325: Exploring the Variation of the Desired Thermal Sensation in Tropical Climate: A Pilot Study

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Abstract

The goal of this study is to extend the knowledge on the behaviour of the semantic offset of the ASHRAE thermal sensation scale. To achieve this goal, a field survey of 100 research participants occupying both air-conditioned (AC) and naturally ventilated (NV) spaces was carried out in the summer month of Bangkok, Thailand. In this field study, the actual and the desired thermal sensation are compared. The paired sample t-test shows that there is a significantly mean difference between the actual and the desired thermal sensation, both for the AC and NV spaces. The data show that approximately 50% of the occasions the desired thermal sensation was other than 'neutral' and majority of participants preferred to be on the cool side of 'neutral' regardless of their ventilation method. Although a possible pattern of variation of the desired thermal sensation on the ASHRAE scale for hot-humid climate was found, this study concluded that further studies are needed to improve our understanding of thermal comfort in hot-humid climate. The semantics of Thai thermal expression and the implication for energy conservation are discussed.

Keywords: thermal comfort, hot-humid climate, preference

1. Introduction

This pilot study was undertaken as a part of the 2501669 Statistics in Architectural Research class project to analyze thermal comfort of building occupants in hot-humid climate. The research described here follows up Humphreys and Hancock [1] thermal sensation study in which the variety of the desired thermal sensation on the ASHRAE scale was explored.

In Humphreys and Hancock's study, the simplicity of ASHRAE scale of subjective warmth, especially the concept of thermal neutrality, was questioned whether it reflexes building occupants' preferred thermal sensation. Their data confirmed that the desired sensation on the ASHRAE scale is often other than 'neutral' and the variation was consistent with an adaptive theory of thermal comfort. Most importantly, Humphreys and Hancock were able to derive a variation pattern of the desired thermal sensation as a function of the actual thermal sensation for cool climate where the means of desired thermal sensation were found to be above 'neutral' (see Figure 1).

Although thermal preference is one of the key concepts in the adaptive thermal comfort model [2-4], the concept has rarely been examined and is still not fully understood. Thus far, only a handful of field studies investigated the concept of thermal sensations and preferences [5-8]. Results from previous field studies suggested that people in hot climates prefer a sensation slightly cooler than neutral [2,5,8,9]. The decision on what the temperature to provide in buildings based on adaptive thermal comfort model, however, has not been settled.

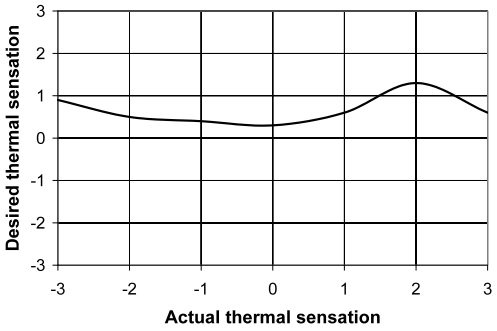

Fig 1. Dependence of the mean desired thermal sensation upon the actual sensation reported from the participants from the United Kingdom (adapted from Humphreys and Hancock, 2007)

The implication of understanding thermal preference can potentially goes beyond the construction of valid semantic scale. For buildings in hot climates such as Thailand, large amount of energy resources are consumed to provide cooling for the built environment [5,10]. Many times, assumptions on the level of thermal comfort were established without adequate logical reasons. For example, the Department of Energy of Thailand has recently launched a national campaign, advising building occupants to set their thermostat at 25 Degree Celsius [11]. Since thermal comfort standard for Thailand has never been established, it was hypothesized that the 25 °C set point was based on foreign standards (presumably, from cool climates).

For Thailand, it is commonly assumed that raising the set point temperature by 1 Degree Celsius will decrease HVAC energy consumption by about 10 percent. Therefore, understanding how much warmer or cooler people would like to feel could potentially affect theoretical estimates of energy consumption.
The objective of this study was to extend the knowledge on the behavior of the semantic offset of the ASHRAE thermal sensation scale. The research hypotheses are that the actual and the desired thermal sensation, reported from participants, are different and people in hot climate sometimes prefer sensations other than 'neutral'.

