ENERGY EVALUATION FOR PERSONAL AIR-CONDITIONING SYSTEM IN A GENERAL MULTI -BED PATIENT'S ROOM

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ABSTRACT

This paper discuss about characteristics and energy performance of personal air-conditioning system for a general multi-bed patient's room. Two types of personal air-conditioning systems are evaluated by the laboratory experiment. Energy performance of a peri-counter FCU (a conventional) air-conditioning system is simulated by CFD to compare with that of personal systems. Compared with the conventional system, personal air-conditioning system has an advantage from the viewpoint of amenity improvement, but may consume more energy for cooling in the system.

KEYWORDS

Multi-bed sickroom, Personal air-conditioning, Energy performance, Thermal comfort, CFD

INTRODUCTION

In a general multi-bed patient's room in Japan, each patient's space is separated by a curtain, furniture, or some other objects. Direct sunlight and window radiation give difference in the thermal environment between beds. The different preferences of patients also complicate the required thermal environment in the room. For air-conditioning in a general multi-bed patient's room, a fan coil unit (FCU) is often installed in the perimeter wall under windows as lake a counter (peri-counter FCU). Such an installation way has a problem with an aspect of that conditioned air does not reach corridor-side beds, and the temperature tends to be set window side patients based on their preferences. From such a reason, patient requests regarding the thermal environment often cannot be satisfied.

Personal air-conditioning can satisfy the thermal environment requested by each patient, on the other hand, energy conservation must be considered. As one of the measures for improving amenities in a multi-bed patient's room, the authors try to propose an air-conditioning system that can meet patient's requirements for the indoor thermal environment while consuming less than or equal to the amount of energy of a conventional air-conditioning system. It is expected that the energy conservation is achieved by effect of reduction of air conditioned air volume with spot cooling and heating, and by alleviation of temperature of supply air for air conditioning and/or supply water for air conditioner.

A mock-up of a multi-bed patient's room applying two types of personal air-conditioning system were built in a laboratory in order to verify the effectiveness by comparing vertical temperature and supply heat, etc. In this paper, supply heat and thermal environment accomplished with two types of personal air-conditioning systems were evaluated by the laboratory experiment. In addition, thermal environment and energy performance with a peri-counter FCU conventional air-conditioning system was simulated by CFD analysis, and compared the simulation results with those of two types of personal air-conditioning systems.

EXPERIMENT OF PERSONAL AIR-CONDITIONING SYSTEM

Experimental Conditions

For the laboratory experiment, two types of personal air-conditioning systems were proposed and applied. To achieve PMV (Predicted Mean Vote) =0 on each bed, thermal environment around beds and the supply heat were discussed for these systems. Experiments were conducted under conditions of cooling and heating peaks hour (outdoor air temperature is 35°C. in summer, 3°C in winter). Figure 1 shows the plan of the laboratory, which was divided into outdoor air chambers, a mock-up of patient's room at the center, and a corridor. This allowed the air-conditioning to be set independently in each section.

Four beds in the patient's room were air-conditioned by a single FCU concealed into the ceiling of the room. An air outlet and inlet, and a flow rate controller to regulate supply flow rate were installed in each bed. Outdoor flesh air treated with an air handling unit was supplied into the mock-up of a

