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Thermal Adaption and impediments: Findings from a field study in Hyderabad, India

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Abstract

Indian thermal comfort standards specify too narrow temperature ranges. Energy consumption in Indian homes is highest among the Asia Pacific Partnership countries. Literature features little thermal comfort field research from Indian residences.

The author conducted a field study in NV apartments in Hyderabad, in summer and monsoon, involving over 100 occupants in 2008. The analysis returned a comfort temperature of 29.23 °C and the comfort band (26 -32.5°C); way above the Indian standard limits (23- 26 °C). Fanger's PMV grossly overestimated the actual sensation.

The occupants' adaptation was limited by economic level, tenure, socio-cultural preferences, fashion, psycho-physical hindrances and attitudes. Higher economic class occupants adopted a non- adaptive lifestyle. This life-style pattern and profligate attitudinal disregard always have overridden the simple behavioural, clothing and metabolic adaptations most necessary to achieve thermal comfort. Conversely, the subjects displaying 'thermal empathy' adapted well exploiting all the adaptive opportunities prior to using high energy intensive environmental controls.

Keywords

Thermal comfort in Apartments; Comfort temperature; Human adaptation; Occupant behaviour; Comfort standards in India

Introduction

India is in energy transition. The energy consumption in Indian residential buildings is the highest among all the Asia Pacific Partnership (APP) countries (Bin and Evans, 2005), and is increasing at a phenomenal rate. It is well known now that, uncomfortable buildings drive the users towards high energy solutions. There is very little thermal comfort research reported from India, especially on residential environments (Sharma and Ali, 1986). Moreover, thermal comfort standards are not prescribed in Indian codes. The National Building Code of India (NBC, 2005) specifies two, too narrow temperature ranges for winter (21-23 °C) and summer (23-26 °C) for all building and climate types. Importantly, these are not validated through empirical studies on local subjects, but are prepared from ASHRAE standards (ASHRAE, 2005), developed based on climate chamber studies on Western subjects.

Human beings adapt in myriad ways (physiological, psychological, behavioural, use of controls etc.) in their journey to seek thermal delight (Heschong, 1979) from discomfort. Conversely, Fanger's deterministic heat balance model (Fanger, 1972) which formed the basis for these standards, excludes all forms of human adaptation other than in clothing (Nicol, 2004). Arguably, various provisions for human adaptation to comfort are vital to achieve sustainable thermal comfort indoors, as comfort zone gets widened due to higher adaptive opportunity provided (Baker and Standeven, 1996).

Researchers have been maintaining that, field surveys among acclimatized populations are the only way in which comfort standards can relate realistically to people's needs (Nicol, 1993, 2004). In order to develop an adaptive model of thermal comfort, the dynamic nature of clothing, metabolic rate and people's interaction with the environment, all need investigation. The adaptive mechanisms play a very important role in widening the neutral zone and in minimizing the area under thermal stress especially in naturally ventilated buildings. Therefore, people's social and psychological attitudes to their thermal environment need to be thoroughly understood.

Arguably, provision of sustainable thermal comfort indoors, demands a deeper understanding of the climate, users, site, material and the envelope-sun interaction and ingenuity from the designer. Contrastingly, design of buildings aimed at providing precise thermal control relying on mechanical controls requires these skills little, shifting the focus from the architect to the services engineer (Heschong, 1979).

About 73% of the energy consumed in Indian residential buildings is used for lighting and ventilation controls to provide thermal and visual comfort indoors (ECBC, 2008). Importantly, the responsibility of providing for visual and thermal comfort is the prime concern of the Architect. Alarmingly, a growing number of apartments in the city, designed to appear like their Manhattan counter parts, even if they are in Madhapur, Hyderabad are coming pre–fixed with oversized air conditioning systems, with little or no attention paid to thermal comfort or adaptation mechanisms of the occupants. This improvident disregard to the adaptation patterns forms the backdrop of this current research.

The author conducted a thermal comfort field study in naturally ventilated (NV) apartments in Hyderabad, with an aim to investigate in to the comfort temperature and adaptation patterns of the occupants (Indraganti, 2009). The present paper focuses on the various methods of adaptation and the impediments the subjects had faced in their quest for comfort in summer.

Methods

Four seasons are observed in the composite climate of Hyderabad (17°27' N, 78° 28" E): summer, monsoon, post monsoon and winter. This field study was conducted in the summer month of May and monsoon months of June and July having extreme and very high levels of discomfort respectively. Forty five flats in various floors of five NV apartment buildings, named KD, SA, RA, KA and RS were investigated. These were 3-6 stories high, post-beam concrete structures with plastered brick infill walls, a construction commonly used locally. The roofs were all concrete flat roofs (150 - 200 mm thick) with 75-150 thick brick jelly concrete weather proof coat. All the buildings have operable windows and balconies. RS is located in the eastern part of the city and the rest are in the residential districts of the central city area.

Over 100 occupants living in the surveyed flats for over 3 months have voluntarily participated in all the surveys. In all the months, the surveys were conducted in two levels: one day of transverse survey followed by four days of longitudinal survey. Each survey constituted two parts: questionnaire administration and simultaneous recording of environment. The environmental data recorded were, air temperature, globe temperature, relative humidity and air velocity.

