically with changes in the external environment, causing the thermal conductivity properties of the building materials to also change.

Attenuation factors were introduced to more accurately assess the energy efficiency of building materials and components in dynamic environments. The attenuation factor takes into account the impact of dynamic changes on heat conduction and quantifies the degree of attenuation of heat conduction. Specifically, the attenuation factor defines the thermal conduction response of a building material or component over different time scales, including short-term and long-term responses.

Short-term response refers to the ability of a building material or component to quickly adjust to heat conduction under dynamic conditions. When the external environment changes, the temperature and humidity inside the building will change rapidly accordingly, and materials need to be able to quickly adapt to this change and adjust their thermal conductivity properties. The short-term response decay factor measures the energy efficiency of a material or component on a short time scale.

Long-term response refers to the persistent ability of a building material or component to adjust to heat conduction under dynamic conditions. Over a long period of time, the temperature and humidity inside the building will gradually stabilize, and materials need to be able to adapt and maintain relatively stable thermal conductivity properties. The long-term response decay factor measures the energy efficiency of a material or component over long time scales.

By introducing attenuation factors, the energy efficiency performance of building materials and components under different environmental conditions can be more comprehensively evaluated. The consideration of the attenuation factor makes the energy assessment more accurate and closer to the actual use environment. This helps designers and engineers make better choices of materials and components, enabling more efficient building energy use.

However, the evaluation and application of attenuation factors also face some challenges. First, the determination of the attenuation factor requires extensive experimental data and simulation analysis to understand the thermal conduction response of building materials and components on different time scales. Secondly, accurate mathematical models need to be established to describe the relationship between attenuation factors and building energy efficiency. Therefore, the study of attenuation factors requires multidisciplinary cooperation and comprehensive research.

Despite some challenges, the introduction of attenuation factors provides an important tool for evaluating the energy efficiency of building materials and components under dynamic non-steady conditions. It can more accurately reveal the energy efficiency performance of the building in the actual use environment, helping to optimize the design and improve the energy efficiency of the building. By expanding the evaluation criteria, we can better understand the energy efficiency properties of building materials and components and contribute to achieving sustainable development goals.

This research takes an additional approach to address the global sustainability challenge of improving energy efficiency for building heating and cooling. It focuses on the often overlooked or underestimated dynamic thermal properties and adequate thermal capacity, which are not typically considered crucial design parameters [1]. This paper presents a novel energy efficiency assessment attitude of multilayered wall assemblies commonly practised in the Chinese construction sector.

Scientific and technological achievements are described in Chapter 2. Further validation is needed to study according to the target standards, data, tools, etc.To achieve the research goal of providing dynamic performance simulation for suggested multilayered assemblies, an ISO 13876-based Excel spreadsheet calculator was meticulously used [2]. This involved considering key thermal physical parameters such as assembly mass (kg), thermal transmittance value (u-value) in W/m2K, internal area heat capacity (k1) in kJ/m2K, and the dimensionless decrement factor (f) for dynamic characteristics under ISO 13786 [3, p. 10]. The factors influencing summer behaviour were identified by PhD Stazi F. [4, p. 31], who emphasised that the internal area heat capacity (k1) and decrement factor (f) are primary summer influencers, while steady-state thermal transmittance (u-value) and decrement factor (f) impact winter performance.

ISO 13786 Is a standard to ensure that we can accurately assess the dynamic thermal properties of building materials and components. Dynamic thermal properties involve the ability of materials or components to respond to heat transfer and storage on time scales. ISO 13786 Provides a systematic method for calculating and evaluating the dynamic thermal properties of building materials and components. The standard harmonizes the field of construction engineering and its entire framework, enabling an accurate comparison of the thermal properties of different materials and components, and helps to guide the architectural design and selection of materials to achieve higher levels of performance and compensation [7].

Table 3.1—Material selection

Influencing factor	Characterization
Thermal conductivity	Its thermal conductivity determines its thermal conductivity, and the high thermal conductivity is more significant, which affects the change rate of indoor temperature.
Heat capacity	Alloy heat capacity refers to the heat absorbed or released by the mass material, which affects the heat capacity of the alloy. The high heat capacity material maintains the temperature while absorbing and losing heat.
Leak tightness	The heat insulation effect of the air sealing layer can effectively reduce the air leakage and the external air leakage, and improve the sealing performance.
Thickness	It is determined by a variety of factors, including ambient temperature, relative humidity, pipe diameter, material characteristics, manufacturing process, design requirements, use environment and construction conditions, etc. In practical application, it is necessary to comprehensively consider and weigh according to the specific requirements and conditions to select the appropriate material thickness.

3.2 Dynamic performance simulation of the multilayered assemblies

To achieve the research goal of providing dynamic performance simulation for suggested multilayered assemblies, an ISO 13876-based Excel spreadsheet calculator was meticulously used [2]. This involved considering key thermal physical parameters such as assembly mass (kg), thermal transmittance value (u-value) in W/m2K, internal area heat capacity (k1) in kJ/m2K, and the dimensionless decrement factor (f) for dynamic characteristics under ISO 13786 [3]. The factors influencing summer behaviour were identified by PhD Stazi F. [4], who emphasised that the internal area heat capacity (k1) and decrement factor (f) are primary summer influencers, while steady-state thermal transmittance (u-value) and decrement factor (f) impact winter performance.

In Chinese construction, the prevalent approach is to design multilayered assembly walls with efficient insulators on the external façade side or inside the assembly [5]. This paper, therefore, aims to provide research on the dynamic characteristics of these walls, which could significantly enhance their thermal physics behaviour and, consequently, their energy efficiency performance [3, 4, 7]. Fig. 3.1 represents a generalised concept of a multilayered assembly wall, a key focus of this study, underlining the practical relevance of our findings.

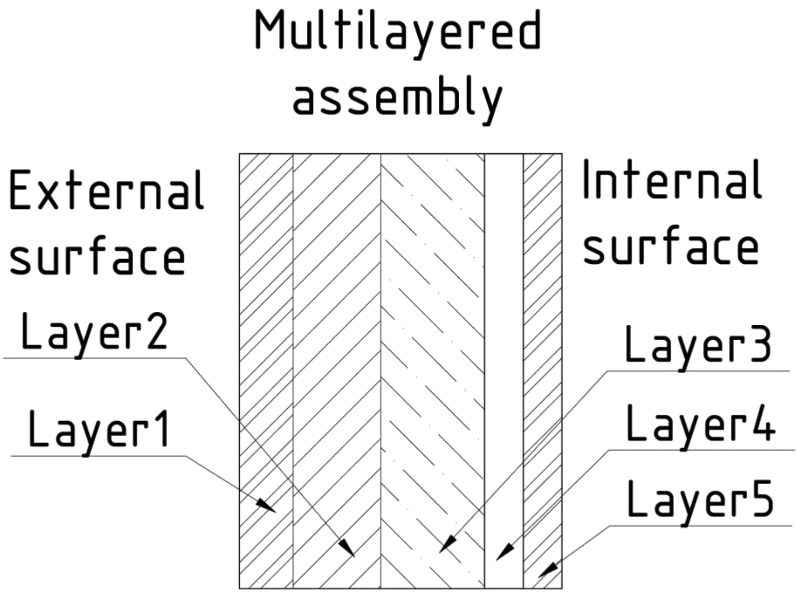


Figure 3.1 The generalised model of the multilayered assembly wall

Clinker surface brick: with high hardness and durability, used as an external wall, to provide excellent wear resistance, weathering resistance, corrosion resistance, while maintaining the appearance of the building beautiful.

Mineral cotton: has the characteristics of light, durable, non-combustible, inconsistent, no moth, in the multi-layer walls, mineral cotton may be used as an insulation layer to provide good heat insulation performance, and has a certain sound absorption effect.

Gypsum board: with light weight, high strength, thin thickness, convenient processing and sound insulation and fire prevention and other properties. In multilayer walls, gypsum board may be used as interior wall material, providing excellent sound insulation, and easy construction and decoration.

Brick: with high strength, durability, compressive resistance, usually as the outermost load-bearing structure.

Asphalt film: commonly used for waterproof treatment, is used as a waterproof layer between brick brick and polystyrene foam plastic, to prevent moisture penetration.

Polystyrene foam plastic: is a kind of light, high insulation performance of building materials, commonly used as insulation layer, can effectively isolate indoor and outdoor temperature differences, improve the thermal insulation performance of the building.

Plumerboard: is a kind of light, easy to process and install building materials, with good sound insulation, heat insulation and fire performance, commonly used as inner wall materials, can provide excellent sound insulation effect and decorative.

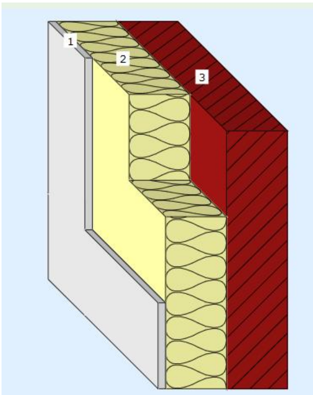
Foam gypsum: it is a kind of light, high insulation performance of gypsum products, often as the transition layer between gypsum board and polystyrene foam plastic, further enhance the insulation effect, and help to reduce the thermal bridge effect between materials.

Advantages of combining multilayer walls： Structural stability, thermal insulation, waterproof insulation performance, sound insulation effect, energy saving and environmental protection, convenient construction, beautiful and practical, environmental protection, energy saving characteristics.

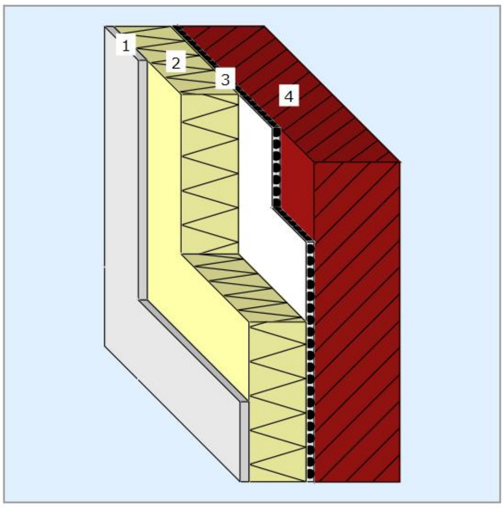
Tab. 3.2 presents the three types of multilayered assembly walls based on an analysis of the most popular construction assemblies commonly used in Chinese construction practice [1, 4, 8, 9].

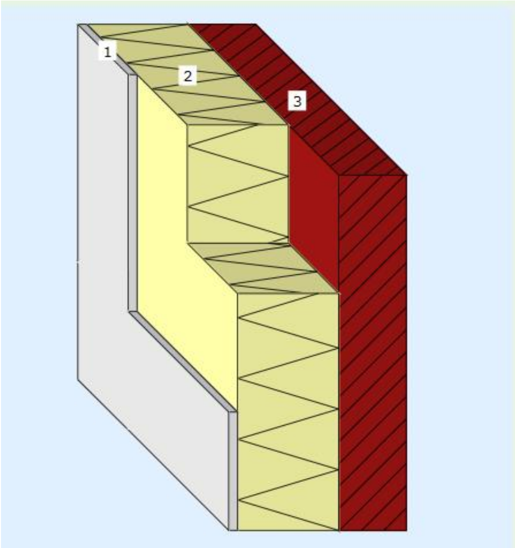
Table 3.2—The multilayered assembly walls for the analysis

Wall type	Assembly constituents and their thermal physics parameters

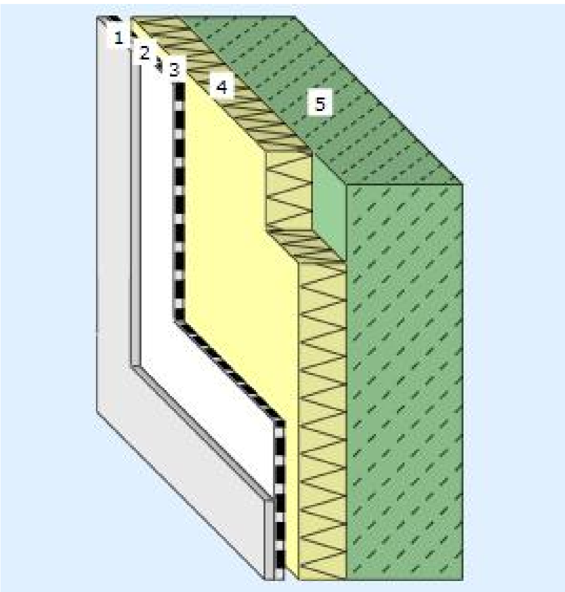
	(layering numbers go from internal to external direction)
1	2
Alternative A **Three-layered wall with insulating brick** 	Layer 1 (Interior Cladding): Gypsum board Thermal Conductivity: 0.17 W/m·K Specific Heat Capacity: 1090 J/kg·K Density: 700 kg/m³ Thickness: 12.5 mm Layer 2 (Insulation): Mineral wool Thermal Conductivity: 0.04 W/m·K Specific Heat Capacity: 1030 J/kg·K Density: 50 kg/m³ Thickness: 100 mm Layer 3 (Exterior Cladding): Clinker facing brick Thermal Conductivity: 0.81 W/m·K Specific Heat Capacity: 840 J/kg·K Density: 1900 kg/m³ Thickness: 100 mm

