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Thermal Performance Simulation and Model Validation Analysis of Door and Window Frames

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Abstract

The outer window is the focus of energy conservation of building envelope, and the window frame is one of the keys of energy conservation of the outer window. The research of new thermal insulation profile is the key to improve the thermal insulation performance of the outer window. In this paper, the thermal performance of the window frame is studied by combining THERM software simulation and laboratory testing. The calculation results show that the relative deviation between the measured value of the heat transfer coefficient of the three vertical window frame nodes and the simulated value is 4.7%, 3.6% and 4.3%, respectively. The calculated value and the measured value are in good agreement.

Keywords

Frame; Thermal insulation performance; Numerical simulation; Test method.

1. INTRODUCTION

As the weak link of building envelope energy conservation, the outer window is one of the main factors affecting the indoor thermal environment and building energy conservation. Statistics show that the energy consumption of doors and windows accounts for about 40%~50% of the total energy consumption of building envelope, and the heat is mainly lost through the glass, window frame and the connection between glass and frame edge, in which the heat loss through the profile accounts for nearly 50% of the total window heat loss [1], Therefore, it is of great significance to study the performance of window frame to reduce the energy consumption of exterior windows and improve the energy efficiency of buildings.

To study the heat transfer performance of window frames, theoretical calculation, software simulation and laboratory testing [2] are mainly used at home and abroad. Many scholars [3-4] optimize the number of cavity [5], cavity proportion and other factors of window frame system through calculation and simulation, and divide the profile into multi-cavity thermal insulation, so as to reduce the convective heat transfer of air in the cavity and improve the thermal insulation performance of the profile. The theoretical calculation and software simulation results can play a reference role, but the actual heat transfer effect of the window frame still needs to be tested in the laboratory. However, laboratory testing is difficult to conduct large-scale testing due to the impact of cost and actual operation. Therefore, according to the design structure of the new profile, this paper uses the software simulation method to analyze the thermal performance of the profile, and then confirms the thermal insulation performance and energy-saving effect of the new profile through the laboratory test method.

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2. INTRODUCTION TO CALCULATION PRINCIPLE AND SOFTWARE OF THERMAL PERFORMANCE OF WINDOW FRAME

This paper uses THERM software to carry out relevant calculations. Thermal software is a software developed by the Lawrence Berkeley National Laboratory (LBNL) of the United States. It is specially used to handle the nodes of doors, windows and curtain walls. It has the advantages of rich functions, simple operation, accurate calculation, etc.

When using THERM to calculate the heat transfer coefficient of the frame, use a thermal conductivity λ= 0.03W/(m · k) thermal insulation plate replaces the actual glass. The thickness of the plate is equal to the thickness of the replaced glass. The depth of the embedded frame is based on the actual size of the embedded glass. The calculation model of the window frame heat transfer coefficient is shown in Figure 1. The winter boundary conditions [6] used in the simulation calculation are: indoor air temperature 20℃, indoor convective heat transfer coefficient 3.6W/(m^2 · k), and indoor average radiation temperature 20℃; The outdoor air temperature is - 20℃, the outdoor convective heat transfer coefficient is 16W/(m^2 · k), and the outdoor average radiation temperature is - 20℃.

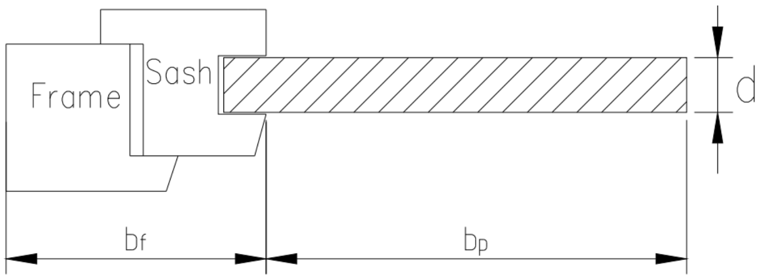

Figure 1. Calculation model of window frame heat transfer coefficient

Under indoor and outdoor standard conditions, calculate the heat flow qw through the section with two-dimensional heat conduction calculation program, and calculate the heat transfer coefficient Uf of the frame according to formula 1-2

$$L_{\mathrm{f}}^{2\mathrm{D}} = \frac{q_{\mathrm{w}}(b_{\mathrm{f}}+b_{\mathrm{p}})}{T_{\mathrm{n,in}}-T_{\mathrm{n,out}}} \quad (1)$$

$$U_{\mathrm{f}} = \frac{L_{\mathrm{f}}^{2\mathrm{D}}-U_{\mathrm{p}}\cdot b_{\mathrm{p}}}{b_{\mathrm{f}}} \quad (2)$$

Where, U_f is the frame heat transfer coefficient, W/(m^2 · k); $L_{\mathrm{f}}^{2\mathrm{D}}$ is the overall linear heat transfer coefficient of the frame section, W/(m · k); Up is the heat transfer coefficient of the plate, W/(m^2 · k); B_f is the projected width of the frame, m; b_p is the width of the visible part of the plate, m.

