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Adaptive model of thermal comfort for offices in hot and humid climates of India

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ABSTRACT

The current Indian indoor comfort standards do not reflect the country's great cultural and climatic diversity. There have been very few reports on the actual environments in Indian offices in the last three decades. We conducted a thermal comfort field study in 28 naturally ventilated (NV) and air-conditioned (AC) offices in Chennai and Hyderabad for fourteen months, and collected 6048 responses from 2787 individuals. Warm humid and composite climates are experienced in these cities, and these two climates cover about 80% area of the country.

This paper proposes an adaptive thermal comfort model for South India based on this data. Mean comfort temperature was found to be 28.0 °C in NV mode, and 26.4 °C in AC mode on all data. Chennai had slightly higher comfort temperature. We found an adaptive relationship between the prevailing outdoor temperature and the comfortable indoor temperatures. Most of the environments in NV mode and about half in AC mode were warmer than the current Indian Standard upper limit (26 °C).

In most cases, the air speed was below 0.20 m/s. Most of the subjects used fans. Air speeds of 1 m/s increased the comfort temperature by 2.7 K in both the modes. Logistic regression predicted 87% and 50% fan usage at 29 °C in NV and AC modes respectively. Several factors prevented further thermal adaptation. We can potentially improve comfort and reduce air-conditioning by providing higher air speeds with energy-efficient fans. Such strategies may be vital given the scale of the scarcity of power.
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1. Introduction

India has vast climatological diversity. The temperature standards in the country do not reflect this [1]. The National Building Code of India (NBC) recommends two temperature ranges for all the buildings in any of the five climatic zones, and the same are followed by the local city governments as well [1,2]. These were modelled using the 1992 version of ASHRAE Std-55 [3], which is now superseded. Designers in India follow Fanger's [4] predicted mean vote (PMV) model. This model relies on steady-state heat transfer theory and laboratory experiments where subjects had little to no interaction with their environments, and has many limitations when used for estimating the thermal sensation of people in real buildings [5,6].

The implications of the direct application of PMV and the uniform temperature prescriptions in real buildings, and especially in warm environments, have been debated at length across the research community [5–7]. An alternative to the PMV approach is the adaptive thermal comfort model, which is based on the idea that outdoor climate influences indoor comfort because humans can adapt to different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors, such as having access to environmental controls, and past thermal history influence building occupants' thermal expectations and preferences [8].

In practice, there has begun a paradigm shift away from the 20th century goals of cool, dry, still air, provided by isothermal environments, towards more dynamic, an isothermal environments with spatial diversity, where occupants may undertake many behavioural and physiological adaptations [9]. The old paradigm of maintaining narrow indoor temperature ranges requires enormous energy. Arens et al. [7] question the relevance of maintaining these, when there is no significant improvement found in the thermal acceptability outcomes of the building

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when compared to a building with wider temperature fluctuations. The needs of India require these kind of fundamental shifts in our thinking about how to create comfort with minimal energy use.

1.1. Thermal comfort knowledge gaps in India

There are very few thermal comfort field study reports from office buildings in India in recent years. Indraganti et al. [10] reported the comfort conditions in summer and monsoon seasons in office buildings in Chennai and Hyderabad in South India. Comfort data from India is not included in the ASHRAE 884-RP databases, which formed the basis of the adaptive model in the ASHRAE Std-55 [11,8]. Even the recent thermal comfort studies reported from the sub-continent focussed mainly on: (1) residential apartment buildings in Hyderabad [12], (2) vernacular housing in the north-east region [13], (3) a railway terminal [14], (4) traditional housing in Kerala [15], (5) hostel buildings [16], (6) post occupancy evaluation of an office building [17] and (6) post occupancy evaluation for energy efficient design of Indian and UK offices [18]. Sharma and Ali's [19] research focussed on naturally ventilated buildings in Roorkie in North India. They recorded the comfort responses of 18 office occupants (six in each year) over a period of three consecutive summer seasons in circa 1978.

Office occupants and their comfort conditions in India are quite different from their counterparts from the west. These need to be investigated in detail in order to develop custom made comfort standards, which is a long drawn process. Field studies of actual thermal conditions and occupant response would also provide vital guidance for both the design and operation of new buildings or retrofits.

