Post-Occupancy Evaluation of Air Conditioned and Mixed-mode Ventilated Office Buildings in India

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ABSTRACT

As a country primarily in a tropical and subtropical climate, India's recent economic growth has been accompanied by an increased demand in air conditioning and, subsequently, energy use. For large office buildings, mixed-mode ventilation (MMV) is an alternative to air conditioning (AC), but this strategy has yet to be widely adopted. This study compares the thermal sensation, preference, and acceptance of occupants in AC and MMV office buildings in India through post-occupancy evaluation (POE) online surveys. This study additionally analyzes the perception and behavior of occupants regarding their use of windows and fans to identify strategies to promote MMV implementation in both India and other regions. The results demonstrate that occupants are generally more satisfied with the indoor environmental qualities in MMV office buildings than in AC office buildings. However, there is a lack of evidence to prove if the higher satisfaction in MMV office buildings level is due to the system's operable windows and fans since some adjustments regarding temperature setting and window/fan usage are also needed in MMV buildings. The analysis was generated through a database from Center for Built Environment (CBE), which included 600 online surveys responses from 12 AC and MMV buildings in India.

KEYWORDS

indoor environmental quality, thermal comfort, mixed-mode ventilation, air conditioning ventilation, window and fan usage

INTRODUCTION

Building energy efficiency is a crucial approach to mitigate global energy and greenhouse emissions. In developed countries, building energy consumption contributes to 40% of global energy consumption, exceeding the other major sectors such as industry and transportation, with a particularly significant growth in energy use contributed by heating, ventilation and air conditioning (HVAC) system (Pérez-Lombard et al. 2008). Developing countries are following the pattern of energy use increase in HVAC, as energy demand for air conditioning is projected to increase rapidly with the economic growth, driven by income growth and higher expectation for indoor comfort. Researchers have also predicted a surge in corresponding CO_2 emissions globally due to the increasing energy demand from HVAC, with the strongest increase in Asia (Isaac and van Vuuren 2009). Continued advances in energy efficiency or controlled use in air conditioning could greatly reduce energy consumption and its impacts (Davis and Gertler 2015). India, similar to many other developing countries near tropical region, has a warm to hot weather for most of the year in most of its climate zones. As of 2011, air conditioner penetration in India is still very low, with only 5% of households owning an air conditioning unit compared to 80% of households in the U.S. (Shah et al. 2015). However, air conditioner purchases in India are currently growing at 20 percent per year, indicating a significant cooling demand and potential energy use increase in buildings with an HVAC system (McNeil and Letschert 2008).

Implementing alternatives to air conditioning for cooling and ventilation can largely reduce the potential energy use in India. According to a report from Australian Greenhouse Office, HVAC systems contribute to over half of the energy and emissions from conventional air-conditioned (AC) buildings (AGO 1999). Natural ventilation (NV) is the process of supplying air to and removing air from an indoor space without using mechanical systems (Brager et al. 2004). In India, NV-cooled buidlings traditionally utilize fans and operable windows for ventilation and cooling in warm conditions. However, under extremely hot weather conditions, AC is still often needed to satisfy occupant's thermal comfort (Brager et al. 2004). As a result, architects and engineers proposed mixed-mode (MM) ventilation as a way of combining the advantages of NV and AC buildings. MM ventilated buildings provide thermal comfort using natural ventilation through operable windows or passive inlet vents (either automatically or manually controlled) whenever outdoor weather conditions are favorable, but revert to AC whenever NV is insufficient to provide acceptable comfort (Luo et al. 2015). However, in the past decade, AC-only buildings have become the standard in India for new construction and retrofit of office buildings due to increasing floor area and the higher expectation for indoor comfort (Jadhav and Lele 2015).

The design and operation of the AC systems in these buildings are often regulated to achieve a standard 'steady-state' temperature setting based on Fanger's thermal comfort model (van Hoof 2008, Drake et al. 2009). This comfort model, which requires high energy demand for consistency, may not accurately represent the preferred thermal condition for Indian occupants. Moreover, it is more difficult for NV and MM ventilated buildings to achieve consistent temperature compared to AC buildings. However, an adaptive comfort model may better satisfy the occupants (Brager and de Dear 1998). While NV and MM ventilated buildings have a much higher energy efficiency than AC buildings, they also have a less controlled indoor environment of thermal, acoustic, and air quality conditions according to a subjective approach survey-based study (Brager and Baker 2009). Since there is already a range of NV and MM ventilated buildings in India, a new adaptive thermal comfort model assumes great importance for the Indian population. It needs to be defined by the range of conditions comfortable for the occupants within the available adaptive opportunities and climatic context. While some survey-based studies have explored the adaptive thermal comfort model in India, they have not concerned with specific ventilation strategy or occupants responses for the building performance (Singh et al. 2011, Indraganti et al. 2014).

Thus, the objective of this study is to understand the thermal sensation, preference, and acceptance of occupants in NV and MM ventilated buildings in India through post-occupancy evaluation (POE), a process of obtaining feedback from current occupants on a building's performance in use. In addition, it is aimed to evaluate the comfort range and the preferred temperature of the occupants in order to support the development of a new adaptive thermal model in India while also informing future construction and design decisions. My hypothesis is that occupants are overall satisfied in the NV and MM ventilation buildings, but some adjustment is needed at specific locations within the building in order to achieve thermal comfort with higher energy efficiency. Satisfaction level of thermal condition may be higher in NV and MM ventilation buildings than in air condition buildings, as some occupants may prefer a varied indoor temperature influenced by air flow from outside in different seasons. The analysis will contribute to an adaptive thermal comfort model in India's specific climate zones and I worked with a collected database from CBE that web-surveyed in 12 NV and MM ventilated buildings in India, with approximately 600 responses.

METHODS

Data Collection

In order to develop a comprehensive understanding of occupants' feedback in various climate zones of India, I used a subset of Center for Built Environment (CBE) Occupant Indoor Environmental Quality (IEQ) Survey database as my data for analysis. This subset survey data was collected by the team of Gail Brager, Sanyogita Manu and Rajan Rawal from August 2015 to February 2017 through the CBE web-based survey tool, which is an efficient way of remotely getting occupant feedback on IEQ and various other aspects of the building. The survey collected about 600 occupant responses from 12 AC and MMV buildings in India and it consists of a core module with eight IEQ categories (Table 1) and additional modules such as window and fan usage. 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). 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. Other general building features such as floor area, number of occupants, type of HVAC system and envelope are filled out by the building manager separately. The survey used for this study is attached in the PDF file and more details about the CBE survey tool can be found in a CBE publication of Zagreus et al. (Zagreus et al. 2004).