3. NUMERICAL SIMULATION OF THERMAL PERFORMANCE OF BUILDING EXTERIOR WINDOW FRAME

3.1. Establishment of window frame calculation model

Plastic steel window frame is mainly made of modified rigid polyvinyl chloride as the main raw material, profile steel as the internal frame, and finally welded under high temperature. It

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is characterized by good sealing and thermal insulation performance, and is widely used in building external windows. The standard test piece used in the calculation in this paper is 75 series internally opened three-glass plastic steel window frame, with the size of 1500mm * 1500mm. The heat transfer coefficient of the selected three nodes of the left frame, the middle mullion and the right frame is simulated and calculated. The overall size and node distribution of the window frame are shown in Figure 2.

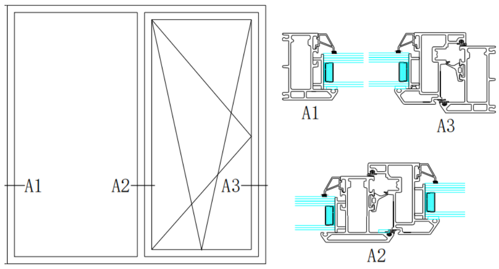

Figure 2. Elevation and node distribution of exterior window

According to the profile design drawing of window frame, after the node is simplified, the node CAD model is established, the simulation is imported into the THERM software, and then the performance parameter information of window frame and internal material is defined. Set the standard calculation boundary conditions in winter, simulate the temperature nephogram of each node (see Figure 3-5), bring the model parameter information and simulation results into formula (1-2), and calculate the heat transfer coefficient U_{fr} of each node.

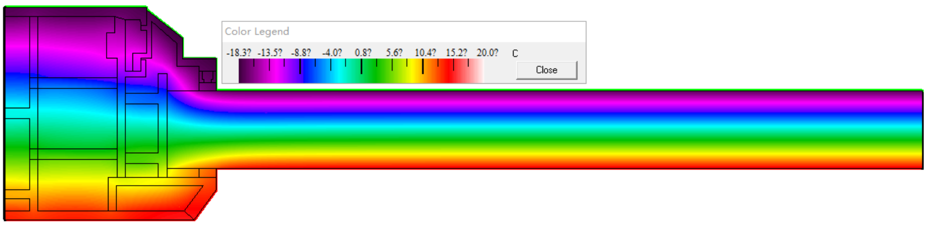

Figure 3. A1 node diagram

The calculation results are as follows: the heat transfer coefficient of the A1 node of the 75 series window frame is 1.138 W/m^2 · k, and the surface temperature of the window frame near the indoor side is about 15℃

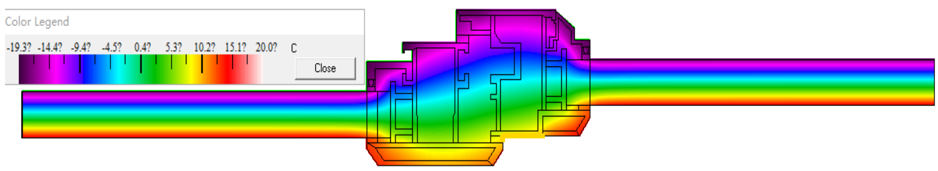

Figure 4. A2 node diagram

The calculation results are as follows: the heat transfer coefficient of the A2 node of the 75 series window frame is 0.942 W/m^2 · k, and the surface temperature of the window frame near the indoor side is about 13℃.

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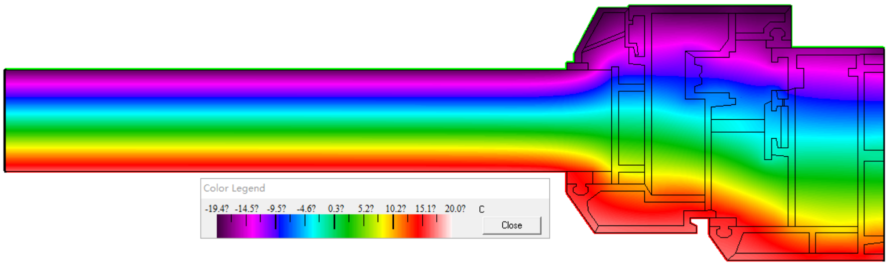

Figure 5. A3 node diagram

The calculation result is that the heat transfer coefficient of the A1 node of the 75 series window frame with inner window is 1.024 W/m² · k, and the surface temperature of the window frame near the indoor side is about 15℃.