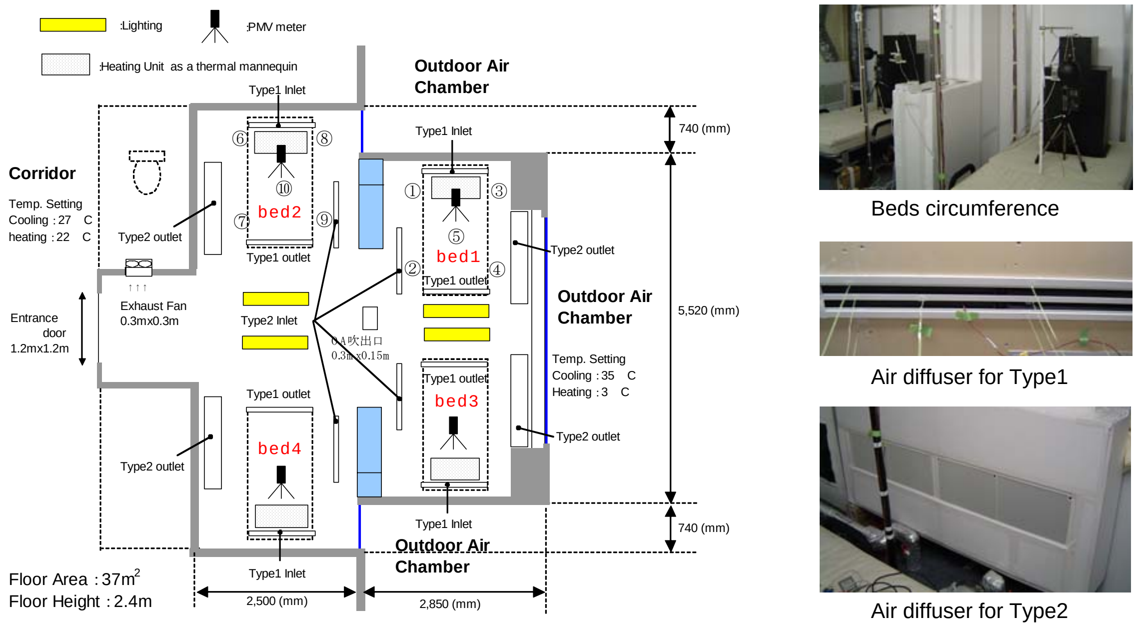
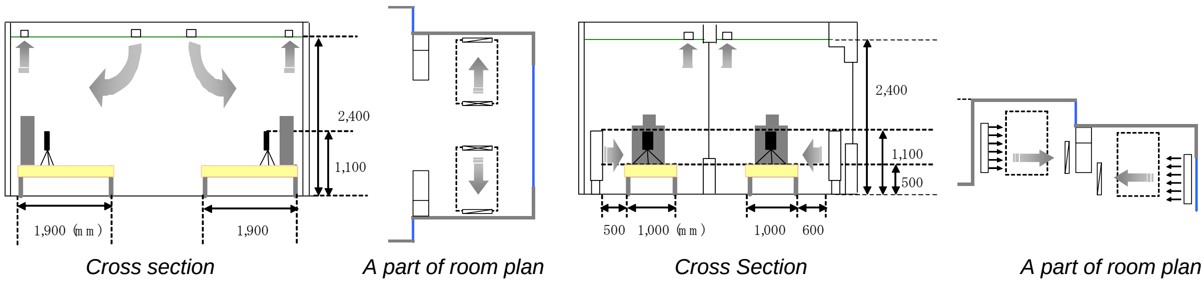


Figure 1 The plan of the mock-up of multi-bed patient's room and specification of the laboratory.



***(a)** Type-1 (Air supply from the ceiling)* ***(b)** Type-2 (Air supply from beside Patients)*

Figure 2 Configuration of Personal air-conditioning system.

patient's room from another air outlet. Supply volume of outdoor air is about 120m3/h (about 15 ACH) and the same amount of air volume was sucked in through the louver of the toilet door for exhaust. The supply temperature of fresh air is about 27°C in cooling, 25°C in heating.

Types of Personal Air-Conditioning

1) Air supply from the ceiling (Type-1)

Cool or warm air is supplied from the ceiling toward the patient. The air flows from the feet of the patient along the bed toward the face, and enters the air inlet located on the ceiling over the head of the bed. Air outlets are a line type which has 0.03 m^2 opening area, and the air inlets are another line type. Air supply angle from the outlet was 45° for cooling, perpendicular to the ceiling for heating.

