Contact Area and Heat Transfer of Subject with Heated Floor

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ABSTRACT

It is often pointed out that when evaluating the energy-saving performance of equipment, it is important to take into consideration how the equipment under consideration is actually used. In evaluating heat transfer by contact during floor heating, it is important not only to evaluate spatial temperature distribution and operative temperature but also to take into consideration heat transfer by contact with the floor in view of the actual state of the floor heating system users. The area of contact of the human body with the floor, the temperature of enclosed space, and the amount of heat transfer were measured by using an EFCT meter.

1. INTRODUCTION

In evaluating heat transfer by contact during floor heating, it is important not only to evaluate spatial temperature distribution and operative temperature but also to take into consideration heat transfer by contact with the floor in view of the actual state of the floor heating system users. The authors, therefore, measured the area of contact of human subjects with the floor for typical sitting positions (sitting on the floor and sitting on a chair) by using a measuring system designed specifically for the measurement of the surface area of the human body in contact with the floor surface. The authors also measured enclosed space temperature and the amount of heat transferred by contact during air conditioning and floor heating by using a an EFCT (Estimated Floor Contact Temperature) meter[1),2)] which is a measuring system mimicking human feet.

2. FLOOR CONTACT AREA

2.1 Contact Area Measurement Method

Figure 1 is a photograph of the floor contact area measurement system used for the purposes of this study. The photograph shows the measurement system in operation. Figure 2 illustrates the measurement system. The measurement system consists of a laboratory room set up as a darkroom, a base measuring 1,800 mm wide, 1,500 mm deep and 1,500 mm high, blackout curtains surrounding the base, and a 25-millimeter-thick acrylic plate placed over the base. Fluorescent lamps were installed along the periphery of the acrylic plate so that by shedding light toward the subject on the plate, the contrast between the areas of contact with the acrylic plate and the rest of the plate was intensified. During the measurement, a subject wearing white whole-body tights and a pair of gloves took specified bodily positions on the measurement system, and the subject was shot with a digital camera from under the acrylic plate. The area of contact was calculated by first subjecting the images thus obtained to the negative/positive inversion treatment as shown in Figure 3 and binarizing the needed areas.

2.2 Physical Data on Subjects

A total of eight male human subjects in their twenties participated in the experiments. Table 1 shows physical data on the subjects. The surface area of the body was calculated by using Kurazumi et al.'s formula[3)]. As representative positions taken during floor heating, the ten floor-sitting positions and five chair-sitting positions shown in Figure 4 were specified as experiment conditions.

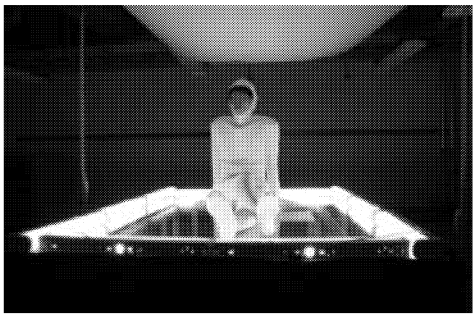


Figure 1　Body–floor contact area measurement system

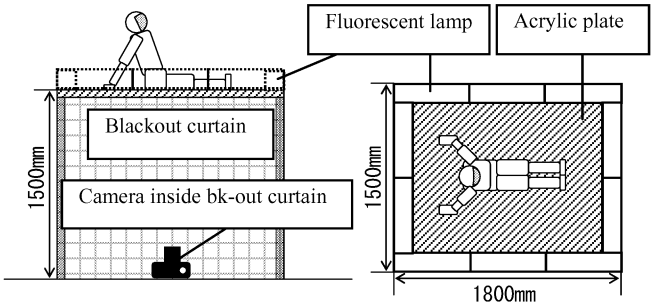


Figure 2　Measurement system
(L: side view, R: plan view)

