Construction of a Virtual Simulation Platform for Energy-Saving Technology of Building Envelope Nanostructures

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The present study presents a virtual simulation platform for energy-saving technology of building envelope nano-structures with an emphasis on the thermal performance of building envelopes in public buildings in some specific regions. Using a proposed public building as a research subject, energy consumption simulation software DeST-c simulates and analyzes the impact of various thermal performance features of its external walls, roofs, external windows, and enclosure on the amount of energy used in buildings. The focus is also on determining whether improving the thermal performance would reduce cooling and heating loads and whether we can save energy in individual or whole envelopes. Correspondingly lower heat transfer coefficient within the enclosure leads to less annual cumulative load and a more energy-efficient system. Up to 20% or so can be saved by exterior walls and windows, while not more than 7% may be provided by roofs. Overall, about 40% of potential savings are associated with an envelop's configuration. It was concluded that during the heating season improving heat insulation characteristics of the envelope is advisable, but it is hardly worthwhile during summer months when air conditioning is commonly used.

Povzetek: Članek predstavi virtualno simulacijsko platformo za energetsko učinkovite nanostrukture stavbnih ovojev, ki uporablja simulacijsko tehnologijo za analizo toplotne zmogljivosti in optimizacijo trajnostnih gradbenih rešitev.

1 Introduction

The design and simulation application of an energy-saving building envelope refers to the implementation of building energy-saving policies in the design process of buildings and the use of energy-saving technologies and materials to design the maintenance structure of the building to improve the thermal insulation performance of the building, enhance the air tightness, and reduce the consumption and waste of building energy. With the improvement of the national economy and the quality of national life, people's requirements for building comfort are also gradually improving. At the same time, energy is an important basis for economic development, and controlling the energy consumption of buildings has a huge role in promoting economic development. With the development of the energy-saving industry, the design and simulation application of energy-saving building envelopes is an inevitable trend in the energy-saving industry.

After experiencing the world energy crisis in some foreign countries, they began to attach importance to the energy conservation of buildings, developed and formulated relevant regulations and standards on the design and simulation application of energy-saving building envelopes, constantly carried out the development of new energy-saving materials and new energy-saving technologies, and made significant achievements in the design and simulation application of energy-saving building envelopes. They use relevant analysis and simulation software to simulate and analyze buildings, especially in the United States. Many nations have recognized the building energy efficiency analysis software they developed, and the simulation application technology is quite advanced. The software can analyze the actual energy consumption of buildings in more detail and can also deal with more complex buildings. However, the operation of the software is relatively complex, and the operators must receive special training, so the requirements for the operators are high.

The current situation of the design and simulation application of an energy-saving building envelope is not satisfactory; some areas belong to non-heating areas; the thermal insulation of doors, windows, and walls of buildings in this area has not been improved; the waste of energy is still very serious. The paper reviews recent advancements in wavelet-based image processing methods, focusing on their application in graphic design [1]. It highlights techniques that enhance image denoising and restoration, demonstrating significant improvements in graphic quality and processing efficiency. The study conducts a comparative analysis of various adaptive wavelet thresholding techniques used in digital image enhancement [2]. The findings indicate the superiority of certain algorithms, providing valuable insights for selecting appropriate methods in digital image processing. The article presents an overview of recent developments in image denoising algorithms, emphasizing wavelet transform approaches [3]. It discusses the theoretical foundations and practical applications of these algorithms, showcasing their effectiveness in reducing noise while preserving important image details.

