博士論文

A THEORETICAL STUDY AND APPLICATION OF SELF-INSULATION EXTERIOR WALL IN THE HOT SUMMER AND COLD WINTER CLIMATE ZONE OF CHINA

中国の夏暑く冬寒い気候地域における外壁保温システムの理論的研究と応用に関する研究

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PREFACE

This thesis presents the selection of exterior wall materials, the calculation analysis method and the technical measures of key joints concerning self-insulation system of exterior wall in the hot summer and cold winter zone of China. And there are many on-site inspections of the pilot project to test the effectiveness of the technical measures. The research results will not only effectively advance the basic theory of the self-insulation system of exterior wall, but also contribute to further development and improvement of the key joint structures, promote the application of the system, enhance energy efficiency of building envelope and provide a theoretical basis for the improvement of relevant energy-saving design specifications in the hot summer and cold winter zone of China.

The study of this topic in the thesis started in early 2013, led by Architectural Design & Research Institute of Zhejiang University, and was completed after four years with the cooperation of the Department of Architecture and Civil Engineering of Zhejiang University.

The thesis was written during the time of studying in the Department of Environmental Engineering, University of Kitakyushu. It mainly focuses on the analysis of the mathematical model and the conclusive comparison of the test data. In the meantime, the whole thesis has been carefully examined and corrected by my supervisor Professor GAO Weijun of University of Kitakyushu.

ACKNOWLEDGEMENTS

The thesis writing has come to an end, but the attention paid to and the research conducted on environment and energy are still going on. Concluding the thesis has given me a lot of sureness and satisfaction. Gratitude has to be offered to a lot of people for their involvement and support in my work and study all the time.

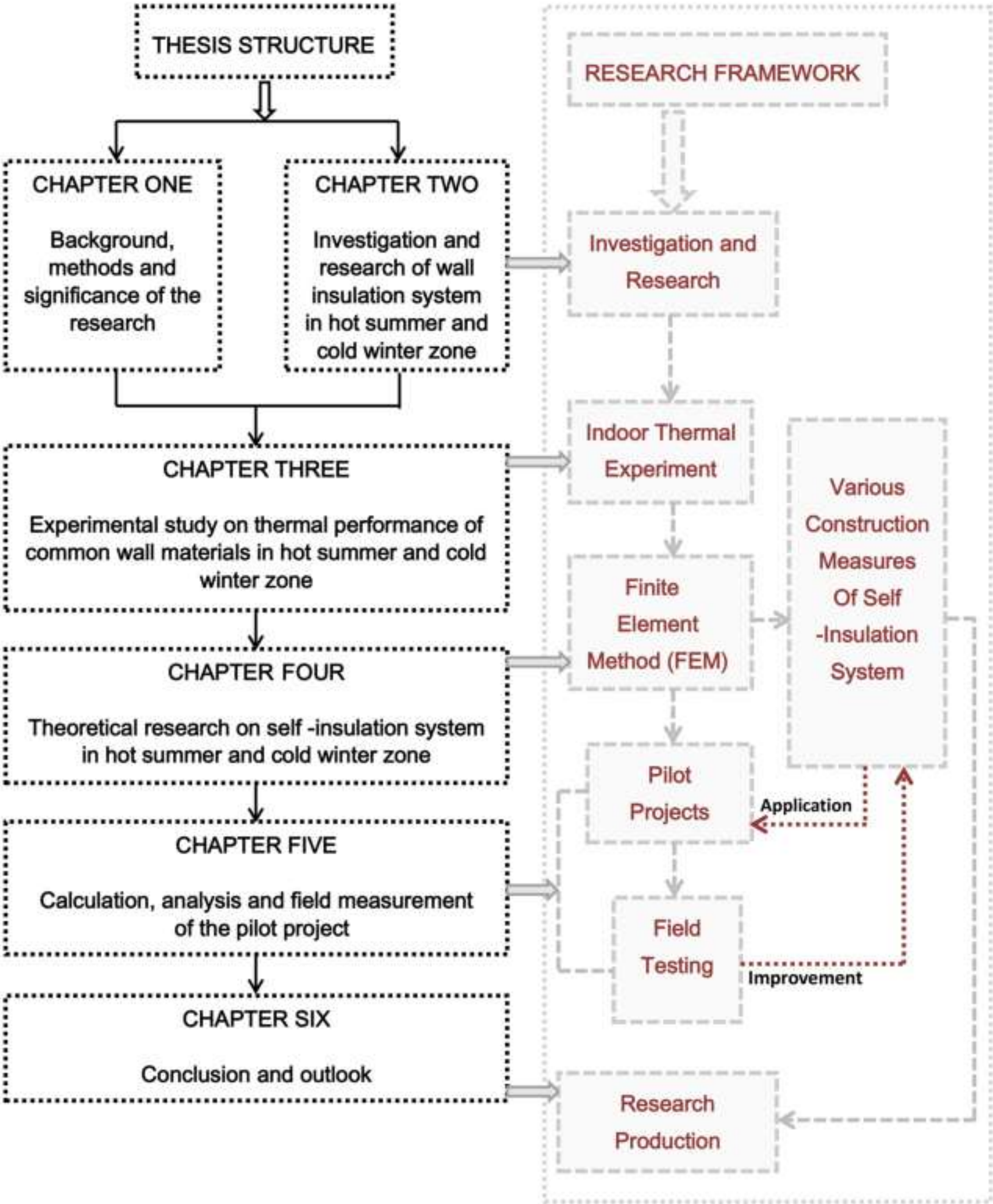
First of all, my sincere appreciation is given to my supervisor Professor GAO Weijun. Having the honor to study under the guidance of Professor GAO in University of Kitakyushu is a crucial opportunity in my life. He gives the best inclusion and edification to my work and studies, helping me with my in-depth research into building energy conservation. His rigorous academic attitude in scientific research and cordial and tolerant way of teaching will be the powerful assistance for me to move on in the field of architecture. I hope that I will live up to his expectations.

I would like to express my heartfelt thanks to the project leader XU Quanbiao, Associate Dean of Architectural Design & Research Institute of Zhejiang University, and Professor ZHANG Sanming of Zhejiang University, for their selfless help in the stage of research. And thanks are extended to all the teachers and colleagues involved in the project.

Thanks also go to the project developers, material manufacturers and construction units of Hangzhou Xixi Xintiandi for their technical support given to this topic.

Finally, warm thanks are given to my husband, children and parents whose selfless dedication and tolerance have given me great strength.

THESIS STRUCTURE AND RESEARCH FRAMWORK



A Theoretical Study and Technical Practice of Self-Insulation Exterior Wall In the Hot Summer and Cold Winter Climate Zone of China

ABSTRACT

The heat insulation performance of building envelope and the airtightness of doors and windows are major internal factors that affect building energy consumption. Of all heat loss, the heat transfer loss of envelope accounts for 70% – 80%, while the heat loss through air infiltration in gaps of doors and windows takes up 20% – 30%. Therefore, the most important part of building energy conservation technology should be the reform of walls and the development of energy efficient walls. However, for a long time, most building walls in China have been constructed merely with concrete or ordinary blocks, both of which have low heat insulation performance. Their thermal performance cannot meet the requirements of relevant energy-saving targets and regulations and there are many problems in relation to durability and fire resistance. Therefore, new technology and products of insulation system of exterior envelope have become major issues to be concerned in the development of building energy efficiency technology. Conducted under collective efforts of designers, researchers, developers, producers of new materials of walls and builders, the study of the thesis is aimed at various problems existing in the wall insulation system of China, and has revealed the basic principles of self-insulation system of the walls in the hot summer and cold winter zone through investigation, theoretical analysis, experimental research and field testing of the pilot project. Based on the results of theoretical analysis and indoor thermal experiments, the selection of self-insulation wall materials to be used in the hot summer and cold winter zone, methods of computational analysis and technical measures of key joints of self-insulation system were proposed and later applied to the pilot project. Finally, the effectiveness of the technical measures was examined through field testing of the pilot project.

The results of the study of the thesis are useful in the exploration of the basic theory of self-insulation system of the walls in the hot summer and cold winter zone and the further development and improvement of key joint construction of the system, which not only plays an important role in the application and popularization of the system in the zone as well as the energy-saving function of building envelope, but also provides a theoretical basis for the perfection of relevant energy efficiency design standards in China. The research contents mainly include the following aspects:

1) The enhancement of the materials' thermal performance. To further enhance the thermal performance of current self-insulation materials in terms of the coefficient of thermal conductivity and the coefficient of thermal storage, and to meet the requirement that the heat resistance of standard wall saves 50% to 65% of the energy.

2) The improvement of the materials' structural performance. The low density of self-insulation materials results in the low strength and high degree of water absorption, which both directly affect the application range and service life of materials. Through improvement of the materials' structural performance, the problems existing in the practical application of self-insulation system could be truly

solved.

3) The proposal of self-insulation-system key joints to develop new type of self-insulation wall materials. Meanwhile, the continuous improvement of self-insulation system of exterior envelope is helpful in accelerating the realization of new standards on building energy efficiency.

4) The computational analysis and field testing of the pilot project. Through comparative analysis of the testing results of the pilot project in three different structures of self-insulation walls, it is found that the best energy-saving effect is attributed to the self-insulation system whose main structure uses autoclaved sand aerated concrete blocks and thermal bridge uses autoclaved sand aerated concrete insulation boards.

To sum up, according to the market quotation and the project cost in Zhejiang Province, the economic performances of various wall insulation systems are compared, including internal insulation system, external insulation system and three types of self-insulation system which are the emphasis of this project. The results show that self-insulation system not only has high energy efficiency, but also has better comprehensive economic performance than internal insulation system and external insulation system. Therefore, self-insulation system of wall shall be applied and popularized with great efforts in the hot summer and cold winter zone.

CHAPTER COMPOSITION:

Chapter One: Introduction. The first chapter is introduction, in which the project origin, research background and research method are introduced, and the practical significance of major research findings is summarized.

Chapter Two: Investigation of wall insulation systems in the hot summer and cold winter zone. The second chapter provides a realistic basis for the whole dissertation. It mainly expounds the investigation findings of self-insulation wall in the hot summer and cold winter zone, including the development history and current situation of wall insulation systems at home and abroad, and limitations and future development of self-insulation wall in the hot summer and cold winter zone.

Chapter Three: Experimental research on thermal performance of common wall materials in the hot summer and cold winter zone. The third chapter elaborates the experiments on the thermal performance of common wall materials in the hot summer and cold winter zone, including experiment object, objective, basis, instrument and method. Key research objects are sintered shale hollow block, autoclaved sand aerated concrete block, sintered shale brick, sintered gangue brick, sintered insulation brick and compound perforated concrete brick. Their performance, advantages and disadvantages are studied in detail by the finite element method in respect to the interaction among porosity, apparent density, mechanical performance and thermal performance.

Chapter Four: Theoretical research on self-insulation system in the hot summer and cold winter zone. The fourth chapter provides systematic analysis of and the study on the theory and numerical computation of self-insulation system in the hot summer and cold winter zone to clarify the basic principles of heat transfer (e.g. heat shielding and insulation) in the self-insulation wall. Also, computational analysis of energy efficiency of different types of self-insulation buildings in the zone is

conducted by changing different parameters, in order to work out the most important factor affecting self-insulation building. Besides, the most effective measures to be adopted in self-insulation wall in the zone are found out through comparative analysis of different structures of key points (e.g. thermal bridge).

Chapter Five: Calculation, analysis and field measurement of the pilot project. The fifth chapter identifies three most economical and effective key compositions of self-insulation wall in Hangzhou on the basis of the above research findings. In order to test their practical energy-saving effects, the pilot project was carried out in A1~A8# buildings in Cluster A of Xixi Xintiandi Estate, Hangzhou, and the effectiveness of technologies applied in the three key compositions was examined through computational analysis and field testing.

Chapter Six: Conclusion and outlook. The sixth chapter concludes the whole dissertation. Based on the results of the longitudinal study in the previous chapters, the future direction and development goal of self-insulation wall in the hot summer and cold winter zone under the new situation are summarized.

Keywords: exterior envelope, self-insulation system, thermal performance, mechanical performance, key joint, economic performance

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CHAPTER ONE: INTRODUCTION

1. INTRODUCTION

1.1 Origin of the Research Project

Self-insulation wall refers to the wall which can reach the national standard of energy saving calculation with only outer wall masonry materials and without additional insulation layer.

To address the key issues of self-insulation wall in the hot summer and cold winter zone, a scientific research project of *A Theoretical Study and Practical Test of Self-Insulation System in the Hot Summer and Cold Winter Zone* has been carried out by Hangzhou Economic Committee, Hangzhou Municipal Finance Bureau, Hangzhou Construction Committee and Hangzhou Leading Group Office on Reform of Walls, with emphasis on the basic principles of self-insulation system in the hot summer and cold winter zone, selection of self-insulation walls, calculation methods of the energy saved by self-insulation system and key joint technology. Meanwhile, relevant pilot projects were conducted, and a set of technologies, which are safe, reliable, advanced, economical, reasonable and convenient for construction, has been developed for the self-insulation system in the hot summer and cold winter zone of China.

This study was aimed at various problems existing in the wall insulation system of China, and has revealed the basic principles of self-insulation system of the walls in the hot summer and cold winter zone through investigation, theoretical analysis, experimental research and field testing of the pilot project. Based on the results of theoretical analysis and indoor thermal experiments, the selection of self-insulation wall materials, methods of computational analysis and technical measures of key joints of self-insulation system were proposed and later applied to the pilot project. Finally, the effectiveness of the technical measures was examined through field testing of the pilot project. The results of this project are useful in the exploration of the basic theory of self-insulation system of the walls in the hot summer and cold winter zone and the further development and improvement of key joint construction of the system, which not only plays an important role in the application and popularization of the system in the zone as well as the energy-saving function of building envelope, but also provides a theoretical basis for the perfection of relevant energy efficiency design standards in China.

1.2 Research Background

1.2.1 Composition of Energy Consumption by Building Heat Loss

With the rapid development of national economy, the energy consumption in China has become increasingly higher, most of which was consumed by buildings. The energy consumption of building and envelope production has accounted for more than 30% of the total energy consumption of China and is likely to continue to increase. The Chinese government has been paying more and more attention to building energy efficiency, which has become a national policy since it was proposed in *Report to the 17th National Congress of the Communist Party of China* to "promote a conservation culture by basically forming an energy- and resource-efficient and environment-friendly structure of industries, pattern of growth and mode of consumption". Since 2005, related departments have launched a series of policies, regulations, rules and technical standards, imposed new requirements for building energy efficiency and carried out the overall energy-saving work of buildings, which make building energy efficiency a crucial research project in China's construction industry in the 21st century.

Major internal factors that affect building energy consumption are the heat insulation performance of building envelope and the airtightness of doors and windows. The heat transfer loss of envelope accounts for 70% – 80% of total loss, while the heat loss through air infiltration in gaps of doors and windows takes up 20% – 30%. As the building wall is dominant in the exterior envelope, the reform of walls and the development of wall energy efficiency technology constitute the most important part of building energy efficiency technology.

1.2.2 Current Situation of Wall Insulation System of Exterior Envelope in the Hot Summer and Cold Winter Zone

The heat insulation performance of building envelope is a major internal factor affecting building energy consumption, and the improvement of the heat insulation performance of exterior walls is an important measure for the realization of building energy-saving targets. However, the heat insulation requirement for exterior wall varies by climate. The main requirement in northern China is heat insulation while it is heat shielding in southern China. The hot summer and cold winter zone is a climate zone of China, belonging to the warm climatic region which is the transient region of subtropical climate and temperate climate. It is on the south of Longhai Line, the north of Nanling Mountains and the east of Sichuan Basin, roughly covering the middle and lower reaches of Yangtze river and consisting of 16 provinces, cities and municipalities. With a population of 550 million and approximately 48% of gross domestic product, it is the most populous as well as an economically and culturally developed region. The zone features a hot summer with intense solar radiation and an average temperature between 25℃ and 30℃ in the hottest month, and a cold winter with an average temperature between 2℃ and 7℃ in the coldest month. Besides, high humidity all over the year and relatively poor natural conditions are also characteristics of the zone. The whole province of Zhejiang is located in the hot summer and cold winter zone.

Thermal process of building is an unsteady heat transfer process under the impact of external integrated temperature. During the day of summer, the exterior envelope is warmed by solar radiation and transfers heat to the indoor space, while at night it dissipates the heat, which means that the heat transfer between interior and exterior surfaces of the envelope changes direction according to the alternation of day and night. In winter, however, the heat is mainly transferred to the outdoor space through the exterior envelope. The energy efficiency technology of walls always adapts to the climatic conditions, and therefore the application of the technology must suit local conditions. The focus of energy efficiency of exterior wall in the hot summer and cold winter zone should be to address the issues of heat shielding in summer and heat insulation in winter.

Currently in the hot summer and cold winter zone, mainly two systems are adopted for exterior wall insulation, namely internal insulation system of exterior wall and external insulation system of exterior wall. For the former system, the insulating layer lies in the internal side of the exterior wall, and is mainly made of the following types of materials: polystyrene insulation board compounded with reinforced gypsum, polystyrene insulation board compounded with polymer mortar, polystyrene insulation board compounded with reinforced cement, polystyrene board pasted by plastering anhydrite, and polystyrene thermal mortar combined with anti-crack mortar and gridding cloth. The internal insulation system is usually constructed in dry conditions in order to accelerate construction progress and improve production efficiency, and has the following advantages:

(1) It has low requirements for technical indicators such as the water and weather resistance for decoration and insulation materials, resulting in the convenience in obtaining materials and low costs due to no need of special protection.

(2) As the internal insulation materials are separated by floors, the construction is only conducted in one floor with no need of scaffold and thus becomes fast and easy.

(3) It can be warmed up or cooled down quickly, and therefore fits the rooms where intermittent heating is adopted, such as movie theater and gymnasium.

However, after many years of engineering practice, some disadvantages are exposed in the following aspects:

(1) As the system acts on the interior wall of the building and the internal side of beam and column, the exterior wall cannot be protected by the insulation materials, which makes the heat transfer there very fast. Under such circumstance, thermal bridge is easily formed there and causes condensation. The impregnation and freeze thawing of condensation water can easily give rise to the mildew and crack of the insulation wall (Figure 1.1).

(2) Affected by the climate, the diurnal and annual temperature ranges on the exterior wall and on the surface of the room are relatively large, which has a direct impact on the stress of the internal wall surface and makes it easy for the exterior wall to be disrupted by thermal stress as well as easy for the hollowing and cracking of the insulation system to occur.

(3) Internal insulation reduces the effective indoor area.

(4) Secondary interior finishing and ornament hanging will cause damage to the original insulating layer (Figure 1.2), and affect the insulation and energy-saving performance.

(5) The reconstruction of buildings for energy efficiency will disturb the daily life of the residents.

Figure 1.1 Mildew caused by condensation of thermal bridge

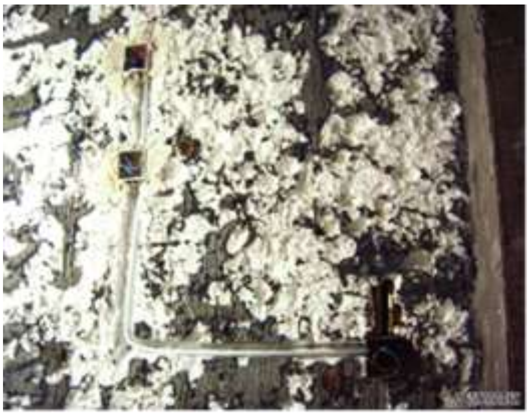


Figure 1.2 Damage to the internal insulation materials caused by interior finishing

Due to the drawbacks of the technology, the internal insulation system of exterior wall has been gradually replaced by the external insulation system of exterior wall, where the insulating layer lies in the external side of the exterior wall. Currently the system mainly adopts the following methods:

(1) Out-hung external insulation system, in which the insulation materials are mainly hung and pasted on the exterior wall by binding mortar or special fitment. Then anti-crack mortar is smeared for fiberglass mesh to be pressed on to form a protection layer, and finally a decorative surface is made. Common insulation materials include rock wool, grass cotton felt, polystyrene foam board (EPS、XPS), polystyrene insulation board compounded with ceramic concrete and decorated with imitation stone, steel mesh sandwich wall panel and phenolic foam board.

(2) One-stroke concreting of polystyrene board to form the external insulation system. The polystyrene board is placed inside the building template and outside the wall, and then the system is formed at one stroke by concreting of the board.

(3) External insulation system constructed by organic thermal mortar (e.g. polystyrene granule) or

inorganic thermal mortar (e.g. vitrified small ball, hole-closed expanded perlite)

(4) Polyurethane insulation system, which is formed by directly spraying polyurethane insulation materials on the base of the exterior wall.

The external insulation system of exterior wall mainly has the following advantages:

(1) It protects the main structure and extends the service life of a building. As the insulating layer lies on the external side of a building envelope, it decreases the stress produced by structure malformation under temperature change, reduces the erosion of the envelope by noxious gas and ultraviolet ray, and avoids damage to the main structure caused by rain, snow, freeze thawing and drying and watering cycle.

(2) It reduces the occurrence of thermal bridge, improves the thermal performance of wall and saves energy. Set at the external side of the exterior wall, the insulating layer can effectively block the thermal bridge formed in beam and column, reduces heat loss, enhances the integrity and effectiveness of exterior wall insulation, and effectively prevent condensation in the thermal bridge.

(3) It is conducive to the stability of indoor temperature and the improvement of environmental amenity. As the structural materials with greater thermal storage are placed at the indoor side, the indoor temperature change caused by solar radiation and intermittent heating is slowed down. Also, when instable thermal effect takes place in the indoor space, the structural materials of the wall can absorb or release heat and to some extent adjust the indoor temperature, so as to enhance the thermal stability of the room and obtain a comfortable thermal environment.

(4) It has a wide range of applicability. The external insulation system can meet the insulation requirements of different climatic regions and various building forms, not only applicable to newly-built projects, but also convenient for the reconstruction of existing buildings. Moreover, the reconstruction could be accomplished without entering the room and will thus not affect the daily life of the residents.

(5) It avoids the damage to the insulating layer during the finishing.

(6) It increases the usable area of a building. The external insulation system has better effect than the internal insulation system with the same insulation materials. The thickness of the wall could be reduced and the insulating layer, which is outside the wall, does not occupy the indoor space.

However, after the engineering practice in recent years, some disadvantages of the external insulation system of exterior wall have been exposed:

(1) High composite cost and construction difficulty. The external insulation system involves the joint work of various materials under complex temperature and humidity conditions, which results in large quantity of wet construction and complex construction technology.

(2) Difficulty in quality control and monitoring. The system has poor weather resistance and impact resistance, especially in the hot summer and cold winter zone where an exterior wall has dual pressure of heat shielding in summer and heat insulation in winter. Moreover, the long rainy season and great seasonal temperature range in the zone often result in cracking, hollowing, water seepage and falling of brick surface (Figure 1.3) of the insulation surface. In particular, the safety of the external insulation system with face brick outside the wall cannot be guaranteed.

The system has poor fire resistance. In recent years, external insulation materials have caused fire disasters in many places, including teachers' apartment at Jiaozhou Road of Shanghai (Figure 1.4), TV Cultural Center at the new CCTV site in Beijing (Figure 1.5), Jinan Olympic Sports Center, Nanjing Central International Plaza (Figure 1.6), Shenyang Royal Wan Xin International Mansion and Harbin Jinwei twin skyscrapers. These fire disasters caused great casualties and property damage, produced adverse social impact, and deepened people's worries about the safety of external insulation system in terms of fire resistance.

The insulation system's durability does not conform to the service life of the building to which it applied. Both external and internal systems have a target service life of approximately 25 years, while the service life of a building is always 50 years or more. How to dispose the systems after they reach their service life is a problem waiting to be solved.

Figure 1.3 The falling of brick surface outside the external insulation system

Figure 1.4 Fire disaster at teachers' apartment at Jiaozhou Road, Shanghai

Figure 1.5 Fire disaster at TV Cultural Center at the new CCTV site, Beijing

Figure 1.6 Fire disaster at Nanjing Central International Plaza

Therefore, it is urgent and essential to study and popularize the exterior wall insulation system which is more suitable for the hot summer and cold winter zone. Systematic research is in urgent need in order to find a new type of exterior wall insulation system which is safer, more reliable, advanced, economical, reasonable and convenient for construction. In this way, both safety and durability problems can be solved to make the service life of the system same as that of the building and to lay a foundation for the second target of saving 65% of the building energy.

1.3 Research Objective and Significance

1.3.1 Limitations of the Original Self-Insulation Exterior Wall

Self-insulation exterior wall refers to the insulation system of exterior wall which is made mainly of single materials and has good insulation performance and additive insulation measures at the concrete thermal bridge. Compared with compound insulation systems such as internal insulation system of exterior wall and external insulation system of exterior wall, the self-insulation exterior wall, especially those made of sustainable materials, has many advantages: high operability, convenience of construction, low composite cost, high quality, good weather resistance, fire resistance, durability and impact resistance, and service life as long as the building's. In recent years, it has won increasing attention in the hot summer and cold winter zone of China. The comparison of advantages and disadvantages among the three insulation systems is shown in Table 1.

Table 1 Comparison of advantages and disadvantages of various insulation systems of exterior wall

Insulation System	Durability	Fire resistance	Weather resistance	Economic efficiency	Construction difficulty	Quality Control	Energy-saving effect
Internal insulation system of exterior wall	Poor	Poor	Normal	Poor	Low	Difficult	Poor
External insulation system of exterior wall	Poor	Poor	Poor	Poor	High	Relatively difficult	Relatively good
Self-insulation system of exterior wall	Good	Good	Good	Good	Relatively low	Easy	Good

The construction of self-insulation wall requires comprehensive consideration of the building's shape coefficient, orientation and plane form, the enhancement of thermal performance of exterior wall and external doors and windows, the reasonable selection of energy-saving construction of key parts of the thermal bridge, the improvement of insulation performance of roof, floor and raised floor, and the movable external sunshade. Difficulties and key problems which need to be resolved immediately are the selection of self-insulation materials of wall and corresponding energy-saving construction of key parts of the thermal bridge. Currently in China, these materials are mainly used for self-insulation wall: light sand aerated concrete block, aerated concrete panel, hollow shale block, compound insulation block, light aggregate block and mud sintered insulation brick. The construction of thermal bridge of self-insulation wall mainly adopts the following methods:

1) Using gelatine powder polystyrene granule or inorganic thermal mortar;

2) Spraying polyurethane insulation material;

3) Extrusion molding or using expanded polystyrene insulation board;

4) Pasting various self-insulation blocks, such as aerated concrete block, vitrified small ball block and foamed ceramic block.

Currently the systematic theoretical and experimental studies of the self-insulation wall applied in China are still deficient in terms of wall materials and corresponding thermal bridge construction. Many problems arise in the application process, especially in the hot summer and cold winter zone where there are too few pilot projects to popularize the system in a large range. Therefore, it is very necessary to study the self-insulation wall materials and corresponding thermal bridge construction to be applied in the hot summer and cold winter zone, and conduct systematic research on the self-insulation exterior wall through investigation, theoretical analysis, experimental research, specialized design, practice of pilot projects and tracking and monitoring of the whole process. The theoretical study and engineering practice of self-insulation wall of buildings in the hot summer and cold winter zone have important theoretical significance and prospect of engineering application.

1.3.2 The Systematic Study and Its Practical Significance

With people's increasing awareness of environmental protection and sustainable development, the energy-saving work of buildings has been carried out in an all-round way across China, and the research, development, application and popularization of self-insulation wall are facing a golden opportunity. Developing self-insulation wall in the hot summer and cold winter zone will bring enormous economic and social benefits. The results of this study can effectively provide a theoretical basis for the self-insulation wall in the hot summer and cold winter zone, further improve its systematic design theories and engineering technologies, play an important role in the application and popularization of self-insulation wall in the zone, and lay a foundation for the further development of energy-saving work of buildings.

1) The emphasis is to solve the practical problems in the engineering application of self-insulation wall by adopting engineering theories, scientific experiments and engineering practice.

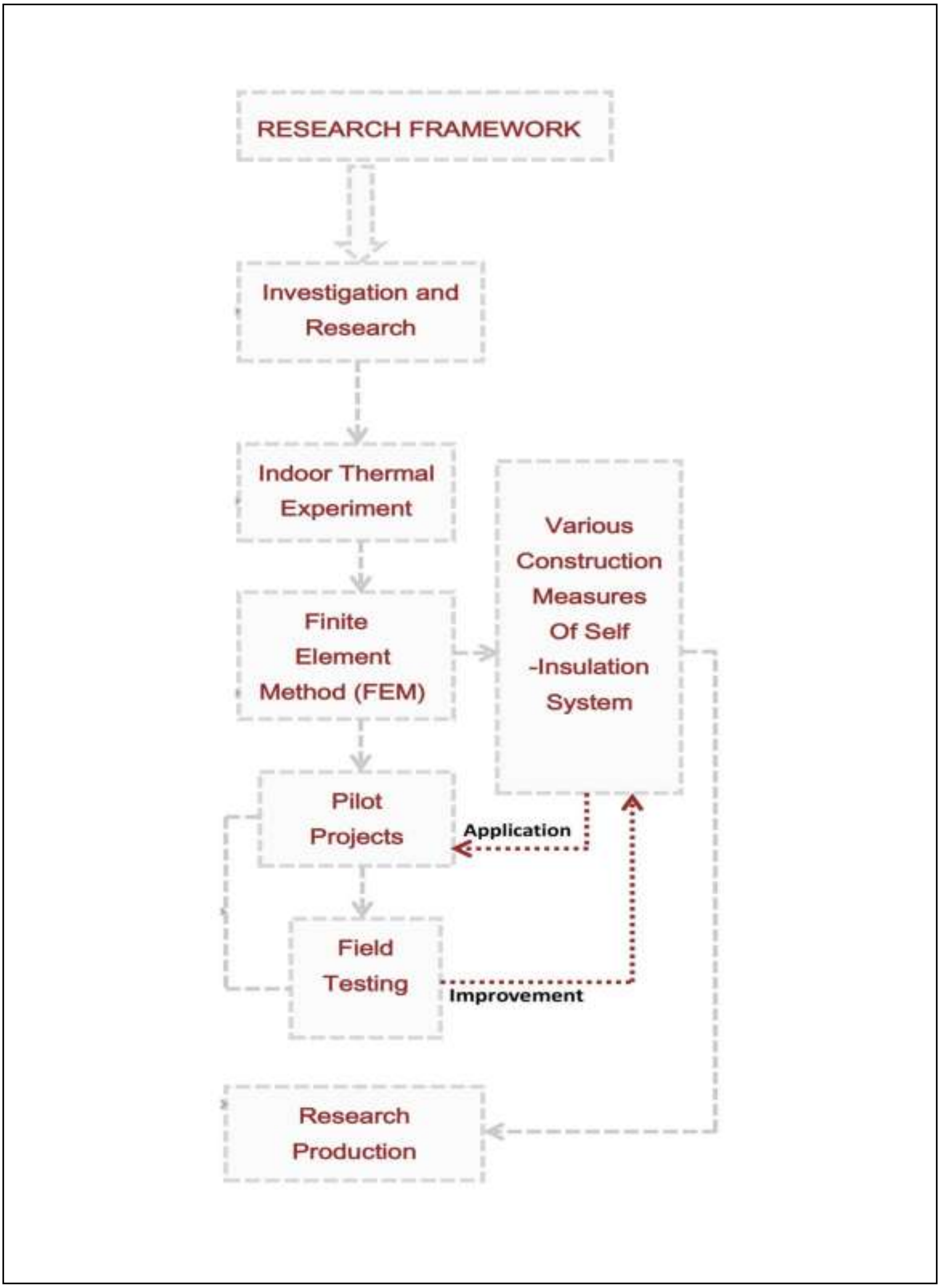
2) Based on the research results and the application in the pilot project, the self-insulation wall should be popularized with great efforts in the hot summer and cold winter zone, especially in Hangzhou, so as to lay a foundation for the further development of energy-saving work of buildings.

1.4 Research Methodology and Framework

1.4.1 Research Framework

This study adopted a comprehensive analysis method, which combines theoretical study, computational numerical analysis, indoor thermal experiments, practice of the pilot project and field testing, and applied a variety of basic theories, including thermodynamics, mathematical equations, building material theory and testing theory. The emphasis was placed on the self-insulation wall in the hot summer and cold winter zone, in order to propose a set of technical measures for the self-insulation wall in the zone (especially in Hangzhou) which are safe, reliable, advanced, economical, reasonable and convenient for construction, and to popularize the self-insulation wall according to the application experience of the pilot project.

The research framework is shown as follows:


RESEARCH FRAMEWORK
Investigation and Research
Indoor Thermal Experiment
Finite Element Method (FEM)
Various Construction Measures Of Self -Insulation System
Pilot Projects
Application
Field Testing
Improvement
Research Production

1.4.2 Research Procedure and Contents

1) Investigation

(1) Extensive collection of domestic and foreign literature and data on self-insulation wall of buildings.

(2) Based on the practical engineering situation, organize experts and personnel to take part in symposiums so as to master the situation of the application of self-insulation wall.

(3) Field investigation of existing self-insulation walls in the hot summer and cold winter zone.

(4) Analyze, generalize and summarize the investigation data to make explicit the common self-insulation wall materials and relevant construction measures.

2) Indoor thermal experiments

Get the basic thermophysical parameters of the common self-insulation wall materials through indoor thermal experiments, judge if they meet the rules and requirements of self-insulation wall materials, and decide on one or two materials which are most suitable for the hot summer and cold winter zone by comprehensive comparison.

3) Theoretical study and computational numerical analysis

(1) Make clear the basic principles of heat insulation of the self-insulation wall through theoretical study.

(2) Conduct research on the computational method of energy efficiency of the self-insulation system.

(3) Conduct comparative analysis on the various construction measures of key joints (e.g. thermal bridge) of self-insulation wall to find effective measures in the hot summer and cold winter zone.

(4) Conduct computational analysis on the energy-saving effects of various self-insulation buildings in the hot summer and cold winter zone and find the most important factor of self-insulation by changing parameters which could affect the energy-saving effect of the self-insulation system.

4) Pilot project and field test

Through the above investigation, indoor thermal experiments, theoretical study and computational numerical analysis, a set of methods and measures on self-insulation wall were proposed aiming at the specific conditions of the hot summer and cold winter zone (especially Hangzhou) and were applied in the pilot project. Field testing was conducted to find out the actual energy-saving effect of the pilot project after the implementation of every measure, which laid a foundation for further improvement, application and popularization of the self-insulation wall. At the same time, analysis of economic performance was conducted on self-insulation systems under different construction measures to find out the most economical and reasonable one.

The project of Xixi Xintiandi constructed by Kunhe Construction Group was chosen as the pilot project. It includes different types of common buildings such as office building, hotel, supermarket and serviced apartment, and has both multi-storey and high-rise buildings. As it covers a wide range of building types, the project is highly representative.

Figure 1.7 The sketch of the pilot project (Xixi Xintiandi)

1.4.3 Major Research Results

This project conducted research on the self-insulation wall in the hot summer and cold winter zone, referred to the existing domestic and foreign literature and adopted a comprehensive analysis method which combines investigation, computational numerical analysis, experiments and field testing. The major research results of this project are as follows:

1) Based on study of domestic and foreign literature and field investigation of different cities in the hot summer and cold winter zone, the advantages and disadvantages of several self-insulation walls were classified and summarized. At the same time, the common materials of the self-insulation system in the zone and the key joint construction measures of various thermal bridges were also summarized.

2) Based on the indoor thermal experiment of various wall materials, the thermal performances of common wall materials in the zone were compared, and the most suitable material for self-insulation wall in the zone (especially in Hangzhou) was put forward.

3) The basic theories and computational method of energy-saving effect of self-insulation system in the zone were thoroughly studied.

4) A large number of computational analyses were conducted on the self-insulation system which uses different wall materials and different key joint combinations of thermal bridge in different types of buildings, in order to compare the energy-saving effects under different combinations of construction and find out the major factor affecting the energy-saving effect of self-insulation system in different types of buildings. Based on the above computational results, the most suitable construction of

self-insulation system in the zone (especially in Hangzhou) was found out.

5) Based on the control groups decided after investigation, indoor thermal experiments, theoretical analysis and computational analysis, the pilot experimental work of the actual project was conducted. At the same time, field testing of energy-saving effect of the control groups was carried out. Finally, the economic performance of the control groups was compared and analyzed.

6) According to the research findings of this project, picture collections and relevant regulations on the self-insulation system in the zone were made after coordination with related municipal and provincial authorities.

CHAPTER TWO: INVESTIGATION OF WALL INSULATION SYSTEMS IN THE HOT SUMMER AND COLD WINTER ZONE

2. INVESTIGATION OF WALL INSULATION SYSTEMS IN THE HOT SUMMER AND COLD WINTER ZONE

2.1 Investigation Method and Research Procedure

In order to understand the development history, application situation and problems of various insulation systems of walls in the hot summer and cold winter zone, the author did field investigation of buildings with various insulation systems of walls in the zone on the basis of literature review and expert symposium. Considering the research contents of this study, the author placed the emphasis on the self-insulation system of wall. The contents of investigation included building type, selection of insulation system, insulating and energy-saving effect, current service life, problems arising in the process of design, construction and use, local climate and natural environmental conditions. Finally, based on the investigation results, the self-insulation systems of wall were classified and summarized according to major wall material and construction measure of key joints of thermal bridge such as beam and column, and it was confirmed that self-insulation wall is the major development direction of wall insulation systems in the hot summer and cold winter zone today.

2.2 Development History and Current Situation of Insulation System of Wall in China and in the World

Insulation technology of exterior wall originated in Europe in the 1940s, and was first applied in Germany and Sweden. In order to mend the cracks in the buildings damaged during the Second World War, Germans pasted a layer of polystyrene or rock wool board outside the exterior wall of buildings. Later, they found out that it not only covered cracks but also had many other advantages: heat and sound insulation, much higher humid resistance and residential amenity. The U.S. has a relatively short history of exterior wall external insulation technology which was introduced from Europe in the late 1960s and was improved and developed according to local climatic conditions and building characteristics. The rapid development of this technology began after the 1973 Energy Crisis because of the shortage of energy. At the same time, under the promotion of the governments, the market capacity of this technology in Europe and America increased by 15% annually. Currently, the energy-saving efficiency of newly-built buildings at the same latitude in Europe and America is about 2 to 3 times of that in China.

Today in European countries, the widely applied external insulation system of exterior wall is constructed by thin plastered external insulation boards. Two insulation materials, namely flame-retardant expanded polystyrene board and fire-resistant rock wool board, have paint on the exterior surface. The external insulation system of exterior wall and its decoration system have been applied in the U.S. for over 40 years with the highest building of 44 storeys. The application is wide both in the hot south and in the cold north, and has significant effect. In the 40 years of application in Europe and America, a large number of fundamental studies have been conducted on the system, such as the durability of the thin plastered external insulation system, the problem of dew point in cold areas, the reactions of different systems under different impact loads and the correlation between experimental results and performance in practical projects. Based on the large quantity of experimental studies, Europe and America have already carried out strict legislation on external insulation of exterior wall, including compulsory certification standard for the system and the standard for component materials in the system. Because of the perfect, standard and strict legislation, the external insulation system of exterior wall in Europe and America generally has a service life of 25 years. In fact, the history of actual practical history of the system in the areas has greatly exceeded 25 years. In 2000, the European Organization for Technical Approvals (EOTA) issued *External Thermal Insulation Composite Systems with Rendering* (ETAG 004), which is the technical summary of years of successful practice and the standard of external insulation system of exterior wall in Europe.

China's insulation technology of exterior wall originated in the 1980s. Restricted by conditions at that time, it was mainly applied in the internal insulation of exterior wall and in the cold areas of the north at first. In practice, the internal insulation technology had gradually showed its defects in the cold northern areas where there was heating supply, because the large temperature difference inside and outside the room could easily cause problems of condensate water and mildew on the interior wall. At the primary stage of development of energy efficiency technology in China, internal insulation technology played its role in the rapid start of it. This is because at that time the external technology was immature and China's energy-saving standard had low requirements for the insulation of envelope. Also, internal insulation has certain advantages such as low cost and convenient installation. However, from the perspective of development, with the enhancement of China's energy-saving standard, internal insulation no longer suits the new circumstance and can have negative impact on buildings. Therefore, it could only act as a transitional measure in some areas, and should be eliminated in cold areas, especially in extremely cold areas.

The study and application of exterior insulation wall is relatively late in China. Since the early 1990s, China has actively introduced various types of exterior insulation systems and first applied them mainly in large cities in the north. To greatly improve the insulation performance of exterior walls, China has gradually developed the exterior wall external insulation technology based on the study and introduction of advanced foreign technologies, and initially formed a complete set of technologies. At present, China basically keeps pace with other countries in the world in this respect. In recent years, China has successively promulgated some laws, regulations and local standards on building energy conservation. *Energy-Saving Design Standards for Civil Buildings (Heating Residential Building Part)* promulgated in 1995 requested the achievement of the target of saving 50% energy from July 1, 1996. *Energy Conservation Law of the People's Republic of China* was enforced formally on January 1, 1998. The Department of Construction implemented *Construction of Building with Exterior Wall External Insulation (One)* 02J121-1 on September 1, 2002. *Energy-Saving Design Standards for Civil Buildings in the Hot Summer and Warm Winter Zone* was put into effect on October 1, 2003. In 2004, some large cities such as Beijing and Tianjin took the lead in implementing the standard of saving 65% energy. On March 1, 2005, *Regulations on Engineering Technology of Exterior Wall External Insulation* JGJ-144 was implemented. In 2005, the governments of Jiangsu, Fujian, Wuhan and Changsha successively put forward standards and policies on building energy conservation, and many places in China began to construct “pilot project of energy-saving building”. On July 1, 2005, *Energy-Saving Standards for Public Buildings* was formally implemented. On January 1, 2006, the Department of Construction put *Regulations on Energy Conservation Management of Civil Buildings* into effect, requesting that newly-built civil buildings reach the standards. In March, 2006, *Report on the Work of the Government* proposed the target of 8% economic growth and 4% energy conservation, which has been the first time since the founding of the nation. Besides, a large number of technical regulations and standards on exterior wall external insulation have been successively implemented by the Department of Construction of various provinces, which greatly promoted the development of the market of exterior wall external insulation. The gradual application and popularization of exterior wall insulation in southern China basically began in 2003. The Twelfth Five-year Plan of China considered energy conservation as an emphasis in work. Building energy conservation, as an important part of it, can definitely promote the vigorous development of exterior wall insulation industry.

Before the 1980s, the development of insulation materials in China was very slow. There were very few insulation material factories which were only able to produce a small number of expanded perlites, expanded vermiculites, slag wools, extra-fine glass wools and microporous calcium silicate, which could not meet the requirements of national construction in terms of product type, standard and quality and fell 30 years behind the foreign advanced technology. For example, before the 1980s, only three factories in China produced slag wool with annual production of less than 10000 tons, and could only produce a single type of loose wool. Also, the number of calcium silicate insulation material producers was three, and their annual production was approximately 8000 m^3. In recent three decades, the development of new type of wall insulation materials in China has been rapid, and it is currently in large scale. Since 2001, China has further promoted the elimination of traditional materials and the popularization of new wall insulation materials, and the range of popularization has been extended to small cities, towns and rural areas as well as to industrial buildings.

At present, China has developed a production and technology system of insulation materials which has a relatively complete variety of materials and forms its initial shape. The gross domestic production of insulation materials is approximately 800,000 tons, consisting of 200,000 tons of mineral rock wool, 40,000 tons of glass wool, 50,000 tons of foamed plastics, 6,000,000 m^3 of expanded perlite (approximately 450,000 tons) and six tons of other materials. Currently wall insulation materials can be classified into organic type (polystyrene board, extruded board, rigid foam polyurethane, polycarbonate, phenolic aldehyde, etc.), inorganic type (water-repellent rock wool, glass wool, inorganic thermal mortar, foam glass, expanded perlite, foamed concrete, microporous calcium silicate board, vitrified small ball, autoclaved aerated concrete insulation board, ceramic fiber, etc.) and compound type (e.g. metal sandwich panel compounded with polystyrene, vitrified small ball and polystyrene granule). Organic materials basically belong to Class B insulation materials and inorganic materials Class A. However, there is still a great gap between the insulation materials of China and those of industrially developed countries, which is mainly showed in two aspects. The first includes the level of production technique and management, which still needs to be improved, and the unstable quality of products. The second is the insufficient scientific research input which retards applied technology research and product development, especially that of insulation materials in buildings, and this has greatly affected the healthy development of insulation material industry. For the development of wall insulation technology, it is an urgent task to promote the work concerning the design, construction and application of new types of insulation materials and other building materials.

In short, after 20 years of research and nearly 10 years of large-scale application, China has formed applied technology standards and regulations for a complete variety of wall insulation technologies. Each type of insulation system has a large quantity of project examples and increasingly mature applied technology. Many well-known foreign corporations in the insulation industry have set up research, development and production bases or branch corporations in China, such as Saint-Gobain, Sto and Owens Corning. At the same time, a great number of large domestic corporations, which are innovative and aim to popularize the technology of exterior wall external insulation (e.g. Jiangsu NIGAO and Beijing Zhenli), come on stage.

2.3 Investigation of Wall Insulation System in the Hot Summer and Cold Winter Zone of China

The hot summer and cold winter zone is a climate zone of China, belonging to the warm climatic region, which is the transient region of subtropical climate and temperate climate. It is on the south of Longhai Line, the north of Nanling Mountains and the east of Sichuan Basin, roughly covers the middle and lower reaches of Yangtze river, and consists of 16 provinces, cities and municipalities, including two municipalities of Shanghai and Chongqing, the whole province of Hubei, Hunan, Jiangxi, Anhui and Zhejiang, eastern Sichuan and Guizhou, southern Jiangsu and Henan, northern Fujian, the south end of Shaanxi and Gansu and the north end of Guangdong and Guangxi. The zone covers an area of 1,800,000 m^2, where locates three large urban agglomerations centering Shanghai, Wuhan and Chongqing. With a population of 550 million and approximately 48% of gross domestic product, it is the most populous as well as an economically and culturally developed region. The zone features a hot summer with intense solar radiation and an average temperature between 25℃ and 30℃ in the hottest month, and a cold winter with an average temperature between 2℃ and 7℃ in the coldest month. Besides, high humidity all over the year and relatively poor natural conditions are also characteristics of the zone.

The requirements for heat insulation of exterior wall vary greatly by climatic conditions. The focus of energy efficiency of exterior wall in the hot summer and cold winter zone should be to address the issues of heat shielding in summer and at the same time take into account heat insulation in winter and dehumidification in transition seasons. With small coefficient of heat transfer and large heat transfer resistance, the external insulation of exterior wall has relatively good performance in heat shielding. However, it always has poor performance in heat insulation because the light weight and low thermal stability make it easy to be affected by solar radiation and temperature variation between indoor and outdoor spaces which results in the rise of interior surface temperature. Self-insulation wall usually has large thermal inertia index, high attenuation value and long delay time, which guarantee its good insulation performance. Therefore, it is a relatively ideal form of envelope wall in the energy efficiency building in the hot summer and cold winter zone.

To explore the practical application situations of wall insulation system in the hot summer and cold winter zone of China, the author carried out investigations in major provinces and cities in the zone, including Jiangsu, Shanghai, Wuhan, Chongqing, Chengdu and Hangzhou. As the focus of this research project is self-insulation wall, the emphasis of the investigation was also placed on it. The field investigations of representative projects are summarized as follows.

2.3.1 Jiangsu Province

Jiangsu Province is located in the center of eastern coastal region of China, with longitude ranging from 116°18’ – 121°57’E and latitude 30°45’ – 35°20’N. It lies across both banks of the lower reaches of the Yangtze River and has a coastal line of nearly 1,000 kilometers. It is on the west of the Yellow Sea, the southeast of Anhui Province and Shandong Province and the northwest of Zhejiang Province and Shanghai. Situated in the beautiful and fertile Yangtze River delta, Jiangsu features flat terrain, vast plain, low hills and no high mountains, numerous lakes, dense water network and adjacency to the sea. Low mountains and hills only locate in its north and southwest ends where the terrain is relatively high, while the rest areas are all plains, constituted by the Huanghuai Plain, the Jianghuai Plain, the Coastal Plain and the Yangtze River delta from north to south. The province is located in the transient region of subtropical climate and warm climate, and the climate across the whole province shows obvious characteristics of monsoon climate. Divided by the line of Huaihe River - General Irrigation Canal, the climate is subtropical humid monsoon climate in the south and warm temperate humid monsoon climate in the north. The whole province features a mild climate, moderate rainfall and four distinctive seasons.

Most areas in Jiangsu belong to the hot summer and cold winter zone. The Department of Construction of Jiangsu attaches great importance to the application and popularization of self-insulation wall, held a seminar themed “Self-Insulation Wall of Energy-Saving Buildings in Jiangsu” in Nantong in late April, 2008, and compiled a collection of materials of the same topic. In the same year, the Department put forward “Notice on the Promotion of Application and Popularization of Self-Insulation Wall in Energy-Saving Buildings”, requesting local governments in the province to make relevant policies according to local conditions and encouraging and supporting research, development, application and popularization of self-insulation wall.

According to relevant documents, the Department of Construction of Jiangsu called for the enhancement of application and popularization of self-insulation wall in energy-saving buildings, the strengthening of design and censorship of building energy conservation, and the priority of self-insulation system in the dwelling structure selection and work orientation. Second, the Department requested local government to give priority to the development of non-sintered products and compound self-insulation technology in combination with local resources and new requirements for walls that solid and sticky materials be forbidden, so as to achieve the goals of standard technology, identified product and designated production. Third, the cooperation with universities, research institutes and enterprises should be strengthened for the multi-approach solution to scientific and technological problems, the development of diversified self-insulation technologies with local characteristics, the gradual improvement of production equipment, production technique and testing method, the continuous enrichment of self-insulation system of energy-saving buildings and the promotion of research on technologies of masonry mortar and thermal bridge. At the same time, as for new problems arising in the process of application and popularization such as great performance difference of products by different factories, uneven product quality and lack of technical bases for project construction and quality supervision, the Department asked local governments to make and perfect application standards for energy-saving self-insulation wall, compile picture collection of energy-saving self-insulation wall and guide the work of design, check of drawings, construction, testing, supervision and acceptance. Recently, *Regulations on Applied Technology of Autoclaved Aerated Concrete Block Self-Insulation System* edited by Suzhou Wall Reform Office has been published. Meanwhile, the Department strengthened the standardized management of technology of self-insulation wall, and initiated the assessment of self-insulation technology (system), stipulating that materials without approval or demonstration by the Department cannot be used in constructions. Besides, the Department further improved the management measures in every step, including design, check of drawings, construction, testing, supervision and acceptance, in order to reduce quality problems. Local resources should be fully used and reasonably arranged to support the development of local enterprises which work on self-insulation wall of energy-saving buildings, and to establish industrial base for the research, development and production of self-insulation wall. The Department considered the application of self-insulation wall as an important factor in awarding energy-saving building, green building, excellent design and high-quality project. In addition, the Department would provide on an irregular basis the directory of self-insulation technologies of energy-saving building wall which are applied and popularized in various areas. In 2008 and 2009, the provincial special fund of building energy conservation respectively listed 21 and 18 projects which adopt the self-insulation technology of wall, in order to encourage and guide the application and popularization of the technology.

Under the promotion of the Department of Construction and after recent years' development and application, self-insulation materials and technologies already have their scale and occupy certain market. Currently, the self-insulation wall materials and technologies applied in Jiangsu can be classified into three categories: sintered type, non-sintered type and compound type.

1) Sintered self-insulation materials include mud sintered brick, shale tailing modular brick and so on. Mud sintered brick is made mainly of the mud from rivers, lakes and sewage disposal plants, and is sintered with large quantities of usable industrial solid waste and special admixture. The raw materials are widely distributed in Jiangsu and have advantages of saving energy and soil and making use of wastes. Therefore, mud sintered brick is applied and popularized in many cities of Jiangsu. Shale tailing modular brick is a type of energy-saving load-bearing brick with high hole density. It is made mainly of

shale tailings by high-vacuum extrusion forming and high-temperature roasting with no need of clay. Its advantages are reasonable design of brick shape and convenience for construction. However, due to the geographical limitation of the raw materials, its current output is limited.

2) Non-sintered materials include autoclaved sand (pulverized coal dust) aerated concrete block (board), ceramic aerated concrete block, compound insulation block and so on. Autoclaved sand (pulverized coal dust) aerated concrete block (board) is mainly made of cement, lime, pulverized coal dust and quartz sand by cast molding and autoclaving. It has advantages of light weight, heat resistance, heat insulation, fire resistance, sound insulation, no leakage and good machinability, and is widely applied in non-bearing envelope and internal parting wall. Ceramic aerated concrete block is made by adding ceramic granule to pulverized coal dust aerated concrete block. Compared with aerated concrete, it has advantages of low shrinkage and high strength. Compound insulation block is a kind of energy-saving hollow block made by embedding light insulation materials into the heat transfer tunnel of hollow brick. The block's strength and heat transfer coefficient could be adjusted according to block thickness, hole pattern and component material.

3) Compound self-insulation system refers to the compound envelope structure by adding insulation construction in the middle of the wall. The envelope or loading structure is usually formed by on-site assembly or installation and monolithic casting of prefabricated parts. Its advantages include good insulation performance, high degree of industrialization and fast and easy construction, which are beneficial for large-scale application and popularization.

4) Expanded and vitrified small ball self-insulation system is constituted by insulation block, masonry thermal mortar and thermal non-removal board. The main raw materials include expanded and vitrified small ball, inorganic cementitious material, pulverized coal dust, construction sand and relevant additives. They are compounded according to certain proportion and then appropriately cured to form the system, which has the main body constituted by insulation blocks and wall filled with expanded and vitrified small balls and thermal mortar. Then, non-removal insulation board made of expanded and vitrified small balls is used as side form of concrete component to conduct thermal bridge treatment, after which the self-insulation wall can be formed and used as self-insulation system of non-bearing structure of energy-saving building. The expanded and vitrified small ball self-insulation system features energy efficiency, long durability, fire resistance and light weight, and has significant social and economic benefits.

The mud sintered brick self-insulation technology jointly developed by Jiangsu Institute of Architecture Science and Nantong Development and Promotion Center for New Construction Technology draws on local resources and is economical and applicable, especially for the hot summer and cold winter zone. Therefore, it is listed as a key recommended project of Jiangsu building technology. This technology won a prize at the first “National Innovation Award for Green Architecture” held by the Ministry of Construction. Currently, the ongoing and accomplished projects adopting this technology have covered an area of over 5,000,000 m^2. A typical example is Chenduxinyuan housing estate in Changzhou (Figure 2.1), a national comfortable housing project initiated by Changzhou

Development Center for economically affordable housing.

There are certain reserves of shale in Nanjing, where shale brick is a non-clay energy-saving wall material popularized by local government. The multilayer exterior wall with brick-concrete structure of buildings in the national comfortable housing project of Nanjing Jufuyuan housing estate was made of loading shale modular perforated bricks which have good thermal performance. Shale brick conforms to the construction module, reduces losses during the construction, improves working efficiency and compensates for normal perforated brick’s disadvantages of low void ratio and poor thermal performance, which can meet the requirements for building energy conservation in the hot summer and cold winter zone and improve the comfortableness of residential buildings. Nanjing Jufuyuan housing estate (Figure 2.2) won the second prize of “National Innovation Award for Green Architecture” held by the Ministry of Construction in 2006.

Figure 2.1 Chenduxinyuan housing estate in Changzhou (mud sintered brick)

Figure 2.2 Jufuyuan housing estate in Nanjing (shale modular perforated brick)

The expanded vitrified small ball self-insulation system developed by Jiangsu Huaweijia Building Materials Technology Co., Ltd. passed the scientific and technological achievement appraisal organized by the Housing and Construction Department of Jiangsu, and was widely applied and popularized in Zhenjiang, Jiangsu. The construction of vitrified small ball insulation bricks is shown in Figure 2.3.

Autoclaved light sand aerated concrete block or board is mainly made of quartz sand, cement, lime and plaster by scientific mixture, stirring, precuring, cutting and curing under high temperature and high pressure. It has advantages of light weight, fire resistance, sound insulation, anti-leakage, good heat insulation effect, little deformation and few cracks, and is widely applied in the self-insulation system in Jiangsu. For example, it was applied in some public buildings such as Jiangsu Construction

Figure 2.3 Construction of vitrified small ball insulation bricks

Figure 2.4 Jiangsu Construction Management Building (sand aerated board)

Management Building (Figure 2.4) and has shown good performance.

2.3.2 Shanghai

Shanghai is an international metropolis located on the southeast of the estuary of the Yangtze River delta, covering an area of approximately 6340.5 km^2. It is adjacent to river and sea, belongs to the subtropical monsoon climatic region and shows characteristics of monsoon and oceanic climate. It has four distinctive seasons with spring and autumn longer than winter and summer, and features warm spring, hot summer, cool autumn and cold winter. The rainfall in Shanghai is moderate around the year, with 60% of the total precipitation in flood season from May to September and an average annual precipitation of 1119.1 millimeters. Due to the large urban area and dense population, the urban heat island effect is obvious in Shanghai. The average temperature is 15.8℃ annually, 3.6℃ in the coldest month January and 27.8℃ in the hottest month July.

