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Air Conditioning, Comfort and Energy in India's Commercial Building Sector

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Abstract

Before India's building sector can fulfil its CO_2 abatement potential, it is imperative for new build projects, especially those which provide for commercial and public functions, to eschew the energy-intensive designs that characterized western commercial buildings of the 20th century. In the absence of an adaptive thermal comfort standard specifically for India's climatic and cultural context, the current trend is simply to design air-conditioned buildings to meet the stringent ASHRAE and ISO "*Class A*" comfort specifications. This paper proposes a holistic Post Occupancy Evaluation (POE) study of a cross section of Indian office buildings purposively stratified across a range of energy intensities with diverse environmental control systems and design approach in different climatic zones to develop an adaptive thermal comfort standard. By climatically adapting indoor design temperatures, the standard will offer India a low-carbon development pathway for its commercial building sector without compromising overall comfort or productivity.

Key words: climate change mitigation, adaptation, thermal comfort, India

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INTRODUCTION

The IPCC's most recent assessment (2007) of greenhouse gas emission mitigation potential identified the buildings sector as where the fastest and deepest cuts are likely to be made in the period up to 2030. Within the global buildings sector, the IPCC's mitigation assessment singled out the economies of China and India as the most promising, simply because of the extraordinary amount and pace of building construction that is taking place in their expanding economies. Before India's building sector can fulfil the CO_2 abatement potential it has been earmarked for, it is imperative for new build projects to eschew the energy-intensive designs that characterized western commercial buildings of the 20th century.

As noted in the McKinsey & Company report (2009), 80 percent of the India of 2030 is yet to be built, and it will be critical to manage emission growth while pursuing development. By following the high-carbon development pathways of warm/hot climate cities such as Singapore and Dubai, the rapid expansion of Grade A, air-conditioned office buildings are a key contributor to India's soaring demand for electricity over coming years [i].

The pressure on energy resources and concomitant CO_2 emissions that arise from adherence to stringent indoor comfort criteria is well recognised in Europe and North America. In India, the National Building Code (NBC) (BIS 2005) stipulates two ranges of inside design conditions that are uniformly set for air-conditioned office buildings regardless of their climatic location across the country. They closely reflect the now superseded ASHRAE prescriptions from last century(ASHRAE 1992), with summer design conditions falling between 23-26°C with relative humidity range of 50-60% and winter conditions between 21-23°C with relative humidity not to be less than 40% (see Part 8, Section 3, 4.4.3). Separately the NBC provides guidelines (see Part 8 Section 1) for designing natural ventilation which pertain to building placement, air flow rates, opening sizes and shading while noting that the *"TSI* (Tropical Summer Index after Sharma and Ali, 1986) *of a person lies between 25*°C *and 30*°C *with optimum condition at 27.5*°C.*"* (Part 8, Section 1, 5.2.3.1 - Limits of comfort and heat tolerance).

The *Energy Conservation Building Code* (ECBC) (BEE, 2007) for India was introduced in 2007 as the first stand-alone national building energy code to provide minimum requirements for the energy efficient design and construction of buildings. The ECBC cross references the NBC for its ventilation guidelines in naturally ventilated buildings, and in its accompanying user guide (BEE, 2009) recommends the de Dear and Brager adaptive comfort model (ASHRAE, 2004) as "additional information" for its users. However the ECBC remains silent on recommended temperature and humidity conditions for air conditioned buildings.