Table 1. Categories included in the CBE occupant indoor environmental quality survey.

IEQ Category	Specific Aspects
Office layout	Amount of space available for individual work and storage
	Level of visual privacy
	Ease of interaction with co-workers
Office furnishings	Comfort of office furnishings (chair, desk, computer, equipment, etc.)
	Ability to adjust furniture to meet your needs
	Colors and textures of flooring, furniture and surface finishes
Thermal comfort	Temperature in your workspace
Air quality	Air quality in your workspace (i.e. stuffy/stale air, air cleanliness, odors)
Lighting	Amount of light in your workspace
	Visual comfort of the lighting (e.g., glare, reflections, contrast)
Acoustic quality	Noise level in your workspace
General comments	Your personal workspace
	Building overall comments

Building Selection

To include both AC and MMV buildings in various climate zones of India, the data collection team administered the surveys in 14 office buildings across four cities in three different climate zones of India (see figure 1): Ahmedabad and Baroda has a hot and dry (H&D) climate, Pune has a warm and humid (W&H) climate and New Delhi has a composite (CT) climate. For this research, I will analyze all of the 14 buildings and treat each response as a data point rather than the average of each building. Among the 14 buildings, 4 buildings are in Ahmedabad with a hot and dry climate. This includes Sangath, an architecture firm designed to primarily operate in fully naturally ventilated mode, but was later retrofitted with air conditioning following the installation of computers. Stantec is an engineering firm and a LEED Platinum building with an efficient HVAC system. EVOSYS is a software development company that has a variable air volume (VAV) type central air conditioning unit that is on throughout the year. And VMS is an engineering consulting company that has a variable refrigerant flow (VRF) type central air conditioning unit, with operable windows and ceiling fans. More information of the selected buildings is listed in Table 2.

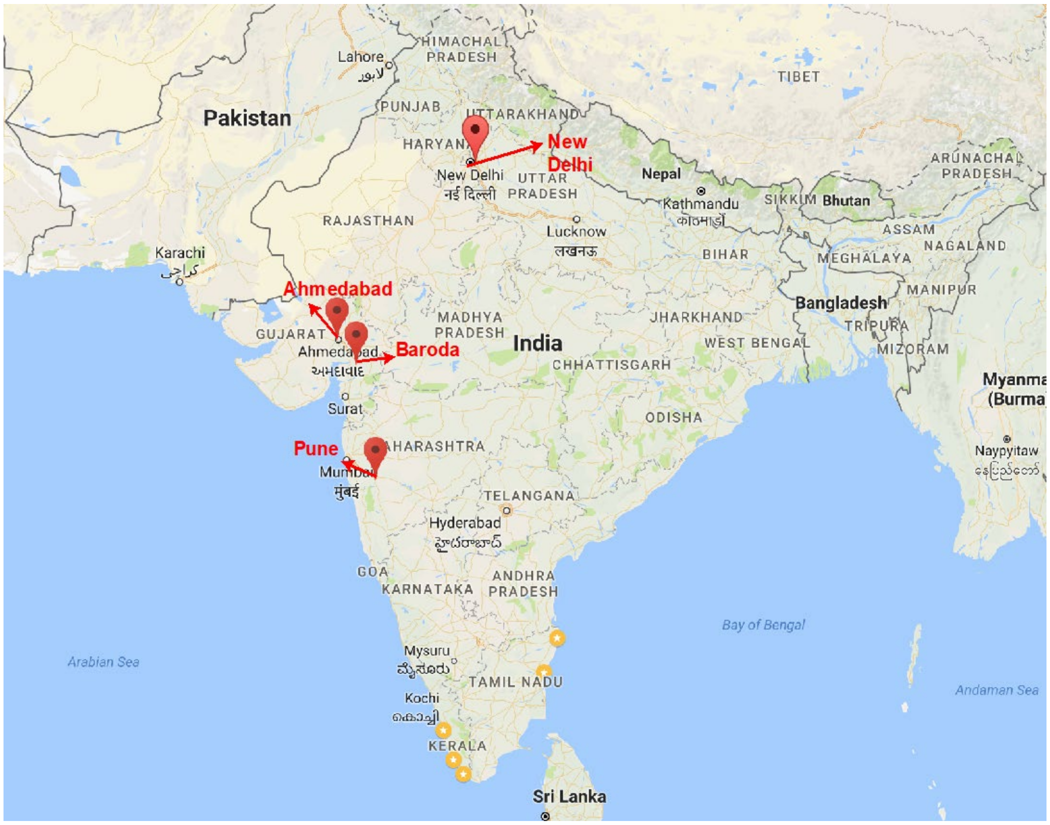


Figure 1. Four different building sites in India. The four sites contain three different climate zones including New Delhi (humid subtropical), Ahmedabad and Baroda (semi-arid), and Pune (tropical wet and dry).

Table 2. Selected Building Information

#	Building Name	City	Climate	HVAC system	Operable Windows	Total Occupancy	No. of Responses
MMV1	VMS	Ahmedabad	H&D	MMV - Overhead VAV air distribution	Y	80	40
AC1	Stantec	Ahmedabad	H&D	AC - VAV air distribution	N	91	31
AC2	Evosys	Ahmedabad	H&D	AC - window air conditioners, Overhead VAV air distribution	N	142	28
MMV2	Sangath	Ahmedabad	H&D	MMV - window air conditioners, evaporative cooling systems	Y	54	48
AC3	Suzlon Aqua	Pune	W&H	AC (VRF) - Demand controlled ventilation	N	779	53
AC4	Suzlon Tree	Pune	W&H	AC (VRF) - Demand controlled ventilation	N	520	44
MMV3	Bayer Eco Commercial	New Delhi	CT	MMV - Chilled water pumping systems, Active chilled beams	Y	26	12
MMV4	Bayer Competence	New Delhi	CT	MMV - Chilled water pumping systems	Y	29	16
MMV5	L&T Green Building	Baroda	H&D	MMV - Underfloor air distribution	Y	1746	128
AC5	Development 20-20	Ahmedabad	H&D	AC	Y	15	18
AC6	TMS	Ahmedabad	H&D	AC - window air conditioners	Y	150	65

Data Analysis

To understand occupant satisfaction level in AC and MMV buildings in three different climate zones of India, I calculated the mean (M) of satisfaction with different indoor environmental quality (IEQ) parameters and building features by averaging satisfaction votes of each occupant by grouping the buildings by AC and MMV. For more detailed analysis in thermal comfort, I categorized the 7-point scale survey votes into three categories including of 'satisfied' (+1 to +3), 'dissatisfied' (-1 to -3) and 'neutral' (0). I also analyzed distribution and percentile ranking of the satisfaction level for thermal comfort related votes of AC buildings compared to that of the MMV buildings.

