

Research Article

Building Thermal Comfort Research Based on Energy-Saving Concept

Feiran Xue and Jingyuan Zhao 

Coll Architecture, Changan University, Xian 710016, Shaanxi, China

Correspondence should be addressed to Jingyuan Zhao; zjyqtt@chd.edu.cn

Received 18 June 2021; Revised 24 July 2021; Accepted 14 August 2021; Published 25 August 2021

Academic Editor: Song Jiang

Copyright © 2021 Feiran Xue and Jingyuan Zhao. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Under the trend of building green and comfortable development, effective control of building energy consumption has become one of the problems that countries are actively facing to solve. People's demand for residential buildings has changed from the past survival type to a comfortable and livable type. The high level of heating energy consumption is worthy of in-depth study. In order to reduce energy consumption, realize the mapping of energy-saving concepts in buildings, and understand the energy consumption of different building materials and the influence of external factors on human thermal comfort, this book has conducted research on building thermal comfort based on energy-saving concepts. First of all, this article introduces the concept and application mode of energy-saving concepts in buildings and the concept of thermal comfort and the SET index of standard effective temperature, including the two-node model and the algorithm involved in the Fanger heat balance equation. In the experimental part, a model based on the concept of energy saving was designed to predict and analyze the energy consumption and thermal comfort effects of the building. In the analysis part, a comprehensive analysis of the effects of temperature, humidity, wind speed, and gender on thermal comfort, methods to improve thermal comfort, cumulative load changes with the heat transfer coefficient of windows, and the effects of windows of different materials on energy consumption was performed. At the same temperature, the wind speed is different, and the degree of heat sensation is also different. When the wind speed is 0.18 m/s and the temperature is 28°C, the thermal sensation is 0.32, and the human sensation is close to neutral. When the wind speed increases to 0.72 m/s, the heat sensation drops to -0.45, and the human body feels neutral and cool. It can be seen that the increase in wind speed has a certain compensation effect on the thermal sensation of the human body. When the wind speed does not change, increase the air temperature. For example, when the wind speed is 0.72 m/s, the temperature is 28°C, and the thermal sensation is -0.45, and when the temperature is increased to 29°C, the thermal sensation is 0.08, which shows that the temperature is improving the thermal sensation of the human body which has a certain offsetting effect. By studying the thermal comfort of buildings based on energy-saving concepts, it is possible to obtain the effect of external factors on thermal comfort, thereby optimizing building materials and using building materials with lower heat transfer coefficients to reduce heating energy consumption.

1. Introduction

Building based on the energy-saving concept is a brand-new architectural design concept. On the basis of providing comfortable activity space, it provides more healthy living quality and efficient working environment for building users. Its development goal is to maximize the building, optimize efficiency, while protecting the surrounding environment and increasing the value of

resource utilization, minimize the negative impact of the building on the surrounding environment, effectively reduce operating costs, and achieve the highest cost performance [1]. The concept of green building should be embodied in the entire life cycle of a building, from material transportation, processing, and production to new construction, operation and maintenance, and final demolition. In addition to introducing many advanced energy-saving and environmentally-friendly technologies,

it is more important for energy-saving buildings to closely integrate natural sciences and the human environment, showing a people-oriented development concept and allowing people, environment, and buildings to develop harmoniously. Therefore, energy-efficient buildings have undoubtedly become one of the most influential development trends in the world today.

The evaluation of comfort is inseparable from architecture. Architectural comfort includes two specific concepts, namely, the comfort of the building and the comfort of the physical environment. The comfort of the building mainly focuses on its use function, including good living experience and convenience of living facilities, including the barrier-free design of the building. In comparison, the comfort of the physical environment largely depends on the individual's state, and it will change with different feelings. With the promotion of intelligent buildings, the endless emergence of intelligent equipment and integrated systems not only provides great convenience for our lives but also improves the comfort of the living environment to a large extent [2].

Based on the above background of energy-saving concept buildings, many scholars at home and abroad have conducted related research. Meyer W believes that energy-efficient building renovation aims to save energy and, thereby, reduce carbon dioxide emissions. The increase in energy efficiency of buildings usually means a reduction in air exchange, coupled with other indoor air quality issues, which may lead to an increase in indoor radon concentration (Rn-222). To investigate the severity of this problem, the author measured the radon concentration in energy-efficient renovation and low-energy houses (passive houses). In a period of 1 year, the orbital etching detector was exposed to every type of building. The author draws reference samples of nonrefurbished nonpassive buildings from the national radon database for comparison, selects buildings with the same radon-related characteristics, and builds them on a geological subsoil equivalent to the geological subsoil of the survey. The compilation method of the reference sample adopted is that the measured values of the refurbished house and the bottom room of the passive house are assigned a measured value from the database. Statistical analysis shows that compared with unrenovated houses, houses renovated to improve energy efficiency have a wider range of indoor radon concentration. In buildings renovated to improve energy efficiency, the average and median radon concentrations have almost doubled. On the contrary, there is no significant difference in the distribution of passive houses and houses that have not undergone energy-efficient renovations. The author's research on energy conservation has a certain significance for improving the energy efficiency of buildings, but the author has no control variables, and a blank control group should be set up for comparative analysis [3]. Middel A pointed out that, in hot desert cities, shading plays an important role in designing outdoor spaces suitable for pedestrians. The study investigated the impact of photovoltaic canopy shading and tree shade on thermal comfort through meteorological observations and field surveys on the pedestrian streets of Arizona State University

