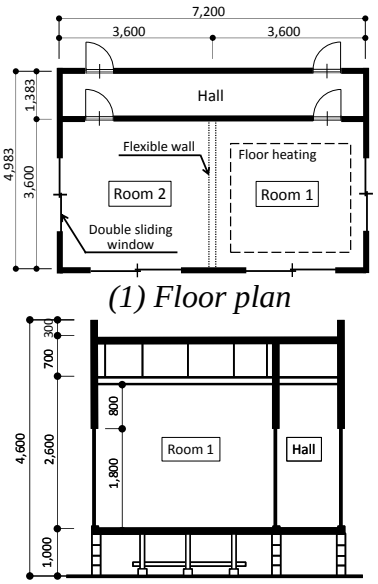


Figure 2. *Plan of the experimental model*

Table 1. *Calculation conditions*

Heat loss coefficient [W/(m^2· K)]		Ceiling	1.6
		Ex wall	1.2
		Floor	1.5
Floor area of room 1		12.96 m^2 (3.6 m × 3.6 m)	
Floor heating area		2.62 m × 3.12 m (ratio of 70% of floor area)	
Diameter of tube		0.0098 m	
Pitch of tube		0.075 m	
Input data	Temperature	Measured values per one minute (hall, room 2, crawl space, hot-water supply)	
	Flow rate of hot-water supply	1L/min	
Control method of hydronic floor-heating system		Room air temperature is kept constant at 21degrees C by the on-off control of the hot-water circulation (Manual operation)	

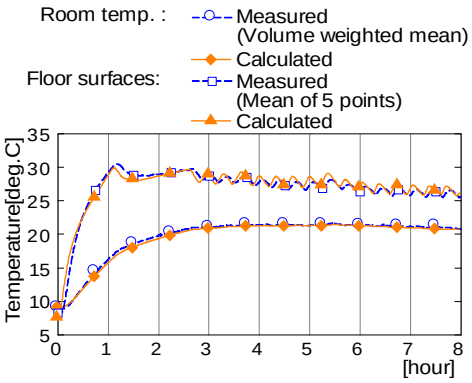


Figure 3. *Room temperature and floor surface temperature*

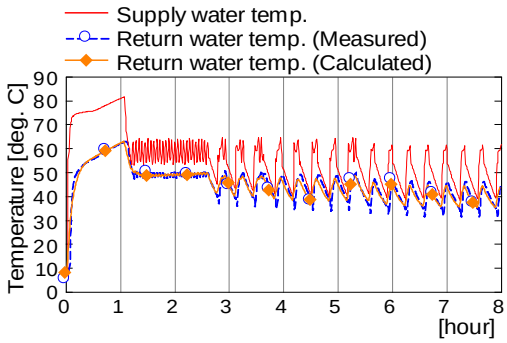


Figure 4. *Supply water temperature and return water temperature*

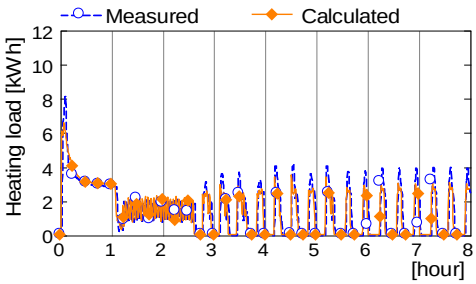


Figure 5. *Heating load*

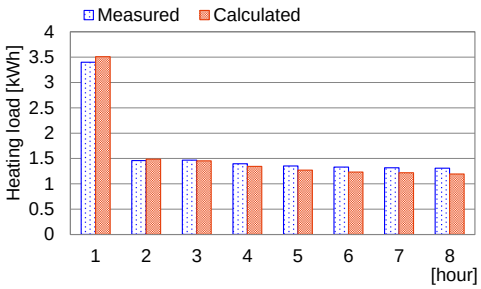


Figure 6. *Total heating load per hour*

heating loads for each hour. The estimate has a smaller margin of error. THERB can predict the thermal environment of a room equipped with the hydronic floor-heating system with absolute accuracy.

PREDICTION OF SENSORY INDEX

The influence of a non-uniform thermal environment, such as that achieved through floor heating, on the comfort of the occupant is evaluated by using the sensory index "COMSET*," which was derived from the heat balance of body parts in combination with THERB (Ozaki et al., 2011).