As for data processing, to build the database from the raw data, I used R package 'readr' and 'stringr' data cleaning and vetting. I vetted data by deleting incomplete records to reduce potential errors. Relevant columns that contributed to my database included coded questions regarding thermal comfort, air flow, window use and fan use. I removed records with same scores in every question or without final identification from the database to avoid ambiguity. The statistical analysis was carried out with R software 3.4.2 and MS Excel 15.32. All the graphs are generated in MS Excel.

RESULTS

Overview of IEQ scores

Figure 2 shows a summary of the average satisfaction level of occupants in five major indoor environmental quality (IEQ) categories for the 12 buildings, including five MMV buildings and seven AC buildings. I used the entire dataset which include a total of 512 responses, among them 268 responses are from AC buildings and 244 are from MMV buildings. The survey questions I used to assess average IEQ scores are the general satisfaction questions such as "How satisfied are you with the temperature of your workspace?" Among the five IEQ categories, acoustic quality and thermal comfort received the lowest satisfaction ranking in both MMV and AC buildings.

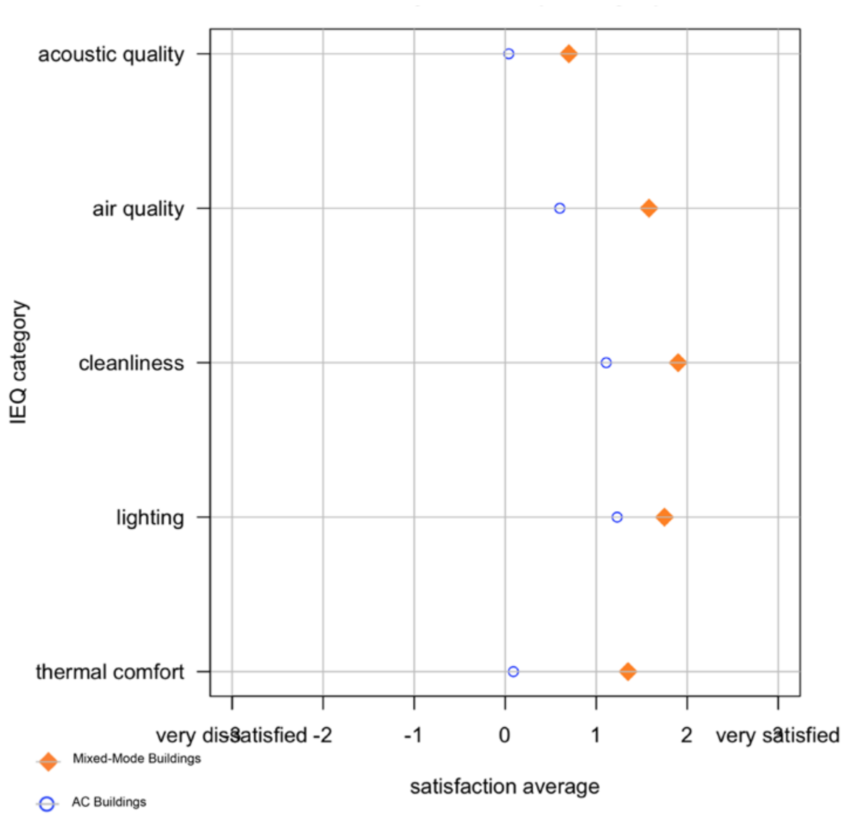


Figure 2. Average Scores by IEQ category.

On average, MMV buildings received significantly better satisfaction votes than the AC only buildings in every IEQ category, especially in the air quality and thermal comfort category, which could be easily impacted by the presence of operable windows and fans in MMV buildings. It was also notable that people are more satisfied with the acoustic environment in MMV buildings because normally they are more susceptible to noise that accompanied with natural ventilation and the mechanics of fans. Since the satisfaction vote has the biggest difference in the thermal comfort category, I focused on analyzing thermal comfort and the use of windows and fans as the potential advantage of MMV buildings in India.

Thermal Comfort

For each IEQ category, the survey began with general questions addressing occupants' level of satisfaction with particular environmental qualities, following this with more specific questions regarding their thermal preferences and behavioral change. Regarding thermal comfort in the building, the survey had follow-up questions about satisfaction with temperature, ability to control temperature, thermal comfort specifically during the summer and winter seasons, and other occupant behaviors. For the thermal comfort votes (TCV), the occupants answered on a discrete 7-point scale from +3 (very satisfied) to -3 (very dissatisfied). These three questions are used as alternate and complementary ways to ask occupants' opinion towards their thermal comfort. Figure 3 shows a comparison of an average of all MMV buildings to that of all AC buildings, and MMV buildings have a higher average in all three questions. Satisfaction percentage analysis are illustrated in Figure 4 and compared with ASHRAE Standard 55-2010, which suggests that there should be no more than 20% of the POE responses dissatisfied with the thermal comfort. As Figure 4a shows, all the MMV buildings are below the 20% dissatisfaction line, while AC-1 and AC-5 have reached the 20% line. Therefore, occupants in MMV buildings are more satisfied with their thermal comfort in terms of the room temperature. Surprisingly, as shown in Figure 4b, MMV buildings have a similar dissatisfied percentage with AC buildings in the ability to control the temperature.