A total of 33 days were spent in surveys resulting in 3962 datasets. ASHRAE's Class – II protocols for field study were followed. Finer details of survey methods are presented in Indraganti (2010, 2010a). All the surveys were conducted by the author herself. All the subjects were interviewed thrice a day, to coincide with the morning, afternoon and evening comfort responses on the survey-day. Figure 1 presents the survey environments and the surveyed buildings.

Figure 1: The instruments, instrument set up, survey environments and the buildings surveyed

The questionnaires were designed, based on McCartney and Nicol (2002). Both the questionnaires had six sections namely, apartment and flat identification; back ground information; current clothing; activity level; thermal comfort responses and adaptation methods. Table:1 shows the important scales used in transverse and longitudinal surveys of this study.

Thermal acceptance was measured directly from the response to the question "*Can you accept the present hot environment or not?*" It measures the subject's overall satisfaction with his/ her thermal environment (de Dear et al, 1997). Subjects' responses to other environmental parameters (Indraganti, 2009a) behavioural adaptation, use of semi- permanent controls, and impediments to adaptation were also investigated in the transverse surveys. The transverse survey was also administered in Telugu, the language spoken locally.

Clothing garment checklists were adapted to the regional customs prevailing in Andhra Pradesh and compiled from the extensive lists published in ASHRAE hand book (2005). In addition, upholstery insulation of 0.15 Clo was added when the subject was seated or found resting (de Dear et al, 1997). Metabolic rates were assessed by a checklist of residential activities and were based on the detailed databases published in ASHRAE hand book. The metabolic rates ranged between 0.7 Met (sleeping) and 2.0 Met (standing working) in this study. Fanger's (1972) PMV values were estimated using ASHRAE comfort calculator (Fountain, 1994).

Table 1 Thermal comfort scales employed in this study

Scale value	Description of scale		
	ASHRAE 's Thermal sensation (TS)	**Nicol's Thermal preference (TP)**	**Thermal acceptance (TA)**
3	Hot		
2	Warm	Much Cooler	Acceptable
1	Slightly Warm	A Bit Cooler	Unacceptable
0	Neutral	No Change	
-1	Slightly Cool	A Bit Warmer	
-2	Cool	Much Warmer	
-3	Cold		

Sample description

The data base constituted the responses of about 35 male subjects (~ 35%) and about 64 female subjects (~65%), who have participated in most of the surveys. They were in the age group of 17- 69 years, with male and female average age of 40.14 years (SD= ~14.0) and 42 years respectively (Table 2). They were all healthy Indian nationals. All of them were assumed to be naturally acclimatised to the climate of Hyderabad.

Table 2 Profile of subjects

Economic Group	Apartment	Subject (Nos)	Weight (kg)	Height (m)	Body surface area (m^2)	Age (years)	Clothing Insulation (clo)	Subject (Nos)	Weight (kg)	Height (m)	Body surface area (m^2)	Age (years)	Clothing Insulation (clo)
		Male						**Female**					
Gr-1	**KD**	**10**	80	1.8	1.9	40.2	0.6	**23**	68	1.6	1.7	43.3	0.6
	SA	**12**	65.7	1.7	1.7	49.6	0.49	**18**	61.7	1.6	1.7	44.1	0.68
Gr-2	**RA**	**7**	77	1.8	1.9	40.7	0.6	**15**	57	1.6	1.6	48.6	0.61
	KA	**10**	65	1.7	1.7	37.2	0.48	**12**	63	1.7	1.7	42.8	0.69
Gr-3	**RS**	**6**	61	1.65	1.67	39.4	0.41	**15**	52.7	1.6	1.54	35	0.65

Denial from a few subjects to participate in the survey resulted in minor variations in the sample size. To facilitate further analysis, the subjects were grouped based on their economic level, tenure and roof exposure. While owners constituted 55%, tenants were 45% of the total sample.

There were differences in the lifestyle, economic condition etc. of the subjects living in the apartments investigated. These resulted in differences in their thermal comfort perception, as also observed in Han et al.'s Harbin study (2008). Therefore, the subjects of the five flats were grouped into three classes as well, to enable further analysis in this direction. Group -1 (Gr -1, higher economic class), constituted subjects from KD, while Group -2 (Gr -2, intermediate economic group) constituted subjects from SA and RA, where as Group-3 (Gr -3, lower economic group) had subjects from KA and RS. Each group had 32- 35% of the total subjects. In order to investigate the differences in comfort responses of RE group and subjects from lower floors (LF), about 29-48% of the total sample was also obtained from roof exposed (RE) flats.

Indoor and outdoor environment

Outdoor environmental data were procured form the local meteorological station. This constituted daily maximum and minimum temperatures and humidity values for all the days of the survey. Mean minimum outdoor temperatures during summer and monsoon sample periods were 27.3 °C and 24.1 °C, respectively. Mean maximum outdoor temperatures of the summer and monsoon sample periods were 40.4°C and 34.2 °C, respectively. Over the summer study period, the mean 8:30 hrs and 17:30 hrs relative humidity (RH) were 38.6 % and 26.7 %, respectively. The relative humidity in the monsoon period was relatively higher. The mean 8:30 hrs and 17:30 hrs relative humidity (RH) were 66.1 % and 46.7 %, respectively.

