APPLICATION OF NEW NANOPOLYMER MATERIALS IN INTELLIGENT THERMAL INSULATION SYSTEM FOR BUILDING EXTERNAL WALLS

by

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In response to the current problem of poor energy consumption control effect and overall high energy consumption of new nanopolymer materials for building exterior walls, the author proposes a thermal insulation energy consumption control technology based on the heat transfer performance model of exterior wall insulation panels. Calculate the current heat transfer performance parameters of exterior wall insulation panels using the reaction coefficient method, determine the proportional relationship between the effective heat transfer coefficients, and establish a heat transfer performance model for exterior wall insulation panels, based on the thermal conductivity index of the new nanopolymer material for the wall, the current control parameters are optimized. The optimal data algorithm is used to obtain the energy consumption decision variable value of the new nanopolymer material for the exterior wall of the building under the condition of clarifying the current heat transfer coefficient, and establish constraint conditions, based on the specific energy consumption data of new nanopolymer materials outside the current wall, establish the current thermal energy information transmission ratio relationship, analyze the current wall energy consumption hotspots, propose the K-means clustering analysis strategy, and apply it to the hot spot clustering control. Energy consumption control is achieved by locating the main cluster head parameters of the hot spot. Simulation results show that the hot spot fit of the aforementioned control methods has been improved by 29%, and the accuracy of the design method in cooling load control statistics is significantly higher than the two traditional methods used for comparison. Due to different weights, the final improvement ratio is determined to be 27%, further verifying the hypothesis. It has been proven that it can effectively improve the energy consumption control effect.

Key words: *thermal insulation, heat transfer, cooling load, new nanopolymer materials*

Introduction

External wall insulation is one of the main measures for energy-saving buildings, and the leakage of cracks in external wall insulation is a serious quality common problem in insulation buildings. Cracking resistance and water seepage prevention are one of the key technologies to be solved in wall insulation systems. Because once the insulation layer and protective layer crack, the insulation performance of the wall will undergo significant changes, which not only cannot meet the design energy-saving requirements, but also affects the service life of the

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wall. The existence of cracks and leaks in insulation walls reduces the quality of the walls, such as insulation, integrity, and durability. After the commercialization of housing, there have been more and more disputes or lawsuits about living environment and building quality issues, as well as cracks and leaks in insulation walls. Building cracks have become a very intuitive and sensitive issue and the primary quality requirement for evaluating building safety, especially in rainy and humid environments in the south.

The waterproof layer of the insulation wall is exposed to nature, corroded by exposure to freezing snow and rain, and affected by changes in drying and moisture expansion. At the same time, most of the insulation materials are porous water absorbing materials. In addition, the materials are suboptimal, the construction is not standardized, and the design is unreasonable. Many factors are the reasons for cracks and leakage [1]. Therefore, without excellent crack resistant and waterproof materials, it is difficult to meet the long-term requirements. At present, building energy-saving exterior wall insulation materials are divided into organic insulation materials (polyurethane foam, polystyrene foam, polymerized phenolic resin foam, *etc.*) and inorganic insulation materials (loose inorganic fibers and products, porous lightweight particle insulation mortar, fiber + porous particle hybrid insulation materials). Organic insulation materials have low thermal conductivity and good insulation effect, but poor fire safety. Ordinary inorganic insulation materials have a high thermal conductivity and poor insulation effect, but have good fire safety. Inorganic nanoporous insulation materials have low thermal conductivity and good high temperature resistance, and are commonly used as space insulation materials. Transforming high tech space insulation materials into civilian use and developing a thin layer, thermal insulation coating is an important way for the future development of insulation material technology [2].

