# Influence of Cold Floors on the Human Body Skin Temperatures and Thermal Comfort

## —찬바닥이 인체피부온도 및 온열적 쾌적감에 미치는 영향—

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〈목 차〉



〈Abstract〉

바닥마감재료가 다른 여름철의 찬바닥이 인체피부온도 및 온열적 쾌적감에 미치는 영향을 검토하기 위하여, 주위벽 및 천정의 온도를 기온과 거의 같게 한 항온실을 이용해서 바닥에 앉은 자세, 의자에 앉은 자세, 서 있는 자세별로 검토했다. 그 결과를 요약하면 다음과 같다.

(1) 평균피부온도는 기온이 낮고 수온이 낮을수록 낮았다. Carpet 마감재료는 서 있는 자세, 바닥에 앉은 자세의 평균피부온도가 낮고, 의자에 앉은 자세가 높았다. Cork 마감재료가 Carpet, Flooring 마감재료에 비해 평균피부온도가 낮았다.

(2) 온냉감평가는 흑구온도가 낮게 되면「중성이다」혹은「서늘하다」쪽으로 평가하고, Cork, Carpet, Flooring 마감재료의 순으로「서늘하다」쪽으로 평가 하였다.

(3) 쾌적감평가는 바닥에 앉은 자세와 서 있는 자세가 의자에 앉은 자세보다 쾌적한것으로 평가하였다. 마감재료는 Cork, Flooring, Carpet 순으로 쾌적하다고 평가 하였다.

(4) 바닥마감재료에 대한 평가는 바닥에 앉은 자세의 경우, Carpet 마감재료는「차가운」「습기찬」의 평가점수가 높고, Cork 마감재료는「평활한」「차가운」「감촉이 좋은」「딱딱한」의 평가점수가 높고, Flooring 마감재료는「평활한」「탄력성이 없는」「딱딱한」의 평가점수가 높았다.「따듯한」-「차가운」의 평가는 바닥온도의 영향을 받아서, Cork, Flooring 마감재료가 Carpet 마감재료보다「차가운」의 높은 점수평가를 하였다.

(5) Carpet 마감재료는 평균피부온도가 34℃를 넘어도 「약간 시원하다」는 평가이고, 서 있는 자세와 의자에 앉은 자세가 바닥에 앉는 자세보다 쾌적하다고 평가한다. Cork 마감재료는 3자세 모두 평균피부온도 33~34℃의 사이에서 가장 쾌적하다. Flooring 마감재료는 온열적중성, 쾌적감의 중성의 평가가 많다.

이상의 결과를 종합하면, 찬바닥이 인체에 미치는 영향은 바닥마감재료별로는 Cork, Flooring이 보다 좋은 평가를 하였음으로, 여름철 바닥마감재료로서는 Cork, Flooring 마감재료가 바람직하다고 생각된다. 자세별로는 서 있는 자세는 바닥에 앉은 자세와 거의 같은 경향을 보이고, 의자에 앉은 자세는 바닥에 앉은 자세와 서 있는 자세 만큼 영향을 받지 않았다. 이후 실험결과를 중심으로 찬바닥의경우, 보다 쾌적한 온열환경범위을 제안하려고 한다

## Ⅰ. Introduction

We experience a kind of nicely cool feeling when we happen to contact with the surface of concrete structures in the summer season. When we have cold-water run through the hot-water floor heating system, we can have the effect of cooling the floor surface and the subsequent thermal relief effect on the soles contacting the floor. In this occasion we achieve the effect of killing two birds with one stone ; using floor heating system not only for heating but also for cooling purpose. However, the study of the floor cooling system on the human body[1] has been little because of the supposed undesirability that soles directly contacting with the cold floor surface experience discomfort. Therefore, this study attempts to examine the floor cooling system on the human body with different floor materials when the floor material is cooled by cold-water running through the hot-water circulation floor panel system. The effect has been examined separately under the postures of directly sitting, sitting on the chair, and standing on the floor.

## Ⅱ. Research Design

### Laboratory and Devices

The experiment was conducted in the climate-chamber of the Home Economics Faculty at Nara Women's University as illustrated in Fig.1. An electric floor heating system(3.4m X 3.4m) was used for the experiment. The floor materials were used for carpet, cork, flooring. Table 1 shows the characteristics of floor materials[2].

**Table 1 Characteristics of Floor Materials**

| | Thickness | Thermal Resistance($m^2h℃/kcal$) |
|---|---|---|
| Carpet | 10mm | 0.1178 |
| Cork | 4mm | 0.0731 |
| Flooring | 8.4mm | 0.0290 |

### Experimental Conditions

Supposing the normal indoor thermal conditions of the summer season[3], the experiment was conducted in the thermal environmental conditions as indicated in table 2. Also, the temperatures of the surrounding walls and ceiling were kept at almost the same level as the air temperature. Relative humidity was kept at 50% and air velocity was maintained at the level of still air (below 0.15 m/s).

