Thermal response of Korean college students in a thermal environment chamber

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ABSTRACT
The thermal comfort response of Korean college students was investigated in a thermal environment chamber both in summer and winter seasons. Eight thermal conditions consisting of four air temperatures (24, 26, 28, 30°C) and three relative humidities (40, 60, 80%) were selected in summer. Eight thermal conditions consisting of five air temperatures (18, 20, 22, 24, 26°C) and two relative humidities (40, 60%) were chosen in winter. In each test, seven females or seven males were questioned in the chamber for 3 h, where thermal and comfort sensations were surveyed every 15 min. To check the repeatability of thermal sensation for the same thermal condition, the same experiments for two cases were repeated twice. The thermal sensation votes of subjects were compared with the predicted mean votes. The correlation between thermal sensation votes and comfort sensation votes of subjects were discussed. The seasonal difference in thermal response was also addressed.

INDEX TERMS
Chamber study; PMV; Thermal comfort

INTRODUCTION
Thermal comfort is one of the important factors in the field of environmental engineering and heating and air-conditioning industry. The predicted mean vote (PMV) model is a widely used tool for the design of thermal environments of buildings, vehicles, etc. The model has been validated in thermal environment chamber studies with Asian subjects as well as in the field (Fanger and Toftum, 2002). In Korea, many studies on thermal comfort have been conducted since the late 1970s. Most of the researches were focused on the field measurements for Korean houses and apartments. A few field studies for office buildings were also performed. Recently, the thermal sensation of Korean college-age subjects was investigated in a small thermal environment chamber. Since Korean thermal sensation was not well known, chamber researches similar to those conducted by Fanger (1970) and Tanabe (1988) are needed.

In the present study, the thermal response of Korean college students was investigated according to the similar procedure and method of Fanger (1970) and Tanabe (1988) in a thermal environment chamber in both summer and winter seasons. The repeatability and temporal variation of thermal response were checked. The thermal sensation vote (TSV) of subjects was compared with the PMV calculated from the thermal and human parameters. The correlation between TSV and comfort sensation vote (CSV) of subjects was discussed. The seasonal difference in thermal response was also addressed.

EXPERIMENTAL
The experimental programme was carried out in a thermal environment chamber. The chamber is 4.5 m wide by 5.5 m long with a ceiling height of 2.4 m. The conditioned air was supplied from four floor diffusers and returned through the ceiling grills. The air change in the chamber was about 12.1 h^{-1}. The locations of the floor diffusers are shown in Figure 1. The eight combinations of air temperature and humidity were chosen for each season as listed in

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Table 1. Each of the eight thermal conditions were maintained during two experiments, namely for females and males. To check the repeatability of thermal sensation for the same thermal condition, the same experiments for two cases were repeated twice. S2 and S8 were chosen in summer, and W2 and W8 were selected in winter. The thermal condition in the chamber was held constant during each 3-h test period. Four physical parameters of air temperature, air humidity, globe temperature and air velocity were continuously monitored at a point E as shown in Figure 1 during the experiments. The 3-h test periods were either in the morning (10:00–13:00) or in the afternoon (14:30–17:30). The summer test was conducted in August 1999 and the winter test was carried out in February 2000.

Fourteen Korean college-age persons (seven females and seven males) were subjects for each season. The subjects were exposed to the thermal environment for 3 h in groups of seven subjects. Each subject participated in all tests for the same season. Anthropometric data for the subjects are listed in Table 2. All subjects wore casual clothes of each season. The clothing of subjects was examined on the basis of ASHRAE Standard 55-1992. In summer, the average clothing of subjects for females and males were in the range of 0.31–0.34 and 0.37–0.39 clo, respectively. In winter, the average clothing of subjects for females and males were in the range of 0.71–0.80 and 0.69–0.72 clo, respectively.

The subjects stayed in the pre-test room for 30 minutes. After entering the environmental test chamber the subjects were seated on folding chairs and asked to read, study or perform equally quiet activities. Quiet conversation was also permitted. The activities of subjects corresponded to 1.1 met. To avoid draft caused by the direct airflow supplied from floor diffusers, the seven subjects were located at the points of B, C, F, G, H, J, and K as shown in Figure 1. After 15 min the subjects reported their thermal and comfort sensations by checking numbers on a ballot with the voting scales shown in Table 3. This physiological–psychological seven-point scale is the one recommended in ASHRAE handbook. After this vote the ballots were collected. The vote was taken and collected every 15 min. This was repeated until 12 votes had been taken.

