Occupant feedback in air conditioned and mixed-mode office buildings in India

Sanyogita Manu1, Chinmay Patel1, Rajan Rawal1, Gail Brager2

1Centre for Advanced Research in Building Science and Energy, CEPT University, Ahmedabad, India
2Centre for the Built Environment, UC Berkeley

Abstract
India has a largely cooling dominated climate where space cooling accounts for approximately 31% of the energy consumed by commercial buildings. Deeper market penetration of air conditioning systems, higher income levels driving higher comfort expectations, and growing floor space have led to a steep rise in associated carbon emissions. India needs to adopt an energy efficient regime in which governments, businesses and individuals transform the way buildings are designed, built and operated, while still maintaining high levels of occupant satisfaction.

Two diverse approaches are practiced in India to achieve energy efficiency. The first relies on passive design strategies based on traditional wisdom. The second relies on high-performance HVAC building conditioning systems. Most Indian climate zones offer opportunities to design and operate buildings as naturally ventilated or mixed-mode. But such design practices need to be promoted on the basis of scientific studies related to occupant behavior, comfort and associated energy consumption.

This paper evaluates occupant satisfaction in a mix of consciously-designed air conditioned and mixed-mode buildings based on online surveys, and limited physical measurements. The survey includes questions about thermal comfort, indoor air quality, air movement, acoustics and adaptive controls such as windows and fans. The paper offers an understanding about the perception and behavior of occupants in mixed-mode buildings in various climate zones of India to help identify strategies to promote efficient mixed-mode buildings in both India and other regions.

Keywords: Occupant satisfaction, Post-occupancy evaluation, Mixed-mode buildings, Thermal comfort, Indian offices

1 Introduction
India boasts a rich tradition of naturally ventilated buildings with context-specific passive design strategies. Until 10-15 years back, naturally ventilated buildings were the norm for most building types. With better penetration of air conditioning systems in the market, higher incomes resulting in higher comfort expectations and the rapid increase in built-up floor space, air conditioned buildings increased in numbers. Today, many people perceive air conditioning as a requirement, rather than a luxury. Most of the new buildings have air conditioning and many of the old ones are being retrofitted with conditioning systems. This has resulted in a wide array of mixed mode buildings that operate in naturally ventilated mode when the outdoor conditions are favourable and switch over to air conditioning during the extreme conditions. They usually have operable windows and ceiling fans.
Since India has a predominantly warm to hot weather, air conditioning generally refers to cooling and mechanical ventilation. During the mild winter season, the cooling is turned off and the windows are either inoperable or kept shut. Buildings with inoperable windows generally have better air-tightness. That is why new air conditioned buildings with sealed envelopes tend to be more energy-efficient than old buildings that are retrofitted, since the latter are originally designed to operate in naturally ventilated mode.

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. To this end, an India specific adaptive thermal comfort model (IMAC) was recently published based on extensive field study of Indian offices in five climate zones and three seasons (Manu, Shukla, Rawal, Thomas, & de Dear, 2016). The results from this study prove that the neutralities predicted by the IMAC models for naturally ventilated buildings followed the outdoor temperatures more closely than the existing international adaptive models for free-running buildings. However, the most significant contribution of the IMAC study was to propose a single, valid and robust adaptive model for mixed-mode buildings where the neutral temperatures ride (not surprisingly) lower than the ASHRAE and EN15251 free running models. For mixed-mode buildings, the IMAC study also shows evidence of neutral temperatures of up to 28.4˚C when outdoor conditions ride at 38-40˚C (Manu et al., 2016).

In addition to implementing an India-specific adaptive comfort model, it is important to understand the performance and operation of mixed-mode buildings in more detail from an occupant’s perspective since a majority of the building stock is increasingly becoming mixed-mode. Occupant surveys are important tools to measure the performance of buildings.

A paper analysing over 34,000 survey responses to air quality and thermal comfort questions in 215 buildings across US, Canada and Finland (C Huizenga, Abbaszadeh, Zagreus, & Arens, 2006), clearly indicated that only 11% of buildings had 80% or more satisfied occupants. Only 26% of buildings met the (then current) ASHRAE Standard 62.1-2004 standards for acceptable air quality.