4. INTRODUCTION TO DETECTION DEVICE AND PRINCIPLE

Through simulation calculation, it can be seen that the heat transfer coefficient of the three frame joints can reach 1.1 W/m² · k. In order to further verify the thermal insulation effect of the frame joints, the heat transfer coefficient of the fabricated frame profiles is tested in the laboratory according to GB/T 8484-2020 Test Method for Thermal Insulation Performance of Exterior Windows and Doors of Buildings.

The calibration hot box method based on the principle of steady heat transfer is used in the experiment to detect the heat transfer coefficient of the exterior doors and windows of the building. One side of the test piece frame is a hot box, which is used to simulate the indoor temperature conditions of the heating building in winter; The other side is a cold box to simulate the outdoor temperature in winter. On the basis of strict sealing treatment for the gap between the frame and the filler plate of the test piece, under the condition that both sides of the test piece maintain constant temperature, air velocity and thermal radiation, after several hours of operation, the whole device reaches a stable state. The heat transfer coefficient of the test piece can be calculated by measuring the thermal parameters of the box on both sides of the test piece.

$$K_{\mathrm{f}} = \frac{Q - M_1 \cdot \Delta\theta_1 - M_2 \cdot \Delta\theta_2 - S_1 \cdot \Lambda_1 \cdot \Delta\theta_3 - S_2 \cdot \Lambda_2 \cdot \Delta\theta_4 - \Phi_{\mathrm{edge}}}{A \cdot (T_1 - T_2)} \cdots\cdots \quad (3)$$

Where: M_1 is the heat flow coefficient of the hot box wall, W/K; M_2 is the heat flow coefficient of the test piece frame; $\Delta\theta_1$ is the weighted average temperature difference between the inner and outer surfaces of the hot box, K; $\Delta\theta_2$ is the weighted average temperature difference between the inner and outer surface areas of the test piece frame; $\Delta\theta_3$ is the average temperature difference on the surface of the filler plate around the test piece, k; $\Delta\theta_4$ is the average temperature difference on the surface of the filler plate inside the test piece, K; S_1 is the area of the filler plate around the test piece frame, m²; S_2 is the area of the inner filler plate of the test piece, m²; Λ_1 is the thermal conductivity of the filler plate around the test piece, W/m² · k; Λ_2 is the thermal conductivity of the inner filler plate of the test piece, W/m² · k; Φ_{Edge} is the heat transfer of the edge line between the test piece and the surrounding filler plate, W/K;

5. VERIFICATION ANALYSIS OF MODEL HEAT TRANSFER COEFFICIENT

5.1. Test process

Test the heat transfer coefficient of A1, A2 and A3 nodes respectively, install the window frame test piece on the equipment test piece frame, use polystyrene foam filler board to fill the

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glass part inside the window frame and the filler board around the frame, and use polyurethane foam adhesive to seal around. T-type thermocouple is used as the temperature sensor, and the thermocouple and the test piece are pasted with tinfoil and transparent tape. When testing the heat transfer coefficient of the three window frame nodes, the set temperature of the cold box is -20℃, the set temperature of the hot box is 20℃, and the ambient temperature is 20℃. After starting the equipment, after the air temperature in the hot box and the cold box reaches the set value, and the heat transfer process of the whole experimental system is stable, record the data every 30 minutes, and test a total of 6 times. After the test is completed, observe the temperature and power change curve with time during the test process, Select a relatively stable section of data to calculate the heat transfer coefficient.

It can be seen from Figure 6 that during the detection of A1 node, the curve tends to be flat after 4:40, the temperature fluctuation range gradually decreases, the temperature fluctuation range of hot box is 19.96℃~20.14℃, and the temperature fluctuation range of cold box is -20.04℃~-19.90℃; It can be seen from the power change curve with time that at the beginning of the experiment, the power of the electric heater fluctuated significantly. After 4 hours of operation, the final power of the electric heater stabilized between 230.20W and 232.52W. During the detection of nodes A2 and A3, when the temperature fluctuation amplitude of the cold box is not more than 0.3k, and the temperature fluctuation amplitude of the hot box is not more than 0.2K, and the above temperature and temperature difference changes are not unidirectional, it means that the heat transfer process of the system is stable and data collection can be performed.