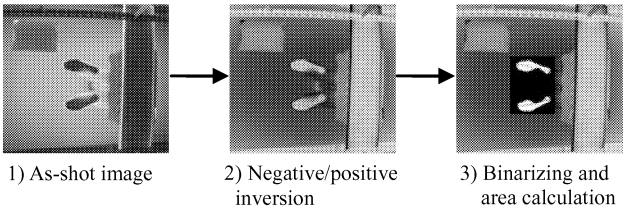
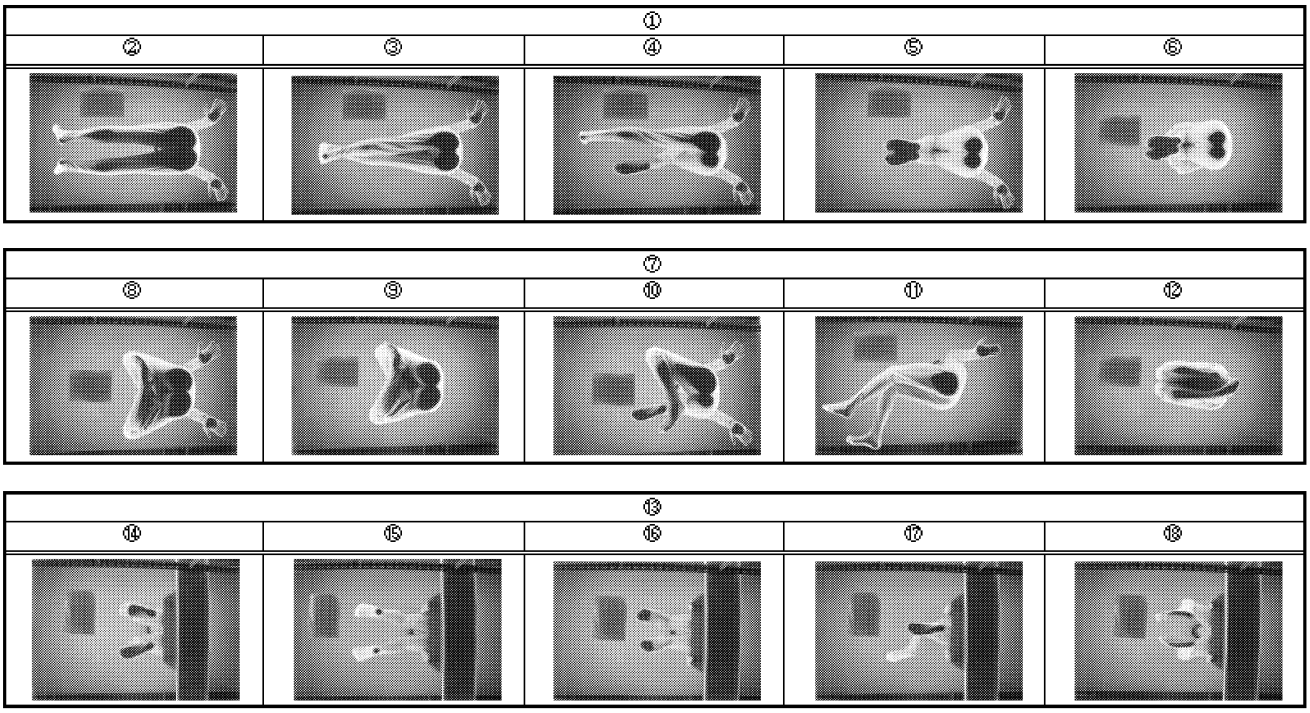


Figure 3　Example of image processing: sitting on chair, both feet on floor

Table 1　Physical data on subjects

Subject	Age	Height	Weight	Body surface area
A	24	176.8	65.5	18007.2
B	22	175.0	66.7	17968.9
C	22	168.0	58.7	16586.3
D	22	165.0	61.2	16587.5
E	22	163.3	78.4	17979.2
F	20	165.0	56.0	16060.5
G	22	185.0	60.2	18141.6
H	22	172.0	82.0	19090.5
Average	22 (1.1)	171.3 (7.4)	66.1 (9.4)	17552.7 (1025.8)

(Standard Deviation)



