Thermal Comfort and Acceptability in Offices in Japan and India: A Comparative Analysis

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India's building energy consumption increased rapidly. Fukushima disaster reshaped Japan's energy perspective. Adaptive comfort standards need to be developed for these countries. We conducted a fourteen month thermal comfort survey in India and a summer season study in Japan. This data was analyzed to develop an algorithm to predict thermal acceptability (TA). A direct question resulted in higher TA, than otherwise in Japan, perhaps due to deep rooted cultural ethos. This trend is reversed in India. At 24 – 30 °C and at 27 – 28 °C of indoor temperature, 80 % thermal acceptability could be achieved in Japan and India respectively.

1. Introduction

After the Fukushima meltdown, Japan's energy perspective is undergoing a paradigm shift. Japan implemented '*setsuden*' (energy saving) measures for large electricity reductions, leading to 1.4% building reduction per year [1]. Tanabe et al. [2] discussed the occupant satisfaction and Indraganti et al. [3] the thermal comfort in offices under the *setsuden* conditions.

On the other hand, India's building energy consumption increased by about 3% per annum. It was 196.04 Mtoe in 2011, of which heating ventilation and air conditioning (HVAC) and lighting contributed a major portion [4]. Moreover, India has a serious energy deficit and it is essential for its building sector to adopt non- energy intensive systems. India and Japan do not have adaptive comfort standards [5]. The current codes in India [5] advocate narrow and uniform temperature ranges, leading to overcooling and wastage.

Arens et al. [6] found that the precisely controlled thermal environments of ASHRAE's (American Society of Heating, Refrigerating and Air-Conditioning Engineers) [7] 'Class A' buildings were undesirable and impractical, offering no improved satisfaction to the users, when compared to the Class B or C buildings. Similarly, de Dear et al. [8] noted the subjects under much lesser discomfort in naturally ventilated apartments in Singapore, even when the indoors were warmer than the standard prescriptions by about 3 K.

Therefore thermal comfort is not a temperature set point. Being a complex adaptive system, the equilibrium can be achieved under several combinations of variables. Thermal comfort is indispensable for user satisfaction which in turn decides the way a building is used, maintained and sold. Thermal acceptability is often used as a metric to assess user satisfaction. The ASHRAE Std-55 [7] mentions thermal acceptability as '*the condition where 80% of the occupants vote within the three central categories on the seven point thermal sensation scale*.' Researchers often record thermal acceptability (TA) through a direct question [9,10,11]. However, thermal acceptability is quite a controversial construct as it can also be assessed with respect to many other comfort scales like thermal sensation (TS), and overall comfort (OC). Several physiological and psychological factors like sweating, expectation levels, thermal history, and others like adaptive opportunities contribute to this [12]. Baker and Standeven [13] even strongly argue that the pursuit of strict temperature standards is an inappropriate goal to achieve acceptance in buildings.

Therefore, more important than thermal sensation is the question of how a given change in the environment would affect thermal acceptability of a space or modify the percentage of persons dissatisfied within a room [14]. Many researchers found evidence that neutrality was not primarily ideal for a significant number of people and that the temperatures beyond the central three categories were judged satisfactory [12]. Thus, procedures to evaluate and estimate the integrated feelings of the users have to be established.

Therefore, this paper makes use of two field study data [10,3] and aims to (1) propose a method to predict the thermal acceptability in offices in India and Japan using logistic regression and (2) compare and discuss thermal acceptability metrics derived through various thermal comfort scales.

2. Methods

2.1 Survey areas

Hyderabad (N17°27' and E78° 28') has composite climate and Chennai (N13°04' and E80° 17') has warm humid wet land coastal climate. These have four distinct seasons: summer, monsoon, post monsoon and winter. The survey was conducted for 14 months in 2012- 13 in 28 office buildings. We undertook another survey in four office buildings (83 office spaces) in Tokyo (N35°41' and E39° 41'), for 3 m in summer 2012 (Fig. 1). Both were paper based surveys in naturally ventilated (NV) and air conditioned (AC) environments.

