COMPARISON OF THERMAL COMFORT BETWEEN RADIANT HEATING AND CONVECTIVE HEATING IN HEATING ROOM

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Abstract

Currently, convective heating with heat pump system, which has high energy efficiency, is popular for room heating. However, it is consider that the convective heating can be improved for energy saving, because heater heats the ambient which includes the space in which no occupants are. Moreover vertical temperature gradient increases even in a room, so it is hard to say providing sufficient thermal comfort for the occupants in the room. Purpose of this study is to find of each heating systems by comparison of occupants thermal comfort on both heating systems. In this paper, a small office room model is assumed for case studies, and the temperature distribution and the air flow distribution of this room were calculated by CFD calculation using ESP-r (Environmental Research simulation software). Furthermore the distribution of SET*(Standard Effective Temperature) was calculated based on the calculated air temperatures using the calculated CFD, the difference of thermal comfort between the convective and radiant heating. Based on the results, it was shown that the radiant heating can satisfy the occupant thermal comfort, even if room air temperature is low. On the other hand, it was confirmed that the occupant thermal comfort depends on the blowing air temperature and blowing air reachable region. Further, radiant heating is not able to circulate the air because generating air flow is difficult. Moreover, convective heating increases the vertical temperature gradient as a problem. Therefore instead of using one or other as a heating system, it is important to combine them efficiently.

Keywords: Thermal Comfort, Radiant heating, Convective heating, SET*, CFD, ESP-r, EES

1. INTRODUCTION

Currently, convective heating with heat pump system, which has high energy efficiency, is popular for room heating. However, convective heating warmed ambient space where do not only involved thermal comfort of occupants but also the vicinity of occupants. Therefore, it is considered that energy saving can be still achieved to improve the way of room heating. In addition, convective heating is not enough to thermal comfort for occupants in the room, because it increases vertical temperature gradient in a room. In the past, many studies are existed which is compare thermal comfort or performance of energy conservation by type or form of heating. Sakaguchi,J. clarifies the actual situation of energy consumption by radiant

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heating and convective heating, and Murakami,S. considers about influence to nonuniform area of radiant or convective by difference in heating system. Furthermore, Omori,T. and Itagaki,M. evaluate thermal environment of a room by using coupled simulation of radiation and convection. Akabayashi,S. and Kaji,K analyze about position of inlet and outlet and air transfer efficiency of local. In these studies, there are a lot of studies about floor heating and convective heating. But it is not verified about the influence that thermal environment of a room is given to radiation characteristic of radiant heating equipment. Therefore, the study of Yoshikawa, K. is modeling of radiant characteristic. It is considered the effective use of radiant heating equipment based on thermal comfort by using method of radiant heat transfer calculation which is considered directivity of radiant heat and calculating the sensible temperature which using human body model. Therefore, this study focus on directivity of radiant heating, and it is verified thermal environment in a room at the time of radiant heating with high directivity. Additionally, the optimal heating system is considered from the point of view of thermal comfort and energy conservation. In this paper, as a preliminary step, to compare influences of radiant heating and convective heating for occupants' thermal comfort, SET* distribution, which is calculated by considered radiant heat environment, is examined.

2. SIMULATION METHOD

2.1 Outline of Analysis

The analysis room model, the cross-sectional view of the model and the floor plan of the model are shown in Figure 1, 2 and 3, respectively. The ordinary small office room is assumed as the analysis model. Total floor area is 22.8 m^2 and a window was provided in the south wall and a door was provided in the north wall. The adjacent rooms were assumed beyond all walls except south and north walls. The south wall faced outdoor and the north wall faced corridor. The specification of room model and the numerical condition are shown in Table 1 and 2, respectively. The simulation period was 168 hours. The calculation results were examined for the time when temperature was in stable state. The heating surface temperature of radiant heating was set at 30°C. The surface temperature of the others was calculated same condition both convection and radiant heating. In addition, the outlet air temperature of convective heating was set at 40°C.By using EES (Engineering Equation Solver) which is equation-solving program, the distribution of SET* was calculated based on the distributions of air temperature and air flow vector which was obtained by CFD calculation. Further CFD calculations were performed using ESP-r.

