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Impact of Assembled Multi-Story Exterior Wall Structures on Interior Thermal Stability

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Abstract: In the face of the challenges posed by global climate change, the construction industry is under immense pressure to transform, with a consensus emerging on the need for more energy-efficient construction methods. Prefabricated buildings, renowned for their green, environmentally friendly, and efficient characteristics, are gradually becoming the new darling of the construction industry. The multi-storey prefabricated façade, as a crucial component of prefabricated buildings, has attracted widespread attention due to its impact on indoor thermal stability. Through systematic research on multi-storey prefabricated façade structures, a theoretical basis can be provided for improving the design of prefabricated buildings and enhancing their indoor thermal comfort. Indoor thermal stability is closely related to energy consumption and directly affects the comfort and health of occupants. In prefabricated buildings, factors such as facade structure design, material selection, and assembly methods play a critical role in influencing the stability of the indoor thermal environment. Studying the impact of multi-storey prefabricated façade structures on indoor thermal stability aims to reveal the effects of different design solutions on temperature control, guiding the future design and construction of prefabricated buildings to achieve greater energy efficiency and livability.

1. Introduction

In the face of global climate change and energy crisis, the sustainable development of the construction industry has received unprecedented attention. Among them, prefabricated buildings have gradually become an important direction in the construction industry due to their efficiency and energy-saving advantages. With the increasing application of prefabricated buildings, the thermal stability of multi-story external wall structures in indoor environments has become the focus of research. The indoor thermal stability directly affects the energy consumption of buildings and the comfort of occupants. Therefore, this paper aims to systematically analyze how prefabricated multi-story external wall structures affect the indoor thermal environment, by exploring how the selection of external wall materials, design of composite structures, and insulation performance collectively impact indoor thermal stability, in order to propose improvement strategies. Through this study, it is expected to provide more precise guidance for the design and construction of prefabricated buildings, and promote the development of the construction industry towards a more efficient, energy-saving, and comfortable direction [1].

2. Factors Affecting Indoor Thermal Stability in Assembled Buildings

2.1. Selection of Exterior Wall Materials

The selection of exterior wall materials is a critical aspect of building design, profoundly influencing indoor thermal stability and energy efficiency. The thermal conductivity of these materials is paramount, as it determines their ability to resist the transfer of heat from the external environment to the interior spaces. Materials with low thermal conductivity effectively act as insulators, minimizing the impact of external temperature fluctuations on indoor thermal conditions. For instance, lightweight porous materials like expanded polystyrene (EPS) and extruded polystyrene (XPS) are renowned for their excellent insulation properties due to the presence of air voids within their structure. These air voids serve as barriers to heat transfer, resulting in reduced heat flow through the exterior walls and consequently maintaining stable indoor temperatures. Furthermore, the thermal capacity of exterior wall materials plays a significant role in maintaining indoor thermal stability, particularly in regions with significant day-night temperature variations. Materials with high thermal capacity, such as concrete, possess the ability to absorb and store large amounts of heat during the day and release it gradually during cooler periods, thereby minimizing temperature fluctuations within indoor spaces. This thermal inertia helps to stabilize indoor temperatures and reduce the reliance on mechanical heating and cooling systems. However, the selection of exterior wall materials is not solely based on thermal conductivity and capacity; other factors such as climate conditions and building requirements must also be considered. While heavy materials like concrete excel in terms of thermal capacity, their relatively high thermal conductivity may not be suitable for all climates, particularly in regions with hot summers or mild winters. In such cases, lightweight materials with lower thermal conductivity, such as EPS and XPS, may be more appropriate as they offer superior insulation properties without compromising thermal stability. Conversely, lightweight materials may exhibit excellent thermal conductivity but lack the thermal mass necessary to stabilize indoor temperatures. In such instances, additional insulation strategies, such as double-glazed windows or external shading devices, may be required to compensate for the lower thermal capacity of these materials. In conclusion, the selection of exterior wall materials is a multifaceted decision that requires careful consideration of thermal conductivity, thermal capacity, climate conditions, and building requirements. By choosing materials that strike the right balance between insulation properties and thermal mass, designers can create buildings that maintain stable indoor temperatures, reduce energy consumption, and enhance occupant comfort and well-being.