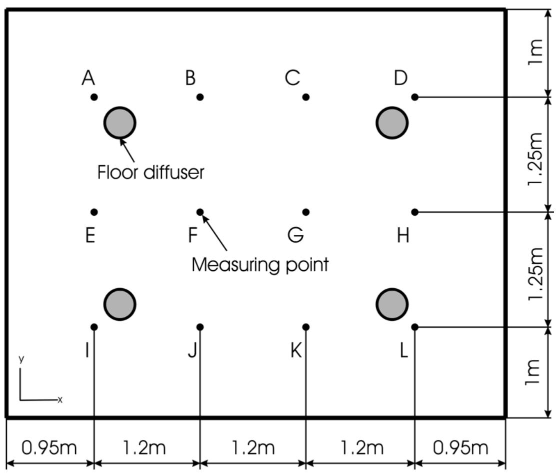


Figure 1 Location of subjects in a thermal environment chamber.

Table 1 Thermal conditions conducted in this study

Summer			Winter		
Case	Air temperature (°C)	Relative humidity (%)	Case	Air temperature (°C)	Relative humidity (%)
S1	24	60	W1	18	40
S2	26	60	W2	20	40
S3	26	80	W3	22	40
S4	28	40	W4	22	60
S5	28	60	W5	24	40
S6	28	80	W6	24	60
S7	30	40	W7	26	40
S8	30	60	W8	26	60

Table 2 Anthropometric data for the subjects

Season	Sex	Number	Age (years)	Height (cm)	Weight (kg)	DuBois area (m^2)
Summer	Female	7	22.0±1.4[a]	162.0±4.1	55.9±5.2	1.58±0.06
	Male	7	19.6±0.5	176.6±3.4	61.5±3.5	1.76±0.06
Winter	Female	7	19.6±0.5	161.4±6.9	51.2±4.4	1.52±0.10
	Male	7	19.6±0.8	178.0±2.3	76.1±11.9	1.93±0.12

[a]Average ± standard deviation.

Table 3 Questionnaire for thermal comfort

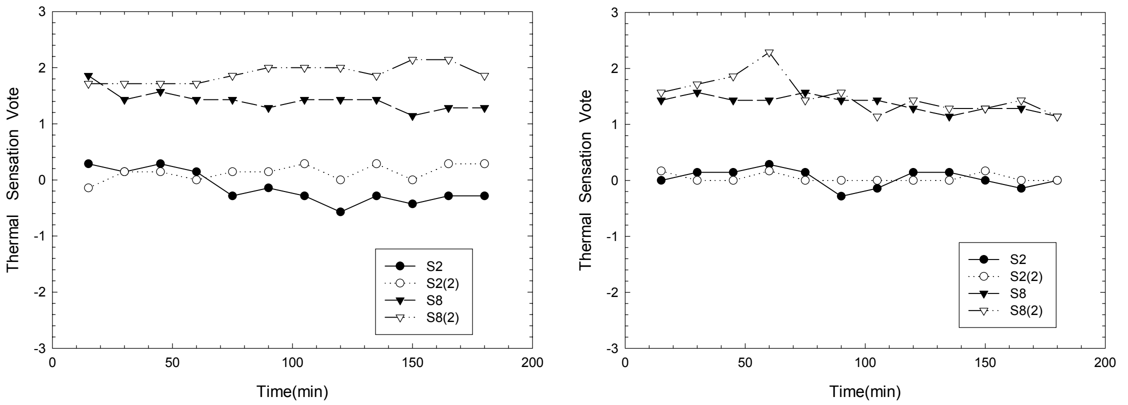
Thermal sensation scale	Comfort sensation scale
–3 Cold	0 Neutral
–2 Cool	–1 Slightly uncomfortable
–1 Slightly cool	–2 Uncomfortable
0 Neutral	–3 Very uncomfortable
+1 Slightly warm	
+2 Warm	
+3 Hot	