Literature review

Nanomaterials refer to materials that have at least one dimension in the 3-D space at nanometer size (1-100 nm) or are composed of them as basic units, including nanoparticles, nanofibers, nanocoats, nanocomposites, *etc.* Nanomaterials have different physical and chemical properties from conventional materials and have been well applied in fields such as environmental protection and energy conservation. Concrete is one of the important materials in construction engineering, and the demand is very high. Various engineering projects have increasingly high functional requirements for concrete strength, durability, and permeability resistance. The main problem faced by concrete engineering is the contradiction between the continuous new requirements for concrete raw materials and concrete engineering, and the insufficient improvement of existing additives and application technologies in concrete. The quality and performance of traditional concrete can no longer meet the needs of today's engineering construction. Improving the performance of traditional concrete using high tech has become an important research direction in the construction and scientific research communities [3]. According to relevant research, adding nanomaterials to concrete can significantly improve its performance. The hardened cement paste is a heterogeneous heterogeneous system, which is composed of various hydration products such as hydrated calcium silicate gel, residual clinker, and many capillary micropores. The hydrated calcium silicate gel accounts for more than 70% of the volume of cement paste, and its particle size belongs to the nanometer scale, therefore, cement hardened paste is a kind of nanocomposite material with hydrated calcium silicate gel as the main body, and the micro-structure of cement hardened paste is very rough. Nanomaterials cannot only fill the voids of cement paste, but also chemically react with calcium hydroxide in cement paste to generate hydrated calcium silicate gel, thus improving the strength and durability of concrete. Wang and Wang [4] analyzed composite walls with cavities as the research object. The simulation shows that when the cavity thickness is 20 mm and 30 mm, the heat transfer coefficients of the air sandwich wall are 1.3 and 1.29, respectively. Therefore, the optimal width of the cavity is 20 mm, and the most suitable material is aerated concrete blocks. In addition, a comparative analysis was conducted on the cavity temperature under different conditions. Practice has proven that intelligent environmental control systems can significantly improve thermal efficiency, providing a solid theoretical basis for further research on external insulation of prefabricated buildings. Zhao *et al.* [5] evaluated the effectiveness of the intelligent blind system in annual energy conservation in Canada. Intelligent blind systems controlled by the IoT or other artificial intelligence (AI) technologies are considered a solution save energy by blocking solar radiation during summer and minimizing unnecessary artificial lighting use through dimming control. It can also almost block the incoming beam of sunlight by tilting the shutter angle, thereby improving the visual comfort of passengers. A simulated sample office was established in OpenStudio and five different intelligent shading control strategies were analyzed. Evaluated factors that affect the performance of louvers, such as slat reflectivity and slat angle control methods. The results indicate that triggering intelligent louvers by indoor temperature settings can significantly reduce annual energy consumption. Compared to traditional uncontrolled manual Venetian blinds, the energy-saving potential can reach 9.3%. Yi *et al.* [6] established a building load optimization scheduling system model that considers the demands of the power grid and customer sides, with the optimization objectives of the total electricity cost and total electricity deviation of building residents. Then, a multi-objective equilibrium optimization algorithm – integrated competition mechanism (CMOEO) was proposed to solve the multi-objective optimization scheduling problem of building loads with multiple decision variables. This algorithm has been improved on the basis of the balanced optimization algorithm, introducing a competition mechanism, replacing the original exploration and development constant coefficients with dynamic factors, and integrating differential evolution.

At present, the research on nanomaterials is in full swing in the scientific community, but the application of nanomaterials in the industrial sector is limited by the drawbacks of high prices. In practical applications, the aforementioned methods have not significantly improved the energy-saving and heat transfer performance of building exterior walls and energy consumption control. After control optimization, the energy consumption is still huge. Therefore, a new heat transfer model for the exterior wall is designed to analyze and design a new control technology for energy consumption in hot spots.

Design of energy consumption control technology for thermal insulation of new nanopolymer materials on building external walls

The new nanopolymer materials for modern building exterior walls generally choose self insulation functional materials, which play a role essentially as a part of the wall. In actual design, concrete blocks are added to enhance the insulation effect. As shown in fig. 1. The thermal insulation energy consumption of new nanopolymer materials for building exterior walls mainly depends on the heat transfer performance of the wall material, as well as the specific thermal conductivity and heat insulation. In actual control, by understanding the actual heat transfer performance, the actual thermal conductivity zone of the external materials of the wall can be determined. Then, by sorting out the heat transfer and insulation points of the thermal conductivity zone, the thermal conductivity zone of the new nanopolymer material outside the wall can be clarified. Relying on parameter optimization recombine partitions and veins, ultimately achieving control objectives. The core energy consumption control process is shown in fig. 2.