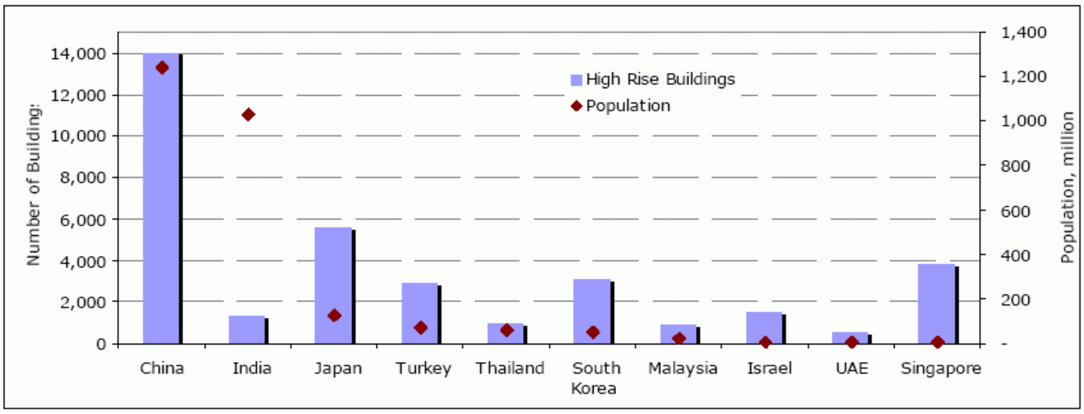
In the absence of a thermal comfort standard specifically focused on India's climatic and cultural context, the recent trend in India is to design air-conditioned office buildings (that often operate at 22.5 ± 1 °C all year round) to meet the stringent "Class A" comfort specifications articulated in documents such as the International Standardization Organization's comfort standard (ISO, 2005) and ASHRAE 55 guidelines for air-conditioned building i.e. emulate the worst of the west.

According to the International Energy Agency (IEA), the buildings sector accounted for the largest share (169 Mtoe[ii] or 47%) of India's final energy use between 1995 and 2005 (IEA 2007). While most of this is incurred in the residential sector (93% in 2005), energy use by the commercial sector is projected to increase very rapidly over coming decades as the sector experiences economic transformation. Emporis (2007) found that India has fewer high-rise buildings per capita than all the other active construction countries across Asia (See Figure 1). This "anomaly" infers a very high growth potential in building

[i] The International Energy Agency estimates that India's electricity generation capacity, most of it coal fired, will more than treble between 2005 and 2030 (IEA, 2009). Gross grid capacity augmentation within that timeframe will approximate 400 gigawatts; equal to the combined Japanese, South Korean and Australian generation capacity today.

ii Million tonnes of oil equivalent

construction into the future to accompany the phenomenal growth in India's economy. Overall commercial floor space is projected to grow at 7% per annum over the next 15 years, and office floor space alone is projected to grow at the rate of 12% per year during the same period (de la Rue du Can, S. et al. 2009). The demand for Grade A office space has increased very fast in India, with around 4.3 million m^2 in 2006 and 5.2 million m^2 in 2007 (Deutsche Bank, 2006). To date, the term "Grade A office" in India refers exclusively to buildings with central air conditioning operated with very tight indoor temperature control and 100% power backup on-site



Source: Emporis, 2007; Note: High-rise buildings are those taller than 20 m (68 feet)

Figure 1: High rise buildings and population for active construction countries across Asia

This increased demand for air-conditioned buildings in India has been attributed to an increased expectation for stable comfort conditions as the workforce shifts away from an industrial production towards a service-orientation that is office-based (Lall 2005). There is ample evidence to show that continuous provision of tightly controlled buildings in western countries has resulted in an elevation of thermal comfort expectations, and served to entrench an energy intensive approach to occupant comfort. Crudely mimicking 20th century mistakes will simply elevate Indian comfort expectations to levels that require unsustainable energy inputs, without substantially improving overall occupant comfort, satisfaction and productivity (Arens et al., 2010).

As noted elsewhere (Thomas 2006) much of the new construction adopts a climate rejecting approach:

> Typically these buildings have "clean" unshaded and extensive glazed facades, sealed windows and deep floor plates, complete with mini power stations capable of 100% generation in case of an electrical blackout. The appeal of such buildings appears to be driven by perceptions of image and appearance. An information sheet by developer DLF (2004) while acknowledging the cost and energy consequences of glass attributes its extensive use to "the influx of MNCs [multinational companies]" and the need "to be in line with the latest trends in the architecture as well as the market requirements for contemporary looking structures"

