A STUDY ON THE INFLUENCE OF DIFFERENT BLOWING SYSTEMS ON INDOOR THERMAL ENVIRONMENT AND AIR QUALITY IN UNDERFLOOR AIR CONDITIONING SYSTEM

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Abstract. The purpose of this study is to investigate the most effective blowing method of underfloor air conditioning system from the viewpoint of comfort and ventilation performance using CFD simulation. In this study, we simulated three types of air blowing systems: floor radiation, floor-supply displacement air-conditioning, and floor chamber. Then, comfort was evaluated from thermal environment and PMV, and ventilation performance was evaluated from air age. As a result, the floor radiation system was able to maintain comfort. However, it was found that the floor-supply displacement air-conditioning system and the floor chamber system caused a great deal of discomfort because the temperature difference between the top and bottom was easily observed. In terms of ventilation performance, it was confirmed that ventilation was efficient in all methods. Of these, the floor-supply displacement air-conditioning system was found to be the most efficient.

1 Introduction

In recent years in Japan, there has been a need to improve the thermal comfort of workers and intellectual productivity in office spaces. In addition, it is essential for buildings to be energy efficient. Underfloor air conditioning system is often used in large office space for comfort and energy efficiency. And the living environment varies greatly depending on the blowing method. In addition, Covid-19 infections spread and impacted on a global scale. In the field of building equipment, ventilation performance is also considered important as a measure against infection.

In this study, Simulations will be conducted for each blowing method of the floor blowing air conditioning system. Based on the results obtained, the thermal environment, PMV, and air age in the space are compared and examined. The most effective blowing system in terms of comfort and ventilation properties will be investigated.

2 Simulation Overview

2.1 Outline of the blowing method

we simulated three types of air blowing systems: floor radiation, floor-supply displacement air-conditioning, and floor chamber. The floor radiation system blows air conditioning air directly onto the floor panel. It is a combination of radiation by cooling or heating the floor panel and floor blowing from near the perimeter. The floor-supply displacement air-conditioning system supplies air conditioning air from the entire floor. The floor chamber system uses the space under the double floor as the air supply path and blows airflow from the floor outlet. Figure 1, Figure 2, and Figure 3 show the system overview of each blowing method.

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2.2 Simulation conditions

Table 1 shows the analysis conditions for the simulation, and Tables 2, 3, and 4 show the conditions for each blowing method. Figure 4 shows the locations of the measurement points. The measurement points are p1~p6 in the living area and p7 in the perimeter area.

The analysis software used was STREAM_v2021.1. The analysis method is steady state analysis. The space is 14.76m*7.02m*5.52m, simulating an office. The air supply is from the floor. The return air was natural outflow from the north side. Solar radiation was assumed to be 1:00 p.m. on September 22 in Yamaguchi City, Yamaguchi Prefecture, and 497 w/m² was given to the space. Human body heat generation was set at 100w/(m²*person) for 15 people, assuming light work. The heat generated by lighting was set at 40 (w/light) for 10 lights. The outdoor air temperature was 34°C assuming cooling operation in summer. Set Case 1 as 19°C blowout temperature, Case 2 as 21°C blowout temperature, and Case 3 as 23°C blowout temperature. The total airflow rate was 2880 m³/h for all systems.

In the floor radiation method, a 5000 mm*90 mm outlet is provided in the perimeter section, and air-conditioned air is blown from the outlet. In the floor-supply displacement air-conditioning method is blown from the entire floor. The floor chamber system has 36 air outlets of 200mm*200mm evenly distributed in addition to one air outlet in the perimeter section, for a total of 37 air outlets.

3 Comfort in the space

A comparison of the indoor thermal environment and PMV will be made based on the simulation results for each blowing method. PMV is a 7-level rating of environmental conditions from +3 to -3 based on subjects' reports of their sensory experiences: +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), and -3 (cold). The range of -0.5 to +0.5 is considered comfortable. The PMV in this study is calculated as 0.6 clo of clothing, 1.2 metabolic rate, and 50% humidity. In terms of evaluation criteria, a thermal environment is considered comfortable if the temperature is between 25°C and 28°C, PMV is within ±0.5, and the difference in air temperature between the foot (FL+0.1m) and head (FL+1.1m) is within 3°C.