In recent years, Shanghai has actively implemented national and local laws, regulations and policies on building energy conservation, and continuously promoted the building energy conservation work orderly according to local conditions. A large number of new technologies which are conducive to energy conservation have been developed under such circumstance, and exterior wall insulation had been widely applied as an effective measure for energy conservation. Among all energy-saving technologies of building envelope, the most widely adopted one is the external insulation system of exterior wall which uses thin plastered expanded polystyrene board. After decades of development and as a pilot project in 1995, it has been developed into a mature construction technique. Although at that time people’s experience was not so much as today, they were strict with every detail in production and application, and therefore the system did not meet the problem of crack or water leakage. However, as there are problems of jerry-building and improper construction in today’s production and application, many quality problems have arisen, such as hollowing, cracking, water leakage and even falling of the insulating layer and even, resulting in the negative attitude towards the application of this system held by both insiders and outsiders. While promoting the application of this system, the Shanghai government organized scientific research to tackle key problems and explore other exterior wall insulation systems which suit the local conditions. Particularly, the government has actively developed, popularized and applied the self-insulation systems of envelope wall, including those made of autoclaved aerated concrete block, Ober compound perforated concrete brick, interlocking concrete block and energy-saving prefabricated wall.

1) Autoclaved aerated concrete block self-insulation wall is an important self-insulation system of exterior wall, mainly made of autoclaved aerated concrete block. The structural thermal bridge can use the same material or thermal mortar. For the former one, the design and construction are relatively complex, including leveling the concrete wall and pasting with binder. For the latter one, the construction is convenient and it is easy to push the thermal bridge and aerated block wall into the same level.

2) Ober compound perforated concrete brick self-insulation wall is mainly made of Ober compound perforated concrete brick. The structural thermal bridge can use inorganic thermal mortar. The bricks consist of internal bricks of the main wall and external bricks of the insulation material

protection layer. They have the same size with current construction module. The major material is normal concrete which is relatively mature and stable, and the insulation materials are polystyrene board and polyurethane, which are relatively economical. The bricks have light weight and adopt a perforated structure.

3) Interlocking concrete block self-insulation wall is mainly made of interlocking concrete blocks, which were successfully invented in 2002 and have been applied in a mature way. On this basis, further research and development of this kind of wall has been conducted. Its basic characteristic that grooves are located on the top, middle, bottom, left and right of the block has been kept. The materials and production technique have also been basically kept – first change the internal form of the block to turn the original single-row holes to three-row holes, then alternately insert insulation boards into the holes to reduce the area of thermal bridge in the block and increase the length of thermal bridge, and at the same time use 3cm-long EPS board as lap joint to hinder heat flux and fill the other holes with grouting material to connect the blocks and form a brand new type of wall material with special appearance. Currently there are initial project construction standards in Shanghai, including *Regulations on the Design, Construction and Quality Acceptance of Interlocking Concrete Block (Revised)* and *Picture Collection of Architecture and Construction Made of Interlocking Concrete Block (Revised)*.

4) Energy-saving prefabricated wall is a new type of self-insulation wall, which is transported after production from prefabricated component factory to construction site for installation. The wall is made of internal, external, insulation and connection layers. The thickness of the internal, external and insulation layers is decided by the designer. As the new type of FRP connector is used to replace the metal dowel in traditional wall, thermal bridge at the connection could be avoided and the overall insulation effect could be improved. This system has the advantage of convenience for industrialized production and mass installation. Currently, local standards on it have been successively implemented and provided technical bases, including *Regulations on the Design of Assembled Monolithic Concrete Residential System* and *Regulations on the Production, Construction and Quality Acceptance of Concrete Components of Assembled Monolithic Residence*.

Hongkou Hardware Mall (Figure 2.5) is on West Baoxing Road, Hongkou District, Shanghai. Its main structure consists of a 24-storey and two 17-storey high-rise buildings. On account of the main structure's high requirements for walls, interlocking concrete blocks, which were developed and produced by Shanghai Zhonghong Technology Development Co., Ltd., were selected as the filling material of the loading wall and the frame structure.

Figure 2.5 Hongkou Hardware Mall in Shanghai (interlocking concrete block)

2.3.3 Chengdu

As the capital of Sichuan Province, Chengdu is located in central Sichuan and the hinterland of Chuanxi Plain, neighboring Longquan Mountains in the east, Yunnan-Guizhou Plateau in the south, Qionglai Mountain in the west and Qinling Mountains in the north. With a total area of 126,000 km^2 and a population of over 11,000,000, it is the largest modern city in southwestern China. Chengdu has an average altitude of 500 meters and features typical basin climate. It belongs to subtropical humid monsoon climatic region with characteristics of temperate climate, four distinctive seasons, long frost-free season, abundant rainfall and relatively poor sunshine. It has an average annual temperature of 16.2℃, an annual extreme maximum temperature of 37.3℃ and an annual extreme minimum temperature of -5.9℃. The hottest months are July and August with average temperature of 25.4℃ and 25.0℃ respectively. The coldest month is January, in which the average temperature is 5.6℃. The total amount of annual precipitation is 918.2 millimeters. The climate of Chengdu has two significant features: cloudy, foggy environment with short sunshine duration, and humidity.

Since 1990 when it was approved as a wall material reform pilot city, Chengdu has stuck to technology innovation and worked on wall material reform and building energy conservation by means of systematic engineering. After achieving the target of limited production and exhaustion of produced clay bricks, Chengdu closed all clay brick factories within its administrative region in 2005, and became the first capital city to do this. Afterwards, the focus of the wall material reform was transitioned to the upgrading of new wall material industry, the updating of products and the development of self-insulation wall.

The technological system of self-insulation wall can well solve the problems currently existing in the engineering application of insulation technology, concerning safety, durability, fire resistance, economic efficiency, construction convenience and maintenance costs. Besides, the development of self-insulation wall can actively deepen the wall material reform and promote industrial restructuring and upgrading and the replacement of technologically innovative products, which can lead the healthy development of large-scale and high-quality new wall material manufacturers in Chengdu and contribute to the overall urban-rural development and the improvement of wall materials.

In 2006, the research project *Research and Demonstration on Key Technology of Self-Insulation Envelope Structure and New Wall Material*, which was initiated by Chengdu Wall Material Energy Conservation Office, was listed among *Chengdu's Key Special Programs of Science and Technology Development Plan in the 11th Five Year*. The project consisted of four subsidiary topics, namely *Research on Production and Application Technology of Sintered Material of Self-Insulation Wall*, *Research on Application Technology of Exterior Wall External Insulation System Constructed by Cast-in-Place Concrete EPS Steel Mesh Board*, *Comprehensive Research and Demonstration on Application Technology of Aerated Concrete Block* and *Research on Quality Monitoring Technology in Production of Building Energy-Saving Sintered Materials*. The project was targeted to solving the self-insulation problems in three major structures, including shear wall, frame and brick-concrete construction, and has already been accomplished.

The self-insulation technological system, which focuses on science and technology and is led by good examples, has provided a basis for governmental policies. The Department of Construction of Sichuan has successively implemented *Notice on Technological Guidelines for Thermal Performance of Self-Insulation Wall* ([2009]250) and *Notice by Department of Housing and Urban-Rural Development on Application and Popularization of Self-Insulation Energy-Saving System in Out-of-Province Construction Projects* ([2010]10), which accelerated the close combination of wall material reform and building energy conservation. In January, 2010, *Notice on Plan of Restructuring of Wall Material Industry and Development Arrangement in Chengdu (2010-2012)* was put forward, in which the industrial restructuring of wall materials, development goal, focus and industry entry criteria were clarified. Chengdu Wall Material Energy Conservation Office has actively promoted the construction of policies and regulations by making and perfecting supporting regulations and policies to adapt to wall material reform and building energy conservation, and developed a long-term mechanism for their development.

Currently, the materials used in self-insulation systems in Chengdu are mainly self-insulated sintered brick and autoclaved sand aerated concrete. Sintered materials boast a long history in China and possess many advantages which non-sintered materials don't have. Self-insulated sintered material can be classified into three major types, namely self-insulated loading sintered perforated brick, self-insulated non-loading sintered brick (block) and self-insulated compound sintered hollow brick. The main purpose of this material is to realize the self-insulation of frame-structured filler wall and brick-concrete loading wall. Self-insulated loading sintered perforated brick is currently the material for frame-structured filler wall in Chengdu. At the same time, Chengdu adheres to the principle of joint development of brick, board and block, and considers autoclaved aerated concrete block as an object of self-insulation system studies. Through the project of *Comprehensive Research and Demonstration on Application Technology of Aerated Concrete Block*, technological indexes for aerated concrete block and masonry mortar, as well as measures to prevent crack and leakage of exterior wall by aerated concrete, were proposed to be applied in Chengdu. Moreover, the project established a complete set of technological construction measures to prevent the crack of aerated concrete, compiled corresponding technical rules, construction methods and structure picture collection of the systematic application of aerated concrete block, built a production line of new type of aerated concrete with annual production of 300,000 m^3, and led the development of high-quality and large-scale manufacturers of aerated concrete.

Shuduhui Residence (Figure 2.6) in Chengdu is a pilot project for the application of self-insulated sintered brick, with a total area of 180,000 m^2. The buildings possess a structure of framed shear wall, and the filler walls were all constructed by self-insulated hollow bricks produced by Pengshan Jiayi Building Material Co., Ltd. At the same time, the kindergarten in the residence was chosen as a pilot project for the application of compound sintered block. The filler walls there were constructed by self-insulated hollow bricks produced by Sichuan Dongri Industrial Co., Ltd. In the reconstruction project of “Xingyan Residence” in Dujiangyan after the Wenchuan Earthquake, filler walls constructed by sintered self-insulated bricks were built, and the bricks were produced by Sichuanzhong Energy-Saving Building Material Co., Ltd.

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Figure 2.6 Shuduhui Residence in Chengdu (self-insulated sintered brick)

2.3.4. Chongqing

Chongqing is located on the upper reaches of the Yangtze River and at the intersection of the Yangtze River and the Jialing River. It belongs to the subtropical inland region of the northern hemisphere as well as the hot summer and cold winter zone of China, and has subtropical monsoon humid climate with an average annual temperature of approximately 18℃. The lowest temperature in winter is 6-8℃ on average. In summer it is hot with the highest temperature above 35℃ in both July and August. The extreme maximum temperature is 41.9℃ and the minimum temperature is -1.7℃. It has a total sunshine duration of 1000 to 1200 hours and annual precipitation of 1000 to 1450 millimeters, featuring warm winter, hot summer, long frost-free season and abundant rainfall.

Energy conservation is an important step to the implementation of Scientific Outlook on Development in the construction field, the realization of the fundamental shift in the mode of economic growth, the promotion of building functions and qualities, and the relief of the resource and environment contradiction. Since 2005, following the working guideline of "guided by public opinions and supported by technology; standards go first and technology goes with it; driven by models, industries follow up; standardized management and ensured quality", Chongqing has actively and steadily carried forward the energy-saving work of buildings. Especially, in recent years, Chongqing has implemented *Ordinance on Building Energy Conservation in Chongqing*, taken the lead in the enforcement of the mechanism of testing and identifying building energy efficiency, and become the first city in western China to adopt the design standard of 65% energy conservation of residential buildings, which has greatly promoted the building energy-saving work in the whole city. However, with the promotion of building energy conservation, some energy efficiency technologies and products have gradually shown their defects and problems in the practical application.

Loading walls in Chongqing are mainly made of sintered shale solid bricks, while the materials for non-loading walls are mainly sintered shale hollow brick, autoclaved aerated concrete block and small lightweight aggregate (ceramic) hollow concrete block. The development of self-insulation wall and further improvement of wall material performance, especially the active development of new materials of self-insulation wall, can not only greatly promote the technical progress and development of wall industry in Chongqing, but also play an important role in wall material reform and industrial restructuring in Chongqing. Therefore, according to the needs for building energy conservation and wall material reform and based on climate, resource conditions, building characteristics and economic level of Chongqing, Chongqing has conducted research on self-insulation wall since 2006 to tackle the problems of safety, durability and economic efficiency existing in the application of insulation technology of exterior wall in the building energy conservation project, and established a technological system of exterior wall insulation which relies mainly on self-insulation system. Moreover, Chongqing has decided on its building energy conversation methods according to local conditions, of which the development of self-insulation wall is the major direction. The application of self-insulation wall has won significant social and economic benefits in practice and has been widely praised and accepted.

Currently in Chongqing, mainly energy-saving sintered shale perforated brick and concrete perforated brick are developed for loading self-insulation wall, while energy-saving sintered shale hollow block, autoclaved aerated concrete block and small ceramic hollow concrete block are mainly developed for non-loading self-insulation wall. Most buildings in Chongqing are high-rise, therefore, the focus of this research was placed on the non-loading self-insulation wall, whose key objective is to improve the thermophysical performance of wall materials. Three types of materials were studied, including energy-saving sintered shale hollow block, energy-saving small ceramic hollow concrete block and autoclaved aerated concrete block.

1) Energy-saving sintered shale hollow block

The following technical measures were adopted to improve the thermal performance of sintered shale hollow block:

(1) Enlarge the size of brick to turn it into block and reduce mortar joints of the block;

(2) Optimize the shape and arrangement of holes;

(3) Make grooves on the end face of block to form air fault between grooves, so as to effectively hinder the cut-through thermal bridge formed by masonry mortar on horizontal and vertical mortar joints

(4) Adjust the proportion of raw materials to increase the porosity of block.

To guarantee the physical and mechanical performance of products and improve their thermal performance at the same time, the hole width was controlled at about 10 millimeters, and meanwhile, the technique of constructing holes vertically was adopted, which not only enhanced the compressive strength of products, but also improved the overall performance of wall through forming forelocks between blocks by masonry mortar. Besides, new production equipment, such as mould, tool post and nose, were invented to adjust production techniques and guarantee mass production and qualified rate. After adjustment, the thermophysical performance of energy-saving sintered shale hollow block was significantly improved.

2) Energy-saving small ceramic hollow concrete block

By drawing experience from the development of energy-saving sintered shale hollow block, the problems of small ceramic hollow concrete block, including poor thermal performance, low strength and production difficulty, were successfully solved by means of adjusting hole structure and arrangement, making grooves on the end face, adjusting raw material proportion, improving the gradation of ceramsite and increasing the amount of ceramsite. The thermal performance of energy-saving small ceramic hollow concrete block after such improvement was significantly enhanced.

3) Autoclaved aerated concrete block

Autoclaved aerated concrete block has excellent thermophysical performance, and can well meet the requirements for self-insulation wall. However, affected by economic and technical conditions, problems of hollowing and cracking occurred in the engineering application in Chongqing. After profound analysis, the following measures were adopted in production to enhance the product quality. The first is the optimization of lime to ensure the proportion of calcium over 65%. The second is the optimization of river sand to reduce the proportion and mud and increase the proportion of silicon. Third, change manual cutting to machine cutting to improve the dimensional accuracy of product. At the same time, the research on application technology was deepened in the following aspects. First, make sure an interval of over 28 days between the production of blocks and the construction of walls by them. Second, guarantee an interval of over one week for header bricks. Third, the interval between placing and plastering must be more than 30 days. On account of these measures, the product quality and engineering quality of autoclaved aerated concrete block were significantly improved.

Based on engineering practice, research on the structure of self-insulation system and relevant application technologies was also conducted. Technical standards and design picture collections were compiled to further improve the technological system of self-insulation wall and lay a foundation for its mass application, including *Regulations on Application Technology of Autoclaved Aerated Concrete Block* (DBJ50—055—2006), *Picture Collection of Buildings with Self-Insulation Wall Constructed by Autoclaved Aerated Concrete Block* (08J107) and *Picture Collection of Buildings with Self-Insulation Wall Constructed by NJ Energy-Saving Sintered Shale Hollow Block* (08J108).

To verify the actual effect of self-insulation wall in application and improve the technology through engineering practice, Chongqing has applied and popularized two major self-insulation systems of aerated concrete block and energy-saving sintered shale hollow brick since 2007, and more than 30 projects were built with a total area of 4,300,300 m^2 and a total cost of over RMB 100,000,000 yuan, covering various building forms including low-rise, multi-storey and high-rise. From the practice of the projects, four major findings could be concluded. First, self-insulation wall has relatively wide applicability, and suits a variety of building forms with building shape coefficient lower than 0.45. Second, it can effectively and widely reduce the energy-saving costs of building by a percentage of 30% to 50%, and therefore has significant social and economic benefits. Third, it adopts traditional construction method, which is fast and can save time and labor. Fourth, there is a wide range of choices of exterior wall’s ornamental surface materials.

Large quantity of project practices has proven that self-insulation wall can effectively solve the problems currently existing in the exterior wall insulation system widely adopted in Chongqing. The self-insulation wall has great performance, good application effect and significant social and economic benefits. It plays a positive role in the promotion of building energy conservation in the hot summer and cold winter zone, the reduction of overall cost of building energy-saving projects and the guarantee of quality and safety of the projects.

Figure 2.7 Zongshen Motor City Residence in Chongqing (sintered shale hollow brick)

2.3.5 Wuhan

Wuhan is the capital of Hubei Province and the largest city in central China. It is in the east of the Jianghan Plain and at the intersection of the Yangtze River and the Han River. With an area of 8476 km^2 and a population of 8.37 million, the city has nine urban areas and four suburbs, among which the population of the urban areas is over six million. The latitude and longitude are respectively 30°33’N and 114°19’E. It’s located on the middle reaches of the Yangtze River and belongs to the subtropical humid monsoon climatic region. It has four distinctive seasons and a frost-free season of approximately 240 days on average. The average annual precipitation is 1284 millimeters, which is concentrated in June, July and August. The average annual temperature is 16.4℃. In summer, the duration of high temperature is long, and the extreme maximum temperature is 41℃. The minimum temperature in the year is -18.1℃.

With the development of economy, the improvement of people’s living standards and quality and the strengthening of national energy conservation and environmental protection, the requirements for building energy conservation ratio has been accordingly enhanced. In the end of 2007, the city circle of Wuhan was approved as a pilot area for the construction of resource-economical and environment-friendly society. Taking this chance, the Wuhan government put forward an energy-saving standard of 65%, which was first implemented in the central area. At the same time, the government published *Design Standards for High Energy Efficient Residential Buildings in the City Circle of Wuhan* and launched relevant pilot projects to provide a reference for the energy-saving standard of 65% through project study and engineering practice. Energy conservation technology always adapts to climate, therefore, the application of it must act according to local conditions. The main requirement in northern China is heat insulation which could be realized by external insulation system of exterior wall, while it is heat shielding in the south, where self-insulation wall could adapt well to the climate of the hot summer and cold winter zone because its life cycle is economical and reasonable and the thermal bridges around the exterior wall can meet the energy-saving requirement after certain measures.

Therefore, the development, application and popularization of self-insulation exterior wall should be the focus in Wuhan. As the performance of autoclaved sand aerated concrete blocks in Wuhan is better than those in other regions, this type of block has been chosen as the main material for self-insulation wall to make full use of local resources.

The construction of self-insulation wall requires the comprehensive consideration of the building's shape coefficient, orientation and plane form, the enhancement of thermal performance of exterior wall and external doors and windows, the improvement of insulation performance of roof, floor and raised floor, and the movable external sunshade, among which the difficulties are as follows:

1) Develop masonry mortar and mortar for coating which have insulation function and suit the autoclaved sand aerated concrete block.

2) Adopt structural measure of hindering thermal bridge to solve the problem of thermal bridge in beam and column of frame-structured self-insulation system. Compare the thermal indicators under different conditions to find the best structural combination.

3) Study and compare the production techniques of energy-saving doors and windows in terms of design, opening method, type and material. Adopt effective ways of sunshade to improve thermal performance of window.

4) Replace the traditional floor floating mortar and floor thermal mortar to realize energy conservation in every room.

To tackle the above difficulties, Wuhan conducted a pilot project of Hankou Garden Qingtong Pavilion ·Biwuyuan Residence (Figure 2.8), which is located on Xingfu Avenue, Houhu Village, Jiang'an District. The residential buildings in this project are three 11-storey frame-structured buildings with a total area of 19,000 m^2, and they are linear buildings facing south and north with good natural ventilation and daylighting. The construction of the project was started in January, 2008 and finished in August, 2009. The project adopted six technological systems and achieved the energy-saving target of 65%.

The main body of self-insulation exterior wall was constructed by thermal mortar and the new type of sand aerated concrete block whose thickness is 275. The new type of sand aerated concrete blocks with thickness of 75 were pasted by thermal mortar on the thermal bridge of beam and column, and were fixed by out-hung steel wire mesh to guarantee the integrity and stability of exterior wall. As for the reinforced concrete part, three 6mm-diameter reinforcing bars were set in every 500mm at altitude, and the distance between every two bars on horizontal level is also 500mm. Besides, steel wire mesh was partly fixed by steel nail and shim. On the middle of the shear wall, a beam ear should be set. The external window was hollow glass plastics-steel side-hung and top-hung window with the heat transfer coefficient K below 2.7W/m^2 • K. The type of glass structure is 5mm+12A+5mm, with airtightness ≥ 4. The connection between wall and door or window was filled with foamed polyurethane. Top plate of bay window was constructed by cast-in-place concrete (with a 1.22mm-thick layer of compound polymer waterproof coating on its surface), insulation block (with interface covered by 30mm polystyrene granule thermal mortar), fiberglass mesh pressed into anti-crack mortar, elastic waterproof prime paint, flexible waterproof putty and exterior surface coating from top to bottom. This exterior window system could save half of the energy compared with normal window. It has good performance of sound insulation, water tightness and airtightness, and can therefore provide an energy-saving and peaceful living environment.

Exterior sunshade system: The exterior window facing south adopts fixed sunshade at the horizontal level, and the window facing west has roller shutter to shade the sunshine and adjust the light quantity, so as to hinder various radiation, reduce greenhouse effect in the room, improve indoor environment and perform the functions of sound insulation, view blocking and prevention of burglary.

Roofing system: On the roofing, 60mm extruded polystyrene boards were paved for heat insulation. A “temperature control cabin” was formed from bottom to top to meet the requirements for comfortableness and energy conservation. From bottom to top on the roofing, there were 120mm cast-in-place concrete board, 60mm extruded polystyrene board insulation layer, 20mm 1:8 cement aerated concrete slag with 2% slope, a leveling layer of 20mm 1:2.5 cement mortar, primer, two layers of 3mm SBS modified bituminous waterproof coiled material, 0.5mm polyethylene film, 25mm 1:4 dry cement mortar, cement, 8-10mm floor tiles to be leveled and compacted, and 1:1 cement mortar to fill the 5-8mm gaps.

Floor system: Add 20mm inorganic thermal mortar on the floor of heating room to establish an independent insulating and energy-saving residence and keep every room comfortable. From bottom to top on the floor were 100mm cast-in-place concrete board, 20mm inorganic thermal mortar and 20mm 1:2 cement mortar. Due to the heavy weight, thermal mortar does not have good insulation performance. After repeated experiments, 20mm thermal mortar can keep balance the weight of itself and meet the requirements for insulation.

Ground surface system: Add 20mm inorganic thermal mortar on the raised flooring of heating room to form a solid insulation system and reduce heat loss.

Figure 2.8 Hankou Garden Qingtong Pavilion ·Biwuyuan Residence (sand aerated concrete block)

2.3.6 Hangzhou

Hangzhou is the capital of Zhejiang Province and lies in the north of Zhejiang, neighboring Shanghai, the largest city in China, in the north. Its longitude and latitude are 30°19'N and 120°12'E. The average altitude is 7.2 meters. The average temperature is 28℃ in the hottest month July, and 3.7℃ in the coldest months January and February. The extreme maximum temperature is 39.7℃ while the extreme minimum temperature is -9.6℃. The average wind speed in summer is 2.1m/s. Hangzhou belongs to typical subtropical climate, featuring cold winter and hot summer. The lowest temperature in winter is usually -3℃, and the highest temperature in summer is approximately 38℃.

The building energy conversation work was started relatively early in Hangzhou. In March 2002, Hangzhou Construction Committee carried forward *Detailed Rules in Hangzhou on Energy-Saving Design Standards for Residential Buildings in the Hot Summer and Cold Winter Zone* and *Technical Essentials for Thermal Design of Energy-Saving Residential Building Envelope in Hangzhou*, and held three training courses on energy conservation, in which more than 300 people participated, including directors from departments of design, real estate development, construction and supervision and technical personnel for engineering design. Currently the external insulation system still dominates the market of energy-saving wall in Hangzhou. The development of research and the popularization of self-insulation system in Hangzhou are relatively slow compared with other provinces and cities in the hot summer and cold winter zone. On June 17, 2008, "Key Technology in Diatomite Self-Insulation Energy-Saving Wall Material", a key project of Zhejiang undertaken by Zhejiang University, passed the technical evaluation. Through the studies of material formula and production technique's influences on product performance, diatomite perforated brick with light weight, high strength, low volume shrinkage and good insulation performance was produced, and specialized masonry mortar and mortar for coating were developed. They together constitute diatomite material for self-insulation wall which has excellent performance. Besides, production standards and rules on application technology were made. In 2007, self-insulated ceramic reinforced aerated concrete block was jointly developed by Taizhou Yiyuan Self-Insulation Wall Material Co., Ltd. and Zhejiang University. However, due to the limited production capacity of the above two materials and their low degree of market recognition, they were not able to be widely applied and popularized. At the same time, the application of self-insulation system in Hangzhou lacks corresponding regulations and standards. There was no overall guidance in the aspects of design, construction and acceptance which can guarantee the quality of self-insulation system, which has actually limited the application of self-insulation system in Hangzhou.

Currently, it is an important project in the energy conservation field of Hangzhou to develop, apply and popularize a self-insulation system to adapt to the local conditions according to the climatic conditions, current situation of energy conservation and characteristics of resources, self-insulation materials and self-insulation system.

Before this project, the Architectural Design & Research Institute of Zhejiang University cooperated with Kunhe Construction Group to conduct two pilot projects of self-insulation system respectively at the residences of Kunhe ·Xixili and Kunhe ·Hejiayuan. Kunhe ·Xixili (Figure 2.9 and 2.10) is located on the north of West Wenyi Road, facing Xixi Wetland in the south and Zijingang Campus of Zhejiang University in the north. It covers an area of over 180 mu (120,000 m^2) and has a total residential area of approximately 330,000 m^2. The building forms are mainly multi-storey terraced houses and high-rise apartments. In this project, the wall materials were autoclaved sand aerated concrete blocks produced by Zhejiang Kaiyuan New Type Wall Materials Co., Ltd. Polystyrene granule thermal mortar was used in thermal bridge joints in the beam and column to constitute self-insulation system. Currently, the first phase of the project has been accomplished and come into use for nearly one year, and has won praise from residents and relevant departments.

Kunhe Hejiayuan (Figure 2.11 and 2.12) is located to the south of Xixi Wetland and belongs to Xihu District. It was planned to build high-rise apartments, multi-storey terraced houses and multi-storey villas there. It covers an area of approximately 870 mu (580,000 m^2) and the planned residential area is about a million square meters. In this project, a variety of self-insulation walls were compared, including combinations of different self-insulation systems such as autoclaved sand aerated block + polyurethane insulation material, sintered shale hollow block + polyurethane insulation material and sintered shale hollow block + polymer thermal mortar.

From these two pilot projects and the comparison of different combinations of self-insulation materials, the advantages and disadvantages of different self-insulation systems were found out, which lays a foundation for further application and popularization.

Figure 2.9 Multi-storey terraced house in Kunhe Xixili (sand aerated block)

Figure 2.10 High-rise apartment in Kunhe Xixili (sand aerated block)

Figure 2.11 Multi-storey terraced house in Kunhe Hejiayuan (sand aerated block)

Figure 2.12 Multi-storey apartment in Kunhe Hejiayuan (shale hollow block)

2.4 Summary of the Investigation

Through the investigation of main regions in the hot summer and cold winter zone of China, the author summarized the common wall materials used in the self-insulation system, and the insulation materials and measures used in key joints of thermal bridge in beam and column. Besides, the author also summarized the problems and future development of the self-insulation system in the zone.

2.4.1 Summary of Common Wall Materials of Self-Insulation System

It can be seen from the wall materials used in the self-insulation system in the hot summer and cold winter zone that every region has applied and popularized the materials in line with local geographical and climatic conditions and specific situations of material production.

Currently, wall materials of self-insulation system used in the hot summer and cold winter zone can be classified by production technique into three types: sintered, autoclaved and placing.

1) Sintered materials of self-insulation wall

(1) Mud sintered brick

Mud sintered brick is made mainly of the mud from rivers, lakes and sewage disposal plants, and is sintered with large quantities of usable industrial solid waste and special admixture. It is mainly used in Jiangsu Province.

(2) Sintered shale materials include sintered shale hollow block, sintered shale perforated brick, sintered insulation brick and so on.

The main raw materials of this type are natural inorganic silicate shale and quartz tailing sand. Sintered shale materials are formed under high vacuum, high pressure and high temperature, thus having the advantages of good heat insulation performance, sound insulation, waterproof, high strength, high void ratio, light weight, elegant appearance and great durability. Widely distributed in the hot summer and cold winter zone, shales play a role in saving energy and soil as well as utilizing waste, and get applied and popularized in many regions including Jiangsu, Zhejiang, Sichuan and Chongqing. Sintered insulation brick is made by the following steps: add river mud and paper sludge into the comminuted shales, then mix, blend, homogenize and mold in vacuum, and finally dry with excessive heat and sinter in high temperature. This type of material can utilize the waste sludge in industry and in life, save farmland and reduce costs on sludge landfill or incineration, thus producing social and economic benefits in terms of environmental protection and energy conservation.

(3) Gangue sintered brick

Gangue sintered brick is formed by comminuting, ageing and blending waste gangue and sintering in high temperature (usually 900-1100℃). The use of gangue sintered brick can promote the comprehensive utilization of gangue and make full use of its residual heat to turn waste into wealth and save energy. It helps solve the environmental problem caused by accumulation of gangue, saves land and reduces construction cost. Besides, it possesses good performances of compression resistance, heat insulation, heat shielding, sound insulation and crack resistance, thus widely applied in practical projects.

2) Autoclaved materials of self-insulation wall

(1) Autoclaved aerated concrete block or board

Autoclaved aerated concrete block or board is mainly made of cement, lime, pulverized coal dust and quartz sand by casting molding and autoclaving. It has the advantages of light weight, heat resistance, heat insulation, fire resistance, sound insulation, no leakage and good machinability, and is widely applied in non-bearing envelope and internal parting wall. This material is widely applied in most areas of the hot summer and cold winter zone of China, but the product quality varies greatly. Currently in China, large manufacturers which have introduced foreign production line of this material include Shanghai Yitong, Nanjing Asahi and Zhejiang New Century.

(2) Ceramic aerated concrete block

Ceramic aerated concrete block is made by adding ceramic granule to pulverized coal dust aerated concrete block. Compared with aerated concrete, it has the advantages of low shrinkage and high strength.

(3) Expanded and vitrified small ball insulation block

Expanded and vitrified small ball insulation block is made by compounding expanded and vitrified small ball, inorganic cementitious material, pulverized coal dust, construction sand and relevant additives according to certain proportion and steam curing. This material can be used in self-insulation system of non-bearing structure of energy-saving building, features energy efficiency, long durability, fire resistance and light weight, and has significant social and economic benefits.

3) Placing materials of self-insulation wall

(1) Compound perforated concrete brick

The brick consists of internal brick of the main wall and external brick of the insulation material protection layer. They have the same size with current construction module. The major material is normal concrete which is relatively mature and stable, and the insulation material is relatively economical polystyrene board and polyurethane. The bricks have light weight and adopt a perforated structure.

(2) Interlocking concrete block

The mechanism of interlocking concrete block consists of three steps: first, change the internal form of the block to turn the original single-row holes to three-row holes; then, alternately insert insulation boards into the holes to reduce the area of thermal bridge in the block and increase the length of thermal bridge; and at the same time, use 3cm-long EPS board as lap joint to hinder heat flux and fill the other holes with grouting material to connect the blocks and form a brand new type of wall material with special appearance. Due to resource deficiency, Shanghai mainly develops concrete materials, which has contributed to the application and popularization of interlocking concrete block.

(3) Energy-saving small ceramic hollow concrete block

The problems of small ceramic hollow concrete block, including poor thermal performance, low strength and production difficulty, were successfully solved by means of adjusting hole structure and arrangement, making grooves on the end face, adjusting raw material proportion, improving the gradation of ceramsite and increasing the amount of ceramsite. The thermal performance of energy-saving small ceramic hollow concrete block was significantly enhanced after the improvement. This material has been applied in Chongqing.

2.4.2 Summary of Insulation Materials Used in Thermal Bridge of Self-Insulation System

In recent years, the number of fire disasters caused by insulation materials around China has been increasing. To halt this trend and examine the source of fire, the Ministry of Public Security put forward *Notice on Further Clarification of Requirements for Fire Supervision Management of Exterior Insulation Materials of Civil Buildings* ([2011]65) in March, 2011, in which it was required that exterior insulation materials of civil buildings use materials with A-class combustion performance. This would bring great change to the use of insulation materials, because the commonly used extruded or expanded polystyrene insulation board, rubber powder polystyrene granule material and rigid foam polyurethane material could not meet the requirement. According to the document, the author summarized the A-class insulation materials currently used in key joints of thermal bridge in self-insulation system.

1) Inorganic thermal mortar

Inorganic thermal mortar is a new type of insulating and energy-saving dry mortar to be used for plastering of both interior and exterior walls. It consists of inorganic light aggregate such as vitrified small ball and hole-closed expanded perlite, cementitious material, anti-crack additive and other bulking agents. Its characteristics are as follows:

(1) Extraordinary temperature stability and chemical stability. Made of pure inorganic materials, inorganic thermal mortar is acid and alkali resistant, anti-corrosion, highly stable without problems of cracking, falling and ageing, and has the same service life as the building.

(2) Easy construction and low cost. Inorganic thermal mortar can be directly plastered on blank wall by the same construction means of leveling cement mortar. Compared with other insulation materials, it has obvious advantage of short construction period and easy quality control, because the machine used in production is easy to operate and the construction of the material is convenient.

(3) Wide range of applicability. Inorganic thermal mortar is applicable to various materials of the wall’s base course, and can be used for the insulation of various kinds of complex walls. It is totally-enclosed with no crack nor cavity pocket and would not cause thermal bridge. Besides, it can be applied to both external and internal insulation system of exterior wall, or applied to the two systems at the same time. It can also be used in the roof and the thermal insulating layer in the underfloor heating, which provides certain flexibility for the design of energy-saving system.

(4) Environmental friendly. Inorganic thermal mortar is non-toxic, odorless, non-radioactive and harmless to environment and human body. At the same time, wide application and popularization of it can make use of industrial wastes and low-grade building materials to produce benefits in environmental protection.

(5) High strength. Inorganic thermal mortar has high bonding strength with the base and produces no crack and hollow. Compared with other materials, it has certain technical advantage in this respect.

(6) High degree of safety and fire resistance. Inorganic thermal mortar is fire resistant and incombustible. Therefore, it can be widely used in dense residential areas, public buildings, large public places, inflammable and explosive areas and places with high requirements for fire resistance.

(7) Good thermal performance. Inorganic thermal mortar has better performance in thermal storage than organic insulation materials, and can be applied for heat shielding in summer in the south. At the same time, its coefficient of heat transfer can reach approximately 0.07 W/(m • K), and its thermal conductivity can be adjusted conveniently to adapt to mechanical strength and practical functions.

It is because of the above advantages that inorganic thermal mortar has become the most widely used insulation material in the hot summer and cold winter zone.

2) Autoclaved aerated concrete insulation board

Autoclaved aerated concrete board is a new type of light, perforated and environmental friendly building material, mainly made of cement, lime and quartz sand by adding different quantities of anti-corrosion reinforcing mesh according to requirements for structure. Its main characteristics are as follows:

(1) Good insulation performance, which is six times better than that of glass, three times than that of clay and 10 times than that of normal concrete.

(2) Light weight and high strength. It density is one fourth of that of normal concrete and one third of that of clay brick. It is lighter than water and weighs roughly same as wood.

(3) Fire resistant and inflaming retarding. Autoclaved aerated concrete board is organic and incombustible, and does not produce noxious gas under high temperature. At the same time, its small coefficient of thermal conductivity results in slow heat transfer, which can effectively prevent fires and protect the structure from the impact of fires.

(4) Good machinability. It can be sawed, bored, grinded and nailed, from which the design purpose is easily seen.

(5) High durability. Autoclaved aerated concrete board is a type of silicate material, which is anti-ageing and difficult to be weathered. It is a durable building material whose normal service life can compete with various kinds of permanent constructions

(6) Environmental friendly. Autoclaved aerated concrete board is non-radioactive with no harmful substance.

3) Foam glass

Foam glass was first invented by Pittsburgh Corning. It is a type of inorganic non-metal glass material made of cullet, blowing agent, modified additive and blowing accelerant by fine grinding, blending, melting, blowing and annealing. It is constituted of large amount of homogeneous bubble structures whose diameter is 1-2mm. More than half of the bubbles in sound absorption foam glass are opened-cell bubbles, while more than 75% of the bubbles in heat insulation foam glass are closed-cell bubbles. The density is 160-220kg/m^3, which can be adjusted by changing technical parameters in production according to the application requirements. Foam glass has won the reputation of “black pearl for energy conservation projects” and has been widely used in heat insulation and shielding for chemical engineering, shipping, refrigeration industry, cold storage, subway, projects in need of fixed temperature and humidity, roofing and exterior wall of common industrial and civil buildings. In China, it used to be applied only in the heat insulation and shielding of deep refrigerating equipment, shipping and cold storage, but in recent years, it has been used in buildings.

Foam glass is a type of inorganic hole-closed material whose characteristics include small coefficient of heat transfer, stable heat insulation function, no water absorption, low vapor permeability, excellent resistance of both high and low temperatures, great durability, high strength, light weight, little deformation, incombustibility, no corrosion, machinability and construction convenience. Moreover, it can be made into colorful materials to beautify the environment, and can be firmly connected to the base by plastering polymer cement mortar.

Compared with insulation materials currently used in construction projects, foam glass has its unique characteristics. It can be used on roofing to form permanent heat insulation layer. Moreover, because of its excellent weather resistance, it is particularly suitable for inverted roofing. After plastering polymer cement mortar and pointing, it could form a complete waterproof layer. When applied to the exterior wall, it can be directly pasted by polymer cement mortar which is convenient for construction. Colorful foam glass can not only contribute to heat insulation and shielding but also serve as decorative materials, bringing about double benefits.

Building energy conservation is an extremely important national policy as well as a systematic project which benefits the nation, the people and the future generations. The promotion of heat insulation and shielding of building has direct and practical effects on the improvement of working and living conditions and the conservation of energy. In China's project of heat insulation and shielding, two major problems have always existed, – high water absorption and low durability of the materials. They greatly reduce the materials' insulation performance, have negative effects on heat insulation and shielding and increase the energy consumption of air-conditioning system. Besides, after water absorption, the insulation layer becomes water storage layer, which could cause damage to waterproof layer and result in leakage even long after the rain. In the structure of exterior wall, because of the need for heat insulation and shielding, the wall shall be thickened to meet the requirements for functions. As most exterior walls use out-bonded materials for heat insulation and shielding, a type of material, which features light weight, good insulation performance, ageing resistance, no water absorption and easiness to bond, is needed. Foam glass is the most ideal material for this, and has excellent performance in both roofing and exterior wall.

4) Foam ceramic insulation board

Foam ceramic insulation board is a type of hole-closed ceramic material with high porosity, mainly made of kaolin tailing, potsherd, river mud and additive by calcining in high temperature with advanced production technique and blowing technique. It is applicable to exterior wall insulation, fire barrier and self-insulation thermal bridge. It has the advantages of fire resistance, low coefficient of deformation, anti-ageing, stable performance, environmental friendliness, good compatibility with the base and the plaster, safety, stability and same length of service life with the building. More importantly, it has

A1-class fire prevention, compensating for the fatal weakness of organic materials which are inflammable and easily ageing. Therefore, foam ceramic insulation board has filled the blank of inorganic insulation materials in China. Its major characteristics are as follows:

(1) Good thermal performance. Its coefficient of thermal conductivity is 0.08～0.10 W/(m • K), roughly same as that of thermal mortar. It has good performance of heat shielding and can serve as heat insulation and shielding material for the external insulation system of exterior wall or deal with thermal bridge of self-insulation system.

(2) Incombustible and fire resistant. It is calcined under a temperature of more than 1200℃. With A1-class fire resistance like fire brick, it is the ideal material to be used in fire barrier and exterior wall insulation which has requirements for fire prevention.

(3) Anti-ageing. The inorganic ceramic insulation materials are durable and anti-ageing and has the same length of service life with the building, which is inapproachable by normal organic insulation materials.

(4) Good compatibility with cement mortar and concrete and stability in pasting with them. They have close coefficients of thermal expansion. Same as the traditional ceramic building materials produced under high temperature, it won't crack, deform nor shrink in various temperatures. After plastering inorganic adhesion agent on both sides, its tensile bond strength with cement mortar can reach more than 0.2MPa.

(5) Very low level of water absorption. It can be well pasted with cement mortar and face brick. Bonding face bricks on its external side is safe and not restricted by building height.

(6) Good weather resistance. It has stable performance and won't deform, age or crack in adverse climatic conditions such as great solar radiation, drastic change of temperature and raining and blowing hard at the same time.

5) Microporous calcium silicate insulation board

Microporous calcium silicate board is a new type of board with excellent performance used in buildings and industries, made of high-quality cement (base material) and natural fiber (strengthening material) by advanced special techniques of forming, adding pressure and high-temperature steaming. It is white and hard with light unit weight, high strength, low coefficient of thermal conductivity, high temperature resistance, anti-corrosion, moth proof, good durability and possibility to be cut and sawed. Therefore, it is widely applied in heat insulation and shielding, fire resistance and sound insulation of equipment pipes, walls and roofing in the fields of electricity power, metallurgy, petrification, architecture and shipping. Its thickness is usually over 30mm and density between 200 and 1000 kg/m^3.

In choosing the insulation materials for wall and thermal bridge in the self-insulation system in the hot summer and cold winter zone, the following factors should be taken into overall consideration:

(1) Unification of technology and economic efficiency

The design of insulation material for self-insulation wall and thermal bridge needs to take both technological advancement and economic efficiency into account. The cost-efficient materials should be chosen according to local economic level, climate, resource and raw material conditions, building structure characteristics and energy-saving design standards.

(2) Consideration of local conditions and utilization of local resources

The hot summer and cold winter zone covers a wide region where natural conditions, economic levels and lifestyles vary from place to place greatly. Each place has its own regular practice which is formed in the long history. Therefore, the selection of insulation materials for wall and thermal bridge should obey local laws, regulations and policies and consider local natural resources, climate, equipment conditions, production conditions and technical conditions to make use of local advantages.

(3) Overall consideration of energy-saving effect

The selection of insulation materials for wall and thermal bridge should consider the overall energy conservation in the whole production process which consists of exploitation, processing, molding and so on, as well as the long-term energy-saving performance of the material after the accomplishment of building.

After an overall consideration of the above factors and Hangzhou's current situation including economic level, climate, resources and raw material conditions, the author concluded that the development of wall materials in self-insulation system in Hangzhou should focus on autoclaved aerated concrete block or board, sintered shale hollow block and sintered insulation brick, and that the development of thermal bridge insulation materials should focus on inorganic thermal mortar, autoclaved aerated concrete insulation board and foam glass

2.4.3 Limitations and Future Development of Self-Insulation System

With the development of wall insulation technology, people began to make requirements for wall insulation system, including high durability, high fire resistance and same length of service life with buildings. Accordingly, self-insulation wall has become the major development direction for the wall insulation system in the hot summer and cold winter zone. Currently, self-insulation system has already been studied and practiced in pilot projects for a certain period of time in the zone, but there are still some problems as follows which need to be solved in application and practice.

1) Most self-insulation technologies are still stuck on the research and application of a single material, without a comprehensive and systematic research on building form, construction material, building structural system and so on.

2) An overwhelming majority of self-insulation technologies have not yet been put into mass production and application. Enterprises have weak research and development ability, imperfect thermal bridge technology and construction techniques, and low application ability in the process of design and construction.

3) The standardization level of self-insulation technology is not high enough. There is deficiency of targeted and unified technique standards, which results in the great variety of performance and quality of products produced by different manufacturers. Also, there is lack of technical basis for construction and quality monitoring.

4) The supervision for self-insulation technology is relatively weak. The application of technology

at the construction site is not standard, which can have negative impact on building energy efficiency and cause quality problems

The future development of self-insulation system should follow the principle of “guided by public opinions and supported by technology; standards go first and technology goes with it; driven by models, industries follow up; standardized management and ensured quality” and be promoted actively and steadily. The major development directions and objectives are as follows:

1) Its development should conform to the policies on building structural system adjustment and wall material reform. The research on building structural system which is conducive to building energy efficiency shall be promoted. The design of the structural system should provide convenience for the application of self-insulation wall.

2) The utilization of waste materials and energy efficient materials should be actively developed according to local conditions. Based on the requirements raised by wall reform policy that solid materials be forbidden and sticky be limited, make full use of river (lake or sea) mud, pulverized coal dust, gangue, tailing and industrial wastes to develop energy-saving bricks and blocks. And it is necessary to enhance the technical performance of existing products, optimize the hole design of blocks, guarantee the environmental friendliness of products, make regulations for production and application management of energy-saving blocks, unify standards and identifications, designate producers and prevent counterfeit and shoddy products.

3) New types of materials featuring light weight, high strength and good performance of heat insulation and shielding should be further applied and popularized, such as sand aerated concrete block, ceramic aerated concrete block and autoclaved aerated concrete. Conduct research on the technology of reducing shrinkage ratio and on the anti-crack and anti-seepage masonry technique.

4) The development of compound-structured self-insulation technology should be further encouraged. Strengthen the research on joint structure and matching technique of compound-structured self-insulation technology. Promote the development of self-insulation technology towards product and industrialization.

5) Scientific and technological research to tackle the difficulties in self-insulation technology should be organized. Promote the cooperation among universities, scientific institutes and enterprises. Popularize the concept of green material and green building, make full use of local resources and make reasonable plans to further develop diverse self-insulation technologies with local features and further enrich the technological system of self-insulation wall. Enhance the research on self-insulation wall, especially on masonry mortar and corresponding technology for thermal bridge.

6) Technical standards should be further improved. Study and make application standards for various self-insulation walls and unify the technical indicators. Compile standardized picture collection of self-insulation wall to provide guidance for design and construction. Manufacturers of self-insulation products shall make their own standards.

7) Standardized management on self-insulation wall should be strengthened. Carry out assessment and identification on self-insulation technology (system) to perfect the management measures of self-insulation system in each step, including design, drawing check, testing, construction and supervision.

8) Pilot projects should be launched so as to improve the popularization and promote the application of self-insulation wall. List self-insulation wall material into the development plan of wall reform. Actively develop region-dominated technology, support local development of self-insulation wall manufacturer and establish industrialized base.

CHAPTER THREE: EXPERIMENTAL RESEARCH ON THE THERMAL PERRORMANCE OF COMMON WALL MATERIALS IN THE HOT SUMMER AND COLD WINTER ZONE

3. EXPERIMENTAL RESEARCH ON THE THERMAL PERFORMANCE OF COMMON WALL MATERIALS IN THE HOT SUMMER AND COLD WINTER ZONE

3.1 Introduction

The hot summer and cold winter zone refers to the middle and lower reaches of the Yangtze River and the surrounding areas. It is on the south of Longhai Line, north of Nanling Mountains and east of Sichuan Basin, and consists of 16 provinces, cities and municipalities, including two municipalities of Shanghai and Chongqing, the whole province of Hubei, Hunan, Jiangxi, Anhui and Zhejiang, eastern Sichuan and Guizhou, southern Jiangsu and Henan, northern Fujian, the south end of Shaanxi and Gansu and the north end of Guangdong and Guangxi. With an area of 1.8 million square kilometers, a population of 550 million and approximately 48% of gross domestic product, it is the a populous and economically developed region.

According to the needs for building energy conservation and wall material reform in the hot summer and cold winter zone and based on local resource distribution, climatic conditions, building characteristics, economic level and current situation of local industry, the major directions for the development of new types of wall in the zone have been proposed: develop various kinds of new energy-saving non-clay wall on the basis of local resources and the utilization of industrial wastes, river mud and paper mill sludge. Common wall materials include shale sintered hollow block, shale sintered perforated brick, autoclaved sand aerated concrete blocks, sintered gangue perforated brick, sintered insulation brick and compound perforated concrete brick.

3.2 Experiment Design

This project would conduct experimental research on the thermal performance of several types of common wall materials in the hot summer and cold winter zone. The object, objective, basis, instrument and method of the experiment are as follows.

3.2.1 Experiment Object

Shale sintered hollow block, shale sintered perforated brick, autoclaved sand aerated concrete blocks, sintered gangue perforated brick, sintered insulation brick and compound perforated concrete brick.

3.2.2 Experiment Objective

The experiment objectives include:

1) Test and measure the thermal performance of various types of new wall materials;

2) Judge if the material could meet the requirements for self-insulation wall in the hot summer and cold winter zone according to existing energy-saving design standards, local standards and relevant regulations.

3.2.3 Experiment Basis

1) *Testing Standards for Energy Efficiency of Residential Building* (JGJT/132-2009)

2) *Heat Flow Meter Method for Testing Steady Heat Resistance and Related Properties of Heat*

Insulation Materials (GB/10295-2008)

3.2.4 Experiment Instrument and Method

The instruments include JW-I detector (Figure 3.1) for testing thermal performance of building walls and glass products, JW-II automatic itinerant detector (Figure 3.2) of building thermal temperature and heat flow, and voltage regulator.

Figure 3.1 JW-I detector

Figure3.2 JW-II detector

The experiment adopted the heat flow meter method, which uses heat flow meter and temperature detector to measure the value of heat flow passing the component and the surface temperature. Then the heat resistance and coefficient of heat transfer could be calculated for the judgement if the building meet the energy efficiency standard. During the test, heat flow meter should be put on the parts to be tested and connected with the heat flow detector by wire. Temperature sensors were placed around the heat flow meter and were connected with the temperature detector by wire. The heat flow temperature detector automatically recorded hourly values. The coefficient of heat transfer could be gotten by processing experiment data on computer software.

1) Instruments

(1) Automatic itinerant detector of building thermal temperature and heat flow (hereafter refers to “itinerant detector”). It is an intelligent data collection instrument. With the latest Single Chip Micyoco (SCM) system inside, it can measure the temperature value of 55 channels and the thermoelectric force value of 20 channels of heat flow, realize the functions of itinerant detecting or fixed-point display, storage and printing, and upload the stored data to the microcomputer for processing.

(2) WYP heat flow meter

Size: 110mm×110mm×2.5mm

Coefficient of feeler:11.6w/(m2 ·mv)(10kcal//m2 ·h ·mv)

Temperature range in use: below 100℃

Calibration error ≤5％

(3) Temperature sensor: copper-constantan thermocouple as temperature sensor

Range of temperature to be tested: -50℃ - 100℃

Resolution: 0.1℃

Uncertainty ≤＋0.5℃

(4) Digital thermometer

Resolution: 0.1℃

Measurement range: -50℃ - 199.9℃

Accuracy ≤＋(0.3%＋1℃)

2) Experiment process

(1) According to the requirements, construct the wall in the specimen holder of the detector. The size of the detector is 1000mm(width)×1000mm(height).

(2) Roast the specimen with heater until it becomes dry (Figure 3.3).

(3) Choose positions to paste heat flow sensor and temperature sensor.

(4) Paste the sensors. Use butter to neatly paste the heat flow meter pieces on the specimen and reinforce them with tape. Paste thermocouple with double faced adhesive tape or butter around the heat flow meter. Paste temperature control lines with tape around the specimen, and paste heat flow meter pieces, thermocouple and temperature control lines on the surface of specimen. Number each channel of heat flow meter and thermocouple, and connect them to the circuit detector in sequence. Connect thermocouple from Channel 2 and display the temperature signal (℃). Connect the heat flow meter in sequence from Channel 66 and display the thermoelectric force value (mv). Then close and fasten the cold box, hot box and specimen holder. Finally connect the environmental temperature control line (Figure 3.4).

(5) According to the requirements, connect the power line and control lines of cold box and hot box. After checking the lines, open the power supply of cold box and set the temperature control point inside cold box. Adjust the power value on the meter to make the temperature difference between hot and cold boxes not less than 20℃. Open the compressor of cold box with two compressors alternately working and each one working for less than 6 hours.

(6) Open the JW-II detector to observe the air temperature changes in cold box, hot box and laboratory. Display temperature and heat flow of each channel on circuit detector, and automatically store the parameters of signal in each channel in every 30 minutes. Online or offline monitor the changes in temperature and heat flow value in a total stabilization time of approximately six hours. Stop monitoring when it reaches thermal stabilization.

(7) Data processing. After the testing, upload data with special software to the microcomputer. Then use Microsoft Excel or WPS Excel to process the data, calculate each group of data, calculate the average temperature on specimen surface, average heat flow density and coefficient of heat transfer during the entire testing period, and produce the relation curve of coefficient of heat transfer and time which can visually display the variation pattern of heat transfer coefficient.

According to calculation formula of the heat flow meter method, calculate the heat resistance and heat transfer coefficient of the parts to be tested.

$R=(T_2-T_1)/E\times C$ ①

$K=1/(Ri+R+Re)$ ②

In the formula:

K – coefficient of heat transfer, $W/(m^2 \cdot K)$;

R – heat resistance of the specimen, $(m^2 \cdot K)/W$;

T_1 – temperature on the cold end, K;

T_2 – temperature on the hot end, K;

E – heat flow meter reading, mv;

C – feeler coefficient on the heat flow meter, $W/(m^2 \cdot mv)$ (scheduled at factory setting);

Ri – internal surface resistance of heat transfer, $(m^2 \cdot K)/W$;

Re – external surface resistance of heat transfer, $(m^2 \cdot K)/W$.

Figure 3.3 Roast the specimen before experiment

Figure 3.4 Paste sensors

All experiments in this project were conducted in Laboratory of Architectural Physical Environment, Civil Engineering Testing Center, Zhejiang University

3.3 Experimental Research on the Thermal Performance of Common Wall Materials in the Hot Summer and Cold Winter Zone

In this section, six types of commonly used wall materials, namely autoclaved sand aerated concrete block, sintered shale brick, coal gangue sintered brick, sintered insulating brick, composite concrete perforated brick and sintered shale hollow block, are selected as the experimental subjects, whose thermal properties are modified respectively by changing the porosity, inserting insulation materials, or other approaches. It is found through the experiments that autoclaved sand aerated concrete block and improved sintered shale hollow block have the best thermal performance. The experimental processes and corresponding conclusions for various materials are as follows.

The illustration of the experiments: the direction shown by the arrow "– – ➤" is the test direction of heat conduction.

3.3.1 Autoclaved Sand Aerated Concrete Block

Autoclaved sand aerated concrete block is a type of light perforated silicate material, mainly made of silicon materials (sand) and calcium materials (lime, cement) by adding gas forming agent (aluminum powder), blending with water, pouring, gas expanding, procuring, cutting, steaming and curing. Gas forming agent, also named air entraining agent, is a key material in making aerated concrete. In most conditions, gas forming agent is degreasing aluminum powder. The aluminum powder mixed into mortar will trigger a chemical reaction under alkaline condition. Aluminum powder is very fine, and the hydrogen produced in the reaction will form many minute bubbles to be retained in the fast-solidified concrete. The large quantity of evenly distributed minute bubbles can bring many excellent properties to aerated concrete block. The bulk density of autoclaved aerated concrete block is just one third of that of clay brick, while its insulation performance is 2-3 times better than that of clay brick and sound insulation one time better. Besides, its anti-seepage performance is also better than clay brick's, and its fire resistance is 6-8 times of that of reinforced concrete. Its construction performance is also excellent. It can not only be produced in various sizes, but also be sawed, bored, grinded and nailed like wood. Moreover, its large size results in high speed of construction. It can be used as stuffing material for various kinds of buildings. Because of its dead load of 500~700kg/m^3 and advantages of heat insulation, fire resistance and high strength, sand aerated concrete has attracted wide attention in the market. Its major sizes (length × height × thickness) include 600mm×250mm×100mm, 600mm×250mm×120mm, 600mm×250mm×200mm and 600mm×250mm×240mm.

3.3.1.1 The Thermal Performance Test of Autoclaved Sand Aerated Concrete Blocks

The tested wall made of the test brick with the wall thickness of 1000mm (W) ×1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results. The experiment has two groups.

1) Experiment 1: The size of autoclaved sand aerated concrete block is (length ×height ×thickness) 600mm×250mm×200mm. Its density is B05-class and the actual measurement of apparent density is 413kg/m^3. The tested wall is 200mm thick with 10mmcement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^{3}and its coefficient of thermal conductivity λ_1 is 0.93W/(m·k). The total thickness of wall is 220mm.