2.2. Combined Structural Design

The concept of composite structural design represents a holistic approach to building construction, encompassing the integration of various structural materials, component configurations, and connection methods to fulfill the objectives of architectural design. This approach aims to optimize both thermal performance and structural integrity to enhance indoor thermal stability and overall building efficiency. One of the primary considerations in composite structural design is addressing the thermal bridging effect, which refers to the increased heat transfer caused by variations in thermal resistance among structural components. By strategically selecting high thermal resistance materials and implementing enclosed cavity structures, designers can mitigate thermal bridging and minimize heat loss or gain through the building envelope. These measures effectively slow down the rate of heat exchange between the interior and exterior environments, contributing to more stable indoor temperatures throughout the day and across different seasons. Additionally, the thermal capacity of building materials plays a crucial role in regulating indoor temperature fluctuations. Materials with high thermal capacity, such as concrete slabs, have the ability to absorb and store heat energy, buffering against rapid temperature changes. By incorporating these materials strategically within the building envelope, designers can enhance the building's heat storage capacity, thereby promoting thermal stability and reducing the need for continuous heating or cooling.Furthermore, the tightness of structural components and their arrangement within the building envelope significantly influences thermal stability. Well-sealed connections between structural elements minimize air leakage, preventing the ingress of cold drafts or the escape of heated air. This ensures that the building maintains a consistent indoor temperature, enhancing occupant comfort and reducing energy consumption.Moreover, thoughtful layout and orientation of structural components can optimize natural light penetration and ventilation, further contributing to thermal stability. Maximizing daylight exposure while minimizing solar heat gain through strategic window placement and shading devices helps regulate indoor temperatures without excessive reliance on artificial heating or cooling systems. Similarly, promoting natural ventilation pathways through careful building layout facilitates efficient air circulation, aiding in temperature regulation and improving indoor air quality.In conclusion, composite structural design offers a comprehensive approach to enhancing indoor thermal stability by addressing thermal bridging, maximizing thermal capacity, ensuring tight building envelopes, and optimizing natural ventilation and daylighting. By integrating these principles into building design, architects and engineers can create energy-efficient, comfortable, and sustainable built environments that promote occupant well-being and environmental stewardship [2].

2.3. Obstruction by Air Layer

The air layer, situated between two layers of materials in the exterior wall, acts as a formidable thermal resistance system, playing a pivotal role in regulating indoor temperatures and enhancing thermal stability. This layer of air, characterized by its lower thermal conductivity, effectively hinders the exchange of heat between the interior and exterior environments, thereby contributing significantly to maintaining consistent indoor temperatures.By virtue of its thermal resistance properties, the air layer mitigates heat transfer even amidst substantial fluctuations in external temperatures. It functions primarily by limiting heat convection, one of the primary modes of heat transfer. Within the enclosed space formed by two solid materials, air acts as a medium that resists convective heat transfer, thus compelling heat to be primarily transmitted through the slower process of conduction. This results in a reduced heat transfer rate within the wall, ensuring that indoor temperatures remain relatively stable despite external variations.Research indicates that incorporating an air layer in prefabricated exterior wall structures can lead to a substantial reduction in heat transfer rates, with potential reductions of up to 45%. For instance, in a configuration featuring double-glazed windows with an intervening air gap, the heat transfer coefficient can be significantly lower compared to an equivalent single-glazed exterior wall. This not only enhances thermal stability but also helps alleviate issues such as condensation resulting from temperature differentials, thereby further enhancing residential comfort and the longevity of wall materials.It's worth noting that the effectiveness of the air layer as a thermal barrier is influenced by factors such as its thickness and sealing. Increasing the thickness of the air layer can enhance its insulating performance, albeit with considerations for potential increases in structural complexity and cost. Moreover, optimizing the design of the air layer to ensure seamless interaction with other building materials is essential for maximizing its thermal stability benefits in practical applications.In conclusion, the presence of an air layer within prefabricated exterior wall structures significantly contributes to enhancing thermal stability and indoor comfort. By leveraging its thermal resistance properties, designers can create buildings that maintain consistent indoor temperatures, reduce energy consumption, and promote occupant well-being. Optimizing the design of the air layer, along with careful consideration of its thickness and sealing, is crucial for unlocking its full potential in enhancing the thermal performance of prefabricated buildings.