In a study of web-based survey responses from 351 US office buildings, the researchers concluded that satisfaction with the amount of space, noise level and visual privacy were the most important parameters for overall workspace satisfaction (Frontczak et al., 2012). Another study based on the same database used Kano’s model of satisfaction and identified ‘temperature’ and ‘noise level’ as basic IEQ factors (Kim & de Dear, 2011). This means that a building’s poor performance in terms of thermal and acoustic performance has a significant negative impact on overall satisfaction levels. Air quality and lighting were assigned to the group of proportional factors exerting negative or positive impacts of comparable intensity on overall occupant satisfaction.

In another study that analysed over 43,000 individual responses to the CBE web-based survey, mixed-mode buildings were found to be performing much better than the overall building stock with regard to thermal comfort and air quality (Brager & Baker, 2009). A post-occupancy
evaluation of a building in Australia highlighted the importance of increased fresh air, daylight, glare control, access to views, noise management, low VOC finishes towards improving user experience of indoor environmental quality (Thomas, 2009). A survey on workplace occupant satisfaction in 16 office buildings in Germany revealed that the occupants’ control of the indoor climate, and the perceived effect of those interventions, strongly influenced their satisfaction with thermal indoor conditions (Wagner, Gossauer, Moosmann, Gropp, & Leonhart, 2007).

The design and operation of HVAC systems aims for an optimum ‘steady-state’ temperature setting based on Fanger’s PMV-PPD model (Fanger, 1970) to provide acceptable thermal comfort (Drake, de Dear, Alessi, & Deuble, 2010). The studies cited here indicate that this ‘static’ approach to thermal comfort in air-conditioned buildings may be detrimental to occupant satisfaction and that a ‘person-centred’ approach to provide variability across time and space is important (Brager & de Dear, 1998). Therefore, it is important to design mixed-mode buildings to operate effectively in both naturally ventilated and air-conditioned modes without compromising occupant thermal comfort and indoor air quality. It is also important to operate these buildings to take advantage of their ‘dual’ character in an optimal way. In order to do this, one must understand the performance of a range of MM buildings in terms of occupant satisfaction and gain an insight into how occupants use these buildings.

2 Methods

2.1 CBE survey

The CBE web-based survey tool (Charlie Huizenga, Laeser, & Arens, 2002) is an efficient way of remotely getting occupant feedback on indoor environmental quality (IEQ) and various other aspects of the building. The survey consists of a core module with eight IEQ categories and additional modules such as window and fan usage. The phrasing of the questions and options were tailored to suit the local culture and parlance to use the surveys effectively in Indian offices. The survey asked occupants to rate their satisfaction with these different aspects on a 7-point scale that ranged from -3 (Very dissatisfied) to 0 (Neutral) to +3 (Very satisfied). The tool also has a unique feature that is helpful for diagnostic purposes; when an occupant votes to be dissatisfied in any category, the tool automatically follows up with branching questions that ask about the reasons for dissatisfaction. Details about the building features such as floor area, number of occupants, LEED compliance and type of HVAC system, envelope and glazing are filled out by the building manager separately. More details about the CBE survey tool can be found in (Zagreus, Huizenga, Arens, & Lehrer, 2004). A list of the most relevant survey questions for this study is illustrated in Table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Questions asked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal comfort</td>
<td>Satisfaction with temperature, ability to control temperature, physical comfort</td>
</tr>
<tr>
<td></td>
<td>during summer</td>
</tr>
<tr>
<td>Indoor air quality</td>
<td>Satisfaction with air quality (i.e. stuffy/stale, cleanliness, odors)</td>
</tr>
<tr>
<td>Air movement</td>
<td>Satisfaction with amount of air movement, ability to control amount of air</td>
</tr>
<tr>
<td>Window usage</td>
<td>Satisfaction with operable windows (summer and winter and monsoon)</td>
</tr>
<tr>
<td></td>
<td>Importance of having an operable window to the user</td>
</tr>
<tr>
<td>Category</td>
<td>Questions asked</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Times adjusted (daily, weekly, monthly)</td>
<td>Time of adjustment Reasons to ‘open’ or ‘close’ a window</td>
</tr>
<tr>
<td>Fan usage</td>
<td>Satisfaction with ceiling fans, Times adjusted during summer (daily, weekly, monthly), Time of adjustment, Reasons to turn ‘on’ or ‘off’ a fan</td>
</tr>
</tbody>
</table>

2.2 Building selection

The survey was administered in 9 buildings across three climate zones of India – hot and dry (H&D), warm and humid (W&H) and composite (CT). Table 1 lists the buildings with their locations and availability of operable ceiling fans and windows. The buildings were classified into three categories:

1. Spatial mixed-mode (SMM) where certain zones of the building are air conditioned and others operate in natural ventilation mode across the year. Such buildings have provisions for operable windows and ceilings fans.
2. Temporal mixed-mode (TMM) where the entire building is air conditioned and switched over between AC and NV modes based on the outdoor conditions. Such buildings have provisions for operable windows and ceilings fans.
3. Air conditioned mode (AC) where the buildings are air conditioned for most part of the year. When outdoor conditions are sufficiently favourable for the MAC to be turned off, mechanical ventilation may be used. There is no provision for natural ventilation (or operable windows) in these buildings.

