Is the PMV Index an Indicator of Human Thermal Comfort Sensation?

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Abstract

This research examined how indoor environmental variables affect the human thermal comfort sensation. To examine the effect, both subjective comfort and thermal sensation were measured by the comfort sensation vote (CSV) and the thermal sensation vote (TSV) in thermal environmental conditions during heating or cooling. CSV was used by Tanabe (1998) and TSV was defined in ASHRAE (1989). In addition, physical environmental variables such as the air temperature, relative humidity, mean radiant temperature, air velocity, and the predicted mean vote (PMV) were used as the indices of thermal comfort sensation, and then the relationships between physical environmental variables and subjective variables were examined. The results showed a significant relationship between the PMV and the TSV, whereas a significant relationship was not shown between the PMV and the CSV even if there was a significant relationship between the relative humidity from the components of the PMV and the CSV. These results imply that PMV does not reflect human thermal comfort sensation adequately, and humidity control may be important in reflecting human thermal comfort sensation in indoor environments.

Keywords: *Human Thermal Comfort Sensation, TSV, CSV, PMV, Relative Humidity*

1. Introduction

People want to live in thermal environments in which they feel comfortable. If the temperature drops due to changes of the weather or seasons, people want to stay in warmer environments, and if it rises, they want to stay in cooler environments. Accordingly, many studies have been carried out to reveal the relationships between the human thermal comfort sensation and physical environment variables in order to meet the needs of these people [1]. The theory of predicted mean vote (PMV) developed by Fanger is the most representative thermal comfort model. PMV is an index that represents the predicted mean vote (on the thermal sensation scale) of a large population exposed to a given environment, and is acknowledged as an international thermal environment indicator [2]. This indicator has a range from -3 to +3, and it includes an air temperature (Ta), relative humidity (Rh), mean radiant temperature (Tr), air velocity (Va), clothing thermal resistance (I_{cl}), and a metabolic rate (M) [3]. The range from -0.5 to +0.5 is a range for comfortableness, and this range has been used as a condition for the air conditioning or as an indicator for indoor environments in order to create a comfortable environment for people.

Some studies that participants rated their thermal comfort sensation within environments with different temperature conditions, however, showed that the level of comfort sensation

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varied insignificantly with the width of temperature changes or changed regardless of temperature conditions [4-6]. These results could be interpreted in two ways. One possible interpretation could be the case that the level of comfort sensation varied insignificantly or did not change because the temperatures used in the studies mentioned above did not reach the discomfort range of PMV. However, the PMV index might have changed enough from comfort to discomfort, because the temperatures used in the studies mentioned above had a large range of room temperature (e.g., from 20℃ to 32℃). Given this fact, those interpretations may not be reasonable. Another possible interpretation could be that the level of comfort sensation changed insignificantly or did not change because the comfort range of PMV did not adequately reflect the comfort sensation people feel. If this interpretation is reasonable, it may be inappropriate to control air conditioning or assess the degree of comfort in an indoor environment based on the PMV index.

Therefore, this study examined the relationships among the subjective thermal comfort sensation of participants in the experimental environment while they performed a simple experimental task, the PMV index, and sub-components of the PMV. Ultimately we examined the effects of indoor environment variables on subjective thermal comfort sensation.

2. Method

2.1. Participants

Eighteen young adults (age: 25.44±2.91 yrs.) participated in the experiment. All participants were requested to have normal (or corrected) eyesight, and therefore had no difficulty perceiving the stimulus presented on a monitor. No participant had had any prior experience in the laboratory and all were naïve with respect to the aims of the study. They waited in the waiting room, which was at room temperature, for about 10 minutes before starting the experiment and were given some instructions about the experimental procedure. In addition, their clothing was set to 1.0 clo (based on ISO 7730 Annex C of the typical combinations of garments). Their activity was set to 1.0 met, because they were seated in a chair while watching a computer screen and were simply asked to press two keys as specified in the task.

2.2. Experimental Environment and Apparatus

The main experiment was conducted in an enclosed test room consisting of a 3.5×5.4×2.1m (l x w x h) space, in which it was designed to control both the temperature and humidity. The temperature, humidity, mean radiant temperature, air velocity, and the PMV were measured for every 1 minute at a height of 1.2m with the KEM's AM-101 (see Figure 1). The measured variables, range, and the tolerance of this equipment are illustrated in Table 1.

2.3. Experimental Task

The experimental task was conducted with E-Prime 1.2 program. The stimuli for experimental task were presented on a 17-inch CRT monitor with a resolution of 1024×768 and a refresh rate of 75Hz. A distance between the participants and the screen was 70cm, and all stimuli were presented in black on a gray background. A stimulus was a square (1.2°×1.2°) with a gap of 0.6° in one of the four sides. The target stimulus had a gap to the left or right sides, and the distractor had a gap to the upper or the bottom sides.