2.4. Effects of Building Orientation and Shading

Building orientation and shading are pivotal factors that profoundly influence the indoor thermal stability of assembled buildings. The orientation of a building relative to the sun's path dictates the amount and intensity of solar radiation it receives throughout the day, thereby significantly impacting indoor temperature dynamics. Buildings oriented towards the equator typically receive more direct sunlight, leading to increased solar heat gain and potentially higher indoor temperatures, particularly during the warmer months. Conversely, buildings oriented perpendicular to the sun's path may experience reduced solar heat gain and more balanced temperature distribution. Strategic shading plays a crucial role in mitigating excessive solar heat gain and maintaining thermal comfort within buildings. Various shading devices, such as overhangs, louvers, brise-soleil, and awnings, are employed to regulate the amount of solar radiation entering the building envelope. By strategically positioning shading elements based on solar angles and building orientation, designers can effectively block direct sunlight while allowing diffuse daylighting to penetrate indoor spaces. This not only reduces solar heat gain but also minimizes glare and improves visual comfort for occupants. Moreover, the integration of natural elements such as landscaping and vegetation can further enhance shading and cooling effects around buildings. Deciduous trees strategically planted on the southern and western sides of buildings provide natural shading during the summer months while allowing sunlight to penetrate during the winter, offering a dynamic solution to seasonal temperature regulation. Green roofs and vertical gardens not only provide insulation but also mitigate the urban heat island effect, contributing to overall thermal comfort and environmental sustainability. Proper consideration of building orientation and shading strategies is essential at the early stages of design to optimize thermal performance and energy efficiency. Advanced building simulation tools can be utilized to assess the effectiveness of different shading scenarios and inform design decisions. By leveraging building orientation and shading techniques effectively, architects and designers can create indoor environments that are resilient to external climatic variations, promote occupant well-being, and minimize energy consumption in assembled buildings[3].

3. Methods for Improving Indoor Thermal Comfort in Assembled Buildings

3.1. Use of Effective Insulation Materials

The use of effective insulation materials is paramount in ensuring the thermal performance and energy efficiency of prefabricated buildings. These materials serve as barriers to heat transfer through the building envelope, thereby enhancing indoor thermal stability and reducing energy consumption for heating and cooling purposes. By selecting and incorporating high-performance insulation materials, designers can create environments that are comfortable for occupants while minimizing operational costs and environmental impact. One of the most advanced insulation materials is vacuum insulation, which boasts exceptional thermal resistance due to its high vacuum core enclosed in an airtight package. Despite its relatively higher cost, vacuum insulation far surpasses traditional materials in terms of thermal performance, making it an ideal choice for achieving superior insulation in prefabricated buildings. Its ability to effectively resist heat transfer helps maintain stable indoor temperatures, reducing the need for mechanical heating and cooling systems and thereby lowering energy bills and carbon emissions. Another innovative insulation material is aerogel, characterized by its extremely low density and high porosity, which contribute to its exceptional thermal insulation properties. Aerogels can be applied in various forms, such as boards or sprays, to effectively reduce thermal bridging effects and enhance overall thermal insulation efficiency. By incorporating aerogel insulation into prefabricated building components, designers can minimize heat loss or gain through walls, roofs, and floors, creating energy-efficient and comfortable indoor environments. Furthermore, graphene, with its unique two-dimensional structure, holds significant promise in the field of building insulation materials. Despite being a relatively new entrant, research has demonstrated that incorporating small amounts of graphene into traditional insulation materials can significantly enhance their thermal conductivity and shielding effects. This innovation not only improves the thermal performance of prefabricated buildings but also contributes to sustainability efforts by reducing energy consumption and greenhouse gas emissions.The adoption of high-efficiency, energy-saving insulation materials represents a crucial step towards sustainable development in architectural design. Beyond their outstanding physical properties, these materials also offer benefits in terms of environmental impact, lifecycle costs, and recyclability or biodegradability. By prioritizing the use of such materials in prefabricated construction, designers can contribute to creating buildings that are not only energy-efficient and comfortable but also environmentally responsible and economically viable in the long term.In conclusion, the use of effective insulation materials is essential for enhancing the thermal performance and energy efficiency of prefabricated buildings. Vacuum insulation, aerogel, graphene, and other advanced materials offer innovative solutions for achieving superior thermal insulation, reducing energy consumption, and promoting sustainable architectural design practices. By leveraging these materials, designers can create built environments that prioritize occupant comfort, environmental stewardship, and long-term economic viability [4].

