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Behavioural adaptation and the use of environmental controls in summer for thermal comfort in apartments in India

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ABSTRACT

Building energy use in India is rising phenomenally. Indian codes prescribe a very narrow comfort temperature range (23–26 °C) for summer. Ventilation controls alone consume 47% of total energy in residences. Thermal comfort field studies in Indian residences were not attempted. The author conducted a field study in apartments in Hyderabad, in summer and monsoon seasons in 2008. This paper presents the occupants' methods of environmental and behavioural adaptation and impediments in using controls.

Only about 40% of the occupants were comfortable in summer due to inadequate adaptive opportunities. The comfort range obtained in this study (26.0–32.5 °C), was way above the standard. Fanger's PMV always overestimated the actual sensation.

The occupants used many adaptation methods: the environmental controls, clothing, metabolism and many behavioural actions. Use of fans, air coolers and A/cs increased with temperature, and was impeded by their poor efficacy and noise, occupant's attitudes and economic affordability. A/c and air cooler usage was higher in top floors. Behavioural adaptation was better in summer and was restricted in higher economic groups always. Thermal tolerance was limited in subjects using A/cs and resulted in "*thermal indulgence*". This study calls for special adaptation methods for top-floor flats.

1. Introduction

Human beings have an amazing ability to adapt. These myriad possible adaptations are important for the evolution of human race and its survival. Several studies identified many adaptive actions that a person might take, to achieve thermal comfort [1–6]. These are physiological, behavioural and the use of personal environmental controls [4,7–9]. For example, physiological adaptation is the first adaptation mechanism which keeps humans in existence from extinction. This happens almost automatically, triggered by hypothalamus in order to maintain the deep body temperature within the close limits of 37 °C. The adaptations to warmness are vasodilatation, sweating, eating less, and acclimatization to heat [5].

It is important to note that, Fanger's thermal comfort model [10] included no adaptation other than in clothing; hence he prescribed uniform comfort conditions, which were followed by ASHRAE standards throughout the world. This was criticized by several researchers.

Excepting a few reports [11,12], there is very little thermal comfort research in India. Thermal comfort standards are not defined in Indian Codes. For all climate and building types, the National building code of India recommends two temperature ranges: summer (23–26 °C) and winter (21–23 °C) [13]. ASHRAE standards formed the basis for these, which were not validated through empirical studies on local subjects. Application of these standards produces overdesigned thermal monotony and unsustainable indoor climates.

Building sector in India consumes the highest energy among all sectors, when compared to the other Asia Pacific Partnership countries [14]. More so, energy consumed in residential buildings is the highest, with 73% of energy being used for visual and thermal comfort indoors (lighting: 28% and ventilation controls: fans – 34%; air coolers – 7%; A/c – 7%) [15]. It is also increasing phenomenally, as buildings are undergoing a paradigm shift, from heavy weight to lightweight construction, using glass and aluminum, caring little about the passive methods of heat control or human adaptation to comfort. These buildings with poor adaptive opportunities often produce intolerable indoor conditions within [16], and eventually become power guzzlers [1]. On the other hand, the use of environmental controls is essential for avoiding the use of high energy solutions [16].

Importantly, occupants in naturally ventilated buildings are comfortable over a wide range of temperatures due to the adaptive

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use of various controls [1,3,6,7,16–20]. The adaptive use of controls is not an isolated action, but is part of a feedback loop [19]. For example, as Nakaya et al. [21] observed, the use of one control may change with the use of another (e.g., closing windows and turning on fans). Moreover, the perceived usefulness of a particular control will change from time to time depending on conditions [19].

Behavioural use of controls links the physiology/psychology of the body and the physics of the building [17]. It forms a major link in the dynamic interaction between buildings and their occupants. The use of controls is also a very important element in linking dynamic simulations of the human body and the simulation of buildings. However, there is little reported from India on the adaptive use of various controls, especially in residential environments.

Therefore, a thermal comfort field study was conducted in naturally ventilated apartment buildings in Hyderabad, for 3 months in 2008 [22], covering summer and monsoon seasons. A detailed discussion on the regression analysis, thermal sensation and comfort temperature are presented in Indraganti [23].

Mere existence of a control cannot improve the adaptive opportunity in a building [19]. It is therefore necessary to understand the availability and adaptive use of various systems used as controls. Thus, the objective of the study was to investigate the possible linkages between the use of controls and the thermal comfort of occupants of apartments in Hyderabad. Presented here are the analysis of (1) the use of various personal environmental controls, (2) the behavioural adaptation methods undertaken and (3) the hindrances faced by the occupants in their adaptation.