COMSET*

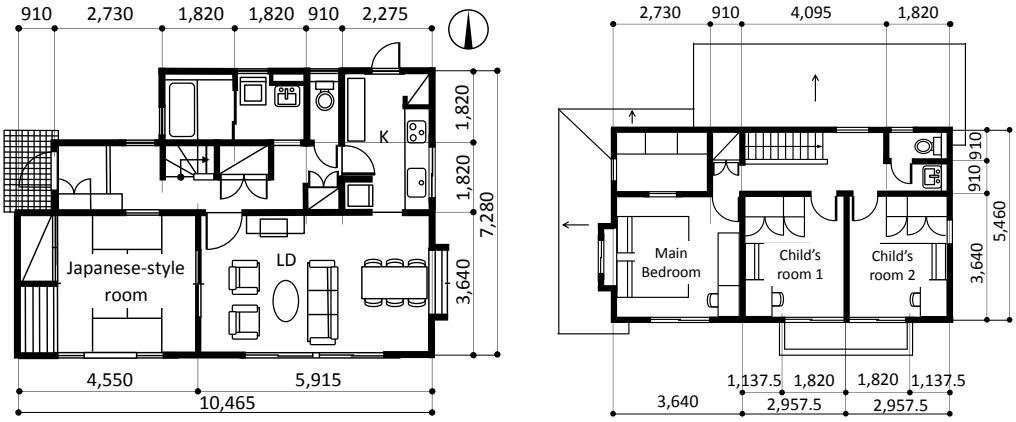
"COMSET*" is a mathematical model for a sensory index (Tanabe et al., 2006), such as the standard new effective temperature "SET*." "COMSET*" is derived from the detailed heat balance of human body parts, taking into consideration the blood circulation (arterial and venous flow) throughout the body, and involving the extremities. By dividing the whole body into 17 segments, each with skin and a core layer, the temperature distribution of the skin and blood at 59 points over the whole body can be predicted. COMSET* can subsequently calculate a generalized sensory index, under conditions such as those of a non-uniform thermal environment. The COMSET* calculations are conducted by setting up the boundary conditions of the surrounding air temperature and humidity, airflow velocity (convective heat flux), radiant heat flux, clothing amount, contact area on the floor for each body segment, and metabolic energy.

The original COMSET* does not take into account heat conduction in the area in contact with the floor. In the present study, the influence of contact thermal conductance on the sensation of warmth is considered by linking the heat balance of buildings and the human body.

EVALUATION OF THERMAL ENVIRONMENT BY COMSET*

The thermal environment and energy conservation of a single-family house, equipped with a space conditioning system or a hydronic floor-heating system, are evaluated based on COMSET*. The prediction is done by linking the simulation of both the building and the human body, by THERB and COM, respectively.

Figure 7 and Table 2 show the building model and Table 3 explains the calculation conditions. The hydronic floor-heating system was constructed in the living room, at a rate of 70% of the floor area. The standing and sitting position in the center of the living room are assumed as the physical posture to calculate COMSET*. The space conditioning system in the living room was not used when the hydronic floor-heating system was operated. The living room is controlled by COMSET* at a comfortable thermal environment temperature (about 21degrees C of COMSET*).



(1) First floor *(2) Second floor*

Figure 7. *Floor plan of the building model*

Table 2. *Outline of buildig model*

Gross floor area	[m^2]	120.07
Floor height	[m]	2.83
Opening ratio	[%]	26.80
Opening area	[m^2]	32.20
Heat loss coefficient Q	[W/(K･m^2)]	2.70
Solar acquisition coefficient μ	[-]	0.07

Table 3. *Calculation conditions*

Calculation region	Okayama (IVb region)	
Calculation date	January	
Air conditioning space	LDK	Space conditioning or floor heating
	Other rooms	Space conditioning
Family structure	2 adults and 2 children	
Posture	Standing position and sitting position	
Floor heating area	14.9 m^2 (ratio of 70% of floor area, LDK)	
Set temperature	20degrees C	
Heating	All day within the whole building	
Control of floor heating	On–off control of hot-water supply	