2) Experiment 2: The size of autoclaved sand aerated concrete block is (length ×height ×thickness) 600mm×250mm×200mm. Its density is B06-class and the actual measurement of apparent density is 563kg/m^3. The tested wall is 200mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3 and its coefficient of thermal conductivity λ_1 is 0.93W/(m·k). The total thickness of wall is 220mm.

3.3.1.2 The Thermal Performance Test Results of Autoclaved Sand Aerated Concrete Blocks

Table 3.1 Thermal performance of walls made of autoclaved sand aerated concrete blocks

Density Class	Test	The Heat Resistance of the Wall R((m^2 K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2 K)/W)	Heat Transfer Coefficient K (W/(m^2 K))	Equivalent Heat Conductivity λ (W/(m·K))
B05	1	1.285	1.435	0.697	0.156
B06	2	1.064	1.214	0.824	0.188

It can be seen from Table 3.1 that autoclaved sand aerated concrete block has a small coefficient of thermal conductivity, which is about one third of that of clay brick (λ=0.58 W/(m·K)) and about one fourth of that of perforated concrete brick (λ=0.738 W/(m·K)). It has light density, which is about one third of that of both clay brick (ρ=1400 kg/m^3) and perforated concrete brick (ρ=1450 kg/m^3). In the hot summer and cold winter zone, the wall with thickness of over 200mm can meet the requirement of 50% energy conservation for self-insulation wall. Working together with other insulation materials, it can meet the requirement of 65% energy conservation. Self-insulation wall made of autoclaved aerated concrete has advantages of safety, good heat insulation and shielding performance, sound insulation, fire resistance, light weight, high accuracy, high strength, anti-seepage, construction convenience, economic efficiency, same length of service life with the building and environmental friendliness. It is an excellent type of self-insulation material for exterior wall, especially suitable for the hot summer and cold winter zone. As one of the small number of self-insulation materials, it still needs further research and development.

3.3.2 Sintered Shale Brick

Sintered shale bricks are made by high-temperature firing with shale as the main raw material. Its main types include sintered shale perforated brick and sintered shale hollow brick. The common shape of holes is rectangle. The void ratio of sintered shale perforated brick reaches over 35% and that of sintered hollow brick can reach over 50%. The hole shape and hole arrangement of sintered rectangle-holed perforated brick and hollow brick improve thermal performance of products and the wall’s role in heat insulation. The design of hole distribution of sintered rectangle-holed perforated brick and hollow brick considers the thermal technical requirements for wall and adopts the principle of thermal bridge partition to make multi-row holes on the thin layer. Through multi-layer heat resistance, the heat insulation performance could be greatly improved. Simply speaking, because of the effect of hole shape and hole arrangement in the brick, the holes will form air interlayers after the construction of all. Therefore, these two types of bricks can greatly improve the wall’s performance in heat insulation, heat shielding and sound insulation. The design of the brick shape conforms to construction practice, makes construction convenient and enhances efficiency by fully considering the construction environment, conditions and conventions. The sintered rectangle-holed perforated brick and hollow brick have light weight, which can meet the requirements for construction technique of traditional buildings to the largest extent. The construction of them needs not to add specialized machines, greatly reduces workers' labor intensity, enhances construction efficiency largely and saves auxiliary materials. The structure and hole size of perforated hollow brick can meet the requirements for pipeline laying and burying as well as secondary finishing. The distance between external surface of perforated hollow brick and its adjacent rib is 40-50mm. The distance between ribs is 50-51mm, which is the best size for installing flush socket-outlet and flush switch and laying water and electricity pipelines, and is not restricted by the laying direction of brick. After grooving the wall surface, the brick will only be affected by 1/6 of vertical strength in the 240mm-thick wall, and by 1/3 in the 115mm-thick wall. The small hole size of perforated hollow brick makes it easy to be repaired. The wall strength would only be subtly affected after repairing. The main sizes (length × height × thickness) include 240mm×115mm×90mmand 240mm×240mm×115mm.

3.3.2.1 The Thermal Performance Test of Sintered Shale Brick

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) Experiment 1: The size of sintered shale perforated brick is 240mm×115mm×90mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity λ1is 0.93W/(m·k). The total thickness of wall is 260mm. The block's apparent density is 1230(kg/m^3) and its void ratio is approximately 34.3% (Figure 3.5).

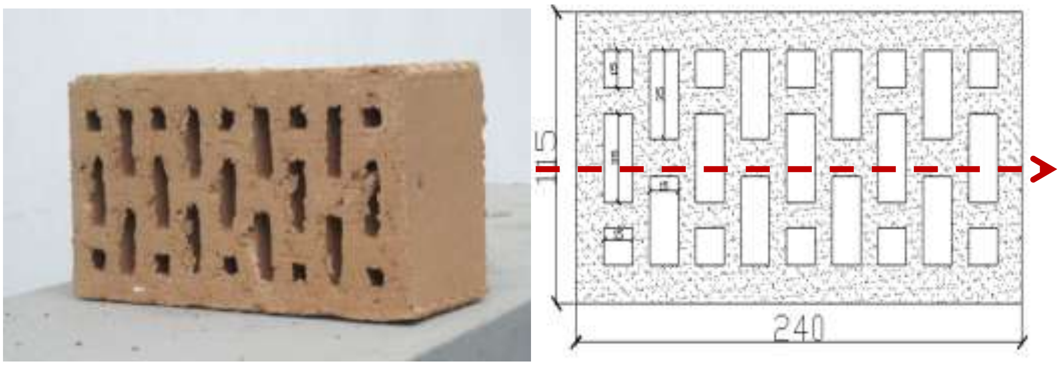


Figure 3.5 Sintered shale perforated brick

2) Experiment 2: The size of sintered shale perforated brick is 240mm×240mm×115mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity λ_1 is 0.93W/(m k). The total thickness of the wall is 260mm. The block's apparent density is 887(kg/m^3) and its void ratio is approximately 45.7% (Figure 3.6).

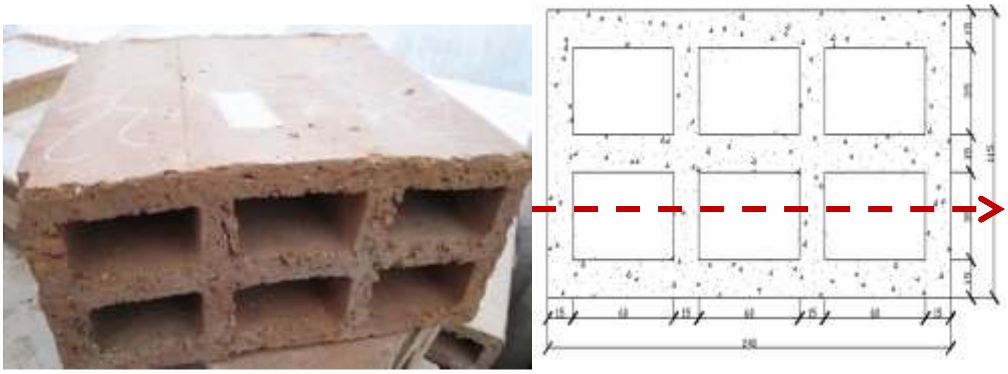


Figure 3.6 Sintered shale perforated brick

3.3.2.2 The Thermal Performance Test Results of Sintered Shale Perforated Bricks

The thermal performance parameters drawn from the above experiments are shown in Table 3.2 and Table 3.3.

Table 3.2 Physical parameters of sintered shale brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×115×90	1230	34.3	1.05
240×240×115	887	45.7	1.05

Table 3.3 Thermal performance of walls made of sintered shale bricks

Wall Block Size	Test	The Heat Resistance of the Wall R($(m^2 K)/W$)	The Heat Transfer Resistance of the Wall R_0 ($(m^2 K)/W$)	Heat Transfer Coefficient K ($W/(m^2 K)$)	Equivalent Heat Conductivity λ ($W/(m\cdot K)$)
240×115×90	1	0.556	0.706	1.42	0.449
240×240×115	2	0.553	0.683	1.46	0.470

It can be seen from Table 3.2 and Table 3.3 that the thermal conductivity coefficient of sintered shale brick is smaller than that of clay brick (λ=0.58 W/(m·K)). Its density is smaller than KP1clay perforated brick (ρ=1400 kg/m^3). Used in the 240mm wall, the thermal conductivity coefficient of sintered shale perforated brick is better than that of sintered shale hollow. Therefore, only enhancing void ratio is not bound to be beneficial. The increase of hole rows on the direction of heat transfer is also essential. In this way, better insulation performance could be acquired under the conditions of same hole shape and hole quantity. Sintered shale hollow brick and perforated brick are widely used in public and civil buildings. Their large number of advantages make them the best products to replace clay brick. They are widely applied as a new type of wall material which had good self-insulation or auxiliary insulation performance.

3.3.2.3 Major Measures to Improve the Thermal Performance of Sintered Shale Brick

Generally, the major measures to improve thermal performance of sintered shale brick include the change of shape to modularize it, reduce thickness of hole wall, stuffing insulation materials into holes and the change of thermal conductivity coefficient.

1) Change the shape to modularize it

The commonly used sintered shale perforated brick is constituted by the staggered arrangement of 32 rectangle holes (Figure 3.6). A large number of experiments have proven that this type of brick has stable thermal performance which is hard to improve. Therefore, to improve the thermal performance, it could be useful to change the shape to modularize the brick and change the size to 240mm×190mm×90mm (with holes for people to grab) which is more fit for conventions of building design and construction, to conform to 3M construction and overcome the defect caused by non-modular sizes

2) Reduce thermal conductivity coefficient

The smaller thermal conductivity coefficient of the material is, the better insulation performance it will have. Therefore, chips could be added to the raw materials. In this way, a large quantity of holes (including open holes and closed holes) could be produced inside the brick after sintering. As the thermal conductivity coefficient of air is very low, this can realize good insulation performance of the sintered brick. Besides, chips can serve as fuel to save coal and reduce pollution.

3) Stuffing insulation materials into holes

Stuffing insulation materials into holes for heat insulation can improve the thermal performance. EPS board has the advantages of light density, small coefficient of thermal conductivity, good stability (same length of service life with the building) and moderate cost, and is thus widely used to stuff blocks and hollow bricks.

3.3.2.4 The Thermal Performance Test Results of Sintered Shale Brick after Improvement

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) The thermal performance test of modularized shale sintered perforated brick

(1) Experiment 1: The size of modularized shale sintered perforated brick is 240mm×190mm×90mm. The tested wall is 240mm thick, with 10mm cement mortar plastering on both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·k). The total thickness of wall is 260mm. The block's apparent density is 1087(kg/m^3), and its void ratio is approximately 37.5% (Figure 3.7).

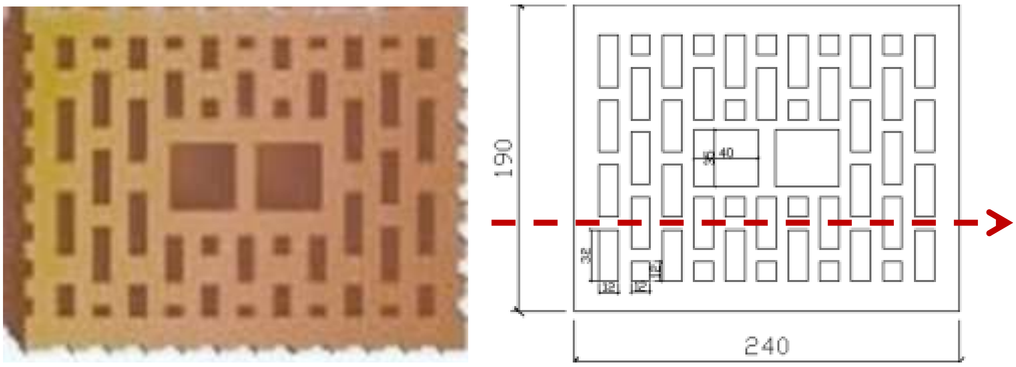


Figure 3.7 Modularized shale sintered perforated brick

(2) Experiment 2: The size of modularized shale sintered perforated brick is190mm×190mm×90mm. The tested wall is 190mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·k). The total thickness of wall is 210mm. The block's apparent density is 1402(kg/m^3), and its void ratio is approximately 32.0% (Figure 3.8).

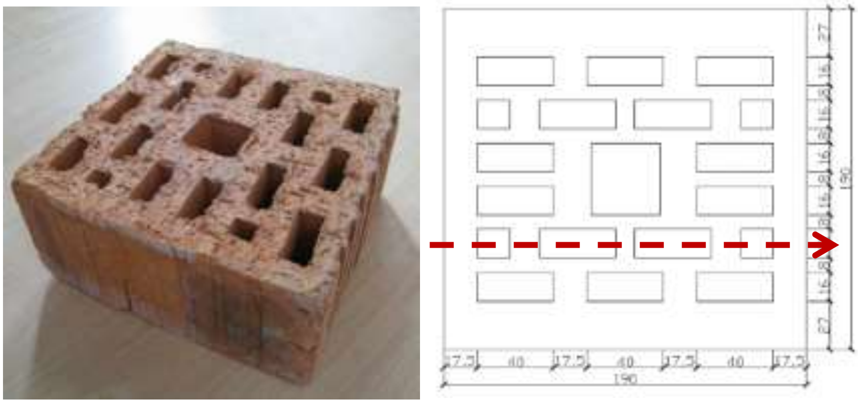


Figure 3.8 Modularized shale sintered perforated brick

The thermal performance parameters of modularized shale sintered perforated brick in the experiments are shown in Table 3.4 and Table 3.5.

Table 3.4 Physical parameters of modularized shale sintered perforated brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×190×90	1087	37.5	1.05
190×190×90	1402	32.0	1.05

Table 3.5 Thermal performance test results of the modularized shale sintered perforated brick

Wall Block Size	Test	The Heat Resistance of the Wall R((m^2 K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2 K)/W)	Heat Transfer Coefficient K (W/(m^2 K))	Equivalent Heat Conductivity λ (W/(m·K))
240×190×90	1	0.610	0.760	1.32	0.410
190×190×90	2	0.550	0.700	1.43	0.375

It can be seen from Table 3.4 and Table 3.5 that the modularization of sintered shale perforated brick can improve the thermal performance. In Experiment 1, used in 240mm wall, the density of modularized shale sintered perforated brick is lower than that of sintered shale perforated brick (ρ=1230 (kg/m^3), and its void ratio is larger than that of sintered shale perforated brick (34.3%). After improvement, the heat resistance of wall increased to 0.610(m^2 K)/W from 0.556(m^2 K)/W, the heat transfer coefficient of wall reduced to 1.32 W/(m^2 K) from 1.42 W/(m^2 K), and the equivalent heat conductivity decreased to 0.410W/ W/(m K) from 0.449 W/(m K). As for Experiment 2, used in 190mm wall, the brick's thermal performance is roughly same as the shale sintered perforated brick's performance in 240mm wall.

2) The thermal performance test of sintered shale perforated brick after adding chips

(1) Experiment 1: The major raw materials of sintered shale perforated brick are shale and chips, and the size is 240mm×115mm×90mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m k). The total thickness of wall is 260mm. The block's apparent density is 1041(kg/m^3), and its void ratio is approximately 33.5% (Figure 3.9).

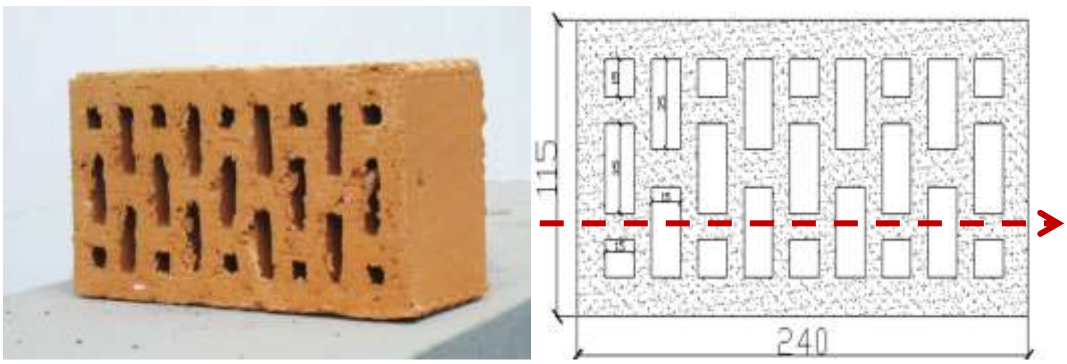


Figure 3.9 Sintered shale perforated brick

(2) Experiment 2: The major raw materials of sintered shale tailing perforated brick are shale, chips and tailing, and the size is 190mm×190mm×90mm. The tested wall is 190mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·k). The total thickness of wall is 210mm. The block's apparent density is 1216(kg/m^3), and its void ratio is approximately 33.5% (Figure 3.10).

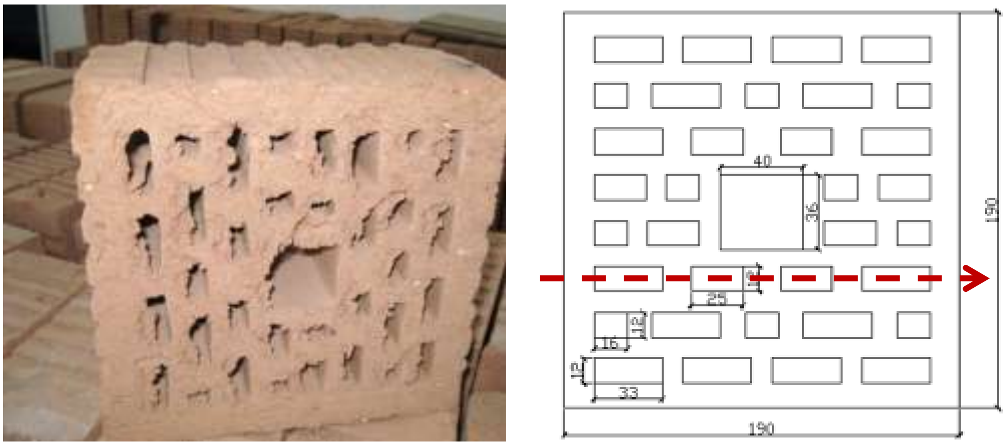


Figure 3.10 Sintered shale tailing perforated brick

The thermal performance parameters of improved shale sintered brick in the experiments are shown in Table 3.6 and Table 3.7.

Table 3.6 Physical parameters of sintered shale perforated brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×115×90	1041	33.5	1.05
190×190×90	1216	33.5	1.05

Table 3.7 The thermal performance test results of the sintered shale perforated brick

Wall Block Size	Test	The Heat Resistance of the Wall R((m^2 K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2 K)/W)	Heat Transfer Coefficient K (W/(m^2 K))	Equivalent Heat Conductivity λ (W/(m·K))
240×115×90	1	0.774	0.924	1.08	0.320
190×190×90	2	0.709	0.859	1.16	0.285

It can be seen from Table 3.6 and Table 3.7 that after adding chips the thermal performance of sintered shale perforated brick has been greatly improved. In Experiment 1, the heat resistance of wall has increased 0.210 (m^2 K)/W, the coefficient of heat transfer has decreased 0.34 W/(m^2 K), and the equivalent heat conductivity has reduced 0.129 W/(m K).

3) Experiment of thermal performance on sintered shale hollow brick after stuffing EPS boards into holes

The major size of sintered shale hollow brick is 240mm×240mm×115mm. EPS boards are stuffed inside. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity λ is 0.93W/(m·k). The total thickness of wall is 260mm.The block's apparent density is 1015(kg/m^3) and its void ratio is approximately 35.8% (Figure 3.11).

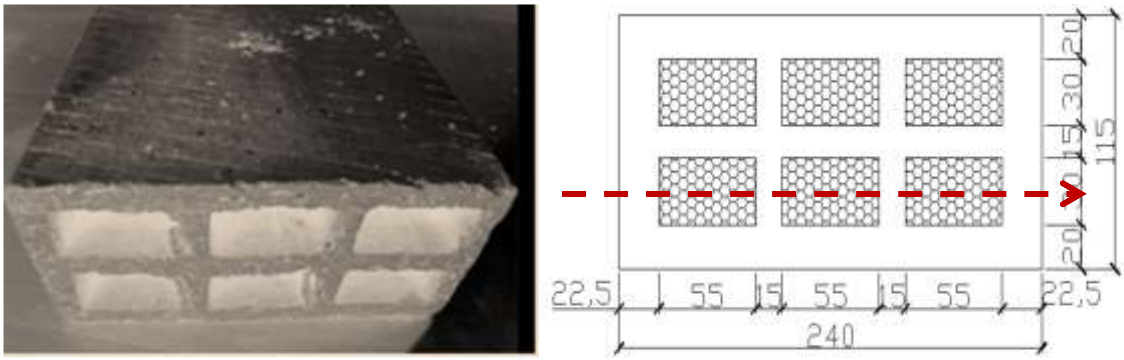


Figure 3.11 Sinteredshale hollow brick

The thermal performance parameters of improved shale sintered brick in the experiment are shown in Table 3.8 and Table 3.9.

Table 3.8 Physical parameters of sintered shale perforated brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×240×115	1041	33.5	1.05

Table 3.9 The thermal performance test results of the sintered shale perforated brick walls

Wall Block Size	The Heat Resistance of the Wall R(($m^2\cdot K$)/W)	The Heat Transfer Resistance of the Wall R_0 (($m^2\cdot K$)/W)	Heat Transfer Coefficient K (W/($m^2\cdot K$))	Equivalent Heat Conductivity λ (W/(m·K))
240×240×115	0.670	0.820	1.22	0.370

It can be seen from Table 3.8 and Table 3.9 that after stuffing EPS boards, the thermal performance of sintered shale hollow brick has been greatly improved. The heat resistance of wall has increased by 0.117 ($m^2\cdot K$)/W, and the coefficient of heat transfer and the equivalent heat conductivity has respectively decreased by 0.24 W/($m^2\cdot K$) and 0.10 W/(m·K).

3.3.3 Coal gangue sintered brick

Coal gangue sintered brick is made from coal gangues as raw material which needs to go through crushing, aging, mixing and other processes till being roasted at high temperature (usually at 900 ~ 1100℃). The sintering of gangues into bricks can promote the comprehensive utilization of coal gangues, making full use of their residual heat value, turning waste into treasure and thus saving energy; it will solve the environmental problems caused by bulk deposition of coal gangues, not only contributing to saving land and reducing construction costs, but also possessing good compressive, thermal insulation, heat-shielding, sound insulation, crack resistance and other properties. As it gangue sintered bricks widely applied to practical engineering, it is necessary to study their thermal performance. The most commonly used gangue bricks mainly include coal gangue sintered perforated brick, coal gangue modular perforated brick, coal gangue sintered hollow brick and so on, whose general sizes (length×height×thickness) are: 240mm×115mm×90mm; 240mm×190mm×90mm; 240mm×240mm×115mm, etc.

3.3.3.1 Thermal performance test of coal gangue sintered brick

The tested wall made of the test brick with the wall thickness of 1000mm (W) ×1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) Experiment 1: The size of the coal gangue sintered perforated brick is 240mm×115mm×90mm. The test adopts a 240mm-thick wall with 10mm-thick cement mortar on its both sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3, and its thermal conductivity λ_1 is 0.93W/(m k). The total wall thickness is 260mm. The void ratio is about 32.9% and the apparent density is 1209kg/m^3 (as shown in Figure 3.12).

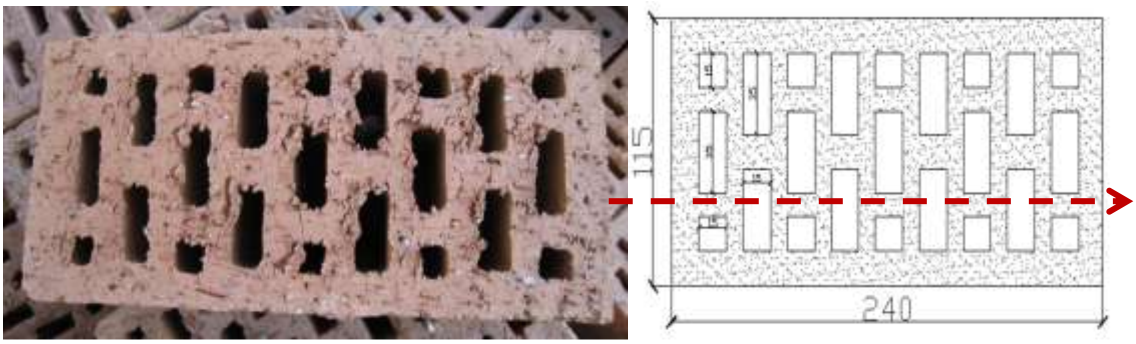


Figure 3.12 Gangue sintered perforated brick and its cross-section

2) Experiment 2: The coal gangue sintered modular perforated brick has the size of 240mm×190mm×90mm, and the test uses a 240mm-thick wall with 10mm-thick cement mortar on its both sides. The dry density ρ of masonry cement mortar is 1800kg/m^3, and its thermal conductivity λ_1 is 0.93W/(m·k). The total wall thickness is 260mm. The void ratio is about 33.4% and the apparent density is 1223kg/m^3 (as shown in Figure 3.13).

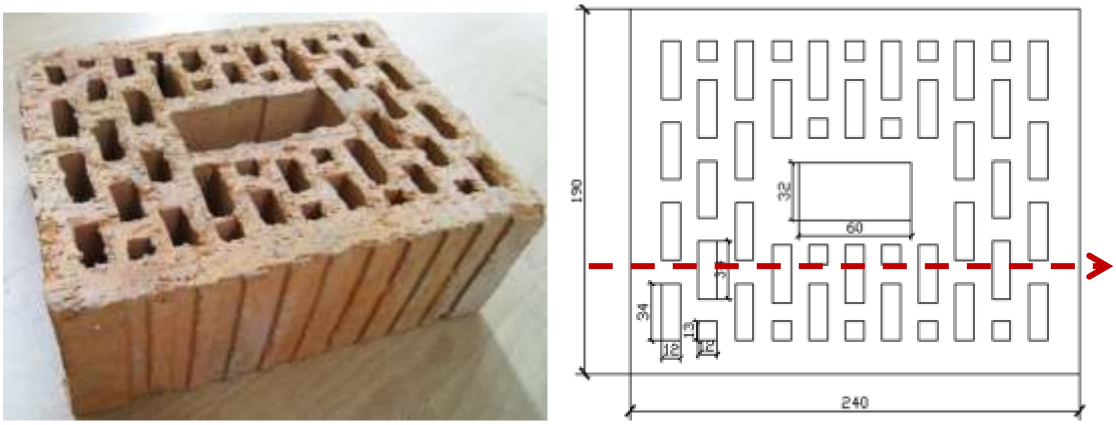


Figure 3.13 Coal gangue sintered modular perforated brick

3) Experiment 3: The coal gangue sintered modular perforated brick has the size of 240mm×190mm×90mm. The test uses a 190mm-thick wall with 10mm-thick cement mortar on its both sides. The dry density ρ of masonry cement mortar is 1800kg/m^3, and its thermal conductivity λ_1 is 0.93W/(m·k). The total wall thickness is 210mm. The void ratio is about 33.4% and the apparent density is 1223kg/m^3 (as shown in Figure 3.14).

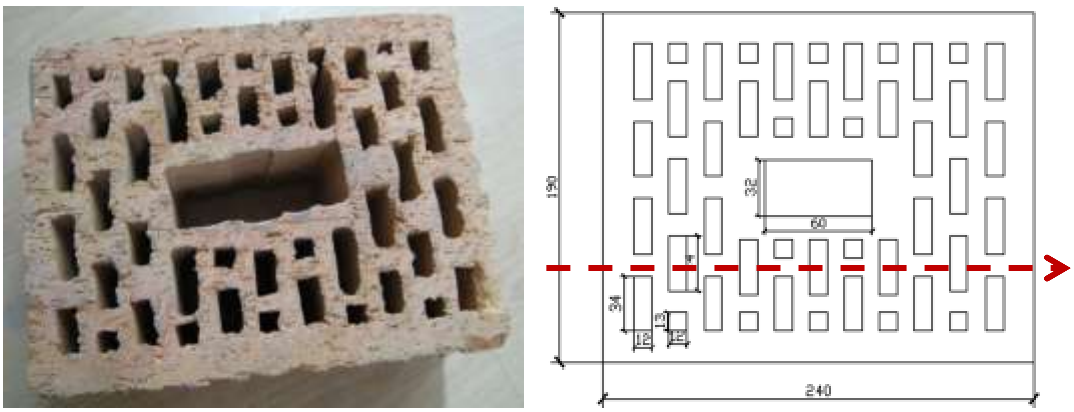


Figure 3.14 Coal gangue sintered modular perforated brick

The thermal performance parameters of coal gangue sintered brick measured by the above three groups of experiments are as follows (see Table 3.10 and Table 3.11).

Table 3.10 Physical parameters of coal gangue sintered perforated brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×115×90	1209	32.9	1.05
240×190×90	1223	33.4	1.05
240×190×90	1223	33.4	1.05

Table 3.11 The thermal performance test results of the sintered gangue perforated brick walls

Wall Block Size	Test	The Heat Resistance of the Wall $R((m^2 \cdot K)/W)$	The Heat Transfer Resistance of the Wall $R_0\,((m^2 \cdot K)/W)$	Heat Transfer Coefficient $K\,(W/(m^2 \cdot K))$	Equivalent Heat Conductivity $\lambda\,(W/(m \cdot K))$
240×115×90	1	0.569	0.719	1.39	0.438
240×190×90	2	0.610	0.760	1.32	0.410
240×190×90	3	0.576	0.726	1.38	0.340

It can be seen from Table 3.10 and Table 3.11 that the heat conductivities of coal gangue sintered perforated brick and coal gangue sintered modular perforated brick are less than that of clay brick (λ = 0.58W/(m·K)) and their densities are less than that of KP1 clay perforated brick (ρ=1400kg/m^3). When used in a 240mm-thick wall, sintered coal gangue modular perforated brick has better thermal performance than sintered coal gangue perforated brick, and when used in a 190mm-thick wall, its thermal performance is equivalent to that of sintered gangue perforated brick in a 240mm-thick wall. Sintered coal gangue modular perforated brick possesses good thermal performance, and it has overcome the drawbacks brought by the non-modular size with its specification in line with the 3M architectural series, which can meet both 240mm-thick and 190mm-thick walls that are quite commonly adopted, thus conforming to the customary architectural design and construction practices.

3.3.3.2 The Thermal performance test of coal gangue sintered hollow brick

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) Experiment 1: The gangue sintered hollow brick has the size of 240mm × 240mm × 115mm, and the test uses a 240mm-thick wall with 10mm-thick cement mortar on its both sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3 and its thermal conductivity λ_1 is 0.93W/(m·k). The total thickness of the wall is 260mm. The void ratio is about 45.7% and the apparent density is 926 kg/m^3 (as shown in Figure 3.15).

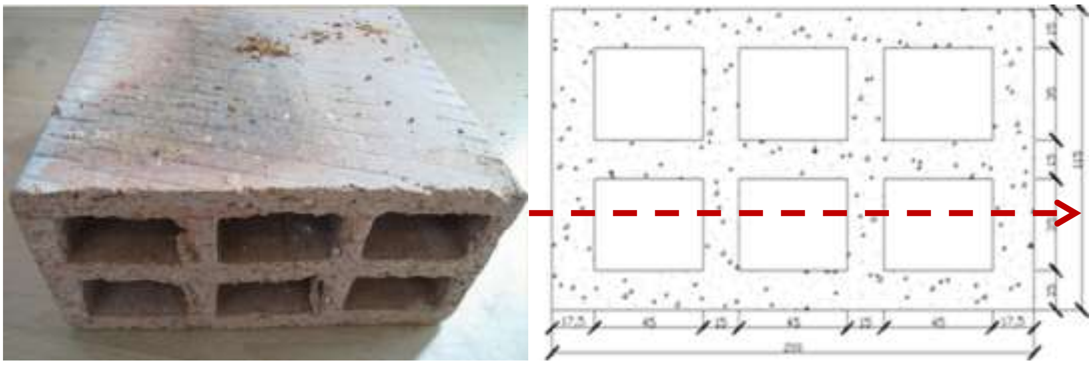


Figure 3.15 Coal gangue sintered modular perforated brick

2) Experiment 2: The coal gangue sintered hollow brick is filled with a row of EPS boards with the size of 240mm×240mm×115mm. The test uses a 240mm-thick wall with 10mm-thick cement mortar applied to its both sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3 and its thermal conductivity λ_1 is 0.93W/(m·k). The total thickness of the wall is 260mm. The apparent density of the block is 929 (kg/m^3) and the void ratio is about 45.7% (as shown in Figure 3.16).

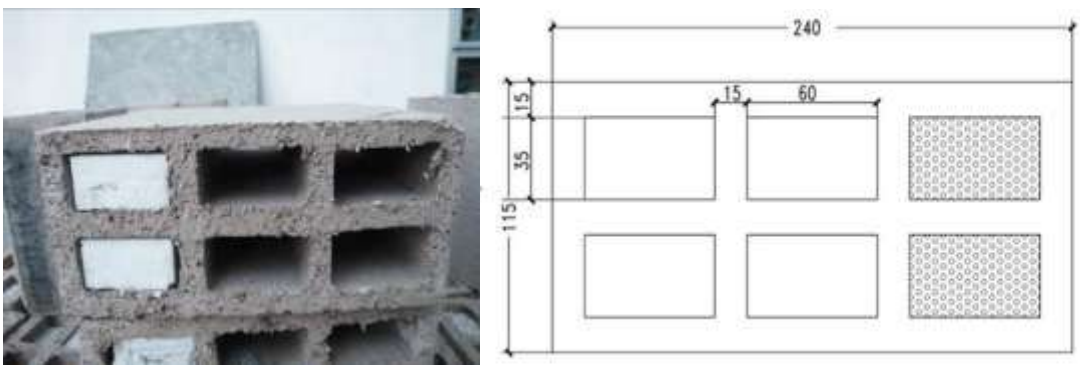


Figure 3.16 Coal gangue sintered hollow brick (filled with EPS) and its cross-section

3) Experiment 3: The size of the coal gangue sintered hollow brick (filled with EPS) is 200mm×200mm×115mm. The test uses a 200mm-thick wall with 10mm-thick cement mortar applied to each of its sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3 and its thermal conductivity λ_1 is 0.93W/(m·k). The total wall thickness is 220mm. The apparent density of the brick is 925 (kg/m^3) and its void ratio is about 50% (as shown in Figure 3.17).

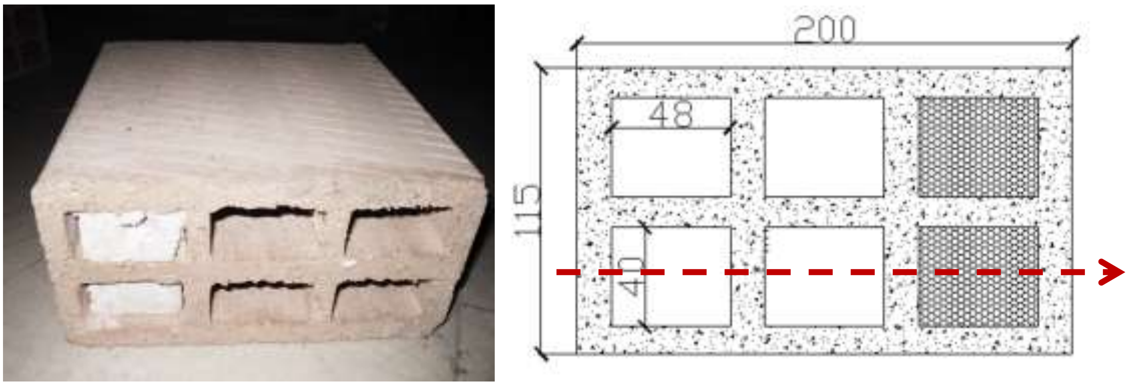


Figure 3.17 Sintered shale hollow brick

The thermal performance parameters of coal gangue sintered hollow brick measured by the above three groups of experiments are as follows (see Table 3.12 and Table 3.13).

Table 3.12 Physical parameters of sintered gangue perforated brick

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
240×240×115	1209	32.9	1.05
240×240×115	1223	33.4	1.05
200×200×115	1223	33.4	1.05

Table 3.13 The thermal performance test results of sintered gangue perforated brick walls

Wall Block Size	Test	The Heat Resistance of the Wall R((m^2·K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2·K)/W)	Heat Transfer Coefficient K (W/(m^2·K))	Equivalent Heat Conductivity λ (W/(m·K)
240×240×115	1	0.569	0.719	1.39	0.438
240×240×115	2	0.700	0.850	1.18	0.350
200×200×115	3	0.658	0.808	1.24	0.315

It can be seen from Table 3.12 and Table 3.13 that coal gangue sintered hollow brick also has good thermal property with its heat conductivity less than that of clay brick (λ = 0.58 W/(m·K)) and its density less than that of KP1 clay perforated brick (ρ=1400 kg m^3).

3.3.4 Sintered insulating brick

Sintered insulating brick is made from crushed shale as raw material which needs to be mixed with river sludge and paper mill sludge and go through mixing, homogenization, vacuum extrusion molding, waste-heat drying and sintering at high temperature. Paper mill sludge is rich in wood fiber and some organic matters, and after firing at high temperature, a variety of minerals in the raw material will conduct a series of reactions including decomposition, combination, recrystallization and diffusion and finally a large number of tiny holes are formed, which will enhance the heat-insulating performance of the sintered brick and reduce the energy consumption in use of the buildings; it can also lower the energy consumption in production through making the most of the heat generated by organic fiber combustion, thus producing social and economic benefits of environmental protection and energy conservation. It can not only solve the disposal problem of urban industrial and domestic sludge, which will save cultivated land and reduce the costs of sludge landfill or incineration, but also contribute to the technology of making building materials such as new wall materials and sidewalk brick.

3.3.4.1 The thermal performance test of sintered insulating brick

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) Experiment 1: The size of sintered insulating brick is 240mm×115mm×90mm. The test uses a 240mm-thick wall with 10mm-thick special masonry mortar applied to its both sides. The thermal conductivity λ_1 of the special masonry mortar is 0.15W/(m·K), and the total wall thickness is 260mm. The apparent density of the insulating brick is 903 (kg/m^3), and its void ratio is about 34.9% (as shown in Figure 3.18).

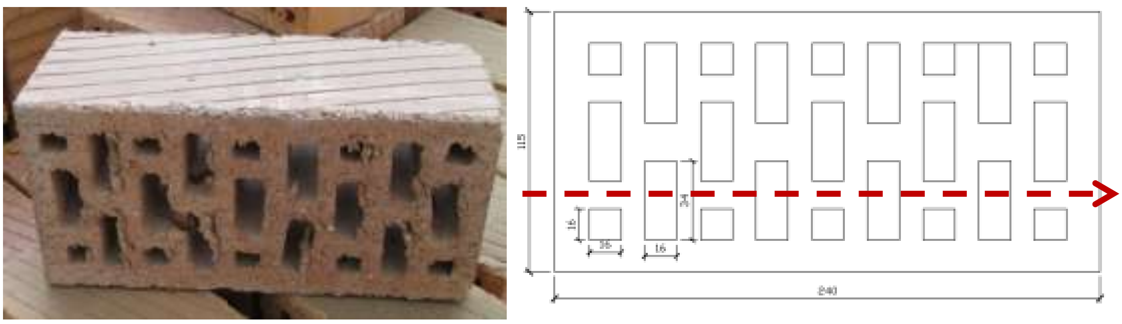


Figure 3.18 Sintered insulating brick

2) Experiment 2: The size of the sintered insulating brick is 240mm×115mm×90mm. The test uses a 240mm-thick wall with 10mm-thick cement mortar applied to its both sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3, and its thermal conductivity λ_1 is 0.93W/(m·k). The total thickness of the wall is 260 mm. The apparent density of the insulating brick is 1011 (kg/m^3), and its void ratio is about 30.1% (as shown in Figure 3.19).

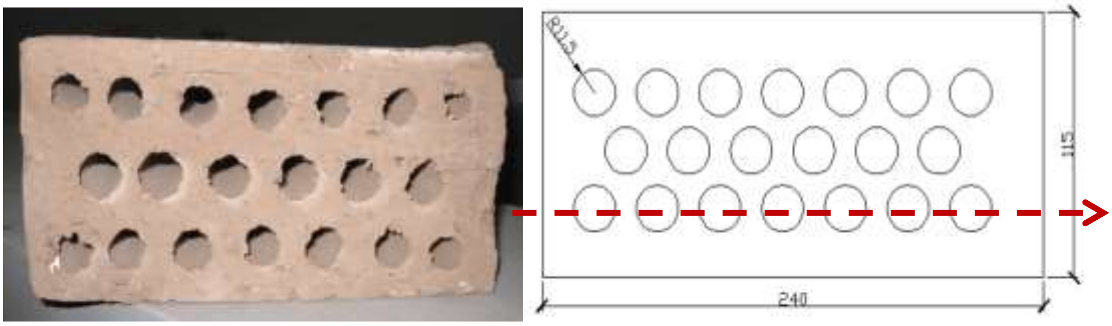


Figure 3.19 Sintered insulating brick

3) Experiment 3: The size of the sintered insulating brick is 240mm×115mm×90mm. The test uses a 240mm-thick wall with 10mm-thick special masonry mortar applied to its both sides. The thermal conductivity λ_1 of the special masonry mortar is 0.15W/(m·K), and the total wall thickness of 260mm. The apparent density of the insulating brick is 1022(kg/m^3), and its void ratio is about 27.7% (as shown in Figure 3.20).

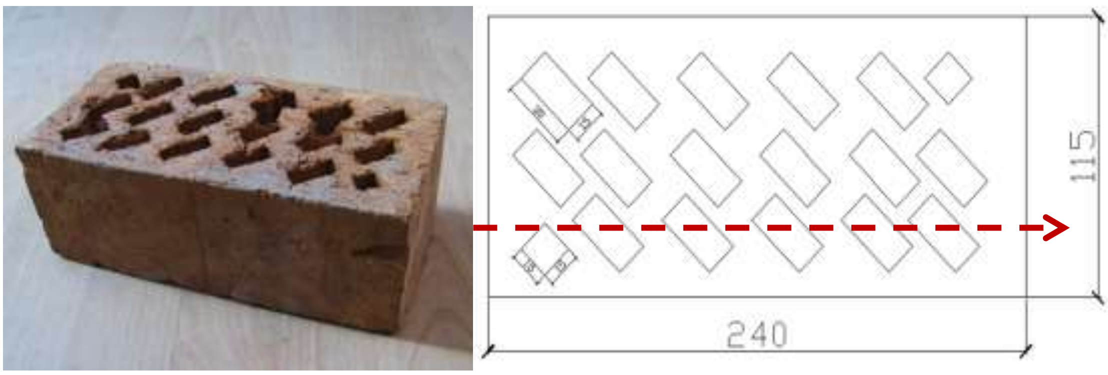


Figure 3.20 Sintered insulating brick and its cross-section

3.3.4.2 The thermal performance test results of sintered shale brick

The thermal performance parameters of the sintered insulating bricks of different hole types tested in the above three groups are as follows (see Table 3.14 and Table 3.15).

Table 3.14 The physical parameters of the sintered insulating bricks

Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c(KJ/kgk)
240×115×90	903	34.9	1.05
240×115×90	1011	30.1	1.05
240×115×90	1022	27.7	1.05

Table 3.15 The thermal performance test results of the sintered insulating brick walls

Size	Test	The Heat Resistance of the Wall R((m^2 K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2 K)/W)	Heat Transfer Coefficient K (W/(m^2 K))	Equivalent Heat Conductivity λ (W/(m·K)
240×115×90	1	0.698	0.848	1.18	0.425
240×115×90	2	0.56	0.71	1.41	0.44
240×115×90	3	0.60	0.750	1.34	0.510

It can be seen from Tables 3.14 and 3.15 that sintered insulating brick possesses the characteristics such as low density and good thermal performance. As for insulating bricks with different hole types, the insulating brick in Experiment 1 with the lowest apparent density and the highest void ratio has the best thermal performance, followed by that in Experiment 3, and the sintered insulating brick with circular holes in Experiment 2 shows the worst thermal performance.

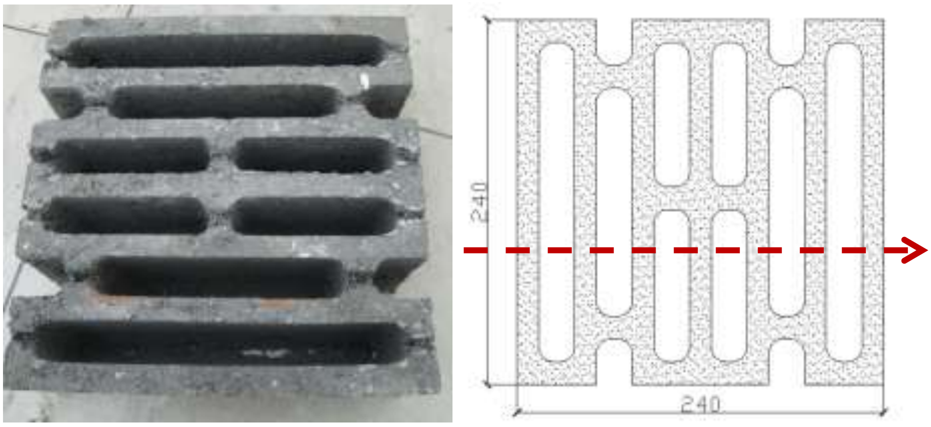
3.3.5 Composite concrete perforated brick

With cement as the cementitious material and sand, stone, etc. as the main aggregate, concrete perforated brick that has rows of small holes is made through adding water, mixing, molding and curing. Its main size is 24mm×115mm×90mm and it has appropriate liner brick matching. Using concrete perforated brick, which has the features of light weight, high strength, good thermal insulating performance, good durability, less contraction distortion, regular appearance and so on, will have low energy consumption in production and contribute to land saving, waste utilization and convenience in construction. Without destroying farmland or using fire coal, its production only consumes less than half of that of sintered clay brick, in line with the national economic and energy-saving development strategy. In addition to good frost resistance, it also possesses regular size, which is conducive to masonry flatness control. With good construction adaptability, the brick has light weight, thus enhancing the convenience of masonry building, saving mortar, reducing construction intensity and foundation load, and increasing usable areas without adding to project costs. However, when the qualities of products, masonry and construction are not well controlled, it is also prone to “cracks”, “infiltration”, “hotness”, “coldness” and other drawbacks, especially the cracking problem.

3.3.5.1 The thermal performance test of composite concrete perforated brick

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

The size of the composite concrete perforated brick is 240mm×240mm×90mm. The test uses a 240mm-thick wall with 10mm-thick cement mortar applied to its both sides. The dry density ρ of the masonry cement mortar is 1800kg/m^3, an its thermal conductivity λ is 0.93W/(m·K). The total wall thickness is 260mm. The void ratio is about 41%, and the apparent density is 1244 kg/m^3 (as shown in Figure 3.21).



3.21 Composite concrete perforated brick

The thermal performance parameters of the composite concrete perforated brick measured by the test are as follows (see Table 3.16).

Table 3.16 The thermal performance test results of the composite concrete perforated brick

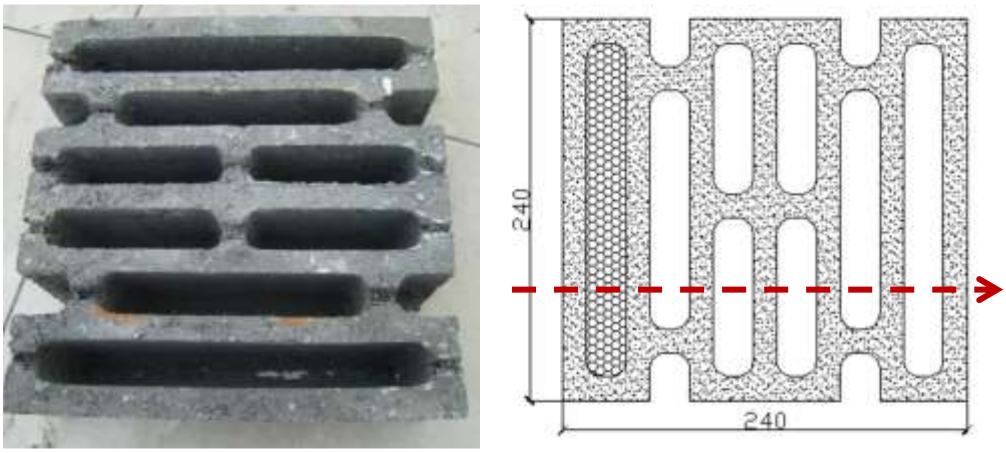
Size	The Heat Resistance of the Wall R((m^2·K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2·K)/W)	Heat Transfer Coefficient K (W/(m^2·K))	Equivalent Heat Conductivity λ (W/(m·K))
240×240×90	0.603	0.753	1.33	0.429

It can be seen from Table 3.16 that the composite concrete perforated brick has lower density than that of the KP1 clay perforated brick (ρ= 1400 kg/m^3), lower thermal conductivity than that of the KP1 clay perforated brick (λ = 0.58 W/(m·K)), and higher void ratio than that of the KP1 clay perforated brick (the void ratio of the KP1 clay perforated brick is about 30%), so it can replace clay brick in public and residential buildings and be widely used as a new wall material with good self-insulation or auxiliary insulation effects.

3.3.5.2 The thermal performance test of the improved composite concrete perforated brick

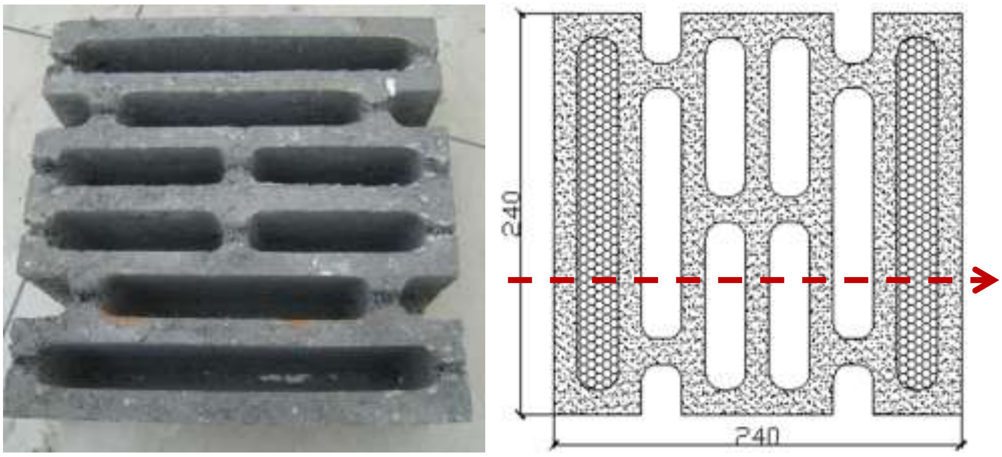
The thermal performance of the composite concrete perforated brick can be effectively improved by the adiabatic treatment of filling it with EPS boards or the optimal design of its hole type, void ratio and hole arrangement. Here, the composite concrete perforated bricks are respectively filled with one row and two rows of EPS boards to test their thermal performances again.

1) Experiment 1: The EPS board is inserted into the first row of the holes of the composite concrete perforated brick, whose size is 240mm×240mm×90mm. The test uses a 240mm-thick wall with 10mm-thick special cement mortar applied to its both sides. The thermal conductivity λ of the cement mortar is 0.93 W/(m·k), and the total thickness of the wall is 260 mm. The apparent density of the composite concrete perforated brick is 1245 (kg/m^{3}), and its void ratio is about 41% (as shown in Figure 3.22).



3.22 Composite concrete perforated brick (plugged with one row of EPS board)

2) Experiment 2: The EPS board is inserted into the two outward rows of holes of the composite concrete perforated brick whose size is 240mm×240mm×90mm. The test uses a 240mm-thick wall with 10mm-thick special cement mortar applied to its both sides. The thermal conductivity λ of the cement mortar is 0.93W/(m·k), and the total wall thickness is 260mm. The apparent density of the composite concrete perforated brick is 1247(kg/m^{3}), and its void ratio is about 41% (as shown in Figure 3.23).



3.23 Composite concrete perforated brick (plugged with two rows of EPS boards)

The thermal performance parameters of the above two types of improved composite concrete perforated bricks are as follows (see Table 3.17).

Table 3.17 Thermal performance test results of the improved composite concrete perforated bricks

Wall Block Size	Test	The Heat Resistance of the Wall R($(m^2 \cdot K)/W$)	The Heat Transfer Resistance of the Wall R_0 ($(m^2 \cdot K)/W$)	Heat Transfer Coefficient K ($W/(m^2 \cdot K)$)	Equivalent Heat Conductivity λ ($W/(m \cdot K)$)
240×240×90	1	0.642	0.792	1.26	0.401
240×240×90	2	0.699	0.849	1.18	0.366

It can be seen from Table 3.17 that the thermal performance of the composite concrete perforated brick filled with EPS boards has been improved. Especially in Experiment 2, the thermal performance of the composite concrete perforated brick with two rows of EPS boards has been obviously enhanced.

3.3.6 Sintered Shale Hollow Block

The main raw materials of sintered shale hollow block are natural inorganic silicate shale and quartz tailing sand. The blocks are formed under high vacuum, high pressure and high temperature. In the production process, no waste is used (e.g. industrial waste residue, domestic waste). Therefore, they have the advantages of good heat insulation performance, sound insulation, waterproof, high strength, high void ratio, light weight, elegant appearance and great durability, and thus become a promising new type of wall material which replaced normal clay bricks and have been used in building, extending and reconstructing non-loading walls inside and outside industrial and civil buildings. The masonry method is generally horizontal. The large size of blocks makes construction convenient and fast, and is conducive to saving mortar and reducing the overall construction costs. Therefore, it is necessary to discuss its thermal performance and values in building energy conservation. It main sizes (length × height × width) include 290mm×240mm×190mm, 290mm×240mm×90mm, 290mm×190mm×190mm and 290mm×190mm×90mm.

3.3.6.1 Thermal Performance test of Sintered Shale Hollow Blocks

The tested wall made of the test brick with the wall thickness of 1000mm (W) × 1000mm (H) in the specimen holder shall be dried before testing so as to avoid the influence of moisture on the test results.

1) Experiment 1: The size of sintered shale hollow block is 290mm×240mm×190mm. The test adopts a 240mm-thick wall with 10mm-thick cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m k). The total thickness of the wall is 260mm. The apparent density of block is 775(kg/m^3) and the void ratio is approximately 61.9% (Figure 3.24).

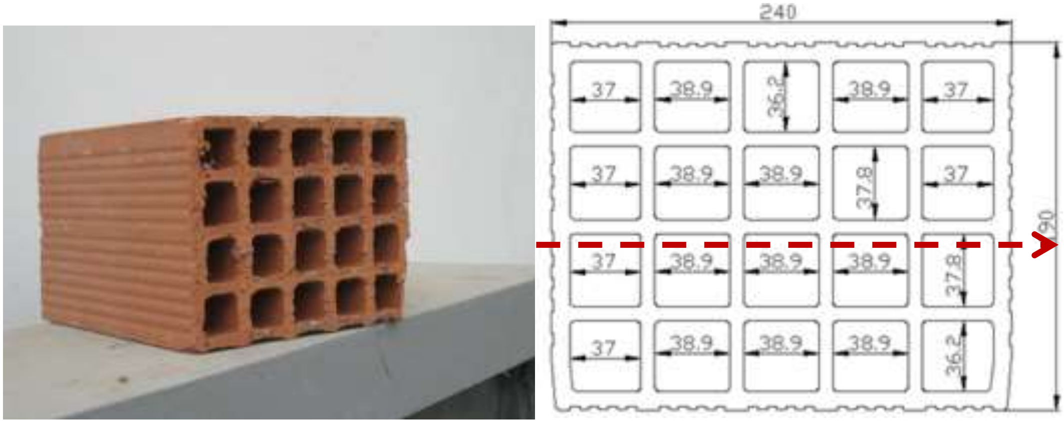


Figure 3.24 Sintered shale hollow block

2) Experiment 2: The size of sintered shale hollow block is 290mm×240mm×90mm. The tested wall is 240mm thick with 10mm-thick cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m k). The total thickness of the wall is 260mm. The apparent density of block is 887(kg/m^3) and the void ratio is approximately 50.0% (Figure 3.25).

