Discussion on fresh air volume in Temperature and Humidity Independent Control of Air-conditioning System

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Abstract. The fresh air volume in Temperature and Humidity Independent Control of Air-conditioning System (THIC) of a typical office was confirmed, under the premise of adopting the refrigeration dehumidifying fresh air unit (7°C/12°C). By detailed calculating the space moisture load and the fresh air volume required for dehumidification in 120 selected major cities in China, it can be inferred that the minimum fresh air volume required for dehumidification in THIC is mainly determined by the local outdoor air moisture and the outdoor wind speed; Then the mathematical fitting software Matlab was used to fit the three parameters, and a simplified formula for calculating the minimum per capita fresh air volume required for dehumidification was obtained; And the indoor relative humidity was simulated by the numerical software Airpak and the results by using the formula data and the data for hygiene were compared to verify the reliability of the simplified formula.

1. Introduction
In conventional air conditioning systems, the minimum per capita fresh air volume required for indoor hygiene requirements is a certain value [1]. As for the office building, the minimum per capita fresh air volume of office buildings is 30m³/(h·person).

However, in the THIC System, the dehumidification task is completed by handled dry fresh air, However the dehumidification capacity of the fresh air is limited, so the impact of outdoor air infiltration in summer is more obvious and should be considered [2-3]. In addition, most of the newly-built buildings in recent years have adopted glass curtain walls. The window-to-wall ratio of many large-scale public buildings is even higher than 0.8. Therefore, the outdoor air infiltration moisture production generated by the outer door and the outer window is increasingly larger. Analyzing the projects that have been in operation, it is found that if there is no adequate consideration for the outdoor infiltration wind at the time of design, there will be some deviation in the control of indoor humidity.

2. Methods

2.1. The establishment of a basic physical model
A typical office was selected as the physical model, as shown in figure 1. The length, width and height of the office are respectively 8m, 6m and 4m. The length and width of the glass wall on the exterior wall are 6m and 4m, respectively. The others are all interior walls. The air outlet is set on the inner wall, and the length and width are 0.6m and 0.3m respectively. The outdoor air unit adopts the refrigeration dehumidification way to deal with the fresh air. The indoor design temperature is 25°C, relative humidity 60%, density of personnel 0.17 person/m².
2.2. Space moisture load calculation

Moisture gain:

\[ W_i = W_h + W_s + W_i, \]  

(1)

Where, \( W_i \) (g/kg) is moisture gain; \( W_h \) (g/kg) is moisture gain from occupant; \( W_s \) (g/kg) is moisture gain from surface of opening water; \( W_i \) (g/kg) is moisture gain from outdoor air infiltration.

Moisture gain from occupant \(^6\):

\[ W_h = g \cdot n \cdot \beta, \]

(2)

Where, \( g \) (g/h) is the amount of adult men's moisture at different room temperatures and different intensities; \( n \) (p) is the total number of people in the room; \( \beta \) is the personnel clustering coefficient.

Moisture gain from surface of opening water \(^5\):

\[ W_s = 0.00363 + 36(a = w B'BP v W q b s), \]

(3)

Where, \( a \) (kg/(N·s)) is the mass diffusion coefficient at different water temperatures; 0.00363 (kg/(N·m)) is the conversion factor; \( v \) (m/s) is the air velocity at water surface, m/s; \( P_{aq} \) (Pa) is partial pressure of water vapor in saturated moist air; \( P_q \) (Pa) is the partial pressure of water vapor in air; \( A_w \) (m²) is the surface area of water body; \( B \) (Pa) is the standard atmospheric pressure; \( B' \) (Pa) is the local atmospheric pressure.

Moisture gain from outdoor air penetration \(^6\):

\[ W_i = 105(l + 0.42(\rho/\Delta w)(\omega_0 - \omega_r)(0.105C_r v^2 h^{0.4})^{-b}, \]

(4)

Where, \( l \) (m) is the sum of the gap lengths of the outer doors and outer windows; \( a \) (m³/(m·h·Pa)) is the gap infiltration coefficient of the outer doors and outer windows; \( \rho \) (kg/m³) is the density of the air under outdoor calculation temperature; \( \beta \) is air permeability index of the doors and windows gap, the index is in the range of 0.56~0.78; \( \omega_0 \) (g/kg) is the outdoor air moisture content; \( \omega_r \) (g/kg) is the indoor design moisture content; \( C_r \) is the thermal pressure coefficient; \( v \) (m/s) is the average outdoor wind speed; \( h \) (m) is the height of the centerline of the door and window from the outdoor ground.

2.3. Determination of fresh air requirement

The fresh air in the Temperature and Humidity Independent Control of Air-conditioning System is responsible for the indoor dehumidification task, therefore there is a certain coupling relationship between the fresh air requirement and the supply air parameters. The relationship is like formula (5).

\[ G = W_i \cdot (\rho/\Delta w), \]

(5)

Where, \( G \) (m³/h) is the total fresh air requirement; \( \rho \) (kg/m³) is the air density of fresh air; \( \Delta w \) (g/kg) is the difference between the space design moisture content and the supply air moisture content.
According to the above thought, 120 sets of data are calculated. The following is a table of partial city data for minimum per capita fresh air requirement needed for dehumidification. There is Table 1.

| City      | Moisture content (g/kg) | Wind speed (m/s) | Fresh air requirement (m³/h) |
|-----------|-------------------------|------------------|------------------------------|
| Wuhan     | 22                      | 3.6              | 47                           |
| Fuzhou    | 21.1                    | 3.4              | 43                           |
| Nanjing   | 21.6                    | 2.4              | 38                           |
| Zhengzhou | 20.4                    | 2.2              | 35                           |
| Beijin    | 18.8                    | 2.2              | 32                           |
| Hanzhou   | 18.8                    | 1.7              | 30                           |

3. Results and discussion

3.1. Fitting among fresh air requirement and outdoor air moisture and wind speed

The following is a ternary quadratic equation that needs to be fitted [7]:

\[ g = b_1 + b_2 \omega + b_3 \omega^2 + b_4 v + b_5 v^2 + b_6 \omega v, \]

where, \( b_1 \) to \( b_6 \) are unknown coefficients. The relationship between \( g, \omega, \) and \( v \) is obtained by finding the values of \( b_1, b_2, b_3, b_4, b_5, \) and \( b_6 \) in the formula.