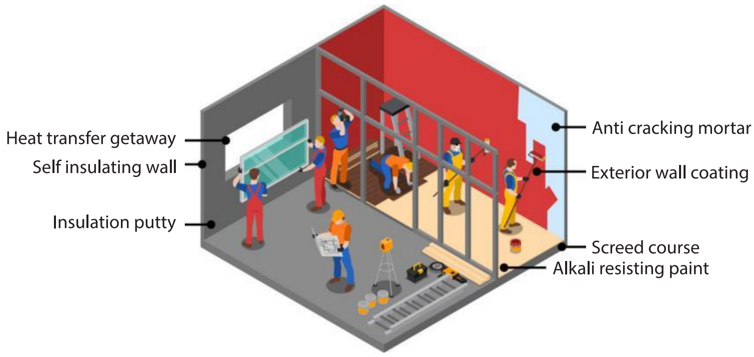

Figure 1. Schematic diagram of energy-saving materials for exterior wall buildings

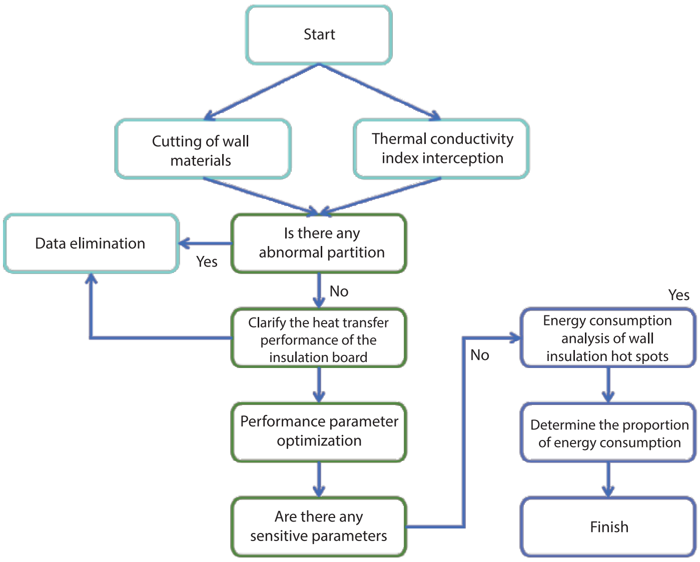

Figure 2. Flow chart of energy consumption control

Heat transfer performance model of exterior wall insulation board

The design of a heat transfer performance model for external wall insulation panels can conduct an orderly analysis of the actual thermal response and effectiveness of the new nanopolymer materials used for building external walls, re data their insulation processes, clarify the relevant indicators of heat transfer coefficient, and provide relational data for subsequent energy consumption control. The model design mainly utilizes the reaction coefficient method of new thermal insulation nanopolymer materials to calculate the heat transfer of the current building exterior wall new nanopolymer materials, especially the exterior wall hanging plates [7]. It clarifies the influence effect and heat distribution law of the hanging plate heat transfer and the exterior wall heat transfer coefficient, and calculates the limit of the non-equilibrium thermal insulation heat transfer coefficient of the hanging plate under the external sunlight refraction of the wall, which is the same as the average value of the current hanging plate heat transfer coefficient, and establishes an objective function, the technology calculates the wall penetration heat load, effective conductivity coefficient, and thermal resistance value of the new nanopolymer material for the wall, thereby completing the construction of a proportional model. Calculate the heat transfer of the current building exterior wall structure using the reaction coefficient method. Assuming the target data interval is 45 minutes, and using the data influence principle of heat transfer isosceles multiple waves, the actual heat value transferred from outdoor to indoor through the new nanopolymer material on the exterior wall during the n time period is calculated:

$$HG(n) = \frac{\sum_{i=0}^{\infty} Y_k t_x (n-t)}{\lambda(x) t_r} \tag{1}$$

where Y_k is the physical heat transfer performance response index of the current new nanopolymer material for building exterior walls against disturbances, T_x – the comprehensive action index of solar radiation, ground radiation, and other factors on the exterior wall of a building under comprehensive solar radiation, and T_r – the actual indoor temperature of the current building, which is usually a constant quantity. The value of t in the formula refers to the time corresponding to the temperature.

