An Introduction to the India Model for Adaptive (Thermal) Comfort

IMAC 2014

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Introduction

Buildings represent around 40% of world's primary energy consumption. They are, therefore, directly responsible for increase in greenhouse gases and can play a key role in climate change adaptation. To achieve an energy efficient building regime, governments, businesses and individuals must transform the way buildings are designed, built and operated. Energy consumption in new and existing buildings can be reduced through design interventions, low-energy systems and behavioural changes.

In India, electricity demand already exceeds supply. The largest and most significant end use of electricity in commercial buildings is air-conditioning. The rapid growth in new floor space combined with an increase in thermal comfort expectations and aspirations, will lead to a surge in demand for air conditioning. If permitted unchecked, the growth in building air-conditioning will add immense pressure on electricity infrastructure and exacerbate the already extreme peak-demand problem in the country.

In order to prevent an increase in energy use associated with space cooling, the deployment of low energy adaptive strategies in building operation is critical. This could also help increase our resilience to the effects of climate change. When the occupants are allowed to adapt to a building's environment by means of adjusting their clothing, cooling or heating set points, operation of windows, or any other measures, they are able to tolerate a wider range of environmental conditions, which, in turn, helps save energy. At present, the predominant trend in India is to design air-conditioned office buildings that operate at 22.5 ± 1°C all year round to meet the stringent specifications outlined by ISO 2005 and ASHRAE 55. These buildings are designed as sealed and fully controlled environments, and do not take advantage of favourable outdoor conditions whenever available. This conventional approach to design and development of air conditioned buildings may elevate Indian comfort expectations to levels that require unsustainable energy inputs.

An Adaptive Thermal Comfort standard can play a major role in reducing energy use whilst maintaining the comfort, productivity and well-being of occupants. It recognises that people's thermal comfort needs depend on their past and present context and that these needs vary with the outdoor environmental conditions of their location. People living year-round in air-conditioned spaces are likely to develop high expectations for homogeneity and cool temperatures, and may become quite critical if thermal conditions deviate from the centre of the comfort zone they have come to expect. In contrast, people who live or work in naturally ventilated buildings, where they are able to control their immediate interior spaces, get accustomed to variable indoor thermal conditions that reflect local patterns of daily and seasonal climate changes. Their thermal perceptions – preferences as well as tolerances – are likely to extend over a wider range of temperatures than are currently reflected in the currently practiced standards.

The ASHRAE 55-2010 standard includes an adaptive thermal comfort model to differentiate the thermal response of occupants in air conditioned and naturally ventilated buildings. However, until now there has been a lack of a contextual model for adaptive thermal comfort for India, even though a large proportion of existing as well as new buildings are either fully naturally ventilated or use natural ventilation for most part of the year, supplemented by air-conditioning. In order to address the lack of thermal comfort guidelines that recognise the climatic and workplace context of Indian offices, the India Model for Adaptive (Thermal) Comfort Study was initiated in January 2012. A standard based on an India specific model would provide design and operation guidance for air-conditioned as well as naturally ventilated buildings. It would allow buildings to operate within broader temperature bands. The specification of a broader comfort band suited to the Indian context has the potential to reduce the use of energy intensive space cooling for Indian buildings.

Study Approach

The 'IMAC 2014' model is developed from the data collected over four survey campaigns in office buildings conducted over a period of one year. These surveys were administered in five Indian cities selected as representative locations for the five climate zones prevalent in India – warm & humid, hot & dry, composite, moderate and cold. In order to document a wide range of indoor environmental conditions, surveys were administered in naturally ventilated, mixed-mode and air conditioned buildings in these five cities during summer, winter and monsoon seasons. The instantaneous thermal comfort surveys (TCS), which were repeated every season, gathered responses related to thermal sensation, preference and acceptability, air movement satisfaction and preference, clothing and activity. These were accompanied by simultaneous measurement of the indoor environmental parameters – air temperature, globe temperature, relative humidity and air velocity. Building Use Studies (BUS) methodology[1] was also used as a post-occupancy evaluation tool to gather long-term responses.[2] It included questions framed to draw responses related to the workspace environment on a seasonal basis from past experiences of the respondents. The BUS questionnaire covered aspects such as thermal comfort, ventilation, lighting, noise, indoor air quality and personal control. A total of 6330 TCS and 2002 BUS responses were gathered from 16 buildings under the IMAC 2014 project.[3]