Table 2 Details of the case study buildings

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Building code</th>
<th>City</th>
<th>Climate</th>
<th>Operable windows</th>
<th>Ceiling fans</th>
<th>Survey period</th>
<th>No. of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial mixed-mode</td>
<td>SMM-1</td>
<td>Ahmedabad</td>
<td>H&amp;D</td>
<td>Y</td>
<td>Y</td>
<td>Mar, 2014</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>SMM-2</td>
<td>Delhi</td>
<td>CT</td>
<td>Y</td>
<td>N</td>
<td>Mar-May, 2015</td>
<td>16</td>
</tr>
<tr>
<td>Temporal mixed-mode</td>
<td>TMM-1</td>
<td>Ahmedabad</td>
<td>H&amp;D</td>
<td>Y</td>
<td>N</td>
<td>Mar, 2014</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>TMM-2</td>
<td>Ahmedabad</td>
<td>H&amp;D</td>
<td>Y</td>
<td>Y</td>
<td>Mar, 2014</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>TMM-3</td>
<td>Ahmedabad</td>
<td>H&amp;D</td>
<td>Y</td>
<td>Y</td>
<td>Mar-Apr, 2014</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>TMM-4</td>
<td>Delhi</td>
<td>CT</td>
<td>Y</td>
<td>N</td>
<td>May-May, 2015</td>
<td>13</td>
</tr>
<tr>
<td>Air Conditioned</td>
<td>AC-1</td>
<td>Baroda</td>
<td>H&amp;D</td>
<td>N</td>
<td>N</td>
<td>Apr-May, 2015</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>AC-2</td>
<td>Pune</td>
<td>W&amp;H</td>
<td>N</td>
<td>N</td>
<td>Sep-Oct, 2015</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>AC-3</td>
<td>Pune</td>
<td>W&amp;H</td>
<td>N</td>
<td>N</td>
<td>Sep-Oct, 2015</td>
<td>45</td>
</tr>
</tbody>
</table>

SMM-1 is the office of an architecture firm. It relies on passive design strategies to maintain thermal comfort inside. It was designed to primarily operate in fully naturally ventilated mode, but was later retrofitted with air conditioners, where occupants turn off the air conditioner.
and open the windows when the outdoor conditions are suitable for natural ventilation. The building has a high vaulted roof structure over the studios that facilities better ventilation. Both the operable windows and pedestal fans are operated by the occupants. It has low openings on the south to reduce direct radiation. At other places, glass brick is sometimes used to provide diffused daylight. The building mass is compact, and the building is partially underground, further reducing the impact of direct radiation. Glazing is approximately 25% of the wall area. The vaulted roofs have an air cavity filled with ceramic fuses (9” long conical pieces mixed with concrete) to provide thermal insulation, and the entire roof is covered with high SRI tiles. The immediate surrounding is heavily landscaped with dense trees and water bodies, generating its own microclimate. The total floor area is spread across four levels, including the mezzanine level.

SMM-2 is located on the outskirts of Delhi in the industrial sector of Greater Noida. The building comprises of several conferences rooms, open plan work spaces and personal cabins. It houses a laboratory for material testing of the products manufactured in the premises. The building has 26-50% of wall area covered with high performance glass and self-operational windows mostly facing north to utilise natural diffused light. Occupancy sensors and efficient indoor lighting balances its lighting requirements. It has individual air conditioning units.