Indoor environmental data were recorded using calibrated digital instruments (Indraganti, 2010). A minimum time interval of two hours was maintained between two consecutive readings taken in any single apartment. The surveys were conducted in the living/dining rooms of the apartments without disturbing the occupant going about his/her daily routine.

Table 3 Summary of outdoor, indoor climatic data, subjective thermal evaluation and calculated indoor climatic and thermal comfort indices

Season (Month), Sample size	Descriptive statistic	Daily outdoor mean temperature	Indoor air temperature (°C)	Indoor relative humidity (%)	Indoor wet bulb temperature (°C)	Indoor air speed (m/s)	Indoor globe temperature (°C)	Thermal sensation (measured) (TS)	Thermal preference vote (TP)	Thermal acceptability (TA)	PMV
Summer (May), 1405	Mean	33.8	34.7	27	23.1	0.5	34.5	1.8	1.3	1.7	3.9
	SD	0.57	1.6	9	0.7	0.5	1.8	1	0.6	0.5	0.9
	Maximum	35.2	39.3	63	26.4	4	42	3	2	2	7.8
	Minimum	32.8	26.7	14	17.8	0	26.7	-2	-1	1	0.1
	r	0.96	0.46	-0.31	-0.03	0.08	0.42	-	0.53	-0.37	0.42
Monsoon (June), 1334	Mean	29.7	30.9	53	23.2	0.5	31.2	0.5	0.7	1.9	2.3
	SD	1.2	1.2	6	1.6	0.4	1.2	0.8	0.6	0.2	0.6
	Maximum	31.5	33.8	76	28.2	2.2	34.1	3	2	2	3.7
	Minimum	27.4	27.4	39	13.9	0	26.6	-2	-1	1	-1.6
	r	0.36	0.42	-0.15	0.08	-0.04	0.4	-	0.6	-0.31	0.38
Monsoon (July), 1223	Mean	28.8	30.3	55	20.4	0.4	30.7	0.4	0.6	2	2.1
	SD	0.62	1.1	6	1.4	0.4	1.1	0.7	0.6	0.2	0.5
	Maximum	30	33.8	68	26.7	2	34.7	3	2	2	3.7
	Minimum	28.2	25.8	39	10.7	0	28	-1	-1	1	-0.6
	r	0.09	0.2	-0.23	0.01	0.01	0.25	-	0.61	-0.25	0.25

(SD= Standard deviation; r= Correlation with thermal sensation; PMV = Fanger's predicted mean vote)

Indoor environment followed the outdoor closely. Details of the indoor and outdoor environment and the subjective thermal responses are presented in Table 3. It can be noted that indoor summer temperature was very high (higher than skin temperature) with low humidity. Humidity and temperature correlated negatively and robustly in May, moderately in June and July. While the temperature in June was around the skin temperature, in July it was lower, relieving much of the thermal stress. Humidity was moderate to high in June and July, more so on the rainy days. Air velocity was found to be moderate. Over 70% of the data were recorded in environments when the air velocity was less than 0.5 m/s

Results and discussion

Subjective thermal responses

Thermal sensation correlated strongly with outdoor (r = 0.61) and indoor temperatures and humidity. Indoor thermal environments in summer were found to be very hot with very little adaptive opportunities available. As a result, only 40% subjects voted comfortable (-1 to +1 on sensation scale) (mean TS = 1.8; mean TP = 1.3). Although 93% subjects preferred it cooler in May, as high as 69% of the subjects accepted their thermal environments. Interestingly, 20% of them voted in the non central three categories of the sensation scale, similar to Han et al (2008). The occupants also felt comfortable in a wide range of humidities (17- 78%).

In June and July the indoor temperature was around and below 32- 34 °C, the usual skin temperature (Keoningsberger et al, 1984) and the adaptive measures available were found to be just adequate in these months. Assumable, this resulted in improvement in thermal sensation, preference and acceptance, yielding a near neutral vote in these months, similar to the findings of Heidari (2006) and Rijal et al (2002). These adaptations are known to affect the thermal acceptance of an environment (Wong et al, 2002) as well. Much as expected, a complex relationship was found between thermal sensation, preference and acceptance, similar to Han et al (2008).

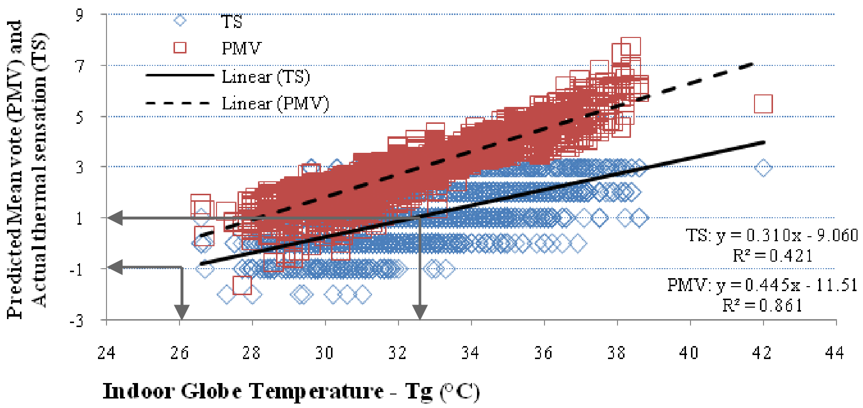

Figure 2: Linear regression of TS and PMV on indoor globe temperature (all data, p<0.001)

The adaptive comfort model is a linear regression model which relies on the fundamental principle that "*if a change occurs such as to produce discomfort, people react in ways which tend to restore comfort*" (Nicol, 1993). It therefore integrates various environmental, behavioural and psychological adaptations and thus forms the basis for sustainable thermal comfort standards.

