STUDY ON THE RELATIONSHIP BETWEEN A HEAT LOSS FROM FLOOR HEATING AND AIR-CONDITIONING IN A LIVING ROOM

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ABSTRACT

With radiant heating, it is possible to set room air temperature lower than when heating with air-conditioning because the human body is heated by a radiation. As room air temperature decreases, heat loss from walls and windows decreases, and so does the ventilation load. It is often said that the radiant heating, such as floor heating saves energy. This study calculates heat flow at the windows and the walls of a living-room using computational fluid dynamics (CFD).

KEYWORDS

Heat loss, Radiation, Floor heating, Air-conditioning, Energy Consumption, Residential building

INTRODUCTION

When heating with radiation, heat is released and received between the human body and heating surface primarily through radiation. Thus, radiant heating is a heating system where indoor air temperature can be maintained more uniformly than heating with air-conditioning, and indoor air temperature can be set relatively low. In general, when the room temperature during heating is set low, there is a decrease in transmitted heat which is lost as it moves to the outdoors through walls and windows, and furthermore there is a decrease in the load due to ventilation, so that heating with radiation enables decreased energy consumption for heating. But very little research has been done regarding the energy consumption of radiant heating (such as floor heating) and air-conditioning.

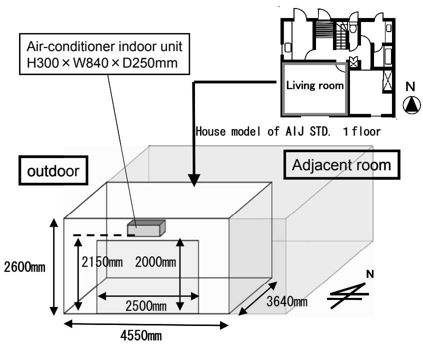

Figure 1. Overview of object of analysis

Table 1. Calculation cases

	Conditions for heat insulation performance
Case 1	Model satisfying next-generation energy conservation standards (region III, Japan)
Case 2	Model which halves the thickness of insulation in case 1
Case 3	Model which halves the thickness of insulation in case 1, except for the floor

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ANALYSIS AND CALCULATION CASES

In this research, we use CFD analysis to clarify the indoor heat balance, and thereby conduct detailed analysis of the balance of heat passing through the walls, floor, ceiling and window of a living room, which is difficult to determine with field measurements. Figure.1 shows an overview of the object of analysis. Analysis is conducted on a 1st floor living room of a standard housing model of the Architectural Institute of Japan. The floor area of the object of analysis is 10 tatami mats ($16.562m^2$). The indoor unit of the air conditioner is placed at the center above the window on the south wall. The ceiling, east wall and north wall of the room face adjacent rooms (room temperature 20℃), and the west wall, south wall and floor face to the outdoors (outside air temperature 0℃). Table 1 shows the calculation cases. The purpose of these calculation cases is to clarify the relationship between heat load and insulation performance of floor heating and heating with air-conditioning. Three types of analysis are performed, with varying insulation performance of the residence, and heat loss is compared during floor heating and heating with air-conditioning. Table 2 shows the specifications of the walls, floor, ceiling and window. Table 3 shows the heat transmission coefficients (Note 1) for shelter performance in next-generation energy conservation standards (region III, Japan) and for each calculation case.

Table 2. Specifications of walls, floor, ceiling and window

	Ceiling	Outer walls	Floor	Window
case1	Plywood 20mm GW 10K 200mm Plasterboard 15mm	Plywood 20mm GW 16K 70mm Plasterboard 15mm	Plywood 10mm GW 10K 100mm	Glass 3mm Sealed air layer 6mm Glass 3mm
case2	Plywood 20mm GW 10K 100mm Plasterboard 15mm	Plywood 20mm GW 16K 35mm Plasterboard 15mm	Plywood 10mm GW 10K 50mm	Glass 3mm
case3	Plywood 20mm GW 10K 100mm Plasterboard 15mm	Plywood 20mm GW 16K 35mm Plasterboard 15mm	Plywood 10mm GW 10K 100mm	Glass 3mm

* Constituent materials are indicated from the top for the ceiling, from the outside for outer walls, and from the top for the floor.
(Abbreviation) GW: Glass Wool

Table 3. Heat transmission coefficients of each part, for shelter performance in next-generation energy conservation standards (region III, Japan) and for each calculation case

	Ceiling	Outer walls	Floor	Window
Next generation energy conservation standards (Region III, Japan)	0.24	0.53	0.48	3.49
case1	0.23	0.53	0.43	2.44
case2	0.42	0.90	0.76	6.35
case3	0.42	0.90	0.43	6.35

Unit: [W/m^2K]

CALCULATION METHOD

Table 4 shows the calculation conditions for CFD. STREAM from Software Cradle Co., Ltd., is used for analysis, and indoor air flow vectors calculation, temperature distribution, mean radiant temperature and SET* are calculated with computational fluid dynamics using a standard $k-\varepsilon$ model. The temperature of the floor surface (plywood) when heating by radiation, and supply temperature of the air conditioner in heating are calculated by adjusting so that SET* becomes about 22℃.