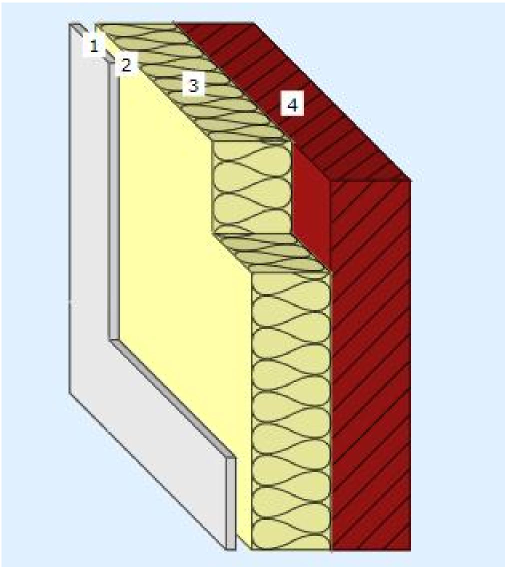
Continue of the Table 3.2

1	2
Alternative B **Four-layered wall with Polystyrene Insulation** 	Layer 1 (Interior Cladding): Gypsum board Thermal Conductivity: 0.17 W/m·K Specific Heat Capacity: 1090 J/kg·K Density: 700 kg/m³ Thickness: 12.5 mm Layer 2 (Insulation): Polystyrene foam Thermal Conductivity: 0.036 W/m·K Specific Heat Capacity: 1300 J/kg·K Density: 30 kg/m³ Thickness: 80 mm Layer 3 (Vapor Barrier): Bituminous membrane Thermal Conductivity: 0.23 W/m·K Specific Heat Capacity: 900 J/kg·K Density: 1050 kg/m³ Thickness: 5 mm Layer 4 (Exterior Cladding): Masonry brick Thermal Conductivity: 0.72 W/m·K Specific Heat Capacity: 800 J/kg·K Density: 1800 kg/m³ Thickness: 120 mm
Alternative C **Three-layered wall with Foam Gypsum**	Layer 1 (Interior Cladding): Gypsum board Thermal Conductivity: 0.17 W/m·K

	Specific Heat Capacity: 1090 J/kg·K Density: 700 kg/m³ Thickness: 12.5 mm Layer 2 (Insulation): Foam gypsum Thermal Conductivity: 0.14 W/m·K Specific Heat Capacity: 900 J/kg·K Density: 300 kg/m³ Thickness: 150 mm Layer 3 (Exterior Cladding): Clinker brick Thermal Conductivity: 0.81 W/m·K Specific Heat Capacity: 840 J/kg·K Density: 1900 kg/m³ Thickness: 100 mm

Continue of the Table 3.2

1	2
Alternative D **Five-layered wall with Expanded Polystyrene (EPS)** 	Layer 1 (Interior Cladding): Gypsum board Thermal Conductivity: 0.17 W/m·K Specific Heat Capacity: 1090 J/kg·K Density: 700 kg/m³ Thickness: 12.5 mm Layer 2 (Vapor Barrier): Polyethylene sheet Thermal Conductivity: 0.33 W/m·K Specific Heat Capacity: 2300 J/kg·K Density: 950 kg/m³ Thickness: 0.2 mm Layer 3 (Air Gap): Air Thermal Conductivity: 0.024 W/m·K Specific Heat Capacity: 1005 J/kg·K Density: 1.2 kg/m³ Thickness: 20 mm Layer 4 (Insulation): Expanded polystyrene (EPS) Thermal Conductivity: 0.035 W/m·K Specific Heat Capacity: 1200 J/kg·K Density: 20 kg/m³ Thickness: 60 mm Layer 5 (Exterior Cladding): Polystyrene concrete wall block Thermal Conductivity: 0.11 W/m·K Specific Heat Capacity: 1060 J/kg·K Density: 300 kg/m³ Thickness: 150 mm

Alternative E **Four-layered wall with Fiberglass Insulation**  	Layer 1 (Interior Cladding): Gypsum board Thermal Conductivity: 0.17 W/m·K Specific Heat Capacity: 1090 J/kg·K Density: 700 kg/m³ Thickness: 12.5 mm Layer 2 (Air Gap): Air Thermal Conductivity: 0.024 W/m·K Specific Heat Capacity: 1005 J/kg·K Density: 1.2 kg/m³ Thickness: 20 mm Layer 3 (Insulation): Fiberglass Thermal Conductivity: 0.04 W/m·K Specific Heat Capacity: 830 J/kg·K Density: 25 kg/m³ Thickness: 100 mm Layer 4 (Exterior Cladding): Clinker brick Thermal Conductivity: 0.81 W/m·K Specific Heat Capacity: 840 J/kg·K Density: 1900 kg/m³ Thickness: 100 mm

The selection of materials has an important influence on the thermal stability of the building. First, the thermal conductivity of the material affects the thermal properties of the building, that is, the heat conduction of the material. High thermal conductivity materials will cause rapid heat transfer, aggravating the change of indoor temperature. Secondly, the heat capacity of the material indicates its ability to absorb or release heat. The high heat capacity material can maintain a stable temperature when heating or dissipation, which helps to improve the indoor comfort. In addition, the reflectivity of materials is also one of the influencing factors, highly reflective materials can reduce the absorption of solar radiation, reduce the indoor temperature. Finally, the absorbing material damages the change of the indoor temperature, and the absorbing material can absorb the heat during the day, striving for the indoor temperature to rise.

For numerical modelling, the ISO 13876-based Excel spreadsheet calculator was used [2]. The main vital parameters of the dynamic performance characteristics are internal area heat capacity (k1), kJ/m2K and the dimensionless decrement factor (f). In addition to the abovementioned dynamic parameters, the mass of the 1m2 assembly, kg, and u-value, W/m2K, as the steady-state thermal characteristic of the multilayered wall was considered in current research.

For numerical modelling, the ISO 13876-based Excel spreadsheet calculator was used [2]. The main window of the calculator interface and its additional references are presented in Fig. 3.2

layer name	thermal conductivity l [W/m.K]	gross density r [kg/m³]	specific heat capacity C [J/kg.K]	layer thickness d [m]	R [m²K/W]
Rsi (int. heat transfer resistance)					0.115
Brickwork 1400 kg/m3 of hollow bricks on cement-sand mortar/ Кладка з пустотілої цегли 1400 кг/м3 на цем-пісч. розчині	0.580	1600	880.000	0.1200	0.207
Bituminose membrane	0.230	1050	900.000	0.0050	0.022
EPS insulation boards / Екструдований пінополістирол	0.039	30	1340.000	0.0800	2.051
Gypsum board / Гіпсокартон	0.370	1000	840.000	0.0125	0.034
Rse (ext. heat transfer resistance)					0.043
		U-value:	*0.4045*	*W/m²K*	
		Total thickness:	*0.218*	*m*	

Figure 3.2 – The interface window of the ISO 13786 calculator

Calculation results according to EN ISO 13786:		
External thermal admittance:	0.953	W/(m²K)

Timeshift external side:	3.93	h
Internal thermal admittance:	4.835	W/(m²K)
Timeshift internal side:	1.78	h
Periodic thermal transmittance:	0.165	W/(m²K)
Timeshift periodic thermal transmittance:	-6.28	h
External areal heat capacity:	15.165	kJ/(m².K)
Internal areal heat capacity:	67.677	kJ/(m².K)
Decrement factor f:	0.407	

Figure 3.3 – The interface window of the ISO 13786 calculator results

As mentioned above, the main parameters of the dynamic performance characteristics are internal area heat capacity (k1), kJ/m2K, and the dimensionless decrement factor (f). In addition to the abovementioned dynamic parameters, the mass of the 1m2 assembly, kg, and u-value, W/m2K, as the steady-state thermal characteristic of the multilayered wall was considered in current research.

Thermal insulation material plays an important role in the indoor thermal stability. The insulation material can effectively disperse the heat of the wall, thus reducing the thermal resistance and improving the insulation performance of the wall. The insulation material can reduce the heat on the wall surface, thus reducing the thermal resistance and improving the indoor thermal stability.

The selection and design of thermal insulation materials are of great significance for the optimization of the thermal resistance effect. By selecting materials with low thermal conductivity and high thermal resistance, it can effectively reduce the heat transfer of the wall and improve the heat insulation performance of the wall. This optimization helps to reduce differences in indoor and outdoor temperatures, thereby improving indoor thermal stability.

The heat capacity of the insulation material also affects the thermal stability of the room. High heat capacity material can absorb or release more heat when heating or dissipation, so as to adjust the change of wall temperature, improve indoor thermal stability.

Therefore, the selection of materials with an appropriate heat capacity is crucial to optimize the thermal properties of the building.

The air layer barrier can also affect the humidity level inside the building, thus affecting the thermal stability of the room.

Reasonable air layer barrier design can prevent moisture penetration, keep the indoor humidity in a comfortable range, and further improve the indoor thermal stability.

Considering the safety of the building, the selection of thermal insulation materials with good fire performance is also the key.

Materials with good fire prevention performance can effectively prevent flame spread, reduce fire risk, so as to ensure the safety and stability of the building.

The rational selection and design of insulation materials and air layer barrier are very important to improve the thermal stability of the building.

By optimizing heat resistance, heat resistance, humidity control, fire resistance to effectively reduce the impact of indoor and outdoor temperature changes on the building, improve the energy efficiency, comfort and safety of the building.

Table 3.3—Air barrier

Influencing factor	Characterization
Air current	The flow between the airflow layers will take away or block the heat, affecting the heat transfer speed between the exterior wall materials. Good air flow can disperse heat and improve indoor thermal stability.
Layer	The change of air layer thickness has a significant effect on the heat insulation effect, and the change of air layer thickness can better block heat transfer and reduce heat transfer.
Hot cutting material	The application of heat resistance materials in air can improve the heat transfer efficiency and prevent heat conduction and fluid flow.
leak tightness	The heat insulation effect of the air sealing layer can effectively reduce the air leakage and the external air leakage, and improve the sealing performance.

EN 15251: The purpose of this standard is to ensure that we can take into account the impact of the internal environment on the energy efficiency of the building, so as to better configure and design the energy efficiency of the building. EN 15251 Provides specifications for indoor environmental input parameters, including temperature, humidity, air quality, etc. The rational configuration and goal of these parameters is to ensure that the building can maintain a good energy efficiency coefficient under different environmental conditions. By following this standard, we can more fully consider the actual use of the building and ensure the energy performance of the building. It does not guide the design and operation of the building, thus improving the performance and comfort of the building to meet the relevant energy efficiency standards and regulatory requirements.

Dynamic thermal properties are essential for understanding how building materials and structures interact with heat over time. It refers to the ability of a material or structure to react to heat transfer and storage on different time scales. Assessing these features can help us to more accurately predict the energy consumption and indoor comfort of a building. These characteristics include thermal conductivity, thermal capacity, and thermal inertia, and a detailed analysis of these parameters can optimize the selection of building materials and structural design to achieve greater energy efficiency and a more comfortable indoor environment.

For example, high-temperature inertial materials can absorb heat during the day and release heat at night, thus reducing the impact of the temperature difference between day and night on the indoor temperature and reducing the dependence on the air-conditioning system. Moreover, materials with low thermal conductivity can effectively reduce heat transfer, maintain a stable indoor temperature, and improve energy efficiency. The evaluation of dynamic thermal characteristics is not only the key to the design of new buildings, but also crucial to the energy-saving renovation of existing buildings.

By systematically evaluating and optimizing these dynamic thermal characteristics, the building can achieve energy saving goals, reduce energy consumption and improve occupant comfort. This correspondence has important practical implications for global climate change and the achievement of the Sustainable Development Goals.

Gasparella et al. (2011) studied the thermal dynamic transport properties of opaque envelope structures under outdoor conditions in summer. They used numerical tools such as the finite difference method and the transfer function method to evaluate the performance of different building materials at high summer temperatures. The results show that the material with high thermal inertia and low thermal conductivity can effectively reduce energy consumption and improve indoor comfort.