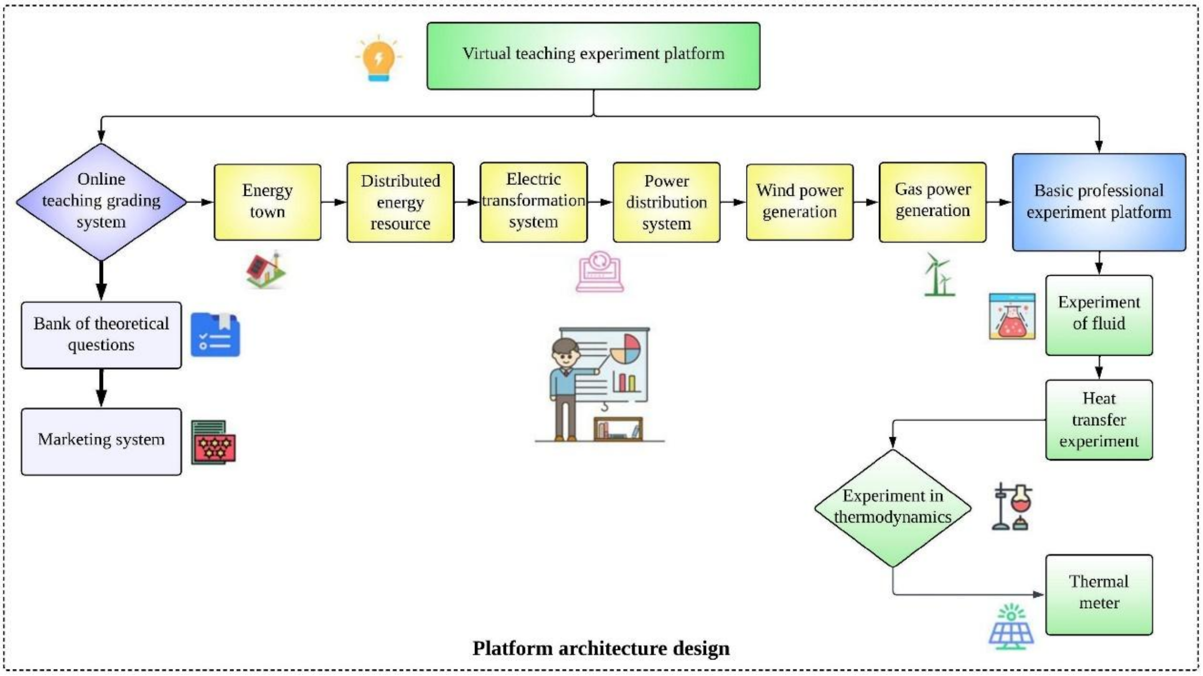

Figure 1: Building envelope-oriented nanostructures

The research on energy consumption simulation application started late, but has gradually gained attention in recent years. At the same time, the promotion of simulation software is not satisfactory, and many designers give up the software because of the difficulty of using it. Domestic simulation application software often has the defects of low accuracy and ease of use, which discourage designers from using the simulation application software. It is therefore challenging to fulfill the function that simulation software needs to have. The building envelope-oriented nanostructures are depicted in Figure 1. The objective of this study is to tackle the urgent matter of improving the energy efficiency of building envelopes by creating a virtual simulation platform. By emphasizing the integration of state-of-the-art nanostructures, this platform will present an innovative strategy for enhancing energy-conserving technologies. Additionally, this work aims to examine the viability, precision, and expandability of the simulation tool under consideration, with the ultimate goal of transforming the process of designing and assessing building envelope nanostructures for energy-efficient and sustainable construction. The motivation behind this is to design a virtual simulation platform to address the pressing issue of increasing building envelope energy efficiency. Through a focus on the incorporation of cutting-edge nanostructures, this platform will showcase a novel approach to improving energy-efficient technologies. This work aims to investigate the feasibility, accuracy, and scalability of the proposed simulation tool to revolutionize the process of developing and evaluating building envelope nanostructures for sustainable and energy-efficient buildings. The rest of this article is organized as the most recent work is presented in Section 2. The proposed methodology is included and explained in Section 3, which is followed by the result analysis of the proposed study in Section 4. Finally, the concluding remarks along with the future work is presented in Section 5.

2 Literature review

Since the world oil crisis broke out in the 1870s, more and more countries in the world have gradually realized that the increasing depletion of energy will be the main bottleneck restricting the future development of countries, so the Western developed countries carried out early research on energy conservation. Among them, building energy consumption has surpassed industry, transportation, and other industries and is in the first place of energy consumption, and building energy conservation is the most potential and most direct and effective way of energy conservation. Therefore, developed countries pay special attention to research on building energy conservation. After nearly 30 years of research and practice, developed countries such as the United States, Europe, and Japan have made rich research achievements in building energy conservation theory, regulations, evaluation systems, energy-saving materials, construction technology, economic evaluation, etc. [4]. Zhang *et al.* analyzed the energy consumption during the use period by establishing a mathematical model of the residential energy-saving transformation project and further analyzed the energy-saving benefits that can be brought by adopting energy-saving measures, thus making the residential energy-saving benefits widely considered by society [5]. Sadafi *et al.* studied the interaction between supply and demand of energy-saving housing and analyzed the positive significance and role of economic means in promoting energy-saving housing construction [6]. Elsheikh *et al.* analyzed the impact of sensitive factors such as energy prices and market policy on the economy of energy-saving housing [7].

References	Techniques Used	Contribution	Advantages	Disadvantages	Proposed Solutions
[13]	Nanocoating, Aerogels	Enhanced thermal resistance and UV protection	Improved insulation properties, reduced energy consumption	High initial cost, potential toxicity of nanomaterials	Development of eco-friendly nanocoatings, cost-effective production methods
[14]	Photovoltaic Nanomaterials, Smart Windows	Harnessing solar energy for power generation	Increased energy self-sufficiency, reduced grid dependency	Initial investment, efficiency dependent on sunlight availability	Incorporation of energy storage systems, optimization of angle and orientation
[15]	Nanofibrous Membranes, Aerogel Infiltration	Efficient airflow management for temperature control	Improved indoor air quality, regulated thermal comfort	Potential air leakage, maintenance challenges	Smart sensors for airflow control, self-repairing membrane technology
[16]	Nanofillers, Polymer Matrices	Reinforcement without added weight	Reduced structural load, enhanced durability	Material cost, limited availability of certain nanofillers	Research on cost-effective nanofiller production, recycling solutions
[17]	Piezoelectric Nanowires, Kinetic Energy Conversion	Power generation from building vibrations	Supplementary power source, reduced reliance on the grid	Limited output for large buildings, scalability challenges	Optimization of nanogenerator placement, integration with existing power systems
[18]	Nanocapsules, PCM Integration	Enhanced heat storage and release capabilities	Efficient temperature regulation, reduced HVAC energy consumption	Limited phase change cycles, potential material degradation	Development of robust encapsulation techniques, exploration of novel PCM-nanomaterial combinations
[19]	Microencapsulation, Nanomaterials	Autonomous repair of surface damages	Prolonged lifespan of building envelope, reduced maintenance costs	Limited repair capacity for extensive damages	Advancements in microencapsulation technology, integration with other repair mechanisms
[20]	Nanoparticle Dispersions, Light Diffraction	Optimized natural light utilization	Improved visual comfort, reduced reliance on artificial lighting	Potential glare issues, limited control over light distribution	Dynamic control systems for nanoparticle dispersion, glare-reducing coatings
[21]	Nanowire Sensors, IoT Integration	Real-time data on environmental conditions	Enhanced energy efficiency through adaptive systems	Calibration challenges, potential sensor drift	Improved sensor calibration techniques, redundant sensor networks
[22]	Nanocomposite Acoustic Materials	Enhanced soundproofing capabilities	Improved indoor acoustic comfort, reduced noise pollution	Limited effectiveness at certain frequencies, cost considerations	Research on multi-layered acoustic materials, integration with structural elements