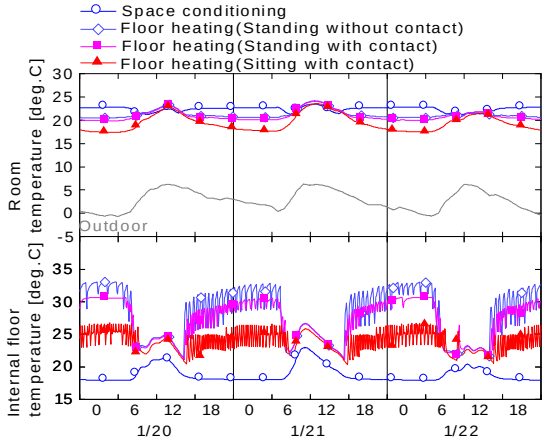


Figure 8. *Room air temperature and internal floor temperature*

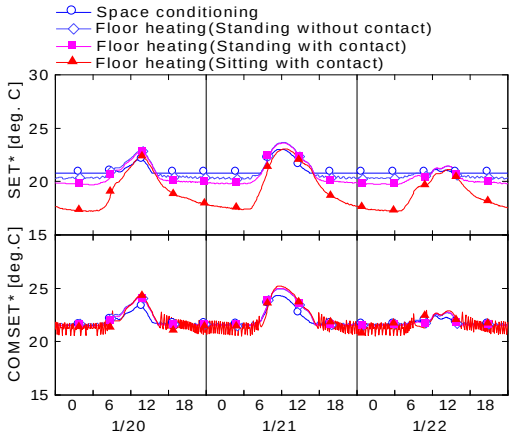


Figure 9. *SET* and COMSET**

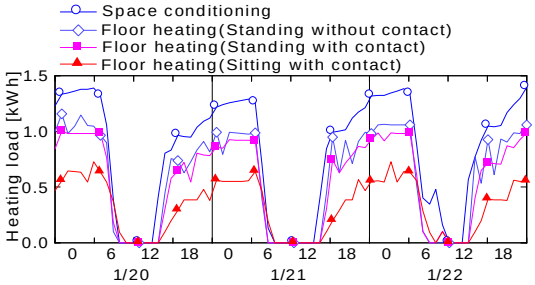


Figure 10. *Heating load*

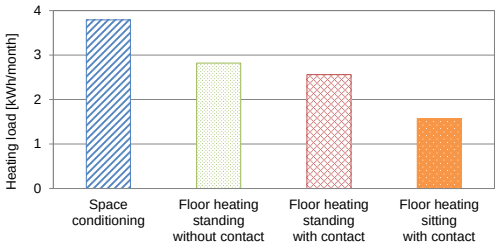


Figure 11. *Seasonal heating load per month*

Figures 8 and 9 show the time variation of air and floor temperature, SET*, and COMSET* of the living room from January 20 to 22. Although the COMSET* is relatively constant for all heating conditions, the air temperature of the room and SET* increase in the following order: space conditioning, floor heating in the standing position, and floor heating in the sitting position.

Sitting position, which is affected significantly by radiative heat and contact thermal conductance from the floor, can lower the air temperature when the floor is heated, if the sensory index of COMSET* is used as a control requirement in keeping with the reality of human behavior.

Figures 10 and 11 show the temporal variation of the heating load and the term heating load for a month (January) in the living room. In comparison with the space conditioning system, the heating loads of the hydronic floor-heating system are

decreased, particularly in the sitting position.

It is necessary to consider the radiative heat and the contact thermal conductance from the floor for each part of the human body in the floor-heating system, because the sensation of warmth from the heated floor is obviously different from that of general space conditioning. If the sensory index of COMSET* is used as a control condition for heating, depending on the physical posture, it is possible that the floor-heating system could dramatically decrease the heating load.

CONCLUSION

The simulation software "THERB," incorporating complete features regarding heat, moisture, and airflow, has been developed to predict the hygrothermal environment and sensory index within whole buildings. The calculation precision of the software with regard to floor heating is verified by comparison with monitoring results. It was found that THERB could predict the thermal environment of a room equipped with a hydronic floor-heating system with absolute accuracy. Furthermore, sensitivity analyses of the heating system and the sensory index provide the following results. 1) Even if the values of COMSET* remain constant, the room air temperature rises when the heating system is changed in the following order: space conditioning, floor heating in a standing position, and floor heating in a sitting position, to cause a sense of warmth. 2) The floor-heating system has the ability to decrease the heating load dramatically, depending on the physical posture, if the radiative heat and the contact thermal conductance from the floor for each part of the human body are realistically considered as control requirements of heating.

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