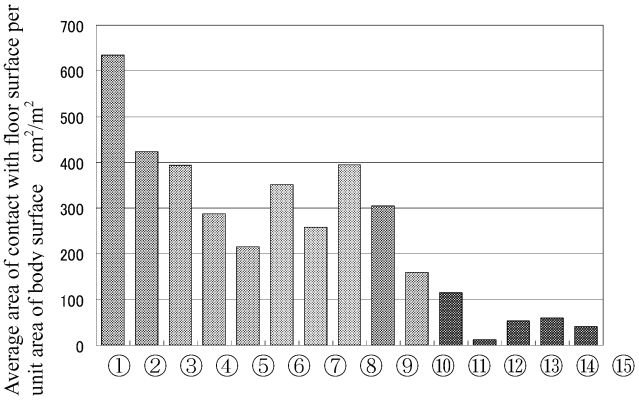
① Sitting on floor (with thrown-out legs)
② With thrown-out legs (body supported by both arms)
③ With thrown-out legs (body supported by both arms, cross-legged)
④ With one knee drawn up (body supported by both arms)
⑤ With both knees drawn up (body supported by both arms)
⑥ With both knees drawn up (body not supported by arms)
⑦ Sitting on floor (others)
⑧ Cross-legged (body supported by both arms)
⑨ Cross-legged (body not supported by arms)
⑩ Cross-legged (body supported by both arms, with one knee drawn up)
⑪ Obliquely (body supported by one arm)
⑫ Japanese style
⑬ Sitting on chair
⑭ With both feet on floor
⑮ With only heels on floor
⑯ With only toes on floor
⑰ With one leg over the other
⑱ With raised feet (only outsides of soles in contact with floor)

Figure 4　Positions taken by subjects (10 floor-sitting positions, 5 chair-sitting positions)

2.3 Measured Areas of Contact for Different Positions

Figure 5 shows the values obtained by dividing the area of contact of the eight subjects with the floor by the body surface area of the subjects. A look at the results for sitting on the floor reveals that the area of contact is large in the "sitting with thrown-out legs" cases. The area of contact is largest when sitting with both legs thrown out and with both arms behind on the floor, and the area of contact in that case (about 6%) is about four times as large as the area of contact in the "sitting on the floor Japanese style" case. In the case of sitting on the chair with the soles in contact with the floor, the area of contact varied by a factor of up to 10 or so depending on how the feet are in contact with the floor. Under all conditions, the area of contact was greater when sitting on the floor than when sitting on the chair.

3 MEASUREMENT OF NEAR-FLOOR ENCLOSED SPACE TEMPERATURE AND HEAT TRANSFERRED BY CONTACT



① With thrown-out legs (body supported by both arms)
② With thrown-out legs (body supported by both arms, cross-legged)
③ With one knee drawn up (body supported by both arms)
④ With both knees drawn up (body supported by both arms)
⑤ With both knees drawn up (body not supported by arms)
⑥ Cross-legged (body supported by both arms)
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⑧ Cross-legged (body supported by both arms, with one knee drawn up)
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⑭ With one leg over the other
⑮ With raised feet (only outsides of soles in contact with floor)

Figure 5 Area of contact with floor surface per unit area of body surface

3.1 EFCT meter

Figure 6 shows a photograph of the EFCT meter used for the experiments. The EFCT meter consists of a human body model filled with silicon rubber (lower unit), water circulation pumps, temperature control system (upper unit), etc., and the temperature of the human body model can be kept at about 37°C. Figure 7 shows the relationship between floor surface temperature and EFCT meter water temperature for the EFCT meter used in the experiments. The temperature setting (37°C) was slightly exceeded, but the water temperature in the EFCT meter remained nearly constant.