Six healthy females were selected as subjected. Each staged condition had four subjects. Table 3 shows the physical characteristics of subjects. Subjects were clothed in cotton shirts, skirts, underwear, and panty hose(0.35 clo). During the experiment they kept the same clothing. Subjects were seated sitting, chair, and

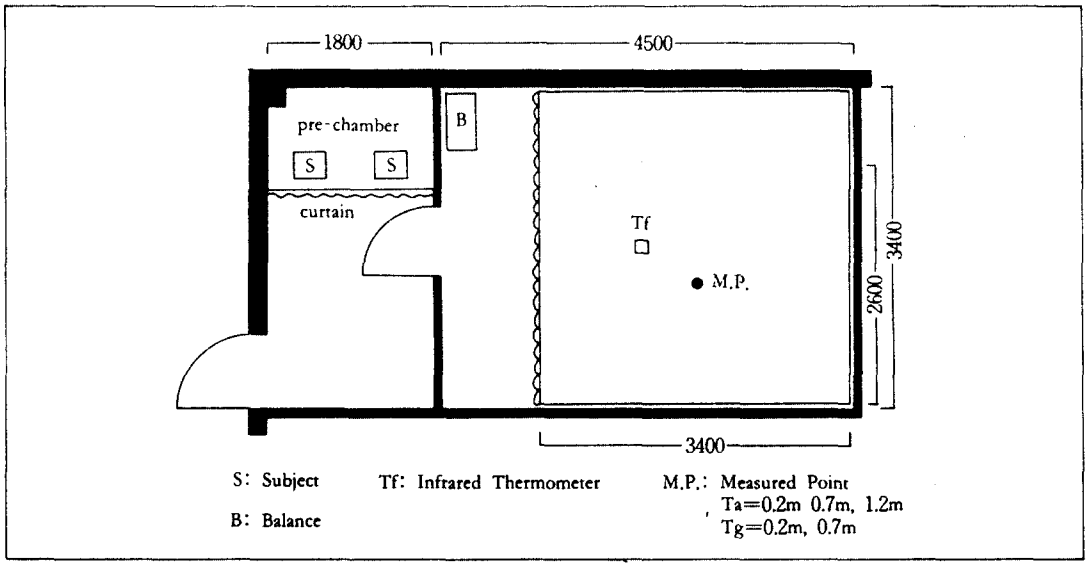


Fig. 1 Climate Chamber

standing. Subjects maintained a resting in the room. The sitting postures of subjects were mostly side-sitting posture. During the experiment they were allowed to change sitting posture.

Table 2 Experimental Conditions

| Tw \ Ta | 27℃ | 30℃ |
|---|---|---|
| 20℃ | • | • |
| 25℃ | • | • |

Air Velocity : 0.15m/s Ta : Air Temperature
Relative Humidity : 50% Tw : Water Temperature

Table 3 Physical Characteristics of Subjects

| Material | Sex | Age year | Height cm | Weight kg | Body Surface Area(As) $m^2$ | Clo Value |
|---|---|---|---|---|---|---|
| Carpet | Female | 25.4 ±2.5 | 157.6 ±3.7 | 48.6 ±2.8 | 1.43 ±0.05 | 0.35 |
| Cork | Female | 24.7 ±1.7 | 161.3 ±5.0 | 49.4 ±5.7 | 1.46 ±0.11 | 0.35 |
| Flooring | Female | 22.0 ±2.6 | 158.8 ±4.8 | 51.1 ±3.7 | 1.47 ±0.05 | 0.35 |

1. Values represented as means(4-6 subjects) ± Standard Deviation
2. Calculated by Fujimoto and Watanabe' Equation[4]
   $As = W^{0.444} \times H^{0.663} \times 0.008883 (m^2)$
   W : Weight(kg)
   H : Height(cm)
3. Clothing : Skirt + Short Sleeved Undershirt
   Brassieres + Panties + Panty Hose
   Material—Cotton and Synthetic Fiber

## Ⅲ. Measuring Items and Method

Thermal Environmental Conditions

Thermal environmental conditions were measured at point as indicated in Fig.1. The water temperature was measured by thermocouple and a hybrid recorder. Air temperature was measured at three different levels (0.2m, 0.7m, and 1.2m respectively) from the floor, by a hybrid recorder and a thermocouple of diameter 0.1mm T. Globe temperature was measured by a globe thermometer of 15 cm diameter at heights of 0.2m and 0.7m from the floor. Relative humidity was measured by an assmann hygrometer and the air velocity was measured by a hot-wire anemometer.

Physical Responses

Skin temperature(9 points) and temperature at contact point under the buttock were measured by a 30-point hybrid recorder and 0.1 mm diameter T thermocouple. The mean skin temperature was calculated based on the weighed average of Hardy-DuBois's 7-point surface area[5]. A rectal temperature was measured at a point of which the sensor was insert 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.

Sensation Vote

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

Schedule and Period of the Experiment

Fig.2 shows the schedule of the experiment. Subjects

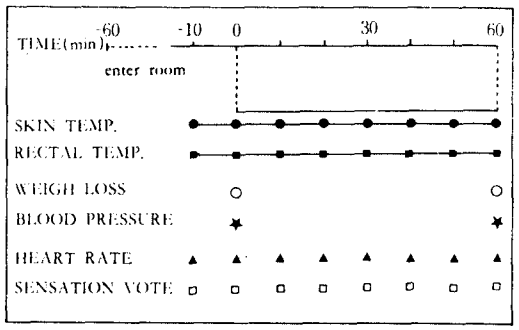


Fig. 2 Experimental Schedule

entered the pre-chamber of about 21℃ 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. 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 adjusted temperature. The subjects were exposed to the floor cool in a sitting postures on the floor for 60 minutes. The experiment was done Oct. 1988(Carpet), Sep.1989(Cork), Jul. 1990(Flooring). In the analyses of final observed the average values(4 subjects) of each value during each exposure.

## Ⅳ. Experiment Results and Discussion

The thermal environmental conditions were adjusted within the range of +/-0.2℃ air temperature, +/-1.0℃ water temperature, and 5% relative humidity. Fig.3 shows the floor temperature of thermal environmental conditions.