Figure- 1. (1) The instrument setup (2) The survey environments in India and Japan (A) Thermo-hygometer (TR 76Ui) (B) Anemometer (Testo 405 and Kanomax) (C) Globe thermometer (Tr-52i)

In India we collected 6042 sets of data from 2787 office occupants and in Japan 2402 sets from 435 subjects. About 22% and 18% of the data was collected in NV mode in India and Japan respectively.

Table- 1 Details of the thermal scales used **[7,9]**

Thermal Sensation	Overall comfort	Thermal acceptability
Hot (3)	Very comfortable (1)	
Warm (2)	Moderately comfortable (2)	
Slightly Warm (1)	Slightly comfortable (3)	Unacceptable (1)
Neutral (0)	Slightly uncomfortable (4)	Acceptable (0)
Slightly cool (-1)	Moderately uncomfortable(5)	
Cool (-2)	Very uncomfortable (6)	
Cold (-3)		

The questionnaires included direct thermal enquiries on sensation, preference, acceptability and overall comfort (Table 1) [3,15]. The surveyors noted down the use of environmental controls, clothing and activity. Simultaneously while the occupants responded, we recorded all the four environmental variables: air and globe temperatures, (T_a and T_g) air movement (V_a) and relative humidity (RH) using standard protocols [7]. Females constituted about 1/4th and 1/3rd of the sample in India and Japan respectively. The subjects' age ranged between 20 – 70 yrs. We interviewed the respondents once or twice, and a dozen times a month in India and Japan respectively. Methods are detailed in Indraganti et al. [3,10].

3. Results and discussion

3.1 Thermal conditions and comfort responses

The indoor and outdoor conditions in India were warm throughout the survey, and in summer very humid as well, much similar to the Tokyo summer (Table 2). Winters in India were very mild. Therefore, it makes the data tenable for comparison. We obtained the outdoor mean temperature (T_{om}) for all the days of the survey from the local meteorological data and estimated the outdoor running mean temperature (T_{rm}).

The majority voted towards the central band of the sensation scale in both India and Japan as shown in Fig. 2. However, in NV mode, a higher percentage voted on the warmer side of the sensation scale throughout. In Japan, Mean sensation in NV mode was 1.17 (SD = 1.3) and AC mode was 0.24 (SD = 1.2). Tanabe et al. [2] noted greater variability in TS in Japan. They found it varying between -0.7 (SD = 1.1) to 2.0 (SD = 1.3).

Table- 2 Mean and Standard Deviation of the indoor and outdoor thermal variables in NV and AC modes (IN: India, JP: Japan)

T_g		RH		V_a		T_{om}		T_{comf}	
IN	JP	IN	JP	IN	JP	IN	JP	IN	JP
28.8	29.4	44.7	52.6	0.17	0.20	25.5	25.9	28.0	27.0
2.0	1.6	11.7	6.4	0.25	0.15	3.0	2.2	2.6	2.5
26.2	27.9	48.2	50.8	0.11	0.25	28.4	28.0	28.0	26.4
1.6	1.2	9.3	4.4	0.17	0.16	3.4	1.7	2.6.	2.8

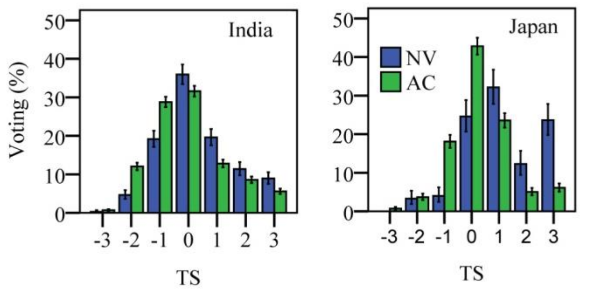


Figure- 2. Distribution of thermal sensation vote in India and Japan (error bars indicate 95% confidence interval)

