

## **REDEFINING APPROPRIATE THERMAL COMFORT STANDARD FOR NATURALLY VENTILATED BUILDINGS IN TROPICS (SINGAPORE AND INDONESIA PERSPECTIVE)**

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### **ABSTRACT**

In naturally ventilated buildings (NVB) located in tropical regions, thermal comfort prediction based on PMV standard has shown some deviation from observed results. Hot and humid environmental conditions throughout the year and personal adaptation make the people in tropics expect and perceive thermal comfort differently. The proposed thermal comfort standard based on adaptive modeling approach is still not convincing enough for application since it sometimes rely on one environmental parameter for prediction. This study has collected more than 1000 data through extensive field survey in Singapore and Indonesia. The potential of combining the fundamental thermoregulation with the adaptive approach that considers behavioral adaptation has been explored. The reciprocal effects from environmental parameters and occupant's behavioral adaptation were investigated. In tropical free running buildings where the air temperature and humidity can not be modified without mechanical means, the people were observed to prefer substantially higher wind speed.

### **INDEX TERMS**

Adaptive behavior, Thermal comfort, Tropical climate

### **INTRODUCTION**

In the past twenty years, the percentage of household in Singapore which installed Air-Conditioner (AC) unit, has increased significantly from only 7.8 % in 1978 to 57.7% in 1998 (Singstat 2000). The increment of AC availability more than seven times indicates an interesting phenomenon of how a higher standard of living requires a better comfortability in living environment. To do so, the occupants actually play active roles in ensuring their living environment is as comfortable as possible. In comparison with other buildings such as offices, occupants in residential NVB have more freedom to control their environment in the form of clothing adjustments, taking bath more frequently, getting more drink, opening windows, switching on fan or AC etc (Wong NH et.al 2002).

It is rather complicated to comprehend the whole mechanism of human thermal perception and control as well as to provide criteria for thermal comfort assessment in NVB. In some publications, it has been presented that it is unreasonable to apply directly thermal comfort standards developed for mechanically controlled (AC) buildings to NVB (Fountain et.al 1996, Brager et.al 2000). Firstly, this inapplicability is due to large differences in environmental controllability. For example, in the tropics, uniformly high air temperature inside and outside spaces and constantly high humidity cannot be modified easily by passive cooling strategies. Secondly, the inapplicability could be due to differential living context which is particularly important in the context of those countries where only a small percentage of buildings are

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equipped with mechanically controlled environmental systems. The present international standards lead to the rather questionable conclusion that the majority of populations in these countries are de facto living in substandard environments (Mahdavi et.al 1996).

The objectives of this study are as follows:

- To evaluate the thermal comfort perception of NVB occupants in tropical region by comparing two countries (Singapore and Indonesia) and for two different seasons (Rainy and Hot season).
- To identify the reciprocal effects of environmental parameters and occupant's behavioral adaptation that affect thermal comfort perception.
- To learn how the prior AC exposure and expectation may play an important role in thermal comfort perception in NVB.

## **METHODS**

The total data of 538 samples from Singapore and 525 data from Indonesia were collected through extensive field survey in the year 2000-2002. For each survey, both objective and subjective measurements were carried out simultaneously. The objective measurements gathered include some personal and environmental parameters that are commonly used for thermal studies (Clothing, Metabolic rate,  $T_a$ ,  $T_g$ , RH,  $V_s$ ). The Class II field research protocol was adopted for this study which required the environmental measurement probes to be placed at one point (1.00 m above floor) nearest to the sitting respondent (Brager et.al 1998).

The subjective measurement adopted includes the seven thermal sensations scale from ASHRAE, comfort perception – Bedford scale, and other relevant perception scales. The respondents were asked to answer the questionnaires, which were relevant to thermal sensation, perception and preference. They were then asked about their preference and adaptive behaviour when they need to maintain thermal comfort in their residence.

The total 1063 data which has been collected need to be grouped according to the seasonal and geographical distribution for the purpose of statistical analysis.

## **RESULTS**

The summary of the objective measurements is shown in Table 1. It is observed that very similar dry bulb and mean radiant temperature have been recorded. Climatic condition in Indonesia had shown substantially lower mean values of wind speed compared to Singapore due to common low rise residential buildings. In the personal parameters, in general, clothing values for Indonesia are higher than the respective value of Singapore. This is due to different culture and dress code (fashion), especially clothing for Moslem women in Indonesia.

Thermal perception analysis based on Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) shows that Indonesia has a higher value (in the warmer perception). In comparison to survey perception votes (SVash and SVbed), the deviation can be as high as 1.81 point for Indonesia and 0.85 point for Singapore. The mean value of survey vote for both thermal perception in ASHRAE scale and comfort in Bedford scale, were found to be lower during rainy season (closer to comfort perception). In term of thermal preference, the climatic condition has played significant role in people votes. About 76-82% of the people prefers cooler environmental condition in the hot season compared to 46-66% that prefer cooler in the rainy season, despite very similar environmental condition between the two seasons.