3.3 Numerical modelling results and discussion

After numerical modelling of the dynamic parameters was performed, cumulative results data were collected in Tab. 3.2, representing the numerical analysis results obtained using the proposed tool.

Table 3.4 – The multilayered assembly walls' performance

Wall type	Wall's performance parameters				
	Wall width, m	The wall mass, kg/m^2	Thermal transmittance *u-value*, W/m^{2}K	Internal areal heat capacity *k1*, kJ/(m^{2}K)	Decrement factor *f*
Wall type A	0.213	232.50	0.576	80.09	0.460
Wall type B	0.218	212.15	0.405	67.68	0.407
Wall type C	0.313	282.50	0.576	80.37	0.351
Wall type D	0.227	56.87	0.294	17.39	0.561
Wall type E	0.215	201.27	0.340	12.92	0.701

A graphical interpretation of the obtained in Tab.3.2 is given in Fig. 3.4 - 3.9.

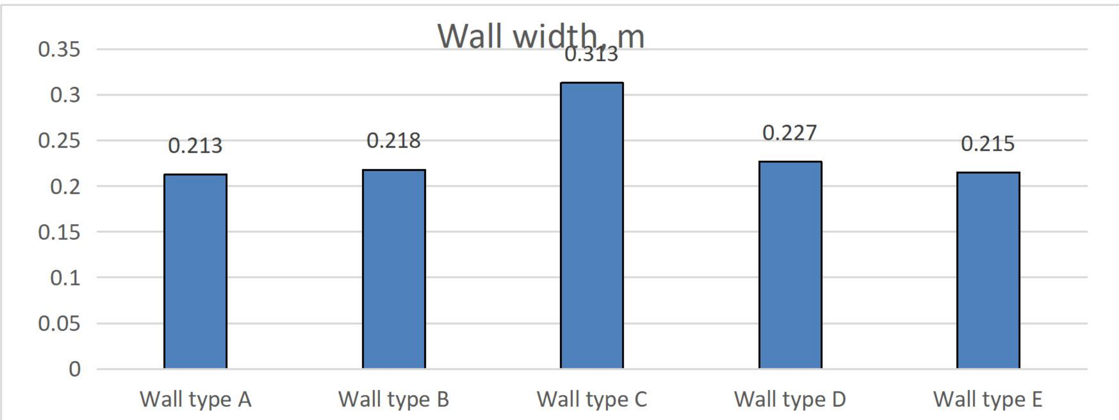


Figure 3.4 Wall assemblies width

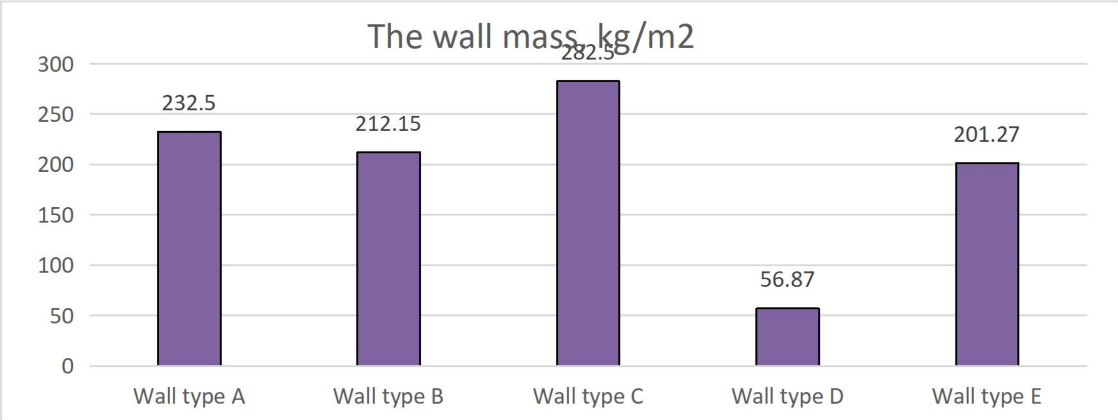


Figure 3.5 Wall assemblies mass

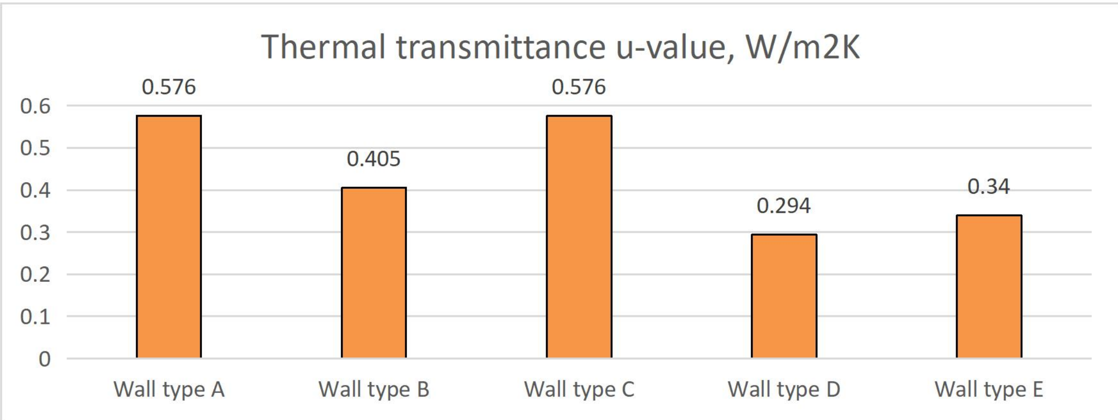


Figure 3.6 Wall assemblies u-value

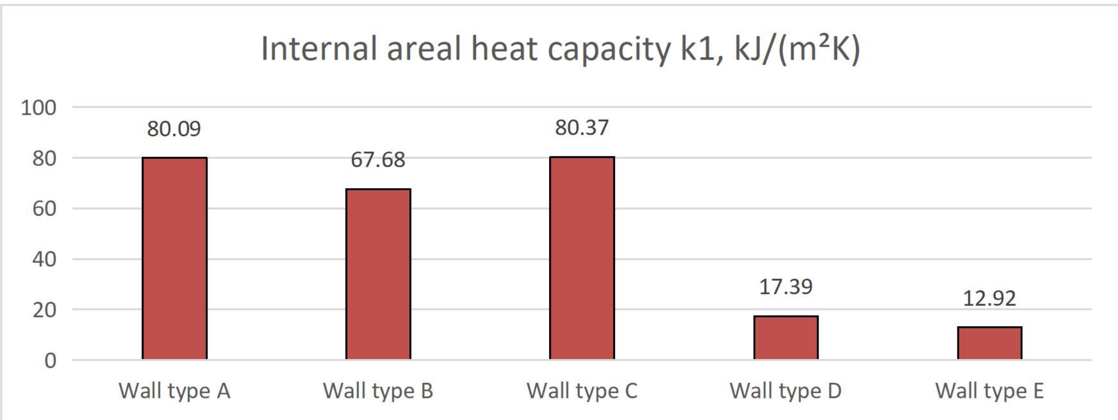


Figure 3.7 Wall assemblies k1 value

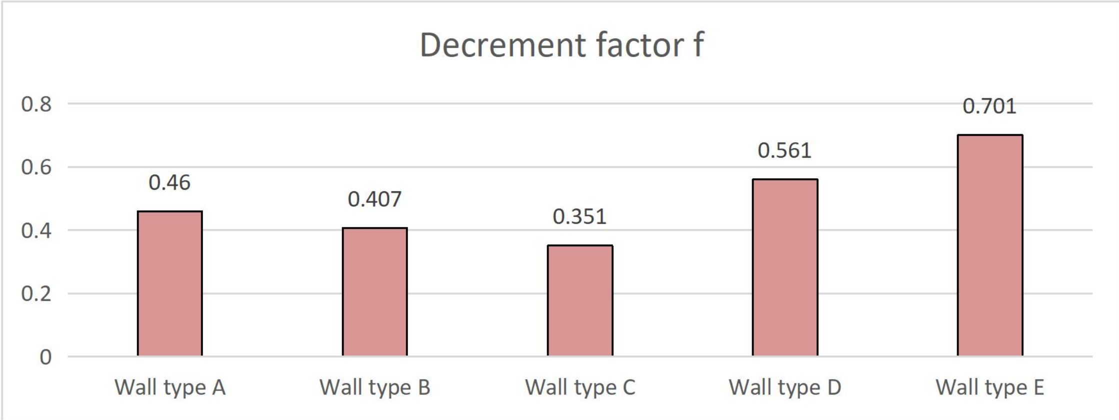


Figure 3.8 Wall assemblies decrement factor value

The abovementioned results show no prominent “best” alternative wall. Here, we have to consider some aspects of choosing wall assembly. Firstly, the higher the internal area heat capacity and lower decrement factor, the better wall assembly in terms of summer behaviour, and the lower the u-value and decrement factor, the better winter behaviour [4]. Thus, from the Tab. 3.2 It could be revealed that wall type C could be considered the best wall for summer performance, but it is not as good as the winter assembly type due to the maximum value of u-value – 0.576. Wall type A could also be considered a good wall for summer performance and even slightly better for winter performance from wall A, with a lower decrement factor value – 0.460. Wall type B has middle results according to the highlighted parameters with 67.68 kJ/(m²K) of k1 value and 0.407 and 0.405 of decrement factor and u-value, respectively.

Secondly, to make the comparison of the different alternatives more interpretable, we can make a normalisation procedure to represent all the results unscaled.

The multicriteria analysis should be applied for the obtained results to reveal the “better” wall assembly, for instance, additive convolution [10]. For the normalisation procedure, we'll use such assumptions: if the considered parameter met the rule "the bigger – the better", the calculation formula will be as follows [10]:

$$x_{norm} = \frac{x_{ij} - x_{imin}}{x_{imax} - x_{imin}}, \tag{3.1}$$

Where x_{ij} - i-th wall value of performance for j-th criteria;

x_{imax}, x_{imin} - maximum and minimum i-th wall value of performance for j-th criteria.

If the considered parameter meets the rule "the lower – the better", the calculation formula will be as follows:

$$x_{norm} = \frac{x_{max} - x_{ij}}{x_{imax} - x_{imin}}, \tag{3.2}$$

Table 3.5 reflects the normalised data according to the formulae (3.3) and (3.4).

Table 3.5 – The multilayered assembly walls' performance

Wall type	Wall width, m	The wall mass, kg/m^2	Thermal transmittance *u-value*, W/m^{2}K	Internal areal heat capacity *k1*, kJ/(m^{2}K)	Decrement factor *f*	The total normalised value for the wall
Wall type A	1.000	0.222	0.000	1.000	0.689	2.910
Wall type B	0.950	0.312	0.606	0.394	0.840	3.102
Wall type C	0.000	0.000	0.000	1.000	1.000	2.000
Wall type D	0.860	1.000	1.000	0.000	0.400	3.260
Wall type E	0.980	0.360	0.837	0.163	0.000	2.340

Table 3.5 shows that wall D is the "best" alternative, with a total of 3.26 points

from the five most common wall types used in the Chinese construction sector.

The bar chart obtained in Table 3.3 results normalised is represented in Fig. 3.9.

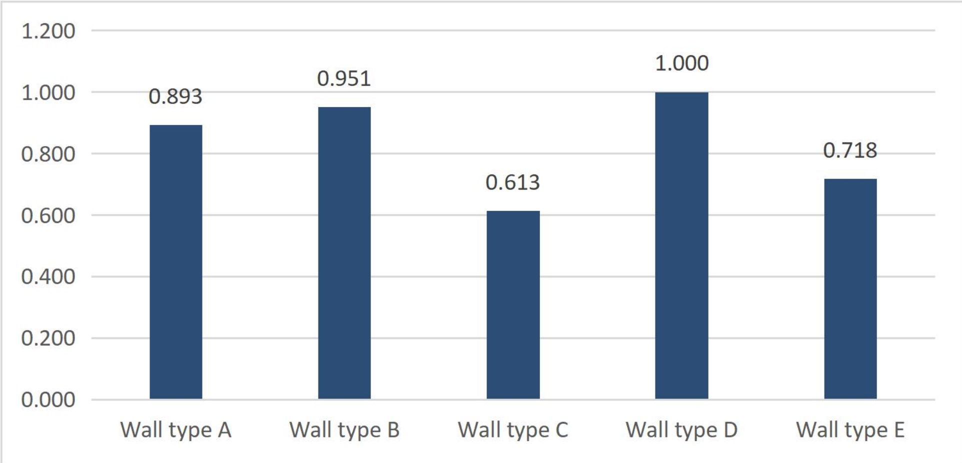


Figure 3.9 MCDA additive convolution assessment

Multi-criterion decision analysis (MCDA) method plays an important role in evaluating the energy efficiency of the building envelope. By changing the weight, the researchers are able to evaluate the performance of different materials under different standards, ensuring that the best combination of materials is chosen to improve energy efficiency and sustainability. Advanced materials and technologies are good at improving the thermal properties of buildings. Smart glass can be automatically adjusted according to the ambient sunlight, reducing the summer heat entry and winter heat loss.Phase change materials in the process of solid waste recovery using materials to absorb a large amount of heat, bringing good indoor temperature regulation characteristics. The application of these technologies significantly improves building energy efficiency and reduces energy consumption.