Figure 1. The Experimental Environment and Apparatus

Table 1. Specifications of Measuring Equipment

Variables	Range	Tolerance
Air Temperature	0~50℃	±0.5℃
Relative Humidity	0~100%	±3%
Globe Temperature	0~50℃	±0.5℃
Air velocity	0~5m/s	±0.1m/s(0~1m/s) ±0.5m/s(1~5m/s)

2.4. Procedures

After reading instructions, the participants entered the test room. The main experiment consisting of two sessions was conducted twice by each participant. One session of the experiment was a heating condition and the other session was a cooling condition. In a heating condition, the room temperature was raised to about 20℃ to 30℃ based on the temperature of the air conditioner sensor. In contrast, in a cooling condition, the room temperature was dropped to about 30℃ to 20℃ based on the temperature of the air conditioner sensor. The presented order of conditions was counter balanced, and a resting time was included for approximately 5 minutes between sessions. In addition, eight task trials were included in a session, and a brief recess was included for 30 seconds between task trials. Participants checked both their thermal sensation vote (TSV) and their comfort sensation vote (CSV) at the beginning of every task trial, and then they performed the task. The TSV was defined by ASHRAE (1989) [7] and the CSV was used by Tanabe (1998) [8]. At this time, participants pressed the '1' key on keyboard when the presented target stimulus had a gap to the left side, and they pressed the '2' key when it had a gap to the right side (see Figure 2).

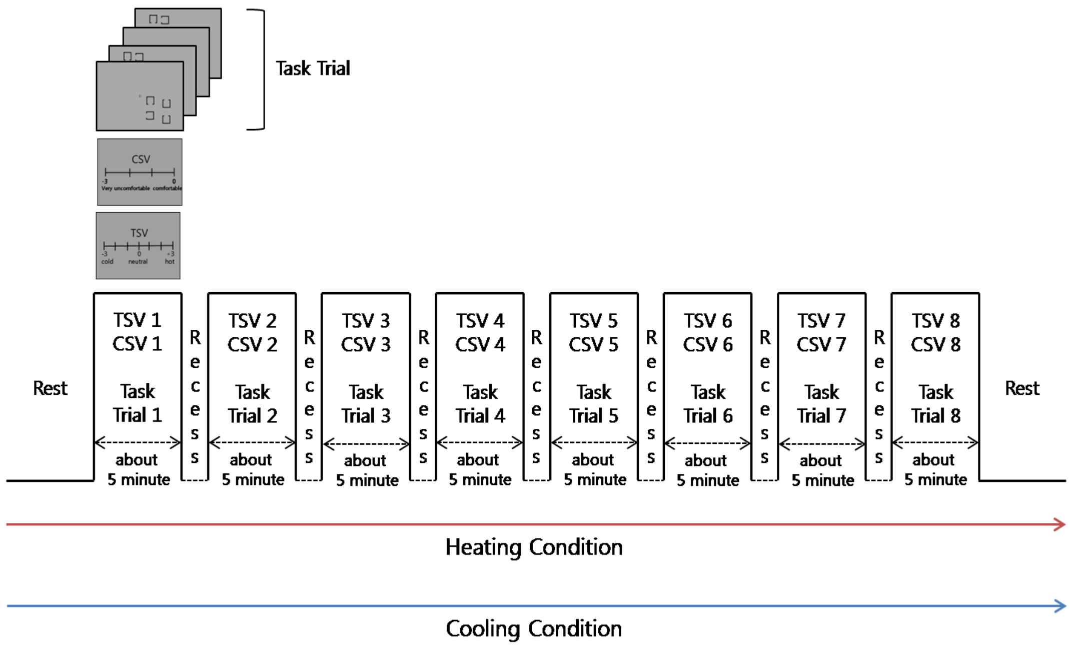

Figure 2. The Experimental Procedures

3. Results

The analysis of correlation among the PMV, physical environmental variables (e.g., air temperature, relative humidity, mean radiant temperature, air velocity) which were used to obtain the PMV, the TSV, and the CSV was carried out in order to examine the effects of indoor environmental variables on the subjective human thermal comfort sensation (see Table 2).

There were significant positive correlations among the PMV, air temperature, mean radiant temperature, and the humidity, and a significant negative correlation between the PMV and the air velocity. In addition, there was a significant positive correlation between the PMV and the TSV. The PMV, however, did not correlate with the CSV as the subjective thermal comfort sensation. On the other hand, the CSV negatively correlated with the relative humidity, and the relative humidity positively correlated with the air temperature and the PMV as a combination indicator of environmental variables, but it negatively correlated with the air velocity.