TMM-1 is a building design and consulting firm located on the seventh floor of an 11-story building that is LEED Platinum rated. Other than installing double-glazed windows, TMM-1 did not attempt to optimize the envelope, but instead reduced their energy consumption by addressing the active systems. They have a very efficient HVAC system, demand controlled ventilation, energy-efficient lighting and lighting controls, and occupancy sensors. TMM-1 has operable windows, but they are not often used by the occupants as the air conditioning is used for most part the year. The envelope is heavily glazed (51-75% of the wall area). In spite of the high WWR and lighting controls, the building seems to rely more on artificial lighting than daylighting. The materials used in TMM-1 conform to LEED 2.1 specifications such as low VOC paints, coatings, adhesive, sealants and fabrics, green label carpets and cleaning materials. It has an open-plan layout with individual or shared cabins on the east and west periphery of the building.

TMM-2 is an office of a computer software developer firm in a heavily urbanized area, located on eighth floor of an 11-story building (similar to TMM-1 being on an intermediary floor of a taller building). It is representative of the most energy intensive building with a business-as-usual envelope and air conditioning system and operation. The office has a variable air volume (VAV) type central air conditioning unit that is on throughout the year. The walls are heavily glazed, with the WWR almost identical to that in TMM-1 (51-75% of the wall area). The windows are operable and have a reflective glazing. The building also has interior blinds and exterior shading.

TMM-3 is an office of a building construction and MEP consulting firm in a less dense and more vegetated area, located on ground and first floor of an 8-story building. It has a variable refrigerant flow (VRF) type central air conditioning unit, operable windows and ceiling fans. The glazing area is in between the other examples (30-50% of the wall area). The windows have a clear glass, compared to the reflective glazing of TMM-2. While the air-conditioning in TMM-2 operates almost continuously throughout the year, in TMM-3 occupants have a choice to operate it when indoor becomes uncomfortable.
TMM-4 is a LEED Platinum rated building located in the same complex as SMM-2. The building which sits like a cube consisting of three floors; the top floor is surrounded by a balcony. The roof has solar panels with transparent underneath to allow daylight penetration inside the space along with occupancy sensors for lighting controls. 33% of wall area consists of high performance glass. Each window unit has motorized louvers sandwiched between two glazing panes. Some of these units are operable but are rarely used for natural ventilation. The facade is made of rigid Polyisocyanurate (PIR) foam to insulate against heat and moisture. The building uses primary and secondary chilled water pumping systems, active chilled beams, primary AHU, cooling towers with variable frequency drive (VFD).

AC-1 is a single 9 storey block of a building complex on the outskirts of Baroda and a LEED Gold rated building. Each floor has large open plan office spaces with over 100 people working on each floor. It uses a VAV air distribution system controlled with a BMS operating system running almost throughout the year. 40% of wall surface has high performance glazing complimented by internal blinds.

AC-2 is part of a building complex spread over 10.5 acres. It is a LEED Platinum and a GRIHA 5-star rated building. With 92% of its energy produced on site, it is a ‘near’ zero-energy building. 76-100% of its wall surface has high performance glazing with external louvers. It doesn’t have the provision of operable windows or ceiling fans. VRF and radiant panels are used for cooling. AC-3 is located in the same complex as AC-2 and has the same building characteristics.

3 Results and analysis

Figure 1 shows the percentile ranking compared to the overall CBE dataset, and Figure 2 shows the mean percentage satisfied per survey category in each building (occupants voting +1 and above were counted as satisfied). In both, green colors designate better performance and yellow designates low performance.

![Figure 1 Percentile ranking of case study buildings compared to CBE database](image-url)

---

Windsor Conference 2016 - Making Comfort Relevant - Proceedings

311 of 1332
Starting first with the comparison to the CBE database (Figure 1), AC-3 and SMM-2 stand out as the best performers of the nine buildings followed closely by AC-2. TMM-1 and TMM-2 are the lowest performers of the nine buildings across most categories but TMM-1 ranked relatively well in thermal comfort, acoustic quality and lighting. These rankings, however, may not reflect the performance of these buildings in the context that they operate since they are being compared with the CBE database comprising buildings primarily from the US. The cultural, social and economic contexts are different and are likely to affect occupant expectations and how they use buildings. For the rest of this paper, comparisons are made between the Indian case study buildings.

In terms of occupant satisfaction (Figure 2), SMM-2 ranks the highest, with more than 90% satisfaction in all categories except thermal comfort (76% satisfaction) and acoustics (78%). These are also the two categories which typically receive the lowest levels of satisfaction in the overall CBE database (this is why buildings might have low levels of satisfaction in Figure 2, but still rank high in the CBE database in Figure 1).

The three AC buildings had high levels of satisfaction in all categories except acoustic quality where AC-2 and AC-3 had less than 60% of the occupants satisfied.