In this study, thermal sensation vote was regressed against indoor globe temperature, which yielded the relation, $\mathbf{TS = 0.31T_g - 9.06}$, with a moderate coefficient of correlation of 0.65 (All data, n= 3962, p<0.001). A neutral-temperature of 29.2 °C and a comfort range (coinciding with TS: -1 to +1) of 26.0 °C and 32.5 °C was thus obtained. This range is much higher than the comfort range of 23 – 26 °C, specified in the Indian Codes (BIS, 2005). This finding has enormous energy implications to building design, HVAC design and practice in India.

The regression analysis of Fanger's PMV with indoor globe temperature identified that, PMV exaggerated the actual sensation in all the cases. As PMV omits most of the adaptation, it returned a higher correlation (r=0.93) coefficient than that of TS (Figure 2).

Through multivariate analysis, the effect of humidity on thermal sensation was found to be limited excepting in the month of June, when the humidity was moderate to high and the temperature was around the skin temperature. About 20% improvement in the coefficient of multiple determination (R^2) of the model was obtained, by adding wet bulb temperature (T_w) as a variable in the multiple regression model (TS = 0.25 T_g +0.16T_w -10.96; June: all data $p<0.01$). It means that, in all the other months, temperature alone explained most of the variation in thermal sensation, very typical of a dry climate. A detailed discussion on regression analysis and multivariate analysis are presented in Indraganti (2010 and 2010a).

Thermal Adaptation

Clothing and metabolism

The occupants adapted through clothing and metabolism to remain comfortable. Clothing insulation varied from 0.19 – 0.84 clo in this study, while metabolism varied from 0.7 – 2.0 Met (sleeping – standing working). Understandably, subjects chose lighter clothing (0.15- 0.3 clo) and took post- meal siestas during the hot mid-day in summer.

Figure 3: Clothing adaptation in women and men using traditional ensembles. Women/men draped the sari/ *lungi* in different ways to suit to the activity, changing the mico-climate around the body.

Some men at home were found in *lungi* (a 2 m x 1.4 m long cloth draped around the waist), and left the torso bare, when at home, during the hot period. Some female subjects were observed using lighter clothing during heavy kitchen work. When these adaptations were limited, due to some temporal and other socio-cultural reasons, they expressed discomfort and gave a high sensation vote.

Older women (age >40yrs) for example, were usually dressed in saris (clo = 0.55~0.66), a culturally more acceptable costume, even when other lighter clothing options were available (long gown = 0.29 clo) (Figure 3). However, the sari/*lungi* offered women/men, much better choice in terms of draping, to change the micro climate around the body suitably (Figure 3).

Adaptive use of windows, doors and curtains

Use of environmental controls like doors, windows, curtains, fans coolers etc., was noted down in all the surveys as binary data (0- closed/ not in use; 1- open/ in use). Evidence was found to show that windows, doors and curtains were operated (opened/closed) adaptively by the users as the indoor/outdoor temperature increased. Similar observation was made by Nicol et al (1999), Raja et al, (2001) and Anderson et al (2009).They were found to be in maximum use at around the upper limit of comfort zone, coinciding with thermal comfort vote of +1.

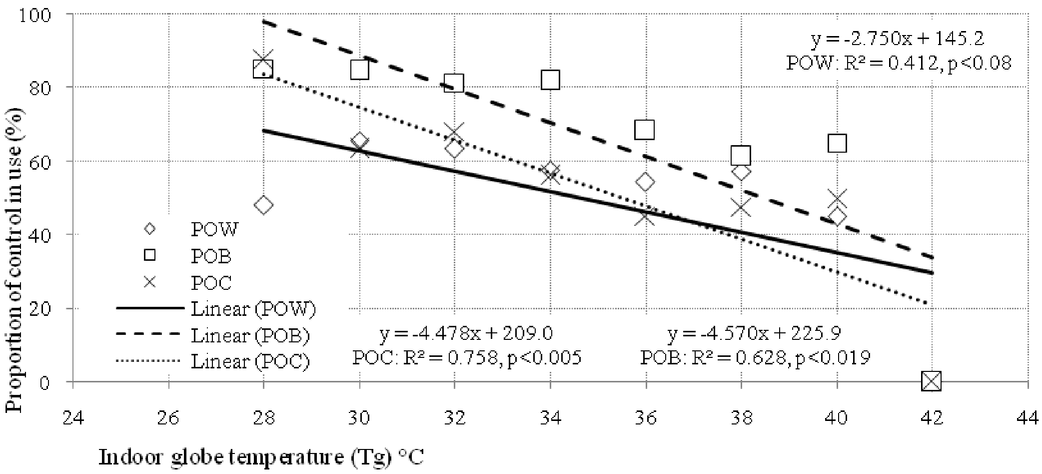

Figure 4: Changes in proportion of use of different controls in use with indoor temperature (All data, all months - binned) (POW/ POB/ POC = Proprtion of open windows/ balcony doors/ curtains)

It was noted that the effect of air movement was most significant for comfort when the subject is at the upper limit of comfort temperature. Contrastingly, at high temperatures, encountered in Hyderabad in summer, excessive natural ventilation caused convective and conductive heat gain and caused radiant heat discomfort as well. This led to the adaptive closure of most windows/ doors and curtains (Figure 4). A discussion on the use of windows in greater detail is presented in Indraganti (2009a).

