濟大論文集(自然), 37, 179-190, 1993
Cheju Univ. Jour. (Natural Sci.),
37, 179-190, 1993

Influence of Simple Floor Heating Appliances on the Human Body

*Bong-Ae Kim**

간이바닥난방기구가 인체에 미치는 영향

金 鳳 愛*

Summary

We examined the influence of floor heating on human body, under such conditions as change, in floor quantity (30, 40, 50 and 60W/m^2) and air temperature (15, 18 and 21℃) in the climate-chamber. Subjects employed are Korean students. An electric carpet (3.6m×2.7m) was used for the experiment. We examined the influence on the human body in both direct and indirect exposure sitting postures of floor heating quantity. As a results, in direct exposure sitting posture, when the floor heating quantity was increased more than 50W/m^2, the temperature at contact point under the buttocks rose more than 40℃. Also, as for thermal sensation vote, when air temperature was at 18℃, and floor heating quantity were at 40W/m^2 (as floor temperature was at 28.5℃) and 50W/m^2 (as floor temperature was at 30.1℃), was observed as warm. As for comfort vote, at 18℃ of air temperature, was observed as comfortable when floor heating quantity was 40W/m^2.

Introduction

Radiant heating is understood to be energy conserving and to be comfortable, at a relatively lower room temperature. In particular, floor heating, evenly distributes vertical room temperature, and it allows the head of the uses keeping to remain cool, while the feet are kept warm (The Japan Society of Home Economics, 1990). However, it is said that if the floor is made too warm, the feet become too hot for comfort, sweat too much, and occasionally swell (Grandjean, 1973). In recent years, the number of houses using electric carpet as a simple floor heating appliance is increasing. However, there is a fear that they may cause a lot of troubles.

In our provious paper (Kim, et. al, 1990) on the

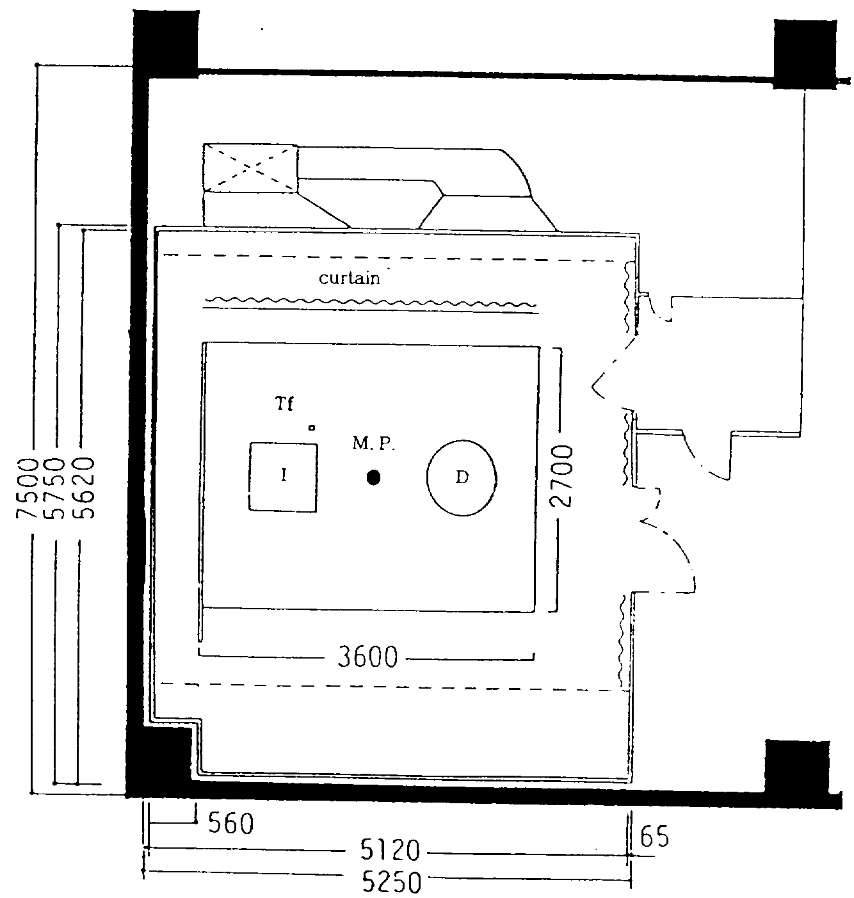
* 자연과학대학 가정관리학과 (Dept. of Home Management, Cheju Univ., Cheju-do, 690-756, Korea)

influence of floor heating on the human body seated on the floor, we cleared the influence of the difference between the heat radiant from the floor and that of heat conduction through the contacting parts of the skin when using electric floor heating systems. Therefore, in this paper we will examine the influence of floor heating on the human body under such conditions as change in the floor heating quantity and the air temperature. Subjects employed are Korean students, who are accustomed to the "Ondol" life, a representative case of floor heating, using electric carpet and, we will examine the influence on the human body of the floor heating quantity.