Tempe Campus. During the course of the year, on selected sunny and calm days representing each season, the researcher conducted a meteorological section every hour from 7:00 in the morning to 6:00 in the afternoon and investigated the heat of 1284 people. On the 9-point semantic difference system, the shadow reduces the thermal sensation vote by approximately 1 point, thereby increasing thermal comfort in all seasons except winter. The type of shading (tree or sun canopy) has no significant effect on perceived comfort, indicating that artificial and natural shading are equally effective in hot and dry climates. Earth's temperature is the reason for the 51% difference in thermal sensation voting, and it is the only statistically significant meteorological predictor. Important nonmeteorological factors include adaptation, thermal comfort voting, thermal preference, gender, season, and time of day. The return of thermal sensation to the physiologically equivalent temperature produces a neutral temperature of 28.6°C, the acceptable comfort range is 19.1°C–38.1°C, and the preferred temperature is 20.8°C. Respondents believe that being exposed to temperatures above neutral and being in the air conditioner will make them feel more comfortable, indicating that they are lagging in response to outdoor conditions. The author's research emphasizes the importance of active solar energy access management to reduce thermal stress in hot urban areas. The study conducted a research on thermal comfort and used PMV voting indicators to illustrate. The survey samples are referenced, but they did not make reasonable suggestions on how to improve thermal comfort [4]. The scope of D Kioupis' research is to propose an effective method for the experimental design and development of geopolymer products that can meet a wide range of end-user requirements. The method involves the application of a multifactor experimental design model through Taguchi's method, which allows the combined effect of selected parameters in the response of the experimental system to be studied by conducting a minimum number of experiments, thus significantly reducing the time and cost of the entire process. The results showed that the use of various raw materials and additives, as well as controlled changes in synthesis parameters and manufacturing conditions, led to the production of geopolymers with a wide range of final properties. This method is used to develop geopolymers with compressive strength, density, and thermal conductivity in the range of 2–55 MPa, 0.6–2.0 g/cm³, and 0.09–0.40 W/mK, respectively. The author studied the relevant characteristics of the abovementioned building materials, but did not analyze the application prospects of these materials, such as the compressive strength and density of these materials, which make them applicable to buildings [5].

This paper studies the thermal comfort of buildings based on the concept of energy saving. First, this article introduces the concept and application mode of energy-saving concepts in buildings and the concept of thermal comfort and the SET index of standard effective temperature, including the two-node model and the algorithm involved in the Fanger heat balance equation. In the experimental part, a model based on the concept of energy saving was designed to predict and analyze the energy

consumption and thermal comfort effects of the building. In the analysis part, it comprehensively analyzes the effects of temperature, humidity, wind speed, and gender on thermal comfort, methods to improve thermal comfort, cumulative load changes with the heat transfer coefficient of windows, and the impact of windows of different materials on energy consumption. The innovation of this article is to integrate energy-saving concepts into modern buildings to increase people's awareness of green and environmental protection, select multiple external indicators for thermal comfort research, select materials with the best energy efficiency, and conduct an in-depth analysis of the thermal comfort of the human body in the building from multiple angles.

2. Building Thermal Comfort Methods Based on Energy-Saving Concepts

2.1. Energy-Saving Concept. The main content of the energy-saving concept is to reduce energy consumption and improve energy efficiency, which is mainly reflected in green buildings in terms of buildings. Green building, as its name implies, is to build an economical, comfortable, energy-saving, efficient, reliable, safe, and healthy living environment at the level of low environmental load by reducing energy consumption, maximizing the use of existing resources, and realizing people and the environment. The purpose of the building is to be mutually beneficial for symbiosis, sustainable development, and harmonious co-existence. With the continuous progress of economy and society, the sustained and rapid development of the national economy, and the improvement of the current social living standards, the society's demand for living environment and management standards continues to rise, and there are new and higher demands for the functions of buildings. Nowadays, a variety of electrical equipment are installed in green buildings. The wide application of electrical automation technology in green buildings has increased the economy, reliability, and living comfort of buildings and improved the ability of building equipment operation and management [6, 7].

Green buildings can indeed reduce energy consumption by about 40% or more, but the initial investment is too much. From the inside of the building, it is necessary to consider heating, ventilation, water supply and drainage, lighting, etc.; from the outside of the building, it is to consider the natural resources that can replace these as much as possible [8]. And, we must comprehensively consider their mutual cooperation. This makes the process of building construction complicated. Another concept of green building is that the consumables of the building itself must also meet the requirements of environmental protection. At present, most building materials cannot be recycled and cannot be reused when buildings are demolished. This wastes resources and even causes pollution. In addition to being recyclable, environmentally-friendly alternative materials can also increase the lifespan of buildings.

The schematic diagram of energy-saving building HVAC is shown in Figure 1. It can be seen that the HVAC of energy-saving buildings involves multiple aspects of heat transfer

and is based on resource conservation, reuse, recycling, and development and utilization of renewable resources. Therefore, the choice of building envelope structure materials in practice also requires the above four characteristics. Materials such as building walls should be environmentally friendly and save energy [9, 10]. Energy-saving buildings need to use green building materials, and the heat resistance of these materials can enable buildings to meet the requirements of minimizing energy consumption. For example, the outer wall of the building with the largest heat dissipation. At present, 60% of the outer wall materials in the construction market have used a large number of green building materials, and the energy-saving effect is very obvious. In addition to heat preservation, it can meet energy-saving requirements, and the weight is also small.

2.2. Thermal Comfort. Comfort is a broad concept. It is not determined by a single factor, but a subjective feeling produced by the human body under the image of comprehensive environmental factors. Since the psychological level has many effects on comfort or not, everyone's feelings are different, so the general understanding is that 80% of people are satisfied with the current environmental comfort conditions, that is, they think they have reached comfortable state. The human body must maintain internal thermal balance under any environmental conditions. Since humans are warm-blooded animals, they need to maintain their own body temperature at a constant state. Therefore, the human body can maintain the heat balance in the body when the surrounding environment fluctuates greatly, and its regulating ability is very strong [11]. When the body's heat production and heat dissipation are maintained in a balanced state, the body temperature can be maintained within the normal range. The human body produces energy mainly through metabolism. This energy is converted into two parts: heat and mechanical work. The human body mainly radiates heat to the surrounding environment through the skin. There are usually three ways: convective heat exchange, radiation heat exchange, and evaporative heat dissipation [12].

