HEAT DISSIPATION CHARACTERISTICS OF HUMAN BODIES UNDER THE AIR-CONDITIONING SYSTEM USING CEILING RADIANT PANELS FOR AN OFFICE SPACE

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Abstract- In this study, we carried out CFD analysis coupled with numerical thermoregulation model of human body for the ceiling radiation air conditioning system in an office space, and we also revealed the heat dissipation characteristics of the human body based on these analysis results. Two cases of the analysis were carried out. One is the ceiling radiation air-conditioning system, and the other is the ceiling supply air-conditioning system (VAV system). As a result, the ratio of radiation heat loss from human body in ceiling radiation air-conditioning system was larger than that in ceiling supply air-conditioning system.

Keywords- CFD, JOS model, Virtual Manikin, Heat balance,

I. INTRODUCTION

In recent years, the adoptions of the ceiling radiation air-conditioning system(CRS) (Fig. 1) in offices have been increasing[2]. Many previous studies showing the effectiveness of the CRS have been conducted, mainly by evaluating the whole-body thermal sensation and the local thermal sensation based on experiments and actual measurements under the cooling condition [3) 4)].

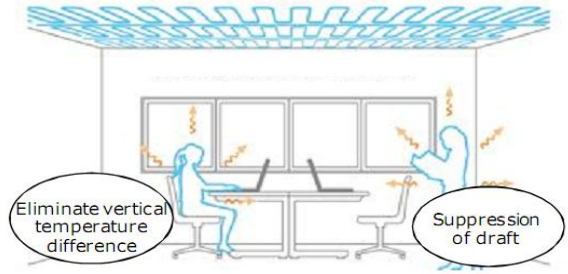


Fig.1. Image of ceiling radiation air-conditioning system 1)

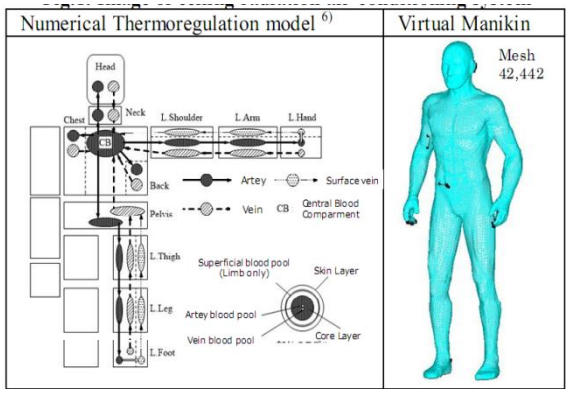


Fig.2. Structure of numerical human model

However, there are few studies focusing on the relaxation effect of room temperature set value due to the decrease of the mean radiation temperature(MRT), and the sensible heat balance of the human body surface.Therefore, the purpose of this study is to reveal the heat dissipation characteristics of the human body by estimating human physiological quantity while reproducing micro climate around the human body in detail using CFD analysis coupled with numerical thermoregulation model of the human body, targeting the CRS introduced in an office space. In the previous study[5], we revealed the heat dissipation characteristics of the human body based on the results of coupled analysis.

The analysis of two cases were carried out. One is the CRS, and the other is the ceiling supply air-conditioning system (VAVS). However, in this analysis, only one numerical thermoregulation model of the human body was installed in the office space, and it was done under the condition that without furniture. Therefore, in this study, we created a new analytic model in which 8 numerical thermoregulation models of a human body and 8 sets of fixtures were installed, in order to assume practical use and then we conducted the analysis same as the previous study.

II. CFD ANALYSIS COUPLED WITH NUMERICAL THERMOREGULATION MODEL OF THE HUMAN BODY

In subject experiments, it is usually possible to measure the skin temperature highly correlated with a thermal sensation, but it is quite difficult to precisely measure the sensible heat (including the ratio of radiation and convection) and latent heat fluxes. For this reason, in this study, the heat dissipation characteristics of the human body was evaluated by the coupled analysis of CFD which can predict the spatial distribution of various physical quantities in the air conditioning space in detail, and numerical thermoregulation model which can precisely estimate physiology of human body. In this study, we define a human body model coupling Virtual Manikin (1.1), as a human body shape and JOS model (1.2) as a human physiology (body temperature regulating function) model (Fig. 2).