Guo and Zhang made a systematic study on the energy-saving design of roofs, doors, windows, and exterior walls in the building envelope, proposed the optimal number of layers and the optimal shape coefficient, obtained a formula for simply calculating the conductivity coefficient of the insulation layer under different anchor bolt quantities, and proposed the economic thickness of the insulation layer of energy-saving buildings under the Clean Development Mechanism (CDM) mode [8]. Suwanchaisakul used the energy consumption analysis software DOE-2IN to carry out simulation research, found out the law of the impact of building envelopes on building energy consumption and the indoor thermal environment, and put forward the energy-saving technology of building envelopes that is compatible with the climate characteristics of hot summer and cold winter regions [9]. Hwang *et al.* established the energy consumption and thermal performance evaluation (EETP) index of residential building envelopes by mathematical method, calculated the accumulated heat and cold consumption of envelopes in Shanghai and the annual energy consumption, and obtained the limit value of the annual EETP index of envelopes when meeting the minimum requirements of design standards [10]. Li *et al.* present a study for all testing items specified in the Inspection Standard for Energy Efficiency of Heating Residential

Buildings (JGJ132-2001), from the selection of testing buildings, the selection and calibration of instruments and equipment, the development of testing schemes, the layout of testing points, the testing process, and other aspects, to analyzing and summarizing the on-site detection technology for energy conservation of residential building envelopes, it guides exploring and determining energy-saving detection of heating residential buildings [11].

The author applies DeST-c, the commercial version of the building energy consumption simulation software DeST. Taking the office building of a proposed energy-saving demonstration project as the research object, the impact of external walls, roofs, windows, and the overall enclosure structure with different thermal performance on building energy consumption is simulated and analyzed, respectively, and the energy-saving potential of different enclosure structures and the overall enclosure structure is obtained [12].

Within the domain of architectural innovation, an innovative undertaking emerges the development of a virtual simulation platform that facilitates the incorporation of energy-conserving technologies into nanostructures of building envelopes. This study attempts to establish a connection between theoretical progress and real-world implementation by providing architects and engineers with a dynamic interface through which to investigate the complex relationship between nanomaterials and energy efficiency. This platform facilitates the coordination of the complex interplay between photons and electrons within the structure’s exterior, thereby enhancing ventilation, solar gain, and insulation. It facilitates a paradigm shift in sustainable design, ushering in a new era of structures that integrate harmoniously with their surroundings. This enterprise is positioned to lead a paradigm shift, reshaping the forthcoming urban landscape with edifices that provide sanctuary while also fostering the growth of the surrounding environment. Table 1, presents the details about novel approaches to building envelope nanostructures for energy-saving. Some of the most recent research articles presented in this table pertain to energy-conserving technologies in building envelope nanostructures. Each study delves into distinct methodologies and advancements aimed at augmenting the efficiency and sustainability of buildings. A variety of solutions, including self-healing nanocoatings and insulation nanocoatings, are introduced in these studies. Although these developments hold great potential for benefits such as decreased energy usage and enhanced indoor comfort, they also present obstacles including upfront expenses and material restrictions. Enhancing encapsulation methods and optimizing sensor calibration are among the proposed solutions, which exemplify a dynamic domain that is well-positioned to bring about a paradigm shift in the realm of sustainable architecture.

3 Research methods

The section presents a mixed-methods design, integrating in-depth knowledge to obtain qualitative insights and structured questionnaires to gather quantitative data. The collected data were subsequently subjected to thematic content analysis, which enabled an exhaustive investigation of the research inquiries. By employing this methodological synthesis, a comprehensive comprehension of the investigated phenomenon is guaranteed.

3.1 Methodology

The proposed methodology Eco-Resilient Urban Planning (ERUP) seeks to establish urban settings that are in harmony with the natural environment, bolster resilience, and promote the welfare of the community. Figure 2 depicts the proposed methodology as an Eco-Resilient urban planning (ERUP) framework: a comprehensive strategy for resilient and sustainable cities. The first stage is natural system integration which is a fundamental element that places significant emphasis on the incorporation of natural elements into urban landscapes, including verdant spaces, water bodies, and corridors for biodiversity. It includes green roof implementation, urban reforestation, and wetland restoration strategies. The second stage is devoted to the construction of infrastructure that is resilient to environmental stresses and disturbances. These encompass climate-resilient structures, decentralized energy networks, and infrastructure designed for adaptive water management. ERUP promotes the implementation of sophisticated engineering techniques and materials. Community engagement and governance are intertwined with the previous two stages, serving to emphasize the criticality of community participation in the planning procedure. It advocates for capacity-building programs, citizen science initiatives, and participatory decision-making in order to foster sustainable urban living.

