Thermal Comfort in Offices in India: Behavioral Adaptation and the Effect of Age and Gender

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ABSTRACT

Reports on occupant’s behavioral adaptation in India are limited in the literature. We analyzed the data from a recent thermal comfort field study of office buildings in two capital cities of Chennai and Hyderabad in India. Behavioral adaptation formed a key mechanism contributing to the subject’s thermal comfort and user satisfaction in buildings. In mixed mode (MM) buildings, use of AC and/or fan during temperature excursions proved to be an important and power saving adaptation. We present the logistic algorithms to predict the use of ACs and fans in MM buildings. Females, young subjects, and thin people had statistically significant and higher comfort temperature than males, older people, and obese occupants respectively. Females accepted the environments better. These findings might determine the design direction of future indoor environments. The occupants have undertaken several behavioral control actions throughout the year without many seasonal differences. Staying in airy place, drinking beverages, changing posture, and avoiding direct sunlight were the most prominent actions.

INTRODUCTION

Human existence hinges on thermal adaptation. In order to maintain the deep body temperature at 37 °C at all times, human beings adapt continuously. The adaptations are mainly physiological, psychological, environmental, and behavioral. Controlled by hypothalamus, physiological vasomotor regulation happens almost instantly. Human-envelop interaction greatly influences environmental and behavioral adaptation in buildings. This in turn also affects thermal satisfaction and energy consumption in them (Nicol & Humphreys, 2004; Brager, et al., 2004). Environmental adaptation by using various controls results in energy saving (Brager & Baker, 2009).

India’s building energy consumption increased by about 3% per annum. It was 196.04 Million ton of oil equivalent in 2011, of which lighting, heating, ventilation, and air-conditioning constituted a major portion (IEA, 2011). India has an ever-widening energy supply-demand gap (Central Electricity Planning Authority, India, 2012). South India faces the maximum energy deficit of close to 30 %. Moreover, India is yet to have custom made adaptive thermal comfort standards. Recent research in Indian buildings proved that occupants in Indian buildings expressed comfort at much higher temperatures than expected (Indraganti, et al., 2014; Indraganti, 2010; Deb & Ramachandraiah, 2010; Dhaka, et al., 2013; Honnekiri, et al., 2014). Researchers attributed this to a wide range of adaptations in some of the studies. Understandably, mixed mode buildings with adaptive use of air-conditioners consume much lower energy than compared to the buildings air-conditioned throughout their active life.
Indraganti (Indraganti, 2010a) reported the behavioral and occupant adaptation in apartments in India. Occupant adaptation with fans and windows and obstacles to adaptation in Indian offices were presented in Indraganti et al., (Indraganti, et al., 2014a). Others studied the mixed mode buildings for adaptation in summer (Honnekiri, et al., 2014). However, occupants undertake several behavioral control actions besides the operation of environmental controls in offices. They need investigation.

Sixty five percent of India’s population is below 65 yrs. This gives it a rich demographic dividend (Basu, 2007). It particularly means that, India would have young population in the work environments and more women than is it now. Thermal necessities of this young group would be major drivers for design decisions in the future. Indian offices have about 25% female occupants now (Indraganti, et al., 2014). Researchers noted that occupant’s age, body constitution, and gender influenced their comfort perceptions in both homes and offices (Indraganti & Rao, 2010; Karyono, 2000; Fanger, 1970). For improving thermal satisfaction in buildings, we need to understand them.

Therefore, this paper aims to explain the effect of age, body constitution, and gender on thermal comfort and highlights the user behavior in undertaking various adaptive control actions in offices in India. We also aim to develop algorithms to predict the use of air conditioners and fans in mixed mode offices. For this study, we use the long-term thermal comfort field study data obtained from offices in India (Indraganti, et al., 2014).

METHODS AND FIELD SURVEY

We conducted a thermal comfort field survey in 28 office buildings from 01-2012 to 02-2013. It was in two State Capitals: Chennai (N13°04’ and E80° 17’ ) and Hyderabad (N17°27’ and E78° 28’) with warm humid wet land coastal climate and composite climates respectively. These have four distinct seasons: summer, Southwest monsoon (SWM), Northeast monsoon (NEM) and winter. The surveys were paper based surveys. About 2787 occupants gave 6042 datasets. In all the offices close to the subjects at 1.1m level from the ground, we measured the indoor air temperature ($T_a$), globe temperature ($T_g$), air velocity ($V_a$), and relative humidity, while they filled in the questionnaires (Fig.1). High precision digital instruments and standard protocols were used with accuracies: thermometers: ±0.5 °C, hygrometer: ±5%, anemometer: ± 0.01 m/s. We spaced the surveys at four to six weeks.