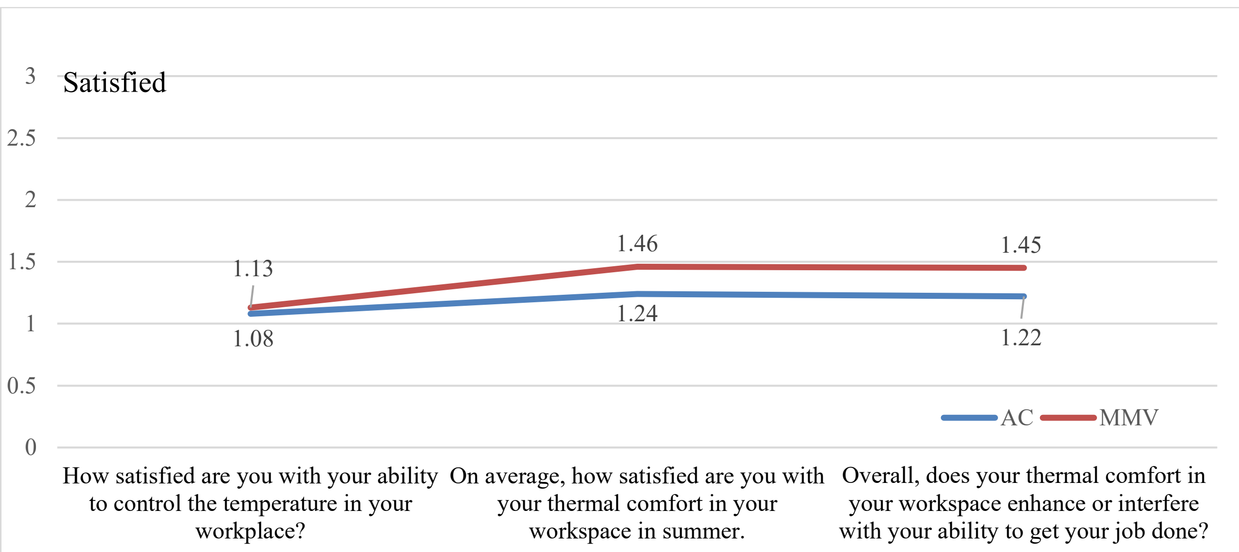
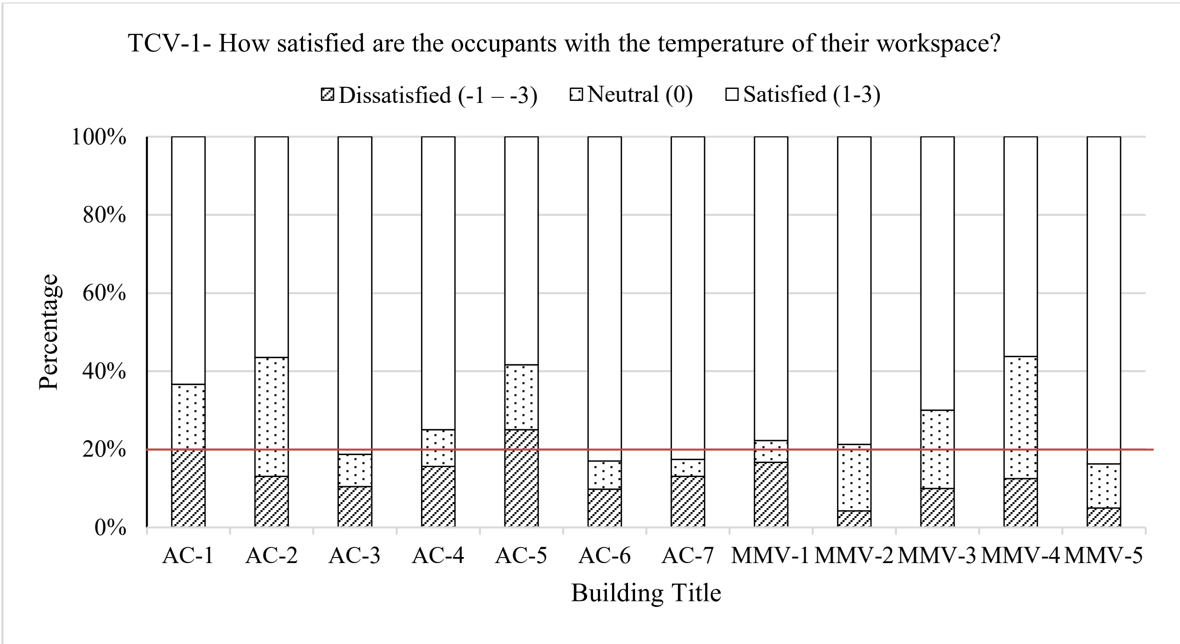
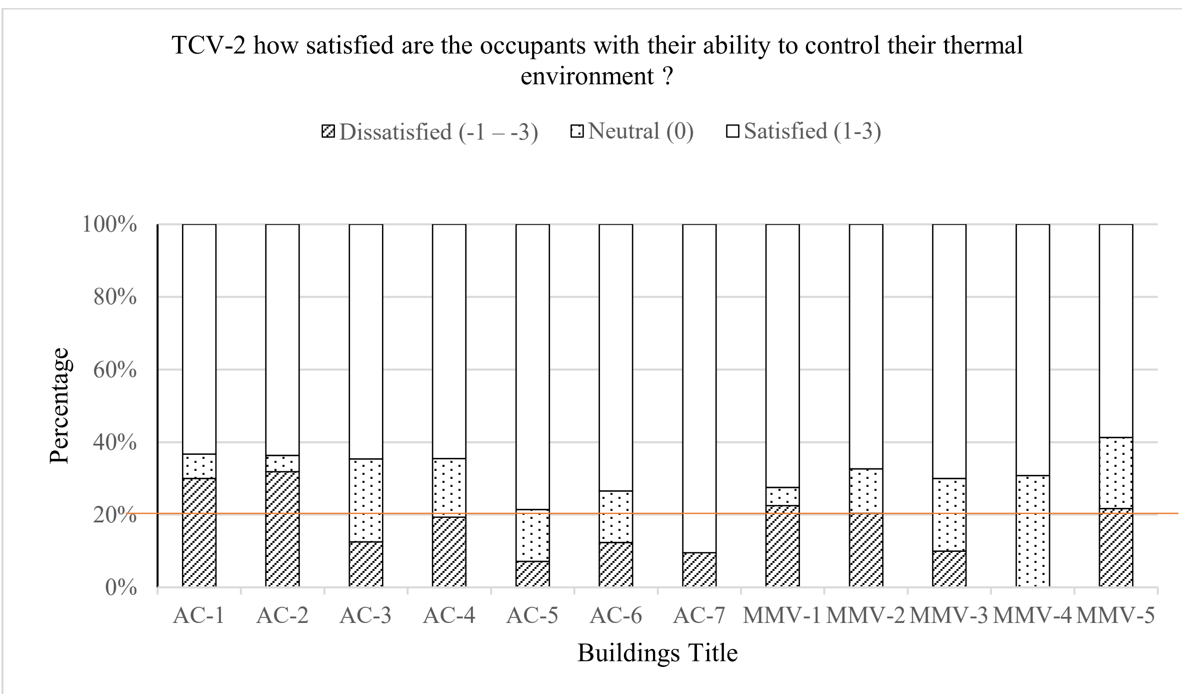