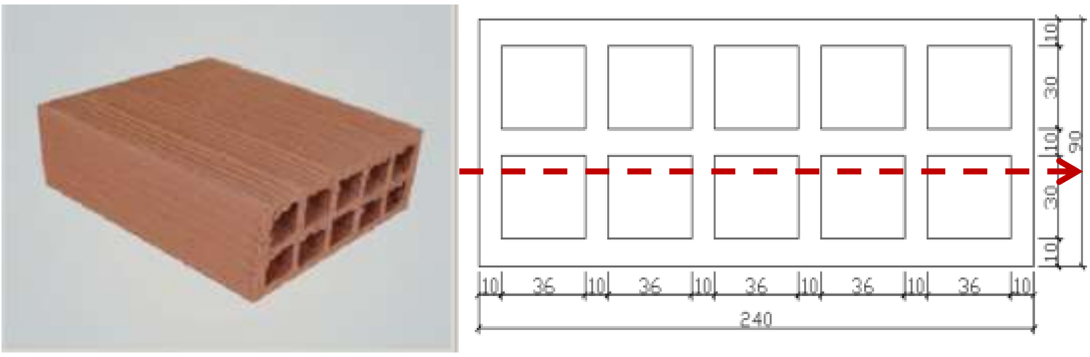


Figure 3.25 Sintered shale hollow block and its sectional view

3) Experiment 3: The size of sintered shale hollow block is 290mm×190mm×190mm. The tested wall is 190mm thick with 10mm-thick cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·k). The total thickness of the wall is 210mm. The apparent density of block is 814(kg/m^3) and the void ratio is approximately 57.4% (Figure 3.26).

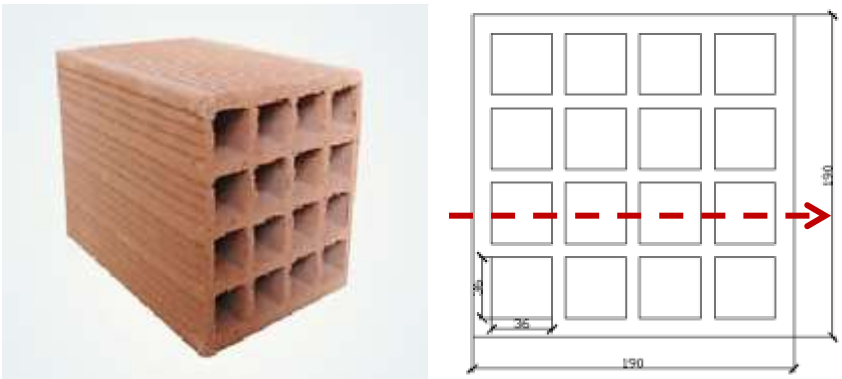


Figure 3.26 Sintered shale hollow block and its sectional view

4) Experiment 4: The size of sintered shale hollow block is 290mm×190mm×90mm. The tested wall is 190mm thick with 10mm-thick cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·k). The total thickness of the wall is 210mm. The apparent density of block is 775(kg/m3) and the void ratio is approximately 61.9% (Figure 3.27).

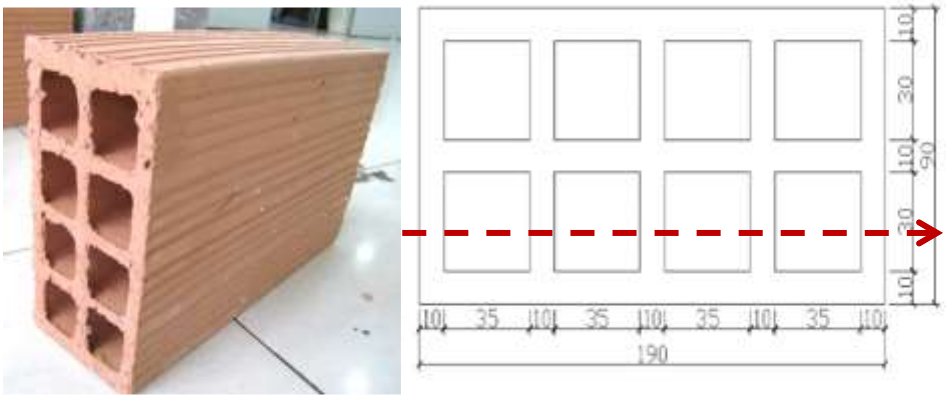


Figure 3.27 Sintered shale hollow block and its sectional view

3.3.6.2 The Thermal Performance Test Results of Sintered Shale Hollow Brick

The parameters of the above four groups of experiments are shown in Table 3.18 and 3.19.

Table 3.18 Physical parameters of sintered shale hollow block

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
290×240×190	775	61.9	1.05
290×240×90	887	50	1.05
290×190×190	814	57.4	1.05
290×190×90	947	49.1	1.05

Table 3.19 Thermal performance of walls made of sintered shale hollow block

Wall Block Size	The Heat Resistance of the Wall $R((m^2 \cdot K)/W)$	The Heat Transfer Resistance of the Wall R_0 $((m^2 \cdot K)/W)$	Heat Transfer Coefficient K $(W/(m^2 \cdot K))$	Equivalent Heat Conductivity λ $(W/(m \cdot K))$
290×240×190	0.663	0.813	1.23	0.374
290×240×90	0.640	0.790	1.27	0.389
290×190×190	0.559	0.709	1.41	0.354
290×190×90	0.520	0.670	1.49	0.382

From Table 3.18 and Table 3.19, it can be seen that sintered shale hollow block has smaller density than KP1 clay perforated brick (ρ=1400 kg/m3), smaller coefficient of thermal conductivity than clay perforated brick (λ=0.58 W/(m·K)) and higher void ratio than KP1 clay perforated brick (void ratio approximately 30%). Therefore, sintered shale hollow blocks can replace clay bricks in the construction of multi-storey and high-rise buildings and be applied and popularized a new type of wall material with good performance of heat insulation or auxiliary heat preservation.

3.3.7 Main Factors Affecting Thermal Performance of Sintered Shale Hollow Block and Improvement Measures

3.3.7.1Main Factors Affecting Thermal Performance of Sintered Shale Hollow Block

Heat transfer refers to the phenomenon that heat is transferred within one object or between objects. Where there is temperature difference in different parts of one object or between objects, there is heat transfer. According to the mechanism, heat transfer can be divided into three basic types, namely conduction, convection and radiation. However complex the heat transfer process is, it is the combination of these three types. Generally, single conduction phenomenon only exists in dense solidity, while common building materials more or less have some holes inside. All of the three types of phenomena exist in the holes. In the sintered shale hollow block, heat transfer mainly consists of conduction on shale surface, convection of air in holes and radiation on internal and external hole surface. When sintered shale hollow block is used to construct envelope, the heat exchange with outdoor environment is achieved by the synthetic action of radiation and convection.

3.3.7.2 Major Measures to Improve the Thermal Performance of Sintered Shale Hollow Block

Generally, the measures to improve thermal performance of sintered shale hollow block include enhancement of void ratio, increasing the number of the rows of holes, reasonable hole arrangement, reduction of thickness of hole wall and filling insulation material into the holes.

1) Sintered shale hollow block with EPS board inside

EPS board can be molded by heating after being heated and pre-foamed by expandable polystyrene beads. It is constituted by fully-enclosed polyhedral honeycombs whose diameter is 0.2-0.5mm and wall thickness is 0.001mm. EPS consist of approximately 98% air and 2% polystyrene. The air entrapped in the honeycomb is a kind of poor conductor and plays a decisive role in the heat insulation performance of foam plastics. Unlike foam plastics containing other gases (e.g. Freon fills the honeycomb of newly-made polyurethane foam plastics), air in the polystyrene foam plastics can stay in the honeycomb for long without any change. In this way, the heat insulation performance can stay stable for long. Besides, it has the following characteristics: (1) low density and thermal conductivity coefficient. When the density of EPS is 18-20(kg/m^3), the coefficient of thermal conductivity is 0.042W/(m K). Stuffing EPS board into sintered shale hollow block will not add to the weight and can effectively hinder the heat exchange and transfer by convection in air of the holes to improve thermal performance; (2) good durability. EPS board has good durability as long as it is not directly exposed to outdoor climatic conditions. Putting it into the holes of sintered shale hollow block can effectively protect the structure. Using it in building envelope can make the envelope possess the same length of service life with the building.

Because of the above advantages and moderate cost, EPS board is widely used as insulating and stuffing material for bricks and blocks.

2) Increase the number of the rows of holes and make rational arrangement for holes

Under the condition of same void ratio, the thermal conductivity coefficient of a hollow block with disorderly arranged holes will be smaller than that of hollow bricks which have orderly arrangement of holes. The difference between them increases as the hole length of hole increases. According to previous studies, when the thickness of air layer exceeds 10mm, heat exchange by convection will occur in the air layer and become increasingly obvious with the increase of thickness of air layer. The air layer of sintered shale hollow block is nearly 40mm, therefore, the priority is to hinder heat exchange by convection. Reducing the hole size of hollow block, increasing the line number of holes, staggered arrangement of holes and dividing the thick air layer into several thin air layers can to certain extent hinder air convection and improve thermal performance of hollow block. Therefore, it can be seen that the number of the lines of holes and their arrangement directly affect the coefficient of thermal conductivity. Arranging the holes in an overlapping manner on the direction vertical to heat flow and dividing a large hole into several small holes can increase heat resistance and decrease thermal conductivity coefficient. In other words, the large number of rows of holes on the direction of heat flow, the better thermal performance.

3.3.7.3 The Thermal Performance Test of Improved Sintered Shale Hollow Block

1) Experiments on sintered shale hollow block with EPS board inside

(1) Experiment 1: The size of sintered shale hollow block is 290mm×240mm×190mm. EPS board is stuffed into the first row of holes. The EPS board's dry density is 18-20(kg/m^3) and its coefficient of thermal conductivity λ_1 is 0.93W/(m k). The tested wall is 240mm thick with 10mm cement mortar

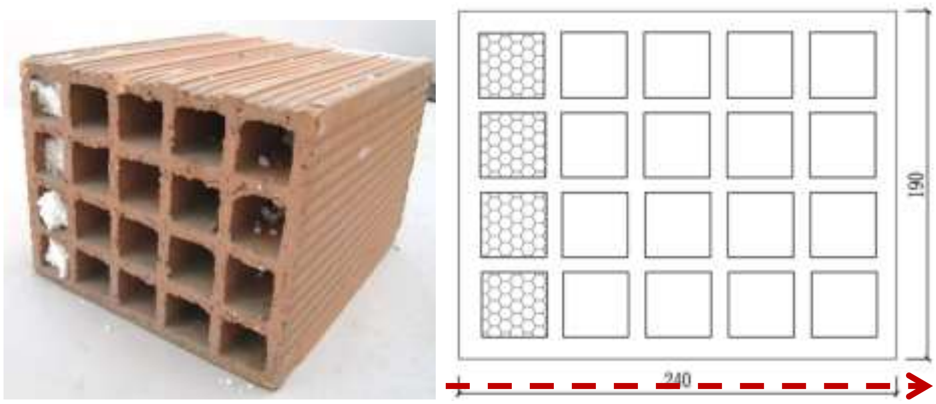


Figure 3.28 Sintered shale hollow block (with a row of EPS boards inside)

plastered on both sides. The cement mortar's dry density ρ is 1800kg/m3, and its coefficient of thermal conductivity λ1 is 0.93W/(m·k). The total thickness of wall is 260mm. The apparent density of block is 756(kg/m^3)(Figure 3.28).

(2) Experiment 2: The size of sintered shale hollow block is 290mm×240mm×190mm. EPS board

(4) Experiment 4: The size of sintered shale hollow block is 290mm×240mm×190mm. EPS board is stuffed into all five rows of holes. The EPS board's dry density is 18-20(kg/m^3) and its coefficient of thermal conductivity λ_1 is 0.93W/(m·K). The tested wall is 240mm thick with 10mm cement mortar plastered on both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity λ1 is 0.93W/(m·K). The total thickness of wall is 260mm. The apparent density of block is 791(kg/m^3) (Figure 3.31).

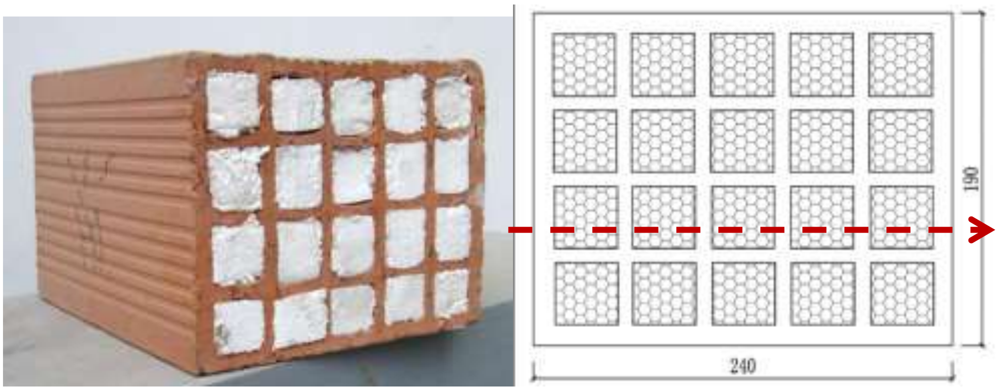


Figure 3.31 Sintered shale hollow block (with five rows of EPS boards inside)

The thermal performance parameters of the sintered shale hollow blocks measured in the above four experiments are shown in Table 3.20.

Table 3.20 Thermal performance of wall after stuffing EPS boards inside the blocks

Wall Block Size	Test	Apparent Density (kg/m^3)	The Heat Resistance of the Wall R((m^2·K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2·K)/W)	Heat Transfer Coefficient K (W/(m^2·K))	Equivalent Heat Conductivity λ (W/(m·K))
290×240×190 (with EPS board inside)	1	756	0.707	0.857	1.17	0.350
	2	781	0.862	1.012	0.99	0.286
	3	787	1.110	1.260	0.79	0.220
	4	791	1.146	1.296	0.77	0.214

It can be seen from Table 3.20 that stuffing heat insulation materials into block holes can significantly improve thermal performance of wall and result in obvious increase of heat resistance of block and decrease of equivalent heat conductivity. Among all experiments, Experiment 3 and 4 have most significant effects. The equivalent heat conductivity had decreased 0.154-0.160 W/(m·K), and the heat transfer coefficient of wall has decreased 0.44-0.46 W/(m^2·K). The differences are obvious.

However, this measure also has its disadvantages. First, the technique of stuffing EPS boards into hollow blocks hasn't been mechanized yet and is at the phase of manual work, which cannot realize mass production and will therefore reduce production efficiency and fail to meet market demands. Second, this measure will increase the production cost, thus reducing its competitiveness in market.

2) Experiments on sintered shale hollow block with increased rows of holes and rational arrangement of holes

(1) Experiment 1: The size of sintered shale hollow block is 290mm×240mm×190mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m ·k). The total thickness of wall is 260mm. The apparent density of block is 959(kg/m^3) (Figure 3.32).

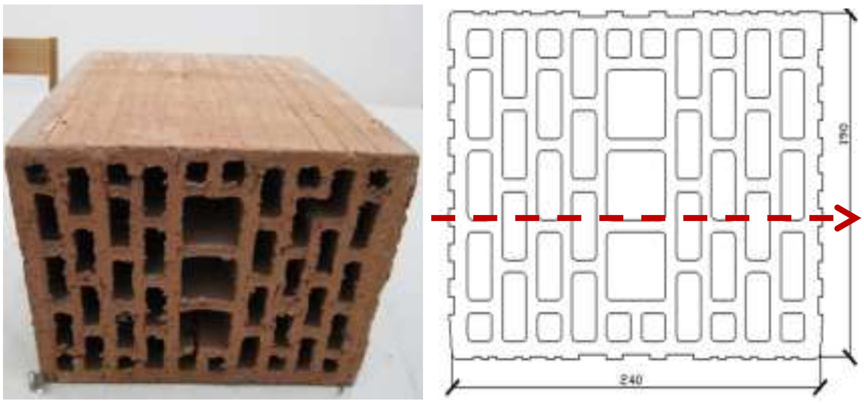
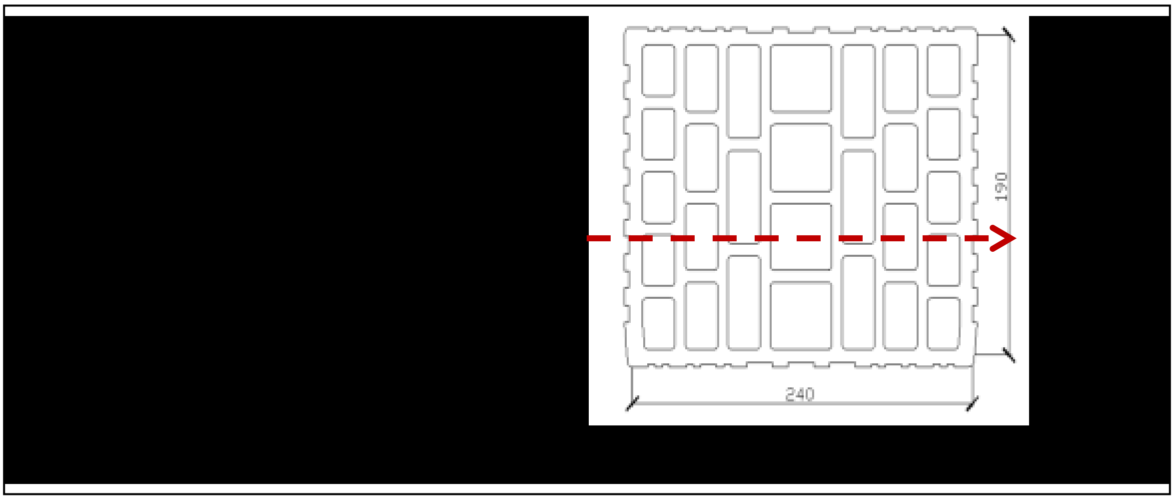


Figure 3.32 Sintered shale hollow block

(2) Experiment 2: The size of sintered shale hollow block is 290mm×240mm×190mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m ·k). The total thickness of wall is 260mm. The apparent density of block is 801(kg/m^3) (Figure 3.33).



(3) Experiment 3: The size of sintered shale hollow block is 290mm×240mm×190mm. The tested wall is 240mm thick with 10mm cement mortar on its both sides. The cement mortar's dry density ρ is 1800kg/m^3, and its coefficient of thermal conductivity $\lambda_1$is 0.93W/(m·K). The total thickness of wall is 260mm. The apparent density of block is 852(kg/m^3) (Figure 3.34).

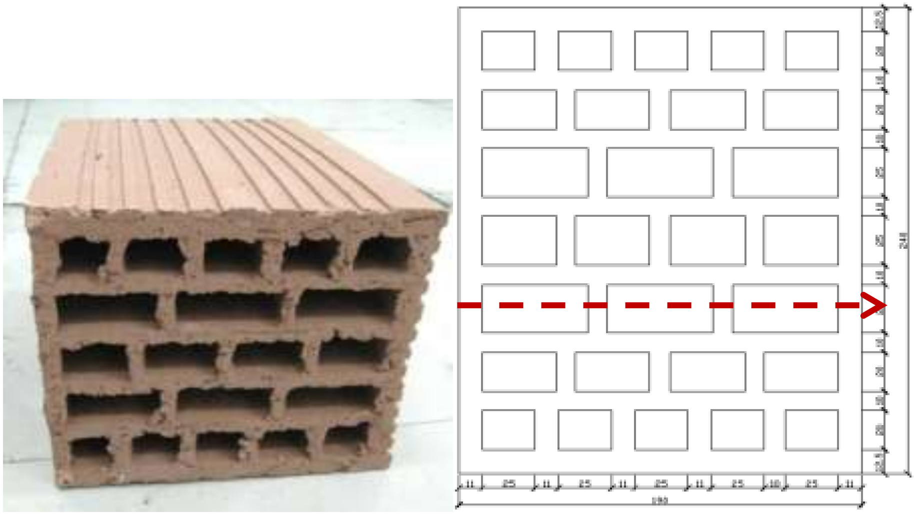


Figure 3.34 Sintered shale hollow block

The thermal performance parameters of sintered shale hollow block in the above three experiments are shown in Table 3.21 and Table 3.22.

Table 3.21 Physical parameters of sintered shale hollow blocks

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c (KJ/kgk)
290×240×190	959	52	1.05
290×240×90	801	60	1.05
290×240×190	852	50	1.05

Table 3.22 Thermal performance of walls made of sintered shale hollow block

Wall Block Size	Test	The Heat Resistance of the Wall R((m^2·K)/W)	The Heat Transfer Resistance of the Wall R_0 ((m^2·K)/W)	Heat Transfer Coefficient K (W/(m^2·K))	Equivalent Heat Conductivity λ (W/(m·K))
290×240×190	1	0.696	0.846	1.18	0.356
290×240×90	2	0.883	1.033	0.97	0.280
290×240×190	3	0.877	1.027	0.97	0.281

It can be seen from Table 3.21 and Table 3.22 that increasing the rows of holes and rational arrangement of holes can also improve thermal performance of block. Experiment 2 and 3 have most significant effects. Compared with blocks without optimization, the equivalent heat conductivity has decreased 0.094 W/(m·K), and the heat transfer coefficient of wall has decreased 0.22W/(m^2·K). The larger thickness of sintered shale hollow block in Experiment 1 than those in Experiment 2 and 3 results in the increase of apparent density and decrease of void ratio, which further gives rise to the insignificant energy-saving effect.

Therefore, on the premise of meeting the requirements for thickness of sintered shale hollow block, increasing the rows of holes to the largest extent, developing hollow brick with multi-row holes and rationally arranging the holes can improve the energy-saving effects. This is also feasible in production technique, because it will neither affect production efficiency nor increase production cost.

3.4 Conclusion

By analyzing the thermal performance of the new wall materials (shale sintered hollow brick, shale sintered perforated brick, autoclaved sand aerated concrete brick, sintered coal gangue perforated brick, sintered insulating brick, composite concrete perforated brick, etc.) commonly used in the hot summer and cold winter zone, this chapter has conducted a research into the optimized configuration of their thermal properties with the method that has combined theories with experiments. It has probed into the influences of the factors such as the hole types and the hole arrangements of the inside air space on the thermal performance of the wall blocks and how to bring their best thermal performance into play through optimized configuration and improvement measures in accordance with the characteristics of each wall material, so as to meet the national criteria for the thermal performance of the building walls in the hot summer and cold winter zone.

The main conclusions of the experiments are as follows:

1) The thermal properties of a shale sintered hollow block are related to its block type, material and hole type. To improve its thermal performance, the first approach is to change the hole type of a hollow block so as to increase the long-way convection, and under the premise of meeting the requirements for a block’s wall thickness and its rib thickness, the number of the hole rows needs to be increased up to the hilt, thus developing a hollow block with multi-row small holes arranged in a reasonable way, which will contribute to the improvement of the shale sintered hollow block’s thermal performance and its energy efficiency. The second approach is to insert EPS boards into a shale sintered hollow block. The EPS board has the advantages of low density, low thermal conductivity, good durability (with the same service life as that of the building), and so on, so to fill a shale sintered hollow block with EPS boards can effectively enhance its thermal performance.

2) With the thermal insulation property which is 3-4 times that of clay brick, the sound insulation property which is two times that of clay brick, the impermeability which is more than double that of clay brick, the fire resistance which is 6-8 times that of reinforced concrete and many other advantages, an autoclaved sand aerated concrete block is an excellent self-insulation material for exterior walls,

especially suitable for the hot summer and cold winter zone.

3) The thermal resistance is an important index to measure the thermal performance of sintered shale brick and sintered coal gangue brick, and the thermal resistance of hollow brick or perforated brick should be improved mainly by upgrading hole types and materials. As for the hole types, mainly depending on whether the hole design of hollow brick or perforated brick is reasonable, their developing trend should be increasing the width of brick, augmenting the number of the rows of holes, reducing the hole wall thickness, making the holes modular, inserting EPS boards into hollow brick and so on. In terms of materials, the material mixed with hot sawdust can reduce the thermal conductivity, etc. of a block, which is one of the best new wall materials to replace clay brick.

4) Mud sintered insulating brick has the advantages of low density, good thermal performance, etc. To replace clay brick with lightweight and energy-saving building brick made from paper mill sludge and river mud can save farmland and reduce the costs of sludge landfill or incineration. Using mud sintered insulating brick can not only deal with the disposal problem of urban industrial and domestic sludge but also solve the secondary pollution resulting from paper mill sludge and river mud in an efficient and low-cost way, thus turning waste into treasure.

Self-insulation wall has many advantages, such as durability, fire prevention, impact resistance, convenient construction, low overall cost, less common defects and the same life span as that of the building, which, in recent years, has been attracting more and more attention in southern China, especially in the hot summer and cold winter zone. According to the indoor thermal performance experiments of different wall materials, this chapter has compared the thermal properties of the wall materials commonly used in the hot summer and cold winter zone at present. Based on the factors such as the resource distribution, the climatic conditions, the architectural features, the economic development level, the status quo of local industries, etc. of this region, the most suitable wall materials for self-insulation system in Hangzhou are: autoclaved sand aerated concrete blocks (Table 3.23) and shale sintered hollow blocks (Table 3.24 and Table 3.25).

Table 3.23 The thermal performance test results of autoclaved sand aerated concrete block walls

Density Degree	Test	The Heat Resistance of the Wall $R((m^2 \cdot K)/W)$	The Heat Transfer Resistance of the Wall $R_0((m^2 \cdot K)/W)$	Heat Transfer Coefficient $K (W/(m^2 \cdot K))$	Equivalent Heat Conductivity $\lambda (W/(m \cdot K))$
B05	1	1.285	1.435	0.697	0.156
B06	2	1.064	1.214	0.824	0.188

Table 3.24 The physical parameters of sintered shale hollow blocks

Wall Block Size	Material Density (kg/m^3)	Void Ratio (%)	Specific Heat Capacity c(KJ/kgk)
290×240×90	801	60	1.05
290×240×190	852	50	1.05

Table 3.25 The thermal performance test results of sintered shale hollow block walls

Wall Block Size	Test	The Heat Resistance of the Wall $R((m^2 \cdot K)/W)$	The Heat Transfer Resistance of the Wall $R_0((m^2 \cdot K)/W)$	Heat Transfer Coefficient $K (W/(m^2 \cdot K))$	Equivalent Heat Conductivity λ (W/(m·K)
290×240×90	2	0.883	1.033	0.97	0.280
290×240×190	3	0.877	1.027	0.97	0.281

CHAPTER ROUR: THEORETICAL RESEARCH ON SELF-INSULATION SYSTEM IN THE HOT SUMMER AND COLD WINTER ZONE

4 THEORETICAL RESEARCH ON SELF-INSULATION SYSTEM IN THE HOT SUMMER AND COLD WINTER ZONE

4.1 Introduction

Standardizing the thermal properties of the building envelope, the “Thermal Design Code for Civil Buildings” divides the building envelope into different parts, including roof, exterior wall, exterior window and so on. The exterior wall consists of two parts, the main wall and the thermal bridge, and the latter one is required to be checked and equipped with thermal insulation structural measures. Based on the above experiments on the thermal performance of self-insulation wall materials, this chapter lays particular emphasis on the research on and the calculation of the thermal insulation performance of self-insulation exterior wall, which includes the structure and the checking of the thermal bridge.

The wall self-insulation system is made up of self-insulation wall materials and corresponding thermal bridge structures. At present, there is a lack of systematic theoretical research into the wall self-insulation system applied in China, and a number of problems have also arisen in the process of application. Therefore, it is necessary to conduct theoretical, computational and numerical analyses of and research on the self-insulation wall system in the hot summer and cold winter zone. Since the emphasis of this dissertation lies in the calculation and pilot application of the self-insulation wall materials, the structural measures of corresponding thermal bridges are only taken as components of the wall self-insulation system and thus not considered as the focus of the experiments; in the fifth chapter, the computational analysis of the thermal bridge construction of the pilot project serves as a corresponding checking so as to conform to the integrity of the exterior wall’s thermal performance required by the “Code”.

The theoretical study will clarify the basic principles of heat transfer and heat insulation of the self-insulation system of exterior walls. At the same time, the related research on the energy-efficiency calculation method of the self-insulation system and the energy-saving computational analysis of a large number of buildings with different types of self-insulation systems in the hot summer and cold winter zone have been carried out. By changing the different parameters influencing the energy-saving effects of the self-insulation systems, the most critical factors that affect self-insulation buildings can be obtained. According to the results concluded through comparing and analyzing the different structural measures adopted by the key joints such as the thermal bridge in the exterior-wall self-insulation systems, the most effective measures that are supposed to be taken by the exterior-wall self-insulation system in the hot summer and cold winter zone are determined.

4.2 Basic theories of the self-insulation system in the hot summer and cold winter zone

There are mainly four requirements for the thermal properties of the exterior walls in the hot summer and cold winter zone, that is, heat insulation in summer which is the most important one, heat preservation in winter, dehumidification and natural ventilation in transition seasons. Building energy conservation, especially residential energy conservation, should focus on a certain heat preservation and good heat insulation effects of envelope walls, the improvement of the thermal performance of outer windows, the control of solar radiation into the room by sunshades, good natural ventilation and so on. The requirements of energy-saving design for envelope walls are: a certain thermal resistance, relatively high attenuation values and comparatively long delay time, light-colored outer surface of the finishes and so on, which are generally easy to meet with for a self-insulation wall. According to "Design Standard for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone" (JGJ 134-2010) and "Design Standard for Energy Efficiency of Public Buildings" (GB 50189-2005), the requirements for the thermal performance of the envelope walls of both the residential and public buildings in the hot summer and cold winter zone are mainly targeted to the heat transfer coefficient and the thermal resistance of walls. Specific indicators are as follows (see Table 4.1 and Table 4.2).

Table 4.1The limiting values of the heat transfer coefficients for the energy-saving envelope walls of residential buildings in the hot summer and cold winter zone

Envelope Structural Parts		Heat Transfer Coefficient K(W/(m^2·K))	
		Index of Thermal Inertia D≤2.5	Index of Thermal Inertia D > 2.5
ShapeCoefficient≤0.40	Exterior Wall	1.0	1.5
	Splitting Wall	2.0	2.0
Shape Coefficient > 0.40	Exterior Wall	0.8	1.0
	Splitting Wall	2.0	2.0

Table 4.2 The limiting values of the heat transfer coefficients for the energy-saving envelope walls of public buildings in the hot summer and cold winter zone

Envelope Structural Parts	Heat Transfer Coefficient K(W/(m^2·K)) or Thermal Resistance R((m^2·K)/K)
Exterior Wall	≤1.5
Basement Exterior Wall (exposed to soil)	≥1.2

It can be seen from Table 4.1 and Table 4.2 that there are two main factors affecting the thermal performance of the walls in the building envelope: the heat transfer coefficient (K) and the index of thermal inertia (D) of the walls.

4.2.1 Heat transfer coefficient calculation of the walls

1) The heat transfer coefficient K refers to the quantity of heat transferred within one square meter

during an hour under the condition of steady heat transfer and the circumstance that the air temperature difference between the two sides of the building envelope is 1℃, and its unit is W/m^2 K.

In a building, when the temperature indoors is different from that outdoors, there will be heat transfer in the building envelopes such as exterior walls, roofs, etc., and the heat always flows from the hotter side to the cooler side. If the indoor and outdoor temperatures do not change over time, the heat transfer in building envelopes will be a steady heat transfer process, which means that the temperature of each point does not change over time during the heat transfer process in the building envelope studied by us.

Suppose there is a flat wall made from homogeneous materials, whose length and width are far longer than its thickness d, with the thermal conductivity of the wall materials being λ and assuming that the indoor air temperature t_i is higher than the outdoor air temperature t_e, that is, $t_i > t_e$, and its steady heat transfer process will be as shown in Figure 4.1.

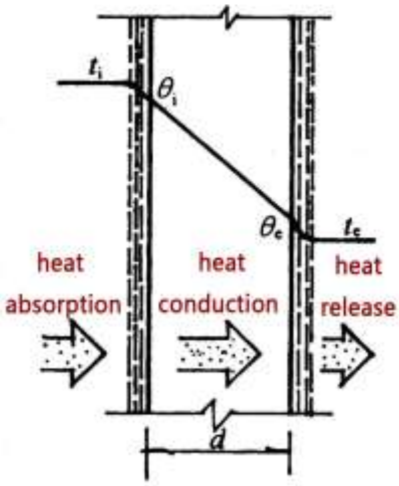


Figure 4.1 The steady heat transfer process in an envelope structure

As can be seen from the figure, the entire heat transfer process can be divided into three stages:

(1) The heat absorption of the building envelope's interior surface

Since $t_i > t_e$, when the indoor heat transfers towards outdoors through the building envelope, it will definitely forms the temperature state of $t_i > \theta_1 > \theta_e > t_e$. The interior surface converts heat with the indoor air and at the same time exchanges heat through radiance with all the relative surfaces of the interior space, and this process is called heat absorption.

$$q_i = \alpha_i (t_i - \theta_i) \qquad (4.1)$$

In this formula: q_i – the heat-flow density on the interior surface of the flat wall, that is, the heat gain from indoors per unit area per unit time, W/m^2;

α_i – the heat transfer coefficient on the interior surface of the flat wall, that is, the sum of the convection heat transfer coefficient and the radiation heat transfer coefficient, W/(m^2 K);

t_i – the indoor air temperature (℃);

θ_i – the temperature of the flat wall's interior surface (℃).

(2) The heat conduction of the building envelope's material layer

The building envelope is made from multi-layered homogeneous materials, with the thermal conductivity of each layer being λ_i, the thickness being d_i, the temperatures on its both sides respectively being θ_i and θ_e, and $\theta_i > \theta_e$. According to the thermal conductivity formula, it can be known that:

$$q_\lambda = \frac{\theta_i - \theta_e}{\sum \frac{d_i}{\lambda_i}} = \frac{\theta_i - \theta_e}{\sum R} \qquad (4.2)$$

In this formula: q_λ – the thermal-conduction heat-flux density, that is, the heat conducting amount that goes through the unit area of the flat wall during the unit time, (W/m^2);

λ_i – the thermal conductivity of each material layer, W/(m K);

d_i – the thickness of each material layer, m;

$\sum R$ – the thermal resistance of the building envelope, m^2 K/ W;

θ_i – the temperature of the building envelope's interior surface, ℃;

θ_e – the temperature of the building envelope's exterior surface, ℃.

(3) The heat release of the building envelope's exterior surface

Since the temperature of the building envelope's exterior surface θ_e is higher than that of the outdoor air t_e, that is, $\theta_e > t_e$, the building envelope's exterior surface releases heat towards the outdoor air and the environment. Similar to the heat transfer of the interior surface, the heat release of the exterior surface is the combination of heat convection and radiation heat transfer. Its calculation is shown in the formula (4.3).

$$q_e = \alpha_e (t_e - \theta_e) \qquad (4.4)$$

In this formula: q_e – the heat-flow density on the exterior surface of the building envelope, that is, the heat amount released towards outdoors within the unit area during the unit time, W/m^2;

α_e – the heat transfer coefficient of the building envelope, that is, the sum of the convection heat transfer coefficient and the radiation heat transfer coefficient, W/(m^2 K);

θ_e – the temperature of the building envelope's exterior surface, ℃;

t_e – the temperature of the outdoor air, ℃.

In summary, when the indoor temperature is higher than the outdoor temperature, the building envelope transfers heat towards outdoors through the above three stages. Because it is a steady heat transfer process, the heat amounts transferred by different interfaces must be equal. That is:

$$q_i = q_\lambda = q_e = q \qquad (4.5)$$

Through mathematical manipulation, it can be obtained that:

$$q = \frac{t_i - t_e}{R_i + \sum R + R_e} \qquad (4.6)$$

Or $$q = \frac{t_i - t_e}{R_0} \qquad (4.7)$$

And will have $$q = K_0 (t_i - t_e) \qquad (4.8)$$

In this formula: R_i —the heat exchange resistance of the interior surface of the building envelope, m^2 K/W, $R_i = \frac{1}{\alpha_i}$;

$\sum R$ – the heat resistance of the building envelope, m^2 K/W, $\sum R = \sum \frac{d}{\lambda}$;

R_e – the heat exchange resistance of the exterior surface of the building envelope, m^2 K/W, $R_e = \frac{1}{\alpha_e}$;

R_0 – the heat transfer resistance of the building envelope, m^2 K/W, $R_0 = R_i + \sum R + R_e$;

K_0 – the heat transfer coefficient of the building envelope, W/m^2 K, $K_0 = \frac{1}{R_0}$.

From the formula (4.7), it can be known that, with the same indoor and outdoor temperature difference, the greater the heat transfer resistance of the building envelope R_0, the less the heat that will be transmitted through the building envelope towards outdoors.

This manifests that the heat transfer resistance of the building envelope R_0 shows the total amount of resistance on the heat transferred from one side of the building envelope to the other. The heat transfer coefficient of the building envelope K_0 indicates the amount of heat transferred per unit area per unit time when the air temperature difference between the two sides of the building envelope is 1℃ or 1K.

As the heat transfer coefficient and the heat transfer resistance of the building envelope are reciprocals, the greater the heat transfer resistance R_0, the less the heat going through the building envelope; the lower the heat transfer coefficient K_0, the less the heat going through the building envelope. Therefore, they both are important thermal performance indexes to measure the building envelope under the conditions of steady heat transfer.

In winter when the outdoor temperature continues to be low and the diurnal temperature variation fluctuates within a relatively small range, the heat continues to flow from indoors towards outdoors. Therefore, the heat transfer of the building envelope in winter can be roughly calculated as steady heat transfer. The two indexes, namely the heat transfer coefficient K_0 and the heat transfer resistance R_0, are commonly used to measure the heat transfer capacity of a building envelope [5].

2) The average heat transfer coefficient of an exterior wall (K_m)

The average heat transfer coefficient of an exterior wall (K_m) is the average value of the heat transfer coefficients of its many parts including its main body and the surrounding thermal bridge (constructional columns, ring beams, floor slabs extending into the exterior wall, etc.). Once the heat transfer coefficients of the main body of the exterior wall and all the parts of the thermal bridge are determined, the key to calculating Km lies in the determination of the area of each part of the thermal bridge, as shown in Figure 4.2.

Calculate by the weighted average method: $$\mathrm{K_m} = \frac{K_P \bullet F_p + K_b \bullet F_b}{F_p + F_b} \qquad (4.9)$$

In this formula: K_m − the average heat transfer coefficient of the exterior wall (W/m^2 K);

K_p – the heat transfer coefficient of the main body of the exterior wall (W/m^2 K);

F_p – the area of the main body of the exterior wall (m^2);

K_b – the heat transfer coefficient of the structural thermal bridge parts of the exterior wall (W/m^2 K);

F_b – the area of the structural thermal bridge parts of the exterior wall (m^2);

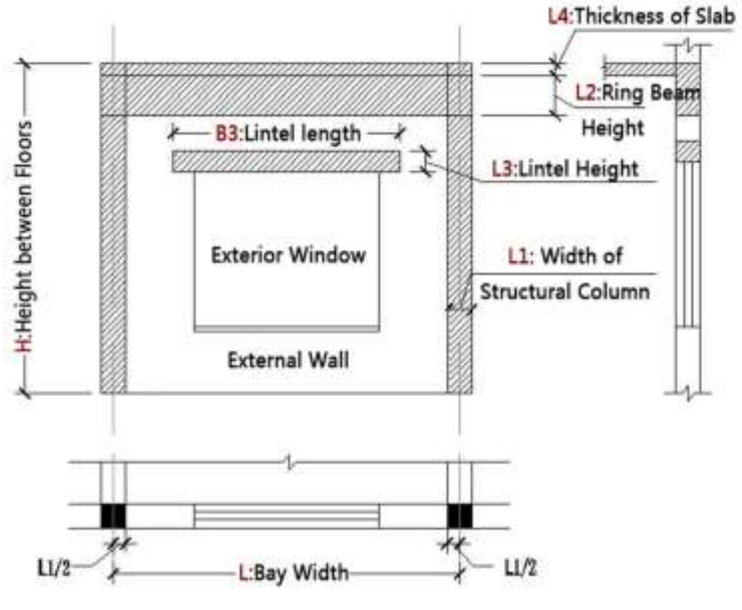


Figure 4.2 The schematic of the main body of the exterior wall and the parts of the surrounding thermal bridge

4.2.2 The thermal characteristic indexes for wall structures

In the presence of simple harmonic heat, the temperature distribution inside the building materials and envelope, the attenuation of the temperature wave amplitude and the phase delay are all directly related to the chosen materials, the structures and the boundary conditions, which involves several major indexes of thermal characteristics.

1) Material heat storage coefficient

As a result of the heat in cyclical fluctuations, building materials possess the ability to store or release heat in order to adjust the temperature fluctuations on the surface of the material layer. In the field of architectural thermal engineering, the ratio of the amplitude A_q of the heat flow fluctuation on the surface of a semi-infinite-thick object to the amplitude A_θ of the temperature fluctuation is called the "material heat storage coefficient" of the object under the simple harmonic heat effect, and is generally represented by S with the unit W/(m^2 K). The calculating formula is:

$$S = \frac{A_q}{A_\theta} = \sqrt{\frac{2\pi\lambda c\rho}{Z}} \qquad (4.10)$$

In this formula: S – the heat storage coefficient of a material, W/(m^2 K);

λ – the thermal conductivity of the material, W/(m K);

c – the specific heat capacity of the material, kJ/(kg K);

ρ– the density of the material, kg/m^3;

Z – the temperature fluctuation period, h.

When the temperature fluctuation period $Z = 24h$, the formula (4.10) can be simplified to the formula (4.11).

$$S_{24} = 0.51\sqrt{\lambda c\rho} \qquad (4.11)$$

It can be seen from the above formula that the heat storage coefficient of a material is not only related to the harmonic period, but also a composite parameter of several basic physical indexes of the material. Its physical meaning lies in the sensitivity degree of the surface of a semi-infinite-thick object to the thermal harmonic effect when the object is under the action of harmonic heat, which means that under the same thermal effect, the higher the material heat storage coefficient, the smaller the surface temperature fluctuation; otherwise, the lower the material heat storage coefficient, the greater the surface temperature fluctuations. When choosing the materials of a building envelope, the study can adjust the amplitude of temperature fluctuation according to their material heat storage coefficients in order to make the envelope have good thermal performance.

2) Material thermal inertia index

The thermal inertia index is a design index to evaluate the thermal insulation performance of an exterior wall or a roof in the energy-efficiency design standards of residential buildings at present. It is a non-dimension parameter denoted by the symbol D that represents the capacity of an external envelope to resist outdoor temperature waves and heat flow fluctuations under the conditions of periodic heat transfer in summer. The greater the value of D, the greater the attenuation degree of temperature waves and heat-flow waves.

Under the effect of harmonic heat, the temperature wave inside the object decays exponentially, that is:

$$A_x = A_e \cdot e^{-\sqrt{\frac{\pi c\rho}{\lambda Z}}x} \quad (4.12)$$

The exponential term can be rewritten as

$$\sqrt{\frac{\pi c\rho}{\lambda Z}}x = x\sqrt{\frac{\pi c\rho\lambda Z}{\lambda Z}} = \frac{x}{\lambda}\cdot\frac{1}{\sqrt{2}}\cdot\sqrt{\frac{2\pi\lambda c\rho}{Z}} = \frac{1}{\sqrt{2}}\cdot S \quad (4.13)$$

Let $D = R_x \cdot S$ (4.14)

D is the thermal inertia index of the material layer whose thickness is x. It is a dimensionless quantity. Therefore, the formula (4.15) can be expressed as:

$$A_x = A_e \cdot e^{\frac{1}{\sqrt{2}}}D$$

This shows that with the same A_e, the higher the thermal inertia index D of a material layer, the smaller the temperature fluctuation at the point that is x m away from the surface. The thermal inertia index D indicates the ability of a building envelope to resist temperature fluctuations under the effect of harmonic heat.

The thermal inertia index of a multi-layer envelope is the sum of the thermal inertia indexes of its all layers. When there is an enclosed air interlayer, since the material heat storage coefficient of the air in this layer is as low as almost zero, the thermal inertia index of the interlayer will be negligible. So, the thermal inertia index of a multi-layer envelope is:

$$D = D_1 + D_2 + D_3 + \cdots + D_n = R_1S_1 + R_2S_2 + R_3S_3 + \cdots + R_{n1}S_{n1} \quad (4.16)$$

When the middle layer of a multi-layer envelope consists of two or more materials, the average thermal conductivity and the average heat storage coefficient of the layer should be calculated first, and the thermal inertia index of this layer should be obtained based on the average thermal resistance. The calculation method is:

$$\bar{\lambda} = \frac{\lambda_1F_1 + \lambda_2F_2 + \cdots + \lambda_nF_n}{F_1 + F_2 + \cdots + F_n} \quad (4.17)$$

$$\bar{S} = \frac{S_1F_1 + S_2F_2 + \cdots + S_nF_n}{F_1 + F_2 + \cdots + F_n} \quad (4.18)$$

$$\bar{R} = \frac{d}{\bar{\lambda}} \quad (4.19)$$

$$D = \bar{R}\cdot\bar{S} \quad (4.20)$$

In these formulas: $\lambda_1, \lambda_2 \cdots \lambda_3$—the thermal conductivity coefficient of the material of each heat transfer area, W/(m K);

$F_1, F_2 \cdots F_3$ – the area of each heat transfer area divided parallel to the heat flow in this layer, m^2;

$S_1, S_2 \cdots S_3$ – the material heat storage coefficient of each heat transfer area, W/(m^2 K).

4.3 Research on the energy-efficiency calculation method of the self-insulation system in the hot summer and cold winter zone

In order to improve the quality of people's living environment in the Yangtze River basin as well as its vast surrounding areas and to promote building energy conservation in the hot summer and cold winter zone in central China, the Ministry of Construction issued *Design Standard for Energy Efficiency of Public Buildings* (GB 50189-2005) in April 2005, which was put into effect on July 1, 2005. In March 2010, the Ministry of Housing and Urban-Rural Development organized to formulate and promulgated *Design Standard for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone* (JGJ 134-2010), which stipulates that from August 1, 2010 onwards, in the hot and cold winter zone, the energy-efficiency designs of all newly-built houses in large and medium-sized cities must conform to the requirements of this standard and meanwhile abolishes *Design Standard for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone* (JGJ 134-2001) carried out on October 1, 2001. The mandatory provisions of the standards must be strictly enforced, and at the same time, the provinces and cities in the hot summer and cold winter zone have also formulated and implemented corresponding local standards and rules. The promulgation of the building energy-efficiency standards in the hot summer and cold winter zone is as follows (see Table 4.3).

Table 4.3 List of energy efficiency standards for residential buildiin the hot summer and cold winter zone

No.	Title	Type	Date of Issue
1	*Design Standard for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone* (JGJ 134-2010)	National Standard	2010.8
2	*Design Standard for Energy Efficiency of Public Buildings* (GB 50189-2015)	National Standard	2015.10
3	*Zhejiang Province Design Standard for Energy Efficiency of Residential Buildings (Revised)* (DB 331015-2015)	Provincial Standard	2015.01
4	*Zhejiang Province Design Standard for Energy Efficiency of Public Buildings* (DB33/1038-2007)	Provincial Standard	2008.01

5	"Notice of Zhejiang Provincial Department of Housing and Urban-Rural Development on Further Strengthening Technical Management of Energy-efficiency Designing of Civil Buildings" issued by the Provincial Department of Construction [2009] No. 218.	Local Rules	2009.10
6	*Jiangsu Province Design Standard for Thermal Environment and Energy Efficiency of Residential Buildings* (DGJ 32J71-2014)	Provincial Standard	2015.01
7	*Jiangsu Province Design Standard for Energy Efficiency of Public Buildings* (DBJ32 / J96-2010)	Provincial Standard	2010.06
8	*Anhui Province Design Standard for Energy Efficiency of Residential Buildings* (DB34/1466-2011)	Provincial Standard	2011.08
9	*Anhui Province Design Standard for Energy Efficiency of Public Buildings* (DB34 /1467-2011)	Provincial Standard	2011.08

The design standards for building energy efficiency listed in Table 4.3 show that both the national and the local standards for building energy efficiency design in the hot summer and cold winter zone put forward two kinds of energy-saving evaluation methods, namely the prescriptive index and the performance index.

There are two concurrent sets of evaluation methods to measure whether the design of building energy efficiency reaches the standard: the static evaluation method based on the prescriptive index system and the dynamic evaluation method based on the performance index system.

4.3.1 Prescriptive index system

The prescriptive index system is a standard static evaluation method that takes the overall thermal performance of a building as the evaluation object. When all the indexes of the designed building such as its shape coefficient, the heat transfer coefficients of each part of the envelope, the average window-wall ratio and the average heat transfer coefficient of the outer windows (including transparent curtain walls) in all orientations, etc. are up to or above the prescriptive indexes in the "Standard", the designed building can be directly decided as an energy-saving building in line with the design standards for energy efficiency. The adoption of the static evaluation method based on the prescriptive index system makes the calculation quite easy, but the shape and the structure of a building are restricted to a great degree, which is not conducive to the creative design of architectural appearances as for architects.

4.3.2 Performance index system

If the design of a building cannot fully meet the prescriptive indexes required by the "Standard", it will have to go through a comprehensive energy-efficiency evaluation by adopting building envelope trade-off options of the thermal performance.

The dynamic method, also known as the dynamic hourly-simulating method based on the theory of unsteady heat transfer, takes various factors into consideration in a detailed way, and thus the results obtained are more accurate. At the same time, this method is in line with international standards but needs to be conducted with the help of a computer software and the local meteorological parameters in typical years.

The dynamic assessment method is to firstly design a virtual energy-saving building (i.e., a building that meets 50% of energy-saving requirements of the "Standard") according to the size and shape of the building that has been designed, which is called the "reference building". After that, calculate the annual energy consumption of the reference building under the specified conditions, and then calculate the annual heating and air conditioning energy consumption of the designed building under the same conditions. When the designed building's heating and air conditioning energy consumption is not greater than that of the reference building, the overall thermal performance of the building envelope can be decided as in line with the energy-efficiency requirements. When the designed building's heating and air conditioning energy consumption is greater than that of the reference building, the calculation needs to be redone with adjusted design parameters until the designed building's heating and air conditioning energy consumption is not greater than that of the reference building.

The construction of the reference building should meet the following requirements:

1) The shape, size, orientation and planar subdivision of the reference building should be the same as those of the designed building;

2) When the shape coefficient of the designed building exceeds that prescribed by the "Standard", all the heat transfer areas and all the adiabatic areas of the external walls and the roofs of the reference building should be calculated respectively in the same proportion, and the sum of all the heat transfer areas divided by the reference volume should be made equal to the corresponding limiting value of the shape coefficient in the "Standard";

3) When the window-wall ratio of the designed building is greater than that prescribed by the "Standard", each window (transparent curtain wall) of the reference building should be scaled down so that its window-wall area ratio can meet the requirements in the "Standard". When the area of the transparent parts of the designed building's the roofs is larger than that prescribed by the "Standard", the area of the transparent parts of the reference building's the roofs should be scaled down so as to comply with the "Standard".

4) The heat transfer coefficients of the reference building's roofs, exterior walls and overhead floors should be the corresponding limiting values prescribed by the "Standard". The heat transfer coefficient of the exterior windows should be the limiting value prescribed by the "Standard".

5) The annual energy consumption of heating and air conditioning under the prescribed conditions for the designed building and the reference building should be calculated by the dynamic method with the same version of the calculation software.

6) The meteorological parameters provided by the "Standard" should be applied to the trade-off calculation. When those of the area where the building is located are not included in the "Standard", the

local meteorological parameters should refer to those of the nearest city based on the geographical location as a basis for design.

The first step of the dynamic simulative calculation of the building's energy consumption throughout the year is to calculate the annual heating and air conditioning energy consumption of the reference building under the specified conditions. Then calculate that of the designed building under the same conditions. When the heating and air conditioning energy consumption of the designed building is not greater than that of the reference building, the overall thermal performance of the envelope can be decided as in line with the energy-efficiency requirements. When the heating and air conditioning energy consumption of the designed building is greater than that of the reference building, the calculation needs to be redone until the heating and air conditioning energy consumption of the designed building is not greater than that of the reference building.

There are many dynamic calculation methods, such as the method of reaction coefficient, the Z transformation method, the space-state method, the method of cooling load coefficient and so on. The method adopted here is the most commonly-used one: the method of DOE-2 reaction coefficient.

DOE-2 is an energy-consumption calculation software developed by Lawrence Burke National Laboratory in the USA. It uses the reaction coefficient method to calculate the reaction of the temperature and the heat flow of the interior and exterior surfaces of a building envelope to a unit of triangular wave temperature disturbance. After the calculation of the reaction coefficients of the envelope's heat absorption, heat release and heat transfer, it then decomposes the arbitrarily changing outdoor temperature into triangular waves that can be superposed. By using the properties of superposition of the integro-differential equations of thermal conductivity, it superposes the envelope's reactions to each triangular wave and gets the temperatures and the heat flows of the envelope's surfaces at any time.

DOE-2 uses reaction coefficient to calculate the heat transfer amount of the building envelope. The basic principles of reaction coefficient are as follows:

When the indoor temperature is permanently zero and there is a unit of isosceles-triangle waveform temperature disturbance outdoors, from the moment of the reaction, the heat absorbed hourly by the exterior surface of the wall per unit area is referred to as the heat-absorption reaction coefficient of the exterior surface of the wall, denoted by the symbol X (j); the heat transferred into indoors through a unit area of the wall is called the wall's heat-transfer reaction coefficient, denoted by the symbol Y (j); on the contrary to the above situations, when the outdoor temperature is permanently zero and there is a unit of isosceles-triangle waveform temperature disturbance, from the moment of the reaction, the heat absorbed hourly by the interior surface of the wall per unit area is referred to as the heat-absorption reaction coefficient of the interior surface of the wall, denoted by the symbol Z (j); the heat transferred into outdoors through a unit area of the wall is also called the wall's heat-transfer reaction coefficient, whose value is the same as that in the former situation, so it is still denoted by the symbol Y (j).

The units of the heat-transfer reaction coefficient and the heat-absorption reaction coefficients of the interior and exterior surfaces of the wall are all W/(m^2·℃). In the symbols, j=0,1,2......, representing the j$\Delta\tau$ hour after the moment when the unit of disturbance produces its effect. Generally, $\Delta\tau$ is taken as an hour, so X (5) represents the heat-absorption reaction coefficient of the exterior surface of the wall five hours after the unit of disturbance produces its effect.

The reaction coefficients can be calculated by reference to special information or using a special computer program. With the coefficients, the gained heat amount HG (n) transferred from outdoors into indoors through the wallboard envelope at the No.n moment can be obtained with the following formula.

$$HG(n)=\sum_{j=0}^{\infty} Y(j)t_z(n-j)-\sum_{j=0}^{\infty} Z(j)t_r(n-j)$$

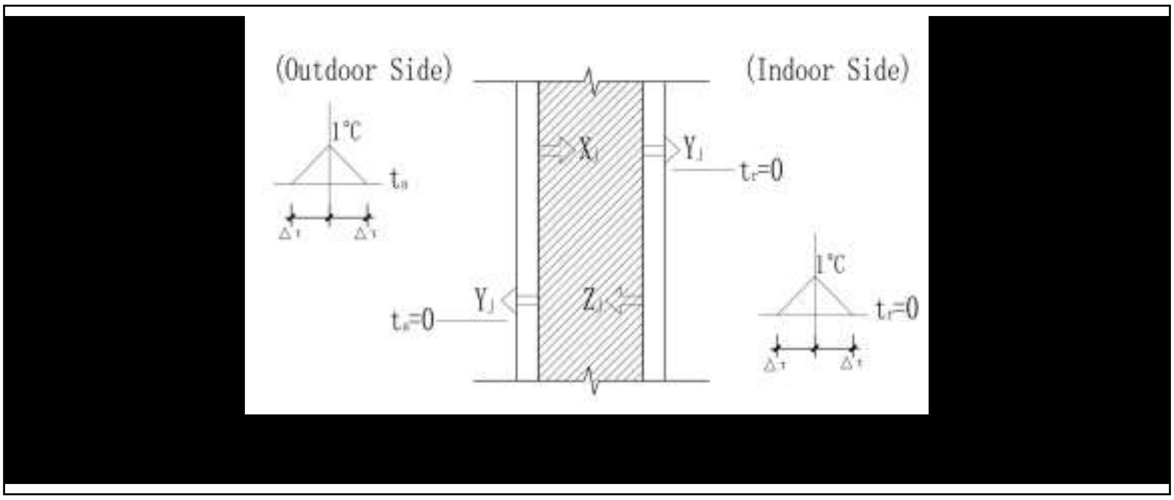
In this formula: $t_z(n-j)$ is the outdoor sol-air temperature at the No. n-j moment; $t_r(n-j)$ is the indoor temperature at the No. n-j moment.

Especially when the indoor temperature t_r is constant, this formula can be simplified into:

$$HG(n)=\sum_{j=0}^{\infty} Y(j)t_z(n-j)-K\,t_r$$

The K in the formula refers to the heat transfer coefficient of the wallboard.

DOE-2 software can simulate the thermal process of heating and air-conditioning of buildings. Users can input the geometrical shape and the size of a building, and they can input the type and the capacity of the air conditioning system of the building envelope and other parameters.



In the hot summer and cold winter zone, among the aggregative energy-efficiency indexes, the heat consumption, the cooling energy consumption, the heating power consumption and the air-conditioning power consumption of a building generally need to be calculated by dynamic methods.