In particular it identifies the internal areal heat capacity κ1 and decrement factor f as the main influencer of the summer behavior, while the steady state thermal transmittance U and the decrement factor f of the winter performance.

Among different highly energy efficient envelopes (with very low Uvalues), the best solution for all year round will be the one with the highest internal areal heat capacity (and as a consequence the highest inner inertia) and an appropriate damping effect on the incoming wave (a low f value, but not too much low). A detailed explanation of this fact is given below.However, as demonstrated above, very low f values configure opaque surfaces behaving as thermal barrier, especially if combined with very low U values. In this case the wall will block not only the incoming heat flux but also the outgoing one thus determining the overheating of the room. So the adoption of high internal areal heat capacity is of particular importance.Moreover very low fvalues are achievable only through new techniques, such as highly stratified multilayered walls or cement-wood envelopes that are a young research field.

Apart from the insulation values, which directly impact energy use, it is also important to consider the level of comfort and quality of life in the dwelling. Here too, Ytong distinguishes itself with its exceptional qualities.

In today's globalization, with the increasingly serious energy crisis and environmental problems, people pay increasing attention to energy efficiency and environmental sustainability. In the field of construction, as an important part of the building envelope, its design and selection directly affect the building energy consumption and indoor environment. Therefore, the requirements for the thermal and environmental performance of multilayer walls are increasingly higher.

In China, with the promotion of energy conservation and emission reduction policies and the improvement of building energy conservation standards, the design and selection of multi-storey wall gradually develop from the traditional single function to the diversified and high-performance direction. More and more architects and designers began to pay attention to the thermal performance and environmental performance of multilayer walls, through the use of new materials and advanced technologies to improve the thermal insulation performance and environmental performance of multilayer walls.

In addition, with the improvement of people's requirements for the indoor environment quality, the design of the multi-storey wall also pays more and more attention to the comfort and health of the indoor environment. For example, in the design, consider the non-toxic harmless of the material, mildew resistance and other factors, as well as by optimizing the structural design and material combination to improve the sound insulation and noise reduction performance of the layer wall.

In the world, the design and selection of multi-layer wall also show the trend of high performance and environmental protection. Many developed countries have formulated strict building energy saving standards and environmental protection laws and regulations, requiring that the building envelope structure must have good thermal insulation performance and environmental protection performance. At the same time, with the continuous emergence of new materials and new technologies, the design and selection of multi-layer walls are becoming more and more diversified and personalized.

In international exchanges, the architectural culture and technical experience of different countries and regions are integrated, which promotes the innovation and development of multi-storey wall design and selection. For example, some European countries pay attention to the insulation and environmental performance of multilayer walls, using many new materials and advanced technologies, while some Asian countries pay more attention to the insulation and beauty of multilayer walls, using many materials and designs with local characteristics.

When evaluating the performance of the multilayer wall, the internal area heat capacity and mass performance. These parameters jointly determine the thermal performance of the multilayer walls, and affect the energy consumption and indoor environment of the buildings.

When selecting the multi-storey wall, it is necessary to comprehensively consider the various performance parameters and the specific needs of the building. Here are some of the key parameters:

Bu value: The Bu value reflects the heat conduction performance of the multilayer wall. For cold areas requiring high insulation, multilayer walls with low Bu values should be selected; for tropical areas that require rapid heat dissipation, multilayer walls with high Bu values may be selected.

Internal area heat capacity: The internal area heat capacity reflects the ability of the multilayer walls to store heat. For the occasions that need to stabilize the indoor environment, the multi-layer wall with a higher internal area heat capacity should be selected.

Quality performance: Quality performance not only affects the thermal insulation performance of the multi-layer wall, but also affects the stability and safety of the building structure. Therefore, when choosing multi-storey walls, we need to consider their quality performance and the specific needs of the building.

When selecting the multilayer wall, it should be considered comprehensively according to the specific needs and regional characteristics, and pay attention to the evaluation of the steady-state, dynamic and physical parameters of the multilayer wall. Through reasonable selection and design, the energy efficiency and environmental protection performance of the building can be improved, to create a more comfortable and healthy indoor environment for people.The conclusion of this study is that:

However, even knowing that a particular wall scored high in the proposed multicriteria decision analysis is not the “best” choice. In this regard, we must supply additional data or criteria for judgment. As such additional criteria, we can provide a Chinese map of climatic zones, for instance, to better understand whether the “ best” wall D fits the requirements of Chinese thermal resistant norms for different climatic zones. In Fig. 3.10, the Chinese climatic zoning is represented.

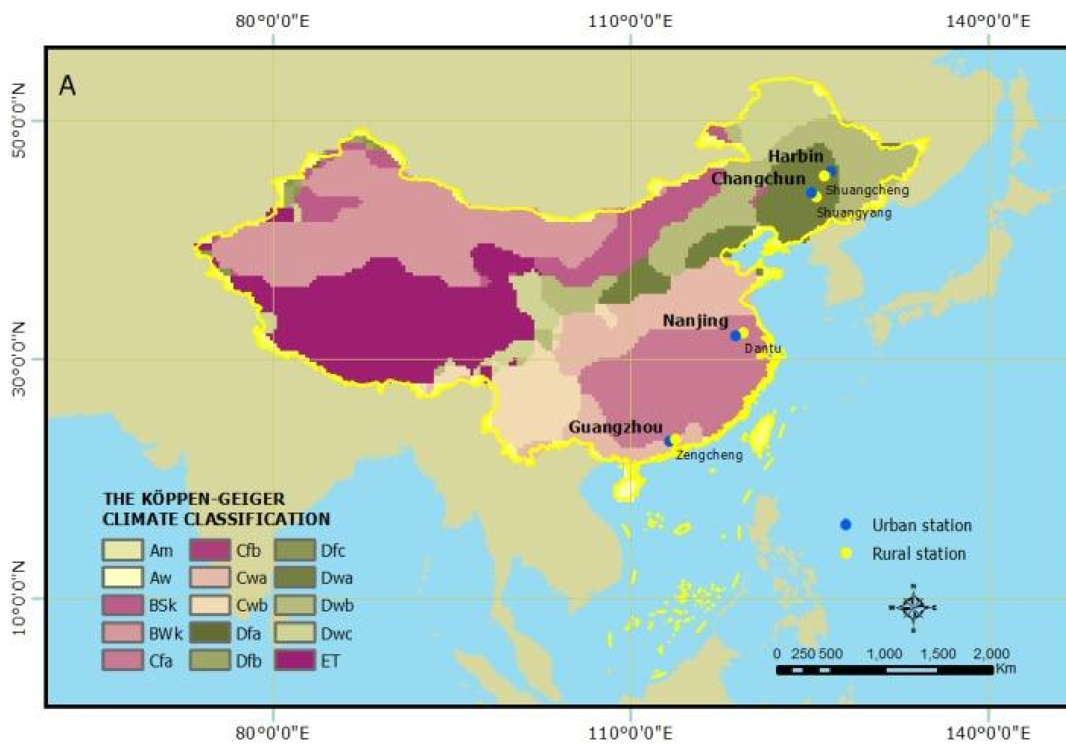


Figure 3.10 China’s Köppen-Geiger climate classification map [11]

From the data obtained from the Internet, it could mentioned that China's current thermal resistance zoning is divided into five particular zones:

China's climatic zones significantly influence building materials' required thermal resistance values (R-values) to ensure energy efficiency and thermal comfort. Here are the general thermal resistance values categorised by different climatic zones in China:

1.Severe Cold Zone:

Typical R-value: ≥ 5.0 $m^2 \cdot K/W$ (u-value: ≤ 0.2) W/ $m^2 \cdot K$

This zone experiences very low temperatures, necessitating higher thermal resistance to maintain indoor comfort and reduce heating energy consumption.

2.Cold Zone:

Typical R-value: 3.5 - 5.0 $m^2 \cdot K/W$ (u-value: 0.2 – 0.286) W/ $m^2 \cdot K$

Buildings in this zone require moderate to high insulation to cope with cold winters and maintain energy efficiency.

3.Hot Summer and Cold Winter Zone:

Typical R-value: 3.0 - 4.5 $m^2 \cdot K/W$ (u-value: 0.222 – 0.333) W/ $m^2 \cdot K$

This zone faces significant temperature variations, necessitating insulation that can efficiently handle cold winters and hot summers.

4.Hot Summer and Warm Winter Zone:

Typical R-value: 2.0 - 3.0 $m^2 \cdot K/W$ (u-value: 0.333 – 0.5) W/ $m^2 \cdot K$

Due to milder winters, buildings in this zone require lower thermal resistance, focusing more on mitigating heat during the summer months.

5.Mild Zone:

Typical R-value: 1.5 - 2.5 $m^2 \cdot K/W$ (u-value: 0.4 – 0.666) W/ $m^2 \cdot K$

This zone has relatively stable temperatures year-round, so lower thermal resistance values are sufficient for maintaining comfort and energy efficiency.

By matching the meeting of particular climate zone thermal resistance and wall type, we can determine which wall assemblies fit more Chinese climatic zones and get pivot table 3.4.

Table 3.4 – Meeting the requirements for thermal resistance of walls

Thermal transmittance *u-value*, W/m^{2}K					
Wall type	Severe Cold Zone (≤ 0.2)	Cold Zone (0.2 – 0.286)	Hot Summer and Cold Winter Zone (0.222-0.333)	Hot Summer and Warm Winter Zone (0.333-0.5)	Mild Zone (0.4-0.666)
Wall type A (0.576)	-	-	-	-	+
Wall type B (0.405)	-	-	-	+	+
Wall type C (0.576)	-	-	-	-	+
Wall type D (0.294)	-	-	+	+	+
Wall type E (0.340)	-	-	-	+	+

From the provided analysis, it could be revealed that wall D meets three of five climate zones' thermal resistance requirements, wall B and E meet only two and wall A meets only one climate zone requirement.

Thus, it could be concluded that a comprehensive analysis of dynamic characteristics, thermal performance and physical parameters was conducted for the five most commonly used types of walls in the Chinese construction sector.

Regarding dynamics characteristics, wall C has a better internal area heat capacity performance – 80.37 kJ/m2K with a maximum mass value of 282.50 kg /m2. Nevertheless, wall A has almost the same internal area heat capacity value – 80.09 kJ/m2K with lesser mass performance -232.50 kg /m2. Wall's D u-value has the most significant value – 0.294 W/m2K, but its internal area heat capacity is only 17.39 kJ/m2K - the lowest of the five wall types. Further research should be provided to comprehensively evaluate steady-state, dynamic and physical parameters of multilayered walls for a better understanding of crucial parameters to focus on during proper wall assembly decision-making.

Conclusion to the chaper3

A)The dynamic characteristics analysis of the central summer and winter influencers, which play a significant role in the energy efficiency performance assessment, was proposed for the typical Chinese multilayered wall assemblies. Even among the five researched alternatives, the best choice is still challenging because comparable characteristics vary from alternative to alternative without total domination in each comparison parameter.

B)From the five wall types, the wall C performance could be considered the best one based on the internal area heat capacity – 80.37 kJ/m2K parameter, but at the same time, with a maximum mass value of 282.50 kg /m2, while the wall A showed medium results in terms almost the exact value of internal area heat capacity – 80.09 kJ/m2K with lesser mass performance – 232.50 kg /m2.

C)Wall D could be considered the best alternative based on its u-value; it has the most significant value – 0.294 W/m2K, but its internal area heat capacity of 17.39 kJ/m2K is one of the lowest of all wall types.

D)Comprehension consideration of thermal, physical, and economic aspects could lead to closer proximity when we choose the best alternative when challenging "the best alternative" choosing issue. In the current research, which considered five parameters: wall width, mass, u-value, internal area heat capacity and decrement factor, the MCDA was performed for "better" alternative figuring. Wall D is considered the "best" wall for this comprehensive consideration.

E)Results have revealed that additional data regarding each alternative could significantly change the final decision. Thus, further evaluation should be provided when a contender “better” alternative is not seen because comparable characteristics vary from alternative to alternative without total domination in each comparison parameter.