RESULTS AND DISCUSSION

Response of Thermal Sensation

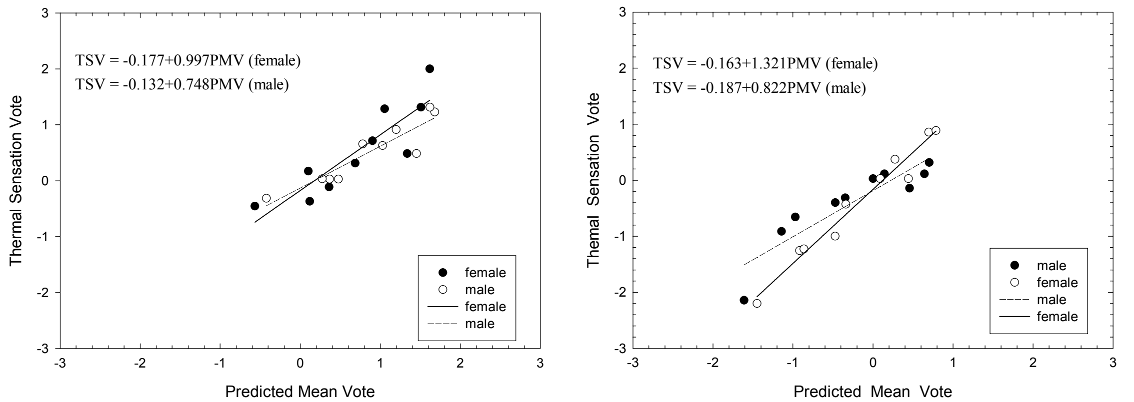
To check the repeatability of thermal sensation, the mean value of all thermal sensation votes is shown in Figure 2 as a function of the time of the vote for two cases in summer. Two experiments for the same thermal conditions give the similar mean TSV values for male. However, the mean TSV values of the same thermal conditions show significant difference for females. The average clothing (0.31–0.34 clo) of female subjects was greatly lower than the standard clothing (0.5 clo) in summer. In winter, the repeatability of thermal sensation for females is good; on the other hand, the repeatability for male is slightly bad. The average clothing (0.69–0.72 clo) of male subjects was lower than the standard clothing (0.9 clo) in winter. The low clothing of the subjects may account for the bad repeatability of thermal sensation.

As shown in Figure 2, the mean TSV value shows temporal variation during the 3-h test period. Therefore, the average of last five mean TSV values from 120 to 180 min was used as a representative TSV value for each experiment. For each experiment the PMV value was calculated using activity, clothing and the four classical thermal environmental parameters: air temperature, mean radiant temperature, air velocity and humidity. The experimental thermal sensation (TSV) is compared with the empirical thermal sensation (PMV) in Figure 3. In summer, the slope of the regression curve is equal to one for females and that is lower than one for males. It means that the thermal sensation of females is very similar to those of Europeans and Americans; however, the males are less sensitive to the thermal environments. The thermal comfort ranges (–0.5 < TSV < 0.5) of females and males are –0.32 < PMV < 0.68 and –0.49 < PMV < 0.84, respectively. The neutral points (TSV = 0) for both females and males are about 0.18, implying that Korean college students like slightly warm environment. In winter, the slope of the regression curve is higher than one for females and is lower than one for males. The thermal sensation of female shows big seasonal difference. The thermal comfort ranges of females and males are –0.25 < PMV < 0.50 and –0.38 < PMV < 0.84, respectively. The neutral points of females and males are 0.12 and 0.23, respectively, which supports the above implication obtained from the neutral points in summer.



(a) female (b) male

Figure 2 Repeatability of the thermal sensation vote (TSV) in summer.



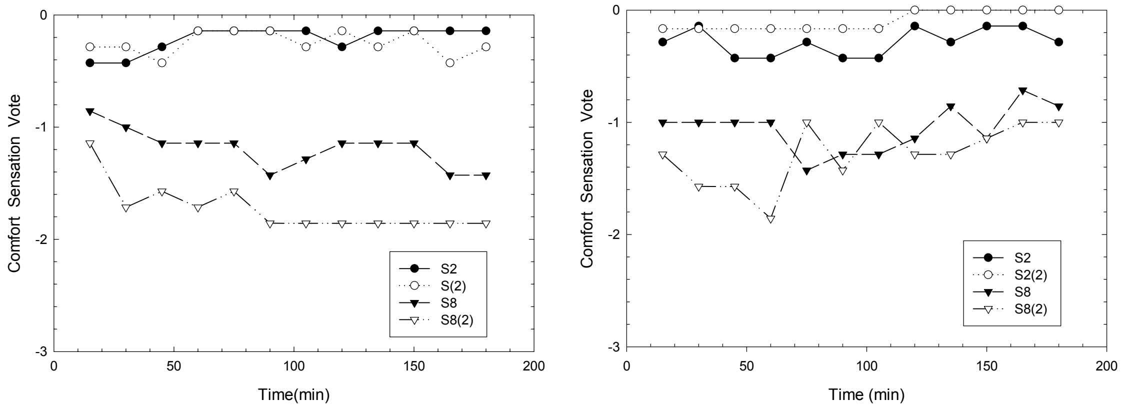
(a) summer (b) winter

Figure 3 Comparison of TSV with PMV.