The body's heat balance can only be maintained when the body's heat production and heat dissipation are maintained in a balanced state. In a certain thermal environment, when the heat exchange between the surface of the human body and the external environment is not maintained in a balanced state, the human body will use its own physiological regulation functions and effective behaviors to adjust the human body's thermal sensation, and these behaviors' regulation is affected by regional climate and geographical environment, climatic conditions, and living conditions. In addition, psychological thermal adaptation is also significantly related to human thermal comfort. Psychological thermal adaptation is, under the influence of microclimate, an individual's thermal experience and thermal history of a certain environment, as well as the thermal expectations and thermal stimuli that arise from it. Climate experience, regional background, and psychological adaptation affect the human body's level of adaptation to the thermal

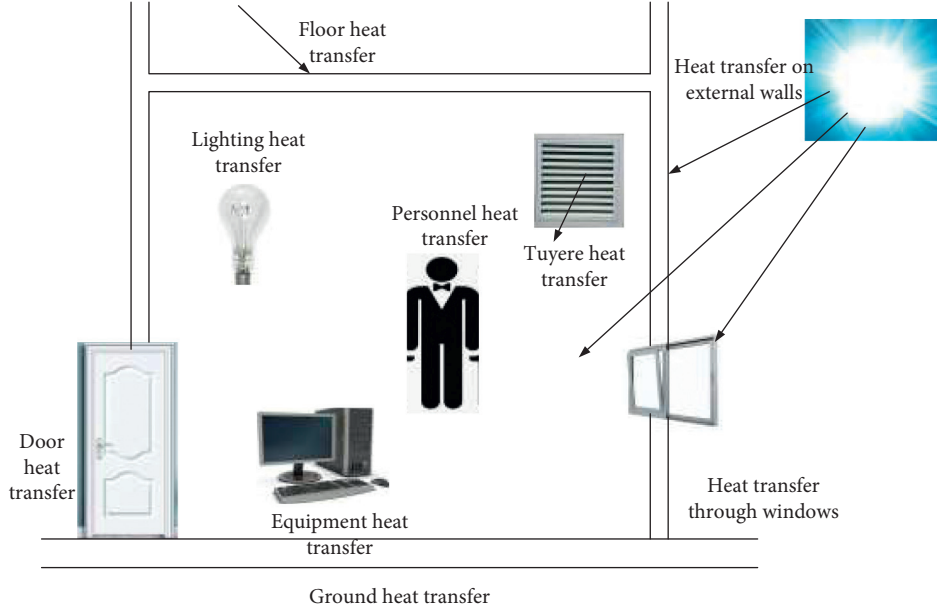


FIGURE 1: Schematic diagram of energy-saving building HVAC (pictures from Baidu Picture).

environment. Therefore, many physical and psychological factors affect the thermal comfort of the human body [13].

2.3. SET Index of Standard Effective Temperature. The standard effective temperature was proposed late. It is based on the effective temperature and the new effective temperature. It is a comfort index that has been continuously verified and revised by several generations of researchers [14].

2.3.1. Two-Node Model. Gagge proposed a two-node human body temperature regulation model, in which the human body is divided into two layers, namely, the core layer and the skin layer [15, 16]. Metabolic heat is generated in the core layer, and then, the metabolic heat is transferred from the core layer to the environment. During this process, a part of the heat will be directly lost to the environment due to human respiration, and the remaining heat will continue to spread to the surface of the skin. Due to evaporation, part of the heat transferred to the surface of the skin will be lost, and the remaining heat will be transferred to the surface of the clothes through the clothes and then transferred to the surrounding environment through radiation and convection. This heat transfer model between people and environment can be expressed by the core layer heat balance equation and the skin layer heat balance equation [17]. The heat balance equation of the core layer is

$$\begin{aligned}
 Q + \Delta Q - W = P_{a,res} + P_{b,res} \\
 + (L + Q_{c1}D_{c1})(m_{dv} - m_{al}) \\
 + Q_{dv}D_{dv}\frac{bm_{dv}}{b\zeta}.
 \end{aligned} \quad (1)$$

Among them, ΔQ represents the heat generated per unit human body surface area regulated by chills, L represents the thermal conductivity between the core layers of the skin, D_{c1} represents the specific heat capacity of the blood, m_{dv} represents the temperature of the core layer, m_{al} represents the temperature of the skin layer, and ζ represents the transmission time. The skin layer heat balance equation is

$$(L + Q_{c1}D_{c1})(m_{dv} - m_{al}) = P_{al} + Q_{al}D_{al}\frac{bm_{al}}{b\zeta}, \quad (2)$$

where m_{al} represents the temperature of the skin layer and P_{al} represents the mass per unit human body surface area of the skin layer. Q_{c1} is used to express the blood flow between the core layer and the skin, and the specific equation is

$$Q_{c1} = \frac{6.3 + 200(m_{dv} - 36.8)}{1 + 0.1(33.7 - m_{al})}. \quad (3)$$

The amount of perspiration U_{kf} is mainly determined by the average temperature of the human body after it rises above the set temperature. After the skin surface temperature increases above its reference temperature, it will promote sweat secretion [18], namely,

$$U_{kf} = 136\|M_c - 36.34\|\exp\left(\frac{\|M_{al} - 34\|}{10.7}\right). \quad (4)$$

The tremor occurs when the temperature of the core layer and the temperature of the skin layer are both lowered, and the increase in the metabolic rate is calculated as follows:

$$\Delta Q = 19.4\|34 - M_{al}\| \times \|36.6 - M_{dv}\|. \quad (5)$$

Either vasodilation or vasoconstriction will cause changes in the body's heat transfer coefficient [19]. The heat flow calculation formula from the core layer to the skin layer is

$$P_{al} = L(M_{dv} - M_{al}). \quad (6)$$

Among them, L , as the heat transfer coefficient from the core layer to the skin layer, includes two parts: variable and constant. The constant part is the heat transfer coefficient term, and the other variable part is caused by blood flow. The increase in the temperature of the core layer causes vasodilation, and the decrease in the temperature of the skin layer causes vasoconstriction [20]. The heat transfer coefficient is expressed as follows:

$$L = 5.28 + \frac{7.33 + 175\|M_{dv} - 36.6\|}{1 + 0.5\|34 - M_{al}\|}. \quad (7)$$

These control functions, together with the human body's heat flow and heat mass equations, establish a model of temperature changes with time and can predict skin temperature and skin humidity, which are the two main parameters for calculating SET. Its advantage is that, under any environmental conditions, human skin temperature and humidity can be calculated by the two-node model [21].

2.3.2. Fanger Heat Balance Equation. Professor P. O. Fanger of Denmark proposed a comprehensive comfort index based on the following: the parameters that determine the comfort state of the human body have nothing to do with the environment, but only with the human body. Fanger believes that what a person feels is not the temperature of the surrounding air, but the temperature of his own skin [22]. On the basis of theory, Fanger conducted experiments with subjects and then used regression analysis to determine the relationship between the average human skin temperature, sweat evaporation heat loss, and metabolic rate:

$$\begin{aligned} M_{\text{hal}} &= 35.7 - 0.028(Q - V), \\ U_{\text{rsw,req}} &= 0.42(Q - V - 58.15). \end{aligned} \quad (8)$$

Among them, Q represents the body's metabolism rate and V represents the amount of external work done.