4 CALCULATION OF THE ECONOMIC EFFECTS

4.1 Dynamic thermal characteristics of the building envelope

The evaluation of the dynamic thermal performance of the building envelopes has been done according to EN ISO 13786:2007 [3]. The detailed method description is reported in Appendix B.

At the cross section of the external envelope the temperature profiles are variable for each instant, depending on inside temperatures, outside temperature, and thermophysical properties of the layers. The dynamic thermal characteristics, reported in Table 4.1, are obtained by imposing a conductive thermal exchange condition and having for each material the values of the thermal conductivity, specific heat, density, and thickness.

Table4.1—Characteristic of materials

NAME	Conductivity （W/m·k）	Density （Kg/m³）	Specific （J/kg·k）	U（W/m²·K）
Materials for Wall	1.40	1800	8	—
Window Material	0.90	—	—	1.20
Roofing material	0.20	950	900	—
Flooring	1.70	2200	840	—

The figure below shows the indoor temperature changes of the office building in different periods of summer and winter. These data are based on energy plus simulations that reflect the thermal stability performance of buildings under different climatic conditions:

Summer temperature change: the temperature is higher during the day, the highest can reach 34℃, and the night temperature can drop to 21℃.

Winter temperature change: the temperature is high during the day, the highest can reach 26℃, and the night temperature can drop to 17℃.

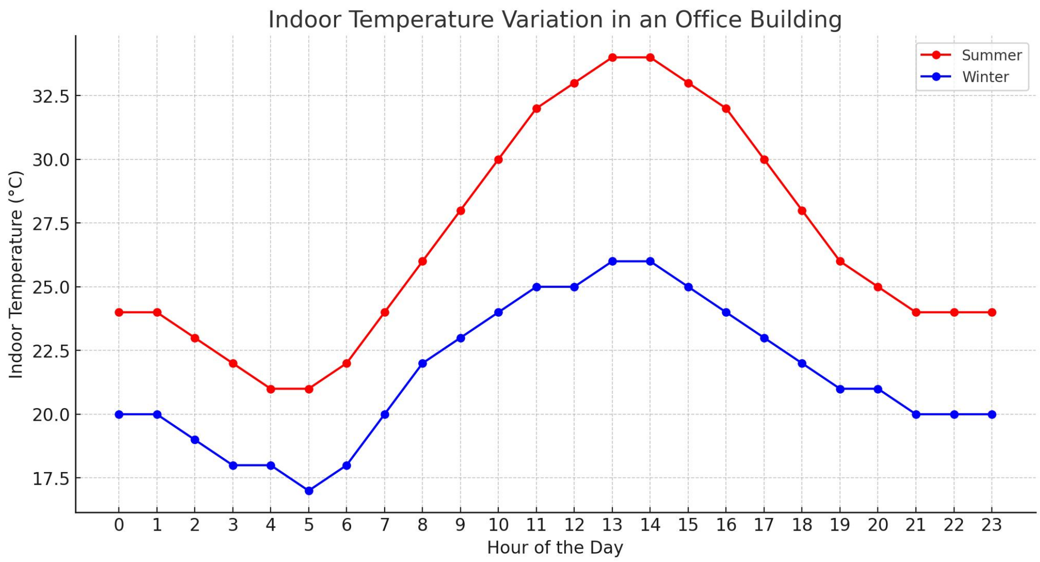


Fig.4. 1 Temperature chart

4.2. Case studies

In this case, a three-storey office building was selected as the research object. The building covers a total area of 3000m2 and contains 20 offices, meeting rooms, rest areas and public corridors. The structure has brick walls, double-glazed windows, an insulated roof, and a concrete floor. The air conditioning system and heating system are fully equipped to ensure a comfortable indoor environment in different seasons.In this case study, we evaluated the thermal properties of three common building materials, （A） Three-layered wall with insulating brick、 （C)Three-layered wall with Foam Gypsum 、 (D)Five-layered wall with Expanded Polystyrene (EPS)， the specific material characteristics are as follows:

Table 4.2—Table of standard performance

NAME	Conductivity（W/m·k）	Density（Kg/m³）	Specific（J/kg·k）
（A）	0.035	20	1300
（C）	1.400	2400	880
（D）	0.030	35	1400

Simulation results: Through energy simulation, we obtained the data of indoor temperature change, energy consumption and comfort of buildings in different seasons. The following are the main data representations of the simulation.

Table 4.3—Highest and lowest performance tables

	NAME	Highest	Lowest
（A）	Summer temperature change（℃）	28	22
	Winter temperature change（℃）	22	18
	Energy consumption data（KWh/m²）	30	25
（C）	Summer temperature change（℃）	32	24
	Winter temperature change（℃）	25	19
	Energy consumption data（KWh/m²）	35	30

（D）	Summer temperature change（℃）	27	21
	Winter temperature change（℃）	23	17
	Energy consumption data（KWh/m²）	28	22
	Energy consumption data（KWh/m²）	35	30

Data analysis: Thermal performance index analysis

Table 4.4—Thermal performance index analysis

NAME	R（m²·K/W）	U（W/m²·K）
(A)	1/0.035=28.57	0.035
(C)	1/1.4=0.71	1.4
(D)	1/0.030=33.33	0.030

Because of their low density and low thermal inertia, the cavity wall and straw wall are suitable for rapid response of environmental regulation. Due to its high density and large thermal inertia, the light wooden wall is suitable for places where heat is released and absorbed slowly. By comparing the energy consumption data of different materials, we found that:

Straw wall has the lowest energy consumption in summer and winter, and has the best insulation and energy efficiency.

The insulation performance of cavity wall is slightly lower than that of straw wall, but better than that of light wood structure wall.

Light wood structure wall has high thermal conductivity and high heat inertia, the highest energy consumption, but good performance in temperature buffer.

By optimizing the material selection, we can significantly reduce the energy consumption of the building. For example, using straw walls instead of traditional light wooden structure walls can save about 20% of air conditioning and heating energy consumption in summer and winter, respectively.

With detailed dynamic thermal performance assessments and energy + simulations, we are able to systematically analyze and optimize the selection of building materials to improve the energy efficiency and indoor comfort of buildings. Choosing the insulation material of straw wall can significantly reduce energy consumption and achieve the goal of green building. The results of the case studies provide a solid scientific basis for building design and energy-saving improvement.

4.3 Computing of the economic impact

4.3.1 Cost-benefit analysis

When calculating the initial investment in the implementation of advanced materials and technologies, we need to consider the material cost, the installation costs, and the associated design and construction costs. The following are the initial investment estimates based on the three walls used in this case study:

Table 4.5—Cost table

NAME	Cost of material; material cost （RMB/m^2）	Fabricating cost （RMB/m^2）	Initial outlay （ Suppose2000m^2）

(A)	50	30	160,000
(C)	100	50	300,000
(D)	70	35	210,000

According to the known conditions, in order to estimate the energy savings and reduced operating costs of different materials, we need to consider the annual operating costs of the air conditioning and heating system, assuming the electricity fee of 0.5 yuan / kWh. The following are the annual operating savings estimated based on the simulation results:

Table 4.6—Energy consumption in different seasons

NAME	Energy consumption of air conditioning in summer （kWh/m²）	Energy consumption for winter heating （kWh/m²）	Total operating costs （RMB/year）
(A)	30	25	55,000
(C)	35	30	65,000
(D)	28	22	50,000

4.3.2 Comparative analysis

By comparing the initial investment and operational savings, we can perform a detailed cost-effectiveness analysis to assess the economic impact of the different materials.

Initial investment as compared to the annual operating costs:

Table 4.7— Each cost comparison

NAME	Initial outlay（RMB）	Annual operating costs（RMB）	Annual savings（Relative to the light wooden structure wall）
(A)	160,000	55,000	10,000
(C)	300,000	65,000	0
(D)	210,000	50,000	15,000

4.3.3 Calculation of investment recovery period

By calculating the asset payback periods of different materials, we can better assess their economics:

Table 4.8— Calculation of the investment payback period

NAME	Initial outlay（RMB）	Annual savings（RMB）	Capital pay-off time（year）
(A)	160,000	10,000	16
(C)	300,000	0	—
(D)	210,000	15,000	14

Conclusion to the chaper4

From these calculations, we can draw the following conclusions:

Although the initial investment of Five-layered wall with Expanded Polystyrene (EPS)materials is relatively high, the economic situation is very good due to the low operating cost but the relatively short payback period.

The initial investment of three-layered wall with insulating brick materials is low, but the operating cost is also low, and the payback period is long.

Although Three-layered wall with Foam Gypsum materials are widely used, their high thermal conductivity and high operating cost make them uneconomical.

In conclusion, through detailed cost-benefit analysis and comparison, we can clearly see that when choosing different materials and technologies. Five-layered wall with Expanded Polystyrene (EPS) material has the best performance in terms of economy and energy saving, and is the preferred solution to achieve building energy saving and improve economic benefits.

Conclusions

In this study, we present a detailed analysis of the thermal properties and energy efficiency of different building materials by using dynamic thermal property assessment models and energy plus simulations. The main findings are as follows:

The importance of material selection: We found that the thermal conductivity, heat capacity and density of different materials have a significant impact on the thermal performance and energy efficiency of buildings. In particular, Five-layered wall with Expanded Polystyrene (EPS) materials perform well in both summer and winter due to their low thermal conductivity and high heat capacity, significantly reducing energy consumption.

A)First of all, thermal conductivity is an important indicator to measure the thermal conductivity of materials. Thermal conductivity represents the amount of heat conducted through a material per unit area per unit time. A lower thermal conductivity means that the material has better thermal insulation properties and can reduce heat transfer. Therefore, when selecting wall materials, materials with lower thermal conductivity should be selected as much as possible to reduce the energy loss of the building. For example, using high-performance insulation materials such as polystyrene boards or rock wool boards to construct exterior walls can effectively reduce indoor and outdoor heat exchange and improve the building's thermal insulation effect.

B)Secondly, heat capacity is an indicator of the material’s ability to store heat. It represents the amount of heat absorbed or released by a unit mass or unit volume of material when the temperature changes. Materials with larger heat capacity can absorb and store more heat in a short period of time, thereby achieving heat balance regulation and energy conservation. For example, high-density materials such as concrete and stone have large heat capacities and can absorb solar heat during the day and slowly release it at night, thus regulating indoor temperature. Therefore, when selecting wall materials, one should consider their thermal capacity characteristics and determine the most suitable material based on the design and use requirements of the building.

C)In addition, the density of the materials also has an impact on the thermal performance and energy efficiency of the building. Higher density usually means a better material insulation and a higher heat capacity. High-density materials can block heat transfer more effectively and reduce energy loss. For example, higher density materials such as bricks and stones can provide better heat insulation and reduce the transfer of indoor and outdoor heat. Therefore, when choosing wall materials, their density should be considered, and combined with the design and use needs of the building to determine the most appropriate material.

In addition to thermal conductivity, heat capacity and density, other material properties such as durability, sustainability and cost should also be considered. Durability refers to the stable performance of materials under long-term use and environmental changes, and is crucial to extending the service life of a building and reducing maintenance costs. Sustainability refers to the impact of materials on the environment during the production, use and disposal stages, providing support for the sustainable development of buildings. Cost is one of the key factors that must be considered when selecting materials, and it is necessary to find economical and practical solutions while meeting design and performance requirements.

To summarize, material selection plays an important role in the thermal performance and energy efficiency of a building. More efficient building energy use can be achieved by selecting materials with lower thermal conductivity, greater heat capacity and higher density. In addition to these basic properties, factors such as material durability, sustainability and cost should also be considered to find the most suitable combination of materials. Future research can further explore new materials and technologies to continuously improve the thermal performance and energy efficiency of buildings and promote the sustainable development of the construction industry.

Economic analysis: Through the cost-benefit analysis, we conclude that the five-layered wall with Expanded Polystyrene (EPS) materials provide the best economic benefits in terms of the initial investment and long-term operation savings. Although the initial investment is high, its payback period and long-term savings are considerable due to low operating costs.

Thermal performance optimization: Through simulation and analysis, we are able to optimize the architectural design, improve indoor comfort, and achieve significant energy saving.

These findings have important implications for architectural design and energy efficiency. The selection of appropriate building materials, especially those with superior thermal insulation performance such as five-layered wall with Expanded Polystyrene (EPS), can significantly improve the thermal stability and energy efficiency of the building, reduce energy consumption, and improve the indoor comfort level.

In this study, the thermal properties and energy efficiency of different building materials were systematically analyzed through the dynamic thermal characteristics evaluation model and energy plus simulation. The results show that the selection of appropriate building materials, especially those with excellent thermal insulation properties such as five-layered wall with Expanded Polystyrene (EPS), can significantly improve the thermal stability and energy efficiency of the building, reduce energy consumption and improve indoor comfort.