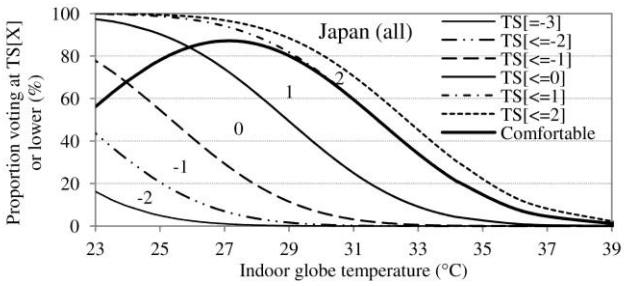


Figure- 3. Probit curves indicating subjects voting at a TS scale point or lower and the proportion comfortable (-1 to +1) (Japan all data)

From Figure 3 we can observe that when the indoor temperature was around 29 °C, 80% subjects vote comfortable (voting on TS -1 to +1). Also, at temperatures higher than this, the proportion voting comfortable rapidly plummets. Similar phenomenon was observed on Indian data also.

3.2 Comfort temperature

The TS and T_g varied with each other significantly in Japan and in India. However, in Japan the modal difference was not significant. TS varied with T_g at a gradient of 0.33 K^{-1} in both the modes in Japan. Using this relationship, we noted a regression neutral temperature of 25.4 °C and 26.8 °C in NV and AC modes respectively for Tokyo in summer. Using 0.5 as the Griffith's coefficient we estimated the comfort temperature (T_{comf}) for all the data sets [16,10,3]. Table 2 features these values. Interestingly, comfort temperatures in Indian offices are similar to those of Tokyo in summer. We noted a significant adaptive relationship between the outdoor running mean and indoor comfort temperatures. For ex., in AC environments, the rate of change of comfort temperature with respect to the outdoor running mean temperature was 0.10 K^{-1} in Japan and 0.15 K^{-1} in India, coming close to 0.09 K^{-1} of Europe [17,10].

3.3 Thermal acceptability (TA)

We measured thermal acceptability using a direct question (0: acceptable; 1: Unacceptable). Two indirect acceptability binary scales were derived from TS and OC: voting comfortable on TS and OC scales as acceptable (a) (TAind = 0), and (b) (Comfort Acceptance: CA = 0) respectively, and vice versa [18]. Table 3 shows the mean non-acceptability as measured through these scales.

Table- 3 Mean thermal non-acceptability (%)

	India				Japan			
Mode	N	TA	TAind	CA	N	TA	TAind	CA
NV	1273	28	25	23	423	24	39	57
AC	3936	29	27	19	1979	8	16	29
All	6048	30	27	20	2042	11	19	34

Interestingly in India, a direct enquiry (TA) resulted in lower acceptance while indirect estimates gave higher acceptability respectively (TAind and CA). This contrasts the Japanese pattern of voting, perhaps due to innate Japanese cultural ethos.

Comparing the performance of the direct and proxy acceptability scales revealed various nuances of these scales. The indirect questions also perhaps related to some physiological conditions while in a direct question, psychological factors overrode these, resulting in subjects' lower acceptance in India. In Japan the modal differences in acceptability were not significant, while they were, in India.

3.4 An algorithm to predict thermal acceptability

Logistic regression best suits the analysis of binary data such as TA, TAind and CA, probability of which varies with a stimulus such as T_g. Logistic regression of thermal non-acceptance was done with indoor globe temperature. This relationship is governed by the logit relationship:

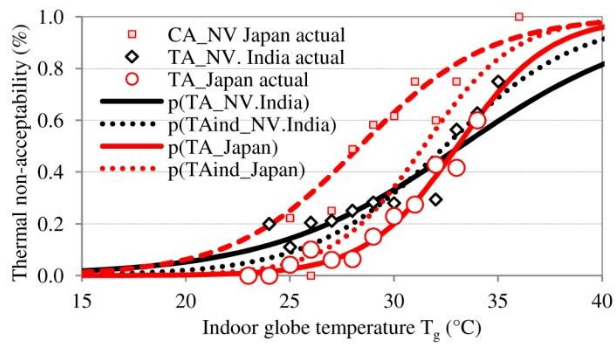
$$\text{Logit}\,(p) = \log\,(p/(1-p)) = bT+c \qquad (1)$$

Whence

$$p = e^{(bT+c)}/(1+e^{(bT+c)}) \qquad (2)$$

Where,

p is the probability that the environment is unacceptable, T is the temperature (in this case indoor globe temperature), b is the regression coefficient for T and c is the constant in the regression equation.