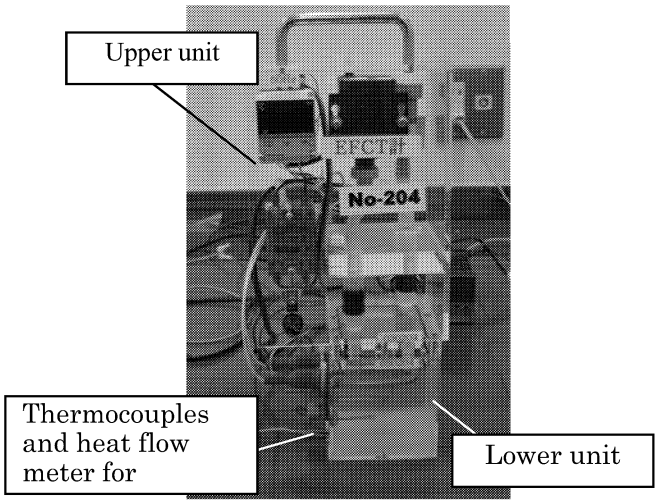

Figure 6 EFCT meter

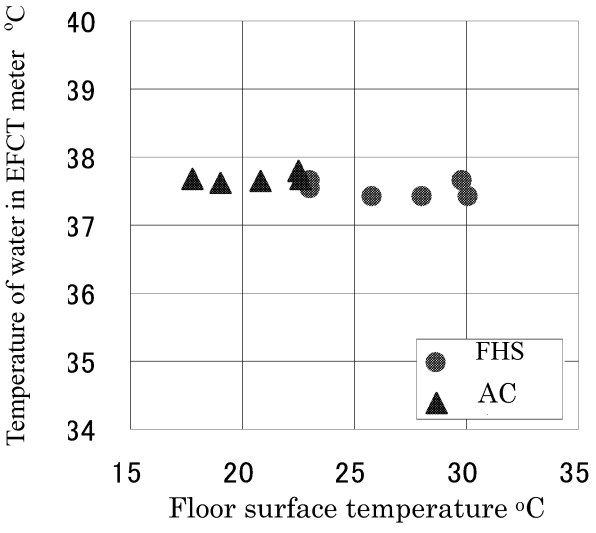

Figure 7 Relationship between floor surface temperature and EFCT meter water temperature

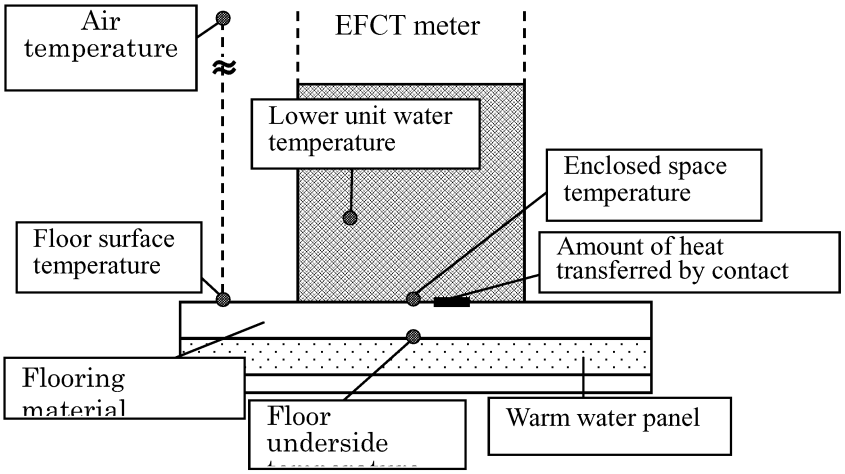

Figure 8 Locations of temperature and contact heat transfer measurement

3.2 Experiment Conditions

By using the experimental house in the climate chamber mentioned earlier, a steady-state thermal environment by air conditioning and floor heating. Assuming a case where a floor heating system is not installed, the water in the warm water underfloor heating system was drained in advance. After a steady state was confirmed by checking on indoor air temperature and temperature in the wall, as the first step, near-floor enclosed space temperature and the amount of heat transferred by contact were measured with the EFCT meter installed on the floor as shown in Figure 8. One hundred minutes worth of measurements were taken while a steady state was maintained, and the averages of the measurements thus taken were used. Assuming winter air conditions, the outside air temperature was set to 5°C, and humidity to 50%. In the tests, temperature was set to 18°C, 20°C, 22°C and 24°C on the remote controllers of the air conditioning system and floor heating system used. To show examples of states observed in the experiments, Figure 9 shows the relationship between floor surface temperature and the mean temperature of the underside of the floor in the cases where the temperature settings on the remote controllers were varied. Figure 10 shows the relationship between floor surface temperature