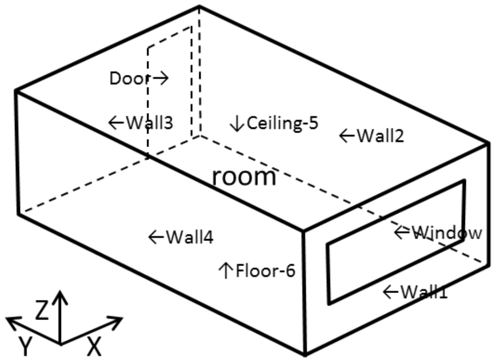


Figure 1: Analysis object model

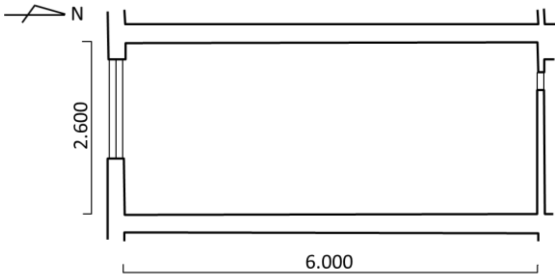


Figure 2: Cross-sectional view of the model (Unit: mm)

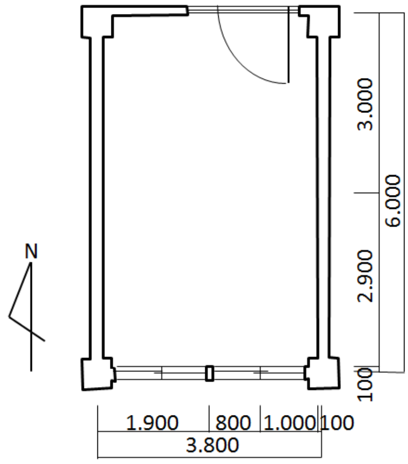


Figure 3: Floor plan of the model (Unit: mm)

Table 1: Specification of room model

Building dimensions (mm)		3800(X) × 6000(Y) × 2600(Z)
Aperture	Dimension (mm)	2800(Width) × 1300(Height)
	Specification	Double-glazing
	Window bottom height (mm)	800
North side door (mm)		900(Width) × 2100(Height)
Building orientation		South

Table 2: Numerical condition

Mesh division		19(X) × 30(Y) × 13(Z) 7410mesh
Turbulence model		Standard k-ε model
Difference scheme		Hybrid method
Solution		SIMPLE method
Outflow conditions	Air outlet area (mm)	200(X) × 300(Y)
	Mass flow rate (kg/s)	0.0714
	Turbulence energy	0.005
	Turbulent dissipation rate	0.005
	Air outlet temperature (°C)	40
Inflow condition	Absorption area (mm)	300(Y) × 200(Z)

Table 3: Heat transfer coefficients of walls

Position	Heat transfer coefficient (W/(m^2・K))
Ceiling	0.3122
Floor	1.217
External wall	0.3896
Partition	1.039
Window	3.009

2.2 Surface Temperature Calculation Method

In order to determine the indoor surface temperature as boundary conditions in CFD calculation, the initial room temperature was determined by assuming that the outdoor temperature is 5°C and substituting the coefficient of heat loss and internal heat generation into equation (1). Incidentally, the value of the design documentation assembly was used in internal heat generation amount of the equation (1). The heat loss coefficient was used value which stipulated in the area of Region Ⅳ according to the geo-climalic regional division of Energy Conservation 1999 in Japan. Therefore, initial room temperature was set at 15°C when the outside air temperature was 5°C.

$$\Delta T = Q_i \div Q \tag{1}$$

ΔT : Temperature difference between indoor and outdoor (°C)

Q_i : Internal heat generation amount 27.158W/m^2

Q : Heat loss coefficient 2.7W/(m^2・K)