Table 1 Results of PMV in each experiment

		COOLING			HEATING		
Type-1	Supply Temp.*1	16°C	18°C	20°C	34°C	38°C	40°C
	PMV	0.00	0.03	0.07	0.08	-0.01	-0.01
Type-2	Supply Temp.	16°C	18°C	20°C	29°C	30°C	32°C
	PMV	0.04	0.05	0.30	-0.01	0.06	0.01

*1 Supply Temp.: *Condition of supply Air Temperature setting*

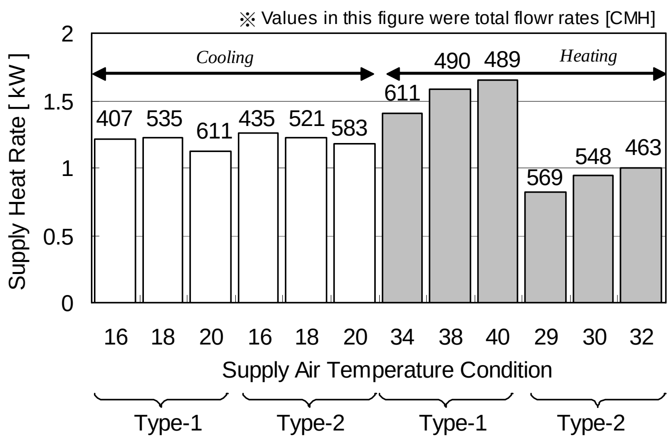
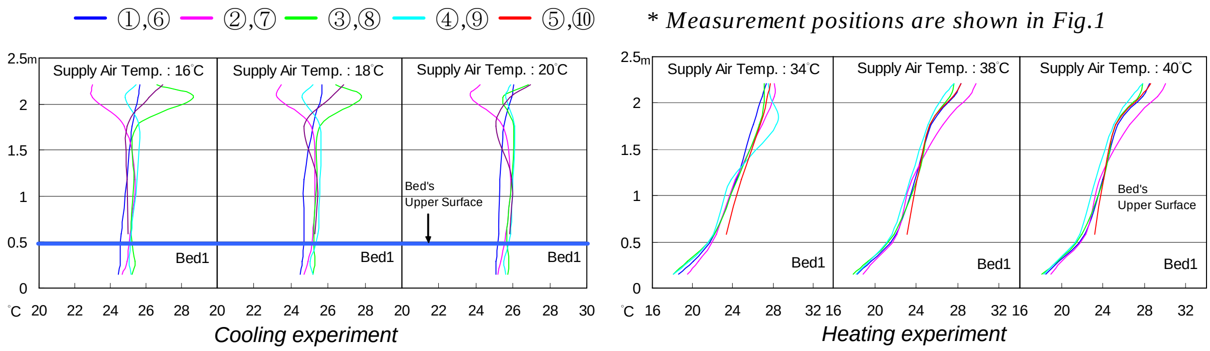
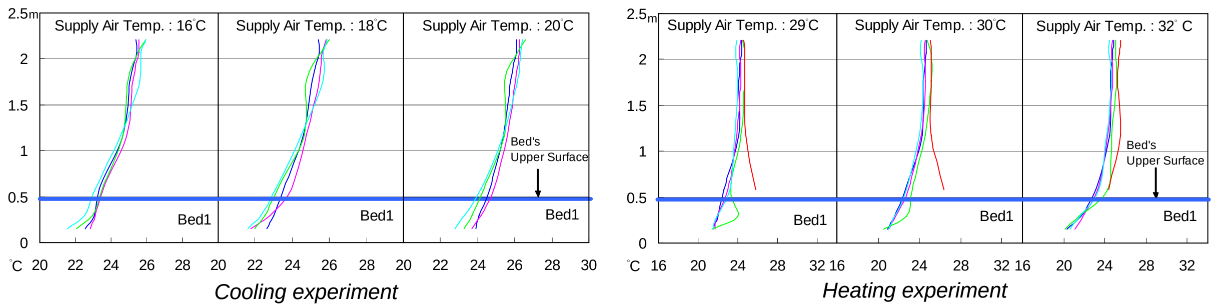


Figure 3 Supply heat in each experimental condition



(a) *Type-1 (Air supply from the ceiling)*



(b) *Type-2 (Air supply from beside Patients)*

Figure 4 Vertical temperature distribution around bed 1 in each experiment

2) Air supply from the bed side (Type-2)

Cool or warm air is supplied from the wall side of the bed toward the patient. The air flows across the patient on the bed, and enters an air inlet located on the ceiling on the opposite side. The air outlet is made of punched metal board (blow section area: 0.24 m^2, aperture area: 0.1 m^2, aperture ratio: 42%). The air inlets are a line type with the opening area of 0.07 m^2.

