Building and Environment 65 (2013) 195–214

Contents lists available at SciVerse ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Field investigation of comfort temperature in Indian office buildings: A case of Chennai and Hyderabad

Madhavi Indraganti [a,*], Ryozo Ooka [b], Hom B. Rijal [c]

[a] Department of Architecture, Center for the Built Environment (CBE), 390 Wurster Hall # 1839, University of California, Berkeley, CA 94720, USA
[b] Department of Human and Social Systems, Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 153-8505, Japan
[c] Department of Restoration Ecology and Built Environment, Tokyo City University, Yokohama, Japan

ARTICLE INFO

Article history:
Received 17 January 2013
Received in revised form
13 March 2013
Accepted 3 April 2013

Keywords:
India
Thermal comfort
Office buildings
Thermal adaptation
Comfort temperature
Comfort standards

ABSTRACT

India's building energy consumption is increasing rapidly. The subcontinent does not have custom made thermal comfort standards. There is little research in this field in the last 26 years. This leaves a lot to be investigated.

We conducted a thermal comfort field study in 25 office buildings in Chennai and Hyderabad for seven months during the summer and south west monsoon seasons in 2012 and collected 2612 datasets from 1658 subjects. The comfort temperature in naturally ventilated (AC off) (NV) mode was 27.6 °C and 28.1 °C in Chennai and Hyderabad respectively. In air conditioned (AC) mode, it was 27.0 °C and 26.1 °C in these two cities. These departed from the limits in the Indian National Building Code. Chennai recorded significantly higher indoor air speeds and thus higher comfort temperature. In 71% cases the air speed was less than 0.15 m/s, underscoring the need for improvement. A majority always sensed the air movement low and desired increased air speeds, despite voting comfortable.

Both the States grappled with daily outages throughout the survey period. All the buildings, excepting two were forced to run without the AC at least for 2 h daily, while none were prepared well for this. Several design and non-design factors seriously impeded environmental adaptation in buildings, limiting the adaptive operation of windows and fans. Consequentially, thermal acceptability was generally low (62.5%). This calls for architect's serious attention towards environmental and thermal adaptation in buildings, in the era of power paucity and prudent consumption.

1. Introduction

India ranks highest at 47% in its building energy use as a part of the final energy use (all sectors) among all the Asia Pacific Partnership countries with 169 million tonnes of oil equivalent being used in building sector [1,2]. This sector has the greatest energy saving potential. India now has high energy deficit in all the five regions ranging from 3 to 18% [3]. Therefore, it is essential for its building sector to adopt non-energy intensive systems with a low carbon foot print [4]. Kwok et al. [5] argue strongly for the inclusion of both mitigation of greenhouse gases and adaptation to climate change to our building codes and standards.

The National Building Code of India [6] specifies two narrow ranges of indoor comfort temperatures (21–23–26 °C) irrespective of the building type or location for winter and summer. These follow the ASHRAE's standard-55 [7], which is not validated on Indians or Indian buildings that is now superseded. Indian subjects are quite in contrast culturally with their western counterparts.

In the absence of the standards, the designers follow the stringent ASHRAE standard [8] and provide for fully air-conditioned (AC) environments to maintain a narrow range of hygro- thermal regime. Evidently, this leads to over design and enormous energy use in India. There is very little reported first hand in the last 27 years, on adaptive thermal comfort field studies in India, leaving a lot to be researched [9–11].

Moreover, the over glazed, open- plan, thin walled buildings designed in profligate disregard to climate or context, coupled with a uniform comfort temperature perform poorly in comparison to the well designed mixed mode (MM) buildings where AC is used only when indoor comfort is compromised.

Indian heating ventilation and air conditioning (HVAC) designers predominantly make use of the Fanger's predicted mean vote (PMV) model [12] to design the indoor environments. Researchers established with conclusive evidence that PMV differs significantly from the actual mean vote for both naturally

* Corresponding author. Tel.: +1 310 907 6882; fax: +1 510 643 5571.
E-mail addresses: maindraganti@hotmail.com, maindraganti@gmail.com (M. Indraganti).

0360-1323/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.04.007

ventilated (NV) and air conditioned (AC) buildings [13]. Therefore, the direct application of PMV for indoor environmental design leads to over cooling most of the time in India. On a national scale, this adds to the increasing energy deficit.

Power deficit in South India is very high and has increased significantly in the last decade. For example, Andhra Pradesh had a deficit of 4.4% in 2007–08, which went up to 18.9% in October 2012. Tamil Nadu faces higher deficit, with a much rapid increase: in 2007–08, the deficit was 2.8% which reached 23.6% in October 2013 [3]. Both the state governments have increased power tariffs heavily in the recent years [14].

In this context, it is important to take a note of the ubiquitous daily power blackouts. Daily power cuts ranging from 2 to 16 h are imposed for most part of the year all over South India. While metropolitan cities face outages for 2–4 h/day villages face 16–18 h/day almost the entire year. The duration of power outage depends on the level in the hierarchy of administrative subdivisions of the region, such as, metro, city, district head quarters, town, *mandal*, *panchayat*, village, hamlet etc. [15–17].