Looking now at the temporal mixed-mode buildings, thermal comfort satisfaction ranged from 51-74% (which was associated with 70-96th percentile in the CBE database, again a result of thermal issues being a pervasive problem in buildings). In TMM-1, of the IEQ categories, occupants were most satisfied with lighting, but the highest satisfaction ratings had nothing to do with IEQ (i.e., office furnishings, general building satisfaction, and cleanliness/maintenance). The satisfaction percentage in TMM-1 was lowest with acoustics, air quality, office layout and air movement. Lack of sound privacy was the main reason for
acoustic dissatisfaction while lack of visual privacy was the basis for dissatisfaction with office layout. The open plan layout may have contributed to this dissatisfaction. A few occupants from TMM-1 opined that the air was stuffy/stale, not clean and had a bad odor; the source for bad odor was mainly from the toilets. However, the complaints were limited to one particular zone. With regards to air movement satisfaction, occupants were mainly dissatisfied with amount of air movement (saying they preferred to have more air movement) and the ability to control the amount of air movement. This is not surprising given that this building does not have fans, and that occupants rarely use the operable windows.

TMM-2 consistently had the lowest levels of satisfaction of all the buildings studied here, with less than 70% satisfied occupants in all the categories except for workspace satisfaction, where it was 77%. This higher satisfaction may, in part, be due to this office having relatively low occupant density (10 sq.m. per person, compared to a more typical 6.5 sq.m. per person for India). Amongst the dissatisfied categories, acoustic quality, office layout and thermal comfort received the lowest satisfaction ratings (39%, 43%, and 53%, respectively). Lack of sound and visual privacy were the main reasons for dissatisfaction with acoustics and office layout respectively. Overall thermal comfort satisfaction was very low in TMM-2 compared to the other buildings. Those who were dissatisfied cited multiple reasons of discomfort such as incoming sun, air movement being too low and the heating/cooling system not responding quickly to the thermostat.

In TMM-3, acoustic quality was the source of dissatisfaction for 45% of the occupants. In TMM-4, 70% or more occupants were satisfied in all categories, except in thermal comfort, where thermal satisfaction was lowest of all the buildings, at only 51%.

3.1 Thermal comfort

Occupants were asked about their opinion on thermal comfort in the building through multiple questions asking about satisfaction with temperature, ability to control temperature, and thermal comfort specifically during the summer. For each question, they answered on a discrete 7-point scale from +3 (very satisfied) to -3 (very dissatisfied). The responses were pooled into three groups of ‘satisfied’ (+1 to +3), ‘dissatisfied’ (-1 to -3) and ‘neutral’ (0). Figure 3 plots the percentage of occupants in each of these groups, for the three thermal comfort questions.

ASHRAE Standard 55-2010 (ASHRAE, 2010) suggests that an acceptable thermal environment is one in which no more than 20% of the occupants are dissatisfied with the temperature. Although one can (and probably should) argue that we should strive for even high levels of acceptability, this is how the standard is currently framed. Using this number, Figure 3a suggests that 7 of the 9 buildings were below this threshold (redline in the graphs), but SMM-2 just barely met it with 20% of the occupants dissatisfied with the temperature in their workspace, and TMM-3 did not meet the threshold, with 22% dissatisfied.

The occupants who express dissatisfaction on the survey are given follow-up questions about the reasons why. In TMM-3, which is located in the hot and dry climate zone, 38% of the dissatisfied occupants reported feeling ‘often too hot’ and 63% were ‘often too cold’ in summer, suggesting that the air conditioning was over-cooling more than necessary. This is surprising since in TMM-3 occupants have a choice to operate the air conditioning or not when the indoor becomes uncomfortable. In TMM-3 in winter, 13% were ‘often too hot’ and 38% were ‘often too cold’. 25% cited low air movement as the source of thermal discomfort. 25% felt their workplace was located in a zone that was colder than other areas in the
building. 50% of the occupants reported the thermostat being adjusted by other people as the source of discomfort, which could be strongly related to the overcooling problem in summer.

In SMM-2 60% of the dissatisfied occupants reported feeling often too cold and 33% were often too hot in summer. 40% cited high humidity or dampness as the source of thermal discomfort.