Fig.4 shows an example of the sequential change of skin temperatures, rectal temperature, comfort vote, and thermal sensation vote, in the case of air temperature at 27℃ and water temperature at 20℃. In the case of carpet, when exposed in the sitting posture, the rectal temperature increased from 37.3℃

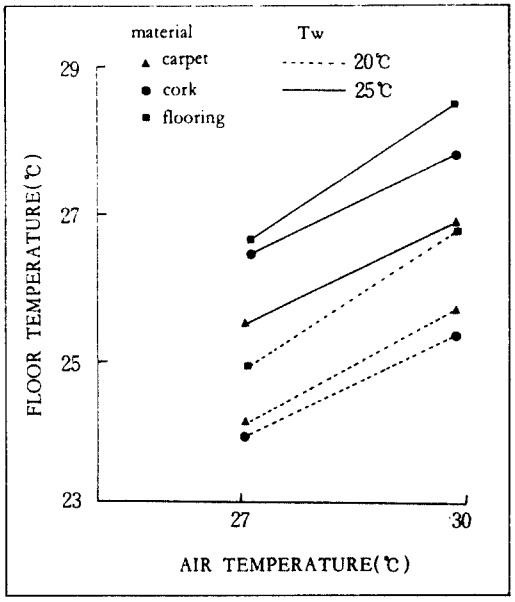


Fig. 3 Floor temperature of thermal environmental conditions

to 37.5℃ when exposed to the floor cooling. However, skin temperature on most part of skin, such as in abdomen, back of hand, and soles, falls distinctively. The change of skin temperature on soles is understood as the result of change in postures. Mean skin temperature falls from 34.4℃ to 34.3℃, 0.1℃ downfall. The sitting on the chair posture, rectal temperature declines slowly from 37.5℃ right after the exposure. Skin temperature on abdomen slightly rises. However, skin temperature on back of hand, shin, and finger tips falls. On the standing posture, rectal temperature slightly rises from 37.3℃ to 37.5℃. Skin temperature on sole in this posture shows less variation than in sitting on the floor posture or sitting on the chair posture. Mean skin temperature falls from 34.1℃ to 33.6℃, 0.5℃ downfall. In all three postures, we can observe mean skin temperature falls, which shows the distinctive effect of the cooled floor on human body. Comfort vote under all the three postures is neutral(0 ; cannot say any comfort or discomfort), and the result of thermal sensation vote is slightly cool (-1; slightly cool).

Fig.5 shows the relationship between air temperature and mean skin temperature by postures and by floor materials. Mean skin temperature falls as air temperature is low and water temperature is low. On the carpet, mean skin temperature is low under the

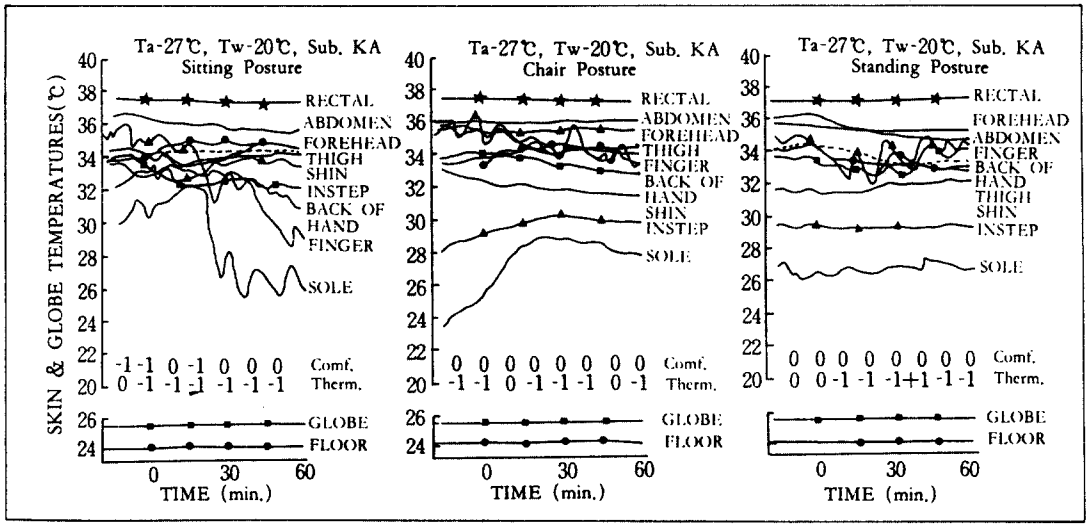


Fig. 4 Sequential changes of skin temperatures, rectal temperature, comfort vote and thermal sensation vote

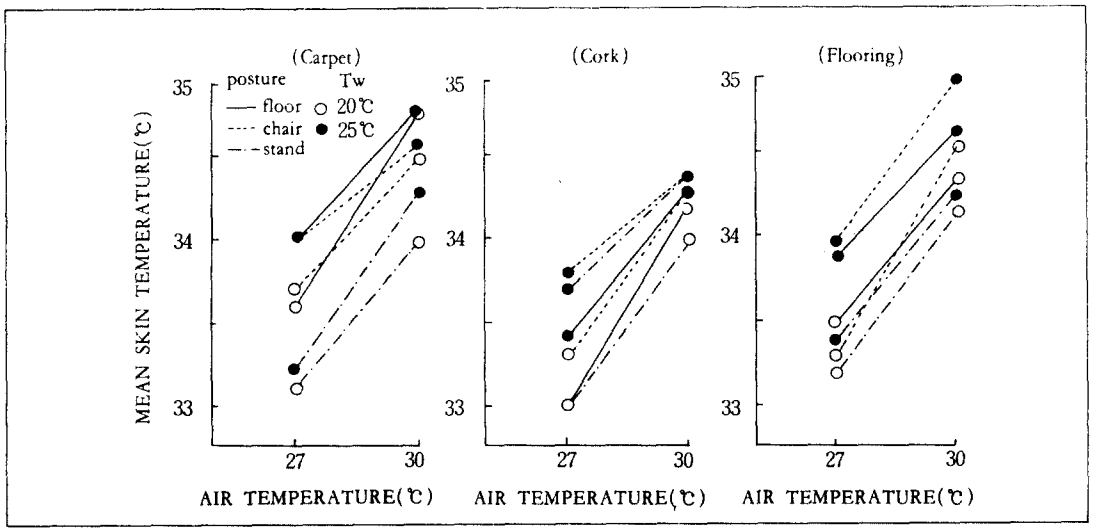


Fig. 5 Relationship between air temperature and mean skin temperature for each sitting posture and floor material