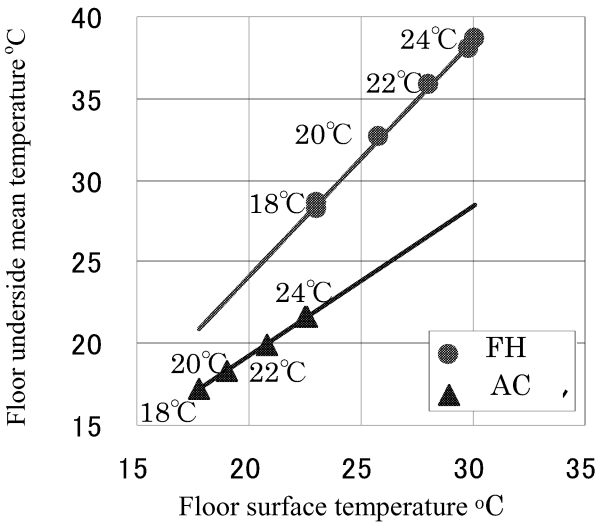

Figure 9 Floor surface temperature and floor underside temperature

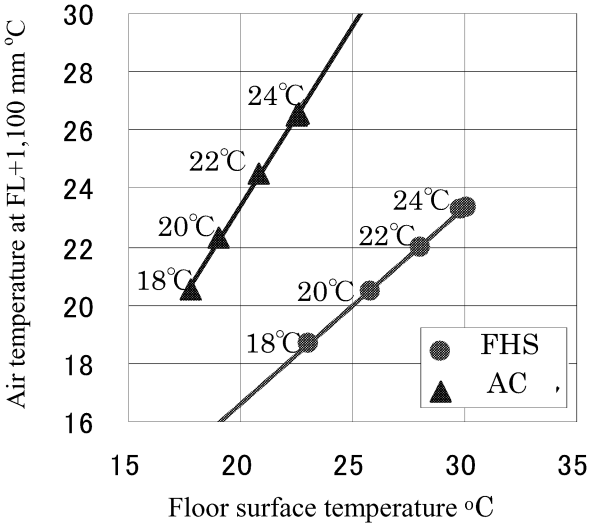

Figure 10 Air temperature at FL+1,100 mm near EFCT meter

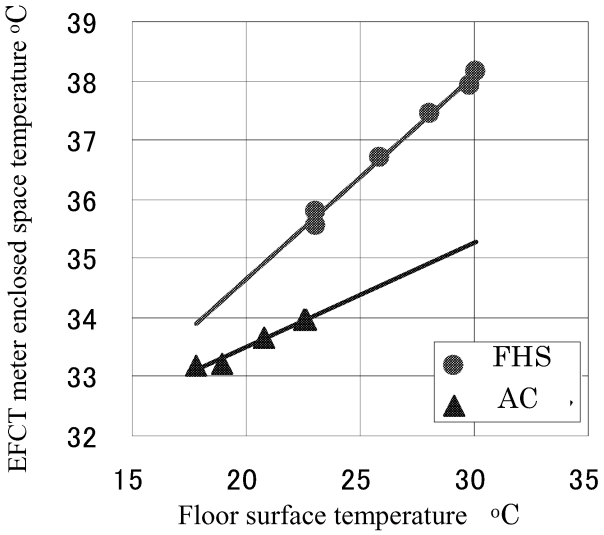

Figure 11 Floor surface temperature and EFCT meter enclosed space temperature

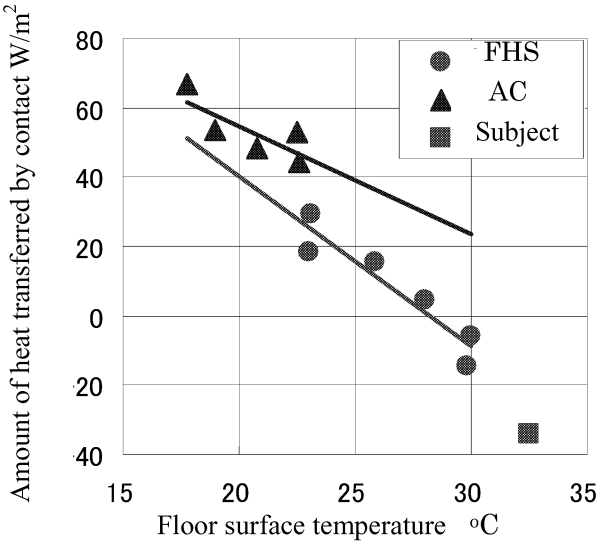

Figure 12 Floor surface temperature and amount of heat transferred by contact

at the thermometer point nearest to the EFCT meter and air temperature at FL+1,100 mm. The temperatures shown in the figures are the temperature settings on the remote controllers. As shown in Figure 10, the temperature of the underside of the floor was lower than the floor surface temperature during air conditioning. In contrast, the floor underside temperature was higher than the floor surface temperature during floor heating. This is because of the effect of the warm water under the flooring. As can be seen from Figure 10, the relationship between floor surface temperature and air temperature varies considerably depending on the air conditioning method.