EXPERIMENTAL RESULTS

PMV

Supply air volume from each air outlet was adjusted to achieve PMV=0 on each bed (based on PMV meter) by manual control for all experiment cases. Table 1 gives the time average PMV[*1] in each experimental condition. PMV measured at 0.6m height above the center of each bed is almost equal among the beds. PMV=0 is achieved in all experiment cases, except in the case of cooling with type-2, where supply air temperature was 20°C.

Supply heat

Figure 3 shows supply heat in each experiment. For cooling, when supply temperature was set highly, supply heat slightly decreased. At a supply temperature of 20°C, the supply heat in the entire patient's room was nearly 10% lower than the other supply temperature conditions. Since PMV=0 could not be achieved at Type-2 with a supply temperature of 20°C, the supply heat was lower than at other supply temperatures.

With regards to heating, the supply heat by Type-1 was about 45% greater than Type-2. Since the supply temperature necessary to achieve the thermal environment of PMV=0 could be set lower for Type2 than for Type1, the supply heat of Type-2 were greatly decreased.

Therefore, the Type-2 system is more advantageous than Type-1 because the supply heat could be decreased to make the same thermal environment in heating operation.

Room temperature distribution

Figure 4 shows vertical temperature distribution in each experiment. The measuring positions were ① to ⑤ in Figure 1.

For cooling, the temperature by Type-1 was about 25°C with almost no vertical temperature differences arroud the patient living area (FL+0.5m to FL+1.7m) as shown in Figure 4(a). As Figure 4(b) shows, the vertical temperature difference by Type-2 was 3 to 4°C, irrespective of the supply temperature setting. With the supply temperature of 16 and 18°C, the air temperature around bed surface was 23 to 24°C, about 1 to 2°C lower than that of Type-1.

Cool air accumulated under the bed with Type2 and reduced the temperature under the bed to about 22°C.

Since cool air was blown with a low air velocity

Table 2 Calculation condition of CFD analysis for two types of personal air-conditioning system

Cooling		bed1	bed2	bed3	bed4	others [°C]	Heating		bed1	bed2	bed3	bed4	others [°C]
Type-1	SA temp. [°C]	18.3	18.3	18.4	18.3	Surface Temp.	Type-1	SA temp. [°C]	38.5	38.2	38.4	38.0	Surface Temp.
	SA volume [CMH]	136	133	142	124	Floor : 25.0 Celing: 25.0		SA volume [CMH]	141	124	131	94	Floor : 18.0 Celing: 29.0
	SA velocity [m/s]	1.26	1.23	1.31	1.15	FA Temp. : 27.1		SA velocity [m/s]	1.31	1.15	1.21	0.87	FA Temp. : 24.6
Type-2	SA temp. [°C]	18.2	17.9	18.3	18.3	Surface Temp.	Type-2	SA temp. [°C]	29.0	29.0	28.9	29.1	Surface Temp.
	SA volume [CMH]	135	126	136	124	Floor : 25.5 Celing: 26.5		SA volume [CMH]	148	140	142	139	Floor : 19.5 Celing: 26.0
	SA velocity [m/s]	0.38	0.35	0.38	0.34	FA Temp. : 27.4		SA velocity [m/s]	0.41	0.39	0.39	0.39	FA Temp. : 25.8

* SA: Supply Air, FA : Supply Fresh Air Turbulent model : Standard Reynolds number model Mesh number : 171(x) x 124(y) x 64(z) = 1,357,056