The irony of such a design approach coupled with a narrow comfort band is that it exacerbates the price paid for comfort when compared to a climate responsive approach based on limited glazing and integrated forms of passive environmental control with air conditioning being applied only when necessary. The built-in inefficiencies of extensive glazing, deep plans and sealed facades, not only increase heat loads and the quantum of cooling required, but also predicate the need for continuous air-conditioning all year round. Furthermore, any efforts to redress the consequent escalation in energy consumption through efficiency measures incurs a three-fold increase in costs for inclusion of high performance glazing and substantial increase in HVAC system costs (often double per unit capacity)

The increased pace and energy intensive nature of development described here exacerbates India's escalating peak electricity demand problem (low load factor). The penalty of a low load factor has more to do with economic inefficiency than environmental and climatic impacts. With peak demand episodes coinciding with weather and climate extremes (i.e. external loads on buildings with air conditioning), the Indian electricity generating sector will require ever increasing capital expenditure to augment generating capacity. For example, the International Energy Agency (IEA, 2009) estimates that India needs US $1.25 trillion in energy infrastructure from 2006 to 2030, and three quarters of this will go to the predominantly coal-fired electricity sector. However, much of that electricity infrastructure will remain idle outside heat-wave episodes. Since one of the main drivers of peak electricity demand in tropical and sub-tropical climate zones is air conditioning, and the penetration of air conditioning under current trends seems likely to increase dramatically as India's overall economic performance improves, the poor load factor on India's electricity grid will inevitably deteriorate further. By improving the grid's load factor the comfort standard resulting from this project can alleviate the infrastructural demands of India's air-conditioning induced peak demand problem.

THE ALTERNATE APPROACH - ADAPTIVE MODEL

The latest revision to ASHRAE's *Standard 55* included an adaptive comfort guideline for application in premises relying on passive design solutions to indoor comfort (ASHRAE 2004). In a nutshell the adaptive concept places the building occupant in charge of creating indoor thermal comfort by exercising a variety of adaptive opportunities such as operable windows, instead of exclusive reliance on energy-intensive HVAC for comfort. Buildings relying on natural ventilation are now permitted and encouraged by *Standard 55*'s linkage of the acceptable range of indoor comfort temperature limits to outdoor weather and climate. The warmer the external climatic context of the building – the warmer the indoor comfort range permitted under the North America's comfort standard (ASHRAE, 2004).

There are a number of built examples of low energy architecture in India such as Torrent Research Centre at Ahmedabad, Institute of Health Management Research at Jaipur, TERI University at New Delhi, TERI offices at Bangalore, Auroville buildings at Pondicherry, Centre for Environment Education at Ahmedabad, Centre for Development Studies at Trivandrum, to name just a few. Environmental control in these buildings is designed and achieved through passive means, sometimes in conjunction with alternate low energy cooling systems which do not rely on refrigerant cooling and in other cases in a mixed mode of operation where supplementary air conditioning is used only when conditions ride outside the acceptable comfort range. (see also Majumdar, 2001)

An independent study (Thomas 2006) of two low energy buildings (Torrent Research Centre in Ahmedabad, and the Transport Corporation of India, New Delhi) revealed positive feedback in terms of low energy and occupant satisfaction. More than five years after their completion, the study adopted the Building Use Studies methodology to elicit overall satisfaction with indoor environmental quality, including thermal comfort.

At Torrent Research Centre, passive downdraft evaporative cooling (PDEC) was implemented in four of the six buildings based on the willingness of the client to accept the approach of designing for a threshold temperature (28-28.5ºC, based on a model of adaptive comfort) which could be exceeded for a certain number of hours per year, rather than the stringent comfort band of conventional air conditioned buildings. Despite the warmer temperature regime, the survey revealed a high level of user satisfaction for overall comfort and thermal comfort in the PDEC buildings with mean scores that were significantly better than scale midpoint and international benchmarks (Thomas, 2006; Thomas 2010). On a seven point scale where 1 is worst and 7 is best, the building scored 4.61 in Temperature overall in summer, 4.97 in monsoon, and 5.84 in winter and 5.16 for Overall Comfort (n=100).