Subsequently, the expression of each quantity in the heat balance equation is summarized, and each term is introduced into the heat balance equation, and the following formula is obtained:

$$\begin{aligned} Q - V - 3.05 \times 10^{-3} [256M_{\text{hal}} - 3373 - R_b] - U_{\text{rsw,rwq}} \\ - 1.73 \times 10^{-5} Q(5867 - R_b) - 1.4 \times 10^{-3} Q(34 - M_b) \\ = 3.96 \times 10^{-8} s_{dv} [(M_{dv} + 273)^4 - (M_{\text{mrt}} + 273)^4] + s_{dv} g_d (M_{dv} - M_b). \end{aligned} \quad (9)$$

In the above formula, S_{dv} represents the area coefficient of clothes, R_b represents the saturation partial pressure of water vapor at ambient air temperature, M_{dv} represents the average temperature of the human body surface, M_b represents the surrounding air temperature, and g_b represents the convective heat transfer coefficient between the human body and the air. In addition, the convective heat transfer coefficient can be divided into natural convection and forced convection [23].

When $\sqrt[4]{2.38(M_{dv} - M_b)} > 12.1\sqrt{P_{bh}}$, the coefficient of natural convection was

$$g_d = \sqrt[4]{2.38(M_{dv} - M_b)}. \quad (10)$$

When $\sqrt[4]{2.38(M_{dv} - M_b)} < 12.1\sqrt{P_{bh}}$, the forced convection coefficient had

$$g_d = 12.1\sqrt{P_{bh}}. \quad (11)$$

For the clothing area coefficient s_{dv} , when $F_{dv} \leq 0.078$,

$$s_{dv} = 1.00 + 1.29F_{dv}. \quad (12)$$

When $F_{dv} > 0.078$,

$$s_{dv} = 1.05 + 0.645F_{dv}. \quad (13)$$

Then, the heat balance equation is combined with the two comfort requirements to meet the three comfort conditions proposed by Fanger, and the famous Fanger comfort equation is obtained:

$$\begin{aligned} H = Q - V - 3.05 \times 10^{-3} [5733 - 6.99(Q - V) - R_b] - 0.42(Q - V - 58.15) \\ - 1.73 \times 10^{-5} Q(5867 - R_b) - 1.4 \times 10^{-3} Q(34 - M_b) \\ = 3.96 \times 10^{-8} s_{dv} [(M_{dv} + 273)^4 - (M_{\text{mrt}} + 273)^4] + s_{dv} g_d (M_{dv} - M_b). \end{aligned} \quad (14)$$

2.3.3. Forecast the Average Comfort Level Voting Index PMV. PMV is a comprehensive index that considers many factors of thermal comfort, and it is also a more authoritative and representative thermal comfort evaluation index. The PMV

model is a comfort equation, which points out the basic influencing factors for thermal environmental evaluation, namely, air temperature, average irradiation temperature, relative humidity, wind speed, clothing amount, and activity

level. They evaluate indoor thermal comfort and occupy an important position [24]. Professor Fanger found the relationship between the six, created the relationship between each other, and formed the judgment equation, the PMV indicator. The PMV index divides the human body's thermal comfort into 7 levels, including cold, cool, slightly cool, moderate, comfortable, slightly warm, warm, and hot, as shown in Table 1, where each different PMV value represents a different value. The degree of hot and cold, such as 0, means moderate. The PMV evaluation model comprehensively considers the effects of six types of indoor environmental factors (temperature, relative humidity, air flow rate, average radiation temperature, clothing thermal resistance, and metabolic rate) on the thermal comfort of the human body [25, 26].

The control method of the environmental thermal comfort system is to directly use the PMV index as the control basis and realize the separate control of each environmental variable through the set PMV index, that is, the PMV index and each environmental variable must be used as the controlled parameter. This control method uses PMV as two functions, one is the evaluation index of the system, and the other is the input of the control system. The temperature is no longer regarded as a single control parameter, but a variety of parameters affecting the room are regarded as control objectives. In the actual control process, because the control system directly uses the PMV value as the control basis, when the indoor environmental factors change, it will have an impact on the PMV value [27].

As shown in Figure 2, the control system directly regards the PMV index as the control basis. The control principle is to monitor the thermal comfort PMV index of the home environment in real time and compare it with the preset thermal comfort mode to obtain the corresponding operation judgment result. Then, according to the judgment result, the control system issues an order, and the actuator regulates the indoor temperature, wind speed, and humidity and also adjusts indoor thermal comfort.

3. Building Thermal Comfort Experiment Based on Energy-Saving Concept

3.1. Experimental Protocol. With the development and popularization of information technology, computers can realize automated management in many fields. On the one hand, it can save labor costs, and on the other hand, it can avoid loopholes in human management. Due to the large amount of energy consumption data, complicated classification, and complex systems in office buildings, traditional human management methods are no longer suitable and inefficient. Based on computer technology, the establishment of a building energy-saving management system can help managers grasp the accurate distribution and level of energy consumption and find out the problems with high energy consumption at the first time so that targeted countermeasures can be taken to truly achieve quantitative energy consumption and energy saving to achieve active and accurate energy management. The database used in this article must manage and store massive amounts of energy

consumption data and can realize functions such as querying basic building energy consumption information and energy consumption status of key equipment and establish a building energy consumption database system based on a local server to realize energy consumption statistics and analysis of related buildings in a designated area, including lighting, heating, and air conditioning.

3.2. Demand Analysis of Energy-Saving Management System. The purpose of designing the building energy-saving management system is to realize the automatic storage and management of energy consumption data, realize the query and analysis of energy consumption data in a visual way, and then provide data support for energy-saving work. The corresponding functional requirements are as follows:

- (1) Visual query of energy consumption data: the management system connects with the database to store, manage, and analyze the collected energy consumption data
- (2) Statistics and analysis of energy consumption data: the management system can classify and subitem statistics on energy consumption data, including hourly, daily, monthly, and year-by-year statistics of energy consumption, and can output energy consumption reports, and the data can be printed
- (3) Energy consumption forecast: based on the building energy consumption database, using the predictive average comfort level voting index PMV, it can predict the short-term energy consumption and thermal sensation trends and realize the advance planning and scientific scheduling of energy use

3.3. Experimental Environment. In order to further study the related strategies of intelligent control, we need to study the relationship between environmental variables and thermal comfort. Thermal comfort needs to control a certain objective environment. Its core variables are indoor air temperature, relative humidity, air flow rate, and average radiation temperature. However, the control of radiation temperature is more difficult to achieve and does not take control considerations. Therefore, we will study the first three environments here. The influence between variables and comfort. Table 2 shows the metabolic rate of the human body under different activities. This study uses this as the experimental environment.