standing posture as well as under sitting on the floor posture whereas it is high under the sitting on the chair posture. This shows the distinctive difference in temperature depending on the different postures. On the cork floor, mean skin temperature is lower in floor sitting posture and in standing posture than in sitting on the chair posture. This is because shin and instep are contacting with the cooled floor and body is by and large closer to the cooled floor.

Fig.6 shows the relationship between globe temperature and thermal sensation vote by postures and by floor materials. On the carpet floor, it is voted as neutral or cool when globe temperature is low. In the standing as well as floor sitting posture, it is voted cool as globe temperature is lower. It is coolest in the floor sitting posture. Flooring materials made little variation in comfort vote. Neutral vote is voted in most cases. The order for coolness by floor materials is carpet, flooring, and cork.

Fig.7 shows the relationship between globe temperature and comfort vote by postures and by floor materials. On the carpet, it is voted a little comfortable when globe temperature is high. In the standing posture, however, it is voted uncomfortable when globe temperature is high. This is because floor temperature is lowered due to the lowered water temperature, which in return makes relative difference with air temperature. It is though that much lower assessment is made when water temperature is 20℃. On the cork floor and flooring, it is voted comfortable when globe temperature is low. In the floor sitting posture, it is voted cool on the face and buttock. On the flooring, we observed little variation in comfort vote in different postures.

Fig.8 shows the assessments on the thermal condition depending on the floor materials, by different postures. On the carpet, it is assessed 「cool」 or 「wet」 in the floor sitting posture. In the sitting on the chair posture, it is assessed 「rough」 or 「elastic」. In the standing posture, it is voted 「wet」 or 「soft」. On the cork floor, it is assessed 「even」, 「cool」, 「good touch」, or 「hard」 in the floor sitting posture. It is voted 「slippery」 or 「bad touch」 in the standing posture. In the sitting on the chair posture, the assessment is in the middle between the floor sitting posture and standing posture. It is analyzed that the assessment of

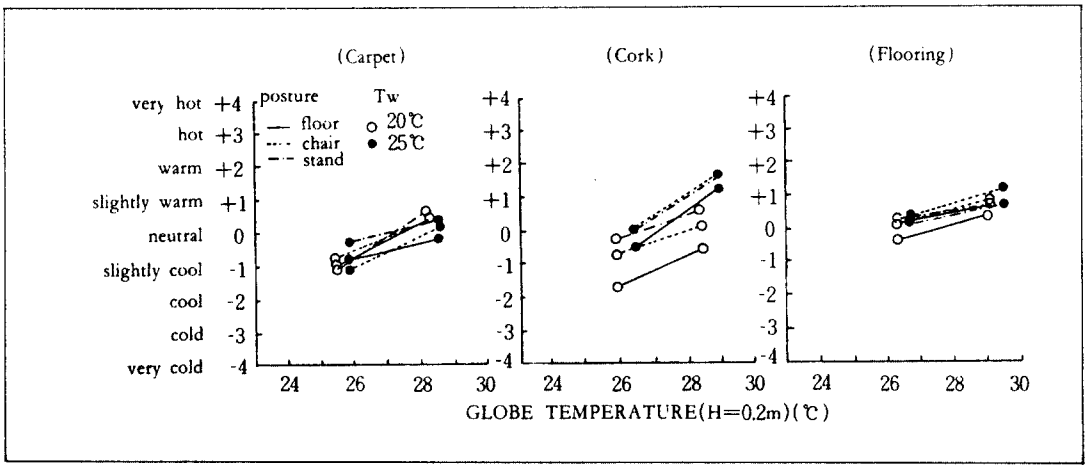


Fig. 6 Relationship between globe temperature and thermal sensation vote for each sitting posture and floor material

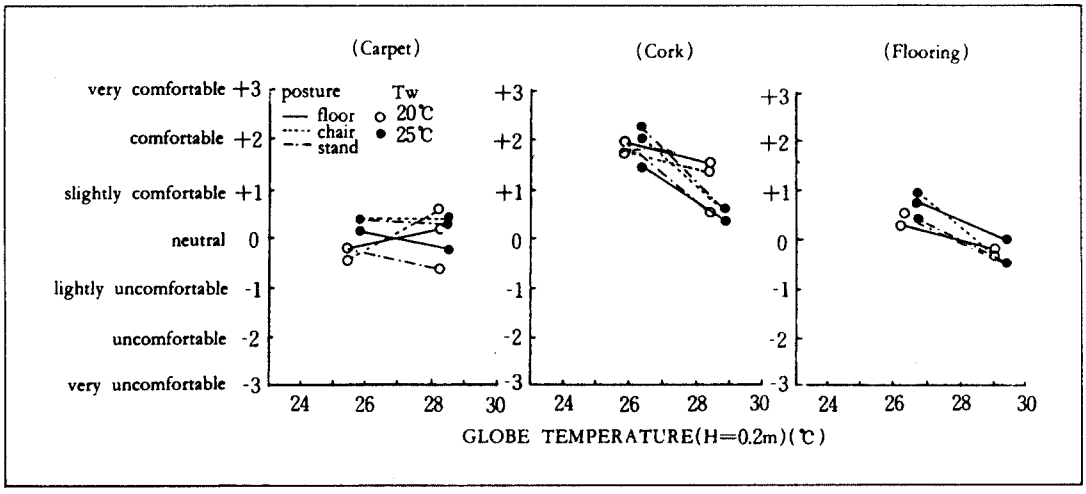


Fig. 7 Relationship between globe temperature and comfort vote for each sitting posture and floor material