Figure 1   (1) The instrument setup, (A) Thermo-hygro meter (TR 76Ui), (B) Hot-wire anemometer (Testo 405) (C) Globe thermometer (TR 52i), (2, 3) Typical survey environments

The Survey Questionnaire

The questionnaire had three sections: (1) personal identifiers, (2) thermal responses and (3) Behavioral control actions undertaken (McCartney & Nicol, 2002). While the survey was going on, the interviewers noted down their clothing ($I_{cl_tot}$), activity (Met) and the personal environmental controls in use in that space. Thermal responses included standard questions on thermal sensation (TS); preference (TP); acceptability (TA); and sensation and preference for other environmental parameters. Indraganti et al. elaborated the methods and questionnaires (Indraganti, et al., 2014). We measured TS with ASHRAE’s seven point scale having: cold (-3); cool (-2); slightly cool (-1); neutral (0); slightly warm (1); warm (2); and hot (3) and TA through a direct question with 0: acceptable; and 1: Unacceptable.

THE SUBJECT AND BUILDING SAMPLE

The occupants were in the age group of 18-70 years and were associated with the environments for
longer than three months. The age and gender profile of the subjects was similar in both the cities as shown in Fig. 2. Women constituted about 21 – 25 % of the sample. Majority of the subjects were in 25-35 years age group.

![Figure 2](image)

**Figure 2** Age and gender profile of the subjects in the survey (M: Male; F: Female)

**Building Types and Modes of Operation**

We surveyed fourteen buildings in each city. These are of three types: (1) fully naturally ventilated, (2) mixed mode (MM) and (3) air-conditioned throughout (ACall). We had thirteen MM buildings, fourteen ACall buildings and one NV building. Of the total 6048 sets of data, 3804 came from the ACall and 2212 were from the MM buildings.

We collected thermal responses from the subjects when the buildings were operated in naturally ventilated (NV) mode and air-conditioned (AC) mode in all the buildings. However, due to frequent power outages, in some ACall buildings, AC was switched-off during an outage and the building was not run NV mode either. Data collected in ACall buildings with AC switched off is termed as ACoff. About 10 % of the data was collected in ACoff mode. We used the data collected in NV and AC modes here.

<table>
<thead>
<tr>
<th></th>
<th>C: Chennai</th>
<th>H: Hyderabad</th>
<th>All: Mean</th>
<th>SD</th>
<th>C: Chennai</th>
<th>H: Hyderabad</th>
<th>All: Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_o$ (°C)</td>
<td>26.9</td>
<td>25.4</td>
<td>25.5</td>
<td>3.0</td>
<td>28.9</td>
<td>27.5</td>
<td>28.4</td>
<td>3.4</td>
</tr>
<tr>
<td>$T_a$ (°C)</td>
<td>29.7</td>
<td>29.0</td>
<td>29.1</td>
<td>1.9</td>
<td>26.5</td>
<td>26.1</td>
<td>26.3</td>
<td>1.6</td>
</tr>
<tr>
<td>$T_g$ (°C)</td>
<td>29.5</td>
<td>28.7</td>
<td>28.8</td>
<td>2.0</td>
<td>26.7</td>
<td>25.6</td>
<td>26.2</td>
<td>1.7</td>
</tr>
<tr>
<td>$V_a$ (m/s)</td>
<td>0.46</td>
<td>0.13</td>
<td>0.17</td>
<td>0.25</td>
<td>0.15</td>
<td>0.05</td>
<td>0.11</td>
<td>0.17</td>
</tr>
<tr>
<td>RH (%)</td>
<td>59.7</td>
<td>43.1</td>
<td>44.7</td>
<td>11.7</td>
<td>50.1</td>
<td>45.6</td>
<td>48.2</td>
<td>9.3</td>
</tr>
<tr>
<td>$I_{cl,\text{tot}}$ (clo)</td>
<td>0.69</td>
<td>0.08</td>
<td>0.70</td>
<td>0.08</td>
<td>0.71</td>
<td>0.09</td>
<td>0.70</td>
<td>0.08</td>
</tr>
<tr>
<td>Met (met)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Table 1. Descriptive statistics of outdoor and indoor environmental variables**