The evaluation of the dynamic thermal performance of different walls is of great importance for the sustainable architectural design and the efficient energy management. This study not only provides a scientific basis for the selection and design optimization of building materials, but also provides scientific goals for achieving green building and energy conservation and emission reduction. Future studies should further explore more materials and technologies to perform long-term performance assessments to drive the sustainability of the construction industry.

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ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Оцінка ефективності огороджувальних конструкцій в контексті їх динамічних характеристик

Тип роботи: Магістерська кваліфікаційна робота
(БДР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
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MULTILAYERED WALL ASSEMBLIES' DYNAMIC THERMAL CHARACTERISTICS COMPARISON

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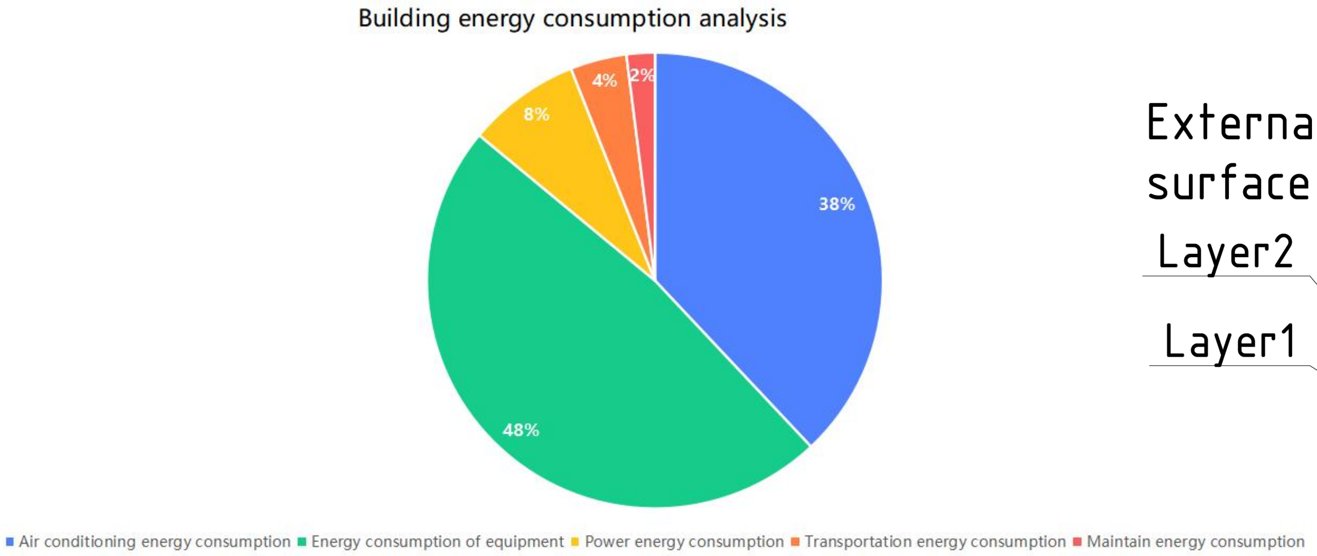
目录Contents

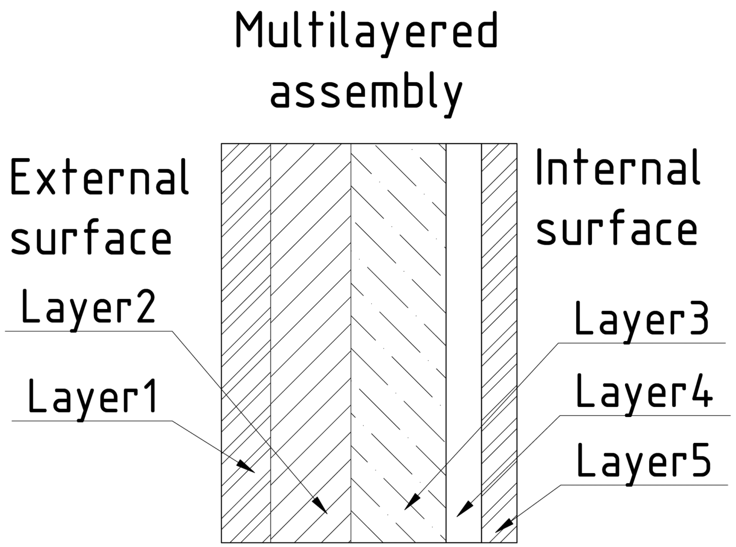
1

Research objectives

The purpose and objectives of the study. The main goals of the research are:

- Provide the analysis of dynamic thermal performance key influencers in terms of winter and summer behaviour for multilayered wall assemblies;

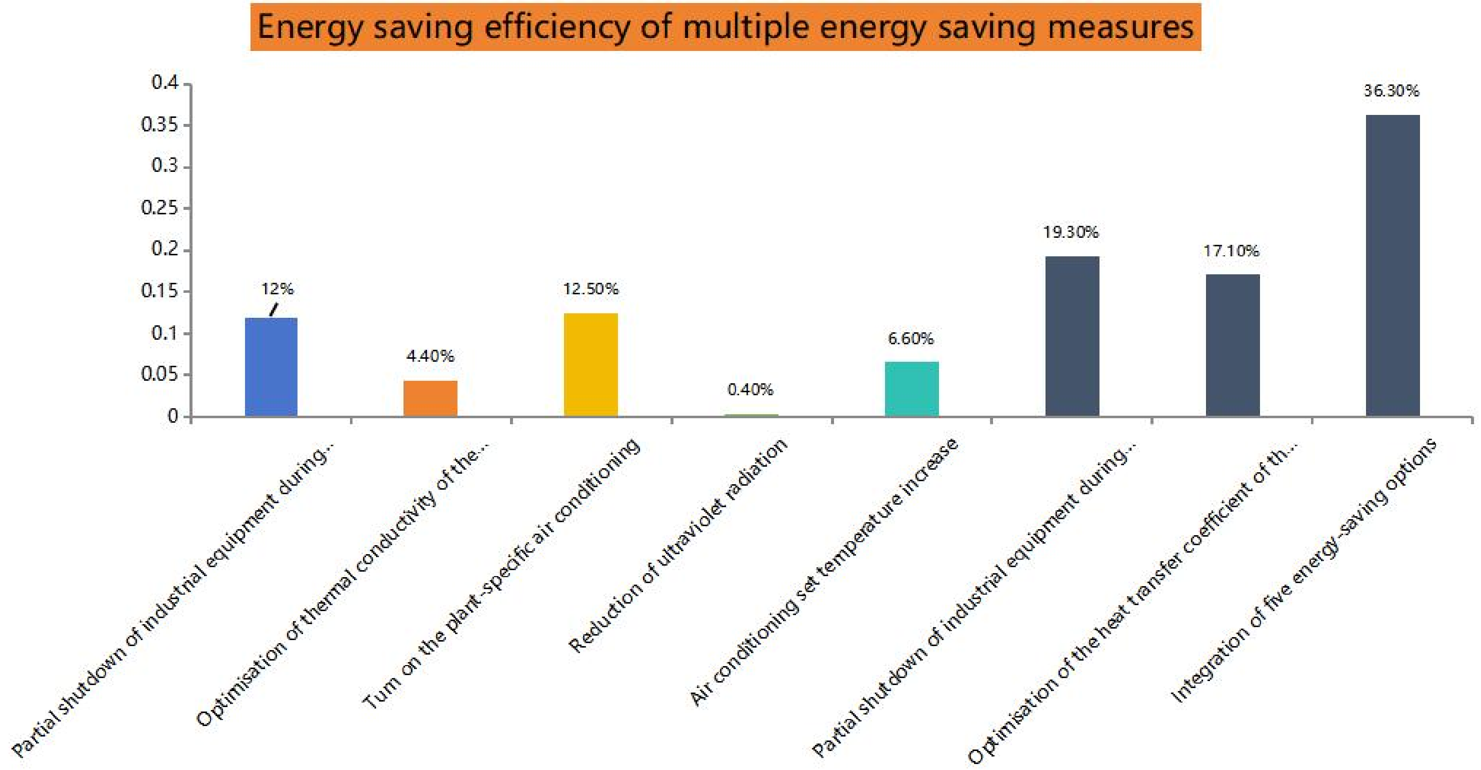




- Research of most commonly used multilayered wall assemblies in Chinese construction sector;
- Numerical modelling of internal area heat capacity and decrement factor for different multilayered assembly walls, considering the mass of the wall and u-value in the multicriteria analysis;
- Climate zoning requirements' meeting check for all the compared alternatives;
- Providing the MCDA assessment of multilayered walls, choosing the "best" alternative, calculating the economic outcomes and the payback period.

As the figure shows

Energy saving efficiency of multiple energy saving measures	
Energy Savings Programme	Energy saving efficiency in industrial plants (%)
Partial shutdown of industrial equipment during periods of inactivity	12%
Optimisation of thermal conductivity of the envelope	4.40%
Turn on the plant-specific air conditioning	12.50%
Reduction of ultraviolet radiation	0.40%
Air conditioning set temperature increase	6.60%
Partial shutdown of industrial equipment during idle time + air-conditioning set temperature increase	19.30%
Optimisation of the heat transfer coefficient of the envelope + opening of plant-specific air conditioning	17.10%
Integration of five energy-saving options	36.30%



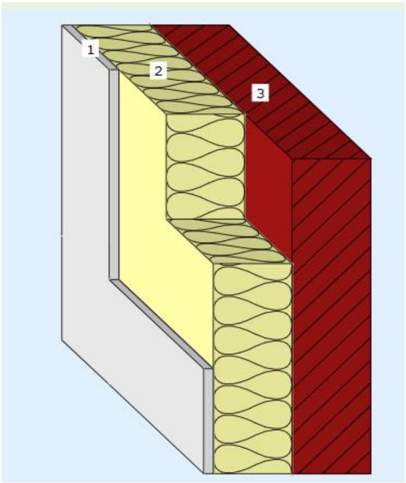
2

The object and subject of the study.

TASK

As the figure shows

The object of the study. The object of this study is a complex of thermophysical, physical, as well as economic indicators of wall assemblies.



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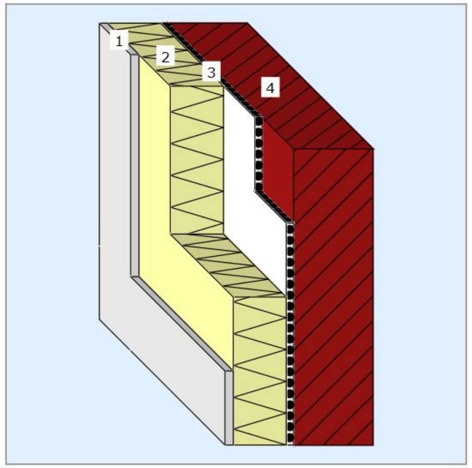

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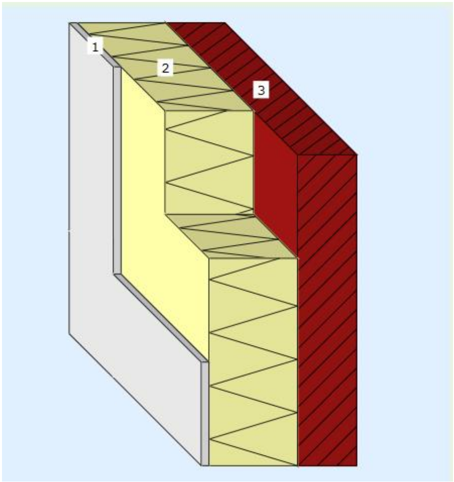

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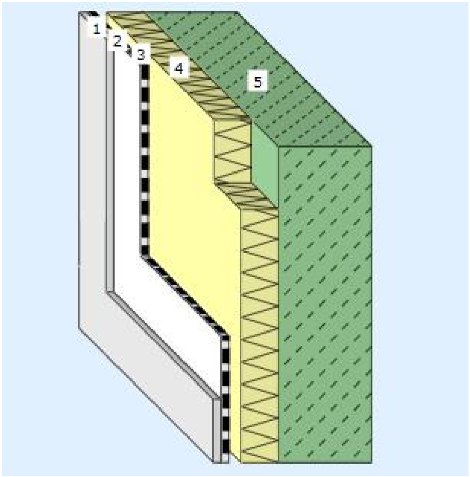