Materials and Methods

1. Laboratory and Devices

The experiment was conducted in the climate-chamber of the Home Economics Faculty at Nara Women's University (Tomo and Isoda, 1986) as illustrated in Fig. 1. An electric carpet (3.6*m*×2.7*m*) was used for the experiment as a flooor



S : Subject
V : Volt-Slider
B : Balance

Tf : Infrared Thermometer
D : Direct Exposure
I : Indirect Exposure

M. P. : Measured Point
Ta=0.2m, 0.7m, 1.2m
Tg=0.2m, 0.7m

Fig. 1. Climate-chamber plan.

heating appliance. Fig. 2 shows the electric carpet section. Electric pressure of the electric carpet was controlled by the manipulation of a volt-slider. In indirect exposure sitting posture, we experimented with the use of insulation material (0.7m×0.7m, thickness 50mm).

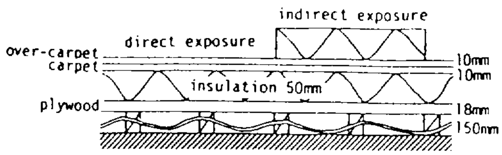


Fig. 2. Electric carpet section.

2. Experimental Conditions

Supposing the normal indoor thermal environmental conditions of the winter season, the experiment was conducted in the thermal environmental conditions as indicated in Table 1. Also, the surface temperatures of the surrounding walls and ceiling were kept at almost the same level as the air temperature. Relative humidity was kept at 50%. Air velocity was kept at the level of still air (below 0.15m/s).

Six healthy Korean female students in Japan were employed as subjects. Each staged condition had 2 to 6 subjects. Table 2 shows the physical characteristics of the subjects. Subjects clothed themselves beforehand so as to feel neither cold nor hot at the air temperature of 21℃. During the experiment they wore the same clothing. Subjects were seated as indicated in Fig. 1 sitting postures directly and indirectly exposed to the heated carpet. The sitting postures of subjects were mostly side-sitting posture. During the experiment they were allowed to change sitting posture.

Table 1. Experimental Conditions

Qf \ Ta	15℃	18℃	21℃
$30W/m^2$		●	●
$40W/m^2$	●	●	
$50W/m^2$	●	●	
$60W/m^2$	●		

Air Velocity : 0.15m/s
Relative humidity : 50%
Ta : Air temperature
Qf : Floor Heating Quantity

3. Thermal Environmental Conditions

Thermal environmental conditions were measured at point as indicated in Fig. 1. The floor temperature was measured by an infrared the-

Table 2. Physical Characteristics of Subjects

Sex	Age year	Height cm	Weight kg	Body Surface Area (As) m^2	Clo Value
Female	25.7 ±1.7	158.3 ±5.9	51.2 ±6.6	1.46 ±0.12	1.07 ±0.45

1. Values represented as means (6 subjects) ± Standard Deviation
2. Calculated by Fujimoto and Watanabe Equation (Fujimoto, et. al, 1968)
   $As = W^{0.444} \times H^{0.663} \times 0.008883 \ (m^2)$
   W : Weight (kg)
   H : Height (cm)
3. Clothing : Skirt + Shirt + Cardigan
   Slip + Brassieres + Panty Hose + Panties
   Material-Cotton, Wool, and Synthetic Fiber

rmometer. Air temperature was measured at three different heights (0.2m, 0.7m and 1.2m, respectively) from the floor, by a hybrid recorder and a 0.1mm diameter T thermocouple. Globe temperature was measured by a globe thermometer of 15cm diameter at heights of 0.2m and 0.7m from the floor. Relative humidity was measured by an assmann hygrometer and air velocity was measured by a hot-wire anemometer.