3.2. Enhanced Insulation Design

Enhancing the thermal design of prefabricated buildings involves material selection, structural optimization, detail processing, and their coordination with the overall energy efficiency strategy of the building. In practical application, it is essential to start from the material level, choosing insulation materials with high thermal resistance and low thermal conductivity such as expanded polystyrene foam (EPS), extruded polystyrene board (XPS), and polyurethane foam, which are the preferred materials for improving the thermal performance of the external walls. Next, at the structural level, implementing a double-layer wall or composite wall structure with a well-designed insulation layer can effectively reduce the formation of thermal bridges and further enhance the insulation effect by utilizing the insulation properties of the air layer[5]. For example, the external wall can be composed inwardly of the structural layer, insulation layer, air layer, and decorative layer. The air layer is not simply a gap that adds to the cost, but a crucial thermal resistance layer that also facilitates future maintenance and repair. The detailed processing of prefabricated buildings should not be overlooked. For areas prone to thermal bridging such as door and window openings and wall joints, efficient heat insulation strips and sealing materials should be applied to prevent unnecessary heat loss while maintaining the integrity and airtightness of the building envelope. Particularly in window selection, using double or triple glazed windows with inert gas in the air gap to reduce heat conduction, along with low-emissivity coatings to minimize heat transfer through radiation, is advisable. Thermal design is closely related to the overall energy efficiency strategy of the building; hence, considerations such as building orientation, window-to-wall ratio, shading devices, and natural ventilation should be integrated at the early design stage to maximize the utilization of natural resources and reduce energy consumption. Through detailed thermal simulation analysis, predicting and optimizing the thermal performance of the building envelope early in the design process ensures a stable and comfortable indoor environment throughout different seasons and times. Ultimately, the strategy of enhancing thermal design in prefabricated buildings is a complex process that requires the integration of multidisciplinary knowledge and expertise. It demands forward-thinking from architects, technical innovation, and a relentless pursuit of detail. Each optimization step challenges traditional building practices and contributes to the sustainable development of prefabricated buildings. This approach not only significantly improves the energy performance of the building but also creates a more comfortable living and working environment with lower energy consumption.

3.3. Maintain Good Building Insulation

Maintaining excellent thermal insulation performance in prefabricated building design requires meticulous attention to detail across various aspects of construction. Windows, being a crucial component affecting thermal insulation, necessitate careful consideration in both material selection and design. Opting for double glazing with low-emissivity coatings and implementing effective window frame sealing techniques are fundamental steps to enhance the thermal insulation of windows. These measures not only minimize energy loss but also contribute to improving overall energy efficiency within the building. Moreover, rational window orientation and size design play pivotal roles in enhancing thermal stability. Strategic placement of windows can optimize natural light utilization, thereby reducing the reliance on artificial lighting and mitigating cooling loads. By minimizing direct sunlight exposure, designers can further regulate indoor temperatures, ensuring a more comfortable environment for occupants while reducing energy consumption. In addition to window considerations, the thermal inertia properties of exterior wall materials are equally important. Materials with high thermal inertia, such as concrete and stone, possess the ability to absorb heat during the day and release it at night. This process helps to mitigate fluctuations in indoor temperature, thereby promoting a more stable thermal environment, especially in regions with significant temperature variations. Furthermore, optimizing spatial layout contributes significantly to improving building thermal insulation performance. Thoughtful space planning, including the strategic placement of internal partitions and furniture layout, can create effective thermal zones within the building. For instance, positioning less frequently used spaces like storage rooms or corridors on the periphery of the building acts as an additional thermal barrier, reducing heat loss in primary living areas and enhancing overall thermal stability. Ultimately, maintaining good thermal insulation performance in prefabricated building design transcends technical considerations—it embodies a holistic design philosophy that integrates thermal insulation with energy-saving principles at every stage of the design process. By carefully considering factors such as material selection, structural design, and spatial arrangement, designers can create environmentally friendly and comfortable prefabricated buildings that serve as effective solutions to address climate change and energy crises. In conclusion, achieving excellent thermal insulation performance in prefabricated building design requires a multifaceted approach that encompasses various design considerations. By prioritizing factors such as window design, thermal inertia properties of materials, and spatial layout optimization, designers can create buildings that are not only energy-efficient but also comfortable and sustainable, contributing to the global efforts to combat climate change and address energy challenges[6].