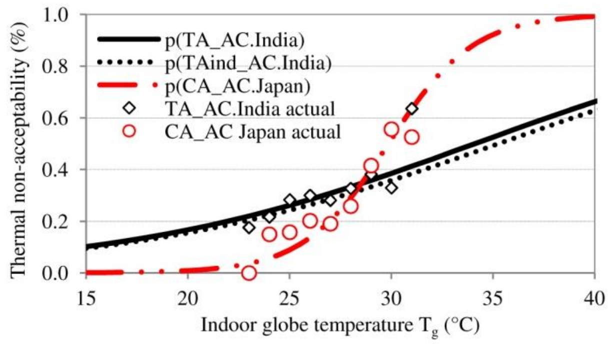


Figure- 4. Logistic regression of various metrics of acceptability with indoor globe temperature for India and Japan

Table- 4 Logistic regression analysis for acceptability (p<0.001)

No.	Case	Equation	$R^2_{(Negelkerke)}$
3	TA_Japan	$\text{logit}(p) = 0.454\,T_g - 15.007$	0.07
4	TAind_Japan	$\text{logit}(p) = 0.459\,T_g - 14.431$	0.08
5	CA_NV.Japan	$\text{logit}(p) = 0.325\,Tg - 9.222$	0.07
6	CA_AC.Japan	$\text{logit}(p) = 0.480\,T_g - 14.334$	0.07
7	TA_NV.India	$\text{logit}(p) = 0.218\,T_g - 7.241$	0.06
8	TAind_NV.India	$\text{logit}(p) = 0.310\,T_g - 10.063$	0.01
9	TA_AC.India	$\text{logit}(p) = 0.114\,T_g - 3.888$	0.11
10	TAind_AC.India	$\text{logit}(p) = 0.111\,T_g - 3.913$	0.01

The results of the logistic regression with direct acceptability (TA), indirect acceptability (TAind) and overall comfort acceptance (CA) are shown in Fig. 4 and Table 4. The actual proportion of acceptability at various temperature bins is also super-imposed on these curves. The actual data matched very closely with the logistic regression lines. The slope of the regression lines in AC mode in India is much lower. It perhaps indicates many other non-thermal factors influencing acceptability. Some of these could be frequent outages, inadequate access to environmental controls as noted [15].

Using these curves, we can predict 80% acceptability in Japan (1) through a direct question at 30 °C, and (2) at 24 – 28 °C in NV and AC modes with indirect scales. On the other hand in

India in NV mode, 80% acceptability could be predicted with a direct question, when the indoor temperature is at 27 °C. An indirect enquiry would yield same at 28 °C. The temperature ranges for 80% acceptability obtained here are very close to the comfort temperature reported in Table 2. Importantly these are much are higher than the ranges specified in the standards [5]. Likewise, de Dear and Brager [18] found little resemblance between the actual levels of acceptability expressed by the subjects and those specified in the ASHRAE Standard 55-92. Arens et al. [6] also noted no major variation in the acceptability outcomes of three different classes of buildings with varying levels of predicted mean vote (PMV) ranges of (-0.2 to + 07). Therefore it may not be prudent to overdesign the systems to meet with the stringent narrow temperature standards.

Brager and de Dear [19] demonstrated that people who were exposed to a narrow range of temperatures (mostly through HVAC systems) developed high expectations for homogeneity and cool temperatures, and were soon critical of the subsequent thermal migrations indoors. Contrastingly, they noted occupants of NV buildings appearing tolerant of – and in fact preferring wider thermo-hygro regimes, as also noted by Mallick [20] and in this study (NV in India).

4. Conclusions

The direct enquiry on thermal acceptability yielded higher acceptability in Japan and lower in India than the indirect methods of assessing acceptability. Logistic regression predicted 80% acceptability in Japan at indoor temperatures of 24 – 30 °C and at 27 – 28 °C in NV mode and at 22 – 23 °C in AC mode in India. Frequent outages, access to controls also could have affected the acceptability in AC mode in India.

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