2.1. Virtual Manikin

In this study, Virtual Manikin[7] was adopted as a human shaped model which can be easily applied to the indoor environmental analysis using CFD. 6 different types of Virtual Manikin's mesh data such as children, adult men and female in standing and sitting positions in a format of each general purpose fluid analysis software. In this study, we used the data of adult men in a sitting position (Fig.3). In addition, we changed the scale of Virtual Manikin so that it fitted into the average body size of JOS model.

2.2. JOS model

In this study, JOS model was used as a numerical thermoregulation model of the human body in order to analyze the heat transfer within a human body. JOS model[8] is a heat transfer model of the node system which expresses the inside of human bodies as 17 regions.

2.3. Coupled Analysis

Human bodies maintain the state of thermal equilibrium by conducting heat exchange to surrounding environment at the surface of skin or clothes. Therefore, sensible and latent heat exchange at the surface of human bodies needs to be calculated precisely as well in a case of conducting coupled analysis of numerical thermoregulation model of the human body and CFD. However, even though the temperature of human body surface is decided, it could change again in accordance with the change of surrounding environment. Thus, in this analysis, convergence calculation in which both sides share the other data as a boundary condition is performed.

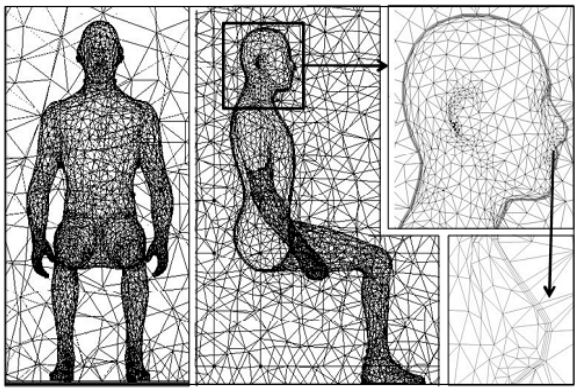


Fig.3. Virtual Manikin of sitting position and surrounding mesh

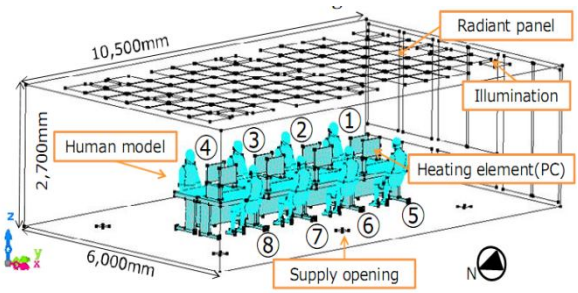


Fig.4. Analysis model of Case1

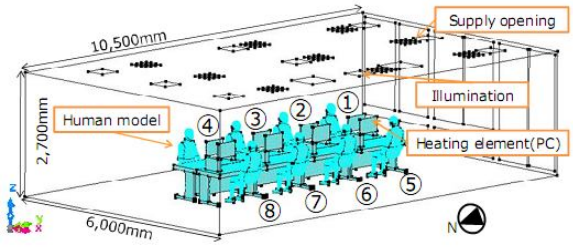


Fig.5. Analysis model of Case2

Table1: Analysis condition (Case1)

Domain	6.0m(X)×10.05m(Y)×2.7m(Z)
Mesh	1,086,548(Unstructured)
Radiation	Mesh : 8,000, Emissivity : 0.90(Surface of wall)
Turbulence model	Low Re-type k-ε model(ANK)
Inlet	Temp : 22℃, Flow rate : 0.067m^3/s, x_{in} = 0.015 , k_{in} =3/2(U_{in}×0.05)^2, ε_{in} = $C_\mu^{3/4}$·$k_{in}^{3/2}$/l_{in}
Outlet	Flow Rate: 0.034 m^3/h, Surface pressure: 0 Pa
Surface of human	Temp· Humidity:Results JOS analysis
Wall boundary in air tunnel	Velocity:Analytical Wall Function, Humidity:insulation, Temp:insulation (Control the processing amount of heat in the radiant panel surface)