3.4. Supplementary Indoor Environmental Conditioning Systems

Supplementary indoor environmental conditioning systems play a pivotal role in ensuring optimal comfort and health within buildings by controlling factors such as temperature, humidity, and air quality. These systems utilize advanced technological mechanisms to achieve either automatic or manual regulation, catering to the diverse needs of occupants in residential, commercial, and industrial settings. In the context of prefabricated multi-layer facade structures, the implementation of an efficient indoor environmental control system necessitates careful consideration of integration and compatibility. Given the unique characteristics of prefabricated components, system design must address interface and installation integration from the outset to avoid complexities and challenges during on-site deployment. By prioritizing seamless integration, designers can streamline the installation process and minimize the need for extensive adjustments post-construction, ensuring optimal system performance from the outset. An indispensable component of an efficient indoor environmental control system is an advanced energy management system. This system operates intelligently, leveraging data collected through sensors to analyze indoor and outdoor environmental conditions. By optimizing energy usage based on real-time data, the system effectively reduces energy waste while maintaining suitable indoor temperatures. This not only enhances energy efficiency but also contributes to cost savings and environmental sustainability. Modern control strategies often incorporate zone control functionality, allowing for independent adjustment of different areas within the building. This approach enables personalized temperature and humidity settings tailored to individual preferences, thereby enhancing overall occupant satisfaction. For example, heating and cooling supply can be optimized based on occupancy patterns, with reduced energy consumption in unused areas while maintaining comfort levels in frequently occupied spaces. Given the space and weight limitations inherent in prefabricated structures, the selection of lightweight, efficient, and space-efficient equipment is paramount. Manufacturers are increasingly focusing on developing compact designs for environmental control devices, facilitating easier installation and integration within prefabricated buildings. These advancements not only simplify the deployment process but also offer greater flexibility in terms of aesthetics and space utilization, contributing to the overall efficiency and functionality of the indoor environmental control system.In conclusion, supplementary indoor environmental conditioning systems represent a vital component of modern building design, ensuring optimal comfort, health, and energy efficiency within prefabricated structures. By prioritizing integration, energy management, and advanced control strategies, designers can create environments that prioritize occupant well-being while minimizing environmental impact and operational costs[7].

3.5. Advanced Building Envelope Technologies

Advanced building envelope technologies represent cutting-edge innovations aimed at enhancing the thermal performance and comfort of assembled buildings. These technologies leverage advanced materials, design principles, and engineering techniques to optimize energy efficiency, minimize heat loss, and create a more comfortable indoor environment. One such technology is the utilization of smart glass in building facades. Smart glass, also known as switchable glass, can dynamically adjust its transparency in response to external conditions such as sunlight intensity and temperature. By automatically modulating the amount of incoming solar radiation, smart glass helps regulate indoor temperatures, reduce glare, and minimize the need for mechanical cooling systems. This technology not only improves occupant comfort but also contributes to energy savings and sustainability. Another innovative approach involves the integration of phase change materials (PCMs) into building envelopes. PCM-based systems leverage the latent heat absorption and release properties of phase transitions to store and release thermal energy. By embedding PCMs within walls, ceilings, or floors, buildings can effectively buffer temperature fluctuations, maintain stable indoor temperatures, and reduce HVAC energy consumption. PCM technologies are particularly beneficial in climates with significant diurnal temperature variations, where they can help mitigate temperature swings and enhance occupant comfort. Furthermore, heat pump systems offer a sophisticated solution for enhancing building envelope performance. Heat pumps utilize thermodynamic principles to transfer heat from one location to another, effectively providing heating in winter and cooling in summer. Advanced heat pump systems, such as ground-source heat pumps (GSHPs) and air-source heat pumps (ASHPs), extract heat from the ground or outdoor air and deliver it indoors at higher temperatures during winter, or vice versa in summer. By leveraging renewable energy sources and advanced heat transfer mechanisms, heat pump systems offer highly efficient and environmentally friendly solutions for indoor thermal comfort control. In summary, advanced building envelope technologies represent promising avenues for improving indoor thermal comfort in assembled buildings. By incorporating smart glass, phase change materials, and heat pump systems into building design and construction, practitioners can create energy-efficient, sustainable, and comfortable indoor environments that meet the evolving needs of occupants and contribute to a greener future.