Assuming steady state wall, heat flux between indoor and outdoor through a wall is equal to heat flux from wall surface to air. Following equation was used to determine the indoor surface temperature. Heat transfer coefficients of walls were shown in Table 3, and the surface temperature of walls is shown in Table 4.

$$T_{si} = T_i - \frac{U}{h}(T_i - T_o) \tag{2}$$

T_{si} : Indoor side surface temperature (°C)

T_i : Initial room temperature (°C)

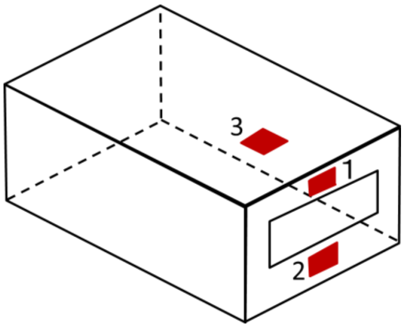
U : Heat transfer coefficient (W/(m^2・K))

h_i : Indoor side heat transfer coefficient (W/(m^2・K))

h_o : Outside air temperature (°C)

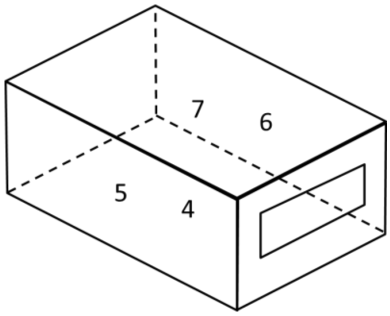
Table 4: Surface temperature of walls

Position (Surroundings)	Temperature(°C)
South wall (Outside)	14.6
East wall (Adjacent room)	15.0
North wall (Corridor)	15.0
West wall (Adjacent room)	15.0
Ceiling (Adjacent room)	15.0
Floor (Adjacent room)	15.0
Window (Outside)	11.7
Door (Corridor)	15.0



1. Upside the window of south wall (Above the floor 2100mm)
2. Under the window of south wall (Above the floor 500mm)
3. Ceiling surface (800mm from the south wall)

Figure 4: Layout of convective heating outlet



4. Floor heating
5. Single wall heating (West wall)
6. Both wall heating (East and West wall)
7. Ceiling heating

Figure 5: Layout of radiation heating surface

A sphere with a diameter of 20mm assumed to be at 700mm above floor represents a human body in thermal environment. Form factor of the point to radiation panel and point to building in the case was calculated by the built –in function of EES. The calculation equation of MRT is explained in Section 4 later.

2.3 Placement of the Heating Equipment

The simulation about convective heating was calculated about three positions of hot air outlet (upside the window of south wall, under the window of south wall, ceiling surface) and that about radiant heating was calculated about four kinds of heating (floor heating, single wall heating, both wall heating, ceiling heating). Hot air outlet area of convective heating was unified 0.06m^2 and differences in temperature and air flow distribution was case study by varying the position of the outlet.

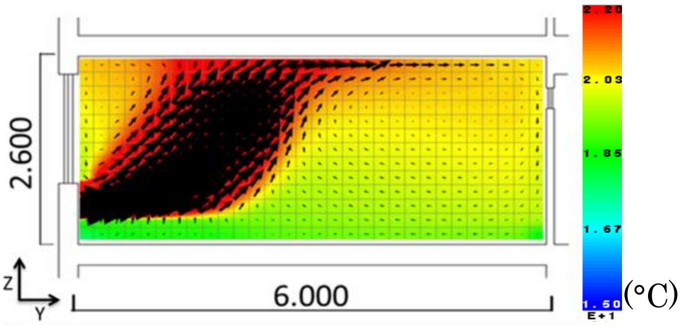


Figure 6: The temperature distribution at the Y-Z cross section in the X-axis 1900mm point