U_{in} : Wing speed[m/s], k_{in} : Turbulence energy[m^2/s^2],
ε_{in} : Dissipation rate of k_{in}[m^2/s^3],x_{in} : Absolute humidity of supply air[kg/kg'],
l_{in}:Length scale[m], C_μ : Model constant(=0.09)[-]

Table2: Analysis condition (Case2)

Domain	6.0m(X)×10.05m(Y)×2.7m(Z)
Mesh	1,169,835(Unstructured)
Radiation	Mesh : 8,000, Emissivity : 0.90(Surface of wall)
Turbulence model	Low Re-type k-ε model(ANK)
Inlet	Temp : 18℃, Flow rate : 0.174m^3/s, x_{in} = 0.015 , k_{in} =3/2(U_{in}×0.05)^2, ε_{in} = $C_\mu^{3/4}$·$k_{in}^{3/2}$/l_{in}
Outlet	Flow Rate: 0.087 m3/h, Surface pressure: 0 Pa
Surface of human	Temp· Humidity:Results JOS analysis
Wall boundary in air tunnel	Velocity:Analytical Wall Function, Humidity:insulation, Temp:insulation

U_{in} : Wing speed[m/s], k_{in} : Turbulence energy[m^2/s^2],
ε_{in} : Dissipation rate of k_{in}[m^2/s^3],x_{in} : Absolute humidity of supply air[kg/kg'],
l_{in}:Length scale[m], C_μ : Model constant(=0.09)[-]

III. OUTLINE OF ANALYSIS

We conducted steady-state analysis by using CFD analysis coupled with eight numerical thermoregulation models, for an air-conditioning performance test room[9] assuming an office space located in the University of Kitakyushu. The conditions and cases of the analysis are shown in Table 1, 2 and 3. In this analysis, Case 1 and 2 assumed the CRS (Fig. 4) and the VAVS(Fig. 5) respectively, and the heat dissipation characteristics of human bodies were evaluated in both cases. In the CRS, the outdour air treated with the outside air conditioner was supplied from the floor. In both cases, the air-conditioning was controlled so that the skin temperature accorded with each other, which is highly associated with thermal sensation (processing heat load of the ceiling panel was adjusted in Case 1, and the air volume in VAV was controlled in Case 2). As a result, processing heat loads by the ceiling panel and under floor air-conditioning turned out to be 1,360W and 460W respectively in Case 1. In Case 2, on the other hand, the air volume of VAV and processing heat load turned out to be 628m^3/h and 1820W respectively (the total amount of processing heat load in both cases accorded with each other due to the analysis under the condition of heat insulation).

In addition, since the analysis model was assumed as interior space in this study, its periphery was supposed to be under the condition of heat insulation and thermal transmission was not taken into account. As a condition of human bodies, clothes amount and metabolic rate was set to be 0.6 clo and 1.2 met respectively, assuming a sitting position in an office environment.

Table.3 Analysis case

Case	Explanation of case				Operating condition of		Condition of GR(guard room)		
	Position	Clothing	Furniture	Air-conditioning system	Supply air volume [m³/h]	Supply temperature [℃]	GR1～4 (Next room) [℃]	GR5 (Ceiling) [℃]	GR6 (Floor) [℃]
Case1	Sitting position (1.2met)	Clothing of summer (0.6clo)	8 set	Ceiling radiation	240 (Floor supply)	22	Adiabatic		
Case2				Ceiling supply(VAV)	628	18	Adiabatic		