Table 3 PMV and Supply heat in each bed calculated based on analytical results

Cooling		bed1	bed2	bed3	bed4	Total or Ave.	Heating		bed1	bed2	bed3	bed4	Total or Ave.
Type-1	PMV	0.23	0.13	0.26	0.13	0.19	Type-1	PMV	0.04	0.27	0.03	0.24	0.15
	Supply heat [W]	314	277	317	252	1160		Supply heat [W]	335	289	319	210	1153
	RA vol. CFD [CMH]	143	126	141	126	536		RA vol. CFD [CMH]	124	121	123	122	490
	RA temp. CFD [°C]	25.4	24.4	25.1	24.4	24.8		RA temp. CFD [°C]	31.4	31.2	31.1	31.3	31.3
	RA temp. Exp. [°C]	25.5	24.7	25.2	25.1	25.1		RA Temp. Exp. [°C]	28.3	28.6	29.2	28.2	28.6
Type-2	PMV	0.12	0.04	0.14	-0.01	0.07	Type-2	PMV	0.01	0.14	0.00	0.12	0.07
	Supply heat [W]	391	360	391	338	1479		Supply heat [W]	164	163	148	166	641
	RA vol. CFD [CMH]	130	131	130	131	522		RA vol. CFD [CMH]	142	143	141	144	570
	RA temp. CFD [°C]	26.9	26.5	26.9	26.5	26.7		RA temp. CFD [°C]	25.7	25.5	25.8	25.5	25.6
	RA temp. Exp. [°C]	25.5	25.2	25.3	25.0	25.3		RA temp. Exp. [°C]	24.7	24.8	24.7	24.7	24.7

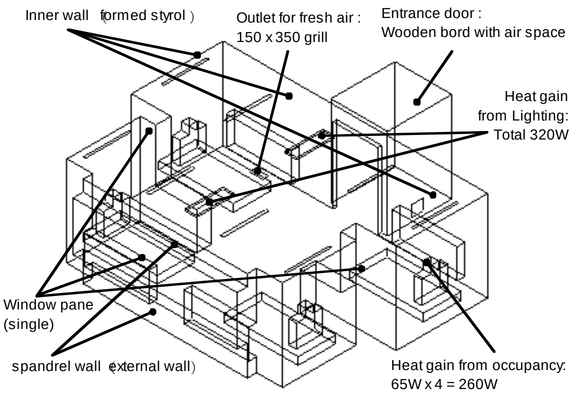


Figure 5 model of multi-bed Patient's room for CFD

from beside the patient, cool air descended before reaching the patient and accumulated under the bed. With regards to heating, the vertical temperature difference for Type-1 was about 8 to 10°C, as shown in Figure 4(a), irrespective of supply temperature setting. When supply temperature was set lower, temperature at the center of the bed became slightly higher. The air with higher supply temperature caused short circuit without reaching it on the surface of a bed. The vertical temperature difference by Type-2 was only about 4°C as shown in Figure 4(b), irrespective of blow temperature setting. The temperature around the bed of Type-2 was higher than that of Type-1. Thus, warm air blown from beside the patient reaches the bed more efficiently.

REAPPEARANCE OF THE SYSTEM PERFORMANCE BY CFD ANALYSIS

Analytical Conditions

Two types of personal air-conditioning system proposed in this paper were modeled to inspect reappearance of system performance by CFD analysis. Figure 5 describes the schematic model of multi-bed patient's room for CFD analysis by using the multi-purpose fluid analysis software STREAM[*2], and Table 2 shows analytical conditions in each air-conditioning type. For this analysis, experimental data on 18°C of supply air temperature set point for cooling, on 38°C of that by Type-1 and on 29°C of that by Type-2 for heating are applied as supply air conditions in each bed. Supply air conditions, and floor and ceiling surface temperature in the room were given from the experimental results for this analysis. Heat transfer through outside and inside walls was calculated by using overall heat transfer coefficient and temperature difference of the air between around wall inside surface and neighboring space. The results of temperature distribution of the room determine temperatures of return air in each air inlet and exhaust air.