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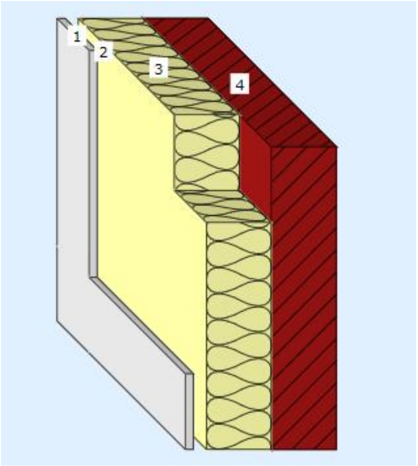
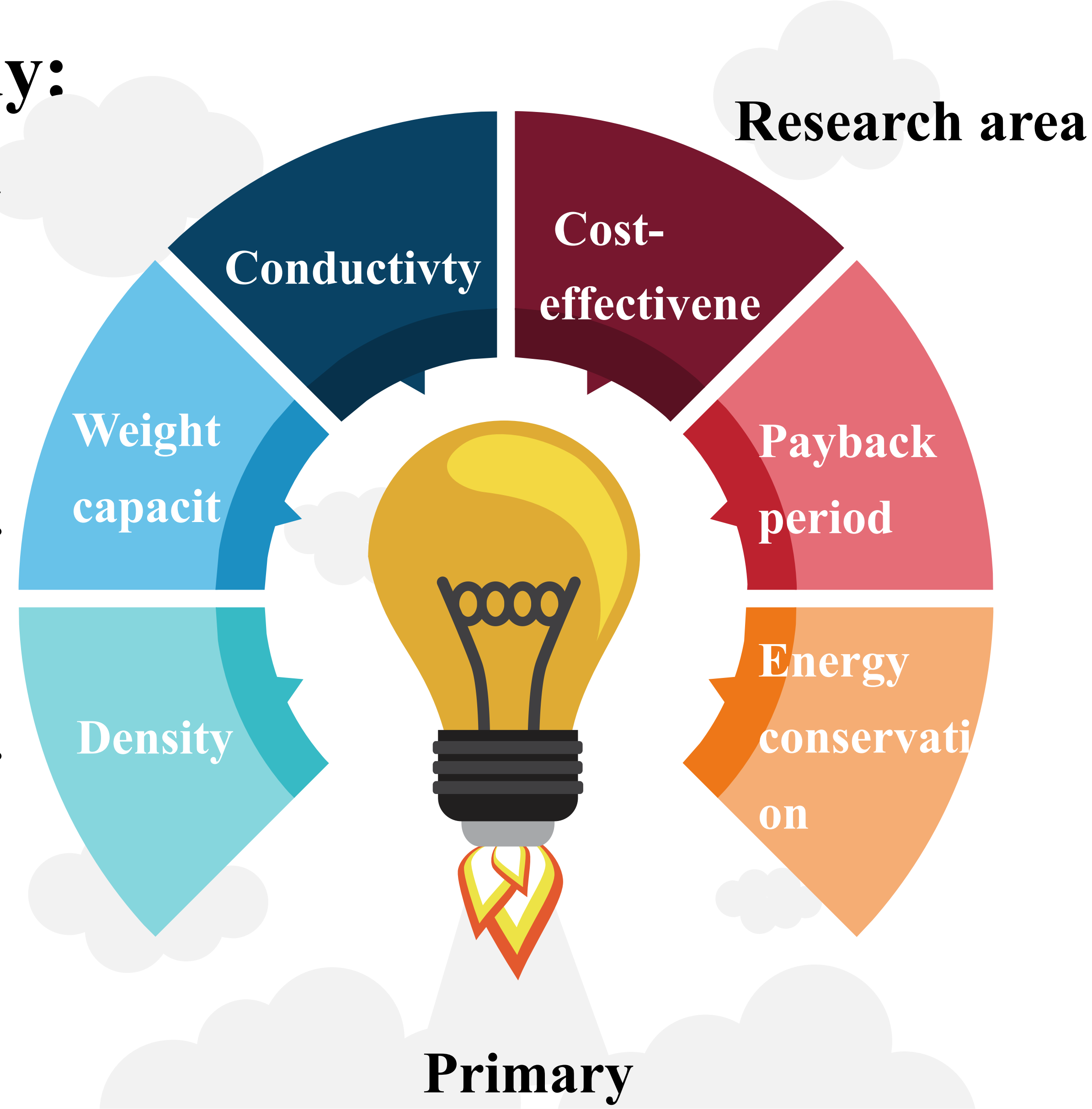


E

The subject of the study:

The subject of the study is a comprehensive assessment of the energy efficiency of multilayer envelope structures, taking into account their dynamic thermal performance parameters.



3

Research methods

Dynamic performance simulation of multi-layer components

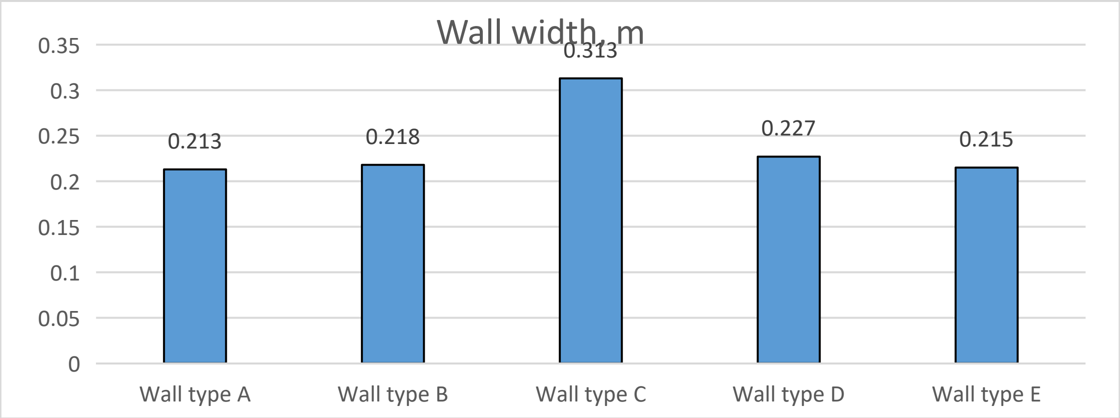
ISO 13876-based Excel spreadsheet calculator was used [2]

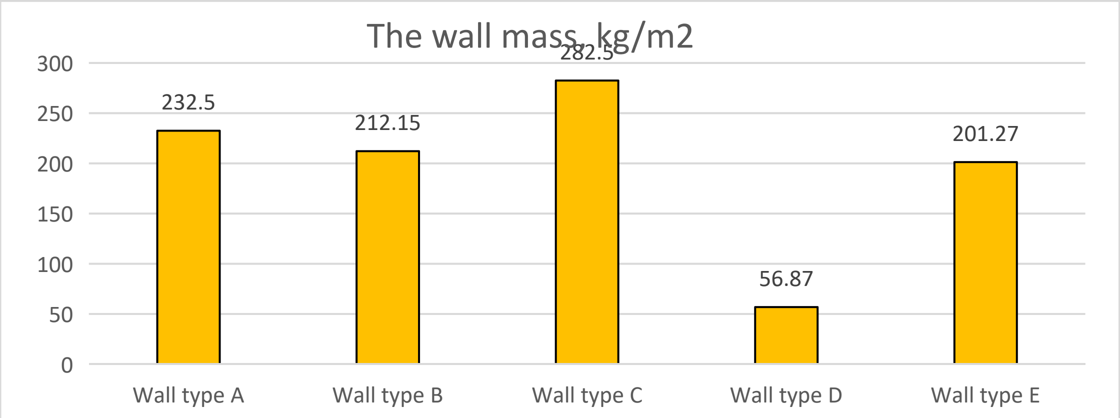
Research methods. Finding the dynamic characteristics of multilayer wall constructions was performed using the calculation package analytically described in [3] and implemented in the MS Excel program "Calculation-tool-Thermal-Mass-ISO-13786"[2]. MCDA analysis of multilayered wall assemblies comprehensive assessment was performed by standard mathematical formulae for providing the additive convolution.

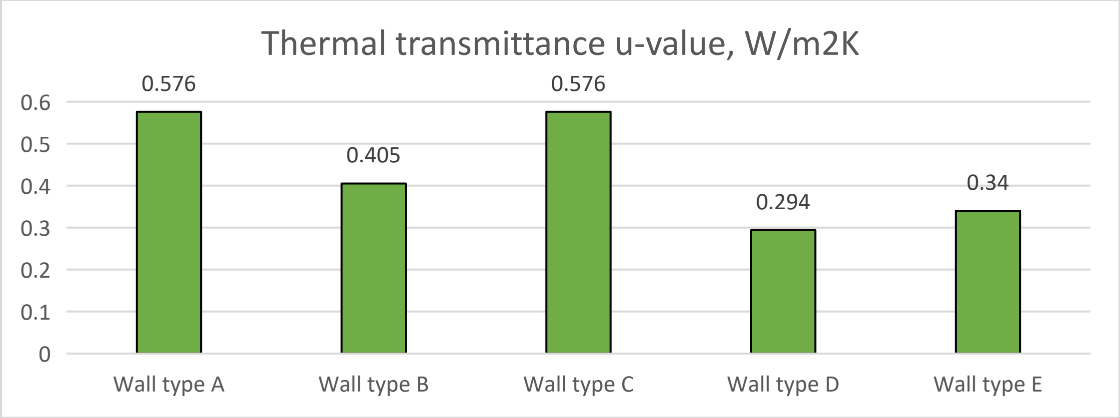
Wall type	Wall's performance parameters				
	Wall width, m	The wall mass, kg/m²	Thermal transmittance *u-value*, W/m²K	Internal areal heat capacity *k1*, kJ/(m²K)	Decrement factor *f*
Wall type A	0.213	232.50	0.576	80.09	0.460
Wall type B	0.218	212.15	0.405	67.68	0.407
Wall type C	0.313	282.50	0.576	80.37	0.351
Wall type D	0.227	56.87	0.294	17.39	0.561
Wall type E	0.215	201.27	0.340	12.92	0.701

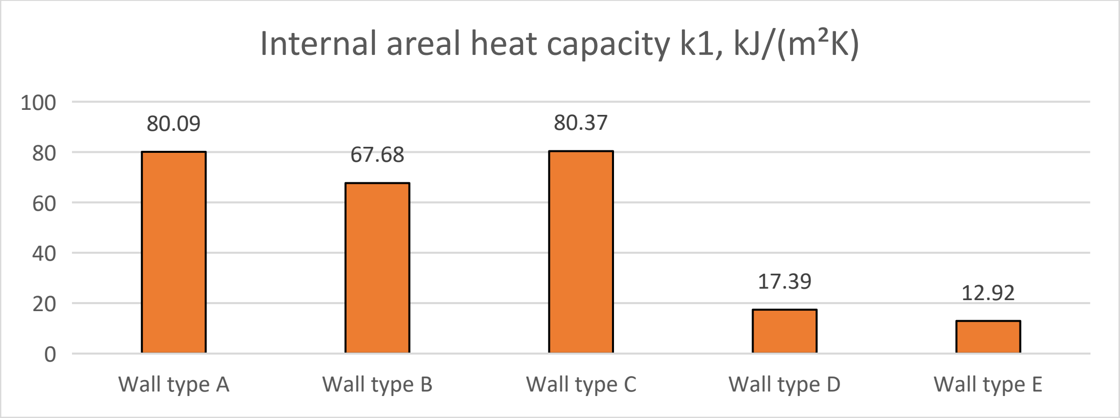
The multilayered assembly walls' performance

Scientific novelty of the obtained results. Obtaining, as a result of calculations, the value of a comprehensive assessment of the buildings assemblies structures, taking into account their dynamic thermal performance influence factors, as well according the steady state parameter and their mass.