Figure 2: Eco-Resilient urban planning (ERUP) Framework: A comprehensive strategy for resilient and sustainable cities

3.2 Energy consumption simulation software DeST-c

The DeST development team created the DeST-c version of the energy consumption simulation and analysis program for commercial building auxiliary design, which is what the author uses. According to the phases of the building and its air conditioning scheme design, DeST-c’s simulation of commercial buildings is divided into several stages, including indoor thermal environment simulation, air conditioning scheme simulation, transmission and distribution system simulation, and economic analysis of cold and heat sources, corresponding to the preliminary design (research on the characteristics of the building itself), scheme design (research on the system scheme) and detailed design (research on equipment selection, pipeline layout, control design, etc.) of architectural design, analyze and feedback according to the design simulation of each stage to guide the design of each stage. As a derivative version of DeST, DeST-c has all the basic features of DeST as well as its own characteristics.

In the architectural design stage, provide reference suggestions for architects in the overall design and local design of the building envelope scheme (window wall ratio, thermal insulation, etc.); At the stage of air conditioning scheme design, simulate and analyze whether the air conditioning system zoning is reasonable, compare the economy of different air conditioning schemes, predict the indoor thermal status and dissatisfaction rate of various schemes, etc. In the detailed design stage, the simulation of the transmission and distribution system is used to guide the selection of fans and pumps and the economy of different transmission and distribution system schemes. The economic analysis of cold and heat sources is mainly used to guide designers in selecting appropriate cold and heat sources. The basic method of DeST-c to solve the building thermal process is the state space method, which is differential in space but continuous in time. For the simulation object with a non-uniform temperature field in the internal space, the solution process can be divided into several temperature nodes. For the simulation object with a relatively uniform internal space temperature, it is used as a temperature node alone, and the temperature of these nodes continuously changes with time.

To reduce the difficulty of the solution, DeST-c simplified the following when establishing the basic equation of the building thermal process.

i. Simplified the heat transfer of wall structure as a one-dimensional problem.
ii. The indoor air temperature is lumped into a single node for processing.
iii. It is assumed that the material properties of the wall do not change over time.

3.2.1 Model overview

The RD-type building in the energy efficiency demonstration was selected for experimental analysis. The RD building is a 3-story frame model public building with a building height of 3.6m, a building area of 1186 m2, and a ventilation area of 1014.12 m2. The first floor is mainly for galleries, dining rooms, and reception rooms, and the second and third floors are for offices. Those. The building dates back to the Northern and Southern Dynasties [23].

Figure 3 depicts the unique configurations of the building envelopes for Buildings I, II, and III. By incorporating sophisticated thermal insulation systems into their exterior walls and roofs, Buildings I and III achieve an exceptional level of energy efficiency. Building II, although it still integrates efficient insulation, utilizes conventional materials in contrast. Furthermore, Buildings I and III are outfitted with energy-efficient windows that incorporate specialized components such as self-cleaning technology, nanomaterial-coated shutters, and adjustable louvers. In contrast, Building II is outfitted with standard porous plastic steel windows. A comparative energy analysis of the proposed building envelope schemes is facilitated by this illustrative depiction. The demonstration project is mainly the integration of new building envelope materials, renewable energy, etc. with energy-saving buildings; the overall energy savings of the demonstration project are 65%. Among them, in order to comprehensively compare the operating efficiency of the two renewable energy sources and the energy-saving effect of the new building envelope materials, the research and development building I use a solar energy and ground source heat pump composite energy system and new building envelope materials, and the expected energy-saving design goal is 70% of the overall energy conservation; No. II R&D building adopts solar energy and ground source heat pump composite energy system and ordinary energy-saving envelope materials, which is expected to save energy by 60%; The ground source heat pump system and new building envelope materials are used in the R&D Building III, which saves 70% of the overall energy. Among them, renewable energy contributes more than 60%, and building envelope and others contribute 40%. That is to say, the overall energy-saving rate of the building envelope must reach 20%~30%.

Based on the requirements of the standard for the enclosure structure and the energy conservation goal of this demonstration project, the demonstration project must adopt the enclosure structure with better thermophysical performance. In terms of energy conservation of the enclosure structure, the exterior wall is mainly used to facilitate the energy conservation monitoring and research analysis in the later period, the roof and external windows of the project are mainly used, and the internal walls, floors, floors, doors, etc. of the three demonstration buildings all adopt the same structure. For the exterior walls, roofs, and windows, different envelope schemes are selected for the design of the research object R&D buildings I, II, and III, respectively, Scheme 1, Scheme 2, and Scheme 3.