3.6. Rational Layout and Ventilation Design

The essence of rational layout and ventilation design refers to organizing spatial structure scientifically and planning air circulation paths inside and outside the building effectively during the design stage, in order to achieve the goal of controlling indoor temperature, reducing energy consumption, and promoting air quality. A rational layout optimizes indoor lighting and heat distribution, while ventilation design directly influences the freshness of air and thermal humidity balance, collectively creating a healthy and comfortable living environment. When implementing a rational layout, the orientation of the building and the layout of windows should be the primary considerations. Ideally, buildings should leverage the variations in natural light and heat distribution to minimize direct exposure to the sun from the west and east, thereby reducing the rise in indoor temperature resulting from excessive sunlight in the summer. For example, windows in living spaces and offices facing south can capture sufficient sunlight in the winter, while in the summer, appropriate shading facilities like sunshades or eaves can be designed to reduce direct heat entry. Optimizing the internal spatial layout is also necessary, such as using an open layout to enhance airflow or creating more efficient air circulation paths by installing partitions and air corridors. The key focus of ventilation design lies in creating effective natural ventilation and mechanical ventilation systems. Natural ventilation utilizes the pressure difference generated by wind and temperature differentials to drive fresh outdoor air into the interior while expelling stale indoor air outdoors. To achieve this, operable windows can be installed in different orientations of the building, such as east-west, to enable effective ventilation convection. In certain environments or seasons where natural ventilation may not meet comfort requirements, mechanical ventilation systems like exhaust fans and air conditioning systems need to be supplemented to regulate indoor air quality and temperature. To further enhance the thermal stability of the building, designers also need to consider the choice of building materials and their insulation performance. Using materials with high thermal inertia, such as concrete and stone, can absorb and store heat during the day and release it at night, thereby reducing the temperature difference between day and night and stabilizing indoor temperature. Additionally, incorporating insulation materials like rock wool or polyurethane foam into exterior walls and roofs can effectively prevent heat loss and reduce energy consumption[8].

4. Simulation and Modeling Techniques

4.1. Numerical Simulation Methods

Numerical simulation methods play a pivotal role in understanding and optimizing the thermal performance of buildings. These methods employ mathematical algorithms to solve complex equations that govern heat transfer, fluid dynamics, and radiative heat exchange within building structures. By accurately modeling these phenomena, engineers and architects can evaluate different design scenarios, predict indoor thermal conditions, and assess the effectiveness of various energy-saving strategies. Finite Element Method (FEM) is one of the most widely used numerical techniques in building thermal simulation. FEM divides the building into small, interconnected elements, allowing for the precise calculation of temperature distribution and heat flow throughout the structure. This method is particularly effective in analyzing complex geometries and heterogeneous materials commonly found in building envelopes. Another prominent numerical approach is the Finite Volume Method (FVM), which discretizes the building domain into control volumes. FVM focuses on conserving mass, momentum, and energy within each control volume, making it suitable for simulating fluid flow and heat transfer phenomena in HVAC (Heating, Ventilation, and Air Conditioning) systems. FVM is often employed to optimize airflow patterns, evaluate ventilation efficiency, and design energy-efficient HVAC systems. Additionally, Computational Fluid Dynamics (CFD) simulation offers a detailed analysis of airflow patterns, temperature distribution, and indoor air quality within building spaces. By solving the Navier-Stokes equations numerically, CFD can predict air movement, identify areas of stagnant air, and optimize natural ventilation strategies. This method is indispensable in assessing thermal comfort, indoor air quality, and energy performance in both residential and commercial buildings.Radiative heat transfer modeling is another crucial aspect of numerical simulation in building thermal analysis. This method quantifies the exchange of thermal radiation between building surfaces and evaluates the impact of solar radiation on indoor thermal conditions. Radiative heat transfer modeling aids in optimizing shading strategies, selecting glazing materials, and designing passive solar heating systems.In summary, numerical simulation methods offer powerful tools for architects, engineers, and researchers to analyze and optimize the thermal performance of buildings. By leveraging these techniques, practitioners can develop energy-efficient designs, improve occupant comfort, and mitigate the environmental impact of buildings [9].