IMAC 2012 derives a significant part of its methodology and analysis design from the ASHRAE RP-884[4] document. It also refers to the CEN Standard EN15251[5] for alternative analysis steps. A key extension is the manner in which the IMAC study recognises and analyses mixed mode buildings which are increasingly prevalent in India. In the IMAC study, buildings that did not have any mechanical cooling or air-conditioning systems installed and had ceiling fans and operable windows, were classified as purely naturally ventilated (NV) buildings. Survey responses from NV buildings were separated from those of the mixed-mode buildings working in naturally ventilated mode at the time of the survey (NV_{mm}). Even though the indoor conditions follow the outdoor in both NV and NV_{mm}, the premise for this distinction is that the occupants in NV_{mm} mode experience AC (air conditioned mode) for a part of the year and, therefore, may have different responses to, and expectations from, the thermal environment of the work space, as compared to those who never experience AC at work. This classification was done during the analysis of the study and it was found that none of the buildings in the composite climate zone could be categorized as NV.[6] Similarly, responses from AC buildings were differentiated from those of the mixed-mode buildings working in air conditioned mode at the time of the survey. The latter were aggregated under the AC_{mm} category. These four categories of NV, NV_{mm}, AC and AC_{mm} are maintained throughout the analysis.

Rigorous quality assurance protocols were developed to check the data at various stages of manual (on-site) data entry and off-site digitization. Erroneous data points were either standardized (according to the protocols established for each variable) or removed based on the degree of error.

In the first stage of analysis, the observed and predicted sensation was correlated with two indoor environmental indices - indoor operative temperature (*top*) and new effective temperature (*et**). This relationship, defined by a simple linear regression model, helped derive the neutrality or neutral temperature. Neutrality is defined as the indoor temperature (in this case, it is expressed in terms of *top* or *et**) at which majority of occupants are likely to feel 'neutral' towards their indoor thermal environment.

In the second stage of analysis, thermal adaptation with change in outdoor conditions was assessed by correlating neutrality with the outdoor temperature. Limits were derived for 80% and 90% acceptability. During the course of the analysis, multiple models were prepared based on different methodologies for calculating neutralities, various indoor and outdoor indices used and the alternative approaches to derive the acceptability limits.

Study Outcomes

A significant finding of the IMAC study is that occupants in Indian offices are more adaptive and tolerant of warmer temperatures. The difference between predicted sensation, derived from Fanger's static PMV model, and observed sensation, derived from occupant responses, showed significant variations ranging from 0.5 unit sensation vote at 23°C indoor *top*, to 1 unit at 29°C for AC dataset, where the predicted sensation was always warmer than the observed. This indicated that the PMV model over-predicted the sensation on the warmer side of the 7-point sensation scale, and that the occupants in Indian offices were more adaptive, even in the AC buildings. Even where both predicted and observed sensation was on the warmer end of the scale at higher indoor temperatures, the predicted sensation was always higher than the observed sensation for all building types. The study results clearly show that the occupants felt cooler than predicted by the PMV model, indicating higher adaptability.

Analysis using Griffith's method used in developing adaptive comfort equations for EN15251, which uses average sensitivity of the dataset to calculate neutrality, showed that in AC buildings, there was a unit change in sensation vote for every 4°C change in indoor temperature, while in NV buildings a unit change in sensation occurred at a 7°C variation. *This indicates that, on an average, occupants in AC buildings were twice as sensitive as occupants in NV buildings*.

The IMAC study proposes two variations of the adaptivemodel as being most appropriate for Indian context. In the first model, neutralities have been derived from the ASHRAE RP-884 method. In the second, Griffith's method has been deployed but it has been contextualised for the Indian dataset. In both models, the neutral indoor *top* is related to the 7-day weighted outdoor running mean air temperature. Each model presents this relationship as four equations for the four building types – NV, NV_{mm}, AC and AC_{mm}. IMAC models are also compared with the ASHRAE 55 and EN15251 adaptive models.

From the IMAC 2014 models, it is clear that in AC buildings, the temperature at which occupants feel 'neutral' does not vary much (24-25°C neutral *top*) with outdoor temperature (16-38°C), which is consistent with the findings from other international studies. However, occupants in AC buildings show a wider acceptance of the indoor temperatures. The model predicts that 90% of the occupants will find the indoor environment acceptable within ±2°C of the neutral temperature, in other words, between 22-27°C indoor *top*. The results clearly question trends to operate buildings at 22.5 ± 1°C all year round.

The models indicate that occupants in NV buildings thermally adapt to the outdoor temperature of their location. The neutral temperature for NV building varies from 20.5-28.5°C for the observed outdoor range with 90% acceptability in the range of ±2.4°C of the neutral temperature.

Mixed mode buildings, where AC is operated only during extreme outdoor conditions, are becoming prevalent in India. Results from the IMAC study show that the occupants in mixed mode buildings (NV_{mm} and AC_{mm}) are more adaptive when compared to those in AC buildings and less adaptive compared to occupants in NV buildings.

The IMAC study models for neutral temperatures and acceptability limits for air-conditioned, naturally ventilated, and mixed mode buildings, as derived through an empirical field study specific to the Indian context, offer an energy efficient pathway for its commercial building sector without compromising occupant comfort.

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