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Thermal comfort in apartments in India: Adaptive use of environmental controls and hindrances

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ABSTRACT

Energy used in buildings in India is ever-increasing. About 47% of total energy in Indian residential buildings is used for ventilation controls alone. Comfort temperatures defined in Indian codes are inappropriate (23–26 °C). There are no thermal comfort field studies in residences reported from India. The author conducted a field study in apartments in Hyderabad, in summer and monsoon seasons in 2008. The present paper discusses the occupants' methods of environmental control, behavioural adaptation and impediments.

Due to poor adaptive opportunities, about 60% of occupants were uncomfortable in summer. 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 adapted through the use of personal environmental controls, clothing, metabolism and many behavioural control actions. Use of fans, air coolers and A/c s increased with temperature, and was impeded by their poor efficacy and noise, occupant's attitudes and economic affordability. Air-coolers and A/c s were mostly used in top- floors, as the available adaptive opportunities were insufficient. Behavioural adaptation was higher in summer and was limited in higher economic groups always. Subjects frequently exposed to A/c environments, tolerated thermal extremes little, and desired "**thermal indulgence**". This study calls for special adaptation methods for top-floor flats.

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1. Introduction

People either modify the environment or adapt themselves behaviourally or do both to remain comfortable in a thermal environment, through several adaptive control actions. Various studies identified many adaptive actions such as, physiological, behavioural and the use of personal environmental controls [1–6]. However, Fanger's heat balance model did not include human adaption other than in clothing and prescribed uniform comfort conditions throughout the world, which is followed by ASHRAE. This was contested by several researchers.

Thermal comfort standards are not defined for India, as there is little past research conducted [7]. For all climate and building types, the National building code of India specifies the use of two narrow ranges of temperature: summer (23–26 °C) and winter (21–23 °C) [8]. These are based on ASHRAE standards, which are not validated through empirical studies on local subjects. Application of these produces unsustainable conditions indoors.

Building sector in India consumes the highest energy among all sectors, when compared to the other Asia Pacific Partnership countries [9]. 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%), [10]. It is also increasing at an unprecedented rate, as buildings become lighter, ignoring the passive methods of heat control and human adaptation to comfort. It is well known now that, buildings with poor adaptive opportunities often produce intolerable indoor conditions within, and consume very high energy [1,11]. Moreover, environmental controls are important in reducing the need for high energy solutions.

Several studies proved that, occupants in naturally ventilated buildings are comfortable over a wide range of temperatures due to the adaptive use of various controls [1,2,4,5,12–14]. Interestingly, adaptive use of controls forms a feedback loop and does not happen in isolation [14]. For example, the use of one control may change with use of another (e.g., closing windows and turning fans on). Moreover, the perceived usefulness of a particular control will change from time to time depending on conditions [14]. Behavioural

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use of controls links the physiology/psychology of the body and the physics of the building [12]. It is thus, a major link in the dynamic interaction between buildings and their occupants. Use of controls is also a key element in linking dynamic simulations of the human body and the simulation of buildings. Most of the current research in other countries is aiming at the prediction of occupant behaviour and their use of various controls focused on developing algorithms to be used in building simulations for office buildings, although a few studied use of various controls in residential and educational environments as well in the recent years [15,16].

However, there are no reports on the use of controls in India. Therefore, a thermal comfort field study was conducted in naturally ventilated apartment buildings in Hyderabad, for three months in 2008. A detailed discussion on thermal sensation, comfort temperature and regression analysis can be found in Indraganti [17].

A building's adaptive opportunity cannot be improved by mere existence of a control [14]. Hence, it is necessary to understand the availability and adaptive use of various systems used as controls. Therefore, an investigation into the possible linkages between the use of controls and the thermal comfort of occupants of apartments in Hyderabad was also carried out. This paper presents an analysis of (1) the use of various environmental controls, (2) the behavioural adaptation methods undertaken and (3) the hindrances faced by the occupants in their adaptation.