4.2. Computational Fluid Dynamics (CFD) Simulation

Computational Fluid Dynamics (CFD) simulation is a sophisticated computational tool widely utilized in the analysis of airflow patterns, temperature distribution, and indoor air quality within built environments. By solving the governing equations of fluid flow and heat transfer numerically, CFD enables engineers and architects to gain insights into complex thermal phenomena and optimize building designs for enhanced occupant comfort and energy efficiency. One of the primary applications of CFD simulation is the evaluation of airflow patterns within buildings. By modeling the flow of air through ventilation systems, ductwork, and occupied spaces, CFD allows designers to identify areas of stagnant air, assess ventilation effectiveness, and optimize air distribution for improved indoor air quality. Furthermore, CFD analysis can help predict the dispersion of airborne contaminants, such as pollutants or pathogens, and inform strategies for mitigating indoor air pollution and maintaining a healthy indoor environment. Temperature distribution analysis is another key aspect of CFD simulation in building thermal design. By simulating heat transfer mechanisms, including conduction, convection, and radiation, CFD enables engineers to predict temperature gradients within building spaces and assess the effectiveness of heating, ventilation, and air conditioning (HVAC) systems. This information is crucial for optimizing HVAC system design, selecting appropriate heating and cooling strategies, and ensuring uniform thermal comfort throughout the building. Moreover, CFD simulation plays a critical role in optimizing natural ventilation strategies and passive cooling techniques. By modeling airflow patterns induced by wind, temperature differentials, and building geometry, CFD allows designers to evaluate the effectiveness of natural ventilation openings, such as windows, louvers, and vents, in facilitating airflow and reducing reliance on mechanical cooling systems. Additionally, CFD analysis can inform the design of passive cooling strategies, such as shading devices, building orientation, and thermal mass, to minimize solar heat gain and optimize thermal comfort in buildings. In summary, Computational Fluid Dynamics (CFD) simulation is a powerful tool for analyzing airflow, temperature distribution, and indoor air quality in built environments. By leveraging CFD techniques, designers can optimize building designs for improved occupant comfort, energy efficiency, and indoor environmental quality, ultimately creating healthier, more sustainable, and more comfortable indoor spaces[10].

