Analysis of Distribution Characteristics and Influencing Factors of Ambient Temperature Field in Buildings

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Abstract. To address the uneven distribution of the thermal environment in buildings and the temperature deviation between the end temperature sensing devices and the thermal environment of the work area, this paper presents a simulation and experimental study of the indoor temperature distribution characteristics and its influencing factors, taking an office in a northern area as the research object. Firstly, a three-dimensional model of the building is constructed based on ANSYS software to simulate the indoor temperature distribution characteristics in summer and winter under the influencing factors of outdoor environment, building orientation, window-to-wall ratio (WWR), and the form and arrangement of indoor terminals. Secondly, based on the simulation and experimental data, the effect of different influencing factors on indoor temperature is analysed, and a formula for fitting the WWR to indoor temperature and a formula for fitting the temperature deviation between the temperature sensor and the working area with the characteristics of influencing factors is proposed, laying a theoretical foundation for indoor temperature end control technology.

1 Introduction

People spend most of their time indoors and as indoor temperature is a complex physical field, it is influenced by many factors, so currently most buildings have an uneven distribution of indoor temperature, making the location of temperature sensors have a great impact on indoor environmental measurement data, which in turn affects the effectiveness of indoor temperature control and the comfort of indoor personnel. People are always accustomed to place indoor temperature sensors near the return air outlet or in an easy-to-install location, and it is not known whether the temperature at this location is representative of the average temperature of the indoor working area. This paper establishes a complete simulation model of the office interior structure and conducts a comparative analysis of the effect of various end forms on indoor temperature.

Jiang[2] took the classroom of a primary school as the object of study, and tested the horizontal and vertical temperature distribution of the classroom. Wang[3] established a mathematical model for numerical calculations and investigated the relationship between WWR and thermal comfort. Shan[4] combined CFD and wireless sensors to study the PMV distribution of the radiation model. The environmental parameters in the office with fan coils were given by simulation and then combined with experimental data to predict the indoor thermal environment parameters. Asumadu-Sakyi[5] studied the daily variation pattern of indoor temperature and quantified the effect of outdoor temperature on indoor temperature as well as other regulating factors, and the results showed that every 1°C increase in outdoor temperature would lead to a 0.41°C increase in indoor temperature. It has also been proposed to replace the return air temperature with the characteristic zone temperature for large space structures to provide feedback on the indoor temperature[6]. However, existing research models are not detailed enough and do not quantify the relationship between room temperature and thermostat temperature.

Therefore, in this paper, for a northern office, based on a combination of simulation and experiment, we study the characteristics of indoor temperature field distribution, analyse the influence of different factors on room temperature, and explore the temperature deviation between indoor working area and thermostat qualitatively and quantitatively.

2 Methods

2.1 Numerical simulation

In this paper, an office in Jilin City was studied, with two rooms, large and small, each with a small air conditioner, denoted by AC1, AC2, respectively, with a supply air angle of 30° upwards horizontally. The size of the office is 10.2m × 7.75m × 3.6m. The windows face east, the personnel sitting posture is simplified to a rectangular shape, and grid-independence has been verified as shown in Fig. 1 and Fig. 2. Among them, point 1 and point 2 are the central position of the room and the heights are 0.6m and 1.7m respectively.

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This simulation is carried out by CFD software, and the specific settings of Fluent are listed in Table 1.

Table 1. Fluent Parameter Setting.

| Item  | Font   | Spacing       |
|-------|--------|---------------|
| Solver| Type   | Pressure-Based|
|       | Time   | Steady        |
| Gravity| Y      | -9.81(m/s²)  |
| Model | Energy equation | On          |
|       | Fluid  | RNGk-e        |
|       | Radiation | Solar Loading |

Among them, the internal heat source has 16 computers, 16 people, 6 lamps and 1 refrigerator. The enclosure structure is set according to the actual building. The air velocity and temperature of the air outlet of the small air conditioner were set according to the measured data of the hotwire anemometer. Velocity-inlet was used as the inlet boundary, and the actual measured air velocity of AC1 was 1.5m/s and the air temperature was 12°C. The air velocity of AC2 was 4m/s and the air temperature was 17°C.

2.2 Experimental setup and validation

Experiment with real-time temperature display using Configuration King. Fig. 3 and Fig. 4 show the experimental apparatus and set-up.