Table 1. The analysis conditions for the simulation

| Simulation software | STREAM_v2021.1 |
|---------------------|----------------|
| Simulation method   | Steady-state analysis |
| Turbulence model    | Standard k-ε model |
| Simulation type     | Temperature analysis/ Radiation/ Ventilation efficiency |
| Analysis area       | 14.76m(X)*7.02m(Y)*5.52m(Z) |
| Air supply method   | Floor blowing air conditioning |
| Return method       | Natural outflow |
| Thermal boundary    | Material surface emissivity (0.9) |
| Solar radiation condition | 497w/m² |
| Heating conditions  | Human:100w/person*15people Lighting:40w/light*10 lights |
| Outside air temperature | 34°C |
| Blowing temperature | Case1:19°C Case2:21°C Case3:23°C |

Table 2. Detailed conditions for floor radiation method

| Outlet size | Under-floor duct section:30mm*30mm Perimeter section:5000mm*90mm |
|-------------|------------------------------------------------------------------|
| Blowing air volume | 720m³/h*duct *4ducts |
| Aperture ratio | Perimeter section:50% |

Table 3. Detailed conditions for floor-supply displacement air-conditioning method

| Outlet size | - |
|-------------|---|
| Blowing air volume | 720m³/h *4places |
| Aperture ratio | 3% |

Table 4. Detailed conditions for floor chamber method

| Outlet size | 200mm*200mm Perimeter section:5000mm*90mm |
|-------------|-----------------------------------------|
| Blowing air volume | 720m³/h *4places |
| Aperture ratio | 15% Perimeter section:50% |
| Number of blowing outlets | 36 air outlets + 1 air outlet (Perimeter section) |
3.1 Results of horizontal temperature distribution

Table 5 shows the average temperature values at the measured points (p1–p6) in the living area section for each blowing method.

The average temperatures for Case 1 were 24.9, 25.6, and 27.1 for the floor radiant, floor-supply displacement air-conditioning method, and floor chamber method, respectively; for Case 2, 26.6, 27.5, and 26.6, respectively; and for Case 3, 28.6, 27.5, and 30.7, respectively. In Case 1, the floor-supply displacement air-conditioning method and the floor chamber method fell within the standard value range. In Case 2, all methods were found to be comfortable and within the standard values. In Case 3, the floor-supply displacement air-conditioning method was within the standard value range. The floor radiation system was 28.6°C, 0.6°C higher than the standard value, and the floor chamber system was 30.7°C, 2.7°C higher than the standard value.

3.2 PMV results

The average values of PMV at the measured points (p1–p6) in the living area section for each blowing method are shown in Table 5. Furthermore, the distribution of PMV is shown in Figure 6.

For Case 1, the values were 0.21 for the floor radiation method, 0.31 for the floor-supply displacement air-conditioning method, and 0.40 for the floor chamber method. All methods were comfortable with average values within ±0.5. In Case 2, the values were 0.49 for the floor radiation method, 0.61 for the floor-supply displacement air-conditioning method, and 0.32 for the floor chamber method. The floor radiation system and the floor chamber system were more comfortable. The average PMV for the floor-supply displacement air-conditioning method was 0.61. The "slightly warmer" result was above ±0.5. Case 3 was 0.75 for the floor radiant method, 0.62 for the floor-supply displacement air-conditioning method, and 0.88 for the floor chamber method. All methods were outside the comfort range. All methods were "slightly warmer" than ±0.5. It can also be seen that "slightly warm" areas with PMV exceeding ±0.5 are observed in some areas around people.

3.3 Results of vertical temperature distribution

The vertical temperature distributions in the living area for each blowing method are shown in Figure 5 and Figure 7. The temperature difference between the feet (FL+0.1m) and head (FL+1.1m) in the living area is then shown in Table 6.

The temperature difference for Case 1 was 2.21°C, 4.08°C, and 3.31°C for the floor radiant, floor-supply displacement air-conditioning, and floor chambered systems, respectively. The temperature differences for Case 2 were 2.3°C, 5.08°C, and 3.31°C, respectively. The temperature differences for Case 3 were found to be 1.68°C, 5.2°C, and 2.57°C, respectively. The floor radiation system was comfortable in Case 1 to Case 3.

The floor-supply displacement air-conditioning method was outside the comfort range for all of Case1-Case3. For the floor chamber method, only Case3 was within the comfort range.