After calculating the heat transfer of the external wall hanging plate based on the previous formula, the heat transfer ratio relationship between the heat transfer $HG(n)$ and the current wall heat transfer coefficient can be determined:

$$\frac{HG(n)}{d_x} = \frac{d_s(1-\varepsilon)}{\int_0^x (1-\varepsilon)} \tag{2}$$

where d_s is the actual trend of the current building exterior wall temperature, which is the change band ε change cycle data of and S – the heat transfer ratio value of the new nanopolymer material outside the wall panel. By analyzing the direct radiation intensity of the current wall and the visual ratio of thermal energy after heat transfer, the influence law of the current wall heat transfer coefficient can be determined. The formula expression:

$$\sum_h \frac{I_{\mathrm{DN}} A_{\mathrm{w}}}{d_s} = \frac{\rho_d}{\varepsilon \rho_d} - \frac{m_c U_t \rho_d}{K_w (1-\varepsilon)} \tag{3}$$

where I_{DN} is the external solar radiation intensity, A_{w} – the wall width to window ratio, m_c – the actual location and area information of the building's exterior wall correction heat plate, ρ_d – the highest limit value of the external wall heat transfer coefficient obtained through the weighted average algorithm based on the location area, $K_w(1 - \varepsilon)$ – the multi-dimensional heat transfer control variable of the new nanopolymer material for the exterior wall of the current building, and U_t – the width to wall ratio of the current data of 0. According to the regular expression of eq. (3), the objective coefficient limit value of the derivative of the actual heat transfer performance of the new nanopolymer material under solar radiation on the current exterior wall can be calculated. The calculation formula:

$$K' = \frac{Q}{A(t_i - t_c)} \tag{4}$$

where Q is the actual heat transfer through the internal structure of the new nanopolymer material on the exterior wall, A – the universal thermal radiation area of the new nanopolymer material on the exterior wall, and t_i and t_c are the actual control temperature of the current wall inside and outside. In addition, if a non-uniform temperature environment is required, it is necessary to introduce a q-value based on the current eq. (4), which represents the thermal density corresponding to Q. The final formula:

$$K'' = \frac{Q}{A\left(t_i - t_c\right)} q \tag{5}$$

According to the final calculation data of eqs. (4) and (5), it is possible to use the objective function of the current external wall with the maximum temperature optimal heat transfer coefficient limit as the highest objective:

$$K_w = \frac{K'\left(\frac{t_s}{\alpha}\right)}{t_i - t_c} \tag{6}$$

where α is the actual energy consumption coefficient, represents the optimal heat exchange rate of the new nanopolymer material outside the current building, and t_s represents the actual load value of heat dissipation and infiltration outside the wall. In order to improve the operability and computability of current data, after obtaining the aforementioned parameters, the design evaluates the temperature changes of new nanopolymer materials for exterior walls of buildings based on the current indoor temperature of public buildings and future predicted values. Set the total energy consumption of the new nanopolymer material for the exterior wall during time period j as p, and based on the current indoor and outdoor temperatures t_i and t_c, as well as the indoor environmental temperature of the wall, establish a functional proportional relationship equation:

$$p = \frac{\left(t_i - t_c\right) j - \alpha}{\beta} \tag{7}$$

where α is the same as the previous formula, it represents the actual energy consumption coefficient of the optimal heat exchange rate of the new nanopolymer material outside the current building and β – the power conduction efficiency coefficient related to the current wall temperature, which is also known as the thermal conversion rate. Because the rated power of the external materials of the wall must not exceed the maximum instantaneous power, eq. (7) needs to meet:

$$0 \le P_j \le P_{\max} \tag{8}$$

Assuming that the energy consumption value is constant during the current j transmission time period, the heat transfer performance model of the exterior wall insulation board:

$$E_j = p \frac{K'' \sum_{j \le t_c}^{P_j} \frac{K'\left(\frac{t_s}{\alpha}\right)}{t_i - t_c}}{P_{\max}} \tag{9}$$

The heat transfer performance model of the external wall insulation board is composed of various coefficients and proportional relationships established and obtained from the aforementioned equation. The purpose of controlling and optimizing it is to reorganize the execution sequence of current energy consumption data through data item theory and optimization algorithms, so as to achieve the functional optimization of the selected new nanopolymer material for building exterior walls.