Fig. 3. Diagram of the measuring instrument

Fig. 4. Tripod instrumentation diagram

The simulated values were lower than the measured values in the lower part of the room, which was due to the fact that the measuring point was located directly in front of the air conditioning outlet, at a distance of about 3 m. The irregular entry and exit of people, the opening and closing of doors and curtains during the experiment will also have some influence on the measured values.

As can be seen from Fig. 5, the data shows a large temperature gradient in the height of the room, while the measured data shows that the room temperature varies less in height, which is due to the high outdoor temperature on that day and the poor cooling effect of the small air conditioner, which cannot achieve the simulated cooling effect and cannot bring the room temperature down to within the comfort range of the personnel. The sudden drop in temperature near the ground is due to the fact that the measurement point is located 3m directly in front of the air outlet. The direct blowing of cold air will have an effect on the sensor.

Fig. 5. Model validation

2.3 Different heating methods in winter

The office is heated by fan coils, geothermal coils and radiators respectively, to study the characteristics of indoor temperature distribution in different heating methods, and one method can be turned on separately in the office for measurement. The physical diagram of each heating method is shown in Fig. 6.

Fig. 6. A realistic view of the three types of heating
3 Simulation and experimental results

3.1 Indoor thermal environment in summer

As AC1 is placed in a small room, for the comfort of the personnel, the airflow from the air conditioner is set at a lower air speed to ensure that only the area where the personnel are located is in a low temperature state. The temperature distribution in the upper part of the room is even, and the higher the height of the room, the higher the temperature. A comparative analysis of the simulation results for temperature clouds at different heights of the horizontal plane throughout the office, at 0.1m, 0.6m, 0.9m, 1.6m, 2.5m and 3.5m respectively, is shown in Fig. 7.

![Fig. 7. Office temperature cloud at different height levels.](image)

3.2 Experimental measurements with different heating methods

Figure 8 shows the time-to-time change in indoor temperature for the three heating methods. The simulation results show that the overall room temperature is high, with the highest temperature reaching 35°C in the space above the external windows. Due to the hollow structure of the building and the use of glass roofing, the temperature of the corridor on the external side of the internal wall reaches 32°C. The simulation takes into account the heat dissipation of computers and the human body, and is set according to the maximum number of workstations, which also causes the overall temperature of the room to be high.

![Fig. 8. Room temperature for three types of heating](image)

![Fig. 9. Vertical temperature cloud map of three heating methods](image)

The fan coil working condition when the temperature fluctuates more in the upper part of the room, the highest temperature measured at 3.5m is about 33°C and the lowest is about 28°C. When the temperature measurement point detects that the room temperature reaches the set value when it stops working due to the characteristics of automatic opening and closing Resulting in large temperature fluctuations at the measurement point at 3.5m. The lower part of the room with radiant floor heating has a higher temperature than the other two methods. Table 2 quantifies and compares the three types of heating.

| Heating method       | Vertical temperature difference (°C) | Fluctuation factor |
|----------------------|--------------------------------------|--------------------|
| Fan Coil Heating     | 7.1                                  | 0.028              |
| Geothermal coils heating | 1.1                                  | 0.131              |
| Radiator heating     | 2.1                                  | 0.015              |

![Table 2. Comparison of the heating methods](image)
3.3 Characterisation of room temperature variation under the combined effect of multiple factors

The effects of summer and winter outdoor temperature, air conditioning temperature, air velocity and WWR on indoor temperature were simulated for 81 sets of working conditions with 4 factors and 3 levels in Table 3. Multiple linear regression analysis was performed on the simulation results to obtain the fitted equations for the influencing factors.

### Table 3. 4-factor 3-level orthogonal test

| WWR | Air conditioning temperature (°C) | Outdoor temperature (°C) | Air conditioning air speed (m/s) |
|-----|----------------------------------|-------------------------|---------------------------------|
| 0.149 | 0.0118x₁ + 0.265x₂ − 2.529x₃ + 2.735x₄ |
| 0.313 | 0.1557 + 0.01x₁ + 0.355x₂ − 0.105x₃ + 4.99x₄ |
| 0.451 | 0.28105 + 0.0118x₁ + 0.265x₂ − 2.529x₃ + 2.735x₄ |
| 0.313 | 0.28105 + 0.0118x₁ + 0.265x₂ − 2.529x₃ + 2.735x₄ |

The larger the regression coefficient, the greater the influence of the factor on the indoor temperature. In winter, the WWR has the greatest influence.