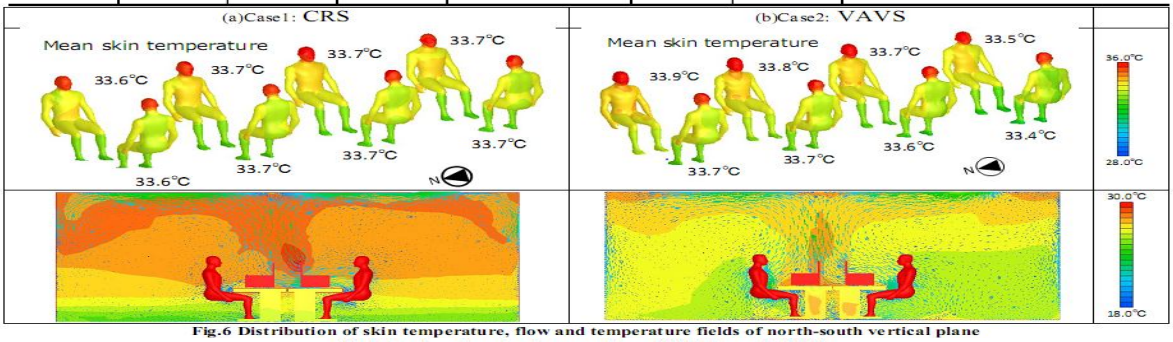


Fig.6 Distribution of skin temperature, flow and temperature fields of north-south vertical plane

Table. 4 Analysis results of CFD and JOS

	CFD					JOS				
	Air temperature [℃]	MRT [℃]	Humidity [%]	Velocity [m/s]	SET* [℃]	Mean skin temperature [℃]	Sensible heat (Body) [W/㎡]	Latent heat (Body) [W/㎡]	Sensible heat (Breath) [W/㎡]	Latent heat (Breath) [W/㎡]
Case1	27.7	27.4	54.0	0.1	28.4	33.7	49.4	17.8	-0.1	4.2
Case2	26.2	29.0	56.7	0.1	28.4	33.7	48.9	18.3	-0.1	4.3

IV. RESULT OF ANALYSIS

4.1. Comparison of air flow and temperature fields

Fig. 6 shows the distribution of skin temperatures and representative air flow and temperature fields. Table 4 shows the analysis results of CFD and JOS models. Although, in both cases, thermal plumes can be seen around the heating elements installed on the table, the airflow field was quiet because the air velocity was less than 0.1m/s. Also, the values of SET* almost correspond with each other in both cases. In Case1, because of the influence of blowout from the floor, temperature stratification slightly can be seen and the room temperature is higher than that of Case2 by 1.5℃ as shown in Table 4. However, MRT value in Case1 is lower than that in Case2 by approximately 1.6 ℃, it was indicated that an equivalent heat environment could be produced with a high temperature setting.

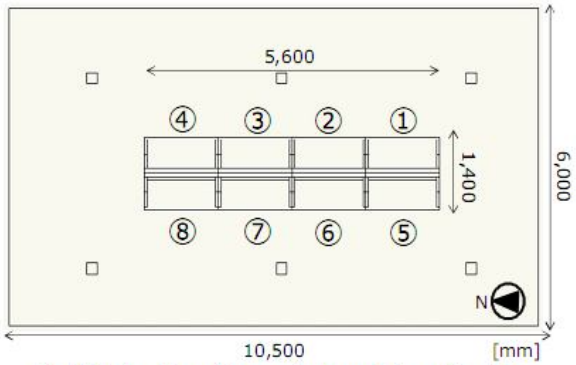


Fig.7 the location of human body models and furniture

4.2. Comparison of skin temperature

Fig.7 shows the location of human body models and furniture in both cases. Fig.8 and Fig.9 show the skin temperature of each part of a human body and the average skin temperature of each human body model. According to Fig. 8, in the CRS, the skin temperatures were generally constant and stable in all eight positions (all eight human body models). On the other hand, as shown in Fig. 9, in the VAVS, there were some differences in the skin temperature of the extremity part. This is probably because of using a analysis model which reproduced air-conditioning performance test room assuming an office in the University of Kitakyushu in this study. That is to say, in the case of the VAVS, a blowout opening is located slightly in south side from the center of the room, therefore the body models on the south side was easy to be affected by the blowout. As a result, the skin temperature got lower. Moreover, in the case of the VAVS, it was indicated that indoor thermal environment is more likely to be unbalanced because of the asymmetry of the layout of the air-conditioning system and furniture, compared to the CRS. The average value of the average skin temperature of 8 human body models in both cases is consistent with the thermal neutral temperature of 33.7 ° C.