4.4 The Energy-efficiency calculation and analysis on the self-insulation systems in the hot summer and cold winter zone

The self-insulation walls have many advantages. For example, they have nice durability, fire prevention and impact resistance. Also, they are convenient to construct and have low overall cost, less common defects and the same life span as the buildings. In recent years, they are getting more and more attention in southern China, especially in the hot summer and cold winter zone. Therefore, it is necessary to study the self-insulation systems' influence on the energy consumption of the buildings and their contribution to the energy-saving effects of the buildings. Taking different types of buildings in Hangzhou as examples and the meteorological parameters of Hangzhou as bases, this section uses the PKPM energy conservation design and analysis software (PBECA) developed by the China Academy of Building Research Shanghai Institute to simulate and analyze the influence that different types of architectural energy-saving designs put on the energy saving effects of heating air-conditioners. It aims to help designers flexibly and effectively apply the results to architectural designs and propose optimized energy –saving solutions.

Hangzhou (approximately 30.00 °N, 120.00 °E) is located in the southeast coast of China, the northern part of Zhejiang Province, the northern bank of the lower Qiantang River and the southern tip of the Grand Canal. It is an important central city in the Yangtze River Delta and a transportation hub in southeastern China. It belongs to the subtropical climate and is influenced by the monsoon significantly. It has short spring and autumn, long winter and summer. In terms of climate, Hangzhou has hot summer and cold and wet winter.

4.4.1 Required energy-saving rate for building energy-efficiency design

It has been stipulated by Article 1.0.3 of *Energy-Saving Standards for Public Buildings* that with equal indoor environmental parameters, the total annual energy consumption of heating, ventilation, air-conditioning (HVAC) and lighting should be reduced by 50% compared with that when no energy-saving measures are taken.

The meaning of reducing 50% of energy consumption takes public buildings constructed during the early stage of China's reform and opening up in the 1980s as the basis for comparison, and those buildings are called "baseline buildings". The parameters of the building envelope, the HVAC equipment and systems, and illumination devices of the "baseline buildings" under the circumstances back then are used here. Keeping the indoor environmental parameters same as those required by current standards, the research calculates the annual energy consumption for HVAC and lighting of the "baseline buildings", which is considered as 100%. Then, when the parameters of the "baseline buildings" are adjusted in line with the standards, which is to say that the parameters of the building envelope, HVAC and illumination devices are set according to the standards, its annual energy consumption for HVAC and lighting should amount to 50%. This is the meaning of saving 50% of energy consumption.

The construction, the heat transfer coefficient and the shading coefficient of the building envelope of the "baseline buildings" accord with the traditional practice of the 1980s. In other words, the value of K of the exterior wall is taken as 1.28W/(m^2·K) (Harbin); 1.70W/(m^2·K) (Beijing); 2.00W/(m^2·K)

(Shanghai); 2.35W/(m^2·K) (Guangzhou). The coal-fired boiler is taken as the heat source for heating, whose efficiency is 0.55; the water chilling unit is taken as the cold source for air-conditioning, whose centrifugal-machine energy efficiency ratio (EER) is 4.2 and screw-machine EER is 3.8; the lighting parameter is taken as 25W/m^2. The goal of reducing 50% of energy consumption required by *Energy-Saving Standards for Public Buildings* is to be jointly achieved by improving the building envelope's thermal performance and enhancing the efficiency of the heating, air-conditioning and lighting equipment. The parameters of the energy-saving target for the lighting equipment's efficiency are set according to *Standard for Lighting Design of Buildings* (GB 50034—2004), which stipulates that the standard specified values for the building envelope and HVAC are those when the designed building's annual energy consumption for heating, air-conditioning and lighting is reduced to 50% of that of the "baseline buildings", which is considered as 100%, due to the adjustment of the building envelope's thermal parameters, the heating and air-conditioning equipment's EER and other elements. Through the calculation and analysis in the process of preparing the standard, the buildings designed according to the standard have equipments for heating, air-conditioning and lighting with better efficiency because of their improved thermal properties of the building envelope. From northern China to the south, the building envelope is responsible for about 25%-13% of the saved energy consumption; the heating and air-conditioning system is responsible for about 20%-16% of the saved energy consumption; the lighting equipment is responsible for about 7%-8% of the saved energy consumption. It is thus clear that after the implementation of this standard, the overall energy-saving rate across the country can reach 50%.

Energy Saving Design Standards for Civil Buildings has proposed the target of energy conservation: The baseline energy consumption is the linearly processed data coming from the calculated values of the heat consumption indexes of the buildings which were constructed during 1980-1981 in general styles comprising four apartment buildings with six storeys and the shape coefficient being about 0.30. For buildings in the hot summer and cold winter zone or the hot summer and warm winter zone, when their major rooms are kept 18^{o}C in winter by using electric heater with EER of 1 for heating and 26^{o}C in summer by using air-conditioner with EER of 2.2 for cooling, the energy consumption is taken as the baseline energy consumption, based on which, the energy-saving target for energy-saving residential buildings is reducing 50%-65% of the energy consumption for heating and air-conditioning annually.

4.4.2 Model selection

In order to guarantee the representativeness of the selected building types, this chapter has chosen the common architectural forms in Hangzhou to construct research models as well as building models, which reasonably simplifies the original building planes on the basis of not affecting the indoor thermal conditions as much as possible. The simplified floor plans of the building models (see Figure 4.4 ~ Figure 4.6) and the basic description of the building models (see Table 4.4) are as follows.

Figure 4.4 The floor plan of a point-block residence

Figure 4.6 The floor plan of an office building

Table 4.4 The basic description of the building model

<table>
<tr><td colspan="2">City</td><td colspan="3">Hangzhou
(approximately 30.00°N, 120.00°E)</td></tr>
<tr><td colspan="2">

Figure</td><td colspan="3" rowspan="2">Hot summer and cold winter</td></tr>
<tr><td colspan="2">Climatic zone</td></tr>
<tr><td colspan="2">Building type</td><td>Point-block residence</td><td>Bar-style residence</td><td>Office building</td></tr>
<tr><td colspan="2">Orientation</td><td>South</td><td>South</td><td>South</td></tr>
<tr><td colspan="2">Structural type</td><td>Frame</td><td>Frame</td><td>Frame</td></tr>
<tr><td colspan="2">The number of storeys</td><td>15 storeys</td><td>6 storeys</td><td>7 storeys</td></tr>
<tr><td colspan="2">Storey height (mm)</td><td>3000</td><td>3000</td><td>3750</td></tr>
<tr><td colspan="2">Shape coefficient</td><td>0.21</td><td>0.23</td><td>0.16</td></tr>
<tr><td rowspan="4">Window-wall ratio</td><td>East</td><td>0.30</td><td>0.21</td><td>0.05</td></tr>
<tr><td>South</td><td>0.35</td><td>0.34</td><td>0.36</td></tr>
<tr><td>West</td><td>0.30</td><td>0.05</td><td>0.05</td></tr>
<tr><td>North</td><td>0.30</td><td>0.34</td><td>0.36</td></tr>
</table>

4.4.3 The envelope structure of the building model

The selected building model adopts a self-insulation system. According to relevant standards and provisions of the "Design Standard for Energy Efficiency of Residential Buildings" (DB33/1015-2003) and the "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007) in Zhejiang Province, the envelope structure of the model is obtained through analysis by adopting the PKPM energy conservation design and analysis software (PBECA). The main wall is made from autoclaved sand aerated concrete block (B06) (thermal conductivity λ=0.18 W/(m ·K)), and the thermal bridge is made from inorganic insulation mortar (thermal conductivity λ=0.07 W/(m ·K)); the roof is made from foam glass insulation board (thermal conductivity λ=0.066 W/(m ·K)). The basic thermal performance parameters of the building envelope are as follows (see Table 4.5 ~ Table 4.7).

Table 4.5 Basic description of the building envelope of the point-block residence

Component	The Main Structure and the Insulation Materials	Thermal Performance W/(m^2 K)	The Limiting Value of the Index W/(m^2 K)	Judgement
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00) + inorganic thermal insulation mortar (20mm) + reinforced concrete (240mm) + cement mortar (20.00mm)	1.34 (D=4.19)	K≤1.50 (D=3.00)	Pass
Interior Wall	Cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm)	K=0.78	K≤2.0	Pass
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + foam glass (50.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.98 (D=2.98)	K≤1.0 (D=3.00)	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	K=2.92	K≤2.0	Fail
Door& Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-
Entry Door	Energy-saving anteport	K=2.77	K≤3.0	Pass

Table 4.6 Basic description of the building envelope of the bar-style residence

Component	The Main Structure and the Insulation Materials	Thermal Performance W/(m^2 K)	The Limiting Value of the Index W/(m^2 K)	Judgement
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00) + inorganic thermal insulation mortar (20mm) + reinforced concrete (240mm) + cement mortar (20.00mm)	K=1.46 (D=3.96)	K≤1.50 (D=3.00)	Pass
Interior Wall	Cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm)	K=0.78	K≤2.0	Pass
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + foam glass (50.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.98 (D=2.98)	K≤1.0 (D=3.00)	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	K=2.92	K≤2.0	Fail
Door & Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-

Entry Door	Energy-saving anteport	K=2.77	K≤3.0	Pass

Table 4.7 Basic description of the envelope of the office building

Component	The Main Structure and the Insulation Materials	Thermal Performance W/(m^2 ·K)	The Limiting Value of the Index W/(m^2 ·K)	Judgement
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00) + inorganic thermal insulation mortar (20mm) + reinforced concrete (240mm) + cement mortar (20.00mm)	K=1	K≤1.0	Pass
Interior Wall	Cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (240.00mm) + cement mortar (20.00mm)	-	-	-
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.65	K≤0.7	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	-	-	-
Door & Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-

Ground	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + reinforced concrete (120.00mm)	R=0.11 (m^2·K)/ W	R≥1.2 (m^2·K)/ W	Fail

4.4.4 Dynamic simulative calculation of the building models

Both point-block and bar-style residences are residential buildings while office buildings are public buildings. The calculating parameter setting adopted by the indoor dynamic energy consumption calculation refers to the following:

The design indexes of residential-building indoor thermal environment and energy efficiency refer to the “Design Standard for Energy Efficiency of Residential Buildings” of Zhejiang Province (DB33/1015-2003), specifically:

1) The indoor calculating temperature of bedrooms and living rooms is 18℃ all day long in winter; 26 ℃ all day long in summer.

2) The calculating parameters of outdoor meteorology adopts the meteorological parameters of the representative city in the energy-consumption-analysis meteorological zone where the residential building is constructed in typical meteorological years.

3) During heating and air conditioning, the ventilation frequency is once/h.

The design indexes of indoor parameters of public buildings refer to the “Design Standard for Energy Efficiency of Public Buildings” of Zhejiang Province (DB33/1036-2007), and the details are in Table 4.8.

Table 4.8 Office building energy-saving indoor calculation parameters

Room Function	Designed Indoor Temperature ℃		Occupied Area Per Capita (m^2/person)	Staff Load (W/ m^2)	Lighting Power (W/m^2)	Electrical Equipment Power (W/m^2)	Fresh Air Volume (m^3/hp)
	Summer	Winter					
Other	26	18	5	181	5	5	5
Standard Office	26	20	4	108	11	20	30

Conduct dynamic simulative calculation on the three types of building models by using the PKPM energy conservation design and analysis software (PBECA):

4.4.4.1 Point-block residence

The air-conditioned area of this building is 7589.68m^2, and its non-air-conditioned area is

2354.22m^2. The building thermal calculation model (see Figure 4.7) and the energy consumption simulation results (see Table 4.9 and Figure 4.8) are as follows.

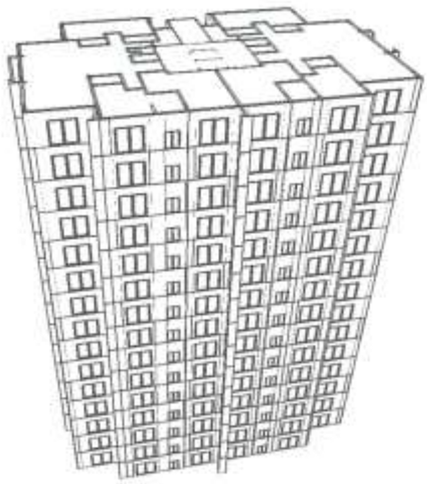


Figure 4.7 The thermal calculation model diagram of the point-block residence

Table 4.9 The dynamic calculation results of the point-block residence model

Load Type	Total energy consumption of the designed building (kW ħ)	Power consumption per unit area of the designed building (kW ħ/m^2)	Total energy consumption of the reference building (kW ħ)	Power consumption per unit area of the reference building (kW ħ/m^2)
Air-conditioning energy consumption	336121	33.80	335533	33.74
Heating energy consumption	217020	21.82	229597	23.09
Total energy consumption of heating and air-conditioning	553141	55.63	565130	56.83

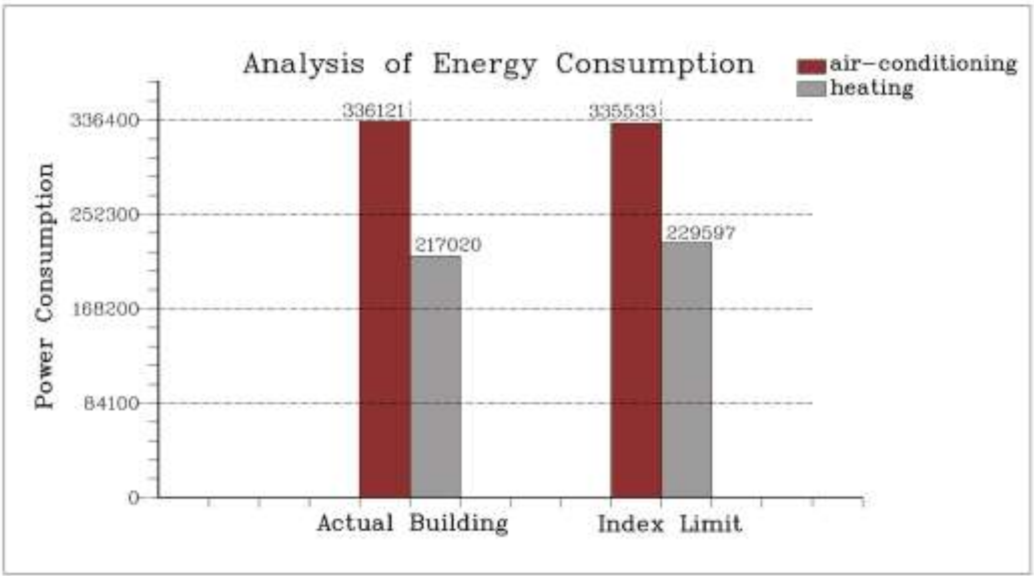


Figure 4.8 Energy-consumption analysis chart of the point-block residence

Table 4.9 shows that the annual energy consumption of the designed building is less than the limiting value of the index and its energy-saving rate is 51.06%. Therefore, according to the "Design Standard for Energy Efficiency of Residential Buildings" of Zhejiang Province, the energy-efficiency design of the point-block residence has reached the energy-saving requirements.

4.4.4.2 Bar-style residence

The air-conditioned area of this building is 2755.17m^2, and its non-air-conditioned area is 1529.58m^2. The building thermal calculation model (see Figure 4.9) and the energy consumption simulation results (see Table 4.10 and Figure 4.10) are as follows.

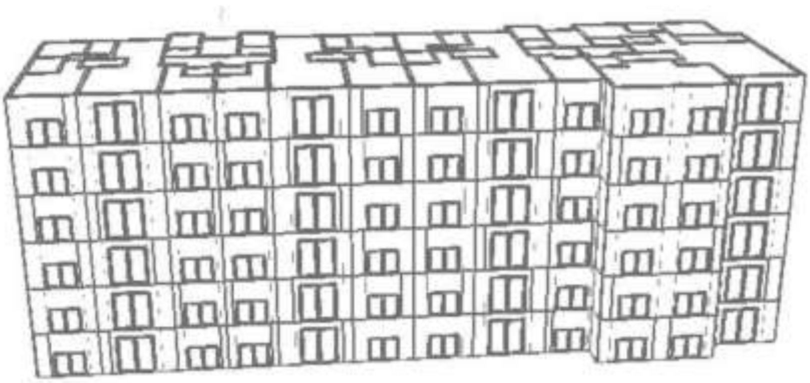


Figure 4.9 The thermal calculation model diagram of the bar-style residence

Table 4.10 The dynamic calculation results of the bar-style residence model

Load Type	Total energy consumption of the designed building (kW h)	Power consumption per unit area of the designed building (kW h/m^2)	Total energy consumption of the reference building (kW h)	Power consumption per unit area of the reference building (kW h/m^2)
Air-conditioning energy consumption	135754	31.68	134969	31.50
Heating energy consumption	93165	21.74	97725	22.81
Total energy consumption of heating and air-conditioning	228919	53.43	232694	54.31

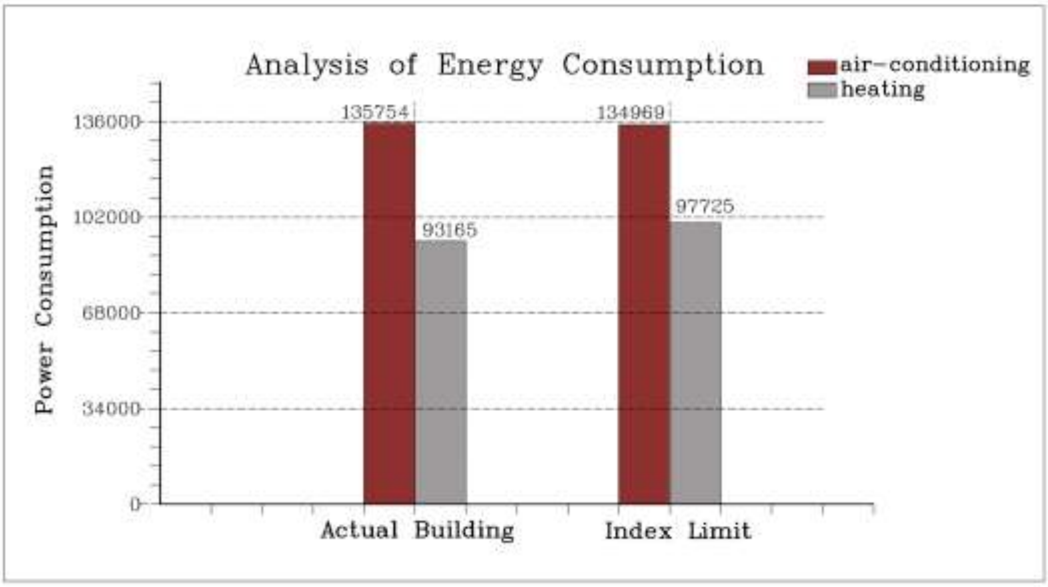


Figure 4.10 Energy-consumption analysis chart of the bar-style residence

Table 4.10 shows that the annual energy consumption of the designed building is less than the limiting value of the index and its energy-saving rate is 50.81%. Therefore, according to *Design Standard for Energy Efficiency of Residential Buildings* issued by Zhejiang Province, the energy-efficiency design of the bar-style residence has reached the energy-saving requirements.

4.4.4.3 Office building

The air-conditioned area of this building is 9155.29m^2, and its non-air-conditioned area is 4842.14m^2. The building thermal calculation model (see Figure 4.11) and the energy consumption simulation results (see Table 4.11 and Figure 4.12) are as follows.

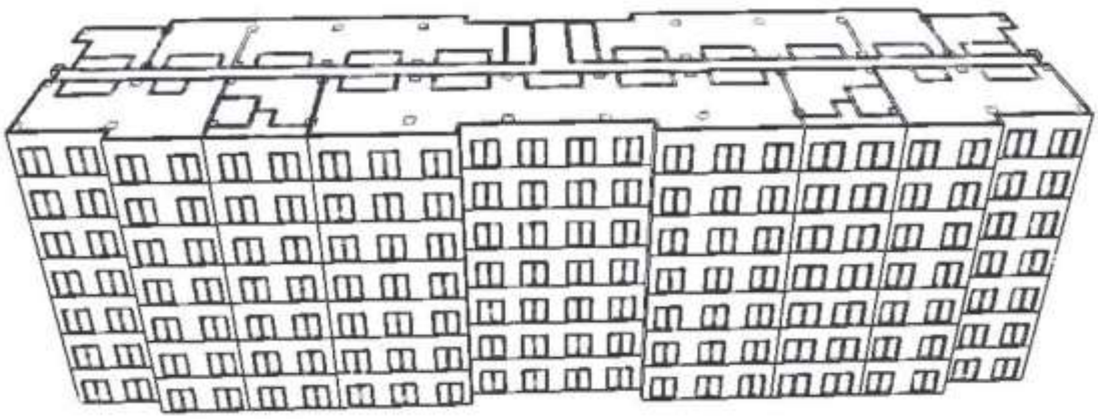


Figure 4.11 The thermal calculation model diagram of the office building

Table 4.11 The dynamic calculation results of the office building model

Load Type	Total energy consumption of the designed building (kW h)	Power consumption per unit area of the designed building (kW h/m^2)	Total energy consumption of the reference building (kW h)	Power consumption per unit area of the reference building (kW h/m^2)
Air-conditioning energy consumption	972582	69.48	959148	68.52
Heating energy consumption	483755	34.56	514465	36.75
Total energy consumption of heating and air-conditioning	1456337	104.04	1473613	105.27

Table 4.11 shows that the annual energy consumption of the designed building is less than the

limiting value of the index. Therefore, according to *Design Standard for Energy Efficiency of Public Buildings* (DB33/1036-2007) of Zhejiang Province, the energy-efficiency design of the office building has reached the energy-saving requirements.

4.4.5 An analysis of the impact of different calculation factors on the simulation results of building energy consumption

In order to better understand the changes of energy consumption, the following parameters in the simulation contents are changed to stimulate and analyze the changes of the air-conditioning and heating energy consumption of the three models.

1) Change the shape coefficient, with the other conditions unchanged;

2) Change the types of wall materials, with the other conditions unchanged;

3) Change the window-wall ratio, with the other conditions unchanged;

4) Change the thickness of the single wall, with the other conditions unchanged;

5) Change the thickness of the thermal bridge's insulation layer, with the other conditions unchanged;

6) Change the thickness of the roof's insulation materials, with the other conditions unchanged;

7) Change the shading coefficient of exterior windows, with the other conditions unchanged;

4.4.5.1The impact of the shape coefficient on the air-conditioning and heating energy consumption of a building

The shaping coefficient of a building refers to the ratio of its exterior surface area in contact with the outdoor atmosphere to its enclosing volume. The changes in a building's shape directly affect its amount of heating and air-conditioning energy consumption. It has been mentioned in much literature that there is a very good linear relationship between the shape coefficient of a building and the building's air-conditioning and heating energy consumption. In order to probe into the influence rules of the shape coefficient on the are-conditioning and heating energy consumption of different types of buildings, only the numbers of the buildings' standard layers such, as 1, 2, 3, ..., are changed, assuming that the other conditions of the buildings remain unchanged; when the total layer numbers of the buildings are different, their shape coefficients change accordingly. The simulation results are as follows (see Table 4.12 and Table 4.13).

Table 4.12 The shape coefficient simulation results

Name		Shape Coefficient	Air-Conditioning Energy Consumption (kWh/m^2)	Heating Energy Consumption (kWh/m^2)	Total Load of Air-Conditioning and Heating (kWh/m^2)
Point-Block Residence	Shape 1	0.52	34.87	57.55	92.42
	Shape 2	0.35	33.72	39.73	73.45
Bar-Style	Shape 1	0.25	31.68	21.74	53.43

Residence	Shape 2	0.23	31.96	19.15	51.11
Office Building	Shape 1	0.39	63.93	80.84	144.77
	Shape 2	0.21	67.41	46.09	113.50

Table 4.13 The rates of the changes of energy consumption along with those of the shape coefficients

Name	Shape Coefficient Change Rate	Air-Conditioning Energy Consumption Change Rate	Heating Energy Consumption Change Rate	Total Energy Consumption Change Rate
Point-Block Residence	↓32.69%	↓3.30%	↓30.96%	↓20.53%
Bar-Style Residence	↓8%	↑0.88%	↓11.91	↓4.34%
Office Building	↓46.15%	↑5.16%	↓43.0%	↓21.6%

Table 4.12 and Table 4.13 indicate that with the reduction of the shape coefficient of each model, the total energy consumption of air-conditioning and heating decreases, and that the change rates of the energy consumption of the point-block residence and the office building are relatively high while that of the bar-style residence is relatively low.

4.4.5.2The impact of different wall materials on a building's air-conditioning and heating energy consumption

Currently, the common types of new wall materials in the hot summer and cold winter zone and their thermal parameters are as follows (see Table 4.14). With other conditions unchanged, the air-conditioning and heating energy consumption of the three types of buildings are probed into by changing their different wall materials. The simulation results are as follows (see Figure 4.13 ~ Figure 4.15 and Table 4.15 ~ Table 4.17).

Table 4.14 The thermal performance parameters of different wall materials

Wall Number	Main Wall	The Heat Resistance of the Wall $(m^2.K)/W$	(Equivalent) Heat Conductivity $W/(m \cdot K)$
1	Shale sintered perforated brick	0.556	0.449
2	Coal gangue sintered perforated brick	0.569	0.438
3	Mud sintered insulating brick	0.698	0.425
4	Shale sintered hollow block	0.877	0.281

5	Sand aerated concrete blocks (B06)	1.214	0.188

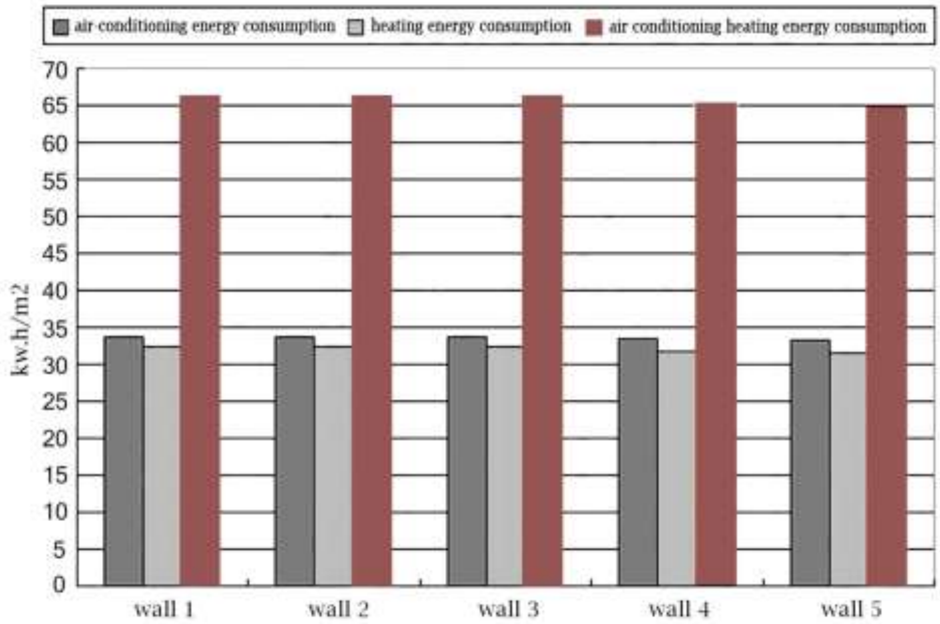


Figure 4.13 The impact of different wall materials on the air-conditioning and heating energy consumption of the point-block residence

Table 4.15 The impact of different wall materials on the air-conditioning and heating energy consumption of the point-block residence

Load Type	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption(kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
Wall 1	33.7	32.44	66.14
Wall 2	33.69	32.42	66.11
Wall 3	33.67	32.39	66.06
Wall 4	33.4	31.73	65.13
Wall 5	33.28	31.43	64.71

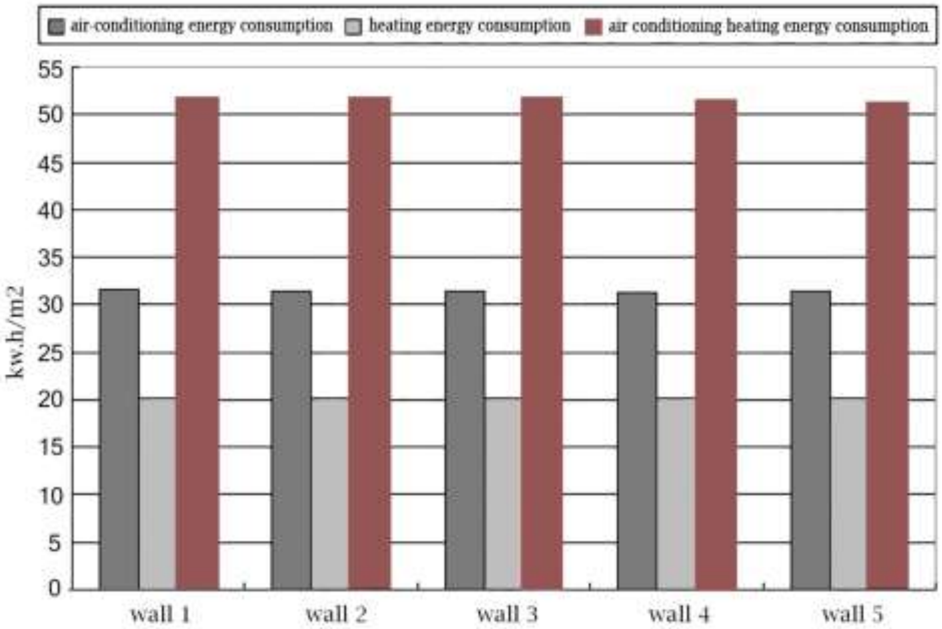


Figure 4.14 The impact of different wall materials on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.16 The impact of different wall materials on the air-conditioning and heating energy consumption of the bar-style residence

Load Type	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption(kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
Wall 1	31.52	20.17	51.68
Wall 2	31.51	20.18	51.69
Wall 3	31.49	20.19	51.69
Wall 4	31.32	20.16	51.47
Wall 5	31.39	20.23	51.62

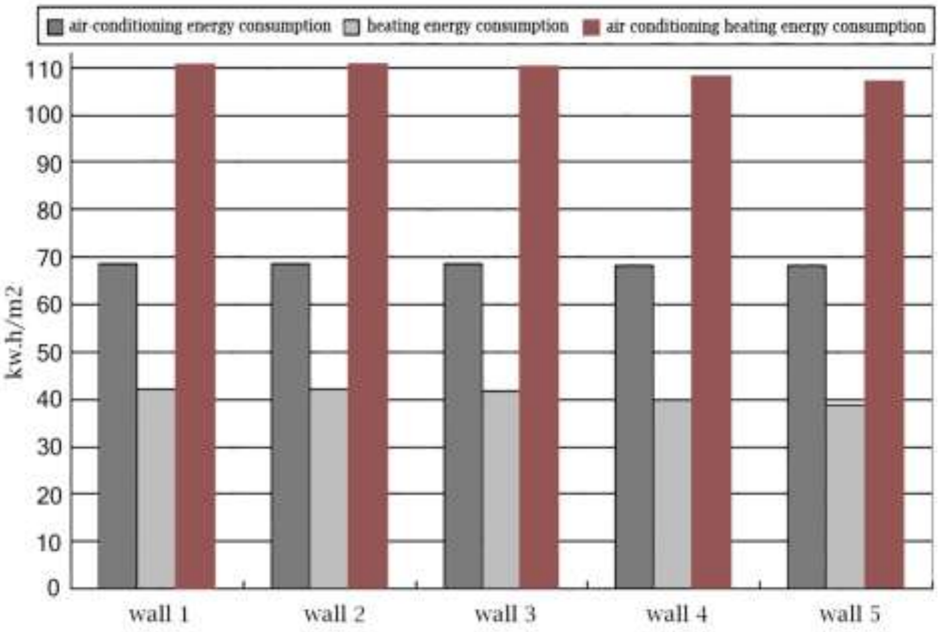


Figure 4.15 The impact of different wall materials on the air-conditioning and heating energy consumption of the office building

Table 4.17 The impact of different wall materials on the air-conditioning and heating energy consumption of the office building

Load Type	Air-conditioning Energy Consumption (kW ћ/m^2)	Heating Energy Consumption(kW ћ/m^2)	Air-conditioning and Heating Energy Consumption (kW ћ/m^2)
Wall 1	68.57	42.04	110.61
Wall 2	68.56	41.93	110.49
Wall 3	68.57	41.57	110.14
Wall 4	68.33	39.88	108.21
Wall 5	68.09	38.89	106.98

Table 4.15 ~ Table 4.17 show that the application of Wall 5, namely autoclaved sand aerated concrete block, leads to the lowest air-conditioning energy consumption of the building, followed by Wall 4 (shale sintered hollow block). The other three types of walls, namely shale sintered perforated brick, coal gangue sintered perforated brick and mud insulating brick, result in relatively high air-conditioning and heating energy consumption of the building.

4.4.5.3Change the window-wall ratio with the other conditions unchanged

The window-wall ratios in different orientations produce varied effects on energy consumption. In order to reflect the impact of different window-wall ratios on energy consumption more accurately, the changes in the air-conditioning and heating energy consumption of the three building types are researched into by changing the window-wall ratio only in one orientation with those in the other orientations unchanged. The simulation results are as follows (see Figure 4.16 ~ Figure 4.18 and Table 4.18 ~ Table 4.20).

Table 4.18 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the point-block residence

Window-Wall Ratio (South-facing)	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
0.1	24.98	33.21	58.19
0.2	25.56	33.12	58.68
0.3	26.21	33.01	59.22
0.4	26.74	32.94	59.68
0.5	27.35	32.82	60.17

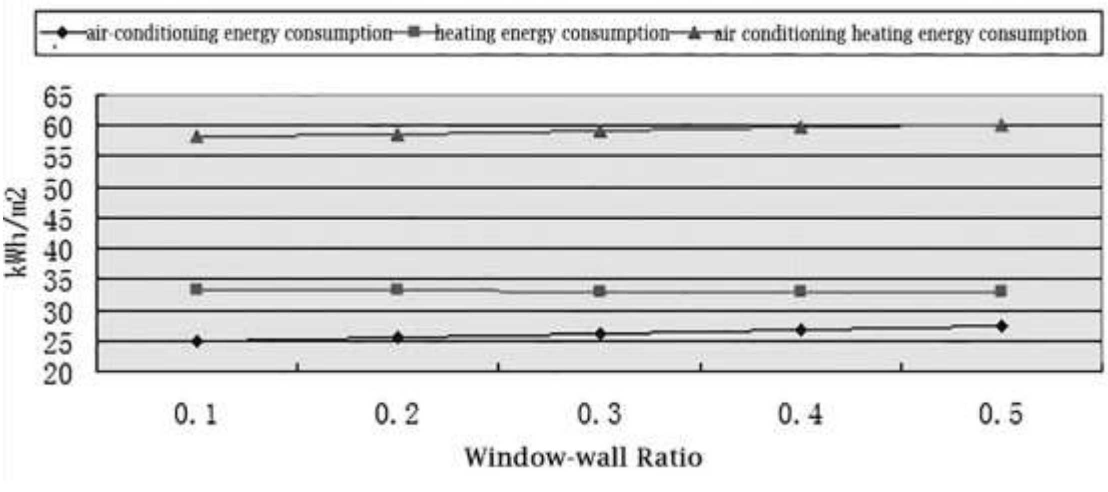


Figure 4.16 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the point-block residence

Table 4.19 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the bar-style residence

Window-Wall Ratio (South-facing)	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
0.1	21.36	30.08	51.44
0.2	22.62	30.22	52.84
0.3	23.65	29.79	53.44
0.4	24.84	29.75	54.59
0.5	26.07	29.28	55.35

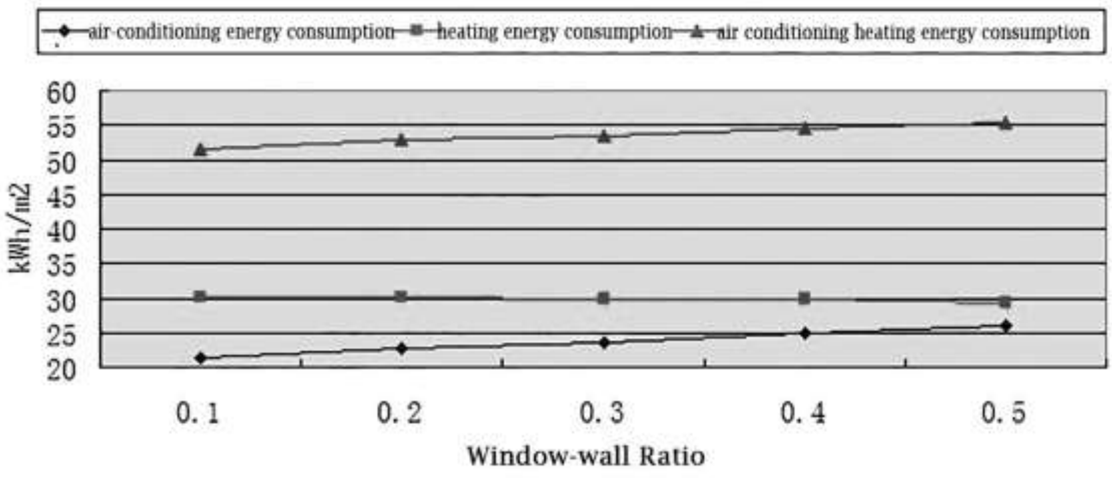


Figure 4.17 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.20 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the office building

Window-Wall Ratio (South-facing)	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
0.1	58.36	50.62	108.98
0.2	59.53	49.86	109.39
0.3	60.62	49.17	109.79
0.4	61.81	48.45	110.26
0.5	62.87	47.75	110.62

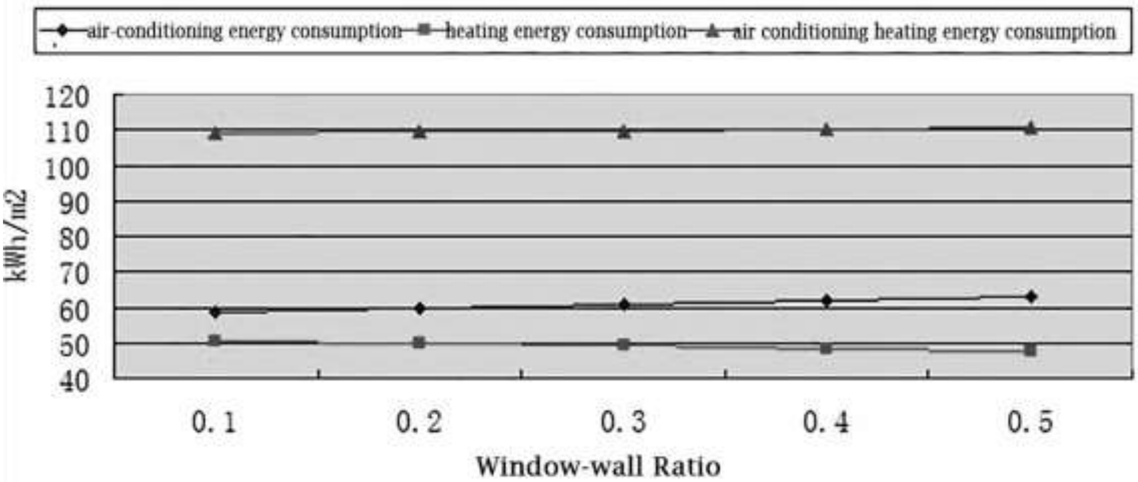


Figure 4.18 The impact of different window-wall ratios (south-facing) on the air-conditioning and heating energy consumption of the office building

It is indicated in Figure 4.16 ~ Figure 4.18 that as the window-wall ratio increases from 0.1 to 0.5, the air-conditioning energy consumption of the three building types rises while their heating energy consumption decreases, and that their total air-conditioning and heating energy consumption increases. The bar-style residence has relatively more obvious changes in its energy consumption. The increase in the window-wall ratio will result in increased heat gained from solar radiation in the room on the one hand and strengthened heat exchange between indoors and outdoors on the other. The former contributes to the improvement of indoor thermal environment in winter, but it leads to the increase of air-conditioning energy consumption in summer; the latter increases the heat consumption of a room in winter, but it is conducive to the indoor heat dissipation in summer. This means that the increase in the window-wall ratio brings both advantages and disadvantages to the indoor thermal environment in winter and summer respectively. Therefore, in order to make full and effective use of solar energy and realize energy saving in buildings, the window-wall ratio must be reasonably determined.

4.4.5.4Change the thickness of the single wall with the other conditions unchanged

The main wall and the thermal bridge together constitute the exterior wall of a building, and the wall accounts for nearly one-third of it, which thus plays an important role in the building's energy efficiency. By increasing the thickness of the wall to increase its heat resistance and reduce the heat transfer coefficient K of the exterior wall, the building energy consumption can be reduced. The changes in the air-conditioning and heating energy consumption of the three building types are studied by changing the thickness of wall materials only with the other conditions unchanged. The simulation results are as follows (see Figure 4.19 ~ Figure 4.21 and Table 4.21 ~ Table 4.23).

Table 4.21 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the point-block residence

Wall Thickness (mm)	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
200	33.75	33.57	67.32
250	33.53	32.73	66.26
300	33.36	31.89	65.26
350	33.33	31.33	64.65
400	33.21	30.79	64
450	33.12	30.33	63.44
500	33.04	29.94	62.98
550	32.98	29.61	62.59

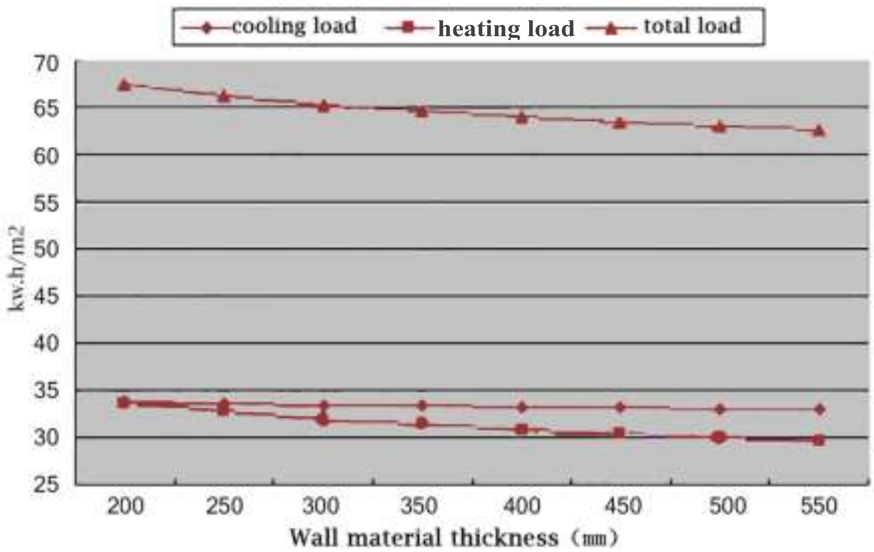


Figure 4.19 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the point-block residence

Table 4.22 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the bar-style residence

Wall Thickness (mm)	Air-conditioning Energy Consumption (kW ћ/m^2)	Heating Energy Consumption (kW ћ/m^2)	Air-conditioning and Heating Energy Consumption (kW ћ/m^2)
200	31.08	28.78	59.86
250	30.99	27.81	58.8
300	30.88	26.95	57.84
350	30.78	26.19	56.97
400	30.7	25.62	56.32
450	30.64	25.14	55.79
500	30.6	24.74	55.34
550	30.56	24.39	54.95

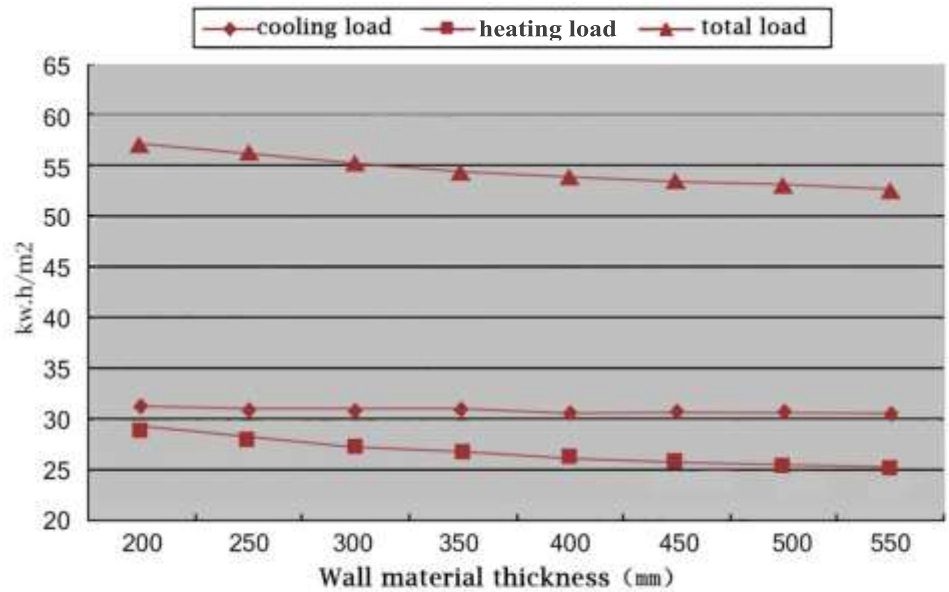


Figure 4.20 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.23 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the office building

Wall Thickness (mm)	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
200	67.4	46.3	113.7
250	67.4	45.81	113.21
300	67.41	45.45	112.86
350	67.42	45.17	112.59
400	67.8	44.88	112.68
450	67.75	44.74	112.49
500	67.61	44.63	112.24
550	67.57	44.52	112.09

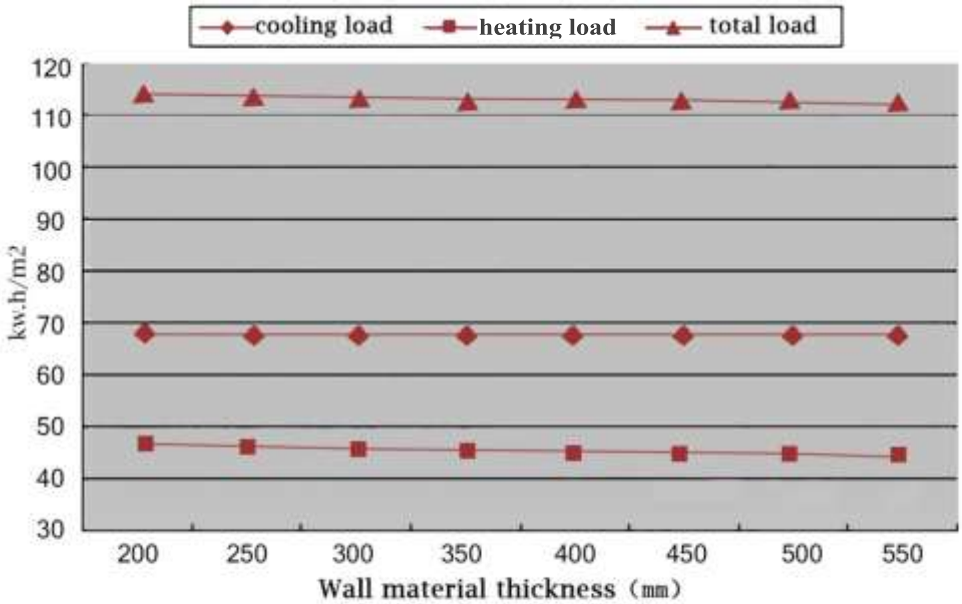


Figure 4.21 The impact of the thickness of wall materials on the air-conditioning and heating energy consumption of the office building

It is indicated in Figure 4.19 ~ Figure 4.21 that as the wall thickness increases from 200mm to 400mm, the heating energy consumption and the total energy consumption change obviously as for the point-block and bar-style residential buildings, and their air-conditioning energy consumption change linearly. When the wall thickness exceeds 400mm, the energy consumption tends to level off, and the changes of the air-conditioning energy consumption, the heating energy consumption and the total energy consumption of the office building tend to be flat, which shows that increasing the wall thickness will obviously reduce residential heating energy consumption but as for public buildings, merely increasing the wall thickness will not only fail to obviously reduce the air-conditioning and heating energy consumption but also increase the investment costs.

4.4.5.5Change the thickness of the thermal bridge's insulation layer with the other conditions unchanged

Thermal bridges exist at the junctions of interior and exterior walls, structural columns, frame beams, doors, windows and other parts, which generally all contain some metal structures. Metal is a good conductor of heat, thus exacerbating the heat transfer and reducing the thermal insulation effect. Moreover, since the temperature of the interior surface of the thermal bridge is relatively low, in winter, the water vapor condenses and forms dew condensation on the surface where the temperature is lower than the dew-point temperature of the indoor air. The exterior wall of a building consists of its thermal bridge and main wall, so by changing the thickness of the thermal bridge's insulation layer, can change the thermal resistance of the entire exterior wall, thus affecting the changes in energy consumption. The simulation results are as follows (see Figure 4.22 ~ Figure 4.24 and Table 4.24 ~ Table 4.26).

Table 4.24 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the point-block residence

The Thickness of the Insulation Layer (mm)	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
20	33.57	32.91	66.48
50	33.27	31.34	64.61
80	33.07	30.48	63.55
110	32.89	29.57	62.46
140	32.79	29.09	61.89
170	32.73	28.76	61.5
200	32.69	28.56	61.26
230	32.7	28.46	61.16

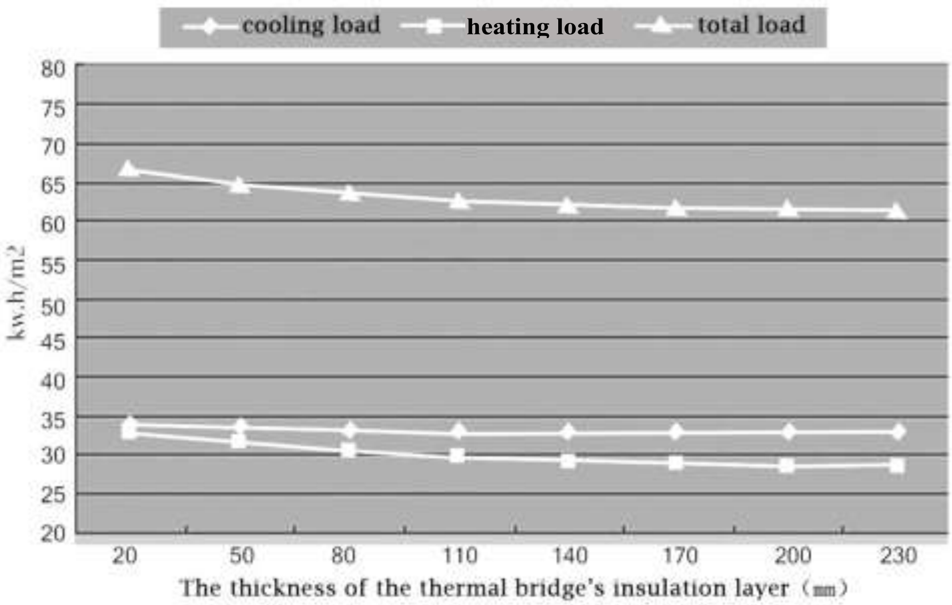


Figure 4.22 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the point-block residence

Table 4.25 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the bar-style residence

The Thickness of the Insulation Layer (mm)	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
20	33.57	32.91	66.48
50	33.27	31.34	64.61
80	33.07	30.48	63.55
110	32.89	29.57	62.46
140	32.79	29.09	61.89
170	32.73	28.76	61.5
200	32.69	28.56	61.26
230	32.7	28.46	61.16

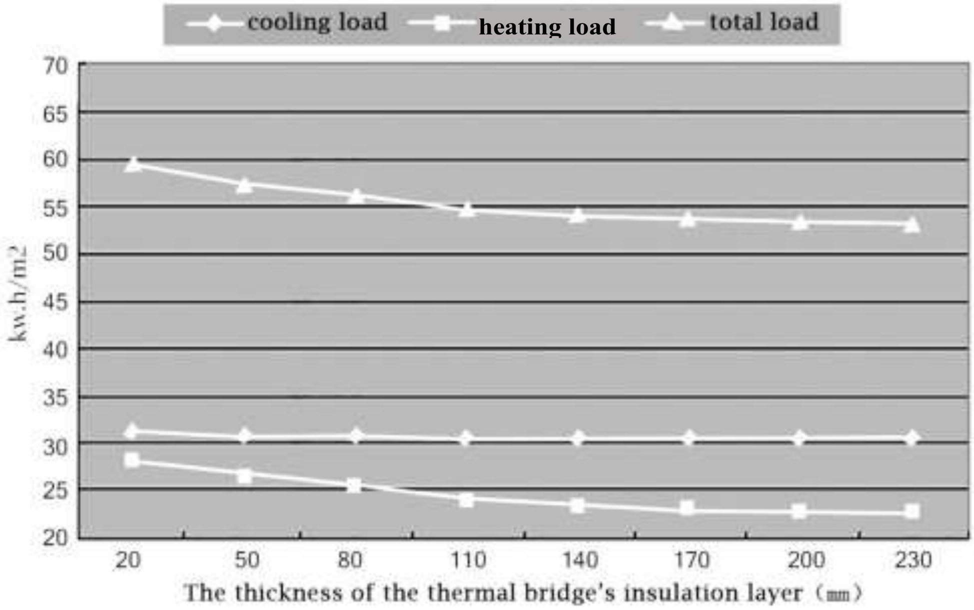


Figure 4.23 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.26 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the office building

The Thickness of the Insulation Layer (mm)	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)
40	31.05	28.05	59.1
60	30.68	26.51	57.2
80	30.57	25.31	55.88
100	30.48	24.04	54.52
120	30.44	23.37	53.81
140	30.42	22.95	53.37
160	30.4	22.69	53.09
180	30.4	22.6	53

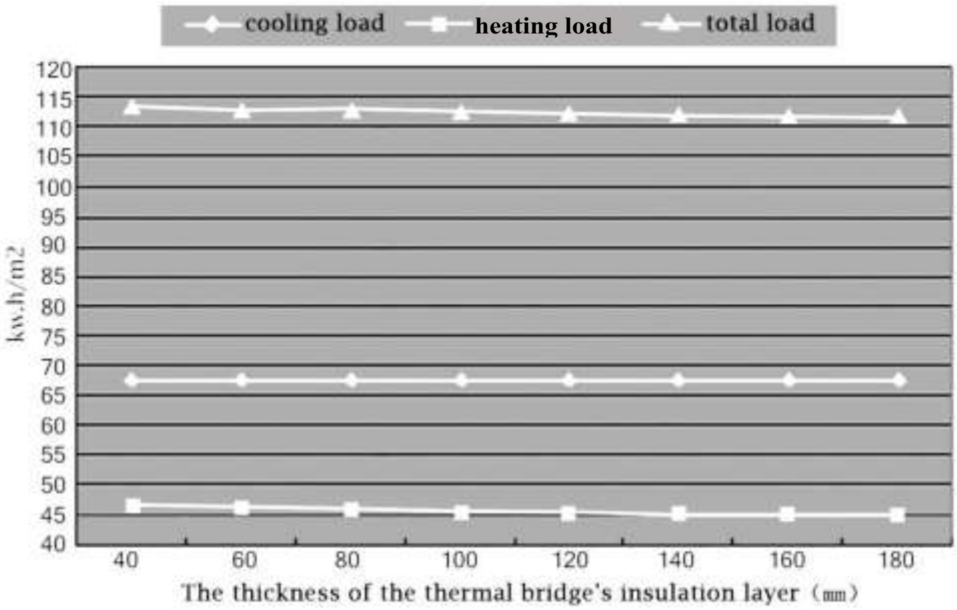


Figure 4.24 The impact of the thickness of the thermal bridge's insulation layer on the air-conditioning and heating energy consumption of the office building

It is indicated in Figure 4.22~Figure 4.24 that as the thickness of the thermal bridge's insulation layer increases from 20mm to 100mm, the heating energy consumption and the total energy consumption change obviously as for the point-block and bar-style residential buildings, and their air-conditioning energy consumption reduces obviously. When the thickness of the thermal bridge's insulation layer exceeds 100mm, the energy consumption tends to level off, and the changes of the air-conditioning energy consumption, the heating energy consumption and the total energy consumption of the office building tend to be flat, which shows that increasing the thickness of the thermal bridge's insulation layer will obviously reduce residential heating energy consumption but as for public buildings, merely increasing the thickness of the thermal bridge's insulation layer will not only fail to obviously reduce the air-conditioning and heating energy consumption but also increase the investment costs. In the hot summer and cold winter zone, too much emphasis on the treatment of thermal bridges is even a waste, which is unreasonable and also unrealistic in engineering.

4.4.5.6Change the thickness of roof's insulation materials with the other conditions unchanged

In a building envelope, the roof insulation measures also play a key role in energy consumption reduction, and the roof should also meet the requirements for insulation in winter. The following part has simulated the situation in which the building energy consumption changes as the thickness of the roof's insulation materials increases under the premise that the roof has met the requirements of the standard. The simulation results are as follows (see Figure 4.25 ~ Figure 4.27 and Table 4.27 ~ Table 4.29).