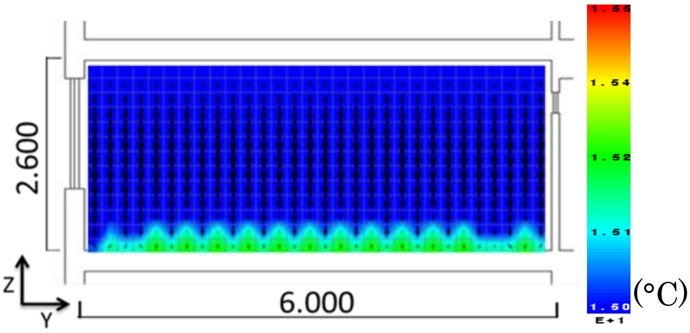


Figure 7: The temperature distribution at the Y-Z cross section in the X-axis 1900mm point

3. CFD ANALYSIS RESULT

In this paper, the difference of indoor thermal environment between radiant heating and convective heating is discussed to compare the analysis results of the case of floor heating with the case of hot air outlet at south side under window.

3.1 Air Temperature Distribution Results of Vertical Cross-Section

3.1.1 The Case of Hot Air Outlet of South Side Under Window

Temperature distribution of the Y-Z cross section in the case of hot air outlet south under window is shown in Figure 6. The hot air blown out horizontally from the floor 500mm reaches ceiling surface to rise sharply. After that it can be seen momentum is weakened by colliding with the ceiling surface, and hot air goes to spread to Y axis direction along the ceiling surface. Further, the air is circulated around the point where distance of approximately 1000mm in the Y-axis direction from the north wall. Hot air blown out from the outlet is keeping the height of 2000mm in the horizontal direction, but the space under the air outlet is not warmed up.

3.1.2 The Case of Floor Heating

Temperature distribution of the Y-Z cross section in the case of floor heating is shown in Figure 7. Warm air can be seen signs of rise in the floor, but it can be seen to have been held down by the downdraft of ambient air. Temperature range is only 0.5℃ because temperature distribution does not appear prominently. It is shown that increase in air temperature is difficult to occur by radiant heating in Figure 7.

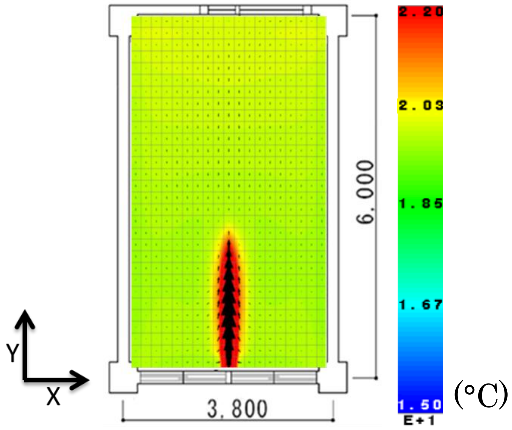


Figure 8: Temperature distribution at the X-Y cross section in the floor 700mm

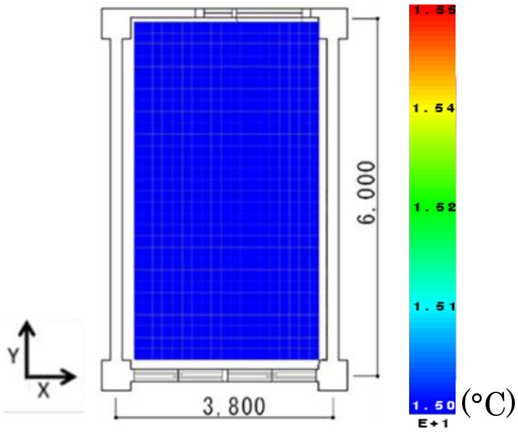


Figure 9: Temperature distribution at the X-Y cross section in the floor 700mm

3.2 Air Temperature Distribution Results of Horizontal Section Vertical

3.2.1 The Case of Hot Air Outlet of South Side Under Window

Temperature distribution of the X-Y cross section in the case of hot air outlet south under the window is shown in Figure 8. The hot air can be confirmed in cross-section of the human seating position above the floor 700mm because air outlet is low position above the floor 500mm. Air temperature decreases toward the south wall from the north wall in the case of other heating. But, this heating system is estimated that it is warmed by involving the air of the south wall around, because hot air is blown from air outlet area