After multiple regression analysis using the regress function in Matlab mathematical simulation, the output is shown in Figure 2 and Figure 3.

\[
\begin{align*}
    b &= \\
    &= \begin{bmatrix}
        25.1250 \\
        -0.0063 \\
        -0.0613 \\
        0.0267 \\
        -9.2095 \\
        0.7467 
    \end{bmatrix}
\end{align*}
\]

Figure 2. Relationship among outdoor air volume and outdoor moisture content and wind speed

The output of Figure 3 above is the values of \( b_1, b_2, b_3, b_4, b_5, \) and \( b_6 \) in order. Therefore, the relationship among \( g, \omega, \) and \( v \) is:

\[ g = 25.125 - 0.0063 \omega^2 - 0.0613 \omega + 0.02674 v^2 - 9.2095 v + 0.7467 \omega v, \]  

\[ (7) \]

3.2. Further simplification

Because the formula above is a simplified formula fitted, it can be further analyzed and simplified. According to outdoor air moisture content and outdoor wind speed, the formula can be further simplified as:

\[ g = 22.5 - 9.2 v + 0.75 \omega v, \]  

\[ (8) \]
Where, \( g \) (\( m^3/(person \cdot h) \)) is the minimum per capita fresh air requirement needed for dehumidification; \( \omega \) (\( g/kg \)) is the outdoor air moisture content; \( v \) (\( m/s \)) is the average wind speed with the most outdoor wind direction at the reference altitude.

After the simplified formula was obtained, it was used to calculate the minimum per capita fresh air requirement needed for dehumidification in 120 cities of China, and the calculated results of the simplified formula were compared with the previous detailed calculation results. It can be seen that the deviation between them is very small, with an average deviation of \( \pm 0.92 m^3/(person \cdot h) \), which is in line with expectations, so the simplified formula is relatively reasonable.

3.3. Numerical Simulation

After obtaining the simplified formula, it can be used to calculate the per capita fresh air requirement needed for dehumidification. Take Nanjing for example \( g = 39.3 m^3/(person \cdot h) \). The data was input into the model, and then Airpak3.0 was used for numerical simulation and calculation \([8]\). The relative humidity in the room is shown in figure 4.

![Figure 4. Simulation results of calculating air requirement simplified formula in nanjing](image)

![Figure 5. Simulation results of health requirement air volume in nanjing](image)

It can be seen from figure 4 that the highest indoor relative humidity is about 65%; the minimum relative humidity is about 55%; in the working area, the relative humidity is about 60%; therefore, it is in line with the initial value of 60%.

Also in Nanjing, if the per capita fresh air requirement needed for hygiene requirements is given, the simulated results of indoor relative humidity are shown in figure 5.

![Figure 4. Simulation results of calculating air requirement simplified formula in nanjing](image)

It can be seen from figure 5 that the highest indoor relative humidity is about 72%; the minimum relative humidity is about 65%; in the working area, the relative humidity is close to 70%; therefore, there is a large difference from the initial value of 60%. Because 65% of the indoor relative humidity is the upper limit of human comfort, and mold begins to appear if the relative humidity is above 70% \([9]\). Therefore, in this environment, the minimum per capita fresh air requirement needed for hygiene requirements (\(30 m^3/(person \cdot h)\)) cannot complete the dehumidification task well.

4. Conclusions

By detailed calculating the per capita fresh air volume required for dehumidification, fitting simplified formula and simulating relative humidity, the following main conclusions can be obtained:

1) If the building which uses Temperature and Humidity Independent Control Air-conditioning System needs to consider the influence of outdoor air infiltration, if the outdoor air moisture content is significantly higher than the indoor air moisture content and the Dedicated Outdoor Air System adopts
refrigeration dehumidifying, the minimum per capita fresh air requirement needed for hygiene requirements cannot meet the indoor dehumidification task. Therefore, we need to increase the per capita fresh air requirement to meet the indoor dehumidification requirements.

(2) In the case of knowing local outdoor air moisture content and outdoor wind speed, the formula for per capita fresh air requirement needed for dehumidification in office building is: \( g = 22.5 - 9.2v + 0.75 \omega v \). Where, \( g \) is the minimum per capita fresh air requirement needed for dehumidification, \( m^3/(\text{person} \cdot \text{h}) \); \( \omega \) is the outdoor air moisture content, \( g/\text{kg} \); \( v \) is the outside average wind speed of the most wind direction, \( \text{m/s} \).

(3) Through the simulation and comparison of indoor relative humidity, in order to obtain a relatively comfortable indoor environment, it can be inferred that when the per capita fresh air volume required for dehumidification is larger than the per capita fresh air volume required for hygiene requirements, the simplified formula of Conclusion (2) is adopted as the standard for selecting fresh air volume reasonably.

These conclusions can provide a reference for the preliminary determination of the fresh air requirement in the actual project of the application of the Temperature and Humidity Independent Control Air-Conditioning System.

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