C: Chennai; H: Hyderabad; SD: Standard deviation

**RESULTS AND DISCUSSION**

**OUTDOOR AND INDOOR ENVIRONMENTS**

![Figure 3](image)

**Figure 3** (a) Field survey data superimposed on the psychrometric chart; (b) Intercity variation in $T_a$; (c) Modal variation in mean $T_g$ when subjects voted on TA scale. Error bars indicate 95% CI.

Outdoors were hot in summer and warm through the rest of the survey. Being a coastal city
Chennai was more humid throughout, and Hyderabad was humid in monsoon seasons. We obtained outdoor daily mean temperature ($T_o$) data from meteorological records. Chennai indoors were significantly warmer and more humid than Hyderabad at 95% confidence interval (CI). All declarations are at 95% CI unless otherwise specified explicitly. Interestingly, we recorded 80% of the data in NV and AC modes when $T_g$ was less than 29.8 and 27.5 °C and $V_a$ was around 0.25 m/s and 0.15 m/s respectively. About 70% and 77% environments in NV and AC modes had humidity ratio ($W_v$) less than 12 g/a/kg da, the upper limit suggested in ASHRAE Std-55 (Fig.3, Table 1) (ASHRAE, 2010; Indraganti, et al., 2014). Occupants achieved indoor air movement primarily by using the common fans and through the operation of openings in addition, in NV mode. A few AC offices in Hyderabad did not have fans however. Women had slightly but significantly higher $I_{ct,tot}$ than men did ($N = 6048$, $p < 0.001$).

**SUBJECTIVE THERMAL RESPONSES**

Fig.4 shows the probit lines of proportion voting on a given TS scale point (X) or lower against $T_g$. It also shows the probits for the proportion voting comfortable (-1 ≤ TS ≤ 1) and juxtaposed with the actual proportion comfortable. From these we can observe that in NV mode, 80% subjects voted in the central three categories on TS when 25.6 ≤ $T_g$ ≤ 28.1 °C.

![Figure 4: Probit lines indicating the percentage voting at a given TS scale point (X) and lower on $T_g$ in NV and AC modes in India. Also shown are the probits for the proportion voting comfortable (-1 ≤ TS ≤ 1) at each 1 K bin of $T_g$. X: Scale value of TS](image)

Thermal acceptability remained the same at around 72 - 71% in both NV and AC modes. Interestingly occupants accepted the NV environments at 28.5 °C ($T_g$-mean) and in AC at 26.2 °C. (Fig. 3b,c) It may be possible that in AC environments, subjects’ acclimatization to the narrower thermal regime perhaps had influenced the TA outcome. Brager and de Dear (Brager & de Dear, 2000) demonstrated that people who were exposed to a small 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.

**EFFECT OF GENDER, AGE, BODY FAT ON THERMAL ACCEPTABILITY AND COMFORT TEMPERATURE**

![Figure 5: (a) Mean $T_{comf}$ significantly varying with gender, body constitution, and age group; The](image)
error bars indicate 95% CI. (b) Logistic regression $T_g$ and TA for both the genders ($p<0.001$). Actual data are superimposed. More men were critical of an environment than women were.

We estimated the comfort temperature ($T_{comf}$) using the Griffith’s method taking 0.5 as the coefficient, similar to others (Griffiths, 1990; Humphreys, et al., 2013). The comfort temperature varied with the outdoor temperature. Mean $T_{comf}$ in NV mode was 28 °C and in AC was 26.4 °C. Notably, women had higher comfort temperature than men (Fig. 5). Similarly, subjects younger than 25 years old had higher $T_{comf}$ than the older group. At normal activity (1.0 met) and at common indoor clothing ($Ict_{tot} \leq 0.7 \text{ clo}$), we noted women having 0.6 K higher $T_{comf}$ than men did. It equaled a sensation scale value of 0.22, ($N = 3239$, $p<0.001$).