2. Research methods

Hyderabad (17°27′N, 78° 28″E) is in the Deccan plateau of India and is the state capital of Andhra Pradesh. It has composite climate, with four distinct seasons: winter, summer, monsoon and post-monsoon [15]. The present study was conducted in summer (May) and monsoon months (June and July) in the year 2008, having extreme and high levels of discomfort respectively.

2.1. Outdoor and indoor data collection

Local meteorological station in Hyderabad provided the outdoor environmental data of maximum and minimum temperature and humidity readings 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 h and 17:30 h relative humidity (RH) were 38.6% and 26.7%, respectively. The relative humidity in the monsoon period was relatively higher. The mean 8:30 h and 17:30 h relative humidity (RH) were 66.1% and 46.7%, respectively.

The surveyed buildings named KD, SA, RA, KA and RS, were all naturally ventilated mid rise apartment buildings (10–18 m high) located in the central and eastern parts of the city [22]. These were built in concrete post and beam construction with cement plastered, 115–230 mm thick brick in-fill walls. A maximum of 113 occupants living in 45 flats of these buildings voluntarily provided 3962 sets of comfort data. Although the same sample was retained in all the surveys, the sample size varied slightly in each month as some subjects refused to participate. The sample had 35% men and 65% women, with an average age of 42 years.

Calibrated digital instruments were used to measure the indoor environment following ASHRAE's class–II protocols for field study. The instruments showed concurrent physical data (air temperature, relative humidity, globe temperature, air velocity), representing the immediate environment of the subject. A minimum time interval of 2 h was maintained between two consecutive readings taken in any single apartment.

The surveys were conducted in two levels: transverse and longitudinal [23]. Most of the subjects participated in both the surveys that spanned a total of 33 days. One day of transverse survey, followed by 4 days of longitudinal survey was conducted every month in all the apartment buildings. The questionnaires were designed based on McCartney et al. [24]. Both transverse and longitudinal questionnaires had six sections: basic identifiers, thermal responses, clothing level checklists, metabolic activity checklists [25], personal environmental controls being used, skin moisture and productivity. In addition, the transverse survey also had questions on the overall comfort, tenure, sensation and preference for other environmental parameters, behavioural and structural adaptation methods adopted and the impediments in using various controls. In addition, the transverse survey was conducted in Telugu, the language spoken locally. All the surveys were conducted by the author herself [23].

ASHRAE seven-point scale of warmth ranging from "cold (−3) to hot (+3) with neutral (0)" in the middle and Nicol's thermal preference (TP) scale with "much cooler (+2); a bit cooler; no change (0); a bit warmer and much warmer (−2)" were used to measure thermal sensation (TS) and thermal preference (TP) respectively. Thermal acceptance (TA) was measured on a nominal scale (1 = unacceptable; 2 = acceptable).

Clothing garment checklists were adapted to the regional customs prevailing in the state of Andhra Pradesh and compiled from the extensive lists published in ASHRAE hand book [25]. In addition, an upholstery insulation of 0.15 Clo was added when the subject was seated or found resting [7]. The metabolic rates were assessed by a checklist of residential activities and were based on the detailed databases published in ASHRAE hand book [25]. The metabolic rates ranged between 0.7 Met (sleeping) and 2.0 Met (standing working) in this study. Fanger's PMV [10] values have been estimated using ASHRAE comfort calculator [26]. The detailed description of the methods, sample, buildings and questionnaires are presented in [23,27]. The subjects were grouped based on their economic level into three groups: subjects of KD as Gr-1 (highest economic level); subjects of SA and RA as Gr-2 (intermediate economic level) and subjects of KA and RS as Gr-3 (subjects of lowest economic level). A detailed discussion on this sample group and their thermal responses is provided in [28].

3. Results and discussion

3.1. Thermal responses of occupants

Table 1 presents a brief summary of the outdoor and indoor environment and the subjective thermal responses recorded during the 3 months of survey, showing the indoor environment following the outdoor environment closely. Indoor environments in summer (May) were very hot with inadequate adaptive opportunities available to the occupants in flats. This resulted in only 40% voting in the three central categories of the sensation scale. Most of the subjects (93%) in summer preferred a temperature on the cooler side of the neutrality, despite 69% of them accepting their thermal environments (in May, mean TS = 1.8; mean TP = 1.3).

In June and July, the indoor temperature was around and below the skin temperature and the adaptive measures available were found to be just adequate. Thermal sensation and preference have improved in monsoon, resulting in a near neutral vote most of the time, similar to Heidari's findings [8]. These adaptations affected the thermal acceptance of an environment [29] as well. Moreover,