2. Method

2.1 Research Participants and Area Studied

This study dealt with two groups of subject responding to their individual thermal environment. These two groups are those in air-conditioned indoor space (AC) and those in naturally-ventilated indoor spaces (NV). A total of six locations within Chulalongkorn University (Bangkok, Thailand) premises were selected as case study sites (see Figure 2) including three air-conditioned spaces (library, departmental office, and lecture room) and three shaded naturally-ventilated spaces (cafeteria and study spaces). Research participants were recruited from actual space users including university affiliates, students, and children.

Fig 2. Example of air-conditioned (top) and naturally-ventilated (bottom) spaces that were used as case study site.

2.2 Equipments and Measurements

Air temperature (T_a) and relative humidity (RH) data were gathered from a HOBO standalone data logger (HOBO H8-007-02) equipped with narrow-range temperature sensor cable (HOBO TMC6-HB). Each air temperature sensor probe was housed inside a cylindrical Mylar radiation shield (1.5-inch diameter) to protect the probe from direct radiation gain. Air velocity (v) was measured by a thermo anemometer (AIRFLOW TA5). Air temperature, relative humidity and air velocity were measured at neck height of the respondent being surveyed (approximately at 1.1 m above ground for seated position).

2.3 Questionnaire

The questionnaire used in this study was based on the format that was used by Humphreys and Hancock [1]. The questionnaire contained a covering letter explaining the aim of the survey and it was translated and written in the Thai language (see table 1).

Table 1: The ASHRAE scale of subjective warmth and its Thai translation.

Code	English Descriptor	Translated Thai Words
+3	Hot	□□□□
+2	Warm	□□□□
+1	Slightly Warm	□□□□□□□□□□□□
0	Neutral	□□□□□□□□□□□□□□□
-1	Slightly Cool	□□□□□□□□□□□□
-2	Cool	□□□□
-3	Cold	□□□□

The questions of the survey in the questionnaire were:
1. Personal information about the respondents including familiarity with the air-conditioned space.
2. Subjective rating of thermal response
- Sensation (using the seven-point ASHRAE scale)
- Preference (using the seven-point ASHRAE scale)
- Humidity and airflow (using a seven-pint scale)
- Adaptation (using an open-ended question for the respondents to fill in)

2.4 Procedure

The study was conducted within two weeks period in July 2007, the summer season of Thailand. Research participants were invited to complete the questionnaire regarding their thermal sensation and preference.
During the completion of the questionnaires, occupants were in the vicinity of the equipment used for taking measurement of temperature, relative humidity and wind speed. Individual parameters, such as clothing insulation and activity level, were observed and recorded by researchers.

3. Results

3.1 Profile of the respondents

This research reports survey results from a total of 100 respondents, age between 12 and 52 with the average at 23. All respondents were of Thai nationalities who conduct their daily routine in the actual spaces surveyed. Table 2 summarizes the distribution of survey samples by gender and space surveyed. The survey sample included 42 male and 58 female responses. The bodies of the respondents averaged at 58 kg (128 lbs) in weight and 166 cm (about 5 ft, 5in.-6in.) in height.

Majority of the respondents wore typical university uniforms (shirt and slack for men and short sleeve shirt and knee-length skirt for women). The survey data showed that approximately 10% of the respondents are not familiar with air-conditioned space.

Table 2: Distribution of respondents by gender and ventilation type.

Gender/ Ventilation Type	AC	NV	Total
Male	24	18	42
Female	26	32	58
Total	50	50	100

Table 3 presents descriptive statistics for each physical environmental variable in both AC and NV case. Mean T_a for AC and NV case were 27.7 °C (81.8 °F) and 31.5 °C (88.7 °F) respectively. Mean *RH* for AC and NV case were 45.1% and 56.1% respectively.

Air velocities for both the AC and NV case were below 0.9 m/s and were not included in detailed analysis.

Table 3: Descriptive statistics of physical environmental variables by ventilation type.