3.2.2 The Case of Floor Heating

Temperature distribution of the X-Y cross section in the case of floor heating is shown in Figure 9. Temperature range is shown at 0.5°C in Figure 9, but temperature is low and no distribution at 700mm above the floor which is a human seated position. Improvement of thermal comfort by air temperature increasing cannot be expected in the seated position from this result.

4. CALCULATION CONDITION OF SET*

SET* is calculated using the temperature distribution results. Calculated area is horizontal X-Y cross section with X-coordinate of 0 to 3800mm, Y-coordinate of 0 to 6000mm. The area is calculated 700mm above the floor which assuming a human seating position. The SET* calculation conditions is shown in Table 5.

Table 5: SET * calculation condition

Condition	Input value
Room temperature (°C)	Calculated value of CFD
Relative humidity (%)	30
Wind speed (m/s)	0.1
Metabolic rate (Met)	1.1
Amount of clothing (clo)	1.1
Mean radiant temperature	Calculated MRT according to equation (3)

The MRT (Mean Radiant Temperature) is calculated according to the equation (3)

$$MRT = \left\{\sum_{\varphi 1i}\left(\theta_g - 273.15\right)^4\right\}^{0.25} - 273.15 \quad (3)$$

T_i : Temperature of surface i (°C)

φ_{1i} : Form factor as seen from point surface 1 to surface i (-)

In addition, the thermal comfort range of SET* is assumed from 22 to 26°C.

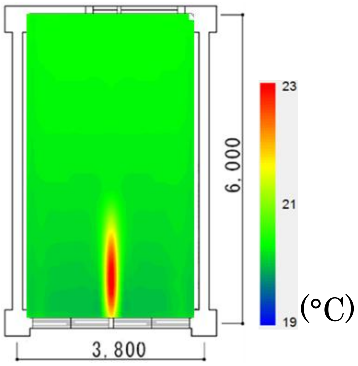


Figure 10: SET* distribution at the X-Y cross section in the floor 700mm

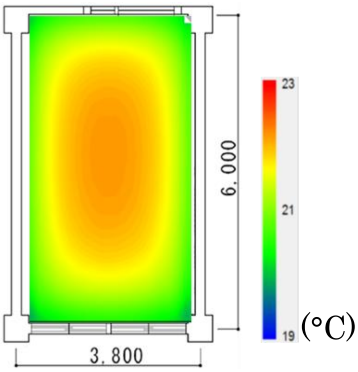


Figure 11: SET* distribution at the X-Y cross section in the floor 700mm

5. SET* CALCULATION RESULT

5.1 The Case of Hot Air Outlet South Side Under Window

The results of SET* of the case of hot air outlet south under window is shown in Figure 10. SET* near the outlet is satisfied with thermal comfort, but that of other area cannot be satisfied. As a result, area where thermal comfort can be obtained is limited in the range of airflow blowing directly.

5.2 The Case of Floor Heating

The results of SET* of the case of floor heating is shown in Figure 11. Although air temperature distribution was about 15°C uniformly, SET* was about 22°C at the area where the center of the room in the depth of 4000mm and in the wide of 2000mm. Furthermore, SET* of the other area in the room is maintained about 21°C, and so floor heating system is easy to obtain the thermal comfort.

6. CONCLUSION

Characteristic has been confirmed that radiant heating can be satisfied with the thermal comfort even if air temperature is low. On the other hand, the thermal comfort of convective heating depends on the outlet air temperature or the range of airflow reaching. Further, radiant heating is not able to circulate the air because generating air flow is difficult. Moreover, convective heating increases the vertical temperature gradient as a problem. Therefore instead of using one or other as a heating system, it is important to combine them efficiently.

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