The multiple linear regression equation for indoor temperature in summer is shown in the following equation:

\[ y = 28.105 + 0.0118x_1 + 0.265x_2 - 2.529x_3 + 2.735x_4 \]  \hspace{1cm} (1)

The multiple linear regression equation for indoor temperature in winter is shown in the following equation:

\[ y = 15.557 + 0.01x_1 + 0.355x_2 - 0.105x_3 + 4.99x_4 \]  \hspace{1cm} (2)

The sensor position was set at a position next to the door, with a certain deviation from the office work area temperature. A multivariate linear fit of this deviation to the four influencing factors was carried out to obtain the effect of the four factors on this temperature deviation.

The multiple linear regression equation for the temperature deviation of the summer sensor is shown below:

\[ y = 28.105 + 0.0118x_1 + 0.265x_2 - 2.529x_3 - 0.304x_4 \]  \hspace{1cm} (3)

The multiple linear regression equation for the temperature deviation of the winter sensor is shown below:

\[ y = 2.528 + 0.007x_1 - 0.04x_2 - 0.038x_3 + 0.922x_4 \]  \hspace{1cm} (4)

There are four independent variables, \(x_1\) represents the outdoor temperature, \(x_2\) represents the air conditioning temperature, \(x_3\) represents the air conditioning air speed, and \(x_4\) represents the WWR, \(y\) represents the dependent variable indoor temperature.

According to the regression equation of the temperature deviation between the sensor and the working area in summer, it can be seen that the influence of the outdoor temperature on the temperature deviation is in the order of 10^-4. This is due to the fact that the outdoor temperature affects both the working area temperature and the sensor temperature, causing both to increase or decrease at the same time, so this influence factor can basically be ignored, and the air-conditioning air speed and WWR have a greater influence on the temperature deviation.

### 4 Conclusions

1. The temperature in the office is high at the top and low at the bottom, the temperature distribution is uniform in the upper half of the office, while the temperature distribution is uneven in the lower half of the office due to the existence of vortices inside the desk.
2. The temperature change in the office under different heating methods is obtained. The maximum disturbance of indoor temperature in the fan coil condition is 7.1°C; the lower temperature in the radiant floor condition is about 1°C higher than the other methods; the overall room becomes higher in the radiator condition and the heating effect is better.
3. The equation for fitting the indoor temperature under the combined effect of multiple factors in winter and summer conditions is obtained. In summer conditions, the WWR and the air velocity at the outlet of the cold source have a greater influence on the indoor temperature, while the outlet temperature of the cold source and the outdoor temperature have a smaller influence on the indoor temperature. The outdoor temperature has a negligible effect on the temperature deviation of the sensor and the working area; in winter conditions, the WWR has the greatest effect on the indoor temperature.

### References

1. R. Niu, Estimated best location for air conditioning indoor temperature sensor, Ph.D. Thesis, Chang’an University, (2018)
2. J. Jiang, D J. Wang, and Y F. Liu, “Winter non-uniform temperature distribution tests in primary and secondary school classrooms in the North West Countryside,” Journal of Xi’an Engineering University, vol. 33, pp. 494-498, (2019)
3. G. Wang, W Y. Wang, M H. Cui, “Study of the effect of window-to-wall ratio on indoor thermal comfort index PMV,” Hebei Industrial Technology, vol. 31, no. 1, pp. 87-90, (2014)
4. X F. Shan, W. Xu, Y K. Lee, et al, “Evaluation of thermal environment by coupling CFD analysis and wireless-sensor measurements of a full-scale room with cooling system,” Sustainable Cities & Society, vol. 45, pp. 385-405, (2019)
5. A B. Asumadu, A G. Barnett, P. Thai, et al, “The relationship between indoor and outdoor temperature in warm and cool seasons in houses in Brisbane, Australia,” Energy and Buildings, vol. 191, no. 5, pp. 127-142, (2019)
6. J L. Feng, “Thermal comfort study and optimization of energy saving control at the end of air conditioning in a shopping mall,” Ph. D. Thesis, South China University of Technology, (2014)