Table 4. Calculation conditions

(1) Calculation code: Software Cradle, STREAM Ver. 6
(2) Turbulence model: Standard k- ε
(3) Boundary conditions:
Wall surface boundary conditions: Generalized log law for wind velocity, and temperature log law for temperature.
There are assumed to be adjacent rooms at 20℃ at the ceiling, east wall and north wall.
The outdoors, at 0℃, is assumed to be at the floor, west wall and south wall.

(4) Radiation conditions:
A radiation rate of 0.9 is assigned to the inside of each wall.
(5) Heating conditions:
-Radiant heat
An arbitrary temperature is fixed on the floor surface (plywood).
- Air Conditioner
The following flow velocity boundaries are assigned to the air conditioner indoor unit.
-Supply air (6.55m^3/min), Downward 45°
Velocity=2.17m/s, K=4.69×10^{-2}, ε =3.98×10^{-1}
Temperature is set arbitrarily, in accordance with the room temperature
-Return air
Velocity=0.722m/s

RESULTS OF CFD ANALYSIS

Amount of heat transmitted, and amount of heat loss due to infiltrations

It is impossible to compare a heat loss in the case of floor heating and heating with air-conditioning by room air temperature. So that we use a sensible temperature (as is SET*) to evaluate thermal conditions of the room. Table 5 shows the results of calculating the amount of heat transmitted from the walls, floor, ceiling and window, and the amount of heat loss due to infiltrations. The amount of heat loss due to infiltrations is calculated from the indoor temperature(Note 2) and outdoor air temperature (0℃), by using CFD calculation results with no ventilation, and letting the air change rate of infiltration be 0.5 1/h. The total amount of heat loss indicates the total of the amount of heat transmitted, and the infiltration heat loss.

Case 1 satisfies the insulation performance in next-generation energy conservation standards (region III). In case 1 with floor heating, the total amount of heat transmitted is 691.1W, the total amount of heat

Table 5. Calculation results for amount of heat transmitted from walls, floor, ceiling and window, and amount of heat loss due to infiltrations

Analysis case		Room temperature [℃]	Outside air temperature [℃]	Total amount of heat transmitted [W]	Amount of infiltration heat loss [W]	Total amount of heat loss [W]	Amount of heat loss per unit floor area [W/㎡]	Mean Radiant Temperature [℃]	Average wind velocity [m/s]	SET* [℃]
case1	Floor heating Floor surface temperature 25.4℃	21.8	0	691.1	156.7	847.8	51.2	21.9	0.03	21.8
	Heating by Air conditioner Makeup air temperature 30.0℃	24.5	0	600.3	176.2	776.5	46.9	20.4	0.19	21.8
case2	Floor heating Floor surface temperature 29.3℃ Half of the insulation	21.6	0	1331.4	155.5	1486.9	89.8	21.8	0.03	21.7
	Heating by Air conditioner Makeup air temperature 45.0℃ Half of the insulation	24.8	0	1599.6	178.7	1778.2	107.4	19.6	0.17	21.7
case3	Floor heating Floor surface temperature 31.6℃ Half of the insulation, except at floor	19.7	0	1364.4	141.4	1505.7	90.9	23.2	0.02	21.5
	Heating by Air conditioner Makeup air temperature 35.0℃ Half of the insulation, except at floor	25.7	0	1048.9	184.7	1233.6	74.5	18.5	0.19	21.5