1.2. Power shortages in India

The energy deficit in India is increasing, with many associated economic implications [20]. The power shortages ranged from 3 to 18% all across the nation in 2013, with the southern region facing the highest shortage. The shortages increased significantly in the last few years [21]. For example, power shortages increased from 4.1 to 18.9% in Andhra Pradesh and 2.8–23.6% in Tamil Nadu over the last five years. The anticipated power deficit for the year 2012–13 in these two South Indian states of Andhra Pradesh and Tamil Nadu is 22.8% and 29.6% respectively. Simultaneously, the power consumption in the last half-decade has gone up by about 13.6% from 2004 to 2010 [21–23], with building sector consuming 187.9 million tons of oil equivalent [23]. This sector has the greatest energy saving potential, and the application of an adaptive model of thermal comfort based on field studies is a practical first step in achieving sustainable thermal comfort indoors [24].

1.3. Objectives

With the aforementioned issues in mind, this paper has the following objectives:

1. To investigate the thermal comfort conditions in Indian buildings used by the regular occupants
2. To study in detail the adaptation of the office occupants and to evaluate the actual comfort temperatures based on the field study data
3. To develop an adaptive model for Indian offices in these climatic zones
4. To find field evidence for the contribution of fans in achieving comfort in warm environments of India.

We undertook thermal comfort field studies for 14 months in 28 offices in two south Indian states, Andhra Pradesh and Tamil Nadu, during January 2012 to February 2013. We investigated the present thermal comfort conditions in these offices and examined the adaptive methods in use, aiming towards the development of an adaptive model of thermal comfort for this region. Indraganti et al. [10] reported the preliminary findings from the summer and southwest monsoon seasons, while this paper analyses the comfort conditions observed throughout the year.

2. Field survey

The field surveys were conducted in Chennai and Hyderabad, the capital cities of Tamil Nadu and Andhra Pradesh states in South India. Chennai (N13°04′ and E80° 17′ and 6.7 m above the mean sea level) has a warm, humid, wetland coastal climate. Hyderabad (N17°27′ and E78° 28′ and 540 m above the mean sea level) has a composite climate.

About 80% of the geographical area of the country experiences climates similar to these two cities. Both the climates have four seasons: winter, summer, southwest monsoon (SWM) and northeast monsoon (NEM). Overall, we collected 6048 sets of data in fourteen months of survey (Table 1).

2.1. The buildings surveyed

Twenty-eight ordinary office buildings located within a radius of 12–13 km of a metropolitan area were selected for the field study. The selection criteria included that the building should be (1) well-maintained, (2) under a management with occupants who would allow and participate in our year-long non-invasive survey, and (3) an office building in typical construction (brick/concrete and glass), where there are more than ten people working. There were originally 26 buildings, labelled C1 − C13 in Chennai and H1 − H13 in Hyderabad. Offices functioning in C5 and H11 were shifted to two new buildings, labelled as C5a and H11a respectively, and the survey was continued at these new locations, thus bringing the total number of buildings to 28.

In Chennai most of the surveyed buildings functioned in air-conditioned (AC) mode and in Hyderabad most of them had both (i.e. they combined operable windows with mechanical cooling, and switched between NV and AC modes.) Due to the state -wide power deficit [21], all the buildings faced a daily blackout for at least two hours throughout the year in Chennai, and in summer and SWM seasons in Hyderabad [25]. Buildings C3 and H7 had diesel operated on-site power generators to run

Table 1
Details of the data collection.

Case	Season (months)	NV	AC	AC_{off}
		(*N*)	(*N*)	(*N*)
Chennai	Winter (1 and 2)	38	446	81
	Summer (3, 4 and 5)	30	605	137
	SWM (6, 7, 8 and 9)	7	617	33
	NEM (10, 11 and 12)	57	854	2
Hyderabad	Winter (12, 1 and 2)	834	779	66
	Summer (3, 4 and 5)	112	563	40
	SWM (6, 7, 8 and 9)	177	268	23
	NEM (10 and 11)	97	178	4
All	1 to 12	1352	4310	386

N: Number of datasets collected; SWM: Southwest monsoon; NEM: Northeast monsoon.

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