Table 4.27 The impact of the thickness of the roof's insulation layer on the air-conditioning and heating energy consumption of the point-block residence

The Thickness of the Roof's Insulation Layer (mm)	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
50	33.57	32.91	66.48
70	33.5	31.54	65.03
90	33.46	30.6	64.06
110	33.44	29.95	63.39
130	33.42	29.44	62.86
150	33.41	29.02	62.43
170	33.2	28.66	61.86
190	33.21	28.4	61.61

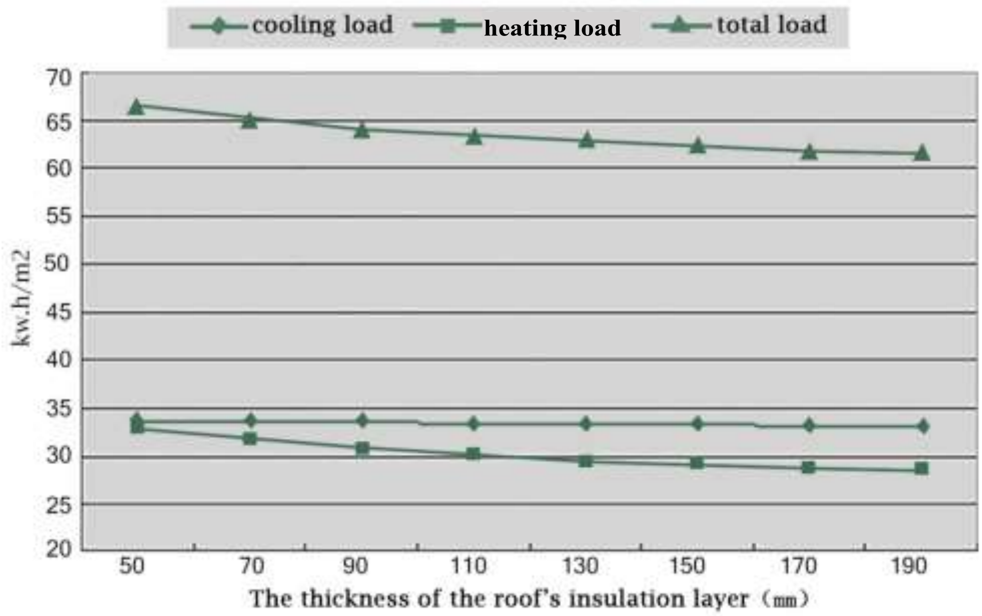


Figure 4.25 The impact of the thickness of the roof's insulation layer on the air-conditioning and heating energy consumption of the point-block residence

Table 4.28 The impact of the thickness of the roof's insulation layer on the air-conditioning and heating energy consumption of the bar-style residence

The Thickness of the Roof's Insulation Layer (mm)	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
50	31.05	28.05	59.1
70	31.19	27.06	58.25
90	31.19	26.18	57.37
110	31.2	25.55	56.75
130	31.21	25.08	56.29
150	31.22	24.71	55.92
170	30.88	24.44	55.32
190	30.91	24.19	55.1

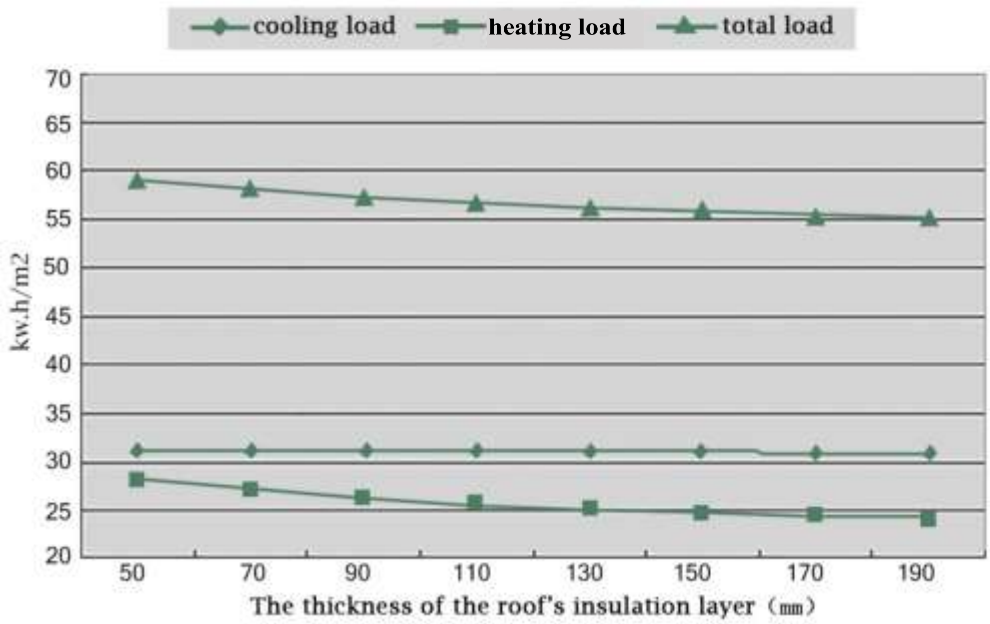


Figure 4.26 The impact of the thickness of the roof's insulation layer on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.29 The impact of the thickness of the roof's insulation layer on the air-conditioning and

heating energy consumption of the office building

The Thickness of the Roof's Insulation Layer (mm)	Air-conditioning Energy Consumption (kW ћ/m^2)	Heating Energy Consumption (kW ћ/m^2)	Air-conditioning and Heating Energy Consumption (kW ћ/m^2)
90	67.41	46.09	113.5
110	67.2	45.69	112.89
130	67.04	45.39	112.43
150	66.91	45.16	112.07
170	66.81	44.97	111.78
190	66.96	44.74	111.7
210	66.86	44.63	111.49
230	66.78	44.52	111.3

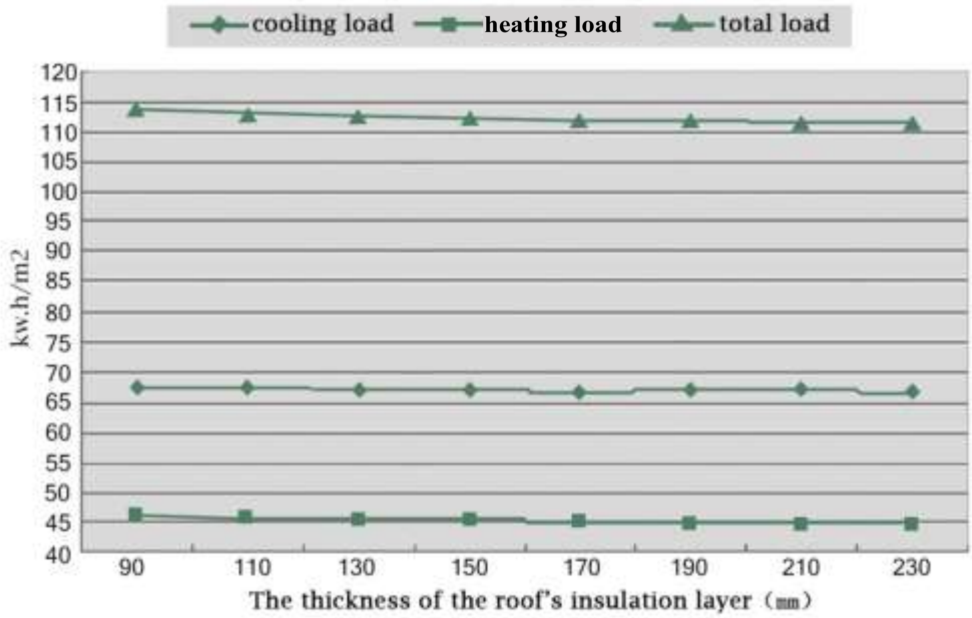


Figure 4.27 The impact of the thickness of the roof's insulation layer on the air-conditioning and heating energy consumption of the office building

It is manifested in Figure 4.25~Figure 4.27 that as the thickness of the roof's insulation layer increases from 50mm to 110mm, the heating energy consumption and the total energy consumption change obviously as for the point-block and bar-style residential buildings, and their air-conditioning energy consumption reduces obviously. When the thickness of the roof's insulation layer exceeds 110mm, the curve of energy consumption tends to be flat, and the changes of the air-conditioning energy consumption, the heating energy consumption and the total energy consumption of the office building tend to level off, which shows that increasing the thickness of the roof's insulation layer will obviously reduce residential heating energy consumption but as for public buildings, merely relying on changing the thickness of the roof's insulation layer will not only fail to obviously reduce the air-conditioning and heating energy consumption but also increase the investment costs.

4.4.5.7Change the shading coefficient of exterior windows with the other conditions unchanged

The exterior windows of a building are lightweight, thin-walled and transparent components in its envelope structures. Influenced by the exterior windows, the heating, air-conditioning and lighting energy consumption usually account for about half of the energy consumption of the entire building. In summer, sunlight enters the building through the glass, thus producing the greenhouse effect, which is the main reason for the high indoor temperature and increased air-conditioning energy consumption. Therefore, effective shading measures are one of the important approaches to reduce air-conditioning energy consumption. The same shading measure taken in different orientations of the building has different impacts on annual energy consumption. Taking the change in the shading coefficient of south-facing exterior windows as an example, from the perspective of energy consumption of air-conditioners throughout the year, the influence of the shading coefficient of exterior windows on air-conditioning energy consumption is simulated and analyzed. The simulation results are as follows (see Figure 4.28 ~ Figure 4.30 and Table 4.30 ~ Table 4.32).

Table 4.30 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the point-block residence

The Shading Coefficient of Exterior Windows	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
0.83	33.57	32.91	66.48
0.8	33.42	33.03	66.45
0.77	33.28	33.14	66.42
0.74	33.13	33.25	66.38
0.71	32.99	33.35	66.34
0.68	32.84	33.46	66.3
0.65	32.69	33.57	66.26
0.62	32.55	33.67	66.22

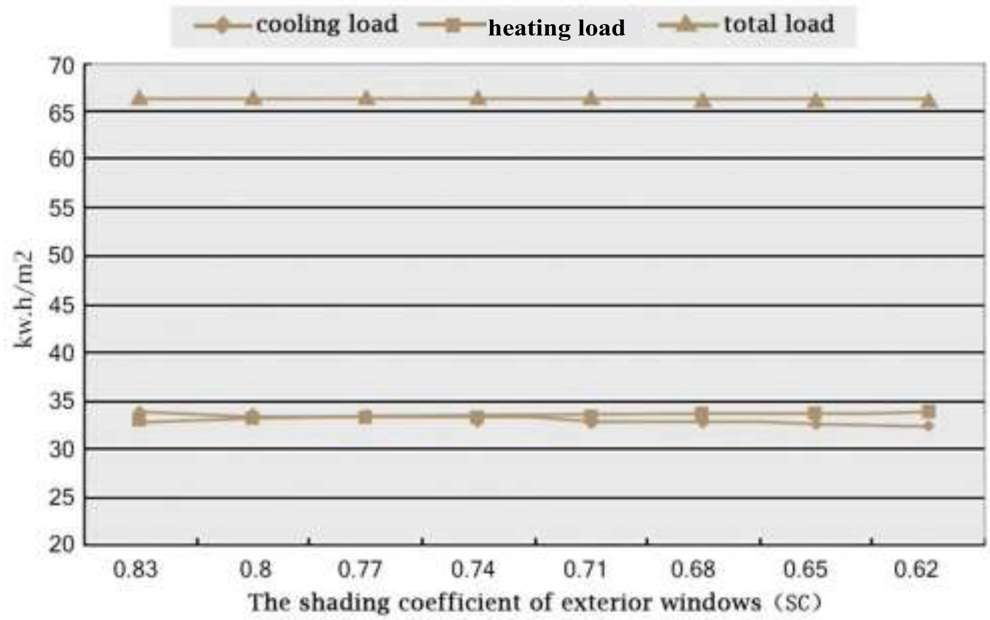


Figure 4.28 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the point-block residence

Table 4.31 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the bar-style residence

The Shading Coefficient of Exterior Windows	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
0.83	31.05	28.05	59.1
0.8	30.9	28.55	59.46
0.77	30.59	28.76	59.35
0.74	30.27	28.96	59.23
0.71	29.95	29.16	59.11
0.68	29.63	29.37	59
0.65	29.31	29.58	58.89
0.62	29	29.78	58.77

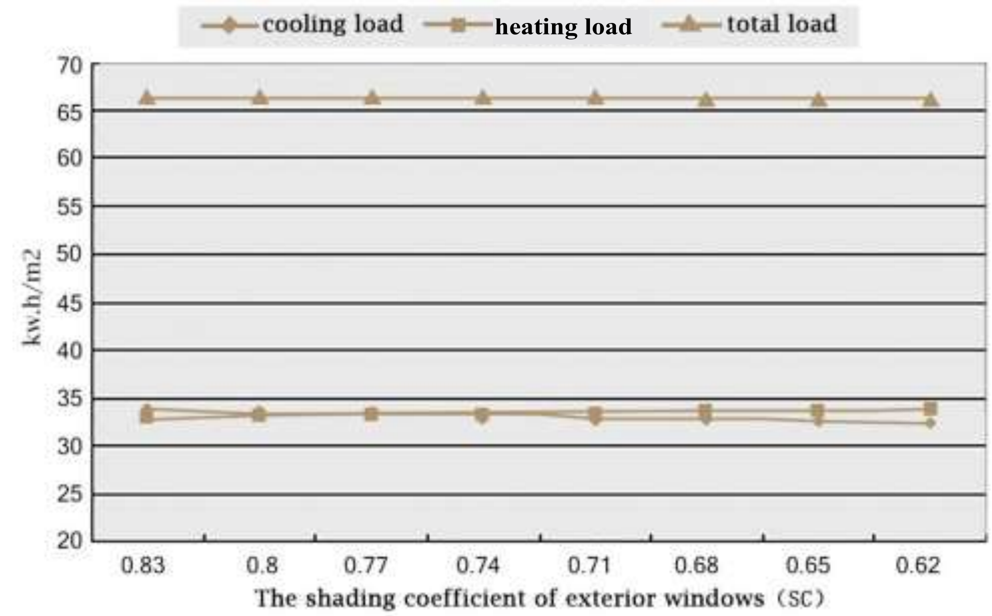


Figure 4.29 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the bar-style residence

Table 4.32 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the office building

The Shading Coefficient of Exterior Windows	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)
0.83	67.41	46.09	113.5
0.8	67.12	46.32	113.44
0.77	66.82	46.56	113.38
0.74	66.51	46.79	113.3
0.71	66.21	47.03	113.24
0.68	65.92	47.27	113.19
0.65	65.64	47.51	113.15
0.62	65.35	47.76	113.11

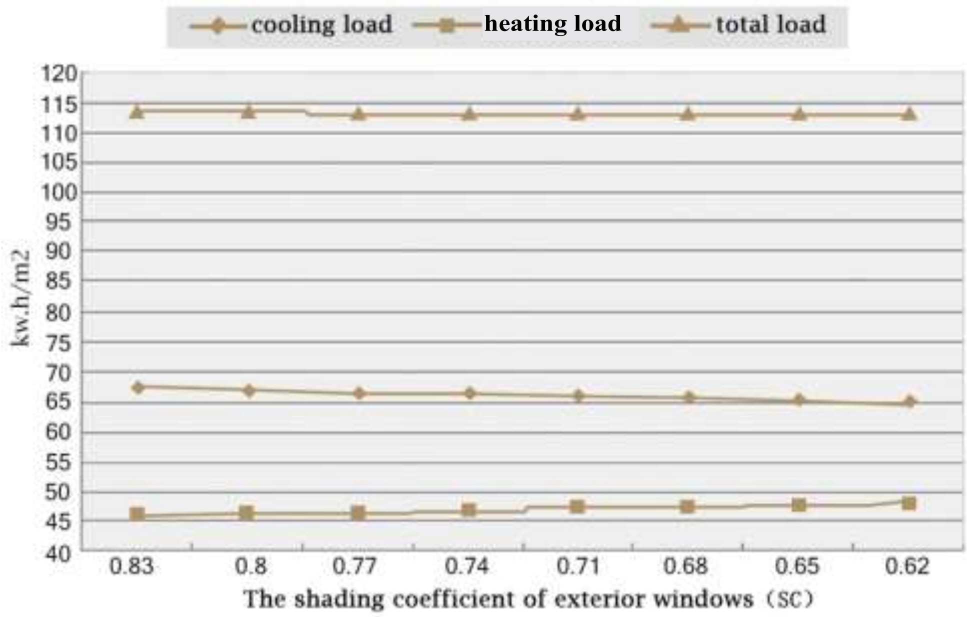


Figure 4.30 The impact of the shading coefficient of exterior windows (south-facing) on the air-conditioning and heating energy consumption of the office building

It is shown in Figure 4.28 ~ Figure 4.30 that with the decrease of the shading coefficient of exterior windows, the heat from the sunlight entering the room through exterior windows will also decrease, which will reduce the cooling load of air conditioners in summer and increase the heating load of air conditioners in the winter. For the hot summer and cold winter zone, the main task is heat shielding in summer with thermal insulation in winter taken into account. Therefore, as the shading coefficient of exterior windows decreases, the air-conditioning energy consumption increases accordingly, and the heating energy consumption decreases. Among the three types of buildings, the energy consumption of the point-block and bar-style residences is only slightly influenced by it.

4.5 An analysis on the key joints of the self-insulation systems in the hot summer and cold winter zone

In the self-insulation systems, the thermal bridges occupy a certain percentage of areas of the building envelope. In order to prevent the dew condensation on the thermal bridge caused by an excessive temperature difference between the inside and outside, it is necessary to make thermal insulation on the thermal bridges. The commonly used thermal insulation materials in the past were polystyrene board paste, polyurethane foam spraying and powder polystyrene particles paint, etc. These insulation materials have advantages such as low density and low thermal conductivity. The Ministry of Public Security of the People’s Republic of China promulgated in 2009 and 2011 “The Temporary Provisions on Insulation Systems and Fire Prevention of Exterior Decoration of Civil Buildings” Public [2009] No.46 and the notice on the Ministry of Public Security of the People’s Republic of China’s further demands on the fire supervision and management of insulation materials for civil buildings

Gong Xiao [2011] No. 65. They require that the insulation materials of external walls should reach grade A in terms of burning grade. The polystyrene boards, polyurethane foam and organic polystyrene powder particles are banned in the external insulation of exterior walls because they cannot reach the required burning grade. Now the only choices are materials with relatively high thermal conductivity such as inorganic insulation mortar and inorganic insulation boards.

Currently, the common inorganic insulation materials on the market are: inorganic insulation mortar, autoclaved sand aerated concrete slabs, nano-aerated concrete slabs, foam ceramic plates, etc.

1) Inorganic thermal insulation mortar

Inorganic insulation mortar is a new kind of heat-insulating and energy-saving mortar material for the painting of buildings' internal and external walls. It uses lightweight inorganic insulation particles as the light aggregate, added with dry-mixed mortar composed of cementitious material, anti-cracking additive and other fillers mortar. Due to its nice performance in energy-saving, waste-using, thermal insulation, fire prevention, frost resistance and aging resistance, its low price and other characteristics, it enjoys a wide range of demands on the market. Main technical characteristics of the inorganic thermal insulation mortar are:

(1) The inorganic insulation mortar has excellent temperature stability and chemical stability. The inorganic insulation mortar insulation system is made of pure inorganic materials. It is with high acid resistance, high alkali resistance and high corrosion resistance. It does not crack or shed, and has high stability. It does not have any aging problem and has the same life span as the walls of buildings.

(2) It is convenient to be used for construction with low overall costs. The inorganic-insulation-mortar insulation system can be wiped directly onto blank walls. Its construction method is the same as the leveling of cement mortar. It uses simple mechanical tools in a convenient way. Compared with other insulation systems, it possesses obvious advantages with short construction period and easy quality control.

(3) It can be applied in various situations and prevent the occurrence of thermal bridges. The inorganic-insulation-mortar insulation system is suitable for a variety of walls with different basic materials and of different complex shapes. It is fully enclosed and seamless, with no cavity or thermal bridge. It can be applied not only to the external insulation of exterior walls, but also to their internal insulation, and can be used for the internal and external insulation of exterior walls at the same time. Moreover, it can be adopted in roof insulation and geothermal insulation, which provides a certain flexibility for the design of energy-saving systems.

(4) It is environmentally friendly and pollution-free. The inorganic-insulation-mortar insulation system is non-toxic and tasteless with no radioactive pollution, which makes it harmless to the environment and human bodies. Meanwhile, some industrial residues and low-grade construction materials can be utilized by its massive promotion and application, which benefits the environment a lot.

(5) It has high strength. The bonding strength between the inorganic-insulation-mortar insulation

system and the base course is quite high, generating no cracks or hollows. Compared to all other insulation materials in China, this is a kind of technical superiority.

(6) It is highly flame retardant and safe. The inorganic-insulation-mortar insulation system is non-combustible and prevents fire. It can be widely applied to intensive residential buildings, public buildings, large public places, flammable places and places which have strict demands for fire safety. It can also serve as arson fence construction and improve the fire prevention standard of a building.

(7) It has good thermal performance. The heat-storage performance of the inorganic-insulation-mortar insulation system is much better than that of organic insulation materials, so it can be used for summer insulation in the southern area. At the same time, its thermal conductivity can be lower than 0.07 W/m·K, and its thermal conductivity can be easily adjusted to meet the demands of mechanical strength and the requirements of actual functional use, thus it can be used on different occasions.

2) Autoclaved sand aerated concrete slab (AAC)

Autoclaved sand aerated concrete takes materials like silica sand, cement and lime as the main raw materials and aluminum powder as a blowing agent. It is a multi-cellular concrete forming slab which is formed after the curing of high pressure steam (during the process, the slab should be reinforced by processed rebar). It can serve as both insulation materials for walls and roof boards. It is a new type of building material with superior performance.

Its main features are as follows:

(1) Unit weight. The unit weight of AAC slab is light, with dry density P = 425-725kg/m^3;

(2) Strength. Cubic compressive strength ≥ 4MPa, single point hanging force ≥ 1200N. As a kind of non-load-bearing maintaining structural material, it can fully meet the requirements of bending, cracking and joint strength under various conditions of use. It is a kind of lightweight and high-strength material for building envelopes.

(3) Thermal insulation and heat shielding. The material not only has good thermal insulation performance [λ = 0.13 (W/m·k)], but also has relatively nice heat shielding performance [the coefficient of heat storage S = 2.75W (m^2·k)]. When thickness of it is reasonable, it can be used not only in the cold zone which has high demands for thermal insulation, but also in the hot summer and cold winter zone which has high demands for heat shielding to meet the requirements of the energy-saving standards;

(4) Sound insulation. The material is a perforated material composed of a large number of uniform and non-connected micro-holes with good sound insulation performance. The average sound insulation of 100mm-thick AAC slab is 40.8dB and that of the 150mm-thick AAC slab is 45.8dB；

(5) Fire resistance. The AAC slab is a non-combustible inorganic material with good fire resistance;

(6) Durability. AAC is an inorganic silicate material with non-aging problems and good durability. Its service life matches the life span of a variety of buildings;

(7) Frost resistance. It has good frost resistance. After the freeze-thaw test, its mass loss is <1.5%

(national standard <5%) and its strength loss is <5% (national standard <20%);

(8) Impermeability. It has good impermeability, five times better than the standard brick;

(9) Green materials. The material is a non-radioactive green material without generating any harmful gas;

(10) Application property. The production of the AAC slab is industrialized and standardized and its installation is industrialized. It can be sawed, cut, planed and drilled. Its application is a dry operation process at fast speed;

(11) Supportiveness. The AAC slab has a complete supporting system, with special connectors, grouting agent, repair powder, interface agent, etc.;

(12) Convenient application with low costs. The application of the material does not require plastering, and instead, one can directly apply putty and spray painting on it;

The AAC slab has scientific and rational design of joints and installation methods, which ensure the exterior plane stability and safety of the wall on the basis of the guarantee of the joints' strength. It uses the rotation capacity of the wall in the plane to give the wall the mobility which enables it to move horizontally to a relatively large extent in the plane. This ensures that the maintenance structure of the building will not be damaged drastically under strong wind or earthquakes and give it rather strong seismic performance.

3) Nano-aerated lightweight concrete slab (NALC)

Nano-aerated lightweight concrete slab is called NALC for short. It a multi-cellular concrete product which takes silica sand, cement and lime as the main raw material. It is reinforced by the rust-proof rebar and is formed after the curing of high temperature, high pressure and steam.

It has the main technical characteristics of the autoclaved sand aerated concrete. The meso-structure of NALC is made up of numerous tiny holes which are not connected with each other, so that it has a good thermal insulation performance with a thermal conductivity of only 0.09W/ m ·K.

4) Foamed ceramic plate

Foamed ceramic plate takes ceramic soil tailings, debris, admixture and other materials as the main raw materials. It is a closed-cell ceramic material with high porosity which is made through advanced producing technology, foam molding technology and high-temperature firing.

Its main characteristics are as follows:

(1) Thermal insulation and heat shielding. The material has good thermal insulation performance [λ=0.08-0.10 (W/m ·k)] and relatively good heat shielding performance [the coefficient of heat storage S $\geqq$1.6W(m^2·k)];

(2) Fire resistance. The foam ceramic board is a non-combustible inorganic material. It is roasted at 1300 ℃ and has good fire resistance, with a combustion grade up to A1 level;

(3) Durability. It belongs to ceramics. It is a durable material without aging problems and has the same life span of as the buildings;

(4) Green material. The material is a non-radioactive green material without harmful gas;

(5) Anti-crack, anti-seepage. The material does not crack, deform, or cause seepage in the expansion caused by heat and the contraction caused by cold;

(6) Less construction procedures, less common quality problems.

5) Foam glass insulation board

Foam glass is a foamed glass product with closed holes formed by mixing glass with a material which can generate a large number of bubbles. Experiencing the melting and foaming at a high temperature, it is formed after cooling.

(1) Light unit weight, at 160 kg/m^3 or so;

(2) Low thermal conductivity, which is smaller than 0.066 (W/m ·k), with stable heat-conducting property;

(3) The foam glass is an insects-free and non-combustible material with high chemical stability. The foam glass has many superb characteristics such as a wide range of operating temperature, high compressive strength, low water absorption, low water vapor permeability coefficient, high dimensional stability and so on. However, it is a brittle material which has weak points such as fragility, vulnerability, etc.

(4) Foam glass is almost impermeable for water or vapor. When it is used in a hot and humid environment for a long period of time, its moisture content will not increase; thus, its thermal conductivity will not be affected by the operating environment or the service life;

(5) Foam glass has high tensile strength and can have a strong bond with adhesive. It has excellent dimensional stability at all temperatures and can effectively prevent cracking of itself and its protective coating.

The application of the foam glass has good prospects. It can be widely used in the insulation of roofing, floors, walls and pipes of high and low temperatures, but because of the higher price and uneven qualities, its application on buildings is not yet universal. Another reason for this is that it has not been sufficiently publicized and developed. Many of its advantages have not been well understood and some of the specific issues in its design and application still need to be addressed through pilot projects.

4.5.1 The proposals for key combinations of the self-insulation system

On account of the climate and resource conditions in Hangzhou, the key combinations which are more suitable for the self-insulation system in this city at present are proposed as follows:

Key combination 1: The main structure is made from aerated concrete, and the thermal bridge inorganic insulation mortar;

Key combination 2: The main structure is made from aerated concrete, and the thermal bridge nano-aerated lightweight concrete slabs;

Key combination 3: The main structure is made from aerated concrete, and the thermal bridge aerated concrete slabs (B04);

Key combination 4: The main structure is made from aerated concrete, and the thermal bridge foamed ceramics;

Key combination 5: The main structure is made from shale sintered hollow blocks, and the thermal bridge inorganic insulation mortar.

The thermal parameters of the insulation building materials are as follows (see Table 4.33).

Table 4.33Reference for the thermal parameters of the building materials

Name of the Material	Density Kg/m^3	Thermal Conductivity W/(m·K)	Heat Storage Coefficient W/(m^2·K)	Burning Grade	Correction Factor α	
					α	Application
Foam glass plate	150.00	0.066	0.70	A	1.10	Roof
Inorganic insulation mortar	350.00	0.07	2.30	A	1.20	Overhead floor
Inorganic insulation mortar	350.0	0.07	2.81	A	1.20	Thermal bridge column / thermal bridge beam / thermal bridge lintel / thermal bridge floor
Autoclaved sand aerated concrete slab	B04	0.13	2.06	A	1.0	
Nano-aerated lightweight concrete slab	B04	0.09	2.06	A	1.0	
Foamed ceramic plate	280.00	0.10	1.60	A	1.0	
Autoclaved sand aerated concrete block	B06	0.19	3.01	A	1.00	Exterior wall / interior wall
Shale sintered hollow block	900.00	0.28	4.143	A	1.0	Exterior wall / interior wall

Note: When adhesive mortar is applied between an aerated concrete block and an aerated concrete slab with the mortar joint ≤ 3mm, the influence coefficient of the mortar joint is taken as 1.0.

4.5.2 The insulation treatment of the thermal-bridge joints in the self-insulation system

As for the links with weak thermal performance in the building envelope such as the window lintels, ring beams, earthquake-resistant reinforced concrete columns, beams, etc., in thermal bridges which form intensive heat-flow channels, the thermal bridge area can be effectively reduced by structural measures. In energy-saving buildings, insulation treatment should be made to the thermal bridge parts including the reinforced concrete beams, columns and short-limbed shear walls in a frame structure and a composite structure, or the reinforced concrete structure in a special-shaped column structure (the insulation treatment plan is shown in Figure 4.31 and Figure 4.32). The insulation measures taken by the self-insulation system to its beams, column joints, shear walls and special-shaped columns are as follows: shrinking the parts of beams, columns, shear walls, etc. by 30-50mm (i.e. the part of self-insulation wall is convex). Insulation blocks made from the same materials can be pasted onto the shrunk parts, and insulation mortar or other insulation boards can also be used.

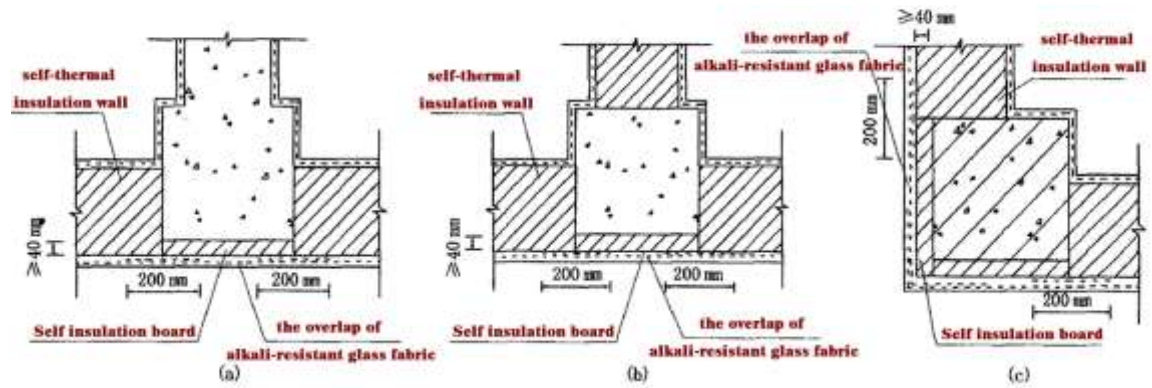


Figure 4.31 Insulation measures for thermal-bridge column joints

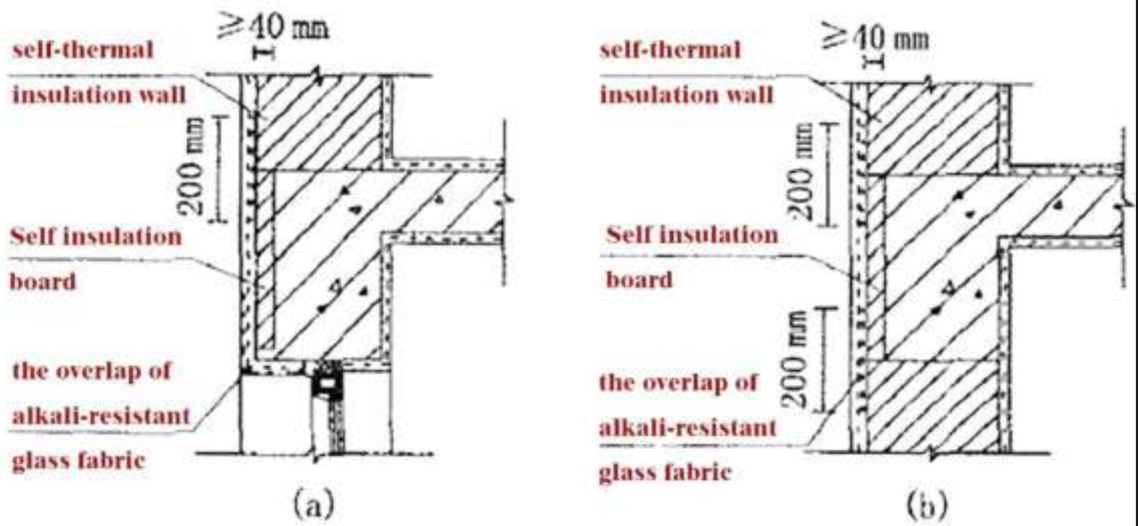


Figure 4.32 Insulation measures for thermal-bridge beam joints

4.5.3 Calculation cases

The PKPM energy conservation design and analysis software (PBECA) has been adopted to make a lot of calculations and analyses on the buildings of different types with different thermal-bridge key-joint combinations in their wall self-insulation systems, comparing the energy-saving effects of different structural combinations in a self-insulation system.

4.5.3.1Model selection

In order to guarantee the representativeness of the selected building types, this chapter has chosen the common architectural forms in Hangzhou to construct research models as well as building models, which reasonably simplifies the original building planes on the basis of not affecting the indoor thermal conditions as much as possible. The simplified floor plans of the building models (see Figure 4.33 ~ Figure 4.35) and the basic description of the building models (see Table 4.34) are as follows.

Figure 4.33 Residential floor plan

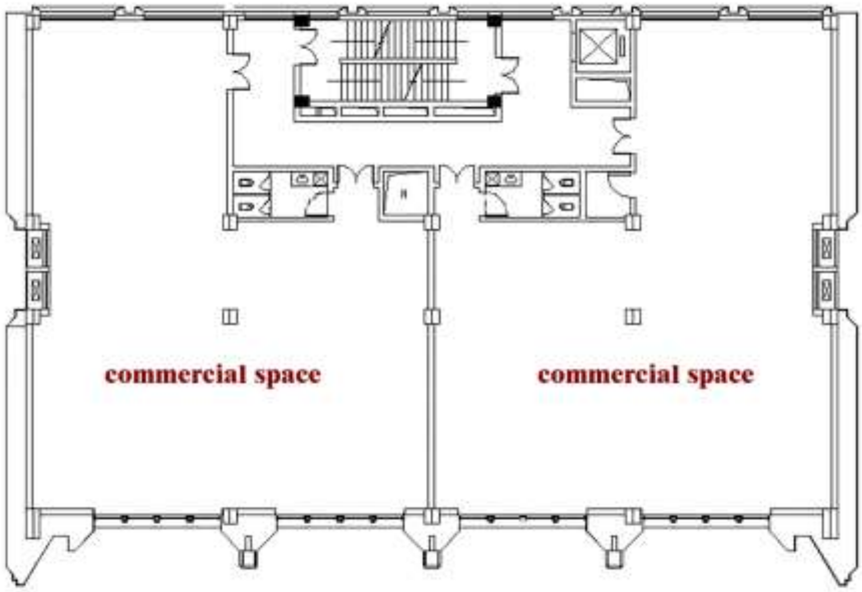


Figure 4.34 Commercial-building floor plan

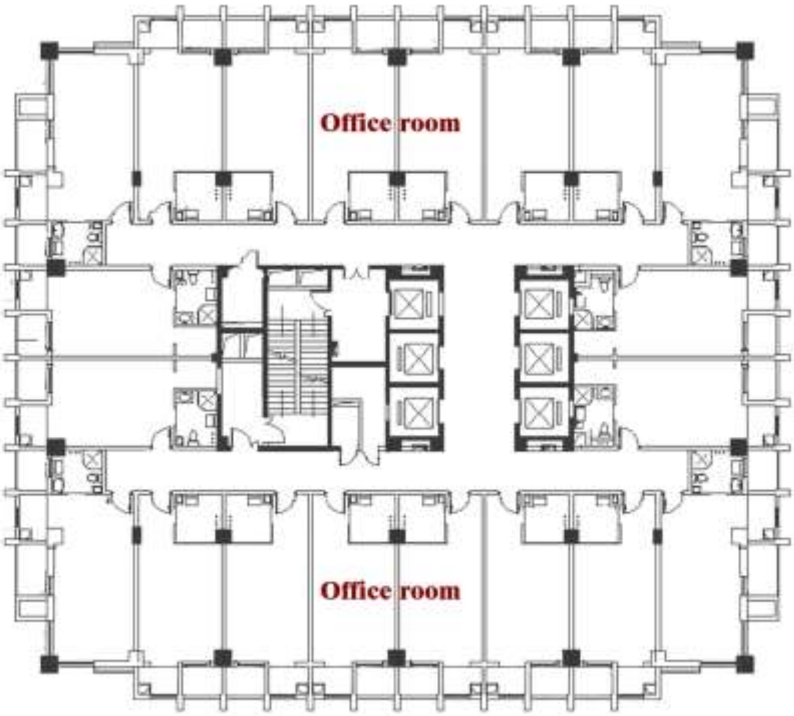


Figure 4.35 Office-building floor plan

Table 4.34The basic description of the building models

City		Hangzhou (approximately 30.00°N, 120.00°E)		
Climatic zone		Hot summer and cold winter		
Building type		Residence	Commercial building	Office building
Orientation		South	South	South
Structural type		Frame	Frame	Frame
The number of storeys			6 storeys	18 storeys
Storey height (mm)		3000	3600	3600
Shape coefficient		0.21	0.23	0.16
Window-wall ratio	East	0.30	0.21	0.05
	South	0.35	0.34	0.36
	West	0.30	0.05	0.05
	North	0.30	0.34	0.36

4.5.3.2The envelope construction of the building models

The PKPM energy conservation design and analysis software (PBECA) has been adopted to make calculations and analyses on the building envelops in the wall self-insulation systems with different thermal-bridge key-joint combinations of different building types.

Key combination 1: The main structure is made from aerated concrete, and the thermal bridge inorganic insulation mortar;

Key combination 2: The main structure is made from aerated concrete, and the thermal bridge nano-aerated lightweight concrete slabs;

Key combination 3: The main structure is made from aerated concrete, and the thermal bridge autoclaved sand aerated concrete slabs (B04);

Key combination 4: The main structure is made from aerated concrete, and the thermal bridge foamed ceramics;

Key combination 5: The main structure is made from shale sintered hollow blocks, and the thermal bridge inorganic insulation mortar.

The thermal parameters of the building envelopes are as follows (see Table 4.35 ~ Table 4.37).

Table 4.35 The basic description of the residential building envelope

Component	**The Main Structure and the Insulation Materials**	**Thermal Performance W/(m^2·K)**	**The Limiting Value of the Index W/(m^2·K)**	**Judgement**
Exterior Wall	Key joint 1 Main wall: cement mortar (20.00mm) + autoclaved aerated sand concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (20mm) + (240mm) + cement mortar (20.00mm)	1.46 (D=4.10)	K≤1.50 (D=3.00)	Pass
	Key joint 2 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + nano-aerated lightweight concrete slab (20mm) Reinforced concrete (240mm) + cement mortar (20.00mm)	1.41 (D=4.10)	K≤1.50 (D=3.00)	Pass
	Key joint 3 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + autoclaved sand aerated concrete slab (30mm) Reinforced concrete (240mm) + cement mortar (20.00mm)	1.40 (D=4.19)	K≤1.50 (D=3.00)	Pass
	Key joint 4	1.45	K≤1.50	Pass

	Main wall: cement mortar (20.00mm) + autoclaved aerated sand concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + foamed ceramic plate (20mm) +reinforced concrete (240mm) + cement mortar (20.00mm)	(D=4.08)	(D=3.00)	
	Key joint 5 Main wall: Cement mortar (20.00mm) + shale sintered hollow block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (20mm) + reinforced concrete (240mm) + cement mortar (20.00mm)	1.41 (D=5.37)	K≤1.50 (D=3.00)	Pass
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + foam glass (50.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.98 (D=2.98)	K≤1.0 (D=3.00)	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	K=2.92	K≤2.0	Fail
Door & Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-
Entry Door	Energy-saving anteport	K=2.77	K≤3.0	Pass

Table 4.36 The basic description of the commercial building envelope

Component	**The Main Structure and the Insulation Materials**	**Thermal Performance W/(m^2 ·K)**	**The Limiting Value of the Index W/(m^2 ·K)**	**Judgement**
Exterior Wall	Key joint 1 Main wall: cement mortar (20.00mm) + autoclaved aerated sand concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (40mm) + (240mm) + cement mortar (20.00mm)	0.94	K≤1.0	Pass
	Key joint 2 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + nano-aerated lightweight concrete slab (40mm) Reinforced concrete (240mm) + cement mortar (20.00mm)	0.96	K≤1.00	Pass
	Key joint 3 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + autoclaved sand aerated concrete (40mm) reinforced concrete (240mm) + autoclaved	0.97	K≤1.00	Pass

	sand aerated concrete (20mm)			
	Key joint 4 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + foamed ceramic plate (40mm) +reinforced concrete (240mm) + cement mortar (20.00mm)	1.0	K≤1.00	Pass
	Key joint 5 Main wall: Cement mortar (20.00mm) + shale sintered hollow block (240mm) + cement mortar (20.00mm) Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (40mm) + reinforced concrete (240mm) + inorganic insulation mortar (20mm)	0.98	K≤1.00	Pass
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + Cement mortar (20.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.64	K≤0.7	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	K=2.92	K≤2.0	Fail
Door & Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-

Table 4.37 The basic description of the office building envelope

Component	**The Main Structure and the Insulation Materials**	**Thermal Performance W/(m^2 K)**	**The Limiting Value of the Index W/(m^2 K)**	**Judgement**
Exterior Wall	Key joint 1 Main wall: cement mortar (20.00mm) + autoclaved aerated sand concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (40mm) + (240mm) + cement mortar (20.00mm)	0.81	K≤1.0	Pass
	Key joint 2 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + nano-aerated lightweight concrete slab (40mm) Reinforced concrete (240mm) + cement mortar (20.00mm)	0.82	K≤1.00	Pass
	Key joint 3 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + autoclaved sand aerated concrete plate (40mm) +reinforced concrete	0.90	K≤1.00	Pass

	(240mm) + autoclaved sand aerated concrete slab (20mm)			
	Key joint 4 Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + foamed ceramic plate (40mm) + reinforced concrete (240mm) + cement mortar (20.00mm)	1.0	K≤1.00	Pass
	Key joint 5 Main wall: cement mortar (20.00mm) + shale sintered hollow block (240mm) + cement mortar (20.00mm) Thermal Bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (40mm) + reinforced concrete (240mm) + inorganic insulation mortar (20mm)	0.98	K≤1.00	Pass
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + cement mortar (20.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (120.00mm)	K=0.64	K≤0.7	Pass
Floor slab	Cement mortar (20.00mm) + reinforced concrete slab (120.00mm)	K=2.92	K≤2.0	Fail
Door & Window	Insulated aluminum general hollow glass window (6mm + 12A + 6mm)	K=3.4 SC=0.83	-	-

4.5.4 Dynamic simulative calculation of the building models

Conduct dynamic simulative calculation on the three types of building models by using the PKPM energy conservation design and analysis software (PBECA):

4.5.4.1 Residential building

The air-conditioned area of this building is 7589.68 ㎡, and its non-air-conditioned area is 2354.22

㎡. The building thermal calculation model (see Figure 4.36) and the energy consumption simulation results (see Table 4.37 and Figure 4.37) are as follows.

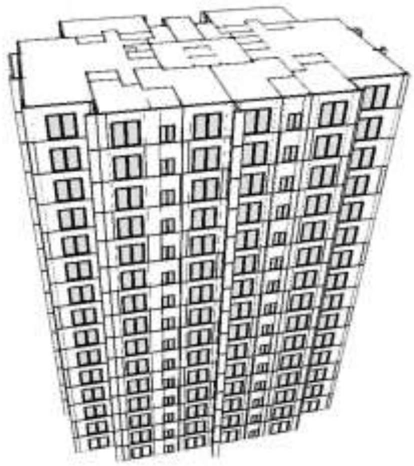


Figure 4.36 The thermal calculation model diagram of the residence

Table 4.37The dynamic calculation results of the residential-building model

Key Joint	Air-conditioning Energy Consumption (kW ħ/m^2)	Heating Energy Consumption (kW ħ/m^2)	Air-conditioning and Heating Energy Consumption (kW ħ/m^2)	The Total Air-conditioning and Heating Energy Consumption of the Reference Building (kW ħ/m^2)
Key Combination 1	33.94	21.97	55.91	57.02
Key Combination 2	33.93	21.96	55.88	57.02
Key Combination 3	33.92	21.99	55.91	57.02
Key Combination 4	33.94	21.98	55.92	57.02
Key Combination 5	33.91	22.23	56.14	57.02

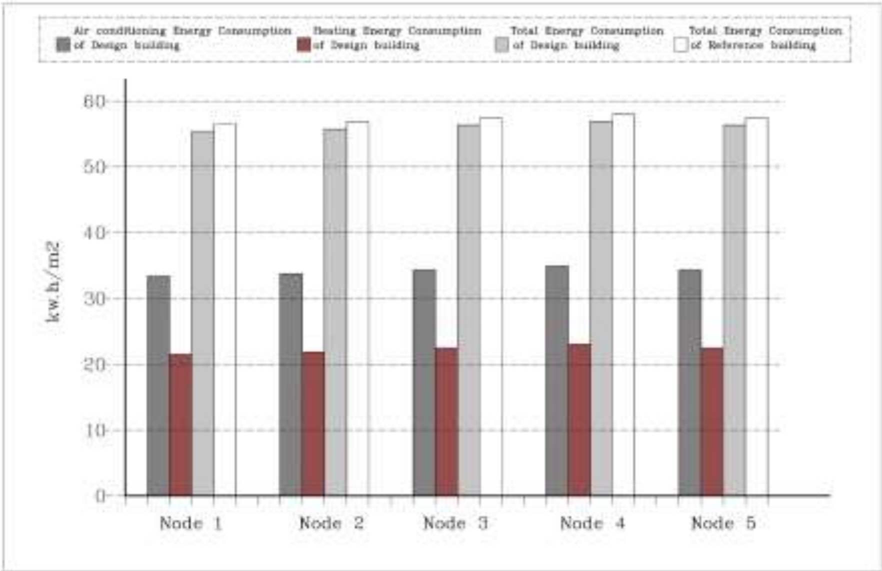


Figure 4.37 The energy-consumption analysis chart of different key joints in the residential building

4.5.4.2 Commercial building

The air-conditioned area of this building is 3349.4 ㎡, and its non-air-conditioned area is 782.46 ㎡. The building thermal calculation model (see Figure 4.38) and the energy consumption simulation results (see Table 4.38 and Figure 4.39) are as follows.

Figure 4.38 The thermal calculation model diagram of the commercial building

Table 4.38 The dynamic calculation results of the commercial-building model

Key Joint	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)	The Total Air-conditioning and Heating Energy Consumption of the Reference Building (kW h/m^2)
Key Combination 1	112.93	23.94	136.42	142.12
Key Combination 2	112.95	23.52	136.47	142.12
Key Combination 3	112.98	23.57	136.55	142.12
Key Combination 4	113.12	23.61	136.73	142.12
Key Combination 5	113.3	23.49	136.79	142.12

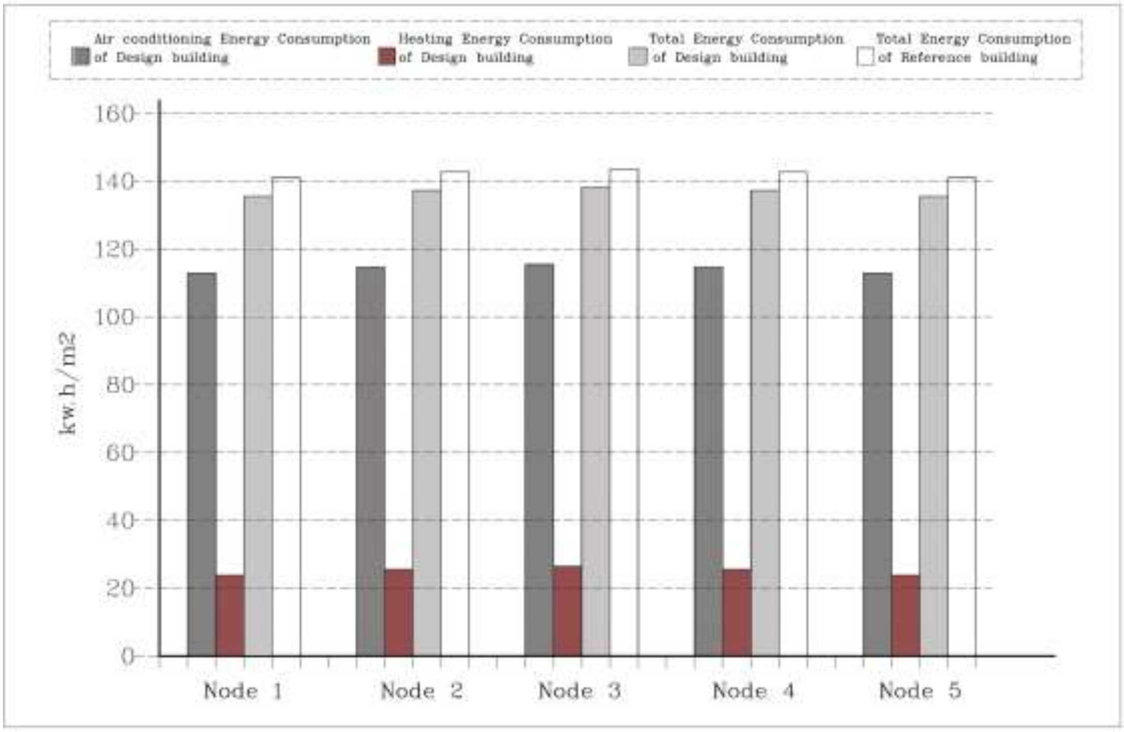


Figure 4.39 The energy-consumption analysis chart of the commercial building

4.5.4.3 Office building

The air-conditioned area of this building is 12443.9m^2, and its non-air-conditioned area is 5347.44m^2. The building thermal calculation model (see Figure 4.40) and the energy consumption simulation results (see Table 4.39 and Figure 4.41) are as follows.

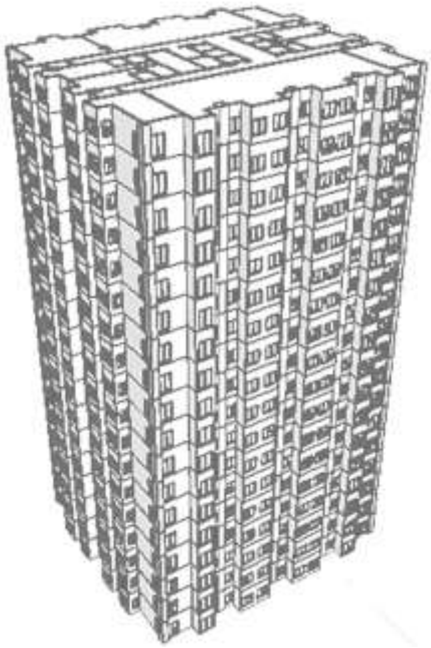


Figure 4.40 The thermal calculation model diagram of the office building

Table 4.39 The dynamic calculation results of the office-building model

Key Joint	Air-conditioning Energy Consumption (kW h/m^2)	Heating Energy Consumption (kW h/m^2)	Air-conditioning and Heating Energy Consumption (kW h/m^2)	The Total Air-conditioning and Heating Energy Consumption of the Reference Building (kW h/m^2)
Key Combination 1	73.52	31.49	105.01	110.27
Key Combination 2	73.51	31.59	105.10	110.27
Key Combination 3	73.49	32.02	105.51	110.27
Key Combination 4	73.51	31.74	105.25	110.27
Key Combination 5	73.8	32.48	106.28	110.27

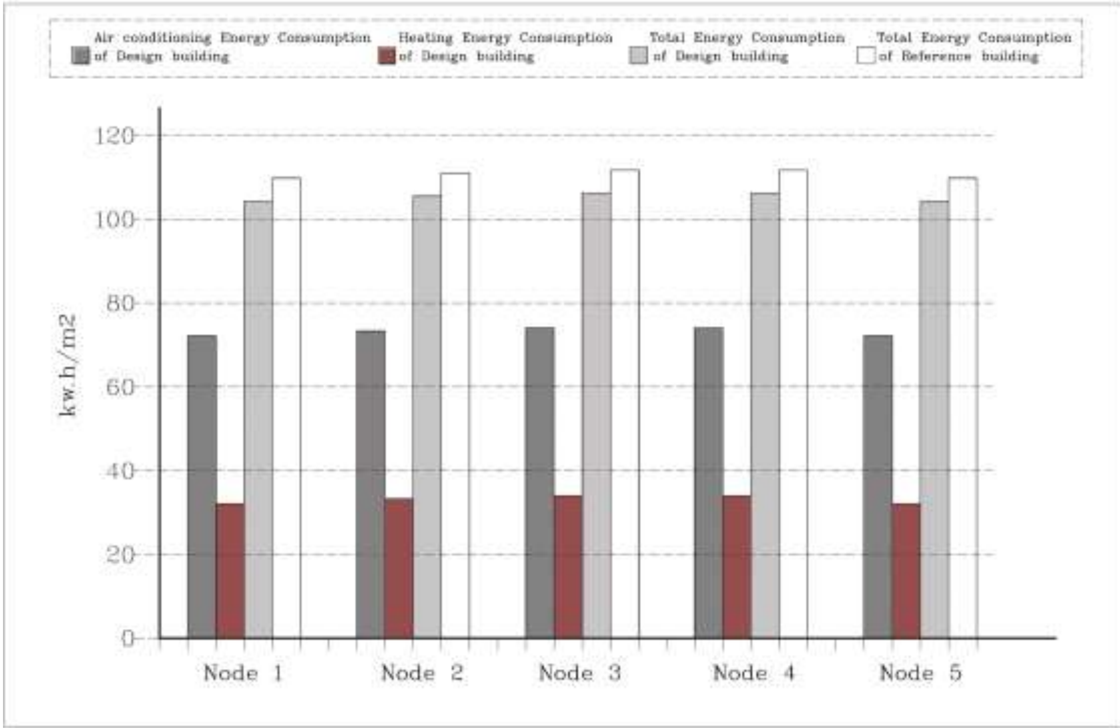


Figure 4.41 The energy-consumption analysis chart of different key joints in the residential building

4.6 Conclusion

Based on the theoretical analyses of the self-insulation systems of different building types in the hot summer and cold winter zone and the summary of the energy-efficiency calculation methods of self-insulation systems, this chapter has made energy-efficiency calculations and analyses of different types of buildings with self-insulation systems through case studies. At the same time, different influencing factors of the energy-saving effect of a self-insulation system have also been compared and analyzed, such as a building's shape coefficient, wall materials, window-wall ratio, wall thickness, thickness of its insulation layer, thickness of its roof's insulation layer, exterior-window shading coefficient, etc. A lot of calculations and analyses have been made on the different types of buildings that adopt different wall materials and different thermal-bridge key-joint combinations in their wall self-insulation systems. Based on the analysis of the energy-saving effects of different structural combinations in the self-insulation systems, and taking economic benefits and many other factors into consideration, it has been decided that the most suitable combinations for the self-insulation system in the hot summer and cold winter zone, especially in Hangzhou, are as follows: Key combination 1: the main structure is made from aerated concrete, and the thermal bridge inorganic insulation mortar; Key combination 3: the main structure is made from aerated concrete, and the thermal bridge autoclaved sand aerated concrete slabs (B04); Key combination 5: the main structure is made from shale sintered hollow blocks, and the thermal bridge inorganic insulation mortar. Then the three combinations as the most suitable ones for the self-insulation system in the hot summer and cold winter zone (especially in Hangzhou) are applied to the pilot project in practice.

CHAPTER FIVE: CALCULATION, ANALYSIS AND FIELD MEASUREMENT OF THE PILOT PROJEDT

5. CALCULATION, ANALYSIS AND FIELD MEASUREMENT OF THE PILOT PROJECT

5.1 Introduction

Through the investigation of the wall insulation systems in the hot summer and cold winter zone, the tests and research on the thermal performance of commonly-used wall materials and the theoretical study and numerical calculation and analysis of the self-insulation systems, based on the climatic characteristics and local resource conditions of the hot summer and cold winter zone, especially Hangzhou, it has been made clear that the most economical and effective wall self-insulation systems in Hangzhou adopt the following combinations: Key combination 1: the wall is made from aerated concrete, and the thermal bridge inorganic insulation mortar; Key combination 2: the wall is made from aerated concrete, and the thermal bridge autoclaved sand aerated concrete slabs (B04); Key combination 3: the wall is made from shale sintered hollow blocks, and the thermal bridge inorganic insulation mortar. In order to test the practical energy-saving effects of the various combinations adopted by the wall self-insulation systems, this research has taken the A1-A8# buildings in Cluster A, Xintiandi, Xixi, Hangzhou as the pilot project, of which A1-A5 are five exactly same office buildings that respectively adopt the above three kinds of key combinations in their wall self-insulation systems. Through the energy-efficiency calculations, analyses and field tests of the pilot project, the effectiveness of the adopted technical measures has been tested.

