Energy and Environmental performance of a green certified office building in the hot dry climate of India

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Abstract. This paper applies a customised post-occupancy building performance evaluation (BPE) approach to evaluate the actual performance of a Platinum-certified green office building in the extreme hot dry climate of India from both technical and occupants’ perspectives. The in-use energy and environmental performance of the office building was examined using energy data on consumption and generation, monitoring of environmental conditions (temperature, relative humidity, CO₂), along with occupant satisfaction survey. Total annual energy use of the building was measured as 100 kWh/m²/year with photovoltaic generation contributing 18 kWh/m²/year. Although total annual energy use was found to be 42% less than the typical office benchmark, about 6% more energy was used than predicted. Indoor air quality was perceived to still be fresh and neither too dry nor too humid. Despite this, some spaces had relative humidity measurement over 70% for more than 50% of occupied hours. Daylight factor was consistently below 2% in many areas due to internal partitions; however, BUS survey (105 responses) results showed that 71% of occupants were satisfied with lighting quality, overall comfort and other variables. Such differences between measured and perceived indoor environment indicate the role of occupant adaptation in building performance.

1. Introduction
Due to rapid growth [1] and global concern for environmental impact, India is an important focus for reducing energy consumption in buildings and green building certification councils have seen this as an opportunity. The Indian Green Building Council (IGBC) claims that India is the second country in the world with the largest registered green building footprint with over 5,142 projects registered for green building ratings, of which 1,645 certified and fully functional (as of February 2019) [2]. Research, however, continually demonstrates that green building rating and certification systems do not always ensure greater energy performance [3, 4], occupant satisfaction [5, 6] or better indoor environmental quality (IEQ) over conventional buildings [7].

The energy performance gap (EPG) has been demonstrated in international research. Research has shown LEED (Leadership in Energy and Environmental Design) certified building using twice the energy beyond model predictions in the USA [8]. In the UK this has been reported as up to five [9] and nine [10] times the energy predicted for exceptionally energy efficient designed buildings. Also, in India [4], LEED certified buildings are not performing as expected with respect to certification, i.e. the LEED Silver and Gold facilities of the same type are performing better than one certified as LEED Platinum. The EPG may not necessarily indicate poorly designed or failed green buildings but simply indicate a lack of rigour in the prediction / certification process. One such study demonstrates the way models can
create this dilemma by underestimating occupant numbers and behaviour in office buildings [9]. Another significant problem is attributed to how the prediction side of some building regulation only predicts heating and cooling load i.e. regulated energy, while the measurement side includes total energy consumption [11]. Nonetheless, the frequency of the performance gap internationally indicates the necessity to demonstrate claims of efficiency, sustainability and comfort through evaluation in India.

Building Performance Evaluation (BPE) can be used to identify, quantify and resolve the gap between ‘as-designed’ and ‘built / in-use’ performance through a systematic collection and analysis of qualitative and quantitative information related to fabric performance, energy performance, environmental conditions and occupant behaviour. BPE can involve feedback and evaluation reviews at every phase of the building delivery from strategic planning to occupancy, adaptive reuse and recycling [12]. This paper seeks to apply a customised post-occupancy BPE approach developed in [13] (I-BPE) for Indian green buildings, to evaluate the actual performance of an IGBC Platinum-rated office building in the hot and dry climate of India, from both technical and occupants’ perspectives. Following the literature review of relevant studies to-date in India (following section), the paper then introduces the case study building and the methods used to evaluate it. The results are then presented followed by a discussion on future application and key conclusions.

2. Review of building performance evaluation in India

There is a growing body of published research on assessing actual building performance in India. Most of these studies are focussed on field studies in thermal comfort (FSTC) utilising thermal comfort questionnaires, interviews, temperature and relative humidity (RH) logging, and spot measurement tools to evaluate environmental parameters of buildings [14]. Interior environment assessment in the literature include spot measurements at the time of survey [15, 16], thermal comfort questionnaires (including long-term/seasonal outlook and/or thermal sensation and preference votes) [15-18] and long-term logging/monitoring of temperature, relative humidity (RH) and other parameters [17, 19]. In addition, several studies, of naturally ventilated domestic and non-domestic, concluded that occupants are comfortable at temperatures greater than comfort ranges recommended by ASHRAE 55, ISO-7730 standards, and the National Building Code of India [16, 20, 21].