Simulation results

Table 3 shows PMV[*1] in each bed calculated based on simulation results of air temperature, air flow and MRT on the center of each bed. PMV values become slightly larger (positive value) in cooling, slightly smaller (negative value) in heating than result of experiments. Vertical temperature distribution by CFD analysis around Bed1 and Bed2 are shown in Figure 6. Compared to experimental results of figure

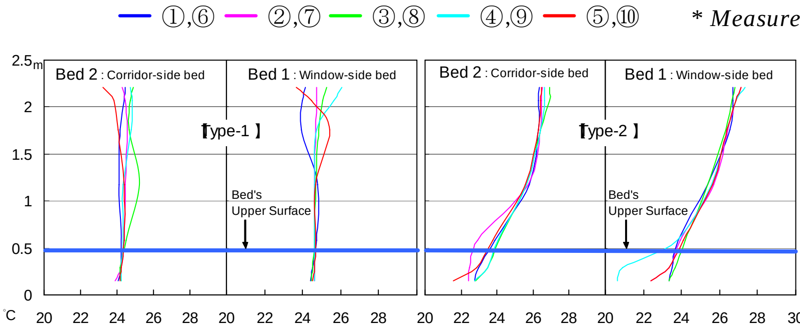


Figure 6(a) Vertical temp. distribution around beds (cooling: CFD)

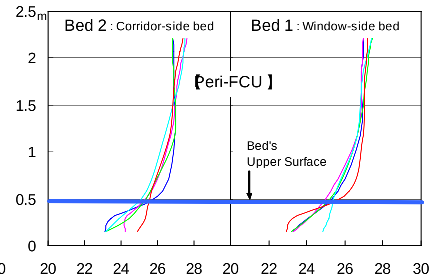


Figure 8(a) Peri-FCU (cooling: CFD)

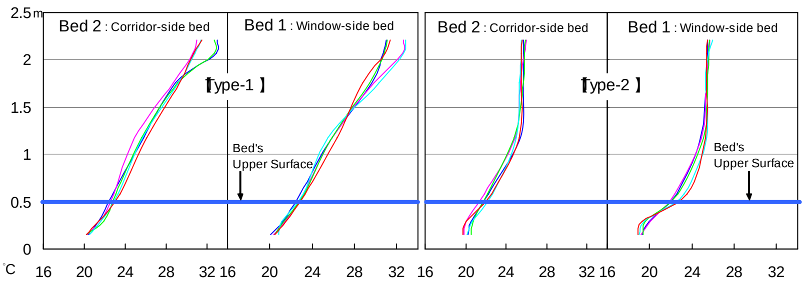


Figure 6(b) Vertical temp. distribution around beds (heating: CFD)

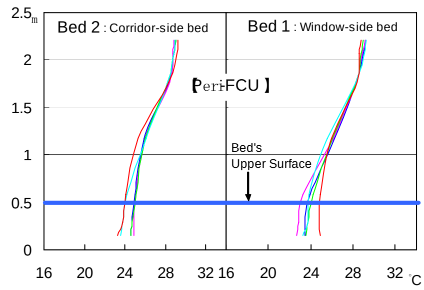


Figure 8(b) Peri-FCU (heating: CFD)

Table 4 Calculation condition for Peri- FCU system

Supply Air		Air Temp. [°C]	Air Volume [CMH/unit]	Air Velocity [m/s]
Cooling	Cooling air	18.2	260.5	0.93
	Flesh air	27.4	120	0.63
Heating	Heating air	29.0	284.5	1.01
	Flesh air	25.8	120	0.63
Return Air	Air velocity	Cooling: 1.39 [m/s], Heating: 1.52 [m/s]		

Table 5 Calculation results for Peri- FCU system

Cooling		bed1	bed2	bed3	bed4	Qs [kW]
Peri- FCU	PMV	-0.48	0.45	-0.50	0.45	911 (RA:23.5°C)
	Air temp. [°C]	23.5	25.7	23.5	25.7	
	Air velocity [m/s]	0.28	0.02	0.29	0.02	
Heating		bed1	bed2	bed3	bed4	Qs [kW]
Peri- FCU	PMV	0.68	0.82	0.64	0.84	920 (RA:24.1°C)
	Air temp. [°C]	26.5	26.7	26.5	26.7	
	Air velocity [m/s]	0.08	0.07	0.11	0.06	