2. Methods

Hyderabad (17°27′N, 78° 28″E) has composite climate, with four distinct seasons: winter, summer, monsoon and post monsoon [10]. It is in the Deccan plateau of India and in the state capital of Andhra Pradesh. The present survey 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. Measurement of indoor and outdoor data

Outdoor environmental data was obtained from the local meteorological station. It constituted 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.

Five naturally ventilated apartment buildings named KD, SA, RA, KA and RS, in the city were chosen for the survey. These are 5–30 year old, small to medium sized apartment buildings, having three to six floors. These are all built as concrete post and beam structures with brick infill walls (230 mm thick), excepting RS which is built using hollow cement block for infill walls. KD and RS have doubly loaded corridors while the rest have singly loaded corridors. All the apartments in all the buildings have operable windows. The floor area of the apartments in KD was the largest (100–200 m^2) while RS had the smallest apartments (75–90 m^2). While KD is planned as a group of two buildings separated by a landscaped court in a large complex having 13 apartments per floor, the rest of the apartment buildings are single block units with 3 or 4 tenements per floor, connected through a corridor or stair way (1200–900 mm wide). The apartments in KD are connected through wider corridors (2000–900 mm wide) or stairways. The apartment buildings in KD, RA and KA, have their longer sides facing the north, while in SA and RS, the longer sides face the east. SA has windows opening into public corridors and very narrow setbacks and open spaces devoid of outdoor play areas. In RA the windows of living rooms open into the public realm, while in KA also the living room windows open into the public realm and the corridors are not protected from sun. RS has the windows of kitchens and living rooms opening into the narrow public corridor exposed to direct sun most of the time. All the buildings surveyed are located in the residential neighbourhoods in the central and eastern parts of the city.

The buildings chosen were typical buildings of the normal apartment building stock, and as no attempt was made to include special buildings or eliminate special buildings, the buildings are assumed to be randomly selected. The inclusion of a particular tenement or the survey respondent in the survey depended on the willingness/cooperation of the occupant to participate in the prolonged process of the survey for over 3 months. This method is adopted based on international practises, also followed in the major bench mark comfort surveys by de Dear et al. [4] and Nicol et al. [14]. We chose this method after discussing with eminent researchers like Fergus Nicol and Michael Humphreys, UK. It has been learnt that, exact random selection of buildings/respondents in practice has not often been done in thermal comfort surveys because of the cost and difficulty. Moreover, in comfort surveys the researcher is usually more interested in the relationship, say between comfort and temperature, where randomisation is not likely to be so important.

A total of 3962 datasets were provided by a maximum of 113 respondents, of whom 35% were men and 65% were women. 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 average age of all subjects ranged between 35 and 50 years across all buildings.

The survey was conducted in forty-five flats located in various floors in the five apartment buildings. Indoor environment was recorded using calibrated digital instruments, following 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, in order to record a notable change in the thermal sensation or indoor temperature of the environment, as occupants act as human meters of their environments. The survey was conducted between 7 am and 11 pm in various apartments, on all the survey days.

The surveys were conducted in two levels: transverse and longitudinal [17]. Most of the subjects participated in both the surveys that spanned 33 days. The transverse survey was conducted on a single day, followed by four days of longitudinal survey, every month, in all the apartment buildings. The questionnaires were designed based on McCartney et al. [18]. Both transverse and longitudinal questionnaires had six sections: basic identifiers, thermal responses, clothing level checklists, metabolic activity checklists [19], personal environmental controls being used, skin moisture and productivity. In addition, the transverse survey also had questions on tenure, sensation and preference for other environmental parameters, behavioural and structural adaptation methods adopted and impediments in using various controls.

The thermal sensation (TS) scale was the ASHRAE seven-point scale of warmth ranging from "*cold (−3) to hot (+3)* with *neutral (0)*" in the middle. Nicol's thermal preference (TP) scale asked on a five-point scale (*much cooler (+2) to much warmer (−2)* with *no change (0) in the middle)* whether the respondent would like a change in the thermal environment. Thermal acceptance (TA) was measured as a binary input *(1 = unacceptable*; *2 = acceptable)*.

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