**Table 1.** Summary of environmental and personal parameters

<b>FACTORS</b>	<b>SINGAPORE RAINY SEASON</b>	<b>SINGAPORE HOT SEASON</b>	<b>INDONESIA RAINY SEASON</b>	<b>INDONESIA HOT SEASON</b>
<b>ENVIRONMENTAL CONDITION</b>				
1. Dry Bulb Air Tmp.	28.5 <sup>0</sup> C 29.7 <sup>0</sup> C	29.7 <sup>0</sup> C 29.9 <sup>0</sup> C	29.2 <sup>0</sup> C 29.6 <sup>0</sup> C	29.8 <sup>0</sup> C 30.7 <sup>0</sup> C
2. Mean Radiant Tmp.	0.29 m/s 75.1%	0.3 m/s 71.2%	0.08 m/s 68.9%	0.07 m/s 68.2%
3. Wind Speed				
4. Relative Humidity				
<b>PERSONAL CONDITION</b>				
1. Clothing	0.26 clo	0.21 clo	0.34 clo	0.27 clo
2. Metabolic rate*	1.2 met	1.2 met	1.2 met	1.2 met
3. Height	164.27 cm	165.21 cm	162.49 cm	160.63 cm
4. Weight	59.25 kg	58.22 kg	55.40 kg	53.79 kg
5. Gender	Male			
=	111 (43.5%) 144 (56.5%) 255	127 (45%) 156 (55%) 283	148 (56.5%) 114 (43.5%) 262	121 (46%) 142 (54%) 263
Female =	50 (19.6%) 80 (31.4%)	47 (16.6%) 137 (48.4%)	63 (24%) 136 (51.9%)	49 (18.6%) 121 (46%)
Total =	30 (11.8%)	12 (4.2%)	22 (8.4%)	33 (12.6%)
6. Age	<20			
	21	21	21	21
	52 (20.4%)	42 (14.8%)	17 (7.3%)	29 (11%)
- 30				
	31			
- 40				
	41			
- 50				
>50				
<i>*Note: Metabolic rate is maintained at the level of common sedentary domestic work with a value of 1.2 met.</i>				
<b>VOTE ANALYSIS</b>				
1. Thermal Perception	PMV = 0.87 PPD = 26.15 SMVash = Survey Mean Vote	PMV = 1.17 PPD = 38.13 SMVash = 0.66 SMVbed = 0.68	PMV = 1.73 PPD = 48.21 SMVash = - 0.08 SMVbed = 0.33	PMV = 1.703 PPD = 60.88 SMVash = 0.92 SMVbed = 0.91
2. Thermal Preference (Mc Intyre scale)	120 (46.9%) 130 (50.8%) Cooler 5 (2%) No	217 (76.7%) 64 (22.6%) 2 (0.7%)	173 (66%) 73 (27.9%) 16 (6.1%)	216 (82.1%) 41 (15.6%) 6 (2.3%)
Change				
Warmer				

Further analysis of the thermal acceptability is shown in Figure 1. Using the ASHRAE and Bedford scale, the data was classified as unacceptably cold (for vote -3, -2), acceptable (for vote -1,0,+1) and unacceptably hot (for +2,+3). In general, the thermal acceptability was found to be higher for the rainy season. The lower temperature and relatively high relative humidity probably cause people to perceive the environment as more thermally comfortable.

If the current standards such as ASHRAE 55-1992 and ISO 7730, which specify acceptable limit of 80% are used, it is found that only Singapore (Rainy and Hot season) and Indonesia (Hot season) in Bedford scale (denoted by \*) exceeded the limit. For both countries, thermal acceptability analysis based on ASHRAE scale (thermal sensation) was consistently lower as compared to Bedford scale (comfort perception). This could be due to non-physiological factors such as adaptive behavior and human psychological perception, which will be discussed in more details later in this paper.

The thermal acceptability in Indonesia for both seasons and scales are always lower than that of Singapore. The possible reason was due to the lower wind speeds (mean value of only 0.07 and 0.08 m/s) and hotter thermal condition during the survey in Indonesia. Taking PMV and PPD as the indication, it shows that in Indonesia, PMV and PPD go beyond the comfort requirements (PMV above 1.7 and PPD around 48-61%). Taking a further look into the figure, surprisingly during the rainy season in Indonesia, higher percentage of people actually experienced unacceptably cold rather than unacceptably hot (bar chart IR in Figure 1).