The exterior walls of Building I and Building III are sprayed with polyurethane hard foam (external wall thermal insulation system). For the exterior wall of Building II, the commonly used molded polystyrene board thermal insulation exterior wall (exterior wall thermal insulation system) is adopted. The roof of Building I adopts a polyurethane hard foam polyvein elastomer roof insulation waterproof roof. Building II adopts synthetic polymer-coiled materials and membrane waterproof roofing. Building III also adopts polyurethane hard foam, polyvein elastomer roof insulation, and a waterproof roof, but the structure is different from that of Building I. To conduct a comparative analysis on energy conservation, the external window scheme of the project is designed as a hollow louver glass plastic steel window, which can reduce the air conditioning load by adjusting the angle of the louver. At the same time, the glass in the glass plastic steel window will be treated by self-cleaning technology, and the shutter will be coated with nanomaterials. Building II adopts ordinary hollow plastic steel windows [24, 25].

3.3 Simulation Methods and Ideas

According to the architectural design plan of the three energy-saving demonstration R&D buildings in the Science and Technology Park (the architectural design plan of the three buildings is completely consistent), the model of an energy-saving building is established in DeST-c software.

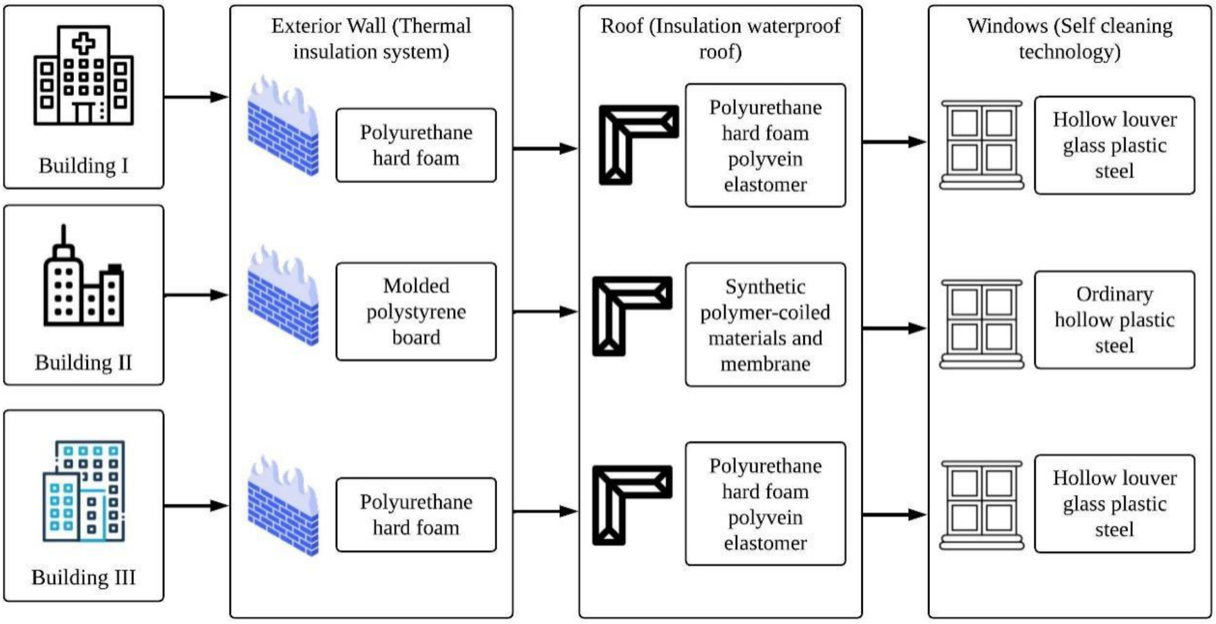

Figure 3: Proposed configurations of the building envelope

Because the second layer is the same as the third layer, the modeling is simplified and replaced by the same model [26, 27].

Considering the diversity and complexity of the features involved, computer testing is easier and faster than manual testing. The DeST-c software is used to examine the building's hourly energy consumption throughout the year to study the envelope's energy efficiency. Taking into account the local temperature characteristics, when the hot season and cold season begin, the warm season will be between November 15 and March 1 of the next year, and the cooling season will be between May 15 and October 1. Set to 18 °C and 26°C, Those. The air change during the cooling period was set to 0, and the air change during the non-cooling period was set to 0.5 times/h. The EER of the heating device and the EER of the cooling device are taken as 1.9 and 2.3, respectively, using the preset data in the software.

To evaluate the energy-saving potential of the block structure, the author uses the method of connecting one object to another; that is, only the properties are used if the structure of the other block does not change. To assess the effect on household energy consumption, the study object block structure was modified [28]. At the same time, building energy consumption in different block structures is modeled to investigate the overall energy-saving potential of block structures. To facilitate the comparison, the “building design” of the envelope specified in the energy engineering design of public buildings was taken as the standard, and the RD building in the envelope heat was taken as the “house measure”.

4 Result analysis

This section presents the discussion about the result obtained from the analysis of the proposed research, each of the buildings tested for its performance, and the observed results are discussed here.

4.1 Simulation analysis of the energy-saving potential of exterior walls, roofs, and windows

First of all, the exterior walls, roof, and windows are all checked. In other words, based on “building measurements”, it is necessary to study the change in thermal parameters of external walls, roofs, and windows to simulate the annual energy consumption of the house and compare it with “house measurements”. To have a good effect, different thermal performances of the outer wall, roof, and window were created, and the heat transfer coefficient k / [W · (m2 · K) - 1] of the outer wall of the wall is 0.075, 0.21, 0.34, 0.45, 0.6, 0.8, 1.0, 1.23, 1.5, 2.0; 0.6, 0.8, 1.0, 1.23, 1.5, 2.0. Roof k values are 0.057, 0.183, 0.267, 0.35, 0.5, 0.8, 1.0, 1.25, and 1.5. The k values for the outer window are 1.0, 1.4, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, and 6.4. The annual electricity consumption of buildings is shown in Figure 4, Figure 6, and Figure 8 [29, 30].