16% of the occupants reported dissatisfaction with the temperature in their workspace in TMM-1, TMM-2 and AC-3. These occupants tended to feel too warm in summer and too cold in winter, suggesting that conditioning wasn’t adequate. The main reason for discomfort were low air movement and hot/cold pockets. In TMM-1, physical measurements showed that the temperature variation across the zones was more than 16°C, which is significant. In TMM-2 and AC-3, occupants also complained about the thermostat being controlled by others as a source of discomfort.

In TMM-4, 33% of the occupants expressed dissatisfaction with the thermal comfort in their workspace in summer (Figure 3b). The primary reasons seem to be poor air distribution since 36% of the occupants reported feeling often too hot and 36% reported feeling often too cold in summer. Dissatisfaction was also high in TMM-2 (28%), SMM-2 (19%) and TMM-3 (16%). These responses align with the dissatisfaction percentages in Figure 3a.

When asked to report their satisfaction with their ability to control temperature in their workspace (Figure 3c), 38% of the respondents in TMM-2 and 25% in TMM-1, TMM-4 expressed dissatisfaction. At least 10% of the occupants across all case studies were dissatisfied with the degree of control they had over the temperature. This number was higher in mixed-mode buildings compared to air conditioned buildings.

![Figure 3](attachment:image.jpg)
3.2 Air quality
In response to the question related to satisfaction with the air quality (Figure 4), 36% of the occupants in TMM-1 expressed dissatisfaction with the air quality at their workspace (Figure 4a) while 44% were dissatisfied with their ability to control the air quality (Figure 4b). 86% felt that the air being stuffy/stale was big problem and 83% reported air not being clean as a problem. 67% of the occupants felt bad odors from toilets, cafeteria, garbage bins and carpets were a major problem.

20% of the occupants in TMM-2 reported dissatisfaction with the air quality in their workspace (Figure 4a). The reasons for this dissatisfaction are not clear since the follow-up questions were not answered but one of the comments reported air conditioners working at a high temperature setpoint and recirculation of indoor air as a source of odor.

13% of the respondents in TMM-3 reported dissatisfaction with air quality (Figure 4a) as well as their ability to control it in their workspace (Figure 4b). The reasons for dissatisfaction have not been stated but may be related to dissatisfaction with thermal comfort due to low air movement as reported in section 3.1. Most of the occupants in air conditioned buildings expressed satisfaction with the air quality. However, at least 7% of the occupants were dissatisfied with their ability to control air quality in their workspace across all nine buildings.

![Figure 4 Occupant satisfaction with air quality](image)

3.3 Air movement
Occupants in SMM-2 reported 100% satisfaction with the amount of air movement in their workspace (Figure 5a). This may be explained on the basis of the responses to the window usage questions where a majority of the occupants reported satisfaction with the operable windows and their ability to open or close them (section 3.5).

Dissatisfaction was highest (30%) in TMM-1 where 40% of the occupants also reported dissatisfaction with their ability to control air movement (Figure 5b). Occupants in this building were also dissatisfied with the ceiling fans and windows which may have contributed to their dissatisfaction with the air movement. More than 20% of the occupants were dissatisfied with the amount of air movement and their ability to control it in their workspace in SMM-1.
Figure 5 Occupant satisfaction with air movement

3.4 Use of windows and fans

Ceiling fans and windows are the most widely used and cost-effective way of increasing air movement and are widely used as an adaptive measure to alleviate thermal discomfort when the indoor temperatures ride high (Manu et al., 2014). Operable windows were available as a provision in all the mixed-mode buildings. However, in most cases the occupants did not operate the windows for multiple reasons that have been highlighted below. As such, one might characterize them as mixed-mode in design, but not in practice.

TMM-4 stands out as one of the mixed-mode buildings where the operable windows are being used, yet the building got the lowest scores in terms of thermal comfort satisfaction. More than 90% of the occupants reported satisfaction with the operable windows in their workplace in summer (Figure 6a). All the occupants found it easy to operate the windows (Figure 6c) and found them effective in helping them to stay comfortable in summer (Figure 6b).

TMM-1, which is the LEED Platinum building where the focus was on efficient active systems, performed poorly with 48% of the occupants dissatisfied with the operable windows in summer. 44% found it difficult to open or close the windows and 33% said that opening the windows was ineffective in maintaining comfort in summer. The difficulty in operating the windows may have to do with accessibility – 95% of the occupants shared control of the windows with others and 64% never adjusted their windows in summer. Windows were either inaccessible (25%) or were kept closed due to noise, glare and odors (33%). 30% of the occupants reported that the management discouraged the use of operable windows.