4. Physical Responses

Skin temperatures (9 points) and temperature at contact point under the buttocks were measured by a 30-point hybrid recorder and a 0.1mm diameter T thermocouple. The mean skin temperature was calculated based on the weighed average of Hardy-DuBois's 7-point body surface area (Hardy and DuBois, 1938). A rectal temperature was measured by a sensor (0.1mm diameter T thermocouple covered with vinyl tube) which was inserted about 10cm into the anus of the subject. Weight loss was measured both before and after the experiment. Blood pressure and heart rate were measured before and after the experiment.

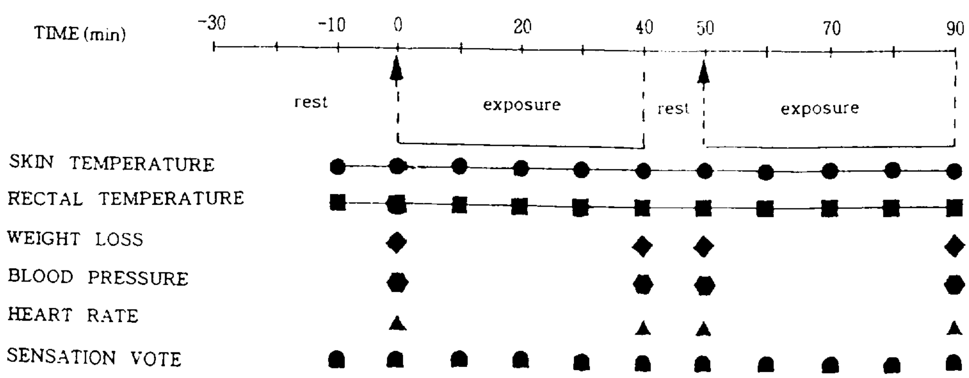
5. Sensation Vote

From 10 minutes before the experiment to 10 minutes after, the feelings of the whole and local body of the subjects were discribed at 10 minute intervals based on a nine-point category scale of thermal sensation vote [-4, very cold: through +4, very hot], and a seven-point category scale of comfort vote [-3, very uncomfortable: through +3, very comfortable].

6. Schedule and Period of the Experiment

Table 3 shows the schedule of the experiment. Subjects entered the pre-chamber at about 21±1 ℃ air temperature about 60 minutes after breakfast or lunch and were clothed in the prepared clothing with proper measurement equipment in or on their bodies. They assumed a comfortable sitting posture on the chair. When the skin and rectal temperatures of the subjects returned to normal conditions after 30 minutes, the subjects were led to the climate-chamber at the adjected thermal environmental conditions. The subjects were exposed to the heated carpet directly (or indirectly) in sitting postures on the floor for 40 minutes. Afterwards the subjects were led to the pre-chamber and rested on the chair for about 10 minutes. Afterwards the subjects were led again to the climate-chamber and exposured to the heated carpet for 40 minutes in the indirect (or direct) sitting posture. The experiment was done in January 1986. The final analyses was

Table 3. Experimental Schedule



calculated from the average values (2-6 subjects) of each value during each posture.

Results and Discussion

1. Thermal Environmental Conditions

The thermal environmental conditions were adjusted within the range of ±0.2℃ air temperature, ±0.5℃ floor temperature and ±5% relative humidity. Fig. 3 shows the floor temperature of thermal environmental conditions.

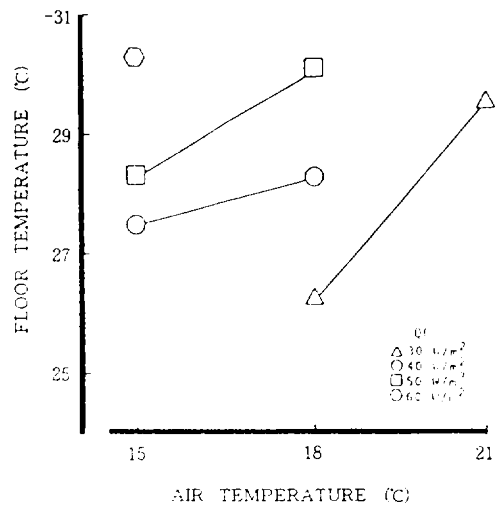


Fig. 3. Floor temperature of thermal environmental conditions.