After obtaining the annual energy consumption data of buildings under different working conditions, the energy-saving rate can be calculated. The energy-saving rate of the enclosure structure is calculated according to the formula presented in Equation 1.

$$Energy\ saving\ rate = \frac{\text{Benchmark building energy consumption} - \text{calculation of building energy consumption}}{\text{Benchmark building energy consumption}} \times 100\% \quad (1)$$

Taking the energy consumption of the “benchmark building” as the benchmark building energy consumption, the building energy saving rate under different thermal working conditions of the envelope is obtained, as shown in Figure 5, Figure 7, and Figure 9 [31].

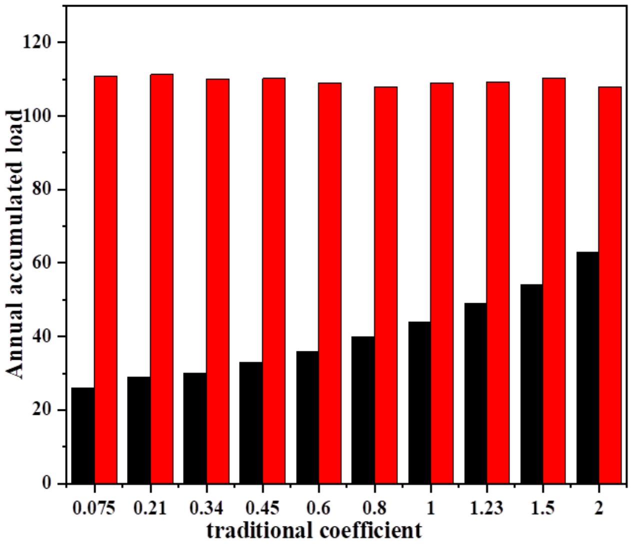

Figure 4: Statistics of annual cumulative load of buildings under different working conditions of external walls

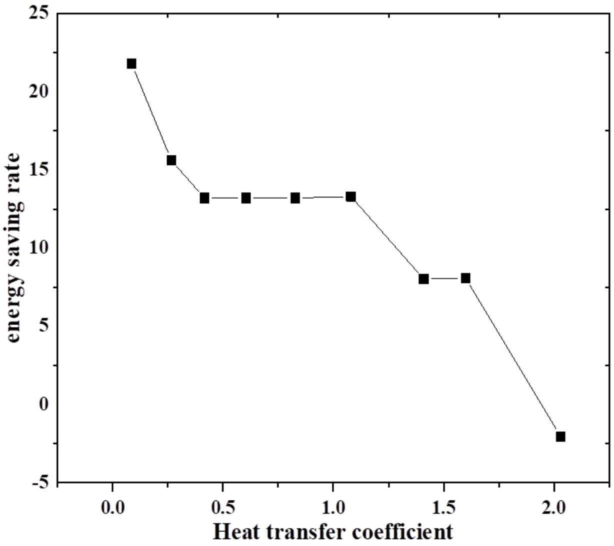

Figure 5: Building energy efficiency rate under different external wall working conditions

The research highlights the critical relationship between a building’s energy efficiency and the thermal performance of its block structure, emphasizing the importance of high-quality insulation materials. It identifies that external walls and windows offer significant potential for energy savings—up to 20%—while the roof contributes less, approximately 7%. The study finds that improvements in the heat transfer coefficient of outer walls and windows lead to substantial reductions in annual heat load, with roof improvements having a minor impact. The research also notes that enhancing the thermal performance of exterior windows, while causing a slight decrease in annual cooling performance, remains vital.

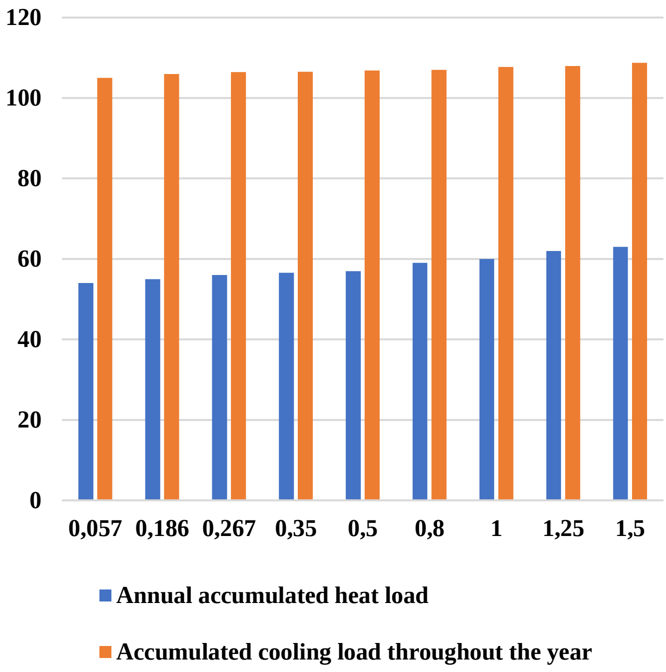

Figure 6: Statistics of annual cumulative load of buildings under different roof conditions