	Variables	Mean	Min	Max	SD
AC	T_a (°C)	27.7	24.1	30.0	1.87
	RH (%)	45.1	39.0	52.0	3.4
	v (m/s)	0.13	0.01	0.59	0.13
NV	T_a (°C)	31.5	30.1	32.8	0.6
	RH (%)	56.1	45.0	68.0	8.4
	v (m/s)	0.43	0.05	0.87	0.19

3.3 The spread of thermal sensations

Table 4 shows the frequencies of the various thermal sensations by ventilation type, rounded to the nearest integer. Mean and standard deviation of the raw scores are also shown.

3.2 Physical Environmental Data

Table 4: Frequencies and descriptive statistics of the actual and desired thermal sensations by ventilation type.

		ASHRAE scale (rounded)									
		-3.0	-2.0	-1.0	0.0	+1.0	+2.0	+3.0			
	Thermal Preference	Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot	Total	Mean	SD
AC	**Actual**	1	4	12	17	14	2	0	50	-0.06	0.87
	Desired	0	10	12	22	6	0	0	50	-0.43	0.80
NV	**Actual**	0	0	7	24	14	3	2	50	0.31	0.79
	Desired	0	2	18	28	2	0	0	50	-0.37	0.63

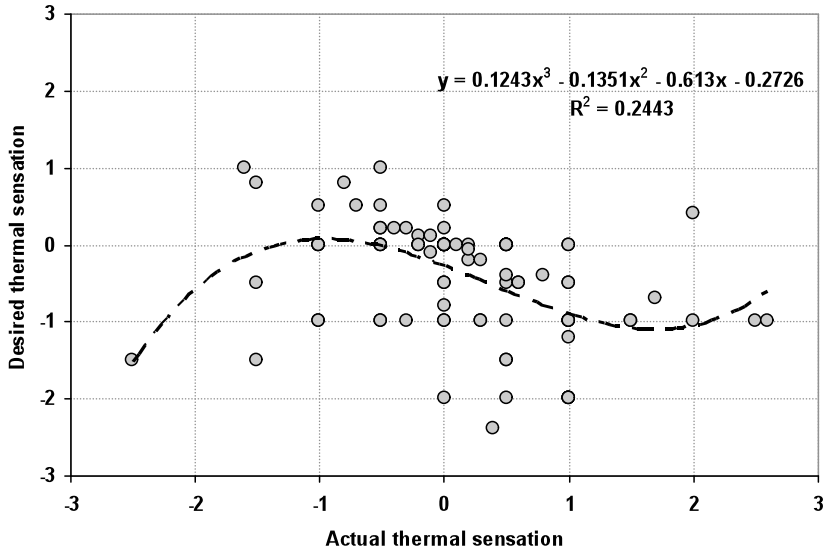

Fig 3. Scatterplot of desired thermal sensation (AC and NV cases) as a function of actual thermal sensation

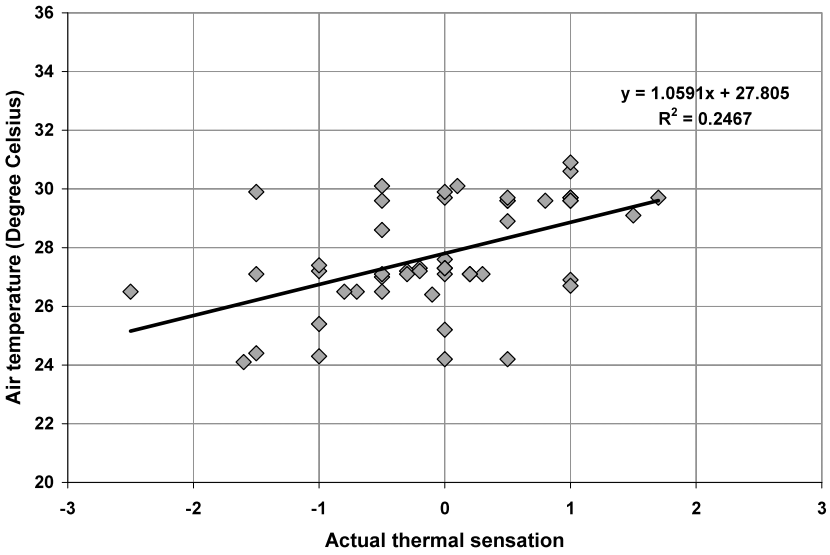

Fig 4. Scatterplot of air temperature as a function of actual thermal sensation (AC case only)