Conversely, Parsons (Parsons, 2002) recorded no gender differences in thermal comfort for the same Met and $Ict_{tot}$. In this context, it is important to note that females in India are mostly (99%) dressed in loose fitting Indian attires, with much better scope for thermal adaptation (Indraganti, et al., 2014). This in part explains higher $T_{comf}$ of women. A Finnish experiment, found TA in females significantly lesser than males. He attributed this in part to the unawareness about the thermostat and HVAC systems (Karjalainen, 2007).

The mean temperature where younger subjects accepted the environment was higher than that of their older counterparts. Women also accepted the environment better. For example, at 32 °C the acceptability among women was about 10.6 % higher as seen in Fig. 5b. We noted a similar trend between the two age groups. Researchers in Indonesia found men feeling warmer than women in offices (Karyono, 2000), unlike the Fanger’s experiment on American and Danish subjects where there were no significant gender differences in comfort sensation (Fanger, 1970). This is despite the fact that women (mean 0.78 clo) had significantly higher clothing insulation than men (mean 0.68 clo) in India ($N = 6048$, $p<0.001$).

Thin subjects (body mass index (BMI) < 18.5 kg/m$^2$) (WHO, 2004) recorded comfort at 27.1°C while fat people (BMI > 25 kg/ m$^2$) expressed comfort at 0.7 K lesser (Fig 5a). Karyono also noted the same 0.7 K difference ($N = 3865$, $p < 0.001$), while Fanger recorded 0.26 K difference between thin and fat college age subjects (Karyono, 2000; Fanger, 1970). However, we found no statistically significant differences in acceptability among thin and fat people.

**ALGORITHM TO PREDICT THE USE OF CONTROLS IN MM BUILDINGS: AC AND FAN**

In the era of power outages and expensive energy tariffs, mixed mode buildings with AC usage limited to the overheated periods come as a welcome respite. As the outdoor conditions became warmer, occupants adopted through ACs in mixed mode offices: for ex. during the mid-day and in summer and monsoon seasons. It formed an important adaptation strategy in addition to the use of fans. Use of AC in Chennai MM buildings was 82% (mean) while in Hyderabad MM, it was 20%. Chennai has very hot and humid climate, which could have triggered higher AC use. On the other hand, fan usage was much higher in Hyderabad MM. It was 78%, as against 43% in Chennai MM. Interestingly; in Chennai ACall buildings, we noted 20% fan usage, while ACall in Hyderabad had very few fans available.

**Figure 6** Logistic regression with outdoor daily mean temperature showing the proportion of (a) AC use in MM buildings in Chennai and Hyderabad; (b) fan use in ACall and MM buildings in Chennai
(C) and Hyderabad (H). Also shown juxtaposed are the actual proportions in 1K bins of $T_o$. For all the equations $p<0.001$, and slopes are significantly different at 95% CI.

The surveys provided binary data on the use of various environmental controls. We then applied the logistic regression on the ‘control usage’ against its stimulus (i.e. temperature) to develop the algorithm (Nicol, 2001; Rijal, et al., 2008). It yielded the following equations as shown in Table 2 and Fig. 6, where $p$ is the probability of a control in use and $T_o$ is the outdoor daily mean temperature.

<table>
<thead>
<tr>
<th>Control</th>
<th>Case</th>
<th>Equation</th>
<th>Sample size</th>
<th>Negelekerke $R^2$</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC C: MM</td>
<td>$\logit(p) = 0.30 T_o - 6.86$</td>
<td>723</td>
<td>0.134</td>
<td>0.043</td>
<td></td>
</tr>
<tr>
<td>H: MM</td>
<td>$\logit(p) = 0.35 T_o - 10.93$</td>
<td>1489</td>
<td>0.394</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Fan C: ACall</td>
<td>$\logit(p) = 0.59 T_o - 17.62$</td>
<td>1389</td>
<td>0.264</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>C: MM</td>
<td>$\logit(p) = 0.75 T_o - 20.89$</td>
<td>672</td>
<td>0.300</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>H: MM</td>
<td>$\logit(p) = 0.51 T_o - 13.07$</td>
<td>1356</td>
<td>0.143</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