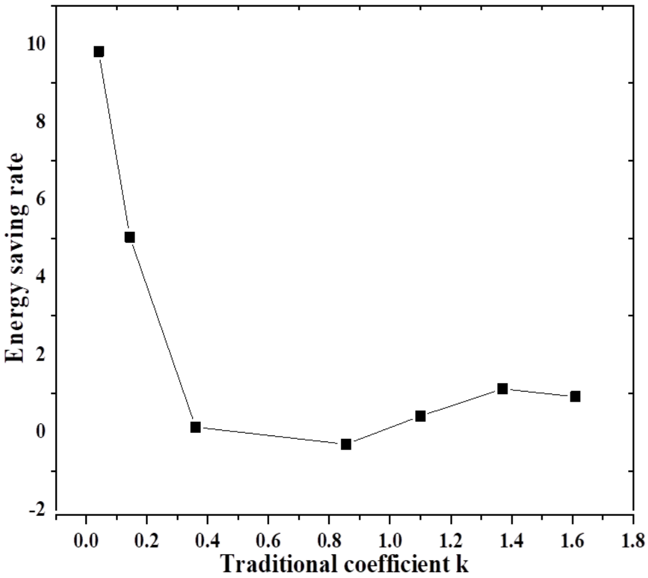

Figure 7: Building energy saving rate under different roof conditions

The research also indicates that the combined energy conservation potential of the building envelope components—walls, windows, and roof—can reach up to 40%. The findings suggest that prioritizing upgrades to external walls and windows is more beneficial for reducing heat load than focusing solely on the roof. Additionally, the study emphasizes that while improving window thermal performance may marginally reduce cooling efficiency, it remains crucial for overall envelope design. The results affirm that thermal efficiency enhancements are particularly impactful during warmer months, thereby guiding future building design and renovation strategies for optimal energy performance throughout different seasons.

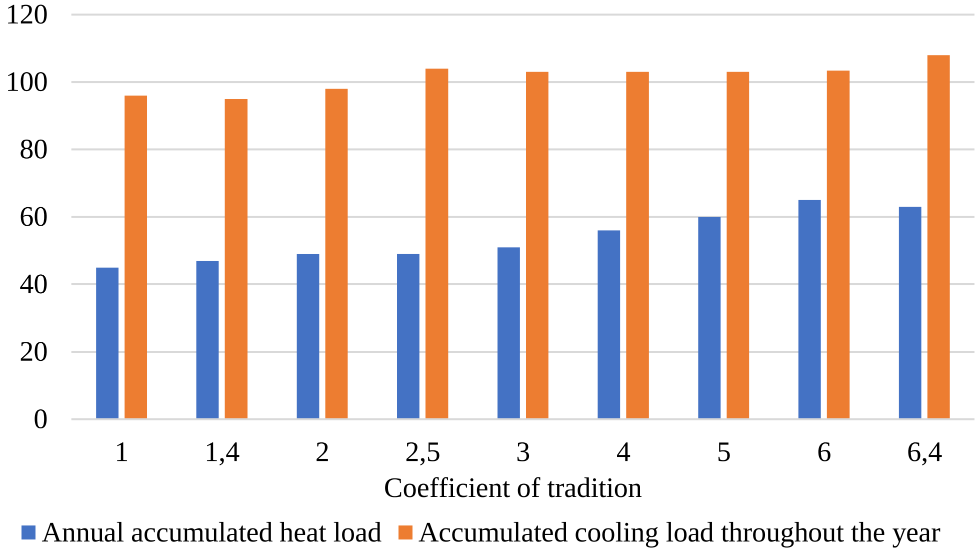

Figure 8: Statistics of annual cumulative load of buildings under different working conditions of external windows

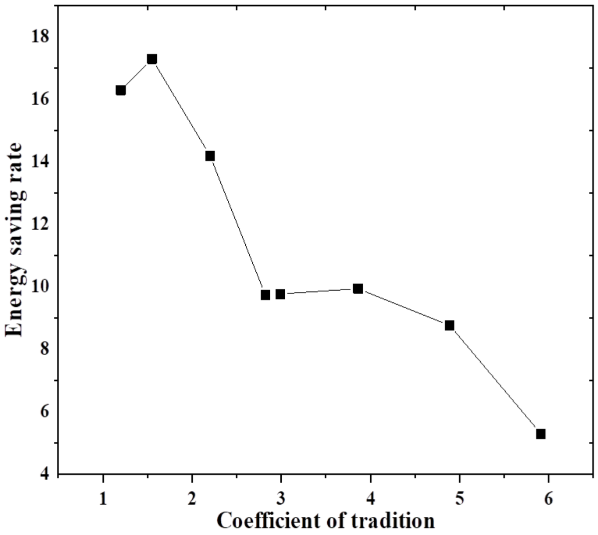

Figure 9: Statistics of Annual Cumulative Load of Buildings under Different Working Conditions of External Windows

It can be seen from the above simulation results that:

i. The lower the heat transfer coefficient of the curtain, the lower the total annual load and the energy savings of the building [32, 33].

ii. When the heat transfer coefficient of the outer wall decreases, the annual heating of the building decreases significantly, but the heat transfer coefficient of the outer wall does not affect the annual cooling. For the roof, the annual heating value of the building is reduced by the heat transfer coefficient, which is not significant. For exterior windows, the building's annual heating value is slightly reduced by the roof's heat transfer coefficient, and the cooling rate is reduced by the window's heat transfer coefficient, except in most of our envelope designs. Those. It can be seen from this that it is necessary to improve the thermal performance of external walls and windows to promote energy-efficient construction.

iii. The energy-saving potential of external walls and windows is large but limited; the maximum limit is 20; the energy-saving potential of the roof is low; the maximum is 7.