In SMM-1, 16% of the occupants reported dissatisfaction with the operable windows and found the windows ineffective in maintaining comfort in summer. 13% found it difficult to open or close the windows in their workspace. 15% of the occupants did not adjust the windows because of complaints from co-workers and 31% said the windows were inaccessible. This was surprising since SMM-1 is the building that paid particular attention to using passive, architectural strategies to achieve low energy use. 9% of the occupants in SMM-1 shared the control of the windows with others in their workspace.

The most frequently cited reasons for opening a window in all the six buildings were, ‘to feel cooler’, ‘to increase air movement’ and ‘to let in fresh air’. Interestingly, the prevailing reasons to close a window were ‘to feel cooler’, ‘outdoor temperature getting warmer than indoors’ (both of these related to having air conditioning on during a hot day), and ‘to reduce outdoor noise.’ These reasons show that window interaction is driven predominantly by outdoor temperature, air quality and noise levels.
More than 70% of the occupants reported satisfaction with the ceiling fans in their workplace in the three buildings that had them – SMM-1, TMM-2, TMM-3 (Figure 7). The most cited reasons to turn on a fan in these three buildings were ‘to feel cooler’ and to ‘increase air movement’ while the reason to turn off a fan was to ‘reduce air movement’ and because ‘a co-worker requested it.’ These are all as one might expect, and the majority of the occupants in these buildings said they were very sure of having the desired effect when they interacted with fans. In TMM-2, 73% of the occupants adjusted the fans daily in summer.
4 Discussion
The surveys revealed SMM-2 as the only building that had more than 70% satisfaction rate across all categories. All AC buildings scored well in all categories except in the case of AC-2 and AC-3 where a satisfaction percentage of less than 70% was reported in acoustic quality. Overall, occupants seemed to be most dissatisfied with acoustic quality, air movement and office layout.

Lack of adequate air movement was repeatedly cited as a source of thermal discomfort. Occupants were also dissatisfied with the ability to control air movement and opined that they needed more of it. Poor air movement may have resulted in hot/cold air pockets in the building – occupants also reported feeling often too hot or cold in summer.

The most cited reasons to turn on a fan were ‘to feel cooler’ and to ‘increase air movement’. Moreover, when asked about the confidence of having the desired effect on turning on a fan, the majority of the occupants voted that they were confident about this effect. This shows that occupants perceive fans as fast-acting and they rely on it for achieving comfort in a short span of time. However, even in buildings that had ceiling fans, occupants refrained from using them because of complaints from co-workers. It is important to provide ceiling fans to ensure occupants have more control over the air movement but it is equally important to design the space plan and controls to ensure occupants are able to use them.

Windows were opened for fresh air, to feel cooler and increase air movement, and closed when the outdoor got warmer than indoors, and to reduce outdoor noise. The key take-away from this result is that the occupants preferred to have air movement and when there was a combination of windows and fans in use, they worked well in providing it. But, similar to the barriers in using ceiling fans, in most mixed-mode buildings operable windows were provided but since the management did not encourage their use, occupants kept them close. They remain closed for long periods of time without regular maintenance making it difficult to operate them in the rare cases where occupants tried to open them. Noise, glare and odor were also cited as reasons for keeping the windows closed. More interesting, complaints from other occupants also affected window operation indicating conflicts between occupants’ preferences.

A result worth noting here is that, for the case studies in this paper the air conditioned buildings provided higher levels of thermal comfort than in the mixed-mode buildings (the only exception was SMM-2). This goes against what might have been expected based on adaptive comfort theory, which suggests that having access to operable windows might produce higher levels of control and satisfaction. This may be explained by two observations – first is that with an exception of SMM-2, all other mixed-mode buildings were not being actively operated in mixed-mode. SMM-1 was designed as a passive building which was later retrofitted with air conditioning. TMM-1 and TMM-2 are located on individual floors of buildings that are typical office buildings with high window-to-wall ratio, designed to be air conditioned throughout the year. On the other hand, all air conditioned case studies are high performance, LEED-rated buildings with optimized envelopes and efficient air conditioning systems. They are better than the ‘business-as-usual’ air conditioned office buildings in India. TMM-4 is also a high performance, zero- emissions building. It is difficult to explain the low satisfaction in the thermal comfort category since the occupants did not respond to the follow-up questions but lack of controls was cited as a source of discomfort.
References