4. Discussion

4.1 Did people sometime desire sensation other than 'neutral'? If so, how warm or cool they like to feel?

The results show that approximately 50% of occasions the desired thermal sensation was found to be other than 'neutral'. The results also show that, on average, participants preferred to be on the 'cool' side of the ASHRAE sensation scale regardless of their cooling mechanism ($GM_{desired}$=-0.40, SD=0.81). This finding supports the hypothesis that was proposed in previous research that people in hot climates prefer sensation slightly cooler than neutral. Similar to Humphreys and Hancock finding, the data also confirm that 'neutral' may not necessarily be the desired thermal sensation.

The paired sample t-test shows that there is a significantly mean difference between the actual and the desired thermal sensation, both for the AC and NV spaces (AC case: $t(49)=1.81$, $p<.05$; NV case: $t(49)=4.19$, $p<.05$). Close examination of the mean difference between the actual and the desired thermal sensation by ventilation type shows that, for AC case, the difference is on the ASHRAE unit scale of less than -0.4. For NV case, the difference is higher and is on the unit scale of -1. Possible interpretation of the difference between desired sensations of the two ventilation types is that people in naturally-ventilated spaces have less control over their thermal environment, while the chance that people in air-conditioned space will be more satisfied with their thermal environment is higher.

4.2 A possible pattern of variation for hot climate

Analysis of the actual and desired thermal sensation (see Figure 3) shows a cubic correlation function, $r^2=.24$, $F(1,96)=10.35$, $p<.05$, that represents a possible pattern of variation of the desired thermal sensation on the ASHRAE scale for hot-humid climate.

From the derived pattern, the upward trend (positive correlation) is evident in the zone from 'cool' to 'slightly cool' and the downward trend (negative correlation) is evident in the zone from 'slightly cool' to 'warm'. This pattern is unique in the way that its trend line takes the mirror shape of the pattern that was found for cool climate. In addition, the data shows that the predicted desired thermal sensation values are mostly below 'neutral'.

4.3 Semantic offset in the expression of thermal sensation

It is interesting to see that participants in neither AC nor NV case have little desire for 'cold', 'cool', 'warm' and 'hot' sensation. Careful examination on how Thai people express their feelings may offers further explanation to the data found in this study.

In contrast to cool climate, the concept of thermal comfort in hot-humid climate is mostly associated with 'coolness', rather than 'warmth'. The expression of 'warmth' in Thai language, aside from the culinary context, is usually viewed as having negative meanings in daily life. On the contrary,

For example, Thai students would prefer to study in a 'slightly cool' classroom rather than a 'slightly warm' classroom, even though, 'slightly warm' might be thermally acceptable based on the PMV/PPD standard. In addition, the word 'hot' or '□□□□' when combine with other words such as 'mind' or 'chest' could be used as phrases or new words that usually have negative meanings. On the contrary, the word 'cool' or '□□□□' usually portray positive meaning. With these associated negative and positive effect in daily usage, aside from physiological response, it becomes clear why people in Thailand would neither desired 'warm' nor 'hot' thermal sensation.

The complexity of thermal expression was also found in the other end of the ASHRAE scale.

While countries in cooler climates might enjoy many cooling-degree-day, Thai people get to enjoy only very few heating-degree-day per year. Therefore, Thais rely heavily on air-conditioning systems in which most if not all of office buildings in Thailand are equipped with air-conditioning systems. Many times, assumptions on the level of thermal comfort were established without adequate logical reasons. This results in lower-than-it-should-be thermostat set point. It is very common to find Thai male and female office workers wear another layer of jacket to 'warm' themselves up while taking up their long-sleeves shirt during lunch time in a non air-conditioned cafeteria. This is probably the reason why the respondents who said that the temperature is slightly cool would prefer to be in the 'neutral' thermal state.