Use of fans air coolers and air conditioners

Indoor comfort hinges on the adaptive use of various electrical controls like ceiling fans, air coolers and air conditioners etc, (Nicol and Raja et al, 1999). The use of controls also depends on the indoor and outdoor temperatures. The effect of air movement on comfort is equivalent to a drop in indoor temperature of up to 4°C (Nicol, 1975).

Ceiling fan is the most commonly used low- energy environmental control (Wong et al, 2002) and is significant to human thermal comfort. Raja et al (2001) present a very interesting fact on the use of fans, that in buildings with lesser open windows, people resort to using electro mechanical controls like fans higher. This finding corroborates the finding of Hwang et al, (2008). Rijal et al (2008) further find that even in mixed mode buildings with adaptive opportunities provided, the same level of thermal satisfaction can be achieved.

While all the surveyed environments were fitted with fans, only about 28% of them were fitted with air coolers, where as the availability of air conditioners was lesser (42%). The occupants in this study were found to be using the fans, coolers and air conditioners as the discomfort/ indoor temperature increased. However, their use varied substantially among different buildings and subject groups (Figure 5). Understandably, use of air coolers and air conditioners was found to be highest in higher economic groups (Gr-1 and Gr-2).

It was observed that the indoor temperatures in RE flats were higher than their lower floor counterparts, due to the intense solar heat gain from the roof. Moreover, other adaptive semi-permanent controls required for thermal comfort were also found to be inadequate/ missing. As a result, availability/ use of air coolers, and air conditioners were found to be highest in RE flats.

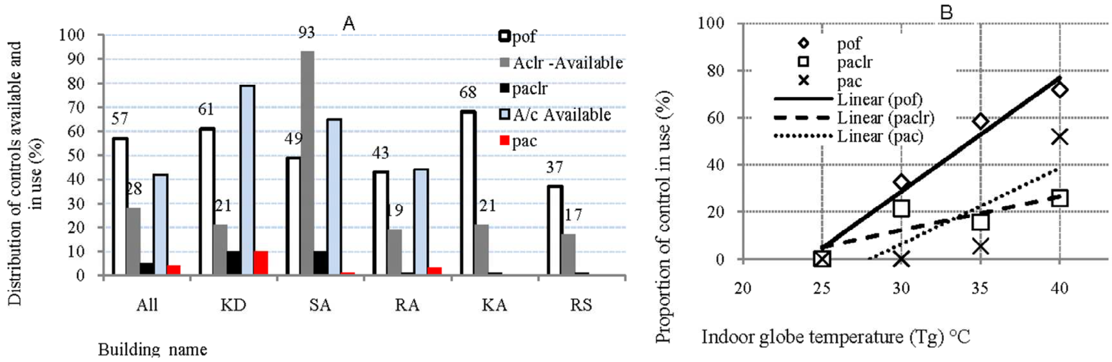

Figure 5: (A) Distribution of controls available and in use (All data); (B) Change of proportion of controls in use with indoor temperature (%) (All data) (pof = proportion of fans in use; Aclr = air coolers; paclr = proportion of air coolers in use; pac = proportion of air conditioners in use)

On the contrary, use of fans was found to be higher in LF flats. This was due to the fact that, ceiling fans re-circulated the hot air accumulated beneath the ceiling, aggravating discomfort. Hence, the subjects in RE flats preferred coolers and air conditioners or in a few cases, pedestal fans to ceiling fans. Importantly, use of coolers and A/cs brought the indoor temperature close to the skin temperature, relieving much of thermal distress. Coolers and A/cs were beginning to be in use when the mean outdoor temperature was around 28.5- 31.3 °C.