Transport Corporation of India headquarters building at Gurgaon, New Delhi (Thomas, 2006) was designed in a climate responsive manner with attention to minimising solar heat loads while maximising daylight availability. Although an air-conditioned building, the thermostat settings (24±1ºC) exceed international "norms" with space temperatures routinely above 26 ºC. The survey of occupants in this building also established a high level of user satisfaction for thermal comfort and comfort overall. On a seven point scale where 1 is worst and 7 is best, the building scored 5.73 for Temperature overall in summer, 5.53 in monsoon, and 5.91 in winter and 5.50 for Overall Comfort (n=94).

Willingness to accept higher temperatures has also been recorded in residential buildings. A field study of occupants in apartment buildings in hot dry climates found the upper comfort limit to be as high as 31.7 and 33.3 ºC, depending on respondents' socio-economic group (Indraganti, 2010).

When designing office buildings and workplaces, it is also acknowledged (See Lall, 2010 paper to this conference) that low energy strategies require sophistication to compete with air-conditioning. Further it is noted that in some cases changed circumstances such as increased densities or traffic noise causes the building to changeover to air conditioning. Anecdotal evidence also suggests that once air conditioning has been tasted there is a resistance to settling for anything less comfortable and in some case

The tolerance of warmer internal conditions seen in the two case studies corroborate Nicol and Humphreys' (2002) assertion that "*optimal indoor environments in a building are a function of its form, its services* [the researchers define this to include controls and building management] *and the climate in which it is placed* following their extensive work in this field across a number of countries.

Although the case studies did not include a coincident study of thermal comfort and measured environmental parameters "on the spot", results from the two buildings suggest that is possible to achieve low energy outcomes and occupant comfort in free running buildings and in air conditioned office buildings where internal temperatures are allowed to vary across a wider adaptive range of temperatures than would be permissible under Class A comfort specifications.

THE PROPOSED STUDY

This study will develop a contextual design approach to comfort that is cognisant of the greenhouse emissions abatement potential of naturally ventilated (free running) and mixed mode (partially naturally ventilated, partially air conditioned) buildings. Based on a culturally-relevant and climatically-appropriate approach, the thermal comfort standard envisaged in this project will mitigate the energy-intensive overcooling that is evident in much of India's recent office developments. It should be clear that the goal is not to compromise levels of comfort, but rather to demonstrate a much wider-than-usual band of comfort deemed acceptable whenever occupants are permitted to adapt to their indoor environment.

The profligate energy consumption and related greenhouse gas emissions that arise from the current default assumption of full air-conditioning, controlled within a narrow temperature band, far outweighs the greenhouse gas savings that are likely to accrue by just addressing technical aspects of building envelope design and HVAC equipment efficiency in isolation. Evidence from much milder climates than India's suggests that even a modest single degree increase in thermostat setting can reduce HVAC energy consumption by as much as 14% (Ward and White 2007).

As noted in the preceding sections mixed mode systems have the potential to drastically reduce energy consumption whilst providing affordable thermal comfort for the majority. While it is important to get the professional bodies to accept and formalise the wider parameters for comfort in the interest of energy economy, an additional challenge lies in optimising the design of mixed mode systems to achieve a symbiosis between comfort expectations, adaptive behaviour by occupants and "seamless" mixed mode low energy design.

In developing energy efficient adaptive comfort guidelines for Indian commercial and public buildings in the broader context of climate change, this project will:

- Validate the adaptive relationship between subjective thermal comfort indoors and the outdoor climatic conditions in India's three most populous climate zones.
- Develop a comfort-energy index that facilitates rational comparisons across the full spectrum of air-conditioned, mixed mode and naturally ventilated commercial buildings.
- Regionalise the adaptive comfort model for Indian climatic contexts and cultural expectations.

The project will focus on the three climatic regions; Warm-Humid, Composite, and Hot Dry, which account for more than the vast majority of India's urban development. These climate zones also encompass all metropolitan and regional cities. The study will focus on a range of office environments, from multinational offices in "Grade A" air-conditioned buildings, through to institutional and public buildings that are often developed with more flexibility in their environmental comfort controls. Such an approach will ensure that the findings will have a relevance not only to "upmarket" (Grade A) commercial buildings where a culture of total air-conditioning currently predominates, but also provide critical feedback for public and institutional buildings that are well-suited to a low energy and low carbon mode of comfort.

