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# Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India

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ABSTRACT

There is little thermal comfort research in residential environments reported from India. Energy consumption in Indian residential buildings is one of the highest, increasing at a phenomenal rate. Indian standards advocate two narrow ranges of temperatures for all building and climate types. In this context, a field study in summer and monsoon was conducted following Class-II protocols, for three months in 2008, in naturally ventilated apartment buildings in Hyderabad. Over a 100 subjects involved, giving 3962 datasets. In May, most of the subjects were uncomfortable, preferring a temperature on the cooler side of the neutrality, despite accepting their thermal environments. Thermal sensation, preference and acceptance improved in June and July as temperature receded. Humidity did not affect comfort sensation much, as summer was hot and dry. Conversely, increase in humidity adversely affected the thermal comfort in June. Adaptive use of controls resulted in moderate air movement indoors, adequate for sweat evaporation most of the time. The subjects used traditional ensembles and slowed down their activities adaptively to restore thermal comfort. Clothing adaptation was found to be impeded by many socio-cultural and economic aspects. The comfort band (voting within −1 and +1) based on the regression analysis was found to be 26–32.45 °C with the neutral temperature at 29.23 °C. This is way above the limits (23–26 °C) set by Indian standards. The PMV was always found to be higher than the actual sensation vote. These findings have far reaching energy implications in a developing country like India.


## 1. Introduction

India is in energy transition [1] ranking highest in energy consumption in residential buildings amongst all the Asia Pacific Partnership (APP) counties [2]. About 73% of the energy consumed in Indian residential buildings is used for lighting and ventilation controls to provide thermal and visual comfort indoors [3]. The aspect of thermal comfort is very important to the designer, as poor thermal comfort forces the users to look for high energy alternatives to achieve thermal comfort. Moreover, poor indoor thermal comfort has several adverse effects on the occupants [4].

A growing number of buildings in India are being built in glass and aluminium, in complete defiance of local climate and context, following the western prototypes. These buildings eventually become power guzzlers. On the other hand, a phenomenal increase in the use of air conditioners in residential buildings is observed in the recent years in India. For a populous country like India, the ramifications of this high energy use are alarming.

However, there is a little thermal comfort research reported from India [5,6] as most of the international thermal comfort research was concentrated in the West [7–9], Australia [10], Asia [11–16] and in a few developing countries in Africa [17]. Interestingly, thermal comfort standards are not specified in Indian Codes. The National Building Code of India [18] advocates the use of two indoor temperature ranges for summer (23–26 °C) and winter (21–23 °C) for all the climatic zones. These are only meant for air conditioned buildings of any type [3]. Moreover, these standards were based on ASHRAE – Std 55 [19], which had systematic discrepancies due to the straightforward application of Fanger's heat balance equation [20]. The consequences of these uniform comfort standards [11] for all types of buildings and climates were critically questioned by the research community [21–25], especially in the wake of the Kyoto Protocol and anthropogenic climate change [26].

While Fanger's model has limitations of real life applicability, the adaptive model has the advantage of normality, so that people's responses are likely to be similar to those in daily life, and the environments fairly typical of the normal building stock [21]. Thermal comfort is considered as an example of a "complex Adaptive System" – a multitude of interacting non linear variables [27]. People are therefore studied in their everyday habitat in all its complexity, so as not to overlook important variables.

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Various psychological, behavioural and other adaptations as contributory factors towards the comprehensive feeling of thermal comfort are included in the adaptive model. In addition, field studies among the acclimatised population form the basis for the development of this model. It is also considered as a useful guide to design and energy decisions. It defines the range of conditions comfortable for the occupants within the available adaptive opportunities and climatic context [21,28]. In this context, the adaptive thermal comfort model assumes great importance in India. Thus, the objective of this study was to understand the thermal sensation, preference and acceptance of occupants living in naturally ventilated apartment buildings. In addition, it was aimed to evaluate the comfort band and the neutral temperature of the occupants moving towards the development of an adaptive model.

## 2. Methodology

A field survey was conducted in Hyderabad, situated at about N17°27′ and E78°28′ and 540 m above the mean sea level in the Deccan Plateau, in India. With a population of 5.7 million, spread over an area of 260 $km^2$, it is the capital of the state of Andhra Pradesh. It is the third most densely populated city in India having a population density of 21,067/$km^2$ [29]. It has 'composite climate' with four distinct seasons: winter, summer, monsoon and post monsoon [3].