「warm」 and 「cool」 is influenced by the floor temperature. On the flooring, all the postures, such as floor sitting, sitting on the chair, or standing on the floor, show a tendency of little variation in comfort vote. The obtained assessments are 「even」 「non-elastic」 or 「hard」.

Fig.9 shows the relationship between mean skin temperature and thermal sensation vote by postures and by floor materials. On the carpet floor, it is observed that a vote of 「neutral」 or 「slightly cool」 is obtained even when the mean skin temperature is 34℃ or higher. On the cork floor, a vote of 「cool」 is obtained when the mean skin temperature is lowered, regardless of the sitting or standing postures. When the mean skin temperature is lower than 34℃, it is voted 「cool」 regardless of the posture. On the flooring, thermal neutral is voted in many cases.

Fig.10 shows the relationship between mean skin

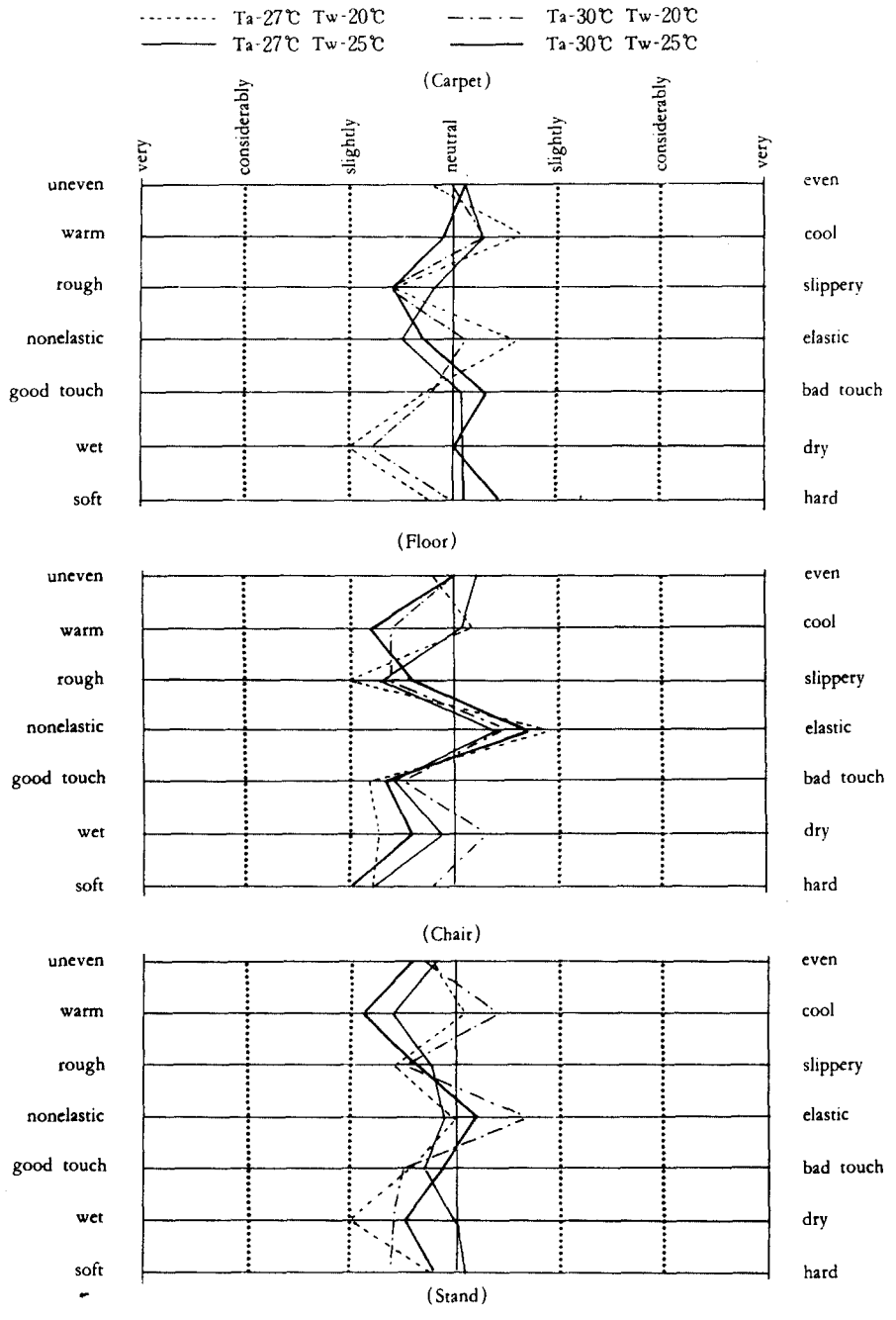