4.4 Implications for energy conservation

The implication of understanding thermal preference can potentially goes beyond the construction of valid semantic scale. Scatterplot of air temperature as a function of actual thermal sensation for AC case is show in Figure 4. Based on the regression trend line, the data show that temperature range of region between 'cool' and 'neutral' which represent the acceptable range thermal sensation, is between 25.7 to 28 Degree Celsius. The results suggest that the '25 Degree Celsius' thermostat setpoint which is set by the Department of Energy of Thailand may not be an optimum value since it does not respond to building occupants' thermal preference. Although it is too early to determine exact value of the appropriate thermostat setpoint for Thailand, the data suggest that the setpoint could be raised by at least 1 to 2 Degree Celsius which would resulting in 10 to 20 percent of HVAC energy reduction. Apparently, a full understanding of the desired thermal sensation could affect not only theoretical estimates of energy consumption, but also how national campaign and energy standards could be established with logical reasons. Further study on this topic is much needed.

5. Conclusion

The goal of this study is to extend the knowledge on the behaviour of the semantic offset of the ASHRAE thermal sensation scale. To achieve this goal, a field survey of 100 research participants occupying both air-conditioned (AC) and naturally ventilated (NV) spaces was carried out in the summer months of Bangkok, Thailand. In this field study, the reported actual and the desired thermal sensation are compared.

The results support research hypotheses that the actual and the desired thermal sensation from participants in hot-humid climate are different. In addition, the data shows that people in hot-humid climate prefer a slightly cooler than neutral thermal sensation. A possible pattern of variation of the desired thermal sensation in tropical climate was derived.

As a pilot study, however, the small sample size does not allow us to accurately determine an absolute variation pattern of the desired thermal sensation in tropical climate. Further studies, especially in hot climate, are needed to improve our holistic understanding of thermal comfort. In pursuing this research further, we plan to expand the study to include thermal responses and preferences in both the cooler and warmer months of the year. Relative humidity and wind speed data which were not explored in this study would be examined for its effect on the desired thermal sensation.

6. References

1. Humphreys, M.A. and M. Hancock, (2007). Do People Like to Feel 'Neutral'? Exploring the Variation of the Desired Thermal Sensation on the ASHRAE scale. *Energy and Buildings*, 39: p. 867-874.

2. De Dear, R.J. and G.S. Brager, (1998). Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions*, 104(1): p. 145-167.

3. Humphreys, M.A. and J.F. Nicol, (1998). Understanding the Adaptive Approach to Thermal Comfort. *ASHRAE Transactions*, 104(1): p. 991-1004.

4. Brager, G.S. and R.J. De Dear, (1998). Thermal Adaptation in the Built Environment: A Literature Review. *Energy and Buildings*, 27: p. 83-96.

5. Jitkhajornwanich, K., A.C. Pitts, A. Malama and S. Sharples, (1998). Thermal Comfort in Transitional Spaces in the Cool Season of Bangkok. *ASHRAE Transactions*, 104(1): p. 1181-1193.

6. Kwok, A.G., (1998). Thermal Comfort in Tropical Classrooms. *ASHRAE Transactions*, 104(1): p. 1031-1046.

7. Kwok, A.G. and C. Chun, (2003). Thermal Comfort in Japanese Schools. *Solar Energy*, 74: p. 859-872.

8. Busch, J.F. (1992). A Tale of Two Populations: Thermal Comfort in Air-Conditioned and Naturally Ventilated Offices in Thailand. *Energy and Buildings*, 18: p. 235-249.

9. Nicol, F., (2004). Adaptive Thermal Comfort Standards in the Hot-Humid Tropics. *Energy and Buildings*, 36: p. 628-637.

10. Khedari, J., N. Yamtraipat, M. Pratintong and J. Hirunlabh, (2000). Thailand Ventilation Comfort Chart. *Energy and Buildings*, 32: p. 245-249.

11. http://www.thaienergynews.com, last visited June 16, 2008.