2. Sequential Change of Skin Temperatures, Rectal Temperature, Comfort Vote and Thermal Sensation Vote

Fig. 4 shows (the examples of) the sequential change of skin, rectal temperatures, comfort vote and thermal sensation vote, in the case of air temperature at 15℃ and the floor heating quantity at 40W/m^2 (as floor temperature was at 27.5℃). When exposed in the indirect exposure sitting posture, the rectal temperature gradually declined and arrived at 37.4℃ after 20 minutes,

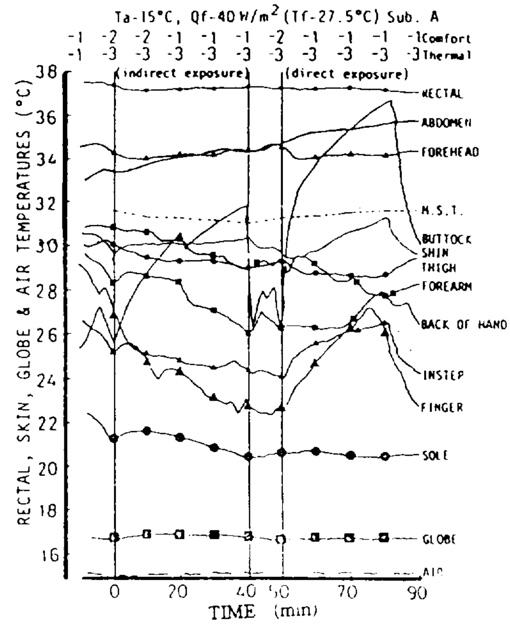


Fig. 4. Sequential change of skin temperature, rectal temperature, comfort vote and thermal sensation vote.

where it showed stability. The skin temperature of the whole body showed a temporary decline, immediately on exposure. Subsequently, in such peripheral parts as the finger tips, the back of hands and the limbs, the skin temperatures declined, while the skin temperature of the forehead and abdomen tended to increase. The skin temperature at the peripheral parts of the body such as the finger tips showed a remarkable decline of about 5℃, the other parts declined no more than about 1-2℃. The temperature at contact point under the buttocks showed a rise of about 6℃. This was interpreted as caused by heat loss controlled at contacting point seated on the insulation material. Mean skin temperature gradually declined by 0.5℃ in 40 minutes of exposure, being about 31℃. The comfort vote was [-1 : slightly uncomfortable] and that for thermal sensation vote was [-3 : cold]. Afterwards, the subjects rested on the chair about 10 minutes, in the case of the direct exposure sitting posture, rectal temperature showed stability at 37.2℃. As for the skin temperature, it rose at all parts of the body, at such parts directly contacted with the floor as parts of the shin, and especially temperature at contact point under the buttocks it rose notably. It was believed that this was because of the influence of the heat conduction from the floor transmitted to the contacting parts of the shin. Also, the skin temperatures of the contacting parts declined after 30 minutes of exposure because of movement of posture. Mean skin temperature rose by 0.3℃ in 40 minutes of exposure. The comfort vote was [-1] and that for thermal sensation vote was [-3], it was the same as indirect exposure sitting posture.

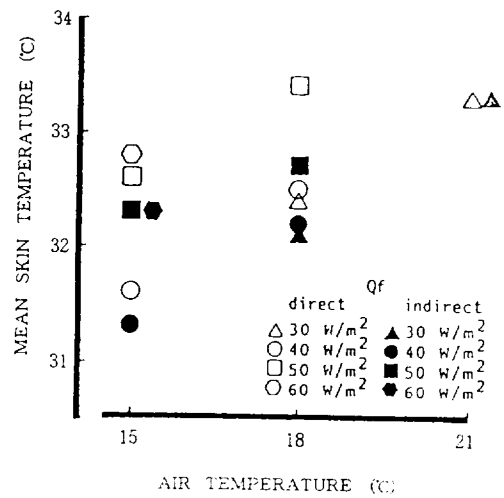


Fig. 5. Relationship between air temperature and mean skin temperature for each sitting posture and floor heating quantity.

3. The Influence of Air Temperature and Floor Heating Quantity on Physiological Responses

Fig. 5 shows the relationship between air temperature and mean skin temperature. In the cases of both direct and indirect exposure sitting postures, it was demonstated that higher the air temperature and the increase in floor heating quantity was, the higher the mean skin temperature became. The mean skin temperature of direct exposure sitting posture was as a whole higher than that of the indirect exposure sitting posture. When the air temperature was 21℃, no difference was observed in the mean skin temperature between direct and indirect exposure sitting postures. This meant that the influence of the heat conduction from the floor was remarkable in the direct exposure sitting posture because of the direct contact to the heated floor. Compared with the results of Japanese subjects who are not accustomed to the floor heating, the mean skin temperature of Korean subjects was as a whole higher. This was interpreted as due to