**Fig. 8.1 Profile of evaluation on the floor for each sitting posture and floor material**

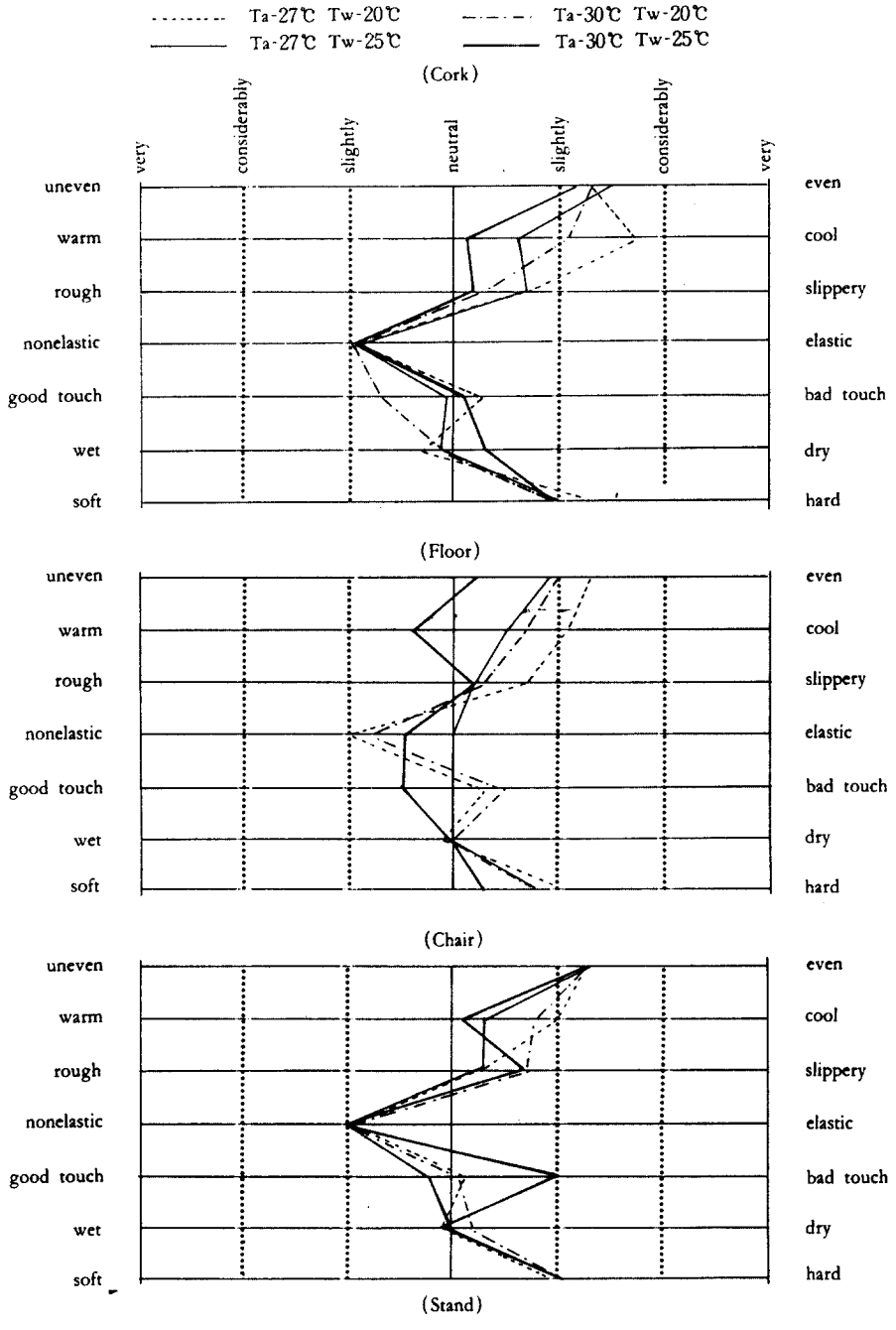


**Fig. 8.2 Profile of evaluation on the floor for each sitting posture and floor material**

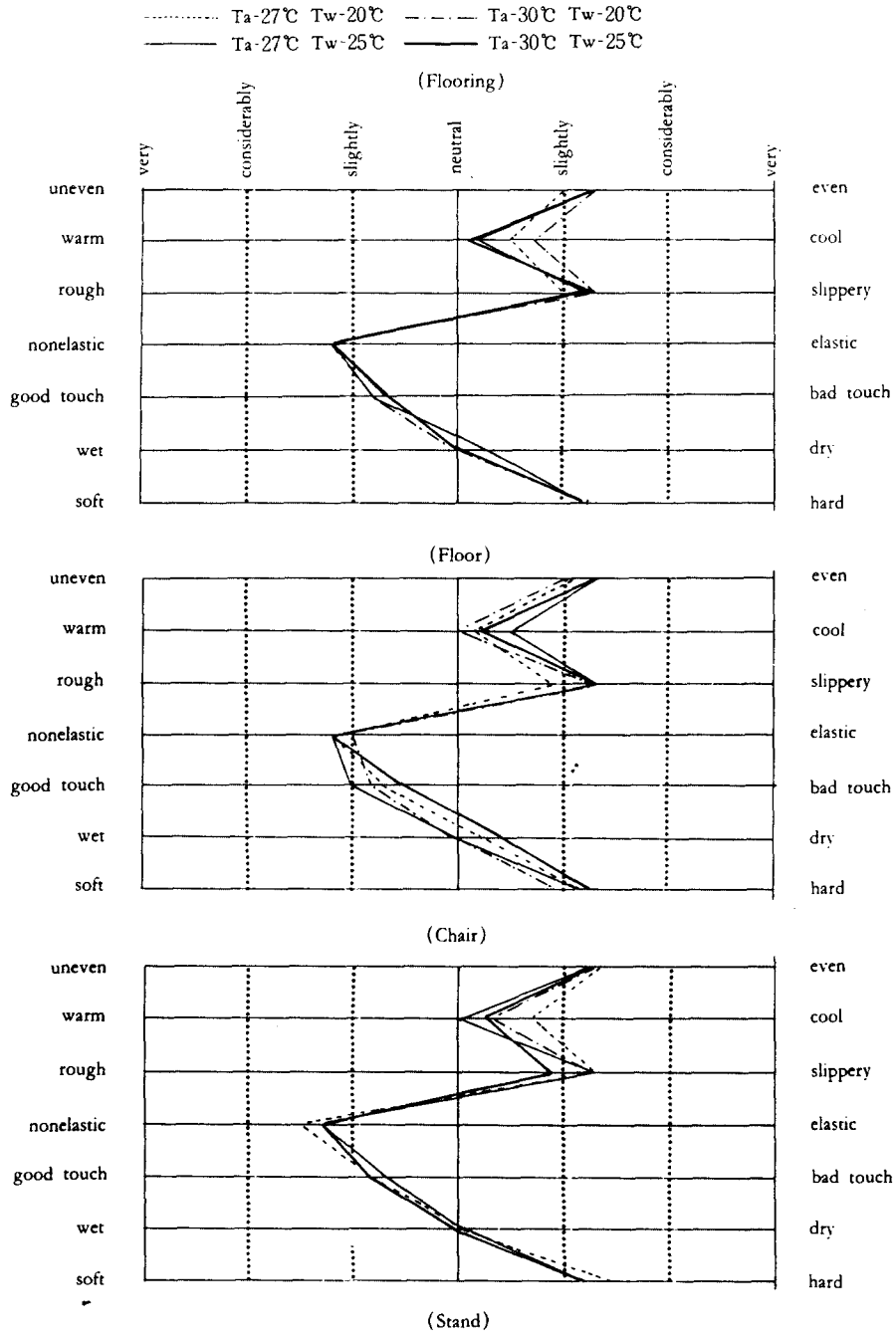


**Fig. 8.3. Profile of evaluation on the floor for each sitting posture and floor material**

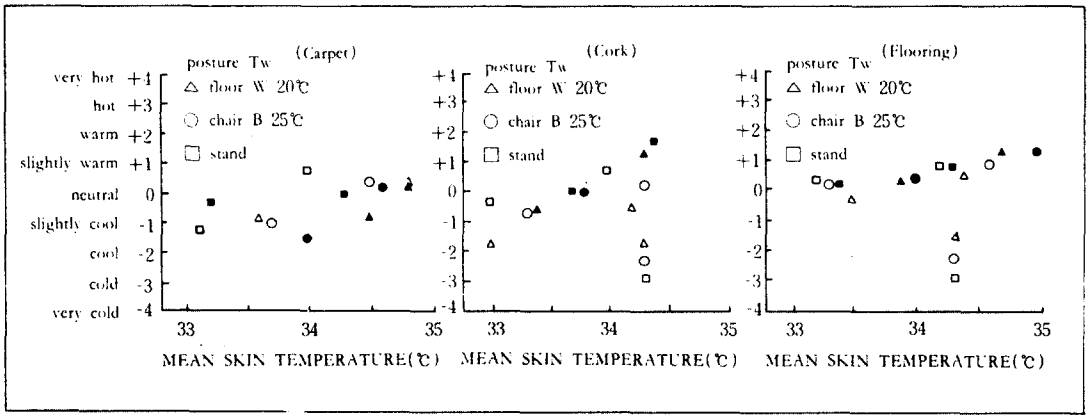


**Fig. 9 Relationship between mean skin temperature and thermal sensation vote for each sitting posture and floor material**

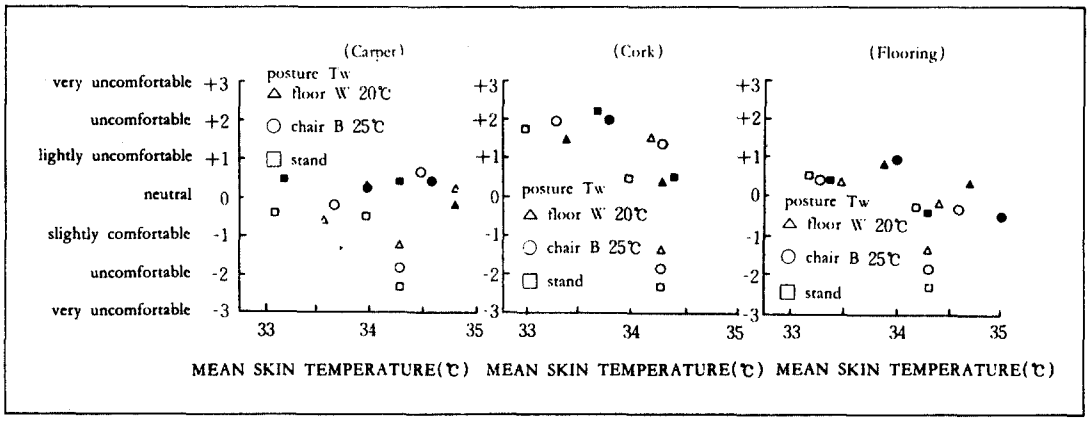


**Fig. 10 Relationship between mean skin temperature and comfort vote for each sitting posture and floor material**

temperature and comfort vote by postures and by floor materials. On the carpet, it is voted 「slightly comfortable」 when the mean skin temperature is around 34.5℃. This finding is contrasted with the conventional understanding of the thermal comfort, which is believed to be obtained between 33℃ and 34℃. The temperature found in this study is slightly higher than the conventional knowledge[6][7]. This is believed to be because of the influence of the cold floor. With regard to postures, more comfort votes are voted in sitting on the chair posture than in floor sitting posture. On the cork floor, comfort votes are voted in all conditions. The most comfort votes are observed in the temperature range between 33℃ and 34℃. The order of comfort vote is standing posture, sitting on the chair posture, and sitting on the floor posture in sequence. On the flooring, neutral votes are observed in general and comfort votes are observed when mean skin temperature is lowered in all postures. Mean skin temperature is high in the order of the standing posture, sitting on the floor posture, and sitting on the chair posture on the carpet, while no