The proposed approach will bring together extensively validated research methodologies, beginning with site visits and documentation of the building as designed and operated and an in-depth Post Occupancy Evaluation (POE) study to elicit overall user experience in the building. This will be followed-up with a more focused occupant evaluation of thermal comfort and the work-place while concurrent and observations of indoor climatic conditions are made with state-of-the-art portable instrumentation. These sources of data will be complemented with observations of operational energy consumed in the provision of occupant comfort and concurrent outdoor weather conditions.

We propose comprehensively covering a range of buildings in order to better understand the nature of comfort expectations as they relate to the various indoor environmental control systems commonly in use across the Indian commercial buildings sector. In each of the three main Indian climatic zones, it is proposed to study a minimum of five different buildings, each with a different approach to indoor environmental control, thereby enabling the study to capture the diversity of commercial building environments. The five environmental control strategies being targeted in our building sample include:

1. Naturally ventilated with no active heating or cooling systems (other than ceiling fans). This category would typically consist of old-style workplaces, and/or passive buildings designed in accordance with traditional climate-responsive bioclimatic principles.
2. "Old style" mixed-mode buildings. Naturally ventilated buildings with supplementary air-conditioning to manage discomfort in extreme weather conditions.
3. Grade-A air conditioned office buildings. Buildings designed in the "Dubai style." These contemporary buildings are currently proliferating in India's rapidly growing urban centres and are characterised by extensive use of under-performing envelope materials (notably unshaded glass), fully sealed facades, and intensive air-conditioning.
4. Energy efficient air-conditioned buildings. Contemporary office buildings where there is a clear energy efficient design intent.
5. Mixed mode green buildings. High-performance contemporary office buildings which operate in passive mode (natural ventilation) for a substantial period of the climatic year, but integrate compressor-based air conditioning for use during weather extremes. In many cases these are owner occupied offices and institutional and public buildings.

The study will generate the following data:

Overall occupant experience of the building, as designed and operated

Overall occupant satisfaction with indoor environmental quality, including lighting, thermal, air quality and noise, as well as perceived productivity and health will be assessed through the administration of an occupant survey. The survey tool will be based on the Building Use Studies Workplace Questionnaire which has been used in over 300 buildings worldwide (Leaman and Bordass, 2001; 2007), including four buildings in India. The questionnaire has been selected for its extensively validated capacity to provide robust feedback on overall comfort, temperature, air movement and quality, lighting, noise, productivity, health, design, image and workplace needs. Perceived productivity and health as related to indoor environmental conditions are widely regarded within the indoor environmental research community as the best available indicators, and enables comparison across buildings (Leaman and Bordass, 2001). While feedback from the buildings can be compared against international norms and benchmarks, the coverage of a minimum of 15 buildings across the 3 predominantly warm-to-hot climatic regions will enable establishment of Indian benchmarks against which building-by-building comparisons can then be made.

The POE questionnaires will be accompanied by a site visit to gain a first-hand understanding of contextual issues such as building design and layout, access to daylight, views, modes of workplace usage (including occupant and equipment loads and intensities) and relevant design-related information as to office fit-out, floor-plan peculiarities, furniture layout and environmental control systems.

Workplace thermal comfort

This aspect of the study follows the *de facto* international protocol developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (de Dear and Brager, 1998). In order to establish the range of environmental conditions deemed acceptable, a detailed survey will be performed to elicit thermal comfort, occupant metabolic regimes, and clothing customs in our sample of office buildings across India. At the same time as the comfort interviews are being performed, researchers will take coincident measurements of the key environmental comfort parameters - air temperature, mean radiant temperature, relative humidity and air velocity at the respondent's workstation. The use of carefully calibrated hand-held equipment will deliver the requisite precision for the project's objectives to be achieved. It should be noted that pilot studies for this project have already been performed (late 2008) to ensure that the survey methodology is appropriate for the Indian cultural context. To ensure adequate coverage of a wide range of conditions the thermal comfort surveys will be repeated at three seasonally distinct times of year.