4.3. Radiative Heat Transfer Modeling

Radiative heat transfer modeling constitutes a critical aspect of building thermal analysis, focusing on the exchange of thermal radiation between building surfaces and its impact on indoor thermal conditions. This modeling technique plays a pivotal role in optimizing building envelope design, selecting glazing materials, and designing passive solar heating systems. One of the primary applications of radiative heat transfer modeling is in evaluating the solar heat gain through windows and other transparent building elements. By simulating the interaction between solar radiation and glazing materials, designers can assess factors such as solar transmittance, reflectance, and absorptance to optimize daylighting strategies and minimize solar heat gain during the cooling season. Additionally, radiative heat transfer modeling facilitates the design of spectrally selective coatings and low-emissivity (low-E) glazing to enhance energy efficiency and thermal comfort in buildings. Furthermore, radiative heat transfer modeling aids in the design of passive solar heating systems, which harness solar radiation to provide space heating and reduce reliance on mechanical heating systems. By analyzing the absorption and distribution of solar radiation within building spaces, designers can optimize building orientation, glazing area, and thermal mass to maximize solar heat gain during the heating season while minimizing overheating during the cooling season. This approach not only improves energy efficiency but also enhances occupant comfort and reduces environmental impact. Moreover, radiative heat transfer modeling is instrumental in assessing the thermal performance of building surfaces and materials. By simulating the exchange of thermal radiation between building surfaces, designers can evaluate factors such as surface temperature, heat flux, and thermal comfort to optimize material selection and building envelope design. This information enables the selection of materials with appropriate thermal properties, surface coatings, and insulation levels to enhance energy efficiency and occupant comfort in buildings. In summary, radiative heat transfer modeling is a valuable tool for optimizing building envelope design, daylighting strategies, and passive solar heating systems. By leveraging this modeling technique, designers can enhance energy efficiency, thermal comfort, and environmental sustainability in buildings, ultimately creating healthier, more comfortable, and more sustainable indoor environments[11].

5. Discuss Limitations of the Study and Directions for Future Research

While this study provides valuable insights into the impact of assembled multi-story exterior wall structures on interior thermal stability, it is essential to acknowledge certain limitations that may affect the generalizability and comprehensiveness of the findings. Firstly, the scope of this study primarily focuses on theoretical analysis and conceptual frameworks rather than empirical data from real-world applications. While theoretical frameworks offer valuable insights, empirical research involving field studies and data collection from actual prefabricated buildings would provide a more comprehensive understanding of the factors influencing indoor thermal stability. Secondly, the study predominantly emphasizes the thermal aspects of assembled multi-story exterior wall structures, overlooking other critical factors such as acoustic insulation, structural integrity, and environmental sustainability. Future research endeavors should aim to adopt a more holistic approach that considers the interplay between various factors to provide comprehensive insights into the performance of prefabricated buildings. Additionally, the study primarily discusses the impact of exterior wall materials and structural design on indoor thermal stability, overlooking the influence of other building components such as roofing systems, flooring materials, and HVAC (Heating, Ventilation, and Air Conditioning) systems. Future research should explore the synergistic effects of these components on overall building performance and occupant comfort. Furthermore, the study does not delve deeply into the economic feasibility and practical implementation of various design strategies proposed for enhancing indoor thermal stability in prefabricated buildings. Future research should incorporate cost-benefit analyses and feasibility studies to provide practical guidelines for architects, engineers, and policymakers in the construction industry. In terms of future research directions, there is a need for longitudinal studies that assess the long-term performance and durability of assembled multi-story exterior wall structures in different climatic conditions. Moreover, comparative studies evaluating the performance of various design strategies and materials in real-world settings would facilitate evidence-based decision-making in the construction industry[12].Furthermore, with the rapid advancement of building technologies and materials, future research should explore innovative solutions such as smart building systems, phase change materials, and advanced insulation technologies to further enhance the thermal stability and energy efficiency of prefabricated buildings. In conclusion, while this study contributes valuable insights, addressing the aforementioned limitations and exploring these future research directions will enrich our understanding of assembled multi-story exterior wall structures' impact on interior thermal stability and pave the way for more sustainable and energy-efficient building practices.

6. Conclusion

Through studying the impact of prefabricated multi-layer exterior wall structures on indoor thermal stability, this article reveals the significance of optimizing design schemes. Utilizing efficient insulation materials, reinforcing thermal insulation design, maintaining good building insulation performance, supplementing indoor environmental control systems, and implementing rational layout and ventilation designs all serve as effective methods to enhance the indoor thermal stability of prefabricated buildings. Practice has proven that a profound understanding and application of these improvement measures are crucial for architects, designers, and construction teams. This not only requires a deep understanding of the characteristics of prefabricated buildings, but also the ability to flexibly adjust design strategies according to practical circumstances. In the future, with continuous technological advancements, it is believed that more innovative materials and design methods will emerge, further advancing the thermal stability of prefabricated buildings to a higher level. Researchers should continue to monitor the latest developments in this field, constantly explore and practice to achieve comprehensive improvements in the environmental adaptability, energy efficiency, and residential comfort of prefabricated buildings.

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