Table 2. The Result of Correlations between Measured Variables

	1	2	3	4	5	6
1.Ta	-					
2.Va	-.53**	-				
3.Tr	.65**	.21**	-			
4.Rh	.67**	-.76**	.04	-		
5.PMV	.98**	-.41**	.77**	.60**	-	
6.CSV	-.07	.02	-.00	-.15**	-.05	-
7.TSV	.73**	-.52**	.39**	.63**	.72**	.05

** p<.01

Note) Ta – air temperature, Va – air velocity, Tr – mean radiant temperature, Rh – relative humidity, PMV – predicted mean vote, CSV – comfort sensation vote, TSV – thermal sensation vote.

Accordingly, the hierarchical regression analysis was performed with the CSV as the dependent variable and environment variables as the independent variables (see Table 3). The way that primarily enters the variable highly correlates with the relative humidity was used as a method of entering independent variables.

Table 3. The Results of Regressions between Predictors (Rh, VA) and the Criterion Variable (CSV)

Model	*B*	*SE*	*β*	*t*	*F*	R^2	Δ R^2
1st step							
Rh	-.008	.003	-.152	-2.595*	$F_{(1,286)}$=6.733*	.023 (Adjusted R^2=.020)	.023*
2nd step							
Rh	-.018	.005	-.324	-3.654***	$F_{(2,285)}$=6.723**	.045 (Adjusted R^2=.038)	.022*
Va	-2.023	.789	-.228	-2.566*			

*p<.05, **p<.01, ***p<.001

Note) Rh – relative humidity, Va – air velocity, CSV – comfort sensation vote.

As a result, the fitness of the regression equation model in which only the relative humidity was entered as a independent variable was statistically significant [$F_{(1,286)}$=6.73, p<.05], and the R-square estimate of the relative humidity on the CSV was 2.3% [β=-.15, t=-2.60, p<.05]. In addition, that of the regression equation model in which both the relative humidity and the air velocity were entered was statistically significant [$F_{(2,285)}$=6.72, p<.01], and the R-square estimate of two variables on the CSV was 4.5% [Rh: β=-.32, t=-3.65, p<.001, Va: β=-.23, t=-2.57, p<.05]. In other words, the R-square estimate of the air velocity on the CSV was 2.2%. After the air velocity was entered, however, the estimate of R-square change due to entering the other variables was not statistically significant.

4. Conclusion and Discussion

This study examined the effects of indoor environment variables on the subjective human thermal comfort sensation. The first point to be considered is that the PMV (a combination of indoor environment variables) was correlated with the TSV, but not with the CSV. This result indicates that the PMV used as an indicator of thermal comfort is suitable for reflecting the subjective human thermal sensation, but not for reflecting the subjective human thermal comfort sensation. In other words, the PMV is more similar to a thermal index rather than to a thermal comfort index. Therefore, the control of the indoor environment variables based on the PMV may be inappropriate when constructing a comfortable environment for human.

The second point is that, although the variation of CSV scores and R-square estimates of the independent variables were small, the subjective thermal comfort sensation was significantly predicted by both the relative humidity and the air velocity. This result indicates that changes of the relative humidity are more likely to be related to the comfortable levels which the human feels to thermal properties of a surrounding area than those of any other environment variables. In addition, It is possible for the air velocity to affect the subjective thermal comfort sensation, but only to a small degree.

As a result, a new indicator is needed to reflect the subjective human thermal comfort sensation appropriately, because the PMV failed to do so. Moreover, it is very important to control the relative humidity than any other environment variables in order to adequately reflect the thermal environment conditions in which humans feel comfortable.

The study has several limitations. First, the scale range of the CSV is limited to 4-point, and thus the CSV is biased to reflect the level of comfort and discomfort. In other words, within the 4-point range, discomfort is reflected in three points from -3 to -1, and only a single point of 0 (zero) reflects a comfort state. Due to the fact that individuals have different perceptual response criterion, participants might have shown the biased responses. For example, participants had to choose zero on the scale although they feel slightly comfortable or they are extremely comfortable. Therefore, future studies are needed to measure subjective thermal comfort with the expanded scale system which has the same degree for comfort and discomfort.

Second, the measurement timing of the subjective thermal comfort sensation and physical environment variables did not match. In other words, the subjective thermal comfort sensation was rated before participants performed the experimental task, while physical environment variables were measured while they performed the experimental task. Strictly speaking, the physical environment may be different while doing experiment (i.e., the early stage of experiment and the intermediate stage of experiment), because heating or cooling is manipulated during the experimental task. Therefore, future studies are necessary to examine how to compensate for this matching method.

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