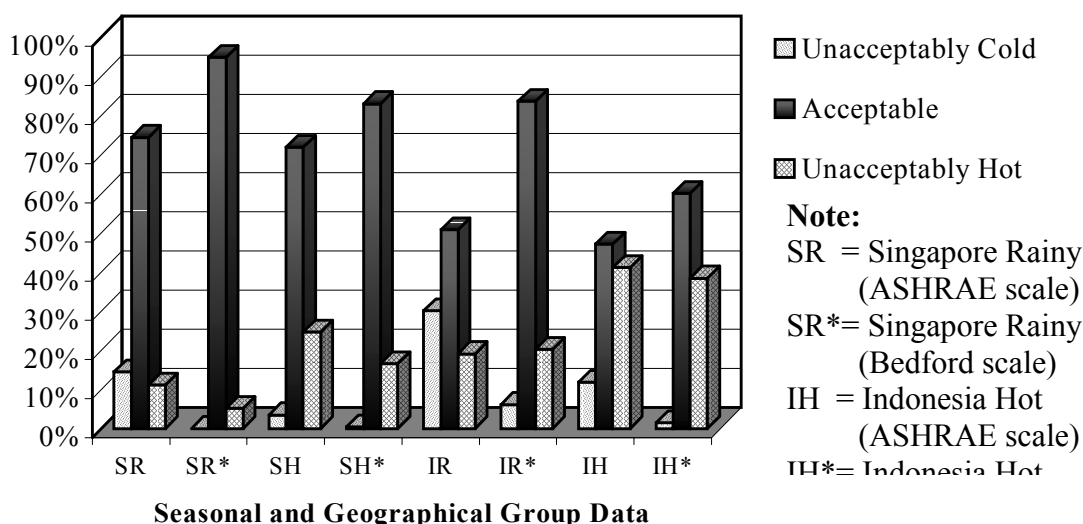


Figure 1. Analysis on Thermal Acceptability based on ASHRAE and Bedford scale

**DISCUSSION**

To further analyze the comfort temperature preferred by the respondents during the survey, linear regression with confidence limit of 95% on the survey vote and operative temperature was applied (see Figure 2). The graph shows that the Neutral Temperature (comfort) for Rainy season is shifted into higher temperature (28.9<sup>0</sup> and 29.7<sup>0</sup> C) compared to the Hot season. This finding is slightly higher than the results of previous thermal comfort study of NVB in Singapore which showed neutral temperature at 28.5<sup>0</sup> C (De Dear et.al 1991) and survey result in Bangkok which was found to be 27.4<sup>0</sup> C (Busch 1992). In most cases, thermal perception vote never goes beyond a maximum value of +2 (warm sensation) even though the operative temperature can be as high as 33<sup>0</sup> C.

To further analyze the comfort temperature preferred by the respondents during the survey,



simply shift up the prediction of PMV into more accurate thermal comfort prediction for NVB. This analysis showed that even in one country but in different AC exposure group and season, the prediction gave different results.

In the future research it is important to investigate further the dynamic relationship of thermal comfort perception and adaptive behavior (include how to control the thermal condition). The justification on the thermal comfort, which is influenced by subjective factors such as previous expectation, preference etc, will be investigated. It is believed that thermal perception is not based on the discrete human cognitive process but rather similar to accumulative process. If the person is dissatisfied with the uncomfortable condition, they take some regulative (corrective) actions, which can be classified in general as personal (taking drink, changing clothing) and environmental adjustments (opening windows, switching on fan, AC etc).

If similar thermal condition occurs everyday (or within certain cycle of time), the occupants adjustment become their habitual actions which gradually lead to what is called adaptation. If it can create effectively more comfortable conditions, positive adaptation input is sent to the human personal perception knowledge. If it fails to provide comfort, it exaggerates into negative adaptation input. The uncomfortable thermal experiences are store in human cognitive process and expectation. When occupant encounters a similar thermal environment in the future, she/he has already a certain perception and thus affects her/his expectation. This understanding gives possible explanation on why thermal acceptability measured in Bedford scale (comfort perception) was higher compared to ASHRAE scale (Figure 1). Thermal comfort acceptability is closely linked to the ability of the occupant to modify (control) their environmental condition.

## CONCLUSION

Undoubtedly, adaptive behavior and psychological factors play an important part in thermal comfort perception for NVB. The main challenge for further research is to quantify these factors into simple and more accurate thermal comfort modeling. The expectation factor needs to consider not only the previous AC exposure but also the ability to control the environment in the form of personal and environmental adjustment. Finally, the finding is expected to spur the effort to explore and develop more occupant centred strategies that may contribute to social and environment benefits, reducing energy consumption and increasing occupants' satisfaction (Brager et.al 2000).

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