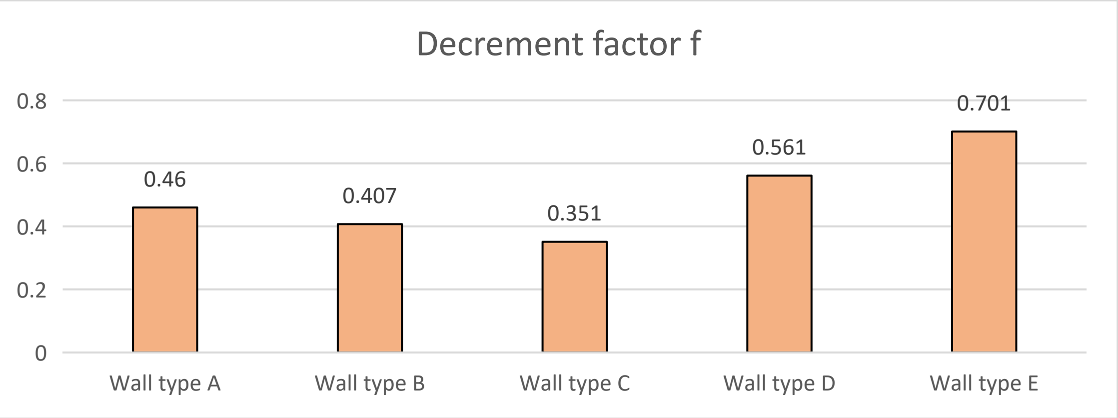


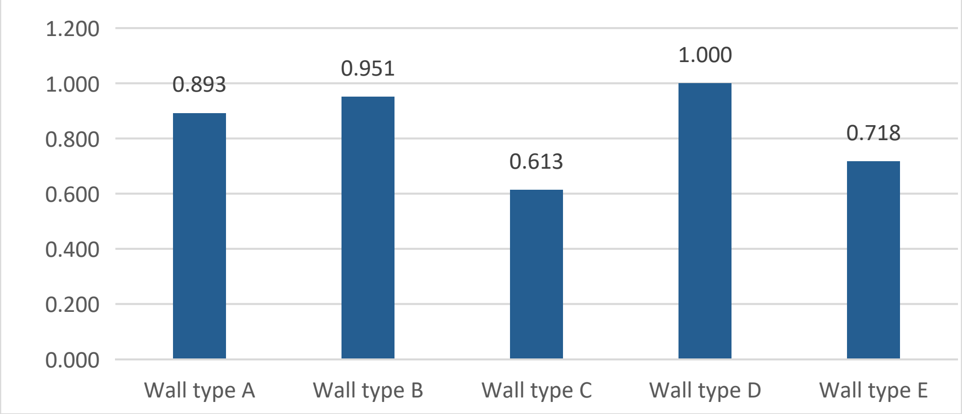






Numerical modeling





Wall type	Wall width, m	The wall mass, kg/m²	Thermal transmittance *u-value*, W/m²K	Internal areal heat capacity *k1*, kJ/(m²K)	Decrement factor *f*	The total normalised value for the wall
Wall type A	1.000	0.222	0.000	1.000	0.689	2.910
Wall type B	0.950	0.312	0.606	0.394	0.840	3.102
Wall type C	0.000	0.000	0.000	1.000	1.000	2.000
Wall type D	0.860	1.000	1.000	0.000	0.400	3.260
Wall type E	0.980	0.360	0.837	0.163	0.000	2.340

4

Conclusion

The practical significance of the results obtained

➢ In this study, the multilayered assembly walls were investigated and analysed, as well the main thermal properties of envelope materials, such as wall and insulation systems commonly used in the Chinese construction sector were investigated. Based on the preliminary research outcomes, the key influencers for winter and summer wall assemblies behaviour of different walls are conducted, and the multilayered envelope was chosen based on MCDA analysis. Results let consider that not all the researched multilayered wall assemblies meet the thermal resistant requirements for Chinese climate zones. Finally, using the dynamic thermal performance simulation tool, comprehensively considering the comprehensive physical and dynamic thermal performance parameters for the selected envelope types were evaluated, and suggestions for the "best" alternative were put forward to achieve an efficient assessment of wall assembly.

Investment payback period calculation

NAME	Initial outlay (RMB)	Annual savings（RMB）	Capital pay-off time（year）
Three-layered wall with insulating brick	160,000	10,000	16
Five-layered wall with Expanded Polystyrene (EPS)	210,000	15,000	14
Three-layered wall with Foam Gypsum	300,000	0	—

Ratiocination:1

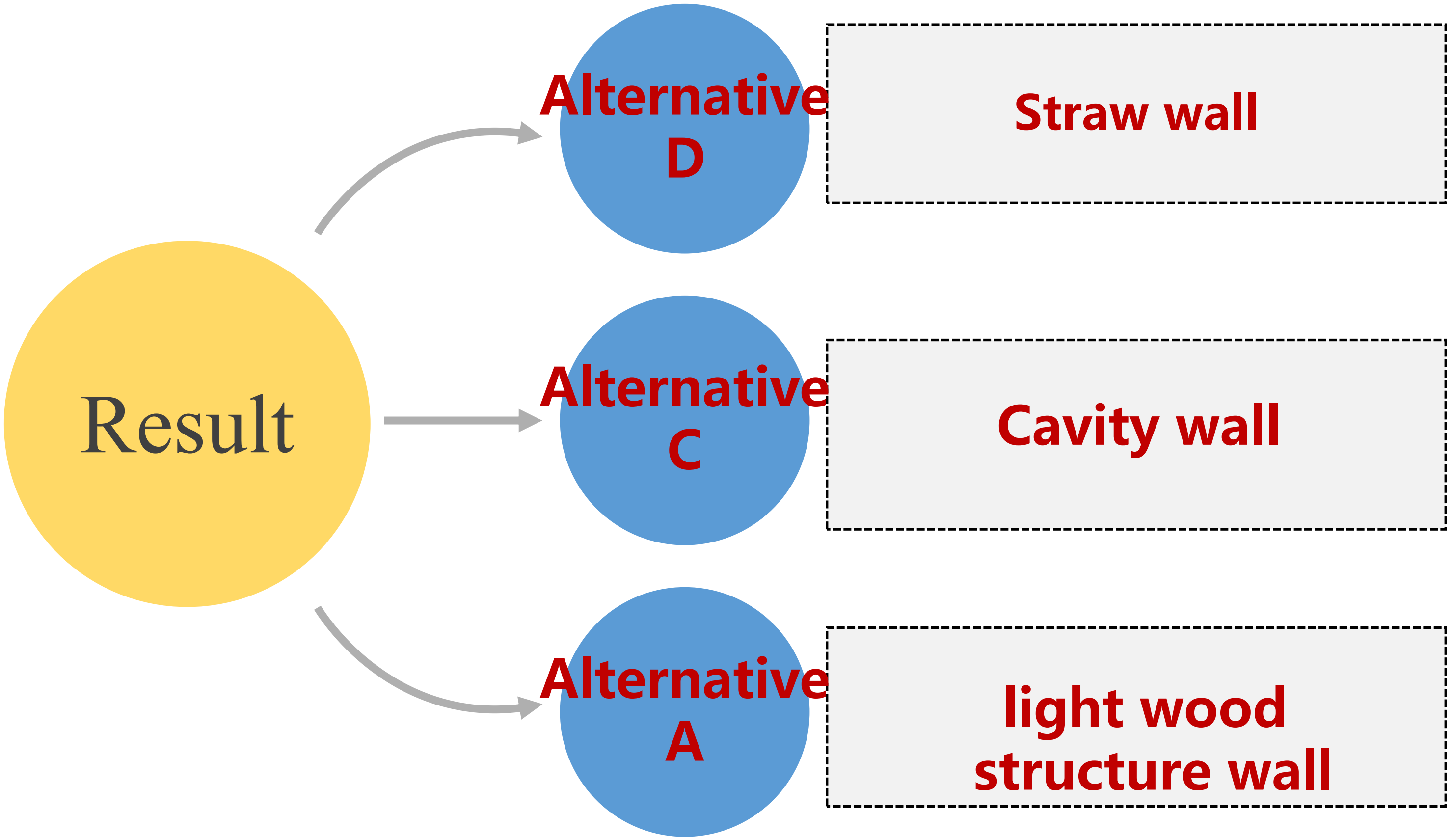
Three-layered wall with Foam Gypsum initial outlay is the highest, but her Annual savings is 0, possibly because her thermal insulation performance is poor, resulting in higher energy bills.。

Ratiocination:2

Three-layered wall with insulating brick the lowest, but its annual savings is 10,000, which may be due to its better thermal insulation performance but longer payback period.

■ (A) Three-layered wall with insulating brick、 (C)Three-layered wall with Foam Gypsum、(D)Five-layered wall with Expanded Polystyrene (EPS)

- ➢Five-layered wall with Expanded Polystyrene (EPS) has a higher initial investment, but the economics are good due to lower operating costs but a relatively short payback period.



5

Prospective to the future

Future

The evaluation of the dynamic thermal performance of different walls is of great importance for sustainable building design and efficient energy management. This research not only provides a scientific basis for the selection and design optimization of building materials, but also provides scientific goals for the realization of green buildings and energy conservation and emission reduction. Future research should further explore more materials and technologies for long-term performance evaluation to promote the sustainable development of the construction industry.

Thank you, judges, for listening.

Opponent's review of graduate student

DENG Xueqin Master's Thesis

Master's thesis was performed according to the topic "Envelopes energy efficiency performance assessment in terms of their dynamic characteristics".

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 actual issue of multi-criteria assessment of multilayered wall assemblies.

It should be noted that the author carried out the thesis on this topic, and the research was dedicated to the multi-criteria assessment, including the dynamic parameters according to ISO13786, of the proposed wall assemblies.

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 dynamic thermal properties of envelope materials – Chinese domestic and abroad study; review of thermal properties of typical wall materials, in namely steel frame-embedded AAC wall insulation, phase change heat storage wall and others, case study of five commonly used wall assemblies in terms of their dynamic properties, in particular internal area heat capacity value $k1$ and decrement factor f, economic part, total conclusions.

At the beginning of the thesis, the author 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 introduction.

In the first section of the thesis, a qualitative review of other scientists' state-of-the-art with a close research direction is performed, emphasising the author's reasonable understanding of the chosen topic. In the second chapter, problems in wall assemblies are considered. In the third section, the numerical modelling of five types of wall assemblies is performed, and MCDA analysis for choosing the best alternative is used.

In the fourth chapter, the economic outcomes, cost-benefit analysis, as well as payback period for the "best" alternative wall assembly are presented in the calculus example.

The research results were reported at the international scientific and practical conference and considered in the Thesis abstracts.

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

The thesis's disadvantages include inaccuracies in the design and the fact that only two dynamic thermal behaviour characteristics were taken into account without explaining other's influence. However, these shortcomings do not affect the positive impression of the work.

The master's qualification work was performed reasonably and by the task and compliance with all requirements. The work deserves a grade (B), 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 of DENG Xueqin

graduate student Master's Thesis

Master's thesis was performed according to the topic "Envelopes energy efficiency performance assessment in terms of their dynamic characteristics".

The master's qualification thesis submitted for review was completed fully and within the deadline. The work comply to the approved topic and task. The subject is relevant and dedicated to the perspective and actual issue of multi-criteria assessment of multilayered wall assemblies.

It should be mentioned that the author carried out the thesis on this topic, and the research was dedicated to the multi-criteria assessment, including the dynamic parameters according to ISO13786, of the proposed wall assemblies. These components are often composed of different materials and structural layers with complex heat transfer mechanisms. The dynamic thermal characteristics of multi-layer wall components refer to the dynamic changing characteristics of temperature distribution and heat flow transfer inside the wall under different times and environmental conditions. Understanding the dynamic thermal characteristics of multi-layer wall components is of great significance for optimising building design, improving building energy efficiency, and reducing energy consumption.

The thesis material is presented in a meticulous and comprehensible manner, ensuring a thorough understanding of the research. The thesis is structured into the following sections: an analysis of the current state of dynamic thermal properties of envelope materials – based on Chinese and abroad studies; the review of thermal properties of typical wall materials, such as steel frame-embedded AAC wall insulation, phase change heat storage wall was also provided to make an impactable impression; as well there were case study of five most commonly used in Chinese construction practice wall assemblies in terms of internal area heat capacity (k1) in kJ/m2K, and the dimensionless decrement factor (f) as the most influencing factors for dynamic characteristics under ISO 13786; an economic chapter; and the total conclusions.

In the introductory section of the thesis, the author meticulously outlines the relevance, objectives, research goals, and tasks, as well as the scientific novelty and practical significance of the study, all framed within the broader context of the nation's sustainable development efforts.

The first chapter offers a thorough qualitative review of contemporary research by other scientists who are engaged in closely related fields. This review underscores the author's solid grasp of the topic and situates their work within the existing academic landscape.

In the second chapter, the focus shifts to the specific issues pertaining to wall assemblies, where the author identifies and analyzes the key problems associated with them.

The third chapter is dedicated to the numerical modelling of five distinct types of wall assemblies used in Chinese construction practice. Here, the author employs a Multi-Criteria Decision Analysis (MCDA) to evaluate these alternatives and determine the most effective solution.

The fourth chapter presents a detailed economic analysis, including cost-benefit calculations and the payback period for the optimal wall assembly alternative. These calculations are illustrated with practical examples to enhance understanding.

The findings of this research were presented at an international scientific and practical conference, and the key points are summarised in the thesis abstracts.

The execution of the thesis adheres to all required standards and formatting guidelines, ensuring a comprehensive and professional presentation. the textual part of the explanatory note, mainly performed under the standards and in compliance with all requirements.

The thesis's disadvantages include inaccuracies in the design and the fact that only a few dynamic thermal characteristics were taken into account without explaining other's influence. Also, there is a poor connection between the second chapter and the goals of the research. However, these shortcomings do not affect the positive impression of the work.

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

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