Response of Comfort Sensation

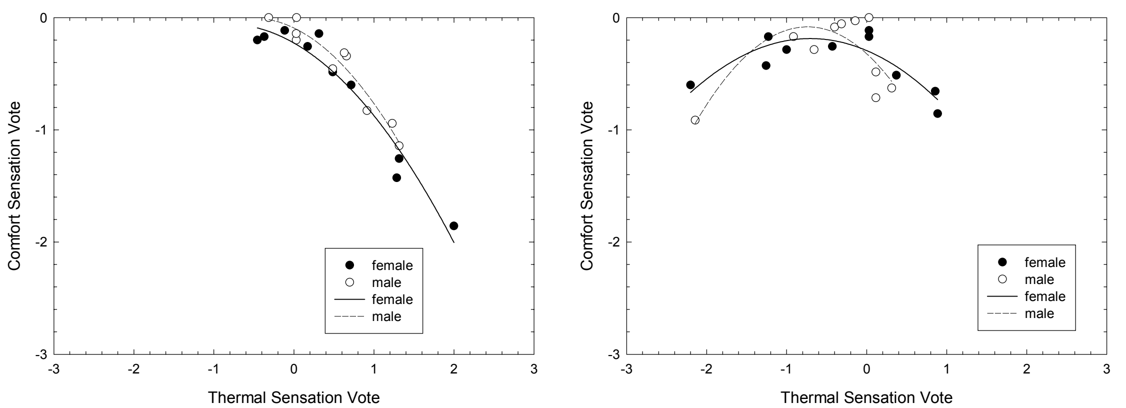
The TSV is an indirect assessment of thermal comfort for surrounding environment, and the CSV is a direct one. To check the repeatability of comfort sensation, the mean value of all comfort sensation votes is shown in Figure 4 as a function of the time of the vote for two cases in summer. The repeatability of case S8 is worse than that of case S2 for both females and males. It might be caused by the fact that the thermal environment of case S8 is hotter than that of case S2. In winter, the repeatability of comfort sensation for males is good; however, that for females is slightly bad for two cases, W2 and W8.

As shown in Figure 4, the mean CSV value shows temporal variation during the 3-h test period. Therefore, the average of last five mean CSV values from 120 to 180 min was also used as a representative CSV value for each experiment. The experimental comfort sensation (CSV) is compared with the experimental thermal sensation (TSV) in Figure 5. In summer, the CSV seems to be highly correlated with the TSV for both females and males, implying that the CSV can be directly estimated from the TSV. In winter, the CSV is insensitive to the TSV and Korean college students seem to feel thermal comfort in a slightly cool environment. From Figures 3(a) and (b), it is concluded that the thermal discomfort increases proportionally to the TSV in a warm environment (TSV > 0) and it slowly increases in a cool environment (TSV < 0).



(a) female (b) male

Figure 4 Repeatability of the comfort sensation vote (CSV) in summer.



(a) summer (b) winter

Figure 5 Correlation between TSV and CSV.

CONCLUSIONS

The thermal and comfort sensations of Korean college students were evaluated in a thermal environment chamber in both summer and winter seasons. The bad repeatability of thermal sensation seems to be related with the low clothing of the subjects who participated in the experiments. The TSV of Korean females equals that of the PMV in summer, however it is more sensitive to thermal environment in winter. The TSV of Korean males is less sensitive than the PMV in both summer and winter seasons. The neutral points of females and males are slightly positive, which means that Korean college students like slightly warm environment. From comparison of the CSV and the TSV, it is concluded that the thermal discomfort increases proportionally to the TSV in a warm environment (TSV > 0) and it slowly increases in a cool environment (TSV < 0).

REFERENCES

ASHRAE (1992). *ANSI/ASHRAE Standard 55-1992. Thermal Environmental Conditions for Human Occupancy.* Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Fanger, P.O. (1970). *Thermal Comfort*. Copenhagen: Danish Technical Press.

Fanger, P.O. and Toftum, J. (2002). Prediction of thermal sensation in non-air-conditioned buildings in warm climates. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate—Indoor Air 2002*, Vol. 5, pp. 92–97. Monterey: Indoor Air 2002.

Tanabe, S. (1988). thermal comfort requirements in Japan. PhD thesis, Waseda University.