4.3. Comparison of human physiological quantity and human body heat balance

The skin temperature of each part of both cases at the position of ② in Fig. 7 and the heat balance of the human body are shown in Fig. 10, 11 respectively.

According to Fig. 10, in both cases, the skin temperature of each part almost agrees. However, from the results of heat balance in both cases, it was found that there was a gap in sensible heat balance (the proportion of radiant heat flux and convective heat flux) of human bodies in Case 1, compared to in Case 2. In Case 1, the radiative heat transfer from the ceiling panel increased by 8%. This result also corresponds that the MRT in Case 1 was lower by 1.6 ℃ (Table 4). As shown in Fig.12, the heat loss rate of radiative heat transfer in Case 1 was higher than that in Case 2 in all parts of the body, especially the heat loss in thighs is high. In this analysis using furniture, it was found that the heat loss by radiative heat transfer in the hidden parts by furniture such as thighs and feet was slightly lower compared to the case not using furniture (Results of previous study[5]).

CONCLUSIONS

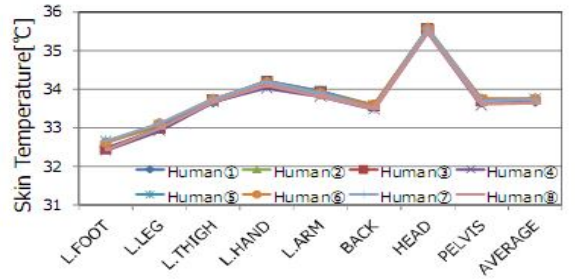


Fig.8 Skin temperature of each region (Case1)

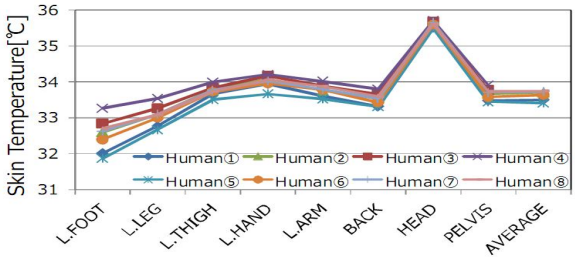


Fig.9 Skin temperature of each region (Case2)