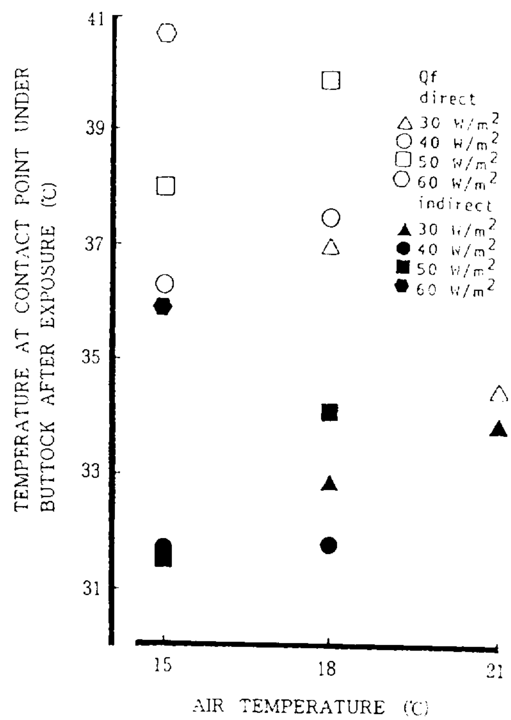


Fig. 6. Relationship between air temperature and temperature at contact point under the buttocks for each sitting posture and floor heating quantity.

differences of the clothing and postures.

Fig. 6 shows the relationship between air temperature and temperature at contact point under the buttocks. In direct exposure sitting posture, the temperature at contact point under the buttocks tends to increase when the floor heating quantity increases, regardless of the air temperature. Also, when floor heating quantity was more than 50W/m^2, The temperature at contact point under the buttocks rose more than 40℃. This meant that the temperature at contact point under the buttocks was caused more by the floor heating quantity, than by the air temperature, and if the floor temperature is too high, there is the possibility of occasional low temperature burns. In indirect exposure sitting posture, the temperature at contact point under the buttocks became high when the air temperature was high, even though floor heating quantity was equal. This meant that the indirect exposure sitting posture as the influence of floor heat was reduced because of the blocking of heat by the insulation material under the temperature at contact point under the buttocks was less affected than the direct exposure sitting posture.

4. Influence of Air Temperature and Floor Heating Quantity on the Psychological Vote

Fig. 7 shows the thermal sensation vote in the combined conditions of air temperature and floor heating quantity. In direct exposure sitting posture at 18℃ of air temperature and floor heating quantity at 40W/m^2 and 50W/m^2 (as indicated floor temperature were 28.3℃ and 30.1℃) thermal sensation vote was voted as warm [+0.3~+0.7]. These conditions were observed as the similar floor temperature in an actual Korean Ondol House investigation (Kim, et. al, 1991). Also, compared with the results of an earlier paper (Kim, et. al, 1990), this paper was similar as to the air temperature but floor temperature was low, and thermal sensation vote was voted as warm. By a synthesis of the major results, it