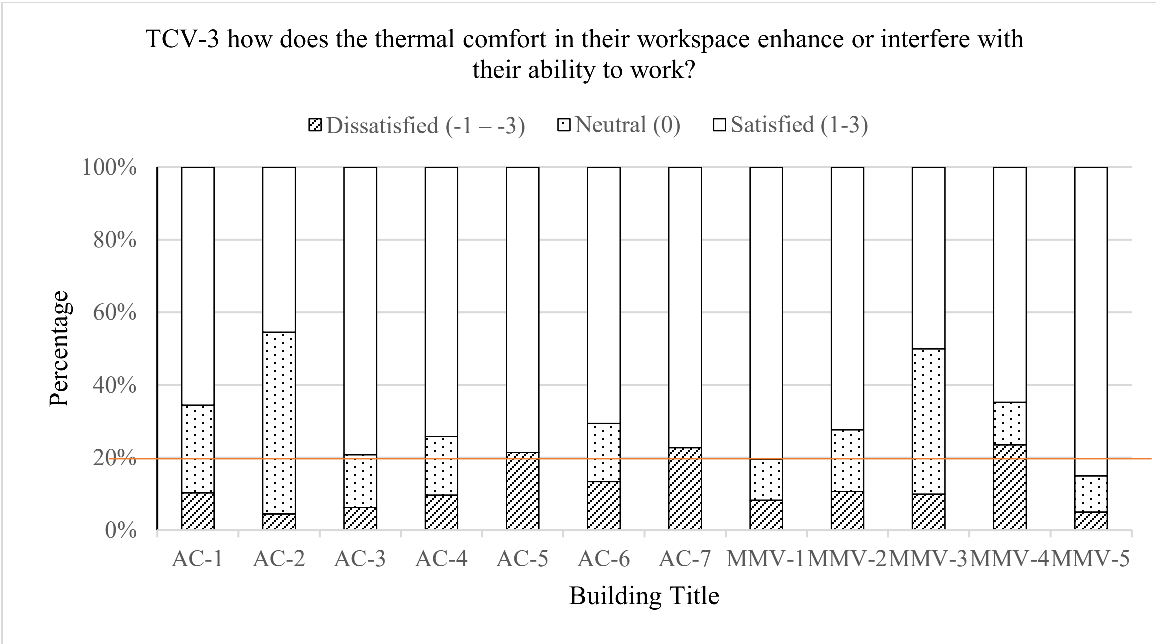
Figure 3. Average satisfaction vote in thermal comfort.


TCV-1- How satisfied are the occupants with the temperature of their workspace?
Dissatisfied (-1 – -3)
Neutral (0)
Satisfied (1-3)
Percentage
0%
20%
40%
60%
80%
100%
AC-1 AC-2 AC-3 AC-4 AC-5 AC-6 AC-7 MMV-1 MMV-2 MMV-3 MMV-4 MMV-5
Building Title

(a)


TCV-2 how satisfied are the occupants with their ability to control their thermal environment ?
Dissatisfied (-1 – -3)
Neutral (0)
Satisfied (1-3)
Percentage
0%
20%
40%
60%
80%
100%
AC-1 AC-2 AC-3 AC-4 AC-5 AC-6 AC-7 MMV-1 MMV-2 MMV-3 MMV-4 MMV-5
Buildings Title

(b)



(c)

Figure 4. Thermal comfort responses by buildings.

Some follow-up questions include asking the reasons why the occupants are unsatisfied with the thermal conditions. As shown in Figure 4a, AC-1 and AC-5 have the highest dissatisfied percentages. The surveys of AC-1 and AC-5 were conducted in April and August, which are all during the summer season of India. In building AC-5, which are located in the hot and dry climate zone, 28% of the dissatisfied occupants reported feeling 'often too hot' and 58% were 'often too cold' in summer. This could imply an unnecessary over-cooling effect in AC buildings that also wastes energy. For building MMV-1 and MMV-2 in a composite climate zone, occupants who are unsatisfied with thermal comfort reported the lack of access to operable windows and fans, as shown in Figure 4b, is unexpected since in MMV-1 and MMV-2 the air conditioners could be adjusted by occupants and there are also operable windows and fans. Therefore in order for MMV to perform well in its thermal environment, the operable windows and fans must be accessible to occupants and should be regulated by a general temperature preference from the most occupants instead of individual choice who sit besides the windows or fans.

Figure 5 illustrates the thermal comfort responses related to the thermal preference of the occupants. We can see that neutral thermal conditions were preferred by the overwhelming majority of respondents, especially who have voted for a satisfactory (1-3) thermal comfort.

Therefore, I conclude that most occupants expressed an expectation to maintain the current thermal conditions by voting ‘no change’ when they experienced a neutral thermal environment. Furthermore, by comparing the detailed evaluation results of AC and MMV groups, it can be seen that occupants in the MMV group expressed fewer complaints (i.e., a desire of a ‘cooler’ environment) even when they expressed low score in thermal comfort. This may be due to the fact that occupants in the MMV buildings had more adaptive opportunities, which can shift occupants' thermal expectation.