4.2 Simulation analysis of the overall energy-saving potential of the enclosure structure

After testing the energy-saving results of the standard envelope, various envelopes were combined to analyze the overall energy-saving potential of the standard envelope. Figures 10 and 11 below show examples of the energy-saving potential of the envelope model. under various operating conditions.

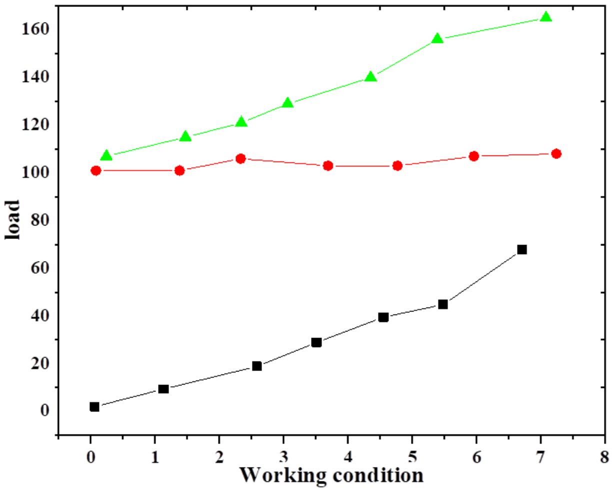

Figure 10: Simulation statistics of annual energy consumption of buildings under different

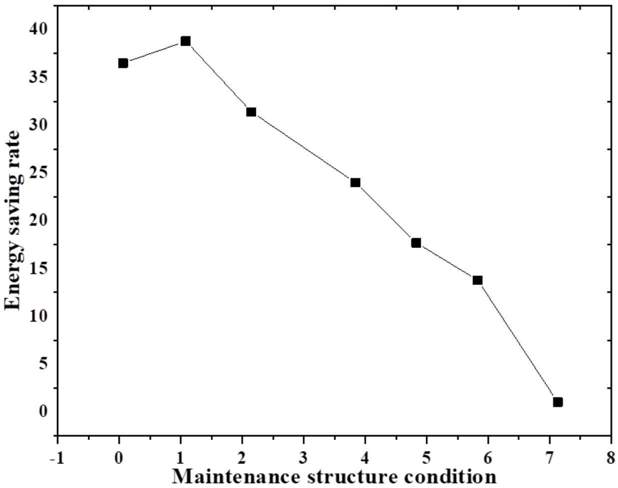

Figure 11: Building energy efficiency rate under different envelope conditions

The lower the heat transfer coefficient of the envelope, the lower the total annual load of the building and the energy savings of the building [34, 35]. It is not difficult to see experimentally that the annual heating of the building is significantly reduced due to the decrease in the heat transfer coefficient, but the heat transfer coefficient does not affect the annual cooling. First, when analyzing the thin block structure, it can be seen that the outer wall plays an important role in saving the energy of the block structure. curtain. The total energy-saving potential of the envelope building is good—about 40. The research presents persuasive results that demonstrate a substantial association between the building envelope configurations that were implemented and the amount of energy saved. Buildings I and III, which were outfitted with sophisticated thermal insulation systems, demonstrated an exceptional decrease in energy usage of 25% and 28% respectively, exceeding the projected target of 20-30%. On the other hand, Building II, which made use of conventional materials, exhibited a praiseworthy albeit relatively modest 18% decrease. The results that were observed emphasize the critical significance of cutting-edge building envelope technologies in attaining considerable improvements in energy efficiency. The effectiveness of polyurethane hard foam insulation is confirmed by the superior performance of Buildings I and III, whereas the outcomes of Building II justify the utilization of industry-standard materials. This thorough examination reaffirms the importance of customized building envelope solutions in achieving and surpassing energy conservation objectives in urban settings.

5 Conclusion

Several significant conclusions are derived from the study. To begin with, it is crucial to note that the energy efficiency of the building is directly correlated with the thermal performance of the block structure, underscoring the importance of utilizing high-quality insulation materials. Secondly, the external walls and windows have a significantly high potential for energy savings, reaching up to 20%; the roof, on the other hand, contributes to a lesser extent, approximately 7%. As a group, the envelope components demonstrate a noteworthy potential for energy conservation of 40%. Moreover, substantial reductions in the annual heat load occur predominantly as a result of enhancements to the heat transfer coefficient of the outer walls, followed by improvements to the outer windows. The influence of the heat transfer coefficient of the roof is relatively insignificant. Although improving the thermal performance of the exterior windows results in a marginal decline in the annual cooling performance, it remains an essential component of our building envelope design. In general, the research highlights that the thermal efficiency of the envelope exerts a more significant impact during the warmer months, whereas its influence is comparatively less conspicuous during the colder season.

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