4. Building Thermal Comfort Analysis Based on Energy-Saving Concepts

4.1. Influence of Temperature, Humidity, and Wind Speed on Thermal Comfort. This study uses the method of controlling variables to compare and analyze the effects of temperature, humidity, and wind speed on thermal comfort. First, the influence of temperature and wind speed on PMV is analyzed. The humidity is fixed at 50%, the air temperature is 27°C, 28°C, 29°C, and 30°C, and the wind speed is 0.18 m/s, 0.72 m/s, and 1.21 m, respectively.

TABLE 1: Thermal comfort level 7 index.

Hot sensation	Cold	Cool	Slightly cool	Comfortable	Slightly warm	Warm	Heat
PMV	-3	-2	-1	0	+1	+2	+3
PPD	100%	66%	33%	0	33%	66%	100%

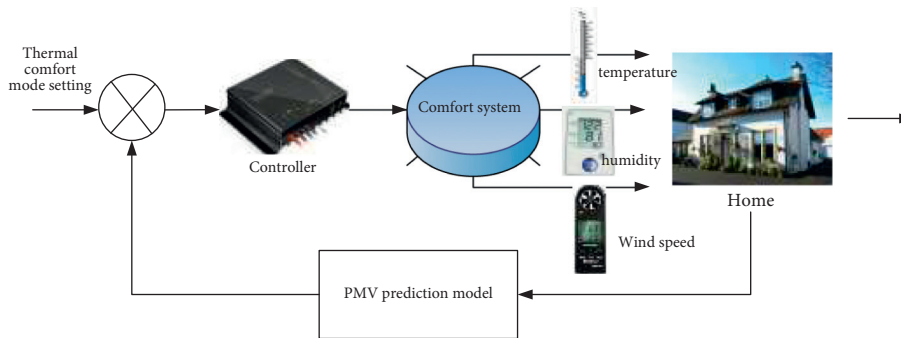


FIGURE 2: Thermal comfort control method (pictures from Baidu Picture).

TABLE 2: Reference table of human activity and metabolic rate.

Human activity	Metabolic heat production rate M	
	W/m^2	Met
Lying down	42	0.6
Sit relaxed	53	0.8
Sit and work	67	1.0
Relax and stand	67	1.0
Standing with light activity	88	1.4
Standing with moderate activity	102	1.8
Heavy activity	155	2.5

Figure 3 shows the effect of different wind speeds on the thermal comfort of the human body when the humidity is 50%. It can be seen from Figure 1 that, at the same temperature, the wind speed is different, and the degree of thermal sensation is also different. When the wind speed is 0.18 m/s and the temperature is 28°C, the thermal sensation is 0.32, and the human sensation is close to neutral. When the wind speed increases to 0.72 m/s, the heat sensation drops to -0.45, and the human body feels neutral and cool. It can be seen that the increase in wind speed has a certain compensation effect on the thermal sensation of the human body. When the wind speed does not change, increase the air temperature. For example, when the wind speed is 0.72 m/s, the temperature is 28°C and the thermal sensation is -0.45, and when the temperature is increased to 29°C, the thermal sensation is 0.08, which shows that the temperature is improving the thermal sensation of the human body which has a certain offsetting effect. In addition, the influence of temperature on PMV is more significant than the influence of wind speed on PMV. When the wind speed is 0.18–1.213 m/s, the maximum value of PMV change is $-0.32 - (-1.63) = 1.31$, and the temperature rises from 27°C to 30°C, the maximum value of PMV change is $-0.01 - (-1.63) = 1.62$. It can be seen that compared to the temperature, the wind speed has a weaker influence on PMV.

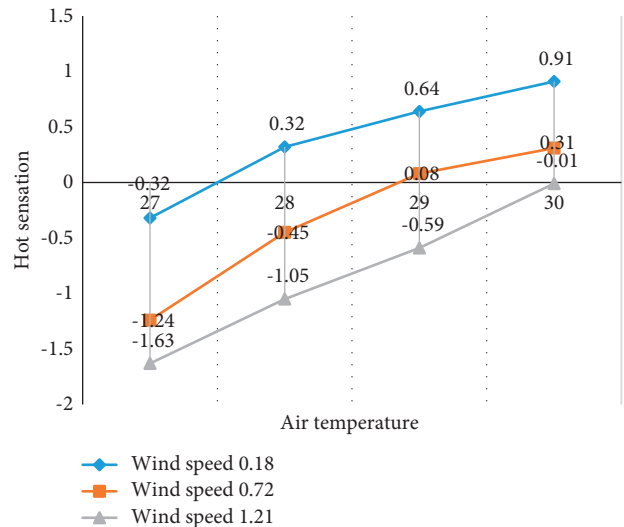


FIGURE 3: The influence of different wind speeds on human thermal comfort.

In addition, this study also studied the influence of humidity and wind speed on PMV. The fixed temperature was 25°C, the humidity was set to 40%, 50%, and 60%, and the wind speed was 0.1, 0.2, 0.3, 0.4, and 0.5 m/s.

Figure 4 shows the effect of humidity and wind speed on temperature. As the wind speed continues to increase, the PMV value continues to decrease, and the decrease is small. The maximum change in the thermal comfort value PMV is $0.51 - 0.02 = 0.49$. Similarly, as the humidity increases, the PMV value also continues to decrease, but the impact is still not significant. The maximum change range of PMV is $0.51 - 0.23 = 0.28$. It can be seen that compared with wind speed, humidity has a smaller impact on thermal comfort. From the analysis of the above two aspects, among the three external factors of wind speed, temperature, and humidity, temperature has the most obvious effect on thermal comfort,