Operational energy consumption related to the provision of comfort

During the study period, an walk-through energy audit of each building in our sample will be performed to identify energy systems being used to provide indoor comfort (heating, ventilation and air-conditioning or HVAC), as separate from other energy uses like lighting, and office equipment. Digital metering will be installed (an average of two meters per building) to monitor the energy used for HVAC functions only. The HVAC energy use data will be collected monthly to enable the development of the comfort energy intensity index as a function of comfort expectations.

Logging of concurrent outdoor weather conditions

Since the independent variable in both recent European (BS EN 15251, 2007) and North American (ASHRAE, 2004) adaptive comfort standards is the mean of outdoor temperature, the present research design includes logging weather conditions prevailing outside the Indian office buildings included in our samples. This approach will enable us to quantitatively define the dependence of thermally acceptable indoor temperature ranges on weather conditions prevailing outdoors, specifically within the Indian context. Our outdoor weather observations will be supplemented with official data recorded by the Indian Meteorological Organization in each of the cities being surveyed.

EXPECTED OUTCOMES AND CONCLUSIONS

Given India's rapid economic growth and concomitant expansion in its commercial sector, much of the country's 2030 commercial building stock is yet to be designed, but soaring demand for air-conditioning can be confidently predicted. Air-conditioning in warm-to-hot climates represents the single-largest energy end-use in commercial buildings. If permitted to grow unchecked, India's air-conditioning will add further pressure on the country's electricity infrastructure and exacerbate the already extreme peak-demand problem. Furthermore, given that much of India's future electricity capacity will be derived from imported fossil fuels, air conditioning under the business-as-usual scenario will deteriorate the country's energy security and add significantly to its CO_2 emissions. With its 2030 contribution to global CO_2 emissions predicted to be third behind the USA's and China's, rapid deployment of cost-effective CO_2 abatement strategies in India is in the planet's best interests. In the context of spiralling CO_2 emissions, this study offers the opportunity to rethink the assumption prevailing within India's commercial property and construction sector that greater energy inputs translate automatically to improved occupant comfort.

It is expected that the study across a range of environmental control systems and comfort regimes will enable the identification of an optimum approach for achieving comfortable low energy intensive buildings. The main research outcome of this project will be a database of occupant comfort, thermal performance and energy consumption observations across a cross-section of commercial office/public buildings located in the main climate zones of India. This resource will form the empirical basis for a draft standard for thermal comfort in India's commercial building sector. The analytical procedures that transformed ASHRAE's comfort field studies into the North American adaptive comfort standard (ASHRAE, 2004; de Dear and Brager, 1998) will form the template for our Indian adaptive comfort standard to be developed in the present project.

The study outcomes for climate-appropriate indoor comfort standards for India, and come at a time when the Bureau of Energy Efficiency's follow-up to its Energy Conservation Building Code for India (2007) is beginning to focus on appropriate thermal comfort regimes for India[iii].

The comprehensive post occupancy evaluation studies of 15 buildings will also generate a rich database of building environmental performance for the different building typologies, design attributes and environmental control systems, as well as a set of regional benchmarks of user experience specific to the Indian cultural context. The detailed insights gained from the POE studies will be beneficial for development of future buildings.

The adaptive comfort model that will be generated has the potential to transform both existing buildings and new build projects. As discussed above, previous research has shown significant savings in energy for small changes to thermostat settings in existing buildings. Furthermore, embedding the adaptive model of comfort into future building stock will enable a greater reliance on natural ventilation and mixed mode systems that will, in turn, generate substantive savings in energy costs and greenhouse gas emissions.

[iii] personal communication, Dr Ajay Mathur, Director General Bureau Of Energy Efficiency, Government of India, December 2009.

In this manner the study outcomes are directly supporting India’s transition to a low-carbon economy.

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