Use of semi-permanent controls

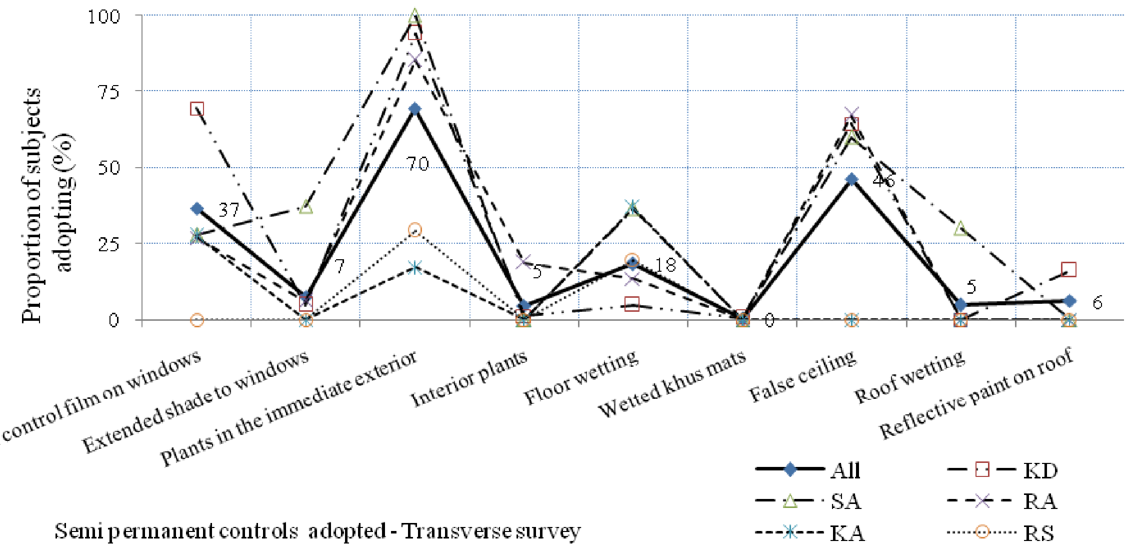

Figure 6 Use of semi-permanent controls in various apartments (Transverse survey, all data)

Use of semi permanent controls was found to be very important to maintain the indoor micro climate: for example double roofs, reflective roofs, roof wetting, radiant roofs (Wong and Li, 2007), sun control film on the windows etc. Their use and other aspects related to their use were recorded in the transverse survey. It was noted that the occupants of flats have used some semi permanent controls adaptively, to control the heat flow (Figure 6).

The author found the *"plants in the immediate exterior"* as the commonly adopted control measure while, '*wetted khus mats, reflective paint on the roof, roof wetting and interior plants'* were least in use (Figure 6). It is imperative to note that plants in the immediate exterior were used by the subjects more as an ornamental feature than in response to the thermal stimuli.

Many occupants in KD adopted (0 ~ 69%) an expensive treatment like sun control film on the windows than in the other buildings. Floor wetting was adopted by the subjects more as a routine practice, than as an adaptive thermal control measure (36% ~ 5%). It is interesting to note that a simple but effective adaptive measure like the use of wetted khus mats was not found to be in use in any of the apartments studied. This is possibly due to the problems associated with the procurement and maintenance of this control measure.

False ceiling was found only in Gr-1 and Gr-2 flats. It was put to use in roof exposed flats (RE) merely as an ornamental treatment, mostly as part of the interior decoration, while simple measures like roof wetting and reflective paint on the roof were not used much. On further investigation during the survey it was found that, most of the occupants were unaware of the efficacy of these controls. A few occupants extended the shade to the windows adaptively, while a few subjects in SA wetted the roofs in the evening in May.

Behavioural control actions

In order to restore comfort in a short span of time, people undertake several behavioural control actions. These actions in turn trigger several behavioural adaptations. The subjects in this study were asked to pick the adaptive control actions undertaken by them in the 15 minutes prior to the survey (Heidari, 2006; Rijal et al, 2002) in all the transverse surveys. While there were individual differences in the way people adapted behaviourally in each building, it was found that '*moving to an airy place*' and '*drinking cold water*' were the most preferred adaptive actions, similar to Feriadi et al, (2004) (Figure 7). Although more than 25% of the subjects preferred *sleeping* as an adaptive action, almost a negligible percentage of subjects used *hand fans*. Similar observations were made by Rijal et al (2002) and Heidari (2006).

From Figure 7, it can be deciphered that the behavioural adaptation changed with building and season as well. Understandable, it hinged on the availability and use of various controls and the degree of thermal adversities faced by the occupants. An analysis of the behavioural control actions in conjunction with the use of electro mechanical controls reveals further facts.

It was noted that use of fans, air coolers and air conditioners was highest in KD and was lowest in RS, with SA, RA (Gr-2), and KA falling in between. Thus, it can be inferred that, higher usage of electrical controls enabled the subjects to exercise limited behavioural adaptations as observed in KD (0-25%). On the other hand, due to the limited availability and use of electrical controls, a higher percentage of subjects (50 - 100%) adapted behaviourally better, by slowing down their metabolic rate (*doing something less vigourously* and *sleeping*) etc, as in RS (Gr-3).

Similarly, a higher percentage of subjects in RS (Gr -3) preferred '*sitting on the floor* and *staying away from heat sources*' than in KD. While the percentage of behavioural adaptations in KD (Gr-1) in May were limited (due to higher use of electro-mechanical controls), it improved substantially in June, where the use of A/c was almost stopped. As the temperature was around skin temperature and the humidity was high, higher air movement was needed for physiological comfort. Therefore, a higher percentage of subjects adapted through '*sitting on the floor*' and '*staying in airy places* in June and also in July.