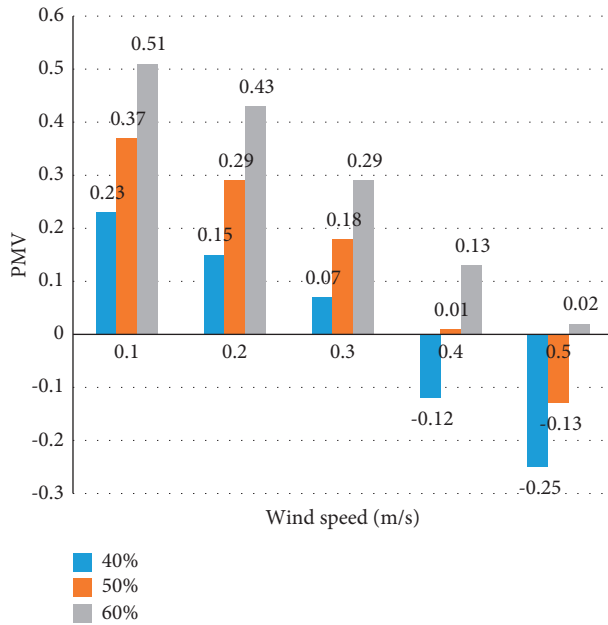


FIGURE 4: The influence of humidity and wind speed on PMV.

followed by wind speed, and humidity has less effect on thermal comfort.

4.2. Influence of Gender on Thermal Comfort. It can be seen from Table 3 that there are obvious differences in the skin surface temperature values of various parts of the male and female bodies. In the test, under normal circumstances, the temperature of the arms, hands, legs, and feet of men is significantly higher than that of women, and the temperature of the head and torso is similar to that of women. In the torso, the male temperature is 34.53, while the female temperature is 34.52, which is not much different. On the legs, the male temperature is 34.05 and the female temperature is 33.69.

Table 4 shows the differences in thermal comfort between men and women. Among them, in each season, there is no significant difference in neutral temperature and average heat sensation from a gender perspective. From the perspective of thermal dissatisfaction, in summer, the thermal dissatisfaction rates of men and women are 31.9 and 29.8, which are significantly higher than those of the other three seasons. Regarding the effect of gender on thermal comfort, the difference in clothing has no obvious effect, but there is a gender difference in the use of fans. In summer, the fan usage rate of men is 72.9%, while that of women is 66.3%. In addition to the fact that the fan usage rate of both is zero in winter, the frequency of use of fans by men is higher than that of women.

4.3. Ways to Improve Thermal Comfort. Figure 5 shows a method to improve its thermal comfort. In winter, most people choose to go indoors to improve their thermal comfort, accounting for 43%. In addition, some people choose to exercise and sunbathe to increase the heat sensation. In the summer, those who choose to enter the room

and improve their thermal comfort in the shade account for a considerable proportion, 47% and 39%, respectively. In the transitional season, people basically choose to exercise and increase the feeling of heat in the sun or shade. In this season, fewer people choose to enter the room, and everyone prefers outdoor activities.

4.4. Accumulative Load Changes with the Heat Transfer Coefficient of the Window. Cooling load refers to the amount of cold supplied to the room at a certain time by continuously maintaining a constant temperature and humidity in an air-conditioned room; heat load refers to the amount of heat that needs to be provided to the room to compensate for the loss of heat in the room.

Figure 6 shows the cumulative cooling and heating load and the total load change with the heat transfer coefficient of the window. It can be seen from Figure 3 that the cumulative heat load of heating increases with the increase of the thermal conductivity of the window, and the increase is more significant. With the increase of the thermal conductivity of the windows, the cumulative cooling load of the air conditioner does not change significantly, and the range of change is small. Judging from the changes in the total load accumulated throughout the year, as the thermal conductivity of the windows increases, the total load has shown a clear upward trend. It can be seen that windows can affect building energy consumption, and the degree of impact is relatively large.

4.5. Impact of Windows of Different Materials on Energy Consumption. As a part of the indoor building environment, the role of windows in energy conservation should not be underestimated. This study selects windows as the object for performance analysis and window renovation.

In addition, this study also analyzed the performance of windows and their impact on energy consumption. Due to the poor thermal insulation effect of the inner windows in some buildings and the weak shading performance, the indoor solar radiation is higher in summer, which increases the heat perception and generally feels more tan; while in winter, due to the poor thermal insulation effect of the outer window, part of the heat loss is large, so the transformation of the window is very important to reduce the heating load and air conditioning cooling load. Here are four commonly used windows performance, as shown in Table 5. Obviously, the energy efficiency of the hollow glass window with inert gas is the best, at 24.03%, and the heat generated is lower than that of the windows of the other three materials, at 79854 J. At the same time, this study also compared the energy consumption effects before and after the window transformation to determine the energy-saving effects of these types of windows.

Figure 7 is a comparison of energy consumption after window transformation. When the hollow glass window with inert gas is used, the heat transfer coefficient is 1.7 and the energy consumption is 75922 J. When the ordinary single-layer window is used, the heat transfer coefficient is 5.2 and the energy consumption is 90238 J. The heat transfer

TABLE 3: Skin surface temperature of various parts of the body.

Gender body parts	Head (°C)	Torso (°C)	Arm (°C)	Hand (°C)	Leg (°C)	Foot (°C)
Male	34.39	34.53	34.01	34.49	34.05	34.62
Female	34.41	34.52	33.66	34.03	33.69	34.13

TABLE 4: Gender differences.

	Spring		Summer		Autumn		Winter	
	Male	Female	Male	Female	Male	Female	Male	Female
Thermal neutral temperature (°C)	24.1	24.5	25.4	25.1	23.9	24.5	22.4	22.9
Average heat sensation	-0.19	-0.07	0.08	0.10	0.02	-0.01	-0.02	-0.09
Percentage of unsatisfied forecasts (%)	4.5	4.3	31.9	29.8	3.5	4.4	3.0	6.4
Clothing thermal resistance (clo)	0.77	0.70	0.51	0.49	0.88	0.89	0.94	0.99
Fan usage rate (%)	13.9	2.8	72.9	66.3	11.4	2.4	0	0

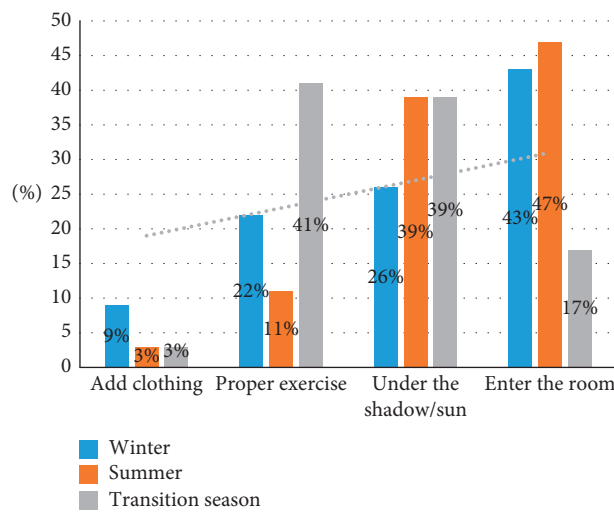


FIGURE 5: Ways to improve your own thermal comfort.