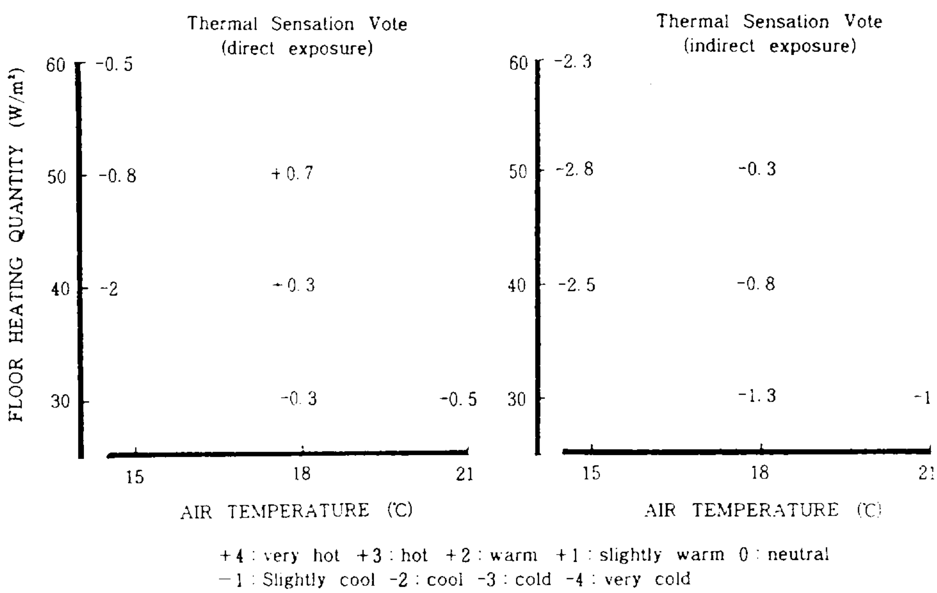


Fig. 7. Thermal sensation vote for each sitting posture in combined conditions of air temperature and floor heating quantity.

was understood that Korean subjects estimated thermal sensation sensation vote by the floor temperature rather than the air temperature. In indirect exposure sitting posture was not observed as warm, and in all cases combined air temperature and floor heating quantity. If we want to have thermal neutral, it is necessary to have air temperature at 18℃ and floor heating quantity at 60W/m^2, or an air temperature of at least 21℃.

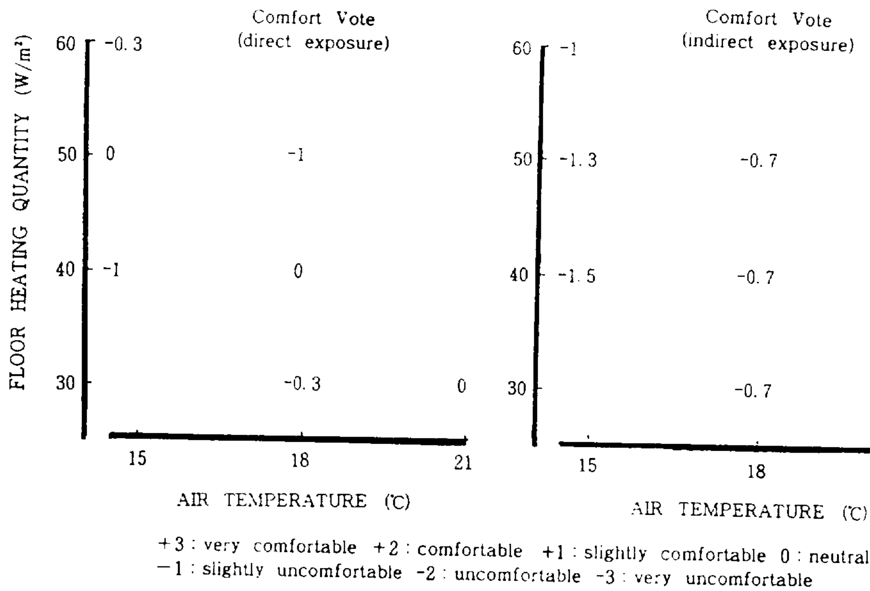


Fig. 8. Comfort vote for each sitting posture in combined conditions of air temperature and floor heating quantity.

Fig. 8 shows the comfort vote in the combined conditions of air temperature and floor heating quantity. In direct exposure sitting posture at 18℃ of air temperature, comfort vote was observed when the floor heating quantity was at 40W/m^2 (as indicated floor temperature was 28.3℃). In indirect exposure sitting posture, comfort vote was not observed in all cases. Chrenko (Chrenko, 1957) reported that in the case of sitting still on the chair half of the subjects feel uncomfort at 33 ℃ of floor temperature (copper temperature by the thermocouple measurement). Compared with a thermocouple measurment, this study by the infrared thermometer measurment showed a lower temperature by about 2℃. The results were the similar to the results of Chrenko's study.

Fig. 9 shows the relationship between globe temperature and comfort vote. In direct exposure sitting posture, comfort neutral vote observed, when floor heating quantity was at 50W/m^2, and globe temperature was at approximetely 17.5℃; when the floor heating quantity was at 40W/m^2, and globe temperature was at 20.5℃; when the floor heating quantity was at 30W/m^2, and globe temperature was at 22.5℃. It was indicated to be due to influecne of remarkable floor temperature. In indirect exposure sitting posture, uncomfortable vote was voted when globe temperature was about 20.5℃. The difference floor heating quantity was not observed.