Optimization of energy consumption control parameters

Based on the aforementioned established exterior wall insulation performance model, the heat conduction law and related data indicators of the current new nanopolymer materials for walls can be determined. By doing so, control parameter optimization can be carried out. The optimization of energy consumption control parameters for new nanopolymer materials for building exterior walls is based on the aforementioned heat transfer performance data, and through the best data algorithm, under the condition of clarifying the current heat transfer coefficient, the process of obtaining the values of energy consumption decision variables for the new nanopolymer materials for building exterior walls. In order to ensure that the values in the optimization process are within the feasible range of optimization, it is necessary to establish certain constraint conditions for the limit value of the exterior wall energy-saving coefficient:

$$\left|T_d > T_v; T_c > T_\varphi\right| \tag{10}$$

where T_d is the general thermal energy of the current wall through the external new nanopolymer material, T_v – the general thermal energy inside the building, T_c – the thermal conductivity of the new nanopolymer material of the wall, and T_φ – the indicates the average decreasing degree of surface heat content of new nanopolymer materials for walls [8]. The constraint conditions for the energy-saving calorific value of the external wall body are: the design adopts genetic average data measurement, which converts the heat conduction coefficient values of data with clear inequality conditions into the problem of average constraint, which is the unconstrained optimal solution, according to the optimization principle. Based on the previous constraints, establish a transformation equation:

$$\text{Peni} = \begin{Bmatrix} |IQ|, \text{ when the } i^{\text{th}} \text{ inequality is not satisfied} \\ 0, \text{ when the } i^{\text{th}} \text{ inequality constraint is satisfied} \end{Bmatrix} \tag{11}$$

where IQ is the Conditional 3 faced by the i^{th} data in the current building exterior wall heat transfer performance model. When converting the heat transfer temperature limit of the wall, it can be converted into an objective function establish an optimization function for energy consumption control parameters:

$$F\left(k_s\right) = \alpha_i + \sum_{i=1}^{n} C + lcr \tag{12}$$

where lcr is the actual ratio of the current wall thermal load, α_i – the heat transfer coefficient under internal insulation between the wall and external materials, and C – the penalty coefficient generated during optimization.

Energy consumption analysis of wall insulation hotspots

After clarifying the proportion relationship of the current heat transfer performance parameters of the exterior wall insulation board and optimizing the energy consumption control parameters, the specific energy consumption data of the new nanopolymer material for the exterior wall can be determined. When there is thermal energy docking between the set hot spot m and adjacent hot spots, there may be heat sharing in the subsequent T events. Therefore, the range of values for insulation point m can be planned as [0, T] to obtain the probability distribution function of the current wall insulation hot spot:

$$P(m \le \alpha) = \begin{cases} 0 & a < 0 \\ \dfrac{a}{T} & 0 \le a \le \mathrm{T} \\ 1 & a > T \end{cases} \tag{13}$$

where a is the threshold of the probability of the current distribution of hot spots on the wall. When its value is less than 0, it indicates that the current distribution is in a normal state. The probability of heat sharing between two isolated hotspots is 1-p, and the relationship between the energy consumption of wall isolated hotspots at wall nodes:

$$F(t) = \frac{P(T_x \le t) - P(T_x \le 0)}{P(T_x \le t)} \tag{14}$$

where T_x is the interval period between the occurrence of thermal energy consumption in the current hot spot and t – the threshold information at different times.

Comparison of heat transfer performance

Based on the energy consumption analysis thresholds and distribution relationships of different wall insulation points provided by the aforementioned analysis results, a K-means clustering analysis strategy is designed and proposed, apply it to hot spot clustering control and achieve energy consumption control through the main cluster head of the hot spot. In practical insulation, the distance between the node clusters of the main cluster heads of the new nanopolymer material in the wall directly affects the analysis of the remaining energy of the cluster heads. Therefore, in the selection process of control analysis, it is necessary to integrate the current wall insulation measurement. At this time, the fitness function relationship between the main cluster and the secondary cluster:

$$f_1 = \alpha g_1 + \beta g_2 \tag{15}$$

$$f_2 = \varepsilon g_1 + \delta g_3 \tag{16}$$

where α and β proportion parameters of the adaptive function that can effectively adjust g_1 and g_2, respectively. Similarly ε and δ are the fitness function that regulates g_1 and g_3, and there is a relationship where the sum of the proportional parameters of the same set of fitness functions is 1. The g_1 is the current wall cluster point energy, g_2 – the distance ratio between current clusters of different materials, and g_3 – the credibility distance between all current skill material cluster points. The specific energy consumption control relationship for external wall insulation of g_1, g_2, and g_3 is:

$$\begin{cases} g_1 = E(i) \\ g_2 = \dfrac{m-1}{\sum_{i=1}^{m} d(i, CH)} \\ g_3 = \dfrac{1}{d}(i, BS) \end{cases} \tag{17}$$

where CH and BS are the passive and active power consumption of the current node's insulation performance, respectively. This value can be determined based on the proportional value provided by the heat transfer performance model of the exterior wall insulation board, where d is the average distance between cluster points and m – the total number of cluster points.

Experimental results and analysis

In order to verify the comprehensive performance of the designed new nanopolymer material insulation and energy consumption control technology for exterior walls, simulation comparative experiments are required. The simulation verification is conducted against the background of typical autumn climate conditions. Simulation utilization of EnergyPLUS simulation software simulates various data parameters of the current building exterior wall. The exterior of the wall panel is equipped with 6 mm sandwich steel plates, and the absorption rate of solar radiation on the exterior wall is 0.25, set the thermal conductivity to 0.08 W/mK. In order to effectively compare the comprehensive performance, the traditional physical light energy adjustment method and hybrid control strategy are designed for comparison [9]. Figure 3 shows the increasing ratio of heat transfer coefficient of new nanopolymer materials for walls in the current simulation environment. The meaning of abbreviations in the figure: WQ is the coolin load, PC – the hybrid control strategy, OZ – the physical light energy adjustment method, TC – the TC method, KJ – the KJ method, Y – the Y method, SD – the statiscical differences, and N1-N7 – the experiment number.

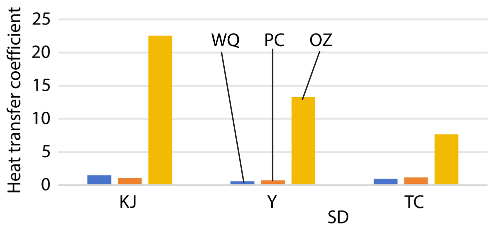

Figure 3. Heat transfer coefficient of energy-saving materials in the wall under different experimental methods

In order to prevent data errors, experiments were conducted to verify the accuracy of wall cooling load control statistics. The comparison results are:

The cooling load control statistics will directly affect the actual design value of the building's exterior wall insulation layer, thereby affecting subsequent control. According to the data statistics in figs. 4 and 5, it can be seen that the accuracy of the design method for cooling load control statistics is significantly higher than the two traditional methods used for comparison. Due to the different weights, the final increase proportion was determined to be 27%, further verifying the hypothesis [10].

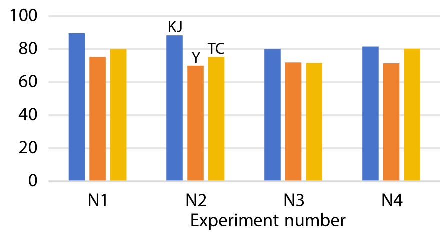

Figure 4. Statistical accuracy of the cooling load control (N1-N4)

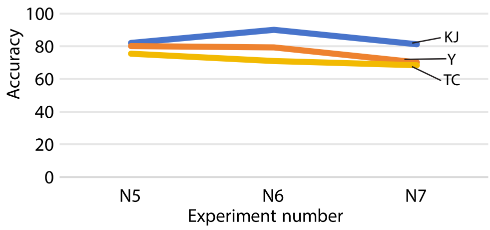

Figure 5. Statistical accuracy of the cooling load control (N5-N7)

Conclusion

The integrated system of nanothermal insulation and coating for exterior walls is composed of thermal insulation putty, flexible fine putty, sealing primer, nanothermal insulation coating, and hydrophobic elastic reflective thermal insulation coating. The author proposes a control method for insulation energy consumption of building exterior wall skill materials, which is based on a heat transfer model and effectively controls wall insulation energy consumption. The experimental results show that the application of this control method can effectively improve the control effect and has distinct advantages.

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