5.2 Pilot Project Profile

The A1~A8# buildings of Cluster A, Xintiandi, Xixi are located in Xihu District, Hangzhou, surrounded by the road greenbelt of Wenyi Road, the river greenbelt of Chaotianmo Port and the road greenbelts of Shuanggang Road and Wuchanggang Road. Constructed in frame structures, the buildings occupy a total land area of 17289m^2, of which A1~A5# buildings are office buildings whose total above-ground floor area is 9091m^2 and building height is 19.10 meters, with five floors above the ground. A6# Building is used for supermarkets whose above-ground floor area is 10744.5m^2 and building height is 21.18 meters, with four floors above the ground. A7# Building is for business whose above-ground floor area is 1855.7m^2 and building height is 18.0 meters with five floors above the ground. A8# Building is for a hotel whose above-ground floor area is 9169.46m^2 and building height is 26.4 meters, with eight floors above the ground.

Office buildings, hotel buildings and commercial buildings are the three most common types of public buildings at present, which are all included in the A1~A8# buildings in Cluster A, Xintiandi, Xixi, Hangzhou. According to the Article 4.1.4 in the “Design Standard for Energy Efficiency of Public Buildings” (DB33/1036-2007), Class-A buildings: public buildings whose floorage of a single building is larger than or equal to 20000m^2 or are fully equipped with air-conditioning systems; Class-B buildings: public buildings whose floorage of a single building is smaller than 20000m^2 and are not or partially equipped with air-conditioning systems; Class-C buildings: public buildings that are out of service in summer and winter when the heating or cooling load is at the peak and are not equipped with any air-conditioning system. In terms of the floorages and the application of air-conditioning systems, the buildings in Cluster A are classified into Class-A buildings and Class-B buildings, among which A1~A5, A7 and A8 belong to the Class B while A6 belongs to the Class A. Therefore, the A1~A8# buildings of Cluster A, Xintiandi, Xixi, Hangzhou possess the representativeness to be taken as a pilot project to study the self-insulation system of public buildings. To obtain the preferred plan for each type of self-insulation systems as well as their heating and air-conditioning energy consumptions will not only help designers to make use of these plans in a flexible and effective way and to optimize the energy-saving design schemes, but also provide developers with quantitative indexes for reference, thus playing a significant guiding role in the entire self-insulation system of public buildings. The photos of the construction site of the pilot project at different stages are as follows (see Figure 5.1).

Figure 5.1 The photos of the construction site of the pilot project at different stages

5.3 Energy-efficiency calculation and analysis of the pilot project

5.3.1 The basic information of the pilot project model

This section has classified the A1~A8# buildings of Cluster A, Xintiandi, Xixi, Hangzhou, into three common types: A1~A5# are office buildings; A6# and A7# are commercial buildings; A8# is a hotel building. Their basic information is listed in Table 5.1. In terms of the wall materials and ways of thermal-bridge treatment, the A1~A8# buildings are further divided into three groups according to the results of the theoretical analysis: ①A1#, A2#, A5#, A6#, A7# and A8#, whose walls are made from aerated concrete blocks (B06) and thermal bridges have taken inorganic-insulation-mortar measures; ② A3#, whose walls are made from aerated concrete blocks (B06) and thermal bridges have adopted the measures of autoclaved sand aerated concrete slabs; ③A4#, whose walls are made from shale sintered hollow blocks and thermal bridges have taken inorganic-insulation-mortar measures. With the PKPM energy conservation design and analysis software (PBECA), the research models have been established for each of them (see Figure 5.2 ~ Figure 5.5).

Table 5.1 Basic information of the building models

Project Name		Cluster A, Xintiandi, Xixi, Hangzhou					
City		Hangzhou (northern latitude=30.00, eastern longitude=120.00)					
Climatic zone		Hot summer and cold winter					
Project		A1#A2#A5#	A3#	A4#	A6#	A7#	A8#
Building type		Class B	Class B	Class B	Class A	Class B	Class B
Orientation		South	South	South	South	South	South
Structural type		Frame	Frame	Frame	Frame	Frame	Frame
The number of storeys		5 storeys	5 storeys	5 storeys	4 storeys	5 storeys	8 storeys
Storey height (mm)		3600	3600	3600	4500	3600	3300
Shape coefficient		0.39	0.39	0.39	0.19	0.32	0.21
Building area for energy-efficiency calculation (m^2)		1514.17	1514.17	1514.17	8833.17	1395.07	9169.64
Window-wall ratio	East	0.06	0.06	0.06	0.40	0.10	0.09
	South	0.35	0.35	0.35	0.42	0.45	0.27
	West	0.15	0.15	0.15	0.12	0.10	0.07
	North	0.19	0.19	0.19	0.39	0.28	0.25
Thermal Insulation Type		Self-insulation					

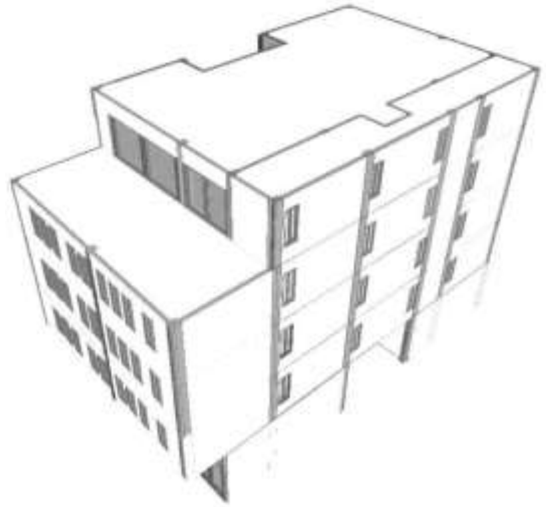


Figure 5.2 A1~A5# model diagram

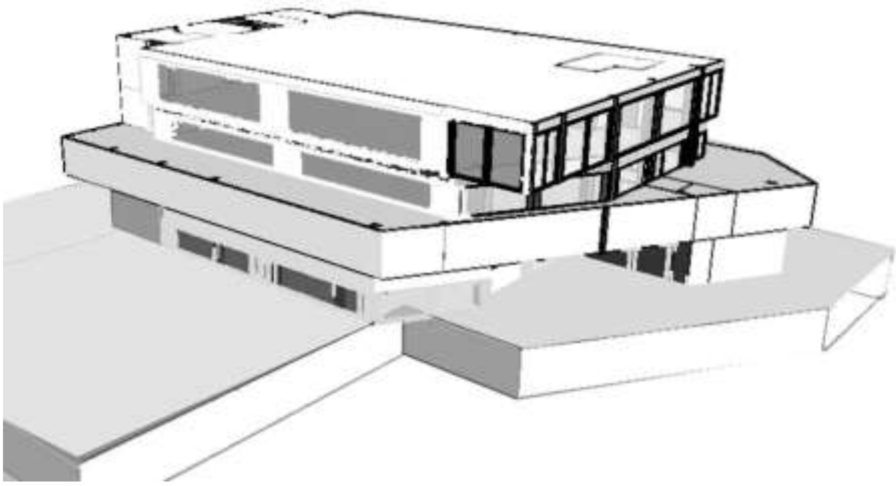


Figure 5.3 A6# model diagram

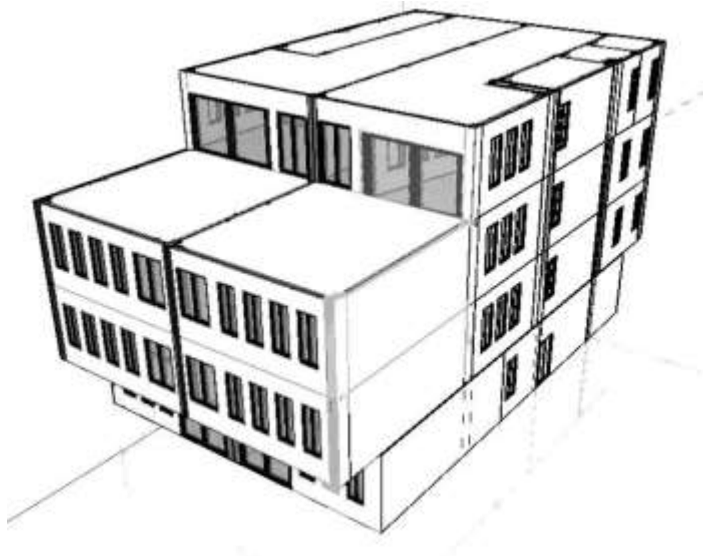


Figure 5.4 A1~A5# model diagram

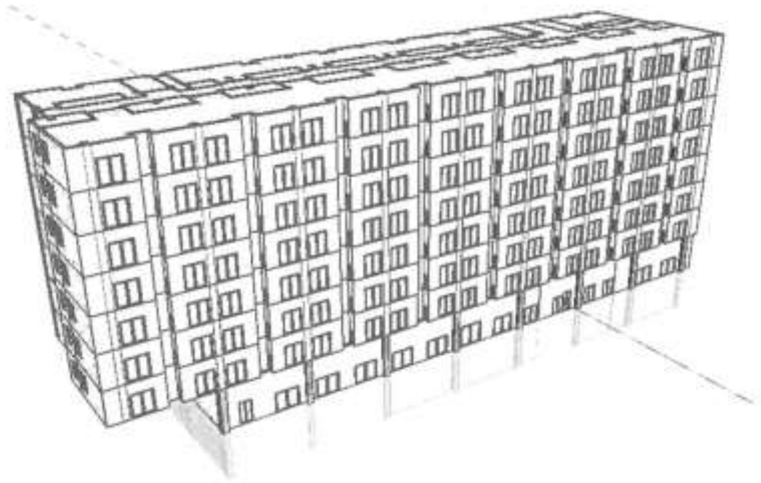


Figure 5.5 A6# model diagram

5.3.2 A structural analysis of the envelopes in the pilot project

According to Zhejiang Province "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007), the constitution of the envelopes in the pilot project have been obtained through the PKPM energy conservation design and analysis software (PBECA). The basic thermal performance parameters of the building envelopes are as follows (see Table 5.2 ~ Table 5.7).

Table 5.2 Description of the envelopes in A1#, A2# and A5# Building

Component of the Envelop	Constitution of the Component	Thermal Performance W/(m^2 K)	The Limiting Value of the Index W/(m^2 K)	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.7	Pass
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (230.00mm) + composite mortar (20.00mm)	K=1.0	K≤1.0	Pass
	Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (30.00mm) + reinforced			

	concrete (250.00mm) + composite mortar (20.00mm)			
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (25.00mm) + anti-crack mortar (5.00mm)	K=1.85	K≤1.0	Fail
Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 (m^2 K)/ W	R≥1.2 (m^2 K)/ W	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent)	K=3.4 SC=0.76	-	-

Table 5.3 Description of the envelope in A3# Building

Component of the Envelop	Constitution of the Component	Thermal Performance W/(m^2 K)	The Limiting Value of the Index W/(m^2 K)	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.7	Pass
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (230.00mm) + composite mortar (20.00mm)	K=0.99	K≤1.0	Pass
	Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (50.00mm) + reinforced concrete (250.00mm) + composite mortar (20.00mm)			
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (25.00mm) + anti-crack mortar (5.00mm)	K=1.85	K≤1.0	Fail

Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 $(m^2 K)/W$	R≥1.2 $(m^2 K)/W$	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent)	K=3.4 SC=0.76	-	-

Table 5.4 Description of the envelope in A4# Building

Component of the Envelop	Constitution of the Component	Thermal Performance $W/(m^2 K)$	The Limiting Value of the Index $W/(m^2 K)$	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.7	Pass
Exterior Wall	Main wall: cement mortar (20.00mm) + shale sintered hollow block (240.00mm) + composite mortar (20.00mm)	K=1.00	K≤1.0	Pass
	Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (25.00mm) + reinforced concrete (250.00mm) + inorganic insulation mortar (30.00mm)			
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (25.00mm) + anti-crack mortar (5.00mm)	K=1.85	K≤1.0	Fail
Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 $(m^2 K)/W$	R≥1.2 $(m^2 K)/W$	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent)	K=3.4 SC=0.76	-	-

Table 5.5 Description of the envelope in A6# Building

Component of the Envelop	Constitution of the Component	Thermal Performance W/(m^2·K)	The Limiting Value of the Index W/(m^2·K)	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.5	Fail
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (230.00mm) + composite mortar (20.00mm) Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (30.00mm) + reinforced concrete (250.00mm) + composite mortar (20.00mm)	K=0.95	K≤0.7	Fail
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (20.00mm) + anti-crack mortar (5.00mm)	K=2.08	K≤1.0	Fail
Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 (m^2·K)/ W	R≥1.2 (m^2·K)/ W	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent)	K=2.6 SC=0.50	-	-

Table 5.6 Description of the envelope in A7# Building

Component of the Envelop	Constitution of the Component	Thermal Performance W/(m^2·K)	The Limiting Value of the Index W/(m^2·K)	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.7	Pass
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (230.00mm) + composite mortar (20.00mm) Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (30.00mm) + reinforced concrete (250.00mm) + composite mortar (20.00mm)	K=1.0	K≤1.0	Pass
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (30.00mm) + anti-crack mortar (5.00mm)	K=1.67	K≤1.0	Fail
Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 (m^2·K)/ W	R≥1.2 (m^2·K)/ W	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent), U-shaped glass [(260 * 100 * 60 * 7) mm + (260 * 100 * 60 * 7) mm] filled with air	K=2.6 SC=0.50 K=2.6 SC=0.38	-	-

Table 5.7 Description of the envelope in A8# Building

Component of the Envelop	Constitution of the Component	Thermal Performance W/(m^2 K)	The Limiting Value of the Index W/(m^2 K)	Judgement
Roof	Fine aggregate concrete (two-way reinforcement) (40.00mm) + foam glass (90.00mm) + cement mortar (20.00mm) + light aggregate concrete slope (30.00mm) + reinforced concrete (100.00mm)	K=0.65	K≤0.7	Pass
Exterior Wall	Main wall: cement mortar (20.00mm) + autoclaved sand aerated concrete block (B06) (230.00mm) + composite mortar (20.00mm)	K=0.97	K≤1.0	Pass
	Thermal bridge: anti-crack mortar (5.00mm) + inorganic insulation mortar (30.00mm) + reinforced concrete (250.00mm) + composite mortar (20.00mm)			
Overhead Floor	Cement mortar (20.00mm) + reinforced concrete (100.00mm) + inorganic insulation mortar (25.00mm) + anti-crack mortar (5.00mm)	K=1.67	K≤1.0	Fail
Ground	Cement mortar (20.00mm) + reinforced concrete (100mm) + compacted clay (200.00mm)	R=0.25 (m^2 K)/ W	R≥1.2 (m^2 K)/ W	Fail
Exterior Window	Insulated aluminum general hollow glass window (6mm transparent +12 air + 6mm transparent)	K=3.4 SC=0.76	-	-

5.3.3 The energy-consumption simulative calculation of the pilot project

The design objectives of the indoor parameters of public buildings refer to Zhejiang province "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007) (see Table 5.8 ~ Table 5.10).

Table 5.8 Indoor parameters of office buildings

Room Function	Designed Indoor Temperature ℃		Occupied Area Per Capita (m^2/person)	Staff Load (W/m^2)	Lighting Power (W/m^2)	Electrical Equipment Power (W/m^2)	Fresh Air Volume (m^3/hp)
	Summer	Winter					
Other	26	18	5	181	5	5	5
Standard Office	26	20	4	108	11	20	30

Table 5.9Indoor parameters of commercial buildings

Room Function	Designed Indoor Temperature ℃		Occupied Area Per Capita (m^2/person)	Staff Load (W/m^2)	Lighting Power (W/m^2)	Electrical Equipment Power (W/m^2)	Fresh Air Volume (m^3/hp)
	Summer	Winter					
General Store	26	18	3	182	12	13	30
Other	26	18	5	181	5	5	5

Table 5.10 Indoor parameters of hotel buildings

Room Function	Designed Indoor Temperature ℃		Occupied Area Per Capita (m^2/person)	Staff Load (W/m^2)	Lighting Power (W/m^2)	Electrical Equipment Power (W/m^2)	Fresh Air Volume (m^3/hp)
	Summer	Winter					
Standard Room	26	20	15	135	15	20	30
Dining Room	26	20	20	135	13	5	25
Other	26	18	5	181	5	5	5

1) A1#, A2#, A5# Building

The air-conditioned area of the A1#, A2# and A5# buildings is 1224.63m^2, and their non-air-conditioned area is 289.54m^2. The energy consumption simulation results are as follows (see Table 5.11 and Figure 5.6).

Table 5.11 The dynamic calculation results of the A1#, A2#, A5# building model

Load Type	Total energy consumption of the designed building (kW ћ)	Power consumption per unit area of the designed building (kW ћ/m^2)	Total energy consumption of the reference building (kW ћ)	Power consumption per unit area of the reference building (kW ћ/m^2)
Air-conditioning energy consumption	137184	90.60	147786	97.60
Heating energy consumption	62505	41.28	61715	40.76
Total energy consumption of heating and air-conditioning	199689	131.88	209501	138.36

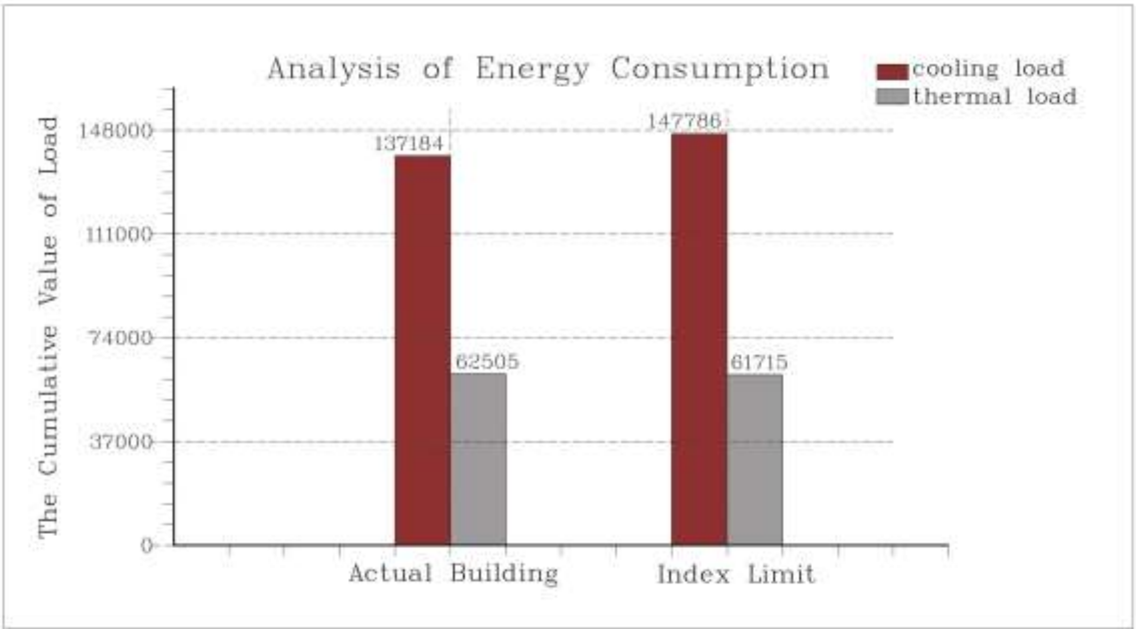


Figure 5.6 Energy-consumption analysis chart

It has been indicated in Table 5.11 and Figure 5.5 that the annual energy consumptions of the A1#, A2# and A5# designed buildings are less than the limit value of the index, so they have met the energy-saving requirements of the Article 4.3.1 in the "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007).

2) A3# Building

The air-conditioned area of the A3# building is 1224.63m^2, and its non-air-conditioned area is 289.54m^2. The energy consumption simulation results are as follows (see Table 5.12 and Figure 5.7).

Table 5.12 The dynamic calculation results of the A3# building model

Load Type	Total energy consumption of the designed building (kW ћ)	Power consumption per unit area of the designed building (kW ћ/m^2)	Total energy consumption of the reference building (kW ћ)	Power consumption per unit area of the reference building (kW ћ/m^2)
Air-conditioning energy consumption	137125	90.56	147786	97.60
Heating energy consumption	62340	41.17	61715	40.76
Total energy consumption of heating and air-conditioning	199465	131.73	209501	138.36

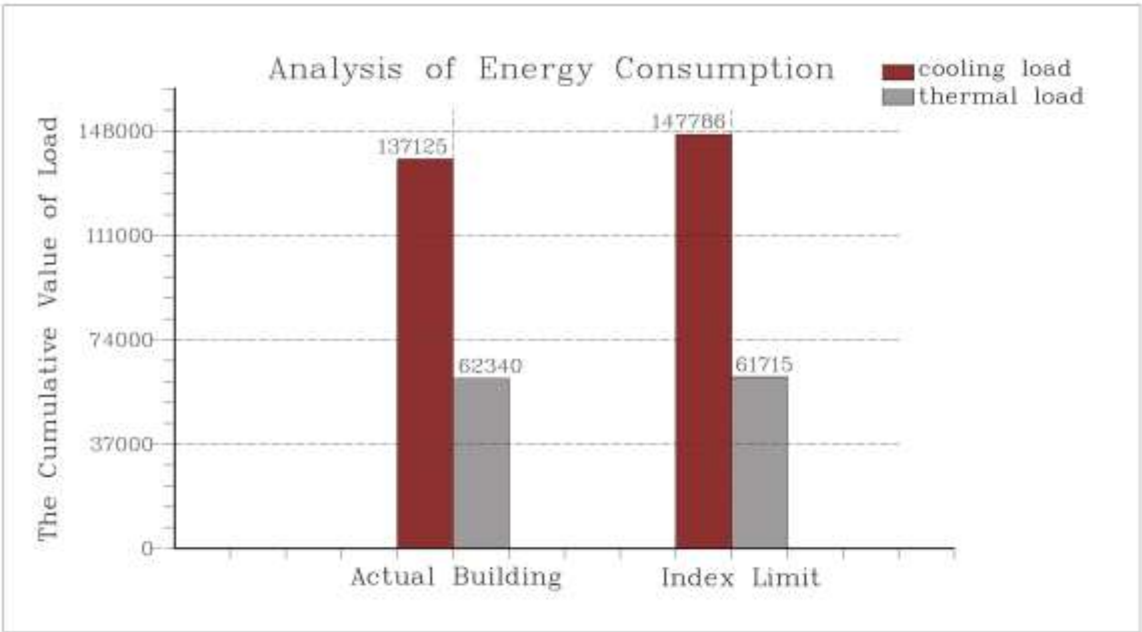


Figure 5.7 Energy-consumption analysis chart

It has been indicated in Table 5.12 and Figure 5.6 that the annual energy consumption of the A3# designed building is less than the limit value of the index, so it has met the energy-saving requirements of the Article 4.3.1 in the "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007).

3) A4# Building

The air-conditioned area of the A4# building is 1224.63m^2, and its non-air-conditioned area is 289.54m^2. The energy consumption simulation results are as follows (see Table 5.13 and Figure 5.8).

Table 5.13 The dynamic calculation results of the A4# building model

Load Type	Total energy consumption of the designed building (kW ħ)	Power consumption per unit area of the designed building (kW ħ/m^2)	Total energy consumption of the reference building (kW ħ)	Power consumption per unit area of the reference building (kW ħ/m^2)
Air-conditioning energy consumption	136276	90.00	149295	98.60
Heating energy consumption	63589	42.00	62503	41.28
Total energy consumption of heating and air-conditioning	199865	132.00	211798	139.88

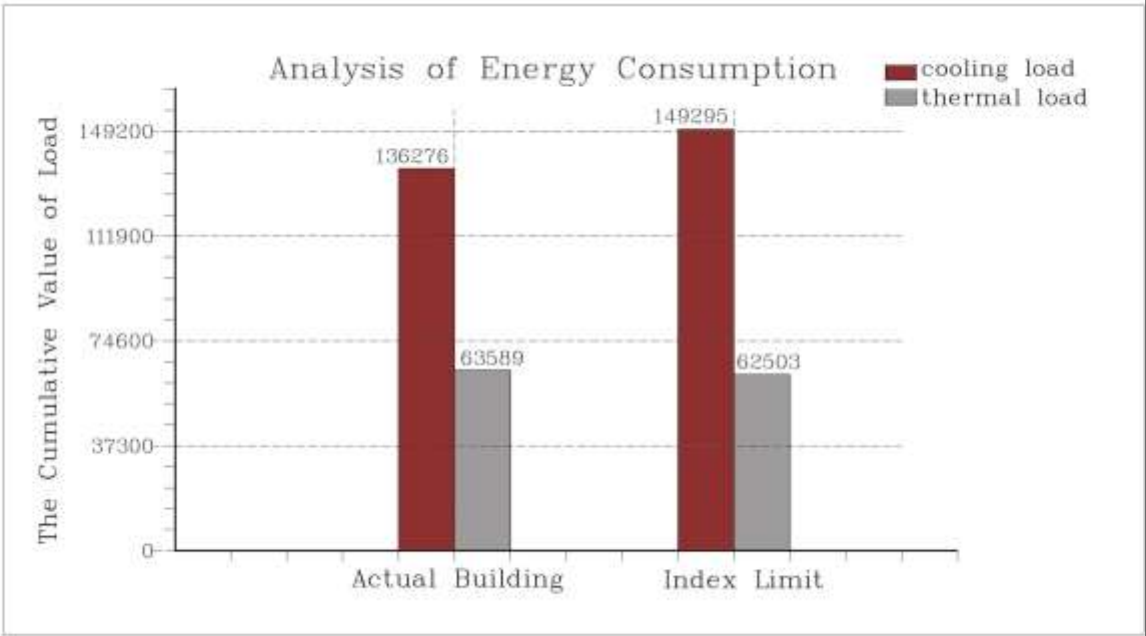


Figure 5.8 Energy-consumption analysis chart

It has been indicated in Table 5.13 and Figure 5.8 that the annual energy consumption of the A4# designed building is less than the limit value of the index, so it has met the energy-saving requirements of the Article 4.3.1 in the “Design Standard for Energy Efficiency of Public Buildings” (DB33/1036-2007).

4) A6# Building

The air-conditioned area of the A6# building is 7553.06m^2, and its non-air-conditioned area is 6953.04m^2. The energy consumption simulation results are as follows (see Table 5.14 and Figure 5.9).

Table 5.14The dynamic calculation results of the A6# building model

Load Type	Total energy consumption of the designed building (kW ħ)	Power consumption per unit area of the designed building (kW ħ/m^2)	Total energy consumption of the reference building (kW ħ)	Power consumption per unit area of the reference building (kW ħ/m^2)
Air-conditioning energy consumption	883055	60.87	920258	63.44
Heating energy consumption	318977	21.99	290494	20.03
Total energy consumption of heating and air-conditioning	1202032	82.86	1210752	83.47

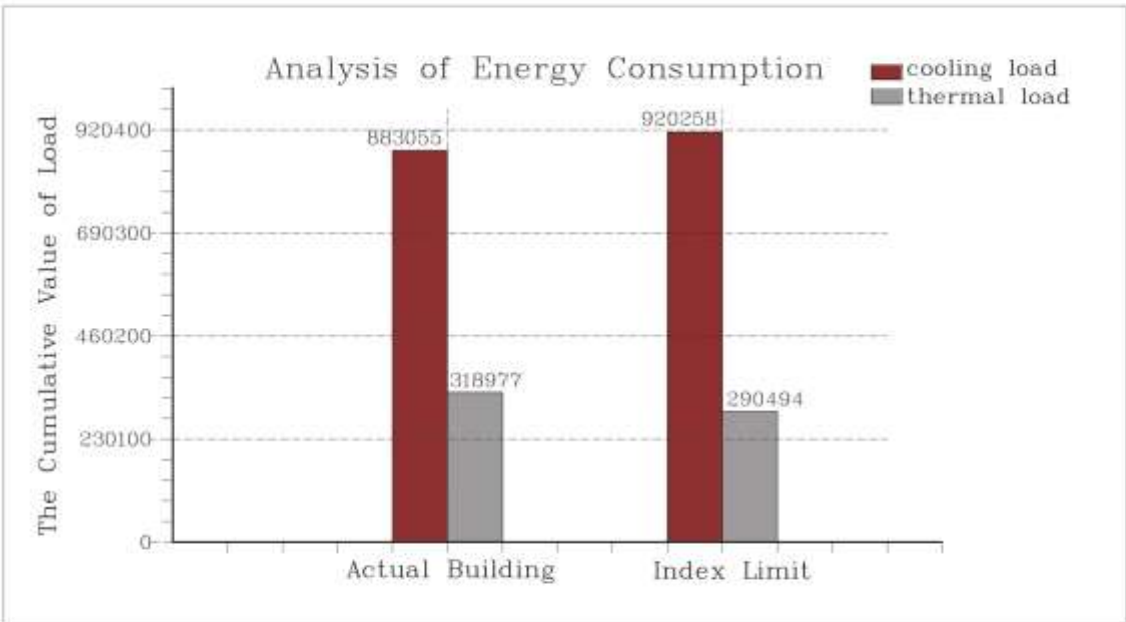


Figure 5.9 Energy-consumption analysis chart

It has been indicated in Table 5.14 and Figure 5.9 that the annual energy consumption of the A3# designed building is less than the limit value of the index, so it has met the energy-saving requirements of the Article 4.3.1 in the “Design Standard for Energy Efficiency of Public Buildings” (DB33/1036-2007).

5) A7# Building

The air-conditioned area of the A7# building is 1112.54m^2, and its non-air-conditioned area is 608.88m^2. The energy consumption simulation results are as follows (see Table 5.15 and Figure 5.10).

Table 5.15 The dynamic calculation results of the A6# building model

Load Type	Total energy consumption of the designed building (kW ħ)	Power consumption per unit area of the designed building (kW ħ/m^2)	Total energy consumption of the reference building (kW ħ)	Power consumption per unit area of the reference building (kW ħ/m^2)
Air-conditioning energy consumption	52074	30.25	73235	42.54
Heating energy consumption	33148	19.26	30845	17.92
Total energy consumption of heating and air-conditioning	85222	49.51	104080	60.46

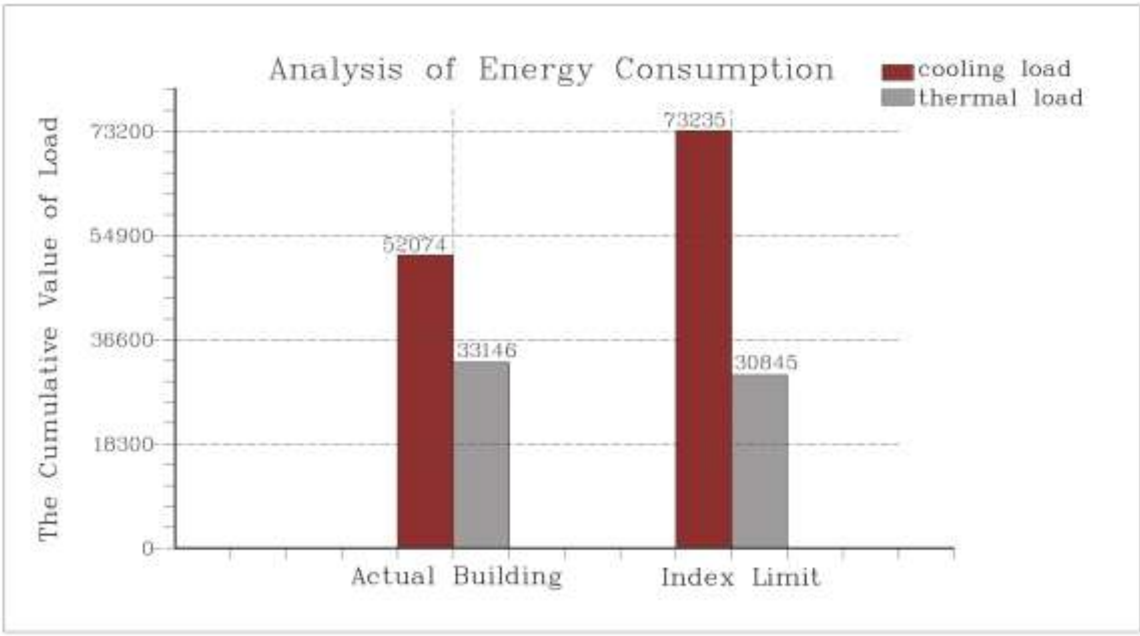


Figure 5.10 Energy-consumption analysis chart

It has been indicated in Table 5.15 and Figure 5.10 that the annual energy consumption of the A3# designed building is less than the limit value of the index, so it has met the energy-saving requirements of the Article 4.3.1 in the “Design Standard for Energy Efficiency of Public Buildings” (DB33/1036-2007).

6) A8# Building

The air-conditioned area of the A8# building is 5850.45m^2, and its non-air-conditioned area is 4300.05m^2. The energy consumption simulation results are as follows (see Table 5.16 and Figure 5.11).

Table 5.16 The dynamic calculation results of the A8# building model

Load Type	Total energy consumption of the designed building (kW ħ)	Power consumption per unit area of the designed building (kW ħ/m^2)	Total energy consumption of the reference building (kW ħ)	Power consumption per unit area of the reference building (kW ħ/m^2)
Air-conditioning energy consumption	385590	37.99	480615	47.35
Heating energy consumption	156499	15.42	132907	13.09
Total energy consumption of heating and air-conditioning	542089	53.41	613522	60.44

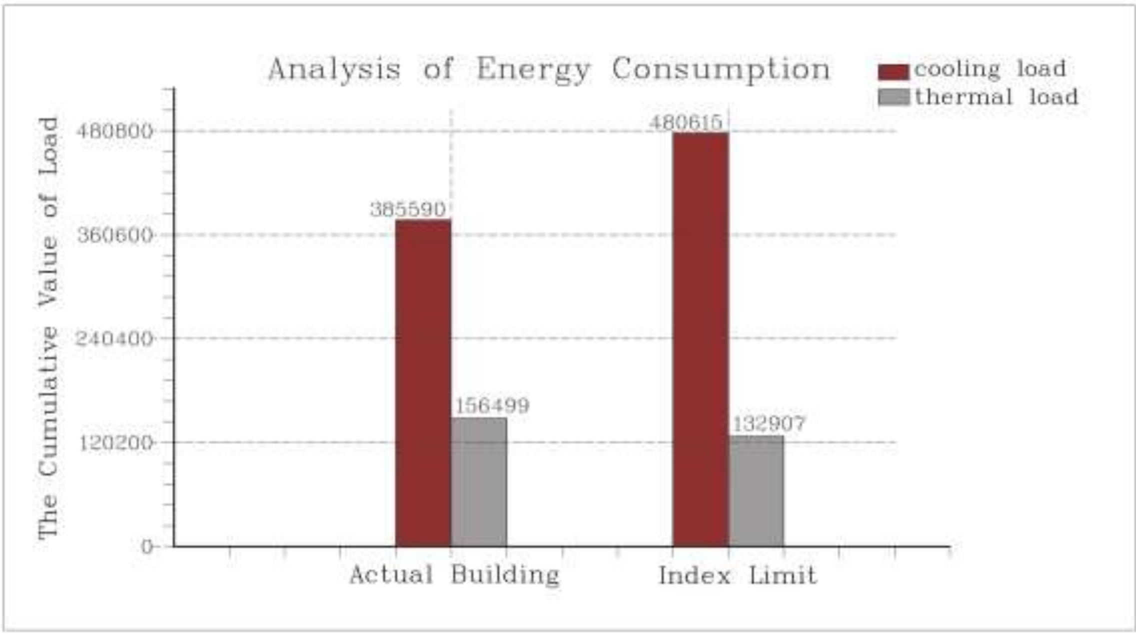


Figure 5.11 Energy-consumption analysis chart

It has been indicated in Table 5.16 and Figure 5.11 that the annual energy consumption of the A3# designed building is less than the limit value of the index, so it has met the energy-saving requirements of the Article 4.3.1 in the "Design Standard for Energy Efficiency of Public Buildings" (DB33/1036-2007).

5.4 Energy-efficiency field testing scheme and result analysis of the pilot project

5.4.1 Building Overview

The A1~A5# buildings of Cluster A, Xintiandi, Xixi are office buildings whose total above-ground area is 9091 m^2 and building height is 19.10 meters with five floors above the ground. These are five identical buildings that respectively adopt three different combinations of self-insulation systems. The energy-saving effects of these five buildings have been tested and compared with each other and with the theoretical calculation results. The wall materials of the A1#, A2# and A5# buildings are made of aerated concrete blocks (B06) and their thermal bridges adopt the self-insulation-system combination 1 of inorganic insulation mortar, and the constitutions of the key joints are shown in Figure 5.12; the wall materials of the A3# building are made of aerated concrete blocks (B06) and its thermal bridges adopt the self-insulation-system combination 2 of autoclaved sand aerated concrete slabs, and the constitutions of the key joints are shown in Figure 5.13; the wall materials of the A4# building are made of shale sintered hollow blocks and its thermal bridges adopt the self-insulation-system combination 3 of inorganic insulation mortar, and the constitutions of the key joints are shown in Figure 5.14.

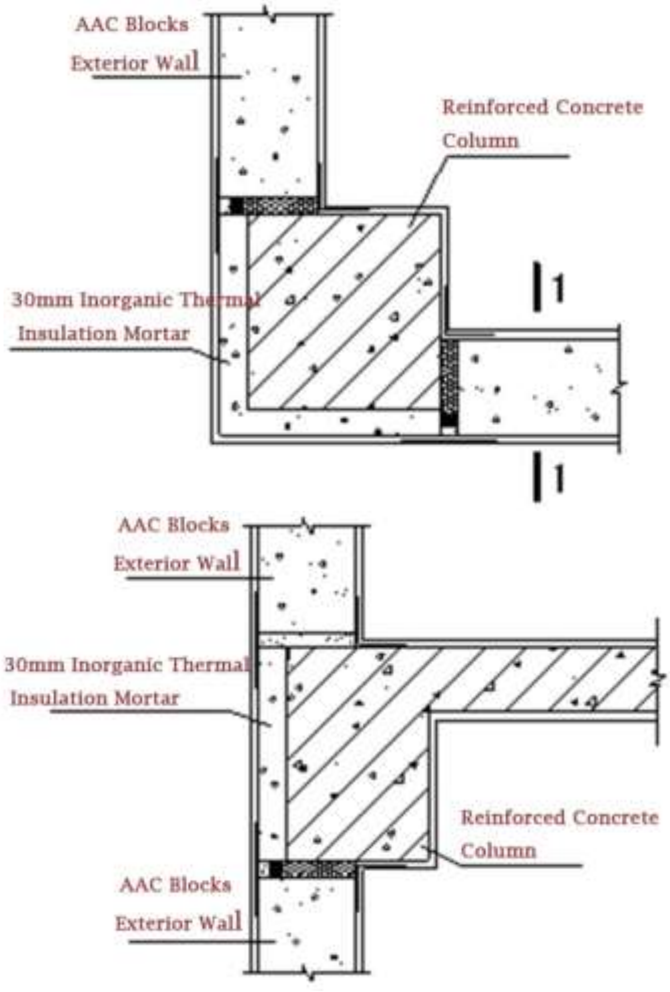


Figure 5.12 Constitution diagram of the key joints in the self-insulation-system combination 1

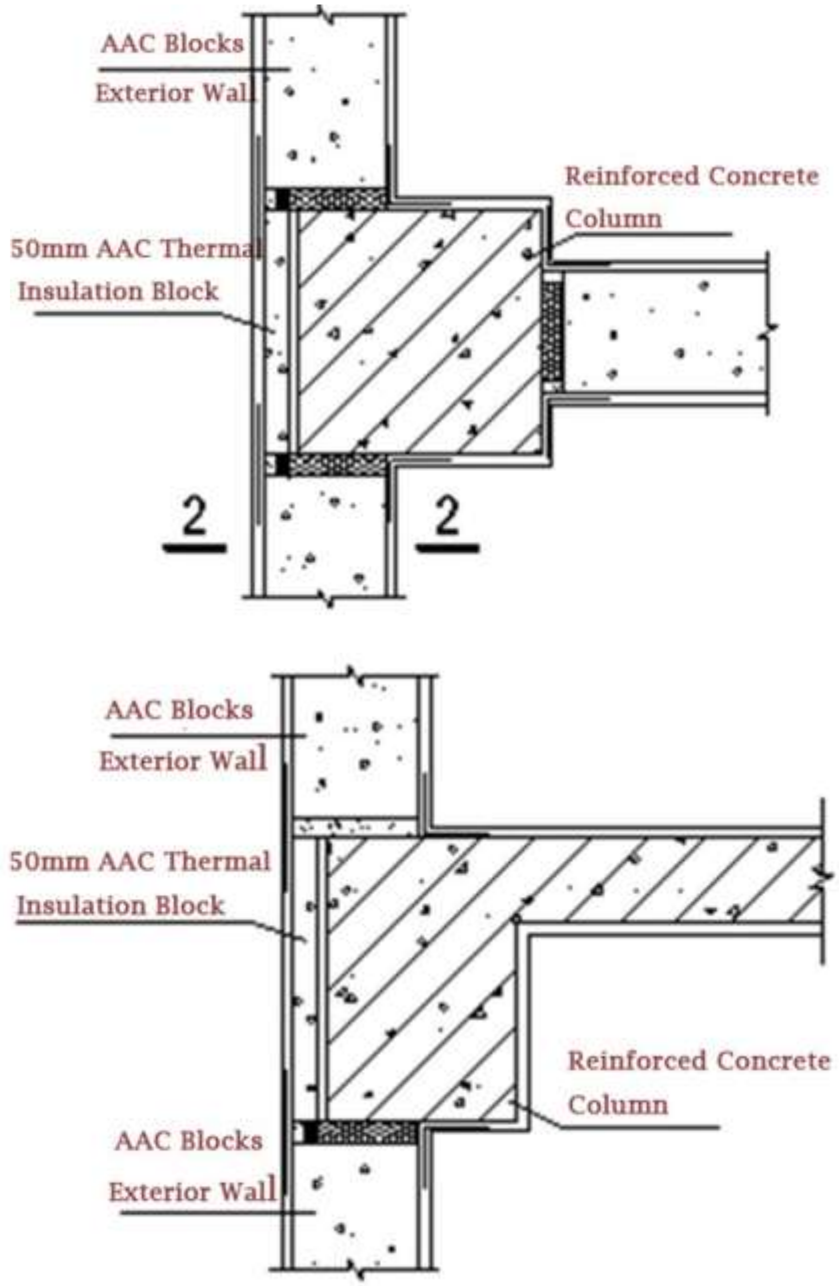


Figure 5.13 Constitution diagram of the key joints in the self-insulation-system combination 2

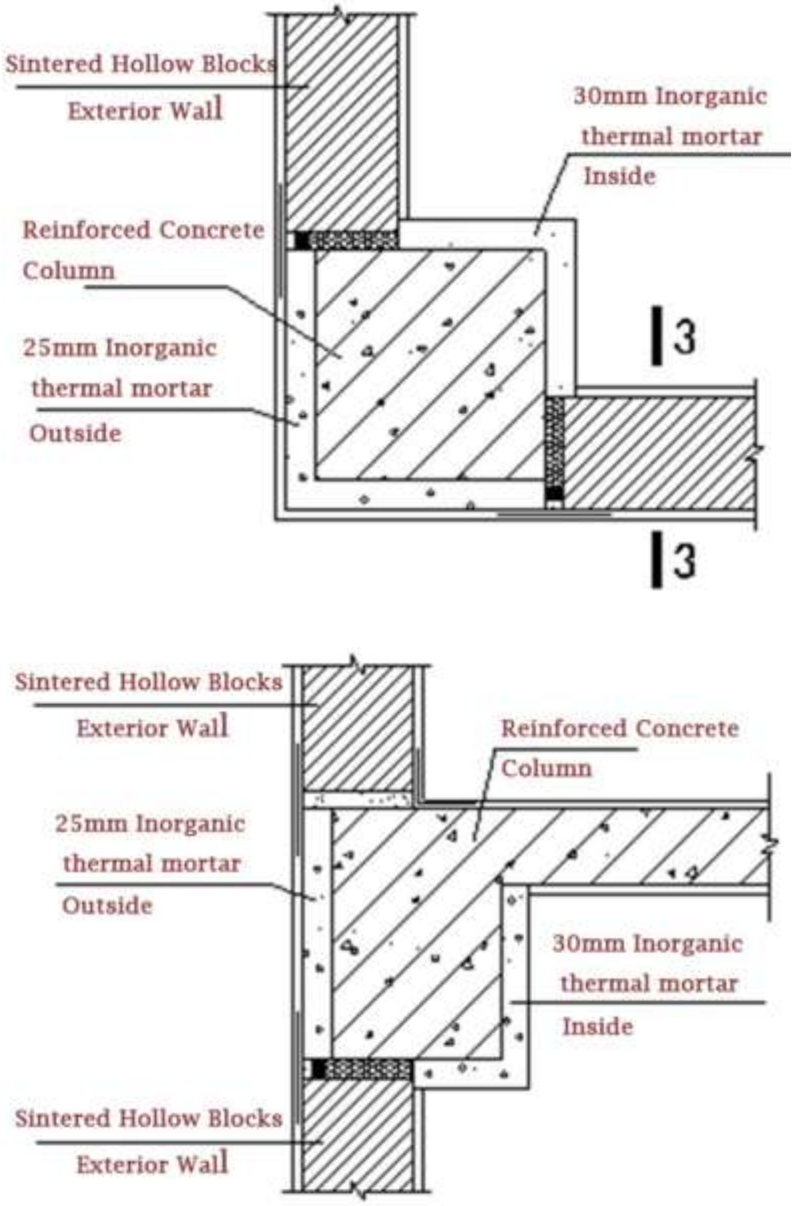


Figure 5.14 Constitution diagram of the key joints in the self-insulation-system combination 3

5.4.2 Assessment and measurement criteria

1) *Zhejiang Province Design Standard for Energy Efficiency of Public Buildings* (DB33/1038-2007)

2) "Thermal Design Code for Civil Building" (GB 50176-93)

3) "Thermal insulation — Determination of the Steady-State Thermal Resistance and Related Properties — Heat Flow Meter Apparatus" (GB 10295-2008)

4) "Energy-Efficiency Testing Standards for Public Buildings" (JGJ / T177-2009)

5) "Graduations and Test Methods of Air Permeability, Water tightness, Window Load Resistance Performance for Building External Windows and Doors" (GB/T 7106-2008)

6) "Zhejiang Province Energy-Saving Engineering Evaluation Guideline for Residential Buildings"

7) Construction drawing design documents

5.4.3 Measurement method introduction

Heat transfer coefficient test of exterior walls: heat flow meter method.

The heat flow meter method tests the heat flux of the tested building envelope and the temperatures on its interior and exterior surfaces by using heat flow meters and thermocouples on the site. With the heat transfer coefficient of the building envelope obtained through data processing and calculation, it can determine whether the building envelope has achieved the energy-saving standard.

When a heat flow goes through the building envelope, due to its heat resistance, the temperature gradient in the through-thickness direction is a decaying process, so that there exists a temperature difference between the interior and exterior surfaces of the building envelope. The corresponding relationship between the temperature difference and the heat flux can be used to measure the heat flux.

The heat flux of the building envelope can be measured by installing a flat heat flow meter on the surface of the envelope. Since the heat resistance of the heat flow meter is generally much lower than that of the building envelope under test, when the heat flow meter is pasted onto the back of the tested building envelope, the heat transfer conditions are affected so little that it can be neglected. Thus, at a steady state, the heat flux flowing through the heat flow meter is also that through the tested building envelope.

According to the Fourier's law, when the temperature difference between the two sides is ΔT, the heat flux flowing through the heat flow meter can be calculated by the following formula:

$$q = \Delta T / (\delta / \lambda) \qquad (1)$$

In this formula, q is the heat flux going through the heat flow meter, W/m^2.

δ is the thickness of the heat flow meter, m.

λ is the thermal conductivity of the heat flow meter, W/(m·℃)

ΔT is the temperature difference between the two sides of the heat flow meter when it is installed onto the building envelope under test.

If the above temperature difference is measured with thermocouples, according to the directly proportional relationship between the thermoelectric potential and the temperature difference within the measurement range of the thermocouple, the heat flux going through the heat flow meter can be obtained, which is $q = C \cdot \Delta E$ (2)

In this formula, ΔE is the thermoelectric power (mV), which can be measured with an automatic itinerant detector of temperature and heat flow.

C is the coefficient of the heat flow meter (W/(m^2 ·mv), whose physical meaning is that when the heat flow meter outputs a unit of thermoelectric potential, the heat flow going through it is C. The coefficient C of the heat flow meter used in the test is a known constant calibrated by its manufacturer according to the national standard. In this test, two types of heat flow meter probes have been used, whose probe coefficients are 11.63 and 23.26 W/ (m^2 ·mv) respectively.

5.4.4 Calculation formulas and error analysis of the heat transfer coefficient of the building envelope

The heat transfer coefficient of the building envelope is defined as the amount of heat transferred through a unit of area during a unit of time when the air temperature difference between the two sides of the building envelope is 1℃ under steady-state heat transfer conditions. The unit is W/ (m^2 ·℃).

By definition, under steady-state heat transfer conditions, the heat flux going through the building envelope should be equal to that through the heat flow meter. Therefore, the heat resistance of the building envelope can be calculated by the following formula:

$$R = \Delta T / q \quad (3)$$

Then, the heat transfer resistance of the building envelope is:

$$R' = R + R_i + R_e \quad (4)$$

In this formula, R_i is the heat exchange resistance of the interior surface, which is taken as 0.11m^2 ·K/W.

R_e is the heat exchange resistance of the exterior surface, which is taken as 0.04 m^2 ·K/W.

The heat transfer coefficient can be calculated by the following formula:

$$K_c = \frac{1}{R + R_i + R_e} \quad (5)$$

In the actual process of field test, in order to improve the accuracy of the test results, multiple measure points are usually adopted for testing. The heat resistance of the building envelope is calculated by using the arithmetic average method, and the specific formula is:

$$R = \frac{\sum \Delta T}{\sum q} \quad (6)$$

Substitute the formula (6) into the formula (5), and the average heat transfer coefficient of the building envelope will be calculated. The calculation formula is as follows:

$$\overline{K}_c = \frac{\sum q}{\sum \Delta T + 0.15 \sum q} \tag{7}$$

The corresponding relative measurement error is:

$$\frac{\delta K}{\overline{K}_c} = \frac{\sum \delta q \sum \Delta T + \sum \delta(\Delta T) \sum q}{(\sum \Delta T + 0.15 \sum q) \sum q} \tag{8}$$

According to the formula (7) and the formula (8), the field test result of the heat transfer coefficient of the building envelope can be expressed as:

$$K_c = \overline{K}_c \pm \delta K \tag{9}$$

5.4.5 Test instruments

JW-Ⅱ automatic itinerant detector of building thermal temperature and heat flow, MW-XQS-1821 intelligent field detector of the airtight performance of windows and doors, anemometer, electric heater, voltage regulator, notebook computer, hygrometer and so on.

Automatic itinerant detector of temperature and heat flow among the test equipment of the heat flow meter method (hereinafter referred to as the itinerant detector):

1) Automatic itinerant detector of temperature and heat flow (hereinafter referred to as the itinerant detector): This is an intelligent data acquisition instrument which adopts the latest SCM system and is able to measure the temperature of 55 channels and the thermoelectric potential of 20 channels of heat flows. It has the functions of circular or fixed-point display, storage, printing, etc., and can upload the stored data to the microcomputer for processing.

2) WYP-type heat flow meter: Dimensions: 110×110×2.5mm; probe coefficient: 11.6w/(m^2·mv); the operating temperature range: below 100 ℃; standard error ≤ 5%.

3) Temperature sensor: The copper-constantan thermocouple is taken as a temperature sensor, with the temperature measurement range of -50 ℃ ~ 100 ℃, the resolution of 0.1 ℃, and the uncertainty ≤ + 0.5 ℃.

4) Digital thermometer: Resolution: 0.1 ℃; measurement range: -50 ℃ ~ 199.9 ℃; accuracy: ≤ (0.3% +1 ℃).

5.4.6 Test process

The accuracy of the test results depends not only on the correct operation of the test equipment, but also on the correct test method.

1) The selection of the tested rooms

The field test had better be conducted when the tested wall is completely dry or at least 3 months after the construction of the main structure is finished. In order to make the heat transfer process close to one-dimensional heat transfer when the heat transfer coefficient of the main part is being tested, and with the air flow inside and outside the rooms taken into consideration, the selected rooms should be easily enclosed.

2) The selection of the test areas

According to thermal calculation requirements, the test areas for an energy-efficiency field test must be the exterior walls, thermal bridges etc. of a building.

3) The selection of measure point positions

First, survey the specific building, and select the positions to paste the heat flow sensor and the temperature sensor. The selection of the tested rooms should not only comply with the principle of random sampling, including choosing representative measure points with exterior walls and staircases in different orientations, but also give full consideration to the safety of pasting the sensor outdoors. Second, double check the measure point positions according to the drawings, ensuring they are not at columns, slab-column joints, cracks, air infiltration and other similar positions. The measure points should not be directly influenced by heating or cooling equipment or fans, and should avoid direct sunlight. The exterior surface of the test area of the protective structure should be protected from rain, snow and direct sunlight.

4) The installation of heat flow meters and temperature sensors

The heat flow meters should be installed directly on the interior surface of the building envelope under test. In order to the ensure good contact, accurate measurement, easy assembly and disassembly, the heat flow meters should be pasted with thermally conductive silicone grease, and fixed with strongly adhesive tapes in a “#” form. To prevent the interspace between the heat flow meters and the walls and the drop of the heat flow meters, the temperature sensors should be installed on both sides of the building envelope under test. The temperature sensor on the interior surface should be installed close to the heat flow meter. The temperature sensor on the exterior surface should be installed at the position corresponding to the heat flow meter. The temperature sensor together with the lead should be in close contact with the surface under test, and the radiation coefficient of the sensor surface should be about the same as that of the surface to be tested. When the indoor temperature is being measured, the temperature sensor should be generally installed in the center of the room 1.5m above the ground, so that the indoor temperature will be more accurate.

5) Check the sealing of the rooms

The building thermal test is to test a wall’s heat transfer flux and temperature. Due to the high heat storage coefficient of a wall, the reaction of the surface temperature of the structure is very slow and can only be observed after several hours. This is the heat storage and exothermic process of a room. The temperature will change as the outdoor cold air enters the room, resulting in a larger temperature difference between the two sides of the heat flow meter and a higher reading. During the test, in order to prevent the rooms from exchanging heat with outdoor air, they need to be sealed tightly. However, many construction sites do not have doors installed during the test, so they can seal the rooms with material insulation boards which are commonly applied to building insulation. The best way is to use a large insulation board which can just seal the door completely. If there is no such large insulation board, it can splice several small insulation boards into a door-size insulation board to seal the door, and then completely tape the edge. The air conditioning holes, if they exist in the rooms, can also be sealed with hole-size insulation boards. In addition, during the test, the windows should also be tightly closed, and the leaks should be sealed with tape.

6) Testing time

The formal test can be only conducted after the heat storage of the wall becomes stable. A cumulative test method is adopted. The data are automatically recorded every 15 minutes. For a light building envelope: the specific heat capacity per unit area is <20KJ/(Kg·K), and the data collected at night should be used (1h after the sunset to the sunrise) to calculate the heat resistance of the building envelope. After four consecutive nighttime measurements, when the difference of the calculation results of two adjacent measurements is ≤ 5%, the test can be ended. For a heavy building envelope: the specific heat capacity per unit area is ≥20 KJ/(Kg·K)), and the heat resistance of the building envelope should be calculated by using day-acquired data (an integer multiple of 24h). Only when the following requirements are met can the test be ended:

(1) The difference between the last calculated value of the heat resistance and that before 24h is ≤5%;

(2) The difference between the calculated value of R in the first INT (2×DT/3) days and that in the last same length of days during the test is ≤5%. (Note: d is the number of consecutive testing days, and INT means the integer part.)

7) Data processing

After the field test is completed, the data are uploaded to the microcomputer by a special software and then processed by the Excel software or Kingsoft spreadsheet tools to calculate the average temperatures of the interior and exterior wall surfaces, the average air temperatures inside and outside the buildings, the average heat-flow densities and the average heat transfer coefficients of each set of data and the data collected during the entire testing period. Then, the curve which indicates the relationship between the heat transfer coefficient and the time will be obtained, visually displaying the rules that former changes with the latter.

5.4.7 Precautions

1) The thermal itinerant detector should be checked before the test whether the displayed circuit temperature is correct and whether the relative temperature error is within the allowable range.

2) The historical data on the thermal itinerant detector should be deleted upon starting up in case its storage space is not enough.

3) The consumable supplies of the printer of the itinerant detector should be checked whether they are enough.