*Measurement positions of Air temp. and velocity are 0.5m on each b

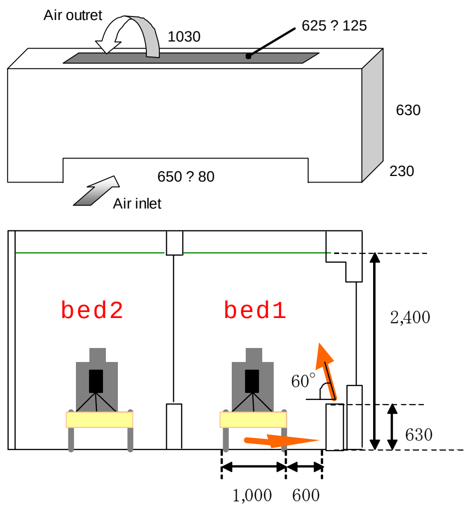


Figure 7 Description of Peri-counter FCU system

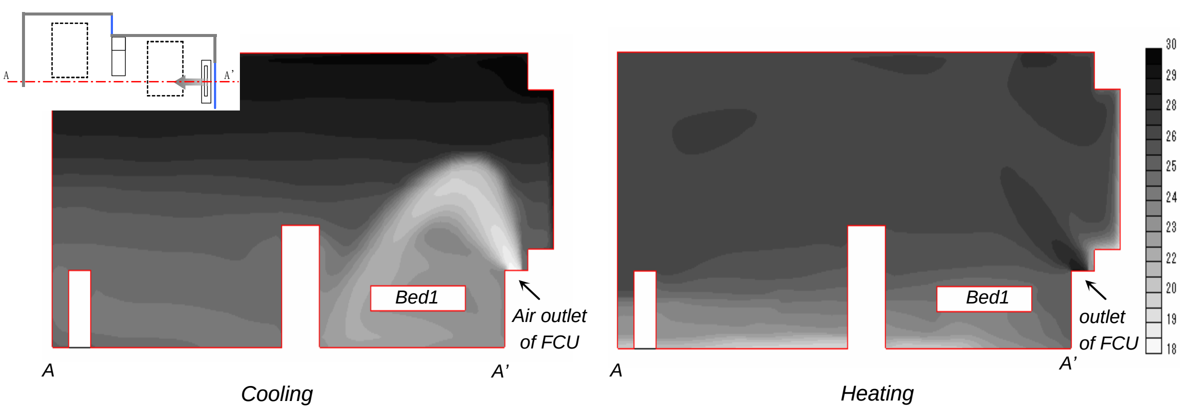


Figure 9 Sectional isotherm of the room for cooling and heating.

4, these of temperature distribution have almost similar shape respectively; therefore, it can be judged that CFD analysis almost can bring temperature distribution around bed to life under this calculation condition.

Supply heat was calculated from the product of supply air volume, air heat capacity ratio and temperature difference between supply air and return air and in each bed (Latent heat was not considered, because absolute humidity change was extremely small in this experiment). As for cooling, supply heat based on CFD analysis was similar to experimental result by Type-1, however, about 20% larger than that of Type-2. For heating, supply heat based on CFD analysis was about 28% smaller than that of Type-1, and about 21% smaller than that of Type-2. Because supply air volumes by CFD almost agree with experimental results, these differences of supply heat between CFD and experiment were caused by calculated return air temperature. It is considered that no consideration of thermal load by infiltration and radiation in analysis was the main cause of these results.

ANALYSIS FOR CONVENTIONAL FCU SYSTEM

Analytical Conditions

To compare the system performance of a personal air conditioning system with that of a conventional system, additional CFD analyses were conducted for a peri-counter FCU system (Peri-FCU). The Peri-FCU system which has two FCUs (There is an air inlet at the bottom, an air outlet at the top surface and diffused angle of supply air is 60°. See Figure 7) on the floor was analyzed under the same conditions of experimental results (flow rate, supply temperature and ceiling and floor surface temperature) by Type-2. Table 4 summarizes this calculation condition.

Analytical Results

1) PMV and supply heat

Table 5 shows PMV estimated at 0.6m height above the center of each bed and supply heat gotten from this analysis. For cooling, when the patient’s room was air-conditioned by the Peri-FCU under the air supply conditions as the experiment with Type2, the PMV value was about -0.5 on the window-side beds, and 0.45 on the corridor-side beds, within the comfortable range of -0.5< PMV <0.5. The supply heat was about 38% less in comparison with that of Type2 based on CFD analysis. If the supply heat is increased in the case of Peri-FCU, PMV value on the window-side beds will grow larger negative.