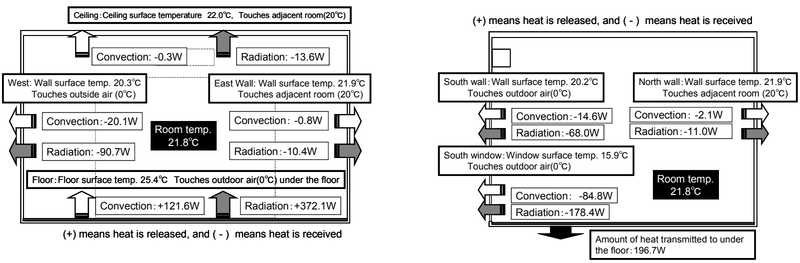
loss due to infiltrations is 156.7W, and the total amount of heat loss is 847.8W. In case 1 with heating by air-conditioning, the values are respectively, 600.3W, 176.2W and 776.5W. In case 2, the thickness of the insulation in case 1 is halved. In case2 with floor heating, the total amount of heat transmitted is 1331.4W, the amount of heat loss due to infiltrations is 155.5W, and the total amount of heat loss is 1486.9W. In case 2 with heating by air-conditioning, the values are, respectively, 1599.6W, 178.7W and 1778.2W. In case 2, the total amount of heat loss increases by about 2 times compared to case 1 for both floor heating and air-conditioning. In case 3, the thickness of the insulation in case 1 is halved (except for the floor). In case 3 with floor heating, the total amount of heat transmitted is 1364.4W, the total amount of heat loss due to infiltrations is 141.1W, and the total amount of heat loss is 1505.7W. In case 3 with heating by air-conditioning, the values are, respectively, 1048.9W, 184.7W and 1233.6W.

The amount of transmitted heat is greater with floor heating than with air-conditioning because the wall surface temperature is relatively high due to the effects of mutual radiation. Also, the room temperature is low and thus the amount of heat loss due to infiltrations is low compared with air-conditioning.

In case 1, the amount of heat loss per unit floor area is 51.2W/m^2 for floor heating and 46.9W/m^2 for air-conditioning, and thus is about 8% less than with air-conditioning. In case 2, the amount of heat loss per unit floor area is 89.8W/m^2 for floor heating, and 107.4W/m^2 for air-conditioning, and thus is about 20% higher with air-conditioning. In case 3, the amount of heat loss per unit floor area is 90.9W/m^2 for floor heating, and 74.5W/m^2 for air-conditioning, and thus is about 18% less with air-conditioning. In both case 1 and case 3, where the under floor insulation is the same, air-conditioning has lower heat loss than floor heating, and saves energy.

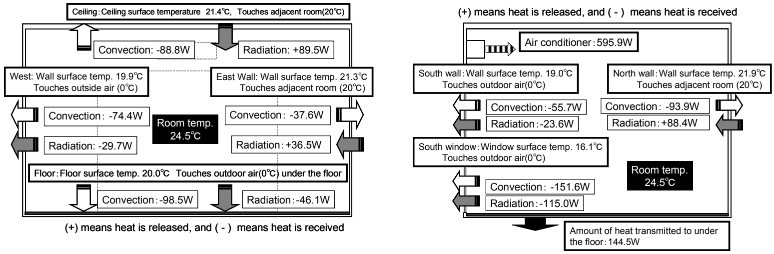
Heat released/received at each wall surface and wall surface temperature

Figs. 2–7 show the heat released/received at each wall surface and the wall surface temperature for each case. In all cases, the temperature of each wall surface, except for the floor, is about 0.4−5.9℃ higher with floor heating than with air-conditioning due to the effects of mutual radiation. With floor heating in case 2, heat transmitted below the floor is 31.9% of the total transmitted heat, and this ratio is 16.2% with air-conditioning. In case 3, the ratio is 18.1% with floor heating and 11.3% with air-conditioning. In case 2, where the thickness of floor insulation is half that of case 3, the ratio of heat transmitted below the floor relative to the total amount of heat transmitted is high. In particular, the rate of increase with floor heating is higher than with air-conditioning because the temperature of the floor is high. With floor heating, the heat transmission coefficient of the floor material has a large impact on the amount of heat loss. Also, in all cases, heat flow due to radiation is larger than that due to convection during floor heating, and, conversely, heat flow due to convection is larger than that due to radiation during air-conditioning.



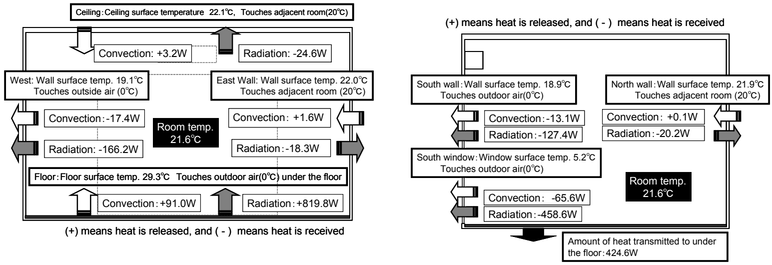
(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 2. Amount of heat released/received at each wall surface and wall surface temperature during floor heating (case 1: Floor surface temperature 25.5℃)