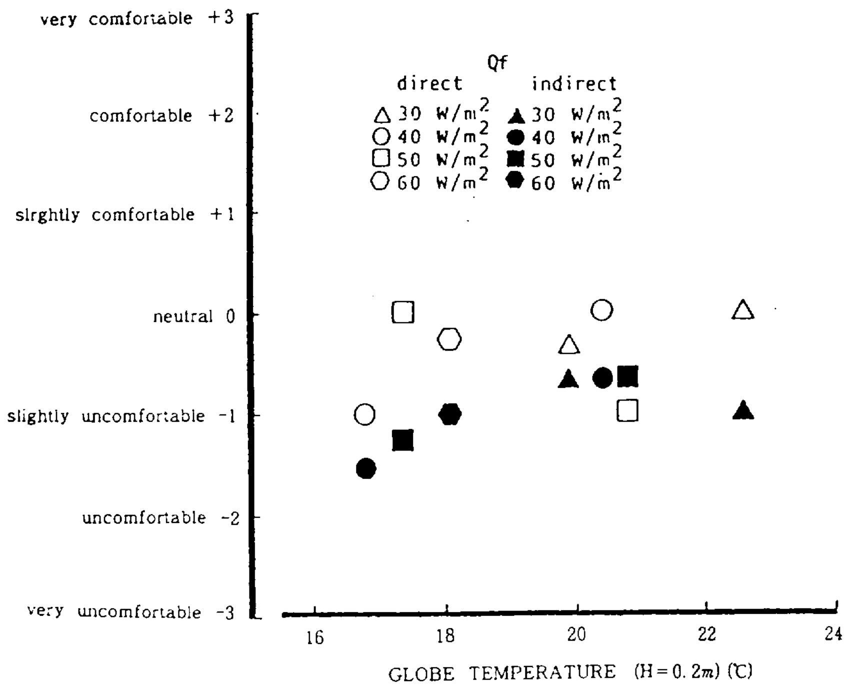


Fig. 9. Relationship between globe temperature and comfort vote for each sitting posture and floor heating quantity.

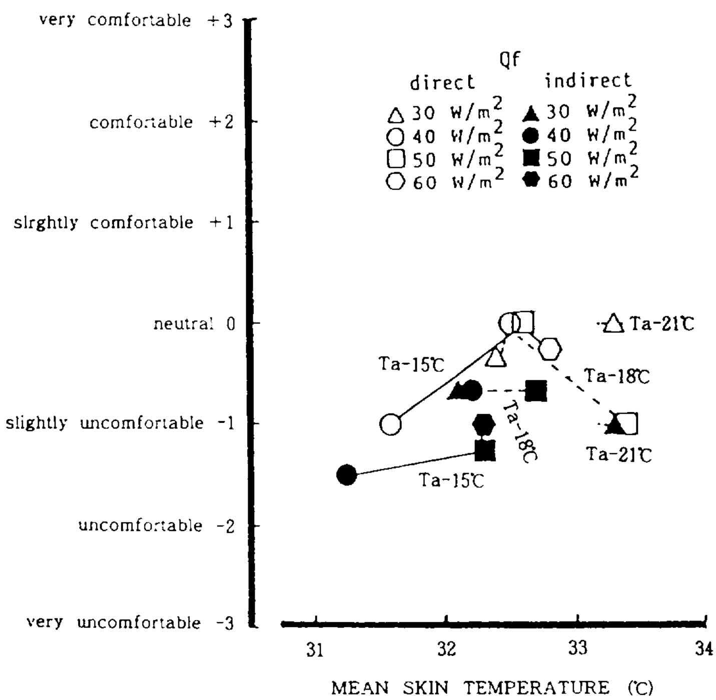


Fig. 10. Relationship between mean skin temperature and comfort vote for each sitting posture and floor heating quantity.

5. The Relationship between Physiological Response and Psychological Vote

Fig. 10 shows the relationship between mean skin temperature and cmfort vote. In direct exposure sitting posture, it was observed as comfort neutral when air temperatures were at 15℃, 18℃, the mean skin temperature was about 32.5 ℃. When mean skin temperature was higher than 33℃ and floor heating quantity was at 50W/m^2, it was voted as uncomfortable. It is understood that if temperature at contact point under the buttocks was more than 40℃, floor temperature was too warm. According to the previous study (Gagge, 1967), comfort zone was formulated when mean skin temperature ranged from about 33℃ to 34℃ in stable state. In case of the direct exposure sitting posture in this study, it is understood that comfort is produced as the physiological influence of warming of the parts.