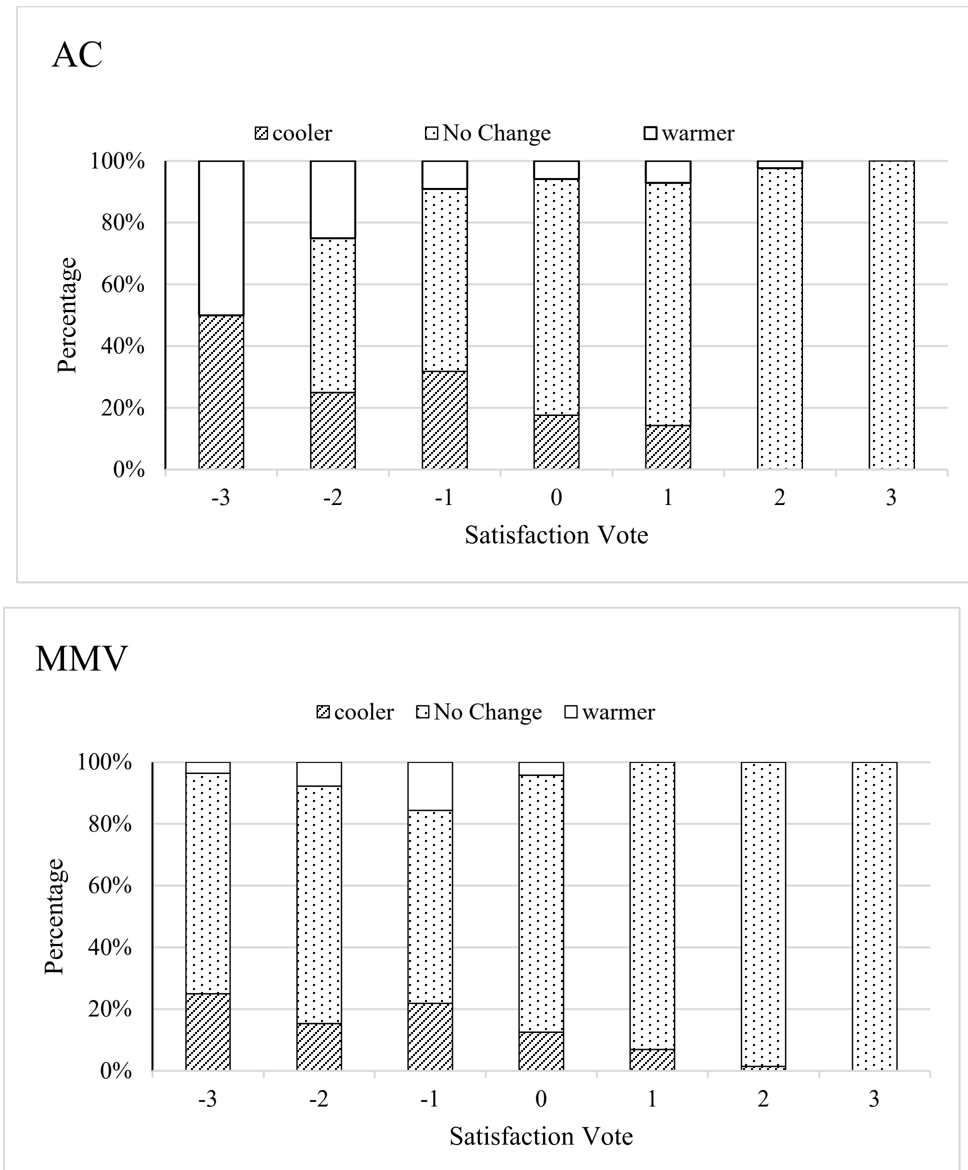
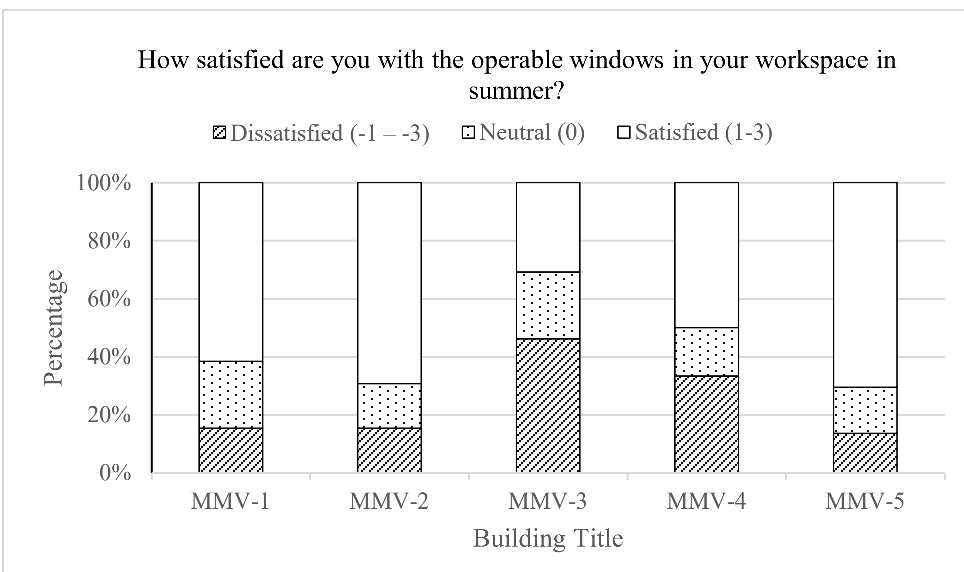


Figure 5. Relationship between thermal comfort and thermal preference.