4 Ventilation performance in the space

The ventilation efficiency is compared from the simulation results for each blowing method. Air age was used to compare the ventilation efficiency. Air age is the time it takes for air entering a room through an opening such as a window or air supply to reach a certain location in the room. In other words, the shorter the air age is, the fresher the air is. The standard air age of 715 seconds, determined from the number of ventilation cycles, is used to compare and study each blowing method.

4.1 Comparison of air age

Table 7 shows the mean and maximum values of air age at chair seat height (FL+0.6 m) for each blowing method.

The maximum values of air age for Case1 were 678, 556, and 622 for the floor radiation, floor-supply displacement air-conditioning, and floor chamber methods, respectively. The maximum values of air age for Case2 were 726, 694, and 829, respectively. The maximum values of air age for Case 3 were 458, 860, 660 respectively.

The maximum values for Case 1 were below the standard value of 715 seconds for all methods, indicating efficient ventilation. In Case 2, the floor radiation method was 726 seconds, 11 seconds higher than the standard value. The floor chamber method was 829 seconds, 114 seconds higher than the standard value. In Case 3, the floor-supply displacement air-conditioning method was 860 seconds, 145 seconds higher than the reference value.

The average values were within the standard values for all methods from Case 1 to Case 3, confirming efficient ventilation.

Table 5. Average of temperature and PMV

(Average temperature [°C] / Average PMV)

| Method                        | Case1       | Case2       | Case3       |
|-------------------------------|-------------|-------------|-------------|
| Floor radiation method        | 24.9/0.21   | 26.6/0.49   | 28.6/0.75   |
| Floor-supply displacement     | 25.6/0.31   | 27.5/0.61   | 27.5/0.62   |
| Air-conditioning method       | 27.1/0.40   | 26.6/0.32   | 30.7/0.88   |

Table 6. The temperature difference between the feet (FL+0.1m) and head (FL+1.1m) [°C]

| Method                        | Case1       | Case2       | Case3       |
|-------------------------------|-------------|-------------|-------------|
| Floor radiation method        | 2.21        | 2.30        | 1.68        |
| Floor-supply displacement     | 4.08        | 5.08        | 5.20        |
| Air-conditioning method       | 3.31        | 3.31        | 2.57        |
5 Conclusion

In terms of room temperature, Case 1 was comfortable for both the floor-radiant and floor-chamber systems; Case 2 was comfortable for all systems; Case 3 was comfortable for the floor-radiant system; and Case 1 was the most comfortable for the floor-radiant system in terms of PMV. Case 1 and Case 2 were comfortable for the floor-radiant and floor-chamber systems. Only Case 1 maintained the comfort level of the floor-supply displacement air-conditioning method. The floor radiation type in Case 3 was found to be the most comfortable with the smallest vertical temperature difference in terms of vertical temperature distribution. For Cases where the vertical temperature difference between the feet (FL+0.1m) and head (FL+1.1m) is outside the standard value range, it is necessary to consider the air blowing temperature, air blowing volume, and number and arrangement of air outlets to alleviate discomfort caused by cold air accumulation at the feet.

Regarding ventilation performance, the average value was below the standard value for all methods, indicating that ventilation is being performed efficiently. However, the maximum value exceeded the standard value in some cases, and it is thought that there are some areas where air is stagnant.

In the future, we plan to examine the air quality during heating and by particle analysis.

References

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2. ANSI/ASHRAE Standard 55-2004 (Supersedes ANSI/ASHRAE Standard 55-1992): Thermal Environmental Conditions for Human Occupancy
3. REHVA (Federation of European Heating, Ventilation and Air Conditioning Associations): REHVA COVID-19 guidance document, April 3, 2020
4. Rei Murata, Indoor thermal environment and energy consumption in classroom with the ground source heat system, Roomvent 2020

Table 7. Average and maximum values of air age [s]

| Method                        | Case 1 Ave | Case 1 Max | Case 2 Ave | Case 2 Max | Case 3 Ave | Case 3 Max |
|-------------------------------|------------|-----------|------------|-----------|------------|-----------|
| Floor radiation method        | 395        | 678       | 437        | 726       | 269        | 458       |
| Floor-supply displacement air-conditioning method | 288        | 556       | 347        | 694       | 428        | 860       |
| Floor chamber method          | 368        | 622       | 513        | 829       | 412        | 660       |