### 2.1. Data collection

All the necessary permissions from the apartment owners' associations were obtained prior to the survey. The survey was carried out in two levels: transverse (level 2) and longitudinal (level 3). All the subjects were briefed about the survey, prior to the interview in all the transverse surveys. No briefing was necessary in longitudinal surveys as they were conducted, the day after the transverse survey in all the months. The subjects were studied under the transverse survey for one day and in longitudinal survey for the next four days every month. All the data recordings and interviews were conducted by the author herself, after the subjects/instruments have settled in the survey environment.

Every subject was interviewed thrice a day in both level 2 and level 3 surveys: morning, afternoon and evening between 7 am and 11 pm. On all the survey days, a minimum interval of two hours was maintained between any two interviews of a single subject. A fresh transverse questionnaire was used every time a subject was interviewed, whereas, the same longitudinal survey questionnaire was used for the three responses of a subject recorded in a day. A total of 33 days were spent in surveys spread in three months [30].

The survey questionnaires were based on McCartney et al. [31]. The transverse survey questionnaire was designed to contain mostly questions. The longitudinal survey had questions designed as phrases with check boxes for responses. The responses of the subjects in longitudinal survey were often recorded by the surveyor. In the transverse survey, the subjects had filled in the questionnaires themselves. The responses of some elderly subjects and non English/Telugu speaking subjects were however, recorded by the author herself.

The transverse questionnaire was translated into the local language 'Telugu' by the author, and was used after testing for similarity in meaning and semantics (Appendix A and B). The choice of the language was left to the subject. The longitudinal questionnaire was prepared only in English (Appendix C). Both the questionnaires had six sections namely: Apartment building and flat identification; back ground information; thermal comfort responses; clothing; activity level and adaptation methods. ASHRAE's seven point scale of thermal sensation, ASHRAE's nominal scale of acceptance, Nicol's five point scale of preference and four point scale of skin moisture were used in this study [28]. In addition, the transverse questionnaire had questions on sensation and preferences for other environmental parameters, behavioural and structural adaptations and tenure. Table 1 presents the thermal comfort scales used in this survey.

This study was aimed at obtaining the occupants' thermal comfort responses within the apartment buildings along with the diverse adaptation mechanisms and practices. Therefore it was necessary to record the indoor environment every time the subject answered the questionnaire. A set of hand held, calibrated digital instruments were used to measure the indoor environment, following a procedure consistent with the Class-II field experiment protocols for thermal comfort [28].

The indoor environmental variables measured were, air temperature ($T_i$), globe temperature ($T_g$), relative humidity (RH) and air velocity ($A_v$). Indoor air temperature and humidity were measured using "Sisedo" Hygro therm from China. Globe temperature was measured using "Eurolab" digital thermo meter, with its temperature probe at the centre of a black painted table tennis ball [32], as shown in Fig. 1.

Air velocity was measured using "Lutron" vane Anemometer (Model: AM-4201). As this instrument is unidirectional, in most of the cases, it could measure successfully the air velocity from a ceiling fan, found in all of the survey environments. However, when cross ventilation currents were observed, especially when the windows and doors were open, the air velocity was also measured by tilting the instrument perpendicular to the direction of flow. The average of all such air velocities recorded, was then taken as the air velocity in that survey environment. All the instruments were calibrated before and after the survey.

The instruments were placed at 1.1 m level from the floor, on a tray, fixed to a tripod stand. The tripod was placed close to the subject to record the environmental conditions simultaneously, as the subjects filled in the subjective thermal comfort questionnaire. The recording was done in living/dining rooms causing least disturbance, while the subjects were engaged in their routine activities (Fig. 1). The readings were noted down in separate data sheets and were later transferred onto the corresponding questionnaires at the end of every survey day. All the completed questionnaires

**Table 1**
Thermal comfort scales employed (transverse and longitudinal surveys).

| Scale value | Description of scale | | | |
|---|---|---|---|---|
| | ASHRAE 's thermal sensation (TS) | Nicol's thermal preference (TP) | Thermal acceptance (TA) | Skin moisture |
| 3 | Hot | | | Profuse |
| 2 | Warm | Much cooler | Acceptable | Moderate |
| 1 | Slightly warm | A bit cooler | Unacceptable | Slightly |
| 0 | Neutral | No change | | None |
| −1 | Slightly cool | A bit warmer | | |
| −2 | Cool | Much warmer | | |
| −3 | Cold | | | |