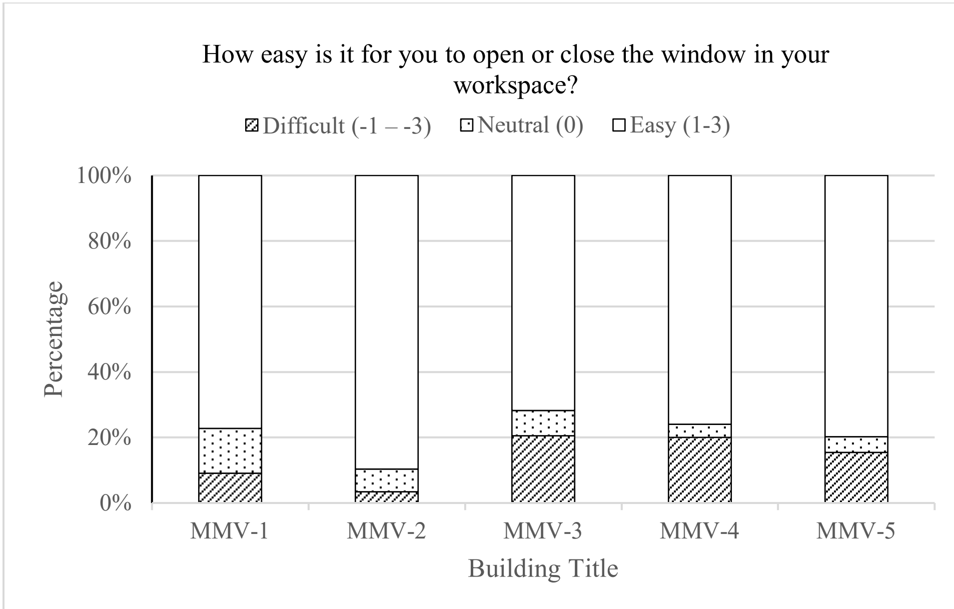
Use of Windows and Fans

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 are high. Operable windows were available as a provision in all the mixed-mode buildings and they could easily affect the occupants' satisfaction with thermal comfort and air quality. However, in some cases the occupants did not operate the windows for multiple reasons that have been highlighted in Figure 6.

More than 70% of the occupants reported satisfaction with the ceiling fans in their workplace in the five MMV buildings. However, except for MMV-2, which has received the highest satisfaction score in thermal comfort, other MMV buildings all have a considerable percentage of occupants reporting the difficulty and inaccessibility to the windows. Figure 5c demonstrates that most people think that operable windows and fans are important to the comfort level of their workspace and MMV-2 has no one responded unimportant.



(a)



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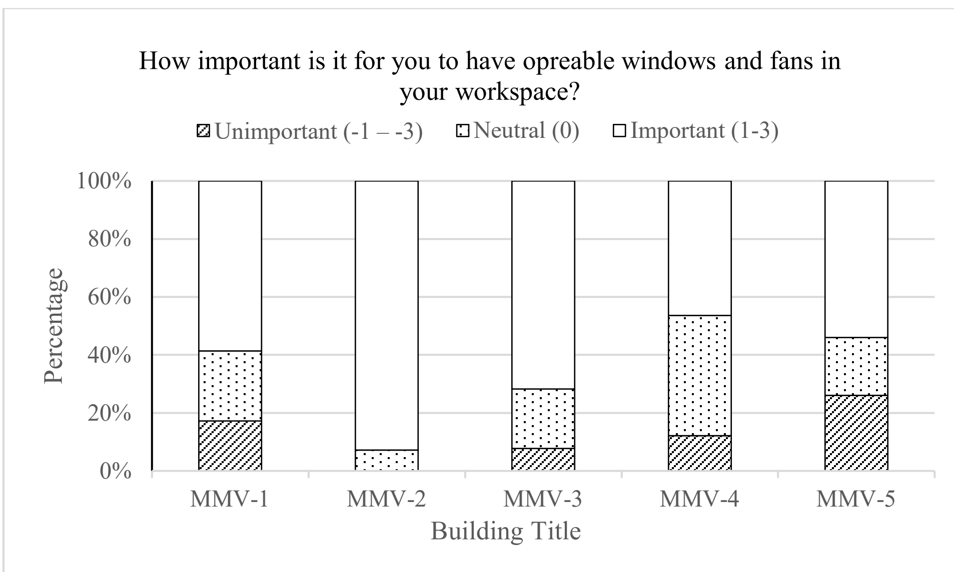

(c)

Figure 6. Window and Fan Usage in MMV buildings.

DISCUSSION

This study analyzed a subset of the CBE Occupant Indoor Environmental Quality Survey database to review occupant satisfaction with indoor environmental quality in Indian air conditioned (AC) versus mixed-mode ventilated (MMV) office buildings. I first analyzed if MMV buildings lead to a higher, equal, or lower general occupant satisfaction than AC buildings. I then compared occupant satisfaction of these two building types based on the five indoor environmental quality (IEQ) categories assessed by the CBE survey: acoustic quality, air quality, cleanliness, lighting, and thermal comfort. Then led by the results, I further discussed the thermal comfort category, which is the IEQ category most different between the two building types. This discussion is followed by a more detailed analysis on the use of windows and fans in MMV buildings as they are directly related to thermal comfort, and to help understand the relationship between the satisfaction score, actual performance of the mixed-mode ventilation and occupants' behaviors.

Occupant satisfaction with IEQ in AC versus MMV office buildings

On average, occupants in MMV buildings were significantly more satisfied than occupants in AC buildings in every IEQ category as shown in Figure 1. Among the five IEQ categories, air quality and thermal comfort category made the biggest difference. These two IEQ categories could be easily impacted by the advantage of having operable windows and fans in MMV buildings and were further analyzed to understand the performance of MMV buildings. It was also notable that occupants were more satisfied with the acoustic environment in MMV buildings because normally occupants were more susceptible to noise that accompanies the natural ventilation system and mechanical fans of MMV buildings.

Among the five IEQ categories, acoustic quality and thermal comfort received the lowest satisfaction ranking in both MMV and AC buildings. A low satisfaction score in acoustic quality could imply that in both AC and MMV buildings there was a relatively unsatisfied acoustic environment including the noise of people talking, office equipment, and outside traffic. A low satisfaction score in thermal comfort could imply a too cold or too hot indoor temperature, little air movement, and the lack of ability to control their thermal conditions. Thermal dissatisfaction was most commonly related to people feeling that they did not have enough control over their environment, in addition to complaints about air movement being too low. ASHRAE publishes standards for both thermal comfort and acceptable air quality in buildings (ASHRAE Standard 55-2004, and 62.1-2004, respectively) and recommends 80% of occupants should be satisfied in both categories (Heinzerling et al. 2013). The satisfaction score average from the CBE database in the U.S., most of which are AC buildings, demonstrate that most buildings are below this 80% threshold. However, in the India subset data analyzed in this study, occupants in general had higher satisfaction scores in both of the AC and MMV office buildings, which might be influenced by the traditional experiences in a hot climate and different expectations.