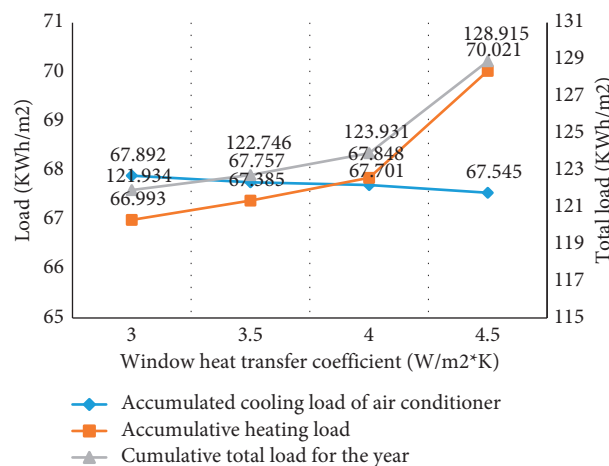


FIGURE 6: Accumulative load changes with the window heat transfer coefficient.

coefficient can achieve obvious energy-saving effect. At the same time, comparing single-layer windows and three-layer insulating glass windows, although the heat transfer coefficient and energy consumption are reduced, the heat

transfer coefficient of three-layer insulating glass is slightly higher than that of insulating glass windows with inert gas (1.7). It is 2.2. Although the airtightness is better, the reduction of heating energy consumption is limited.

TABLE 5: Performance comparison of several typical windows.

	6 mm single window	6Low-E+12+6 hollow glass window	6Low-E+12+6 hollow glass window (inert gas)	Three-layer hollow glass window
Heat transfer coefficient	4.3	2.0	1.6	1.8
Shading coefficient	0.91	0.81	0.57	0.85
Heating	98432	84325	79854	80359
CO ₂	79378	63875	56798	60953
Energy saving efficiency	—	15.98%	24.03%	20.11%
Price	200	350	400	≥500

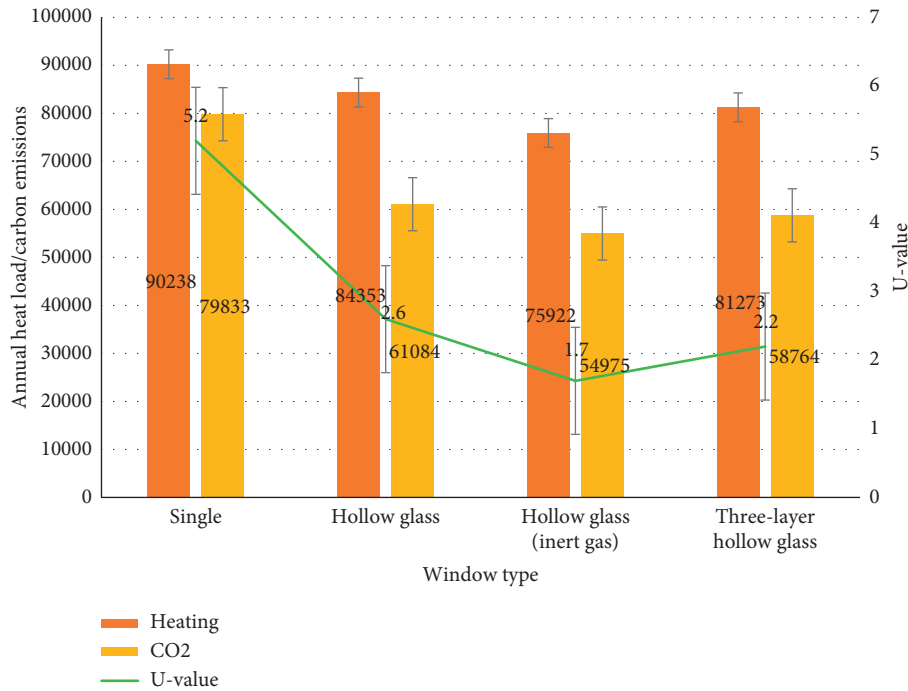


FIGURE 7: Comparison of energy consumption after window renovation.

5. Conclusion

With the continuous development of the national economy and the continuous development of the construction of energy-saving resources, building energy-saving has become an increasingly important part of engineering projects. Due to prejudice and misunderstandings about building energy-saving, the development of energy-saving buildings is hindered to a certain extent. Based on the concept of energy-saving, this paper conducts an in-depth study on the thermal comfort of buildings and concludes that external factors such as wind speed, temperature, and humidity have different degrees of influence on the thermal comfort of the human body. Among them, temperature has the greatest impact, and the choice of building materials is also required, considering the heat transfer coefficient and energy consumption. At the same time, there are some shortcomings in this article. The study of materials in this article only selects the form for transformation research, which is not comprehensive enough. It can also start from

other aspects of the building, and the selected material samples are also relatively small; in addition, for energy conservation, the combination of the concept and the building is also not in place, and there is no certain optimization plan for energy saving. The authors hope that, with the in-depth study of building materials, this research can be further improved. This article's research on the thermal comfort of buildings based on energy-saving concepts has certain significance for the realization of energy-saving and emission reduction in buildings in China. China is now in the industrialization stage of rapid urbanization. The problems of energy scarcity and ecological destruction will be further aggravated. Therefore, it is necessary to continuously improve the level of Chinese energy conservation and environmental protection technology to provide technical support for large-scale energy conservation and emission reduction work. Therefore, building energy efficiency is an inevitable choice for our country to transform the form of development and adjust the economic structure.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by Science and Technology Innovation Team in Key Fields of Shaanxi Province, Resilient Urban and Rural System Planning Theory and Practice Construction System Adapting to Climate Change (2020TD-029).