When heating with the Peri-FCU was analyzed under the same air supply conditions as the experiment with Type2, the PMV value for each bed became positive (see Table 5). The supply heat increased in about 43% on the Peri-FCU system in comparison with that of CFD results by Type2 from the reason why return temperature rose. When the supply heat is adjusted to achieve PMV=0 in each bed, however, the heat supply may decrease some of that in Peri-FCU.

2) Vertical temperature distribution

Figure 8 shows the vertical temperature distribution in each case, and Figure 9 shows the sectional isotherm of the room for cooling and heating. Vertical temperature distributions were plotted at ① to ⑤ in Figure 1 for the window-side bed (bed1) and at ⑥ to ⑩ for the corridor-side bed (bed2). As to cooling, the Peri-FCU produced a vertical temperature difference of about 5°C around a patient living area (FL + 0.6 to 1.8 m) on each bed as shown in Figure 8(a). At a height of FL + 1.8 m, the air temperature at each bed became about 28°C. As Figure 9 shows, diffused cold air from FCU reached on the surface of the windows side beds. Patients who are on the windows side bed may feel a sense of draft in this situation. PMV value became negative on the window side bed as shown in Table 5, due to fast wind (but not faster than 0.5 m/s at the center part of the window-side bed). Under the influence of supply air, Peri-FCU makes up an environment in which it was slightly cold on the window side and slightly warm on the corridor side. This result represents it hard to satisfy the requests of each patient.

With regards to heating, when the patient’s room was air-conditioned by the Peri-FCU system using the same supply air conditions as the Type2, the vertical temperature distribution for each bed was from 24 to 29°C as shown in Figure 8(b). Particularly in the patient living area, the temperature was as high as 25 to 28°C. As Figure 9 shows, Peri-FCU tended to make a small vertical temperature difference because supply air temp-erature is low and supply air can meet skin heat load effectively.

CONCLUSION

According to the results of the experiment, it is confirm that the Type-2 system which is a personal air-conditioning system supplying air from the wall side of the bed toward the patient is more advantageous than Type-1 which is a personal air-conditioning system supplying air from the ceiling toward the patient because Type-2 can decrease the supply heat in comparison with Type-1 to make the same thermal environment in heating operation. Because the supply temperature on Type-2 can be set much lower (about 29°C) than Type-1(more than 34°C).

To compare the system performance of a personal air conditioning system with that of a conventional system, CFD analyses were conducted for a peri-counter FCU system (Peri-FCU) and Type-2 of personal air-conditioning system as complementary approach.

Though the Peri-FCU may be able to achieve PMV= -0.5 at windows side beds and PMV=0.5 at corridor side beds for cooling with lower supply heat than that of Type-2 (estimated supply heat doesn't deserve an argument.), Peri-FCU can achieve a thermal comfort of patient's in the room only with this conditions, and can not meet suitable difference of individual patient's needs. For heating, Peri-FCU system doesn't have adopt flexibility on its air-conditioning to meet patient's preference but the system may make up neutral thermal environment on thermal comfort in the room with similar amount of energy of Type-2.

From these results, proposed personal air-conditioning systems have an advantage from the viewpoint of amenity improvement in comparison with conventional Peri-counter FCU system. It is expected that proposed personal air-conditioning systems in this paper can achieved the energy conservation by the effect of spot cooling and heating, but greater energy for cooling can be consumed by the system within suppositions of this paper. However, when sickbed is not occupied by patients in operation of the patient's room, the personal air-conditioning systems have a possibility to save energy consumption by stopping individual patient's air conditioning.

NOTES

*1 closing thermal insulation : 0.7 clo for cooling, 1.1 clo for heating. Metabolic rate: 1.0 met (Patients are sitting on their bed and keeping quiet.)

*2 STREAM ver.6, Software Cradle Co.,Ltd