For these general satisfaction averages, I compared the results of my study with that of Frontczak et al., who analyzed the CBE database in the U.S. to determine the influence of several parameters of indoor environmental quality and building features on occupant satisfaction (Frontczak M. et al. 2011). Frontczak et al. concluded in their work that IEQ satisfaction is generally high in office buildings, and to maximize IEQ satisfaction, many different categories should be addressed. Greater space and storage, lower noise levels, and constant thermal comfort are primary factors in maximizing the satisfaction of occupants in office buildings. The results of my study in India aligned with Frontczak et al.'s study that occupants within buildings in the study sample were generally satisfied with their space of work, even if slight dissatisfaction was observed with temperature and sound privacy (acoustic quality). However, differences with Frontczak et al.'s study were found in the ranking of some IEQ parameters. In AC buildings, for example, satisfaction with air quality (M=1.75) and with lighting (M=1.62) received a higher ranking in the India building sample compared to the US building sample. My analysis confirmed that the quality of the thermal and the acoustic environments are areas of primary concern to satisfy of workplace occupants in India. As a matter of fact, it must be considered that, in some cases, occupants may show greater satisfaction and engagement with their tasks in the shared workplace, possibly due to superior communication with their co-workers.

Thermal Comfort in AC versus MMV office buildings

As shown in Figure 2, MMV buildings performed much better than the AC buildings, particularly in the thermal and air quality satisfaction categories. For the thermal comfort satisfaction in MMV buildings, I found that the highest scoring buildings were in more moderate climates of India, while buildings in hot climates scored lower on average. My results in the thermal comfort analysis included three different questions investigating occupants' responses towards the thermal comfort in their working environment. For MMV buildings, I expected that people would be more satisfied with their ability to control the temperature because of the windows and fans. However, the result showed two MMV buildings (MMV-3, MMV-4) actually have a low score in the satisfaction score of the ability to control the temperature. These two buildings were the largest offices in the dataset and have the most responses. The result might imply a notable fact that although MMV buildings have features such as operable windows and fans, few people are actually allowed access to control these features.

From the relationship between thermal comfort satisfaction vote (satisfied or unsatisfied) and thermal preference vote (prefer warmer or cooler temperature), I concluded that most occupants expressed an expectation to maintain the current thermal conditions by voting ‘no change’ when they experienced a neutral thermal environment. In the group of MMV buildings I have studied, I observed some general trends related to the types of mechanical systems and controls. The best performing buildings in thermal comfort had either radiant cooling or only mechanical ventilation, but no air-cooled systems in the spaces primarily occupied by workers (i.e., they may have had air-conditioning in large assembly rooms). The lowest performing MMV buildings tended to be changeover systems, where there were problems with the window interlock systems. This might suggest the importance of a well-integrated design where the mechanical and natural systems can work well together, and occupants have the ability to override automated controls as needed or desired (Ravindu et al. 2015). Furthermore, by comparing the detailed evaluation results of AC and MMV groups, I found that occupants in the MMV group expressed fewer complaints (a desire of a “cooler” environment) even when they expressed low score in thermal comfort. This might be caused by the fact that occupants in the MMV buildings had more adaptive opportunities, which could potentially shift occupants' thermal expectation. These adaptive opportunities are the operable windows and fans, which have been analyzed as well to show the occupant’s feedback on the performance of MMV buildings.

Window and fan usage in MMV buildings

As for the window and fan usage in MMV buildings, I found that although most occupants expressed a preference on these adaptive opportunities, many of the occupants did not actually make use of them. There was still a lack of evidence to ascertain if the windows and fans were actually are the reason for the higher satisfaction score in thermal comfort. 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. 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.

From the analysis, I concluded that it is important to provide ceiling fans and operable windows to ensure occupants have more control over the air movement, and it is equally important to design the space plan and controls to ensure occupants are able to use them. The occupants preferred to have air movement and when there was a combination of windows and fans in use, as they worked well in providing it. It is also important to operate these buildings to take advantage of their 'dual' character in an optimal way (both air-conditioning and natural ventilation). In order to do this, one must understand the performance of a range of MMV buildings in terms of occupant satisfaction and gain an insight into how occupants use these buildings.

LIMITATIONS AND CONCLUSION

There are certain limitations in this research due to the scale of the project and limited depth of analysis given that the actual indoor and outdoor temperature data are not available. Besides that, sample variation is also a big challenge for the effectiveness of the data. For instance, since the surveys are not taken in a controlled environment, elements such as time and location vary for each subject; these could all contribute to the occupants' satisfaction with their workspace. Besides each subject of occupant, the individual difference existing in each building is also a huge factor of data variance. Slight variations in categories such as office types, occupancy rates, and lighting can easily change people's perceptions while filling up the surveys, yet each data point was given the same level of importance and treated equally as if they are from the same building. Therefore, while the trends in occupant satisfaction are clear, the exact causal mechanisms are less so, and would require more rigorous case studies and field monitoring beyond the scope of the survey methods used in this research.

Providing occupants with a quality indoor environment should be a goal of any building design and is particularly important for developing countries with a rapid growth of new building construction. Improving the quality of office buildings critically depends on the accountability and learning from existing precedents. The voices of the occupants become an invaluable component of such assessments. This study strongly suggests architects should include mixed-mode ventilation in their office building design in India, as this strategy generally provides occupants a better working environment and higher satisfaction level in general. However, while bringing in the operable windows and fans for adjusting temperature, more specific strategies and management should be enforced to ensure that operable features are accessible to and could benefit the majority of the occupants. Mixed-mode ventilation could also help developing countries save a great amount of energy. As the developing countries such as India and China move towards embracing high-performance, green buildings as the industry standard, post-occupancy evaluations used to identify the performance of buildings should be a standard part of that process. Everyone benefits from learning how a building performs in practice.

ACKNOWLEDGEMENTS

I thank my senior thesis instructor Dr. Kurt Spreyer and Dr. Patina Mendez, my GSI Alison Ecker and Leslie McGinnis for their invaluable teachings and advices throughout my final year at Berkeley, especially for Alison who has patiently edited each part of my thesis as it progressed step by step. I also thank Professor Gail Brager at the Center for Built Environment in the College of Environmental Design at UC Berkeley who kindly helped me to navigate with my thesis direction in the beginning and constantly encouraged me find my own path. Professor Brager showed great generosity and openness to share me with her data and experiences in previous studies. I am immensely grateful to Haripriya Sathyanarayanan who became my mentor in the Spring semester for guiding me through the whole analysis and writing process and constantly giving me constructive advice. Finally, I greatly benefitted from members of my peer editing cohort: Steven Wong, Halley Nathwani, Helen Kou and Shehnaz Mannan. This research would be impossible without the help I received from these people.

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