3.3 Experiment Results

For comparison of the effects of enclosed states, Figure 11 shows the results of measurement of floor surface temperature and the enclosed space temperature measured with the EFCT meter. In the results related to air conditioning, the floor surface temperature in the non-enclosed areas ranged from about 18°C to 23°C, and the enclosed space temperature measured with the EFCT meter in the same areas was about 33°C to 34°C. Thus, the enclosed space temperature during air conditioning was always lower than the temperature of the EFCT meter. During floor heating, floor surface temperature ranged from about 23°C to 30°C, and enclosed space temperature ranged from about 35.5°C to 38°C. In the case where the floor surface temperature during floor heating was about 30°C, closed space temperature was about 38°C, which was higher than the temperature of the water in the EFCT meter. When the floor surface temperature was about 23°C, enclosed space temperature was higher during floor heating than during air conditioning by 1.5°C to 2°C. The reason why enclosed space temperature varies even at the same floor surface temperature is that during floor heating, there is warm water under the flooring.

Figure 12 shows the measured values of floor surface temperature and the amount of heat transferred by contact in the enclosed space of the EFCT meter. In the figure, a positive value of heat transferred by contract means that heat flows from the EFCT meter toward the floor. In the case of the human body, this means that heat is being lost to the floor from the soles. A negative value of heat transferred by contact means that heat flows into the EFCT meter from the floor. In the case of the human body, this means that the feet are receiving heat from the floor. During air conditioning, regardless of the conditions, the amount of heat transferred by contact was always positive, indicating that heat was being taken away by the floor. During floor

heating, heat transfer became 0 when floor surface temperature was around 28°C. At higher floor surface temperatures, heat transfer became negative, and heat was received from the floor. The enclosed space temperature when the floor surface temperature was 28°C, at which heat transfer by contact was 0, was about 37.5°C according to Figure 11. This is very close to the point at which the enclosed space temperature exceeds the EFCT meter water temperature. In the case of the human body, this is the point at which the temperature of the part in contact with the heated floor becomes higher than the body temperature and the direction of heat flow is reversed from radiation to the floor to reception from the floor. When the floor surface temperature was around 23°C, the amount of heat transferred by contract was larger during air conditioning than during floor heating, indicating that the amount of heat that flows from the feet to the floor is smaller during floor heating than during air conditioning if floor surface temperature is the same. These results indicate that even in cases where floor surface temperature during air conditioning is more or less the same as that during floor heating, contact thermal sensation that occurs when the human body comes into contact with the floor is different. This means that if different heating methods are involved, the effect of contact with thermal sensation cannot be evaluated in terms of floor surface temperature alone.

The "subject" plot in Figure 12 is an example of a test result obtainable from the case in which a subject equipped with a heat flow meter attached to the buttocks sits on the floor during floor heating. This result is shown for reference purposes only because there is only one data set, but it shows fairly close agreement with the measurement results obtained from the EFCT meter. Strictly speaking, the amount of heat received from the floor is greater than indicated by the approximation line. A like reason is that the tendency to receive heat from the floor was strong because human body temperature (about 36 to 37°C) was slightly lower than the temperature of the warm water in the EFCT meter (37.5°C). Because these results can be improved by controlling the temperature of the warm water in the EFCT meter with higher accuracy, it has been suggested that the EFCT-meter-based measurement of heat transfer by contact can be used to estimate the amount of heat transferred by contact with the human body.

4. CONCLUSION

The area of contact of the human body with the floor, the temperature of enclosed space, and the amount of heat transfer were measured by using an EFCT meter, and the following results have been obtained:

· Of the representative bodily positions taken by the subjects, the position of sitting on the floor with thrown-out legs showed the largest area of contact with the floor equal to about 6 percent of the surface area of the human body.

· When floor surface temperature was the same, the temperature of the enclosed space between the EFCT meter and the floor was higher during floor heating than during air conditioning by 1.5 to 2°C.

· Even when floor surface temperature was the same, the amount of heat transferred by contact during air conditioning differed from that during floor heating, indicating that thermal sensation resulting from contact with the floor cannot be evaluated in terms of floor surface temperature alone.

REFERENCES

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