4) The detecting circuits of the itinerant detector should be set the same as those that are actually used.

5) The power supply should be reliably grounded. The power cables of high-current heaters cannot be too close to the thermocouples or heat-flow-meter feeders.

6) Effective measures should be taken to prevent the heaters from producing direct radiance to the indoor measure points.

5.4.8 Field test of the pilot project

1)Thermal test of the thermal bridge in the A2# Building

(1) Layout of the measure points

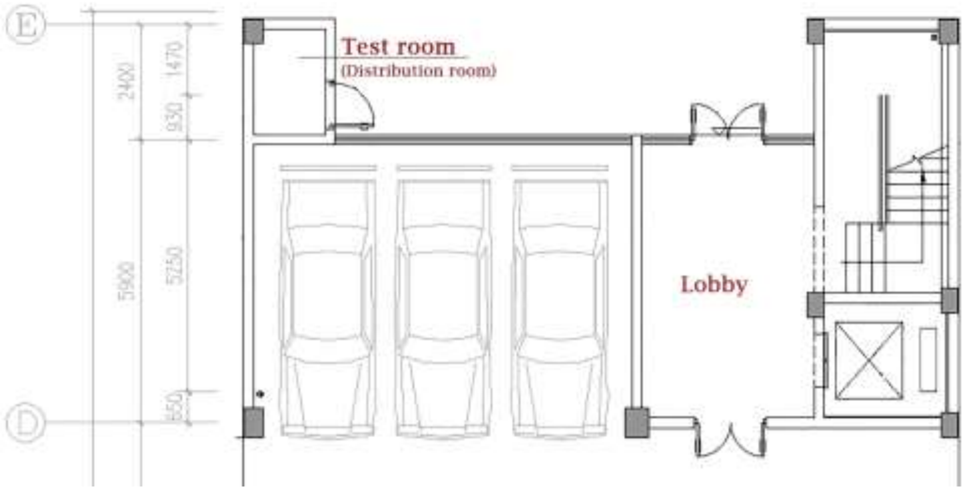


Figure 5.15 The floor plan of the first floor of the A2# Building

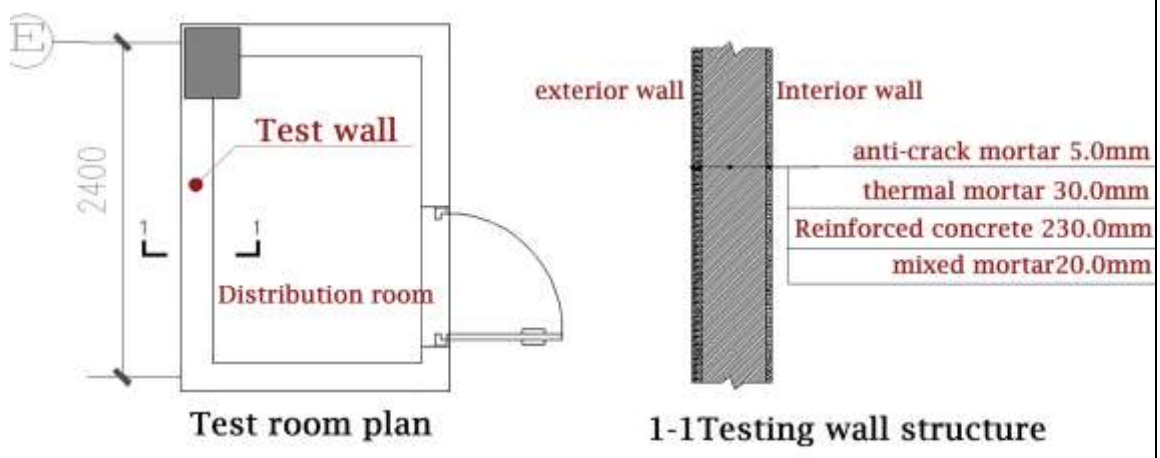


Figure 5.16 The plan of the tested room and the structural diagram of the tested wall in the A2# Building

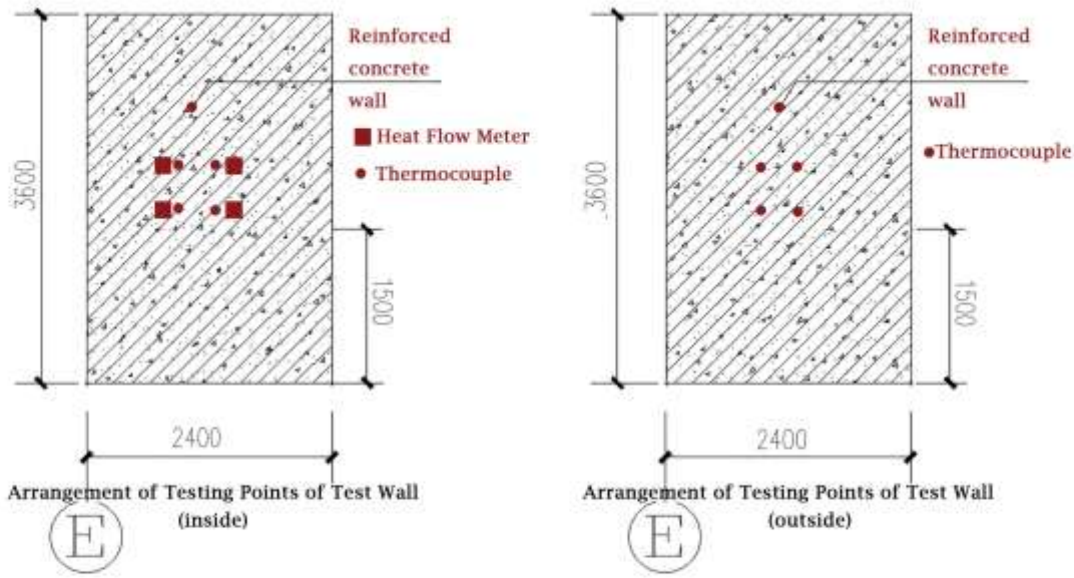


Figure 5.17 The layout plan of the wall measure points in the A2# Building

(2) Test requirements

a. The power distribution room on the first floor of the A2# Building is selected as the tested room for the thermal test of the thermal bridge in this building (Figure 5.15 ~ Figure 5.17). The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from reinforced concrete, and its structural constitution is (from outside to inside): anti-crack mortar (5.00mm) + inorganic insulation mortar (30.00mm) + reinforced concrete (230.00mm) + composite mortar (20.00mm);

c. The thermal conductivity of the inorganic insulation mortar is less than 0.070 W/(m K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.18)

Figure 5.18 The photos of the field test of the thermal bridge in the A2# Building

(4) An analysis of the test results

Table 5.17Data Acquisition

Test-Piece Name	The heat transfer coefficient of the thermal bridge in the A2# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter（mV）			
2013-6-25 1:30	42.1	42.1	43.1	42.6	29.6	29.2	29.3	29.2	2.16	2.2	2.17	2.21
2013-6-25 2:00	42.1	42.1	43.2	42.7	29.4	29.3	29.3	29.3	2.15	2.21	2.15	2.18
2013-6-25 2:30	42.2	42.1	43.2	42.7	29.6	29.3	29.4	29.3	2.15	2.21	2.15	2.2
2013-6-25 3:00	42.2	42.2	43.2	42.7	29.6	29.3	29.4	29.3	2.17	2.21	2.15	2.2
2013-6-25 3:30	42.1	42.1	43.2	42.7	29.5	29.2	29.3	29.2	2.17	2.21	2.17	2.19
2013-6-25 4:00	42.1	42.1	43.2	42.7	29.5	29.3	29.4	29.3	2.17	2.2	2.15	2.2
2013-6-25 4:30	42.2	42.2	43.2	42.7	29.6	29.2	29.3	29.2	2.15	2.2	2.17	2.2
2013-6-25 5:00	42.2	42.2	43.2	42.7	29.6	29.3	29.3	29.2	2.17	2.2	2.15	2.2

Table 5.18 Data Analysis

The average temperature on the interior surface of the tested wall T1 (℃)	42.5
The average temperature on the exterior surface of the tested wall T_2 (℃)	29.4
The temperature difference between the interior and exterior surfaces of the tested wall △T (℃)	13.1
The average heat-flow density of the tested wall q (W/ m^2)	25.36
The heat resistance of the tested wall R (m^2 k)/ W	0.517
The heat transfer resistance of the tested wallR_0 (m^2 k)/W	0.667
The heat transfer coefficient of the tested wall K (W /(m^2 k))	1.50
The theoretical calculating value of the heat transfer coefficient of the tested wall (W /(m^2 k))	1.46

2) Thermal test of the main wall in the A2# Building

(1) Layout of the measure points

Figure 5.19 The layout plan of the measure points in the A2# Building

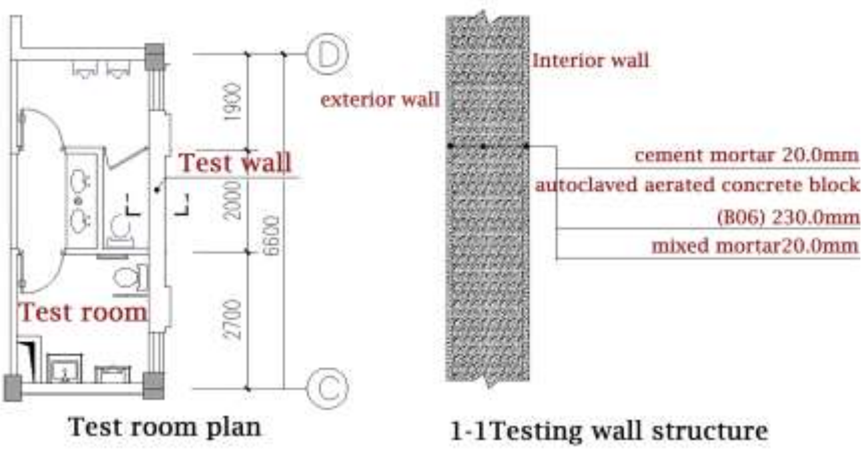


Figure 5.20 The plan of the tested room and the structural diagram of the tested wall in the A2# Building

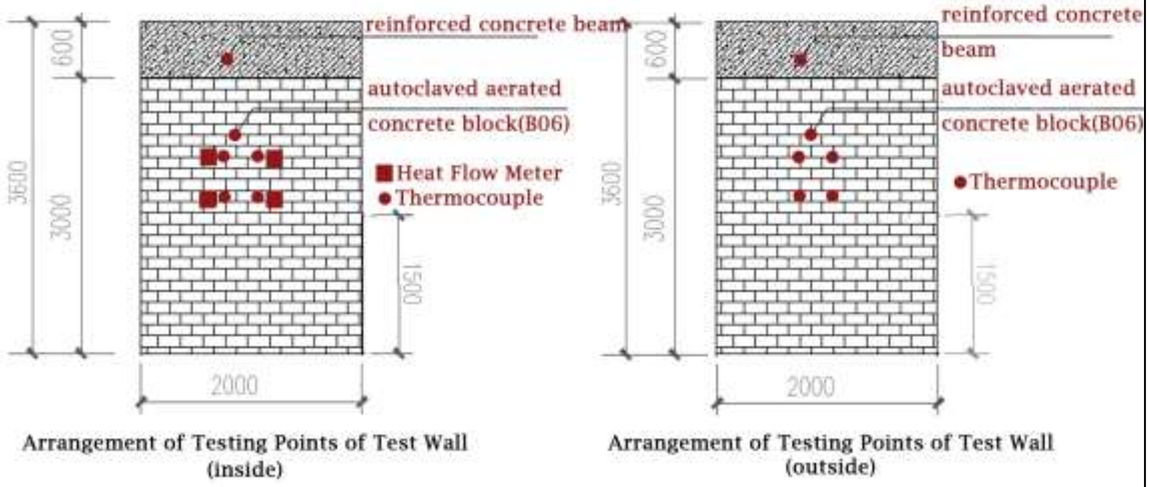


Figure 5.21 The layout plan of the measure points in the A2# Building

(2) Test requirements

a. The toilet on the second floor of the A2# Building is selected as the tested room for the thermal test of the main wall in this building (Figure 5.19 ~ Figure 5.21). The main wall of the tested room must be constructed with autoclaved sand aerated concrete blocks. The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from autoclaved sand aerated concrete blocks (B06), and its structural constitution is (from outside to inside): cement mortar (20.00mm) + autoclaved sand aerated concrete blocks (B06) (230.00mm) + composite mortar (20.00mm);

c. The thermal conductivity of the autoclaved sand aerated concrete blocks is less than 0.19 W/(m ·K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.22)

Figure 5.22 The photos of the field test of the self-insulation wall in the A2# Building

(4) An analysis of the test results

Table 5.19Data acquisition

Test-Piece Name	The heat transfer coefficient of the main wall in the A2# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter （mV）			
2013-6-25 1:30	44.6	44.6	45.6	45.1	27.9	27.5	27.6	27.5	1.26	1.3	1.27	1.31
2013-6-25 2:00	44.6	44.6	45.7	45.2	27.7	27.6	27.6	27.6	1.25	1.31	1.25	1.28
2013-6-25 2:30	44.7	44.6	45.7	45.2	27.9	27.6	27.7	27.6	1.25	1.31	1.25	1.3
2013-6-25 3:00	44.7	44.7	45.7	45.2	27.9	27.6	27.7	27.6	1.27	1.31	1.25	1.3
2013-6-25 3:30	44.6	44.6	45.7	45.2	27.8	27.5	27.6	27.5	1.27	1.31	1.27	1.29
2013-6-25 4:00	44.6	44.6	45.7	45.2	27.8	27.6	27.7	27.6	1.27	1.3	1.25	1.3
2013-6-25 4:30	44.7	44.7	45.7	45.2	27.9	27.5	27.6	27.5	1.25	1.3	1.27	1.3
2013-6-25 5:00	44.7	44.7	45.7	45.2	27.9	27.6	27.6	27.5	1.27	1.3	1.25	1.3

Table 5.20 Data analysis

The average temperature on the interior surface of the tested wall T1 (℃)	45.0
The average temperature on the exterior surface of the tested wall T_2 (℃)	27.7
The temperature difference between the interior and exterior surfaces of the tested wall ∆T (℃)	17.3
The average heat-flow density of the tested wall q (W/ m^2)	14.89
The heat resistance of the tested wall R (m^2 k)/ W	1.162
The heat transfer resistance of the tested wall R_0 (m^2 k)/W	1.312
The heat transfer coefficient of the tested wall K (W /(m^2 k))	0.76
The theoretical calculating value of the heat transfer coefficient of the tested wall	0.71

K (W /(m^2 k))	

3) Thermal test of the thermal bridge in the A3# Building

(1) Layout of the measure points

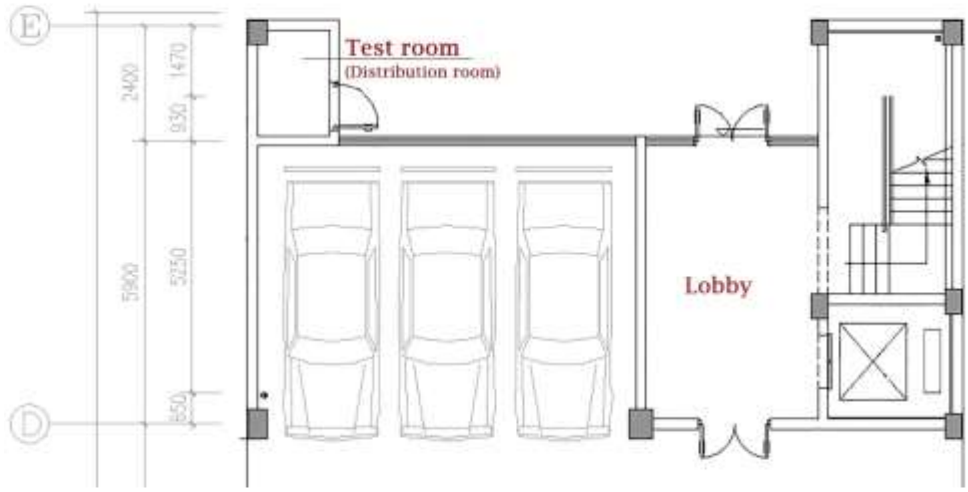


Figure 5.23 The layout plane of the measure points in the A3# Building

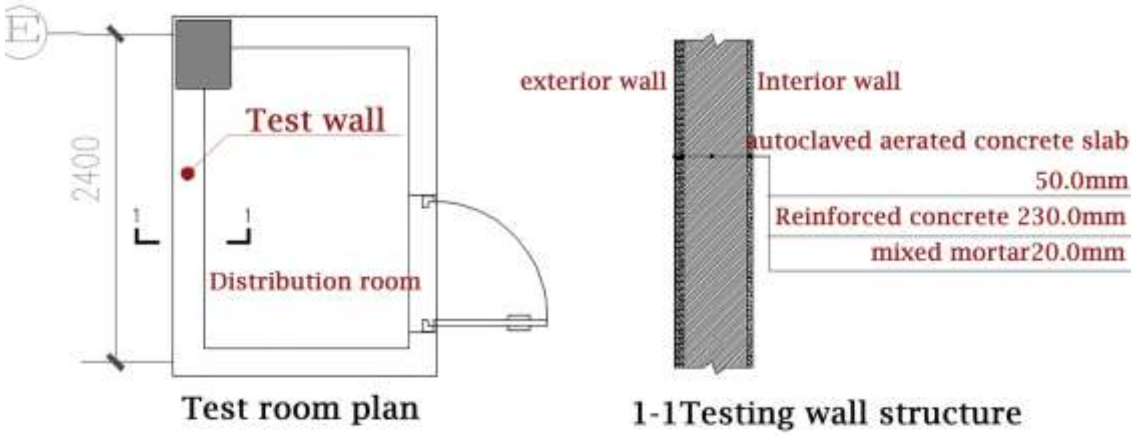


Figure 5.24 The plan of the tested room and the structural diagram of the tested wall in the A3# Building

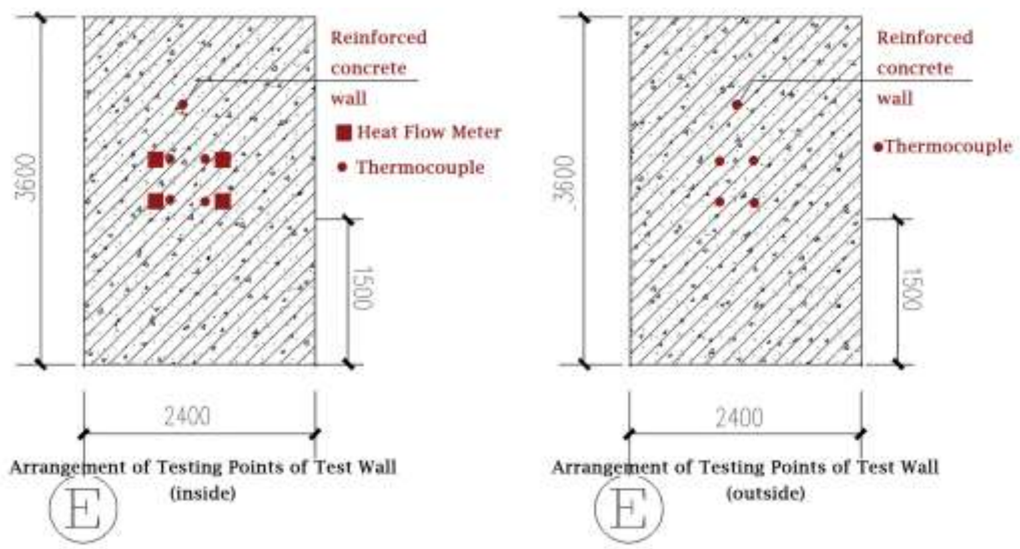


Figure 5.25 The layout plan of the measure points in the A3# Building

(2) Test requirements

a. The power distribution room on the first floor of the A3# Building is selected as the tested room for the thermal test of the thermal bridge in this building (Figure 5.23 ~ Figure 5.25). The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from reinforced concrete, and its structural constitution is (from outside to inside): autoclaved sand aerated concrete slabs (B04) (50.00mm) + reinforced concrete (230.00mm) + composite mortar (20.00mm);

c. The thermal conductivity of the inorganic insulation mortar is less than 0.070 W/(m K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.26)

Figure 5.26 The photos of the field test of the thermal bridge in the A3# Building

(4) An analysis of the test results

Table 5.21 Data acquisition

Test-Piece Name	The heat transfer coefficient of the thermal bridge in the A3# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter（mV）			
2013-6-29 2:00	41.1	41.1	42.1	41.6	29.7	29.3	29.4	29.3	1.91	1.83	1.82	1.91
2013-6-29 2:30	41.1	41.1	42.2	41.7	29.5	29.4	29.4	29.4	1.91	1.82	1.85	1.93
2013-6-29 3:00	41.2	41.1	42.2	41.7	29.7	29.4	29.5	29.4	1.92	1.82	1.82	1.91
2013-6-29 3:30	41.2	41.2	42.2	41.7	29.7	29.4	29.5	29.4	1.93	1.83	1.82	1.93

2013-6-29 4:00	41.1	41.1	42.2	41.7	29.6	29.3	29.4	29.3	1.93	1.85	1.83	1.91
2013-6-29 4:30	41.1	41.1	42.2	41.7	29.6	29.4	29.5	29.4	1.92	1.85	1.83	1.93
2013-6-29 5:00	41.2	41.2	42.2	41.7	29.7	29.3	29.4	29.3	1.92	1.82	1.83	1.91
2013-6-29 5:30	41.2	41.2	42.2	41.7	29.7	29.4	29.4	29.3	1.93	1.85	1.82	1.91

Table 5.22 Data analysis

The average temperature on the interior surface of the tested wall T1 (℃)	41.5
The average temperature on the exterior surface of the tested wall T_2 (℃)	29.5
The temperature difference between the interior and exterior surfaces of the tested wall △T (℃)	12
The average heat-flow density of the tested wall q (W/ m^2)	21.81
The heat resistance of the tested wall R (m^2 k)/ W	0.550
The heat transfer resistance of the tested wall R_0 (m^2 k)/W	0.700
The heat transfer coefficient of the tested wall K (W /(m^2 k))	1.43
The theoretical calculating value of the heat transfer coefficient of the tested wall K (W/(m^2 k))	1.41

4) Thermal test of the main wall in the A3# Building

(1) Layout of the measure points

Figure 5.27 The layout plan of the measure points in the A3# Building

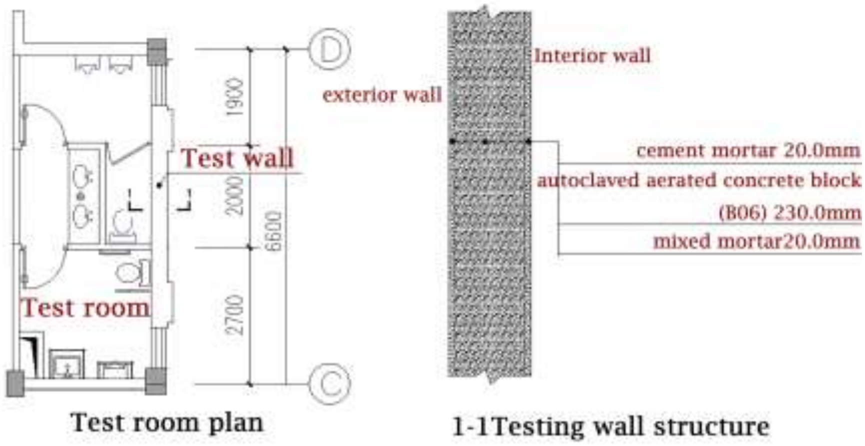


Figure 5.28 The plan of the tested room and the structural diagram of the tested wall in the A3# Building

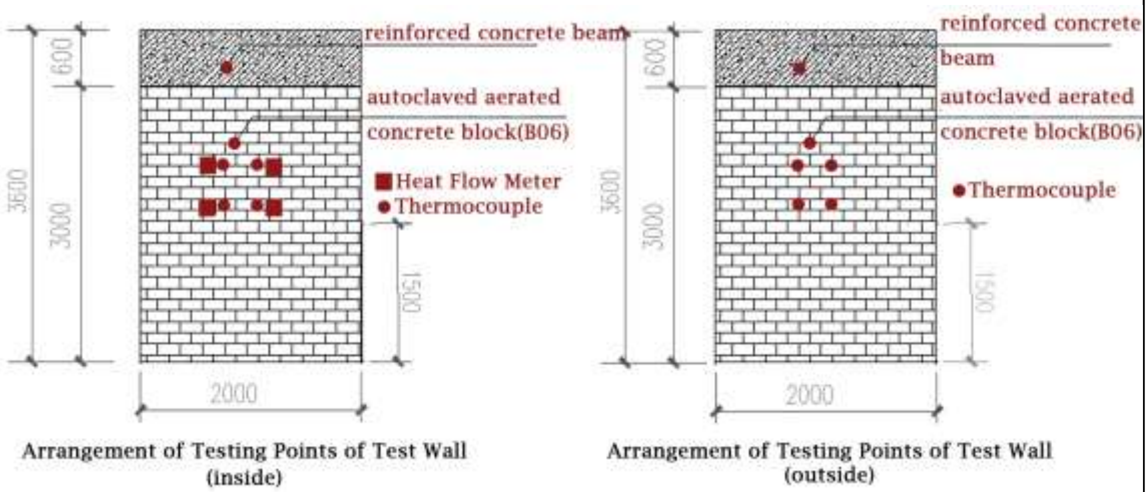


Figure 5.29 The layout plan of the measure points in the A3# Building

(2) Test requirements

a. The toilet on the second floor of the A3# Building is selected as the tested room for the thermal test of the main wall in this building (Figure 5.27 ~ Figure 5.29). The main wall of the tested room must be constructed with autoclaved sand aerated concrete blocks. The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from autoclaved sand aerated concrete blocks (B06), and its structural constitution is (from outside to inside): cement mortar (20.00mm) + autoclaved sand aerated concrete blocks (B06) (230.00mm) + composite mortar (20.00mm);

c. The thermal conductivity of the autoclaved sand aerated concrete blocks (B06) is less than 0.19 W/(m ·K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.30)

Figure 5.30 The photos of the field test of the wall in the A3# Building

(4) An analysis of the test results

Table 5.23 Data acquisition

Test-Piece Name	The heat transfer coefficient of the main wall in the A3# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter（mV）			
2013-6-29 1:30	32.7	43.4	43.4	44.4	43.9	26.9	26.5	26.6	26.5	1.18	1.22	1.19
2013-6-292:00	32.7	43.4	43.4	44.5	44.0	26.7	26.6	26.6	26.6	1.17	1.23	1.17
2013-6-29 2:30	32.7	43.5	43.4	44.5	44.0	26.9	26.6	26.7	26.6	1.17	1.23	1.17

2013-6-29 3:00	32.7	43.5	43.5	44.5	44.0	26.9	26.6	26.7	26.6	1.19	1.23	1.17
2013-6-29 3:30	32.6	43.4	43.4	44.5	44.0	26.8	26.5	26.6	26.5	1.19	1.23	1.19
2013-6-29 4:00	32.6	43.4	43.4	44.5	44.0	26.8	26.6	26.7	26.6	1.19	1.22	1.17
2013-6-29 4:30	32.6	43.5	43.5	44.5	44.0	26.9	26.5	26.6	26.5	1.17	1.22	1.19
2013-6-29 5:00	32.6	43.5	43.5	44.5	44.0	26.9	26.6	26.6	26.5	1.19	1.22	1.17

Table 5.24 Data analysis

The average temperature on the interior surface of the tested wall T_1 (℃)	43.8
The average temperature on the exterior surface of the tested wall T_2 (℃)	26.7
The temperature difference between the interior and exterior surfaces of the tested wall ΔT (℃)	17.1
The average heat-flow density of the tested wall q (W/ m^2)	13.96
The heat resistance of the tested wall R (m^2 k)/ W	1.225
The heat transfer resistance of the tested wall R_0 (m^2 k)/W	1.375
The heat transfer coefficient of the tested wall K (W/(m^2 k))	0.73
The theoretical calculating value of the heat transfer coefficient of the tested wall K (W/(m^2 k))	0.71

5) Thermal test of the thermal bridge in the A4# Building

(1) Layout of the measure points

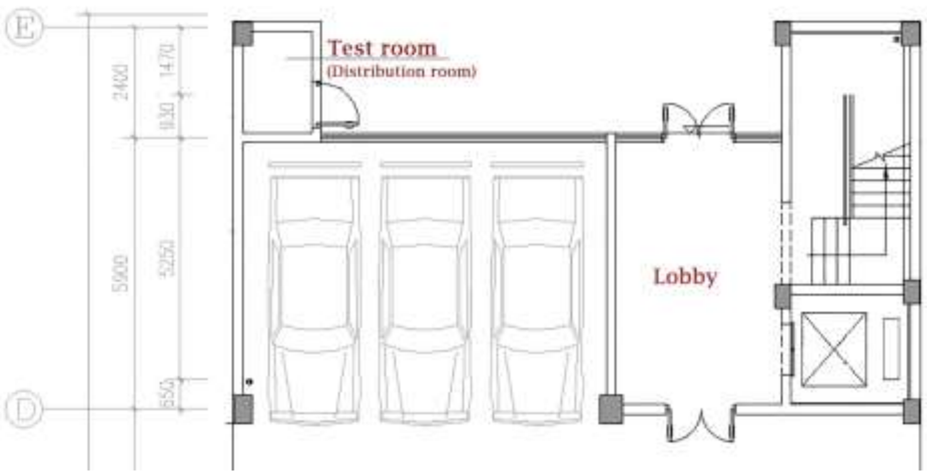


Figure 5.31 The layout plane of the measure points in the A4# Building

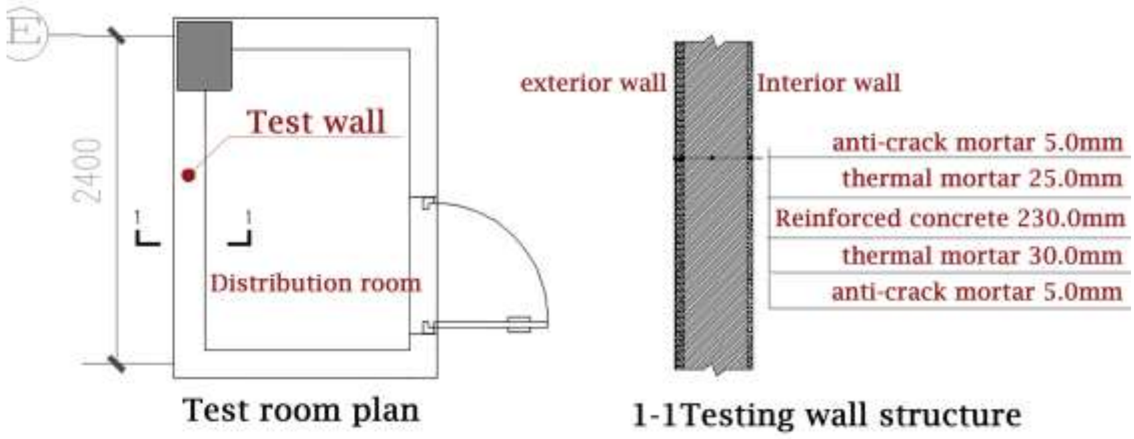


Figure 5.32 The layout plan of the measure points in the A4# Building

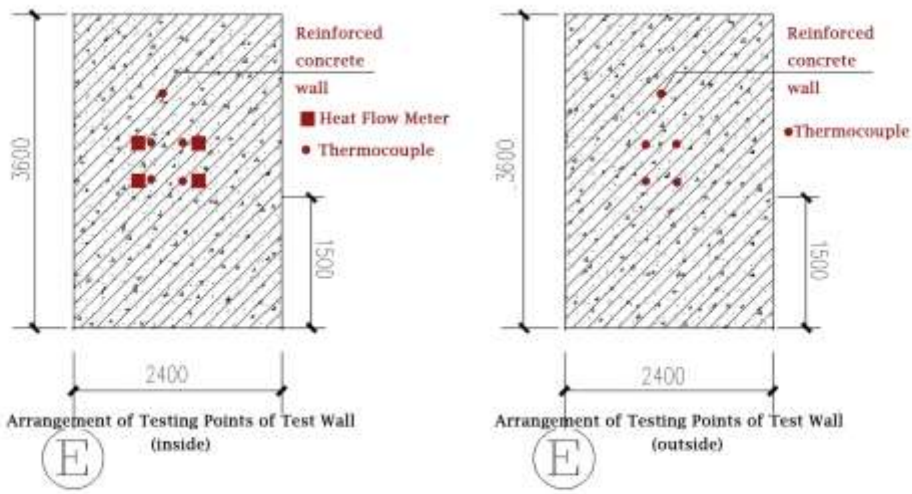


Figure 5.33 The layout plan of the measure points in the A4# Building

(2) Test requirements

a. The power distribution room on the first floor of the A4# Building is selected as the tested room for the thermal test of the thermal bridge in this building (Figure 5.31 ~ Figure 5.33). The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from reinforced concrete, and its structural constitution is (from outside to inside): anti-crack mortar (5.00mm) + inorganic insulation mortar (25.00mm) + reinforced concrete (230.00mm) + inorganic insulation mortar (30.00mm) + anti-crack mortar (5.00mm);

c. The thermal conductivity of the inorganic insulation mortar is less than 0.070 W/(m·K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.34)

Figure 5.34 The photos of the field test of the thermal bridge in the A4# Building

(4) An analysis of the test results

Table 5.25 Data acquisition

Test-Piece Name	The heat transfer coefficient of the thermal bridge in the A4# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter（mV）			
2013-7-3 1:00	42.6	42.6	43.6	43.1	31.5	31.1	31.2	31.1	1.33	1.27	1.34	1.36
2013-7-3 1:30	42.6	42.6	43.7	43.2	31.3	31.2	31.2	31.2	1.32	1.28	1.32	1.35
2013-7-3 2:00	42.7	42.6	43.7	43.2	31.5	31.2	31.3	31.2	1.33	1.28	1.32	1.35
2013-7-3 2:30	42.7	42.7	43.7	43.2	31.5	31.2	31.3	31.2	1.35	1.28	1.32	1.34

2013-7-3 3:00	42.6	42.6	43.7	43.2	31.4	31.1	31.2	31.1	1.34	1.28	1.32	1.36
2013-7-3 3:30	42.6	42.6	43.7	43.2	31.4	31.2	31.3	31.2	1.34	1.27	1.32	1.35
2013-7-3 4:00	42.7	42.7	43.7	43.2	31.5	31.1	31.2	31.1	1.32	1.27	1.34	1.35
2013-7-3 4:30	42.7	42.7	43.7	43.2	31.5	31.2	31.2	31.1	1.34	1.27	1.32	1.35

Table 5.26 Data analysis

The average temperature on the interior surface of the tested wall T1 (℃)	43.0
The average temperature on the exterior surface of the tested wall T_2 (℃)	31.3
The temperature difference between the interior and exterior surfaces of the tested wall ΔT (℃)	11.7
The average heat-flow density of the tested wall q (W/ m^2)	15.37
The heat resistance of the tested wall R (m^2 k)/ W	0.761
The heat transfer resistance of the tested wall R_0 (m^2 k)/W	0.911
The heat transfer coefficient of the tested wall K (W /(m^2 k))	1.10
The theoretical calculating value of the heat transfer coefficient of the tested wall K (W/(m^2 k))	1.04

6) Thermal test of the main wall in the A4# Building

(1) Layout of the measure points

Figure 5.35 The layout plan of the measure points in the A4# Building

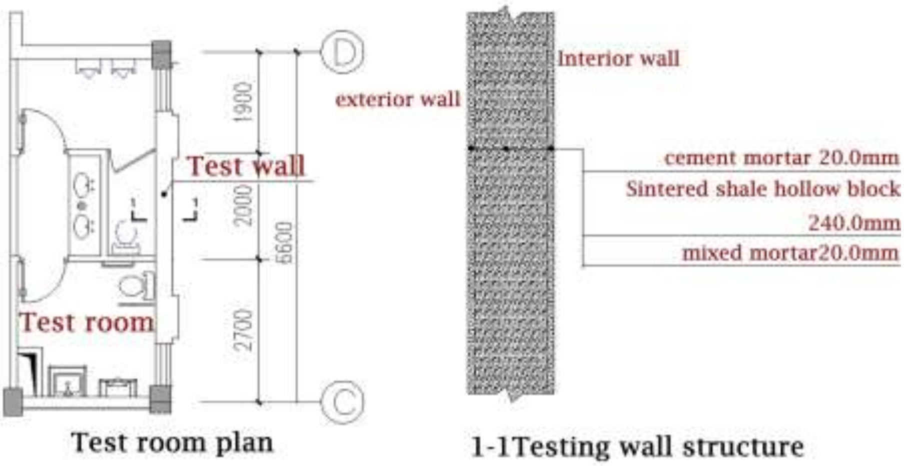


Figure 5.36 The layout plan of the measure points in the A4# Building

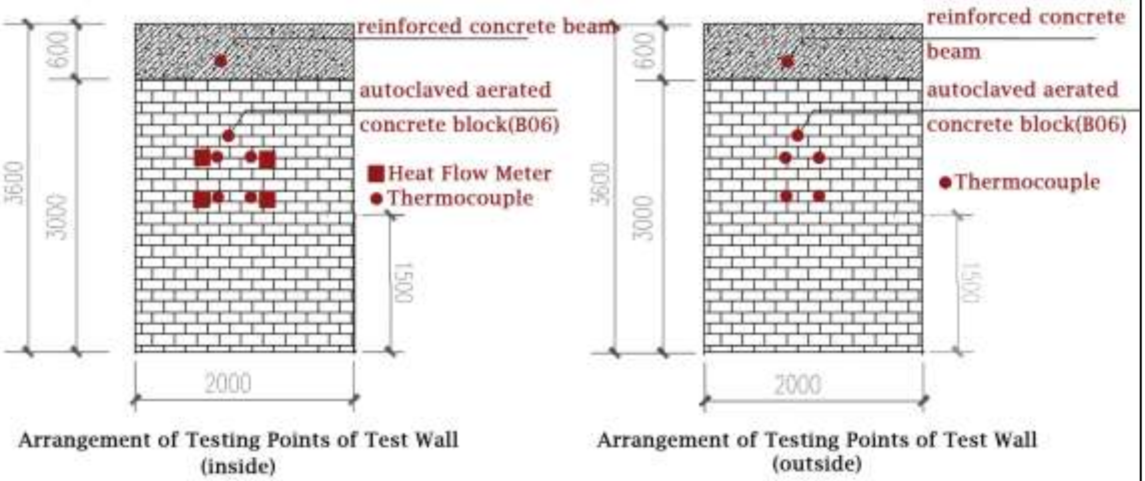


Figure 5.37 The layout plan of the measure points in the A4# Building

(2) Test requirements

a. The toilet on the second floor of the A4# Building is selected as the tested room for the thermal test of the main wall in this building (Figure 5.35 ~ Figure 5.37). The room must be closed (the door and window of the tested room are required to be installed before the test). The field test should be conducted after the wall has been completely dry;

b. The tested wall is mainly made from sintered shale hollow blocks, and its structural constitution is (from outside to inside): cement mortar (20.00mm) + sintered shale hollow blocks (240.00mm) + composite mortar (20.00mm);

c. The thermal conductivity of the sintered shale hollow blocks is less than 0.28 W/(m·K);

d. Before the test, the tested room should be heated with heating equipment. The formal test should be conducted after the heat storage of the wall becomes stable.

(3) The photos of the scene (see Figure 5.38)

Figure 5.38 The photos of the field test of the wall in the A4# Building

(4) An analysis of the test results

Table 5.27 Data Acquisition

Test-Piece Name	The heat transfer coefficient of the main wall in the A4# Building											
Time	The Surface Temperature of the Hot Wall (℃)				The Surface Temperature of the Cold Wall (℃)				Electrodynamic Potential of the Heat Flow Meter（mV）			
2013-7-3 1:30	43.4	43.4	44.4	43.9	30.4	30	30.1	30	1.35	1.32	1.36	1.38
2013-7-3 2:00	43.4	43.4	44.5	44.0	30.2	30.1	30.1	30.1	1.34	1.35	1.34	1.37
2013-7-3 2:30	43.5	43.4	44.5	44.0	30.4	30.1	30.2	30.1	1.35	1.32	1.34	1.37
2013-7-3 3:00	43.5	43.5	44.5	44.0	30.4	30.1	30.2	30.1	1.37	1.32	1.34	1.36

2013-7-3 3:30	43.4	43.4	44.5	44.0	30.3	30	30.1	30	1.36	1.35	1.34	1.38
2013-7-3 4:00	43.4	43.4	44.5	44.0	30.3	30.1	30.2	30.1	1.36	1.35	1.34	1.37
2013-7-3 4:30	43.5	43.5	44.5	44.0	30.4	30	30.1	30	1.34	1.35	1.36	1.37
2013-7-3 5:00	43.5	43.5	44.5	44.0	30.4	30.1	30.1	30	1.36	1.35	1.34	1.37

Table 5.28 Data analysis

The average temperature on the interior surface of the tested wall T1 (℃)	43.8
The average temperature on the exterior surface of the tested wall T_2 (℃)	30.2
The temperature difference between the interior and exterior surfaces of the tested wall ΔT (℃)	13.6
The average heat-flow density of the tested wall q (W/ m^2)	15.73
The heat resistance of the tested wall R (m^2 k)/ W	0.865
The heat transfer resistance of the tested wall R_0 (m^2 k)/W	1.015
The heat transfer coefficient of the tested wall K (W/(m^2 k))	0.99
The theoretical calculating value of the heat transfer coefficient of the tested wall K (W/(m^2 k))	0.94

7) An analysis of the test results

It is indicated in the above test results that:

(1) The results of the field tests in each building are close to those of the indoor tests and the theoretical calculation, and all of them have met the energy-saving requirements for self-insulation.

(2) Comparing and analyzing the test results from the A2#, A3# and A4# buildings, it is found that the A3# Building with the key combination 2 of the wall self-insulation system (the wall is made from aerated concrete, and the thermal bridge autoclaved sand aerated concrete slabs) has the best thermal-insulation and energy-saving performance, followed by the A2# Building which has adopted the key combination 1 of the wall self-insulation system (the wall is made from aerated concrete, and the thermal bridge inorganic insulation mortar) and then the A4# Building which has adopted the key combination 3 of the wall self-insulation system (the wall is made from sintered shale hollow blocks and the thermal bridge adopts inorganic insulation mortar both inside and outside).

5.5 Economic performance analysis of various insulation systems

To promote the application of wall self-insulation systems in the hot summer and cold winter zone, in addition to solving some problems existing in the wall self-insulation systems themselves, their economic performance is also an important factor in deciding whether they can be widely popularized and applied. With the current market conditions and the construction cost quotas in Zhejiang province, a preliminary comparison of their economic performance has been drawn in the following part, which has also combined with the specific practices of the commonly-used wall internal-insulation system and wall external-insulation system and the three wall self-insulation systems promoted by this research project.

1) The scheme for internal-insulation walls

This scheme adopts walls made from 240-thick sintered shale perforated bricks, and XPS gypsum plaster boards are used for internal insulation.

Table 5.29 Economic performance analysis of the wall internal-insulation system

Names of the Materials	Costs（yuan/m^2）
240-thick sintered shale perforated bricks	79.2
Internal-insulation materials	60
Exterior whitewash	25
Interior whitewash	20
Total	184.2

2) The scheme for external-insulation walls

This scheme adopts walls made from 240-thick sintered shale perforated bricks, and 30mm-thick inorganic insulation mortar is used for external insulation.

Table 5.30 Economic performance analysis of the wall external-insulation system

Names of the Materials	Costs（yuan/m^2）
240-thick sintered shale perforated brick	79.2
External-insulation materials	55
Exterior whitewash	25
Interior whitewash	20
Total	179.2

3) The first scheme for self-insulation walls

This scheme adopts walls made from 230-thick autoclaved sand aerated blocks, and 30mm-thick inorganic insulation mortar is used for the thermal bridge.

Table 5.31Economic performance analysis of the wall self-insulation system (1st Scheme)

Names of the Materials	Costs（yuan/m^2）
230-thick autoclaved sand aerated blocks	100.8
Thermal-bridge insulation materials	55x0.26=14.3
Putty	22
Total	137.1

4) The second scheme for self-insulation walls

This scheme adopts walls made from 230-thick autoclaved sand aerated blocks, and 50mm-thick sand aerated blocks are used for the thermal bridge.

Table 5.32Economic performance analysis of the wall self-insulation system (2nd Scheme)

Names of the Materials	Costs（yuan/m^2）
230-thick autoclaved sand aerated blocks	100.8
Thermal-bridge insulation materials	50x0.26=13
Putty	22

Total	135．8

5) The third scheme for self-insulation walls

This scheme adopts walls made from 240-thick sintered shale hollow blocks, and 25mm-thick inorganic insulation mortar is used for the exterior side of the thermal bridge while 30mm-thick inorganic insulation mortar is used for the interior side of the thermal bridge.

Table 5.33Economic performance analysis of the wall self-insulation system (3rd Scheme)

Materials	Costs（yuan/m^2）
230-thick autoclaved sand aerated blocks	88.9
Thermal-bridge insulation materials	55x0.26x2=28.6
Exterior whitewash	25
Interior whitewash	20
Total	162.5

In summary, although the wall materials used in the wall self-insulation systems are more expensive than those adopted by the wall internal-insulation system and the wall external-insulation system, since the wall self-insulation systems only need additional insulation materials in the thermal bridge part, they can save a lot of costs on insulation materials. Furthermore, with simple construction process and thus low labor costs, each of the three wall self-insulation systems proposed by this research project has better overall economic performance than the other two systems. Therefore, from an economic point of view, the wall self-insulation systems are worthy of promotion in the hot summer and cold winter zone.

5.6 Conclusion

Through the theoretical analyses and the field tests of different types of building self-insulation systems in the hot summer and cold winter zone, the following conclusions have been drawn:

1) Energy-efficiency calculation has been made for the pilot buildings on the three self-insulation systems with different constructional measures. The calculation results indicate that the energy efficiency of each pilot building has met the requirements of relevant national norms.

2) Energy-efficiency field tests have been carried out in the pilot buildings on the wall self-insulation systems with three different constructional measures. The test results are basically similar to the theoretical calculation results, which are in line with the requirements, and the energy-saving effects are good.

3) The comparative analysis of the test results of the pilot buildings with self-insulation systems that adopt three different constructional measures shows that the wall self-insulation system whose main structure adopts autoclaved sand aerated concrete blocks and thermal bridge adopts autoclaved sand aerated concrete insulation boards has the best energy-saving effect.

4) With the current market conditions and the construction cost quotas in Zhejiang province, combining with the specific practices of the commonly-used wall internal-insulation system, wall external-insulation system and the three wall self-insulation systems promoted by this research project, a preliminary comparison of their economic performance has been drawn. The results show that the wall self-insulation systems not only have good energy-saving effects, but also possess better comprehensive economic performance than the other two types of systems. Therefore, the wall self-insulation systems should be vigorously popularized and applied in the hot summer and cold winter zone.

CHAPTER SIX: CONCLUSION AND OUTLOOK

6. CONCLUSION AND OUTLOOK

6.1 Conclusion

In nearly three years, led by Hangzhou Economic and Information Technology Commission, Hangzhou Municipal Finance Bureau, Hangzhou City Construction Committee and Hangzhou New Wall Materials Management Office, the Architectural Design & Research Institute of Zhejiang University has worked together with the Architectural Technology & Research Institute of Zhejiang University, Canhigh Construction Group Co., Ltd., Zhejiang Kaiyuan New Wall Materials New Century Tourism Group Co., Ltd., Hangzhou No.4 Construction Engineering Company and other units to carry out the scientific research project “The Theoretical Analysis and Pilot Project of the Self-Insulation Systems of Walls in the Hot Summer and Cold Winter Zone”. Based on the existing basic data of domestic and foreign studies, the research has taken the self-insulation systems of walls in the hot summer and cold winter zone as the research object and mainly adopted the comprehensive analysis method which combines investigation and study, numerical analysis, experimental research and on-site testing together. The main research results of the project are:

1) Investigation and study

(1) According to the study of the domestic and foreign literature and the field investigation of different cities in the hot summer and cold winter zone, the research reviewed the history and present situation of wall insulation systems at home and abroad, categorized and summarized the advantages and disadvantages of several currently-used wall insulation systems.

(2) According to the investigation and study, the research summarized the commonly used wall materials of the self-insulation systems and the construction measures of the key joints of different thermal bridges at present in the hot summer and cold winter zone.

(3) According to the results of investigation and study, the research summarized the existing problems in the self-insulation systems in the hot summer and cold winter zone and the future directions for development.

2) Indoor thermal tests on the commonly-used self-insulation wall materials

(1) The research analyzed the thermal performance of the new wall materials (shale sintered hollow block, shale sintered perforated brick, autoclaved sand aerated concrete block, sintered gangue perforated brick, sintered insulation brick, composite concrete perforated brick, etc.) commonly used in the hot summer and cold winter zone through the tests.

(2) The research studied the optimal collocation of the thermal performance of these wall materials by theoretical and experimental methods. It analyzed the influencing rule of the factors such as the hole types and arrangement ways of the air space on the thermal performance of the blocks. According to the characteristics of each wall material, it explored the optimal configuration and improvement measures to optimize the thermal performance of the blocks in order to meet the national standards on the thermal

performance of buildings' walls in the hot summer and cold winter zone.

(3) Based on the results of the thermal tests and the factors such as the resource distribution, climatic conditions, architectural features, level of economic development and the development status of local industries in Hangzhou, the research found that the most suitable wall materials for the self-insulation systems in Hangzhou are autoclaved sand aerated concrete blocks and shale sintered hollow blocks.

3) Theoretical research and numerical analysis

(1) The research summarized and studied the basic heat transfer theories and energy-saving calculation methods of the self-insulation systems in the hot summer and cold winter zone.

(2) The research established calculation models of different types of buildings with self-insulation systems in Hangzhou and carried out energy-saving calculation. Based on the basic energy-saving calculation, the research changed different influencing factors that affect the energy-saving effects, such as the shape coefficient of buildings, the wall materials, the window-wall ratio, the thickness of walls, the thickness of insulation layers, the thickness of roof insulation and the shading coefficient of exterior windows, and got the relationship between different factors and the energy-saving effects, which helps further optimize the various structural measures that influence the self-insulation systems to get the best energy-saving effects.

(3) The research studied the key structures of the thermal bridge parts of the self-insulation systems of walls. It analyzed the results together with the wall materials obtained from the thermal tests and proposed the most suitable wall self-insulation systems for Hangzhou.

(4) The research made a lot of calculation and analyses on different types of buildings, which used different wall materials and had different combinations of key joints of thermal bridges in the self-insulation systems. According to the analyses of the energy-saving effects and economic benefits of different structure combinations in self-insulation systems as well as many other factors, the research determined the most suitable combinations of self-insulation systems for the hot summer and cold winter zone, especially for Hangzhou: the wall self-insulation system 1: the autoclaved sand aerated concrete as the main structure, the inorganic insulation mortar as the thermal bridge; the wall self-insulation system 2: the autoclaved sand aerated concrete as the main structure, the autoclaved sand aerated concrete insulation boards (B04) as the thermal bridge; the wall self-insulation system 3: the sintered shale hollow masonry blocks as the main structure, the inorganic insulation mortar adopted both inside and outside the thermal bridge.

4) The pilot project and field tests

(1) Based on the investigation and study, indoor thermal experiments and a large number of theoretical and computational numerical analysis results above, the research put forward three types of self-insulation systems of architectural walls according to the specific conditions of the hot summer and cold winter zone (especially Hangzhou). In the pilot project, the pilot buildings include different types of commonly-used buildings such as office buildings, hotels, supermarkets and serviced apartments. The pilot buildings which include multi-storey buildings and high-rise buildings have wide coverage and strong representativeness. Five of the pilot buildings are identical buildings and the research adopts three types of self-insulation methods of walls respectively on them to compare the energy-saving effects.

(2) The research did the energy-saving calculation on the eight pilot buildings which are with the optimized combinations of the three self-insulation systems respectively. The results of the energy-saving calculation show that all the three combinations of the self-insulation systems meet the national rules and requirements of the energy-saving effects.

(3) The research carried out field tests in the pilot project to detect the actual energy-saving effects of the three different self-insulation systems and to lay the foundation for the further improvement and popularization of the self-insulation systems of architectural walls. The results of the energy-saving tests on the three self-insulation systems are basically the same as the theoretical calculations, which reach the national regulations and requirements of energy efficiency.

(4) The research analyzed the economic performance of different insulation systems and the three self-insulation systems with different constructional measures to find out the most economical and reasonable self-insulation scheme. According to the results of energy-saving field tests and economic performance analyses, the most suitable self-insulation systems for Hangzhou area are the wall self-insulation system 1: the autoclaved sand aerated concrete as the main structure, the inorganic insulation mortar as the thermal bridge; and the wall self-insulation system 2: the autoclaved sand aerated concrete as the main structure, the autoclaved sand aerated concrete insulation boards (B04) as the thermal bridge.

(5) According to the results of this research, the “Detailed Atlas of Sand Compacted Aerated Concrete Blocks and Boards” in Zhejiang Provincial Standard Atlas and the “Application Regulation of Autoclaved Autoclaved Wall Systems of Autoclaved Sand Aerated Concrete” (First Draft) in Zhejiang Provincial Regulations were written and complied to promote the application of self-insulation systems of walls in Hangzhou.

6.2 Suggestions and Outlook

With people's increasing awareness of environmental protection and sustainable development, the energy-saving work on buildings has been carried out all across the country. It is the golden time in the history to study, develop, promote and apply the self-insulation systems of architectural walls. The development of the self-insulation systems of architectural walls in the hot summer and cold winter zone will bring outstanding economic and social benefits.

The future development of the self-insulation systems of walls should follow the working guideline of "guided by public opinions and supported by technology; standards go first and technology goes with it; driven by models, industries follow up; standardized management and ensured quality" and move forward vibrantly and steadily. The main future development directions and goals are as follows:

1) The development of the self-insulation technology of walls should be done together with related policies and requirements on the adjustment of buildings' structural systems and the reformation of wall materials in China, which does good to the study of architectural structural systems that benefit the energy-saving effects of the buildings. The design of the structural systems should facilitate the use of the self-insulation technology of walls.

2) The energy-saving and waste-friendly materials should be actively exploited according to local conditions. It is necessary to take the requirements of the policy on wall reformation –"solid ban and clay limit" into consideration, make full use of wastes like the river (lake, sea) mud, fly ash, coal gangue, tailings and industrial waste to produce energy-saving bricks and blocks, improve the technological performance of the existing products, optimize the hole design of blocks, ensure that the products are environment-friendly, standardize the management of the production and application of the energy-saving blocks, unify the standards, unify the marks, set up fixed points for production and prevent fraud.

3) The use of new materials with light weight, high strength and nice thermal insulation performance such as the sand aerated concrete block, the ceramic block aerated concrete block and the autoclaved sand aerated concrete sheet should be further promoted. The research on shrinkage-reducing technologies and the supporting anti-impermeable masonry methods should be made.

4) The development of composite self-insulation structure technology should be greatly encouraged. The study on the key joints and supporting technologies of the composite structural self-insulation technology should be improved. The producibility and industrialization of the self-insulation technology of walls should be promoted.

5) The scientific research on the self-insulation technology of walls should be organized. The cooperation among universities, research institutes and enterprises should be strengthened. Under the concept of green building materials and green buildings, local resources should be fully used, rational distribution should be made, diversified self-insulation technology of walls with local characteristics should be developed and the technological systems of the self-insulation of walls should be further enriched. The research on the self-insulation systems of walls should be strengthened, especially the research on supporting technology of masonry mortar and the treatment of thermal bridge.

6) The technical standards should be improved. The research and formulation on the application standards of different types of the self-insulation technology of walls should be carried out; different types of technical indicators should be unified. The standardized atlas of the self-insulation systems of walls should be written and complied, the design and construction of the self-insulation technology of walls should be guided. Various types of companies that produce the products with self-insulation systems should make business standards.

7) The standardization of management on the self-insulation technology of walls should be strengthened. The assessment and management of the self-insulation technology (system) of walls should be carried out. The management measures during the steps like design, plans, testing, construction and supervision of the self-insulation technology systems of walls should be further explored and improved.

8) The pilot projects should be actively carried out and used as demonstrations. The publicity should be strengthened to promote the application of the self-insulation technology of walls. The optimization of the self-insulation materials for walls should be listed in the reformation plan of wall materials. The local leading technology should be actively cultivated, the development of the local manufacturers of the self-insulation technology of walls should be supported, the industrialized bases should be cultivated.

FIGURE: PANORAMIC PICTURE OF PILOT PROJECT

PANORAMIC PICTURE OF PILOT PROJECT

(Picture source: Hangzhou Xixi Xintiandi project developers)

Figure 1 Airscape

Figure 2 Airscape of the A area

Figure 3 Perspective of the A area

Figure 4 Perspective of the B area

Figure 5 Landscape of the B area

Figure 6 Perspective of the A area

Figure 7 Perspective of the A area

Figure 8 Landscape of the A area

Figure 9 Overall perspective

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