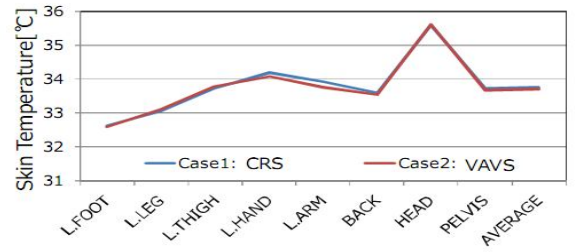


Fig.10 Skin temperature of each region at representative position

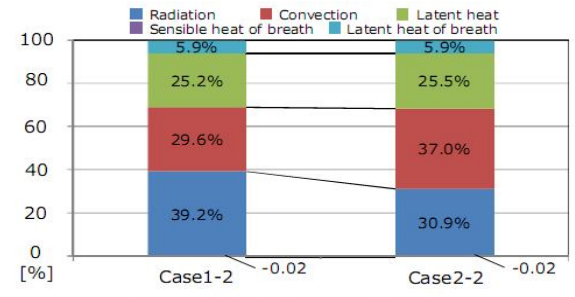


Fig.11 heat loss from human body

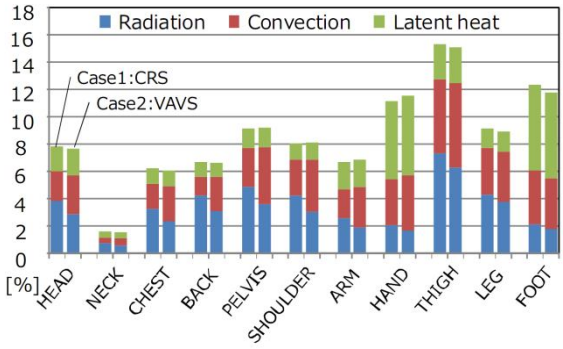


Fig.12 heat loss from human body of each region

In this study, we carried out CFD analysis coupled with numerical thermoregulation model of human body for the ceiling radiation air conditioning system in an office space, and we also revealed the heat dissipation characteristics of the human body based on these analysis results. The results were as follows:

1. Although, in both cases, thermal plumes can be seen around the heating elements installed on the surface of the table, the airflow field was quiet because the air velocity was less than 0.1m/s.
2. In the CRS, the skin temperatures were generally constant and stable in all positions, but in the VAVS, there were some differences in the skin temperature of the extremity part.
3. Since MRT in the CRS became higher than that of the VAVS, the ratio of radiation heat loss from the human body in the CRS became larger than that of the VAVS. As a result, the setting temperature could be raised by 1.6℃.
4. In analysis using furniture, it was found that the heat loss by radiative heat transfer in the hidden parts by furniture such as thighs and feet was slightly lower compared to the case not using furniture.

REFERENCES

[1] http://www.kubota-ci.co.jp/products/building/ceiling_panel/
[2] whats-new.html
[3] Sei Ito, Minoru Kawashima, Miichiya Suzuki, Yoshito Arai, Mitsuhiro Takahashi, Koji Murakami, Tatsuo Nobe, “Study on Cooling Performance of a Celing Radiant Cooling System in High Rise Office Building Aimed at Achieving ZEB”, Shimizu Corporation Research Report,No.91,pp.65-72,2014.
[4] Shiro Tsukami, Shunsuke Komori, Yuta Kanemaru, Yasuyuki Shiraishi, “Study on Air-conditioning System using Ceiling Radiant Panel for an Office (Part 1) The Basic Performance based on Steady Cooling Experiment”, Architectural Institute of Japan,pp.1219-1220,2015.,
[5] Kaoru Takigasaki, Ryuichiro Yoshie, Hiroyuki Kawahara, Kenji Takahashi ,“Study on Ceilling and Heating System Part1 Measurement of Thermal Environment at Cooling and Heating Condition”, Air-Conditioning Sanitary Engineers of Japan, G-4,2005.
[6] Takefumi Mori, Yasuyuki Shiraishi, “Heat Dissipation Characteristics of a Human Body under the Air-conditioning System using CeilingRadiant Panelsfor an Office”, Architectural Institute of Japan, pp.1349-1350, 2016.
[7] Software Cradle Co., Ltd., “SCRYU/Tetra,Version11 User's Guide Foundation part” pp.2.79, 2015.

[8] Kazuhlde Ito, Taro Hotta,"Development ofVirtual Manikins and Its Grid Library for CFD Analysis", Air-Conditioning Sanitary Engineers of Japan,No.113,pp.27-33,2006.

[9] Li Xu, Takahiro Sato, Kazuaki Ogawa, Shinichi Tanabe,"Numerical Comfort Simulator for Thermal Environment (Part22) Development of Human Thermoregulation Model JOS with the Vascular System Using AVA", Architectural Institute of Japan,pp.361-362,2002.

[10] Noriyasu Sagara,Yuji Ryu, Akihito Ozaki, Weijun Gao, Yasuyuki Shiraishi,"The Outline of The HVAC System Performance Testing Apparatus of The University of KItakyushu" Architectural Institute of Japan pp.1209-1210, 2002.

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