Conclusions

In order to examine the influence of simple floor heating appliances on human body in both direct and indirect exposure sitting postures, manipulating air temperature and floor heating quantity in the climate-chamber where temperature on the surface of walls and ceiling were controlled to correspond to the air temperature of the room, we conducted the experiment using electric carpet. The major results can be summarized as follows :

(1) The mean skin temperature of direct exposure sitting posture was as a whole higher than that of indirect exposure sitting posture. As the floor heating quantity increased, the mean skin temperature also increased. In direct exposure sitting posture, the temperature at contact point under the buttocks increased when the floor heating quantity was increased. When the floor heating quantity was increased, the temperature at contact point under the buttocks rose to more than 40℃.

(2) As for thermal sensation vote, direct exposure sitting posture at 18℃ of air temperature and at 40W/m^2 (as floor temperature was at 28.5 ℃), 50W/m^2(as floor temperature was at 30.1℃) of floor heating quantity, was observed as warm (+0.3～+0.7). These conditions were observed as similar to the floor temperature of an actual Korean Ondol House investigation. In indirect exposure sitting posture, on the whole, thermal neutral votes were observed as cool.

(3) As for comfort vote, direct exposure sitting posture, at 18℃ of air temperature, was observed as comfortable when floor heating quantity was at 40W/m^2. It was observed neutral vote when globe temperature was about 18℃, and mean skin temperature was at 32.5℃. When mean skin temperature was higher than 33℃, regardless of floor heating quantity, it was voted uncomfortable. In indirect exposure sitting posture, comfort vote was less, it was voted as uncomfortable when globe temperature was higher than 22℃.

References

Chrenko, F.A., 1957. The Effects of the Temperature of the Floor Surface and of the Air on the Thermal Sensations and the Skin temperature of the Feet, *Brit. J. Industr. Med.* 14, 13.

Fujimoto, S., T., Watanabe A., Sakamoto, K. Yukawa, and K. Morimoto, 1968. Studies on the Physical Surface Area of Japanese, Part 18, Calculation Formulas in Three Stages over All Age, *Japanese Jounal of Hygiene,* 23(5) ; 443. (in

Japanese)

Gagge, A. P., J. A. J. Stolwijk, and J. D. Hardy, 1967. Comfort and Thermal Sensations and Associated Physiological Responses at Various Ambiant Temperatures, *Environmental Research*, 1. 1.

Grandjean, E. 1973. Ergonomics of Home, Taylor and Francis Ltd. London, 197.

Hardy, J. D. and E. DuBois, 1938. The Technic of Measuring Radiation and Convection, *Journal of Nutrition*, 15. 461.

Kim, B., N. Isoda, and T. Yanase, 1990. Influence of Floor Heating Temperature on the Human Body Seated on the Floor, *Journal of Archit Plann. Environ. Engng*, AIJ, 417, 19~29.

Kim, B., N. Isoda, and T. Yanase, 1991. An Investigation on the Thermal Environment of the Korean Ondol House, *Journal of ARAHE*, 1. 81~88.

The Japan Society of Home Economics, 1990. Design and Management for Housing, 46. Asakureshoten, Tokyo. (in Japanese)

Tomo, Y. and N. Isoda, 1986. Performance of Man-Thermal Environmental Test System, the Tenth Symposium on Man-Thermal Environyent System, -Memorial Meeting-, 132~135. (in Japanese)

〈국문초록〉

간이바닥난방기구가 인체에 미치는 영향

인공기후실을 사용하여 기온(15, 18 및 21℃)과 바닥가열량(30, 40, 50 및 60W/m^2)을 변화시키면서, 바닥난방이 인체에 미치는 영향을 해명했다. 피험자는 젊은 여성을 채용했다. 실험은 전기카페트를 사용해서 직접 바닥에 앉은 자세와 간접적으로 바닥에 앉은 자세에서의 영향을 바닥가열량에 의한 인체 영향을 검토했다. 결과로써 직접 바닥에 앉은 자세에서는 바닥가열량이 50W/m^2 이상이 되면 접촉부위의 온도는 40℃를 넘는 경우가 있었다. 온냉감평가는 기온 18℃-바닥가열량 40W/m^2(바닥온도 28.3℃), 기온 18℃-바닥가열량 50W/m^2(바닥온도 30.1℃)에서 따뜻하다는 평가로 되었다. 쾌적감평가는 기온 18℃-바닥가열량 40W/m^2(바닥온도 28.3℃)에서 쾌적한 측의 평가로 되었다.