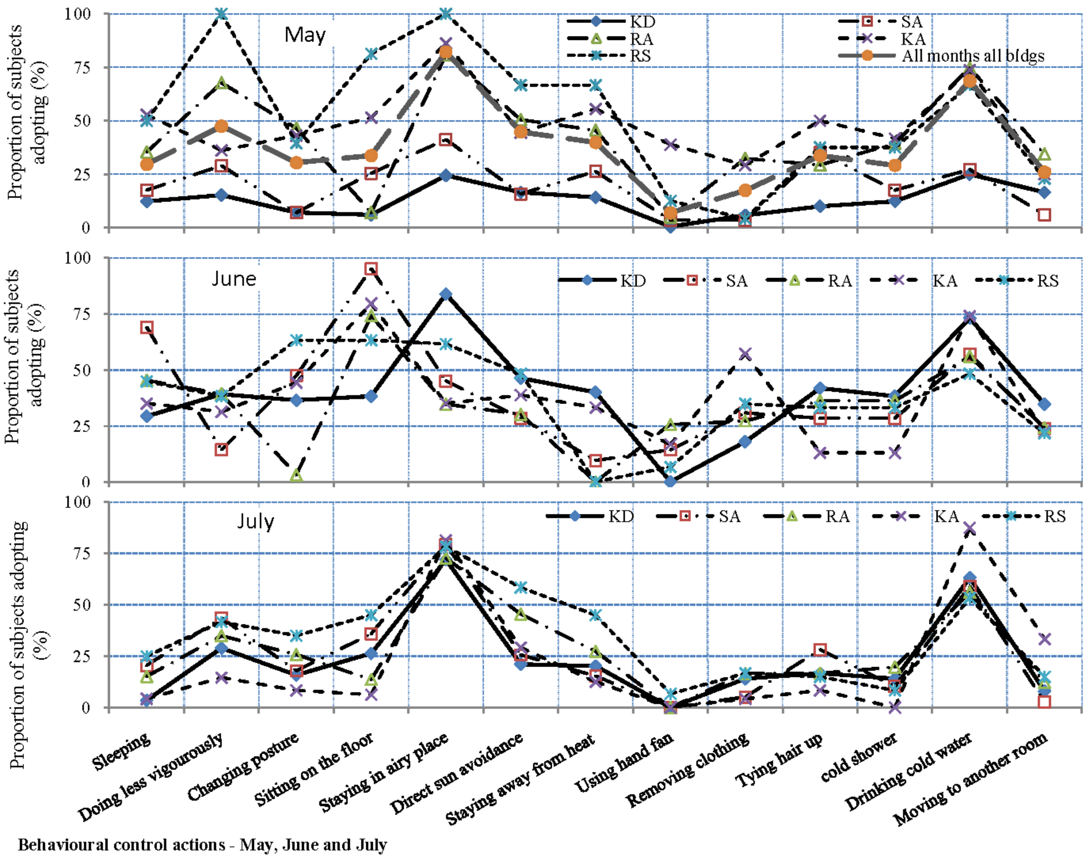

Figure 7 Behavioural control actions used in summer and monsoon indicating higher adaptation in summer, a period of greater thermal distress

Moreover, as the thermal adversities experienced in May ceased in June, and July, the individual differences in the pattern of behavioural adaptations in various buildings also ceased. They appear to cluster around the average, as shown in scatter plot for July. Even under moderate conditions, '*sitting in airy place*' and '*drinking cold water*' were most preferred. While actions like '*tying hair up*' (highest in Gr-3 and lowest in Gr-1), and removing clothing were affected by the gender of the subject, '*taking cold shower*' is considered more as a part of daily routine in June and July. In the month of May '*taking cold shower*' is however used as an adaptive action by subjects during the morning and also late in the evening.

In this study, some of the behavioural adaptation actions like *postural changes*, *sleeping*, *staying away from heat source* and *moving to another room* were found to be limited by many temporal household activities of the occupants (Humphreys and Nicol, 2008) and varied with geographic location and socio cultural patterns followed locally. For ex., *removing clothing, changing posture, moving to another cooler zone* could also have socio- cultural connotations to it (Heidari, 2006).

Impediments in using controls

There were many impediments in using the environmental, semi permanent structural and electrical controls. Most prominent among the impediments were privacy, security and non availability of control (Table 4).

Use of windows/ doors and Privacy/ security

Windows and external doors opening in the public realm i.e., the public corridors and passage-ways seriously hindered the usage of controls and almost negated adaptive opportunity available. For example, in RA and SA the windows opening in to the public realm were rarely opened, despite the thermal necessity. Moreover, improper shading devices, stray animals and birds dysfunctional latches and bolts fitted to the windows and doors also deterred the subjects from using these controls adaptively.

Table 4 Degree of impediment and hindrance in using the controls as faced by the occupants (%) (Transverse survey)

Apartment	Mosquitoes	Bad odour	Dust	Noise	Loss of privacy	Security	Non availability of control	Economic reason	Others
All	34	27	51	46	61	55	65	51	63
KD	14	12	39	39	59	45	60	7	64
SA	12	4	60	41	73	93	83	80	64
RA	23	59	61	63	55	40	42	35	52
KA	64	16	80	43	70	62	68	84	56
RS	60	36	30	41	68	53	86	99	74

While the economic affordability was the major challenge in lower economic groups bad odour and noise were major impediments in RA. On analysing impediments in conjunction with contextual features of the neighbourhood, it was identified that, these contextual features have indeed impeded the adaptive use of controls by the occupants: for example, RA is ensconced by construction activity and *Hussain Sagar*, a highly polluted lake in close proximity.

Tenure

Tenure also adversely affected way controls were put in place and used. Tenant occupied flats were fitted with least variety and number of semi-permanent controls. For example, additional metal grill shutters to external doors, bamboo screens, metal grills to open balconies, special planter boxes to windows were found to be mostly in use in owner occupied apartments only. (Indraganti, 2009a)

In fact, availability of these was found to have greatly enhanced the use of doors/ windows and indoor comfort in turn. More particularly, passive measures of heat control in roof were not provided in any of the tenant occupied flats. Eventually, the thermal acceptance was found to be lower in tenant group. Ignorance on the efficacy of a control measure and tenancy status also negated some of the available adaptive opportunity.