meaningful variation by postures is observed. On the cork floor, it is lower in the sitting on the floor posture and in the standing posture than in sitting on the floor posture and in the standing posture than in sitting on the chair posture. This may be because shin and feet are contacting with the cool floor as well as body as a whole is closer to the floor. Also, body movement in the standing posture is made in bigger scale, which causes the effect of air velocity influencing body temperature. On the carpet, comfort votes are voted as globe temperature is higher in the sitting on the chair posture. Discomfort votes are voted in the standing posture as globe temperature is higher. On the carpet, either 「neutral」 or 「cool」 votes are voted as globe temperature is lowered. Besides, in the standing posture as well as in sitting on the floor posture 「cool」 votes are voted as globe temperature is lowered. On the cork floor, either 「neutral」 or 「cool」 votes are voted when globe temperature is 29℃ or lower. One feel the coolest in the floor sitting posture. On the flooring, 「neutral」 votes are overwhelmingly frequent in general. On the carpet, either 「cool」 or 「wet」 votes are frequent in the sitting on the floor posture, while 「rough」 or 「elastic」 votes are frequent in the sitting on the chair posture. In the standing posture, either 「slippery」 or 「bad touch」 feeling is voted. Comfort vote in the sitting on the chair posture is in between the floor sitting posture and standing posture. 「Warm」 and 「cool」 feelings may be affected by the floor temperature. On the flooring, we can observe the same tendency, showing no meaningful difference regardless of the sitting or standing postures. Only 「even」, 「non-elastic」 or 「hard」 feelings are frequently voted. Mean skin temperatue is comparatively lower on the cork floor than either on the carpet floor or on the flooring. The order for comfort is cork floor, flooring, and carpet floor in sequence. On the carpet floor, it is voted either 「neutral」 or 「slightly cool」 even when the mean skin temperature is 34℃ or slightly higher. On the cork floor, it is voted cool in all three postures when the mean skin temperature is lowered. When the mean skin temperature is 34℃ or lower, it is voted cool. On the flooring, thermal neutral votes are frequently voted.

## V. Conclusion

This study has examined the floor cooling method on skin temperatures and thermal comfort depending on the variation in sitting and standing postures during the summer season, with different floor materials, using the climate chamber in which temperature on and around the surrounding walls and ceiling are almost identical with the air temperature in the room. The results are summarized as follows :

(1) Mean skin temperature is lowered as air temperature is low and as water temperature of the floor cooling system is low. Other things being equal, mean skin temperature is lowered in the standing and sitting on the floor postures, whereas it is high in the sitting on the chair posture. Also, mean skin temperature is lower on the cork floor than on the carpet floor or on the flooring.

(2) It is voted either 「neutral」 or 「cool」 in thermal sensation votes when globe temperature is lowered. The order for thermal sensation by floor material is cork, carpet and flooring in sequence.

(3) In comfort vote, floor sitting and standing postures show more response of comfort than in sitting on the chair posture. The order for comfort by floor material is cork, flooring, and carpet in sequence.

(4) As for the assessment of the floor material in the floor sitting posture, the response of 「cool」 or 「wet」 is frequent on the carpet, while responses of 「even」, 「cool」, 「good touch」 or 「hard」 are frequent on the cork floor. It is voted 「even」, 「non-elastic」 or 「hard」 on the flooring. The assessment on the 「warm」, 「cool」 spectrum is influenced by the floor

temperature. Cork floor and flooring are highly assessed than the carpet floor.

(5) It is voted 「slightly cool」 on the carpet floor even when the mean skin temperature is 34℃ or higher. It is voted more 「comfortable」 in the standing and sitting on the chair postures than in the floor sitting posture. On the cork floor, it is voted the most 「comfortable」 in all three postures when the mean skin temperature is in between 33℃ and 34℃. On the flooring, either 「thermal neutral」 or 「neutral」 in comfort votes is frequent.

## References


1) Navins, R.G., Feyerherm, A.M.: Effect of Floor Temperature on Comfort, Part 4, Cold Floors, ASHRAE Trans., p.Ⅲ 2.1~Ⅲ 2.8, 1967.
2) Architectural Institute of Japan, Architectural Planing Date Collection, No.2, p.77, 1960.
3) Architectural Institute of Japan, Architectural Planing Data Collection, No.1 Environment, p.112, 1989.
4) Fujimoto, S., et al. : Studies on Physical Surface Area of Japanese, Part 18, Calculation Formulas in Three Stages over All Age, Japanese Journal of Hygiene, Vol.23, No.5, p.443, 1968.
5) Hardy, J.D. and DuBois, E.F. : The Technic of Measuring Radiant and Convection, Journal of Nutrition, Vol.15, p.461, 1937.
6) Gagge, A.P., Stolwijk, J.A.J., and Hardy, J.D. : Comfort and Thermal Sensations and Associated Physiological Responses at Various Ambient Temperatures, Environmental Research, p.1~20, 1967.
7) Kim, B.A., et al. : Influence of Floor Heating Temperature on the Human Body Seated on the Floor, Journal of Archit. Plann. Environ. Engng, AIJ, No.417, Nov.,p.26, 1990.