With its heat-balance approach and narrow temperature prescriptions, PMV model becomes too expensive to adhere in India. Arens et al. [18] found no difference in the comfort/acceptability outcomes of three different classes of buildings [19], with varying PMV ranges from −0.2 to +0.7. Furthermore, the recommendation and the consequences of uniform comfort standards were critically questioned by researchers across the globe [20,21].

PMV model is based on the climate chamber experiments of the 1960s [10], the conditions of which drastically differ from the real life settings of present day Indian offices. The adaptive model on the other hand, takes an exploratory approach based on field studies in real environments. This includes myriad adaptations people undertake to achieve comfort, which are too significant to be sidelined. Nicol et al. [22] define the adaptive comfort as a function of the possibilities for change as well as the real thermal conditions achieved. They further note the necessity of having thermal standards for buildings which clearly define the conditions conducive for adaptation rather than just the thermal boundaries of the indoor environment.

In order to develop an adaptive model, it is necessary to amass a large database from the local population. With this in view, we conducted a thermal comfort field study in warm humid and composite climatic zones of India during March–September 2012. These two zones cover an area of about 80% of the country [6]. The field study spanned summer and south west monsoon seasons in two important metropolitan cities in South India; Hyderabad and Chennai. The current paper discusses (a) the thermal comfort temperature, (b) the adaptation of the office users, (c) the role of air movement in achieving comfort at elevated temperatures and (d) the impediments to adaptation in these two cities in two seasons.

2. Methodology

Chennai (N13°04′ and E80° 17′ and 6.7 m above the mean sea level) has warm humid wet land coastal climate. Hyderabad (N17°27′ and E78° 28′ and 540 m above the mean sea level) has composite climate. These two South Indian cities have four major seasons: winter, summer, south-west monsoon and north east monsoon. The monsoon in Chennai is longer while winter is extended in Hyderabad. The seasons and the details of the data collected during these are shown in Table 1. Thermal comfort field studies were conducted in these cities from March to September 2012. The present paper deals with the findings of these surveys.

Table 1
Details of the seasons and the datasets collected.

Season	Months	Chennai		Hyderabad	
		NV	AC	NV	AC
Summer	3, 4, 5	167	605	152	563
South west Monsoon	6, 7, 8, 9	40	617	200	268

Chennai, the capital of Tamil Nadu state lies on the coast of Bay of Bengal while Hyderabad, the capital of Andhra Pradesh state sits on the Deccan plateau. Being a port town, Chennai has a large industrial base and is the fourth most populous metropolitan area (1189 km^2) in the country with a population of 8.92 million. It has a population density of 26,702 persons/km^2 in the metropolitan city area.

Largely known for its emerging role in the information technology and pharmaceutical industries, Hyderabad is the sixth largest city in India. It has a population of 7.75 million in the metro area and 6.8 million in the metropolitan city (18,480 persons/km^2).

2.1. Buildings and selection

We selected 25 buildings typical to the normal building stock, about a half from each city. They are numbered from C1 − C12 and H1 − H11 in Chennai and Hyderabad respectively. Buildings C7 to C11 are in an academic campus. The buildings C7- C11 and C6 are located in heavily landscaped campuses. In addition, the offices in buildings C5 and H11 were shifted to the new buildings C5a and H11a, respectively during course of the survey. All the buildings are situated in the metro areas of the cities. In Chennai the buildings are all located within a diameter of 26 km while in Hyderabad they are within 25 km diameter.

These are all multi storied buildings varying from two to sixteen floors and where possible all the floors were surveyed. Appendix 1 and 2 and Table 2 present the details of buildings and the subjects involved in each of these respectively. The buildings are all 1–30 years old in concrete post and beam construction with cement plastered brick infill walls, a typical construction method used locally. The ones built in the last five years have large expanses of curtain glazing in lieu of the brick walls and some operable windows. Some of the windows were fitted with sunshades and rain protection devices. Most of the fixed glazing/windows were provided with aluminium venetian blinds or had fabric curtains.

The investigated offices are the typical facilities that deal with computer operations, engineering and architectural design, technical discussions, administration etc. While most buildings are AC and MM, one building in Hyderabad had no air conditioners. All the buildings grappled daily with a minimum of 2 h of black-out, and were then run in AC off/naturally ventilated (NV) mode. Two buildings, H7 and C3 have large diesel power generators to run the air conditioners also during the outages that occurred during the office hours. In all the other buildings, diesel generators were used to power electric lights, computes and in some cases fans during the daily blackouts.

2.2. Data collection – field survey

We designed the transverse surveys in all the buildings with a periodicity of 3–6 weeks, after elaborate liaison with the heads of the departments and obtaining permissions. However, some offices refused the survey after the first few months. A few more moved to different locations within the cities. Therefore, we conducted the