Logit($p$): Probability of a control being in use

From these equations, we can estimate that 89.4% and 28.5% ACs would be in operation when the $T_o$ is at 29 °C for MM buildings of Chennai and Hyderabad respectively. Higher AC use in Chennai is perhaps due to its warmer thermo-hygro regime. Similarly, at $T_o$ of 29 °C, nearly 40%, 68% and 85% fans would be on in Chennai-ACall, Chennai-MM, and Hyderabad MM buildings. Rijal et al. noted 81% fans on at 29 °C in Pakistan (Rijal, et al., 2008). It is important to note that in mixed mode buildings of Hyderabad, subjects have made use of the fans more than the ACs, making great energy dividends.

**ADAPTATION THROUGH BEHAVIORAL CONTROL ACTIONS**

Occupants in real environments continuously adapt through various behavioral control actions. These vary with the thermal stimuli and happen in immediate response to the stimuli, throughout the day and year. These can vary with season. Therefore, we included a multitude of behavioral actions listed in Fig. 7 in the questionnaire. In all the surveys, the subjects chose from the fourteen possible behavioral control actions they must have undertaken during or fifteen minutes prior to the survey (Rijal, et al., 2010). These were noted down as binary data, an action in use: 1 and, not in use: 0. On analysis of the responses, we noted very few seasonal changes in the pattern of behavioral adaptation. Nevertheless, there were slight differences in NV and AC modes, overall.

![Figure 7](image-url) Proportion using various behavioral control actions round the year in both NV and AC modes. *Staying in airy place* is an important behavioral action. Error bars indicate 95% CI of mean.
Among all the adaptive actions, ‘staying in airy place, drinking cold/hot beverages, changing posture’ were most prominent in both NV and AC modes. In addition, in NV mode, occupants also ‘avoided direct sun light, rested, rinsed face and hands and stayed away from heat sources.’ A higher percentage of subjects adapted through behavioral actions in NV mode than in AC mode, possibly due to the warmer conditions in NV. Similarly, subjects in Swiss offices consumed significantly more cool drinks as the temperature went up (Haldi & Robinson, 2008).

As the conditions in the offices continued to be slightly warm throughout the year, the adaptive actions generally used in winter conditions like, ‘stay in a warmer place, move close to direct sunlight, move away from airy places,’ were not used much. The seasonal differences were also not significant. ‘Staying in airy place’ was the most frequent behavioral action in summer (used by about 30 – 21 % in NV and AC modes). More importantly, subjects adopting this action encountered 0.9 K warmer indoor ($T_a$) environments and lower air speeds than otherwise ($N=1487, p < 0.001$). Similarly, mean $T_a$ in AC when people ‘avoided direct sun’ was $\frac{1}{3}$ K higher than otherwise, ($N=4310, p = 0.001$). As we can see, subjects have adopted through these actions and responded to their immediate thermal environment.

Actions like drinking cold and hot beverages and adding/removing clothing/slippers were some of the actions that subjects adopted in both summer and winter over a wide temperature regime. Female occupants predominantly preferred to use extra layers (sweaters or Dupatta/shawls) adaptively when challenged by cold drafts. Indian ensembles like sari and Salwar-Kamiz were much more tenable for adaptation unlike the western outfits of men (Indraganti, et al., 2014). In addition, men had dress code while women had none. Liu et al. also observed season specific clothing adaptation in Chinese workplaces (Liu, et al., 2012). In addition to these, Rijal et al. found subjects taking extra showers and resting in summer in residential areas (Rijal, et al., 2010).

**CONCLUSIONS**

This paper discussed the behavioral adaptation and the effect of age, gender and body constitution on thermal comfort in Indian offices, relying on a recent field study data. The occupants undertook several behavioral control actions throughout the year. In mixed mode (MM) buildings, use of AC during temperature excursions proved to be an important and power saving adaptation. We presented algorithms to predict the AC and fan usage in always air-conditioned (ACall) and MM buildings in Chennai and Hyderabad. Females, thin people and the subjects under 25yrs age group had higher comfort temperature than males, ‘over 25 yrs’ age group and obese people. Women accepted the environments better. All these differences are statistically significant. The engineering significance of these differences may be limited, but these would determine the design direction of indoor environments of the future.

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