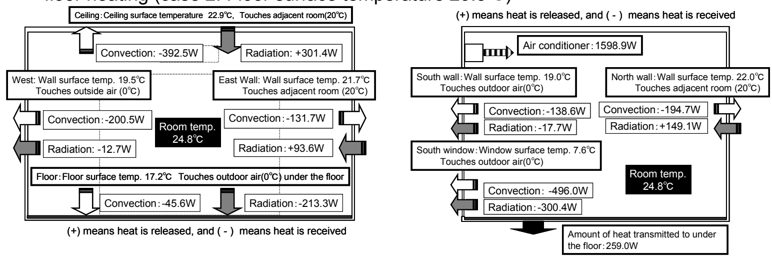
(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 3. Amount of heat released/received at each wall surface and wall surface temperature during hot-air heating (case 1: Air conditioner blowing temperature 30℃)



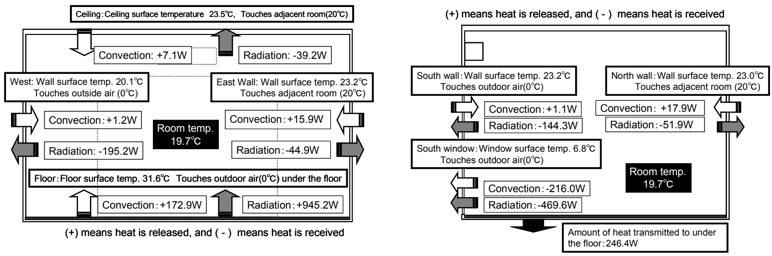
(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 4. Amount of heat released/received at each wall surface and wall surface temperature during floor heating (case 2: Floor surface temperature 29.5℃)



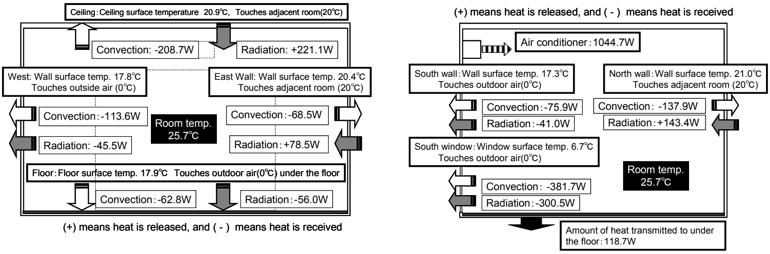
(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 5. Amount of heat released/received at each wall surface and wall surface temperature during hot-air heating (case 2: Air conditioner blowing temperature 45℃)



(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 6. Amount of heat released/received at each wall surface and wall surface temperature during floor heating (case 3: Floor surface temperature 31.6℃)



(1) Diagram viewing from south wall (2) Diagram viewing from east wall

Figure 7. Amount of heat released/received at each wall surface and wall surface temperature during hot-air heating (case 3: Air conditioner blowing temperature 35℃)

CONCLUSIONS

In this research, we used CFD analysis to clarify the indoor heat balance, and thereby conduct detailed analysis of the balance of heat passing through the walls, floor, ceiling and window of a living room during radiant heating (floor heating) and air-conditioning. The conclusions are as follows:

(1) In CFD calculation results where SET* (which acts as an evaluation of comfort) becomes about 22℃, the wall surface temperature is higher with floor heating than when air-conditioning, and thus the amount of heat loss due to heat transmission is high. Also, the room temperature is low and thus the amount of heat loss due to infiltrations is low compared with air-conditioning.

(2) In case 1, which satisfies next-generation energy conservation standards (region III, Japan), the total amount of heat loss with floor heating is about 8% higher than when air-conditioning.

(3) With floor heating, the heat transmission coefficient of the floor material has a large impact on the amount of heat loss.

(4) With floor heating, heat flow due to radiation is larger than that due to convection. Conversely, with air-conditioning, heat flow due to convection is larger than that due to radiation.

(5) With floor heating, the temperature of the floor heating panel (i.e. the heat source) is high, and thus it is necessary to strengthen insulation at the part where the floor heating panel is installed. Also, the indoor wall surface temperature is higher than with air-conditioning due to radiation from the floor surface, and thus care is also needed regarding strengthening of insulation at outer wall parts.

NOTES:

1) Heat transmission coefficients were calculated using the heat transfer coefficients given below.

Table 6. Heat transfer coefficients used for calculating heat transmission coefficients

	Heat transfer coefficients [W/m^{2}K]	
	Outdoor side αo	Indoor side αi
Outer Walls	23	9
Ceiling	9	9
Floor	7	7
Window	23	9

2) For SET*, room temperature and average wind velocity, analysis was conducted using the average value for the interval from 0.5m to 1.8m above the floor, while taking into account the vertical temperature distribution and temperature at the air-conditioner blower section.