Attitudes, social and cultural preferences

Thermal attitudes emanate from habituation and acclimatization and that they form thermal perceptions. Thermal perceptions, in conjunction with adaptive behaviour and use of various controls lead to thermal neutrality; and it varies for each economic group and population as observed in Indraganti and Rao (2010). The comfort band of lowest economic group (Gr-3) was found to be (27.3 – 33.1 °C) with neutral temperature at 30.20 °C, about 2 K higher than that of Gr-1. Free answer responses of occupants in higher economic groups (Gr-1 and Gr-2) indicated a predilection for seeking comfort effortlessly even at an expense. It also resulted in the overt use of air conditioners in these two groups. This desire was also fuelled by the tag of modernity and higher social status perceivably associated with the use of air conditioners at homes.

Facilitated by the proliferating electro – mechanical cooling systems, the common adaptation methods *viz*, clothing, metabolic, behavioural and environmental etc., were sometimes overridden by the social and cultural preferences also (figure 7, May). Arguably, the clothing choices (with higher clothing insulation) made by a few subjects, emanated more from the fashion/ social demands than thermal requirements of the season. A predisposition for a non-adaptive life style coupled with a higher clothing insulation has resulted in a cyclic system of low tolerance for thermal extremes and a greater preference for lower comfort temperatures. This had resulted in higher use of fans and A/c s (KD, RA), and lower neutral temperature.

Attitudinal Impediments

The analyses of respondent anecdotes provided insights into the thermal attitudes and beliefs and impediments to the adaptation methods. Profligate attitudinal disregard was observed towards the adaptive use of environmental controls like opening windows, doors, curtains etc., when electrical controls like fans are available under moderate temperatures in July. Clothing adaptation was also found to be impeded by socio –cultural/ temporal demands and acceptability.

Psychological preparedness of the subjects to receive thermal extremes over short periods during the summer was observed in some of the older subjects in all the apartments, more so in RS, KA and RA. This had shown to improve thermal acceptability of the subjects towards the overheated environments. As a result, the subjects who have displayed '**thermal empathy'** adapted through, clothing, activity, and behaviour and environmental controls etc., better. They chose to exploit all the adaptive opportunities prior to using high energy intensive environmental controls. (For ex: appropriate clothing, low metabolic activities during hot mid day and the use of openings etc.)

On the contrary, some tenants displayed indifferent attitude towards the operation and maintenance of personal environmental controls for several reasons. Due to this negligence, such subjects have had poor application of controls and as a result have voted low on the overall comfort and thermal acceptability scales. Similarly, older subjects have displayed slight attitudinal sluggishness towards the use of controls.

Interestingly, female subjects of this study, mostly house wives displayed a positive attitude towards accepting the thermal extremes of the "*HOME*" environment and used the controls better. Contrastingly, some male subjects showed an indolent attitude towards the thermal adaptation. This has resulted in poor acceptance vote among men (Indraganti, 2010a). Responses to open ended questions unfolded that, lassitude often felt during the summer, prevented the occupants from using some of the traditional behavioural control actions: environmental control practices like roof wetting, using hand fans and taking cold showers. The subjects in turn preferred to bear the discomfort for a short while, if other adaptive actions were already exploited fully.

It is essential to note that the subjects with a thermal history of high exposure to air conditioning always displayed an attitude towards quick thermal gratification and had narrow tolerance limits. This desire for **thermal indulgence** has often placed an overwhelming demand constantly for cool indoor temperatures and had resulted in higher use of mechanical controls even beyond summer. As observed by Humphreys (1995) and Shove (2002), it is a ratchet like path dependency!

Conclusions

The author conducted a thermal comfort field study in Hyderabad in summer and monsoon in 2008 in naturally ventilated apartments following Class- II protocols for field study. Over 100 subjects participated in surveys conducted in two levels giving 3962 datasets of comfort responses. The following are the conclusions:

1. About 60% of the subjects were uncomfortable in summer due to inadequate adaptive opportunities in apartments. However, the percentage of subjects comfortable improved in June and July. The regression comfort temperature was way above the figure specified in the Indian codes. Also, PMV exaggerated the actual sensation.
2. The occupants have used various controls adaptively, as the indoor temperature increased. Although the use of ceiling fans was as high as 84%, use of air coolers and conditioners in use (0-10%) was much lesser. Window/door opening realm critically hindered the adaptive operation of the opening and resulted in higher indoor temperature. High maintenance cost was a major challenge faced by many subjects in using the A/cs and coolers.
3. The adaptation was also limited by several factors such as privacy, economic level, tenure, socio-cultural preferences, fashion, psycho-physical hindrances and attitudes. "*Sitting in airy place* and *drinking cold water*" were the most preferred behavioural control actions. Behavioural adaptation was higher in summer and lower in higher economic groups, especially in groups, which used A/cs more and adopted a non-adaptive life-style.
4. This life-style pattern and profligate attitudinal disregard overrode many simple comfort adaptations always, resulting in '**thermal indulgence'**. On the other hand, subjects displaying '**thermal empathy**' adapted well, choosing to exploit all the adaptive opportunities prior to using high energy intensive environmental controls.

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