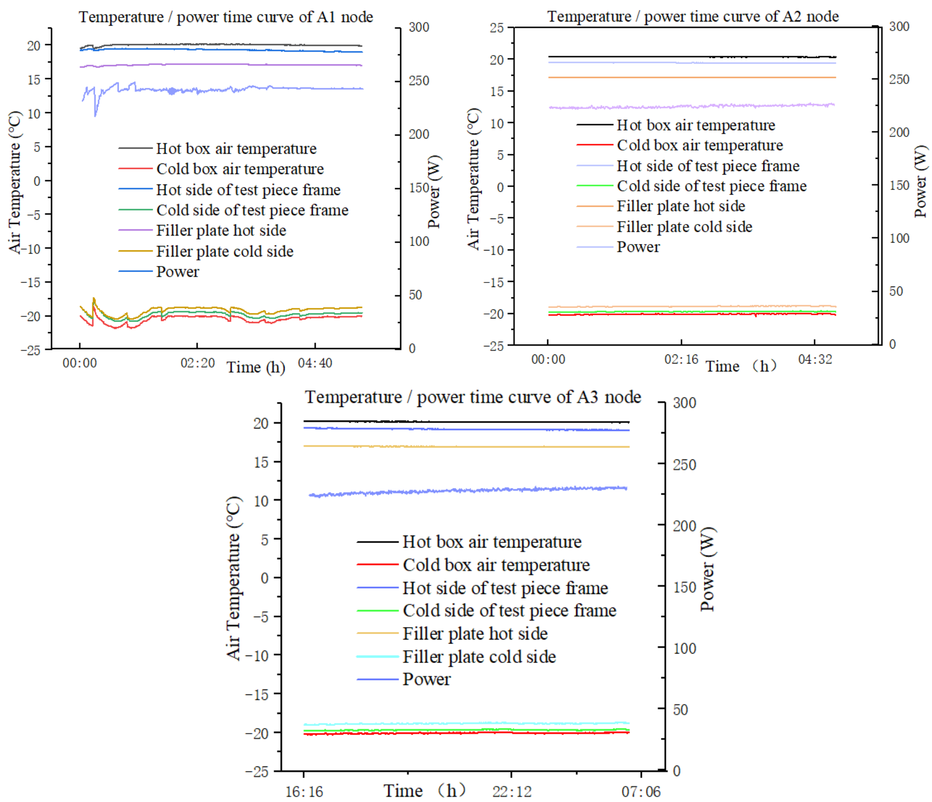

Figure 6. Temperature/power-time change curve during detection

5.2. Analysis of test results

Summarize the measured value and calculated value. Under the same indoor and outdoor boundary conditions, through comparison, it is found that the variation trend of the measured value and the simulated value is consistent, but the overall calculated value is relatively large.

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The main reason is that the model is simplified during the simulation process, resulting in a slight deviation between the calculated value and the measured value. The relative difference between the measured value and the calculated value of A1, A2 and A3 nodes is 4.7%, 3.6% and 4.3% respectively. From the above error calculation, it is shown that the simulated calculation results of the window frame heat transfer coefficient in this paper are in good agreement with the measured values, and meet the requirement that the deviation between the measured value and the calculated value is less than 5% in the Guidelines for Energy Efficiency Identification of Building Doors and Windows, and the test data are valid.

Table 2. Calculation result analysis of node heat transfer coefficient

Node	Measured value W/m²·k	Simulated value W/m²·k	Difference W/m²·k	Relative difference %
A1	1.087	1.138	0.051	4.7
A2	0.909	0.942	0.033	3.6
A3	0.982	1.024	0.042	4.3

Note: relative difference=(simulated value - measured value)/measured value

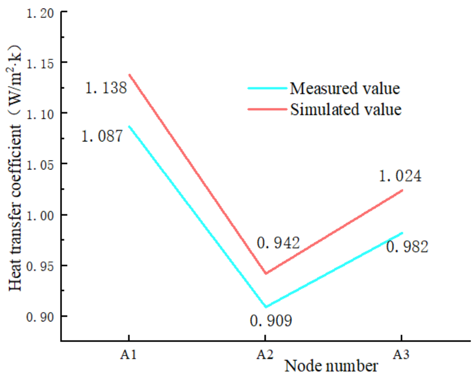

Figure 7. Comparison of measured and simulated values

6. CONCLUSION

The heat transfer coefficients of three new vertical window frame joints were accurately measured using the calibrated hot box method. The test results showed that the temperature distribution on the hot side of the window frame was consistent with the measured temperature distribution; The heat transfer coefficients of the three vertical window frame nodes are 1.087W/($m^2 \cdot k$), 0.909W/($m^2 \cdot k$) and 0.982 W/($m^2 \cdot k$) respectively. The relative deviation between the calculated value and the measured value is within 5%, and the data is in good agreement. The physical model of the surface based on the window frame system is highly reliable. The simulation calculation is a convenient, fast and accurate calculation method, which plays a certain role in the subsequent research on the thermal performance of the window frame.

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