References

- [1] S.-B. Tsai and K. Wang, "Using a novel method to evaluate the performance of human resources in green logistics enterprises," *Ecological Chemistry and Engineering S*, vol. 26, no. 4, pp. 629–640, 2019.
- [2] A. Zl, A. Dc, A. Rl, and B. Aa, "Artificial intelligence for securing industrial-based cyber-physical systems," *Future Generation Computer Systems*, vol. 117, pp. 291–298, 2021.
- [3] W. Meyer, "Impact of constructional energy-saving measures on radon levels indoors," *Indoor Air*, vol. 29, no. 4, pp. 680–685, 2019.
- [4] A. Middel, N. Selover, B. Hagen, and N Chhetri, "Impact of shade on outdoor thermal comfort-a seasonal field study in Tempe, Arizona," *International Journal of Biometeorology*, vol. 60, no. 12, pp. 1–13, 2016.
- [5] D. Kioupis, S. Tsivilis, and G. Kakali, "Development of green building materials through alkali activation of industrial wastes and by-products," *Materials Today: Proceedings*, vol. 5, no. 14, pp. 27329–27336, 2018.
- [6] W. Poortinga, L. Steg, and C. Vlek, "Environmental risk concern and preferences for energy-saving measures," *Environment and Behavior*, vol. 34, no. 4, pp. 455–478, 2016.
- [7] U. M. Namil and H. Tetsuji, "A hydrometallurgical method of energy saving type for separation of rare earth elements from rare earth polishing powder wastes with middle fraction of ceria," *Journal of Rare Earths*, vol. 34, no. 5, pp. 536–542, 2016.
- [8] C. Armando, A. Lauro, G. Umberto et al., "Energy saving in a water supply network by coupling a pump and a pump as turbine (PAT) in a turbopump," *Water*, vol. 9, no. 1, p. 62, 2017.
- [9] B. M. Todorović and D. Samardžija, "Road lighting energy-saving system based on wireless sensor network," *Energy Efficiency*, vol. 10, no. 1, pp. 1–9, 2016.
- [10] G. Fei, C. Shi, C. Zhang, and L. Hongjie, "Printed smart photovoltaic window integrated with an energy-saving thermochromic layer," *Advanced Optical Materials*, vol. 3, no. 11, pp. 1524–1529, 2016.
- [11] T. H. Arimura, H. Katayama, and M. Sakudo, "Do social norms matter to energy-saving behavior? Endogenous social and correlated effects," *Journal of the Association of Environmental and Resource Economists*, vol. 3, no. 3, pp. 525–553, 2016.
- [12] W. Nie, F.-C. Zheng, X. Wang, W. Zhang, and S. Jin, "User-centric cross-tier base station clustering and cooperation in heterogeneous networks: rate improvement and energy saving," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 5, pp. 1192–1206, 2016.
- [13] O. Arouk, A. Ksentini, and T. Taleb, "Group paging-based energy saving for massive MTC accesses in LTE and beyond networks," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 5, pp. 1086–1102, 2016.
- [14] Y. Guo, L. Duan, and R. Zhang, "Optimal pricing and load sharing for energy saving with cooperative communications," *IEEE Transactions on Wireless Communications*, vol. 15, no. 2, pp. 951–964, 2016.
- [15] P. Xu, Y. Shen, L. Chen, J. Mao, E. Chang, and Y. Ji, "Assessment of energy-saving technologies retrofitted to existing public buildings in China," *Energy Efficiency*, vol. 9, no. 1, pp. 67–94, 2016.
- [16] J. Wang, Y. Wang, D. Zhang, and S. Helal, "Energy saving techniques in mobile crowd sensing: current state and future opportunities," *IEEE Communications Magazine*, vol. 56, no. 5, pp. 164–169, 2017.
- [17] W. Zhou and W. Huang, "Contract designs for energy-saving product development in a monopoly," *European Journal of Operational Research*, vol. 250, no. 3, pp. 902–913, 2016.
- [18] R. Khan and S. U. Khan, "Achieving energy saving through proxying applications on behalf of idle devices," *Procedia Computer Science*, vol. 83, no. 2, pp. 187–194, 2016.
- [19] A. Novikova, T. Csoknyai, and Z. Szalay, "Low carbon scenarios for higher thermal comfort in the residential building sector of South Eastern Europe," *Energy Efficiency*, vol. 11, no. 4, pp. 1–31, 2018.
- [20] M. Dhahri and H. Aouinet, "CFD investigation of temperature distribution, air flow pattern and thermal comfort in natural ventilation of building using solar chimney," *World Journal of Engineering*, vol. 17, no. 1, pp. 78–86, 2020.
- [21] K. Xu, D. Chen, F. Yang, and Z. Zang, "Sub-10 nm nanopattern architecture for 2D material field-effect transistors," *Nano Letters*, vol. 17, no. 2, pp. 1065–1070, 2017.
- [22] Z. Chen, D. Chao, M. Chen, and Z. Shen, "Hierarchical porous LiNi_{1/3}Co_{1/3}Mn_{1/3}O₂ with yolk-shell-like architecture as stable cathode material for lithium-ion batteries," *RSC Advances*, vol. 10, no. 32, pp. 18776–18783, 2020.
- [23] Y. Benjelloun, J. D. Sigoyer, J. Carlut et al., "Characterization of building materials from the aqueduct of Antioch-on-the-Orontes (Turkey) - Sciencedirect," *Journal of Field Robotics*, vol. 33, no. 5, pp. 561–590, 2016.
- [24] S. Shaw, B. Yuan, X. Tian et al., "Building materials from colloidal nanocrystal arrays: preventing crack formation during ligand removal by controlling structure and solvation," *Advanced Materials*, vol. 28, no. 40, pp. 8892–8899, 2016.
- [25] S. Shaw, J. L. Colaux, J. L. Hay, F. C. Peiris, and L. Cademartiri, "Building materials from colloidal nanocrystal arrays: evolution of structure, composition, and mechanical properties upon the removal of ligands by O₂ plasma," *Advanced Materials*, vol. 28, no. 40, pp. 8900–8905, 2016.
- [26] T. Azamov, "Temperature models of technological processes in the production of ceramic building materials," *Acta of Turin Polytechnic University in Tashkent*, vol. 8, no. 1, p. 5, 2018.
- [27] S. V. Piddubnyi, H. O. Tatarchenko, and V. M. Sokolenko, "Express method for the evaluation of the frost resistance of silicate building materials," *Materials Science*, vol. 56, no. 2, pp. 240–246, 2020.