Generally, POE/BPE studies differ from FSTC in that they include the addition of a long range questionnaire on such variables as work area satisfaction, lighting, productivity, and health [15]; a review of project information, interviews with key stakeholders [18]; design and system installation review, monitoring plan walkthrough, monthly energy bill collection for one year combined with seasonal energy monitoring, data logging of electricity distribution, spot measurements of lighting, temperature, RH, and envelope temperature [22]; and aggregated, sub-metered and appliance energy consumption monitoring [23]. The largest gap in BPE methods relate to those generally applied before post-occupancy, e.g. evaluation of systems installation, commissioning, and fabric performance. In summary, most studies are focused on thermal comfort and less on energy consumption, with little cross-over between the two subjects.

3. Case study and research methods

A previously developed BPE methodology [13] developed for the Indian context (I-BPE), as part of a Newton Fund UK-India research project, was tested on a green office building as part of a postgraduate dissertation (by one co-author), with the intent to provide feedback on the relevance and effectiveness of the I-BPE methods as a research tool in the Indian context. A key aim of the case study is to better understand the challenges in applying the methods and tools of the I-BPE methodology, and how these might be improved to continue BPE studies in India.

The case study building, the operational headquarters of a company located in Rajasthan, India, was originally constructed in 1966 and has been retrofitted many times over its life. It was finally renovated to receive an IGBC Platinum rating in the category of existing building - operation and maintenance in 2017. The building is comprised of five levels with a gross floor area of 9,867 m² and a built-up area of 7,800 m²; however, much of the second and third floors are currently unoccupied. The building is
occupied from Monday to Friday from 9:30 – 18:30. Occupancy varies every day with 80 permanent occupants, 15-25 part-time occupants, 20-30 daily visitors.

The building is constructed of reinforced cement concrete (RCC) and masonry to create a heavy mass structure. To its benefit, the building is oriented long-ways along the north and south and is designed around a central atrium which allows daylight into the centre of the building. To each side of the central atrium are double loaded corridors with open office space in the centre. The central atrium was originally open to the sky but was covered to restrict bird intrusion. The covering is translucent, but it has reduced the level of daylight in the space. The building uses a mix of cassette ceiling air conditioning (AC) units and a variable refrigerant flow (VRF) system for cooling; the offices on the fourth floor are cooled with split ACs, and the auditorium has separate chiller plant for cooling. In addition, tower air conditioners are in place as back-up cooling units. The auditorium also has a separate chiller plant for cooling. The stairwells and the lift lobbies & corridors of the fourth floor are naturally ventilated. The remainder of the building is mechanically ventilated throughout the entire year, and all windows are fixed. The site uses grid electricity and a 100kWp photovoltaic (PV) array; there are also onsite diesel generators used as a backup during power outages. The building also performed excellent in ‘site and facility management’ and ‘water efficiency’ categories achieving targets such as waste collection and disposal, eco-friendly commuting and landscaping practices, heat island reduction (roof and non-roof) and outdoor lighting pollution reduction.

3.1. BPE field study methods

The field study was carried out for one month in the monsoon season (5 July – 6 August 2018). The primary components of the study included design and construction audit, energy audit, environmental audit and occupant survey. Table 1 shows the I-BPE recommend study elements divided in four levels of increased complexity. For each level, the table indicates the action taken and/or tools used.

| Table 1. Adaptation of the I-BPE methodology for this study (NP = not performed) |
|---------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| **Level 1**                     | **Level 2**                   | **Level 3**                   | **Level 4**                   |
| Review of design intent         | Collection and review of design docs.: Plans and IGB credit doc. | Review of services and energy systems: NP | Interviews with key stakeholders: facility manager (FM) |
| Technical building survey      | Inspection of build quality and services: photographic survey | Controls interface survey: NP | Review of installation and commissioning of services: NP |
| Energy assessment               | From BMS: Electricity use: Jan 2017 – Jun 2018 monthly & incomplete daily data | Energy monitoring: NP | Sub-metering: From BMS: Diesel generator (Jan – Dec 17) & PV (Apr 17 – Mar 18) monthly & incomplete daily data |
| Environ. monitoring             | Temperature, and RH spot readings: tool: WatchDog A160 | Temperature and RH monitoring: 5-min. 4-week duration; tools: Hobo UX-100, 1-button | Additional spot read/logging (e.g. CO₂, lux, wind speed); CO₂ spot reading/logging: tool: WatchDog A160, Tinytag Light reading: Lux meter |
| Occupant feedback               | Occupant satisfaction survey: BUS (78 of 105 returned) | Semi-structured interview: 10 interviews | Thermal sensation and preference survey: self-completed diary (~15 returned; incomplete) |
|                                 |                               |                               | Focus group: NP |

In addition, the site diesel generators used in the first month of the study and the tower air conditioners used in the remaining 3 months.
4. Results

4.1. Review of design intent
According to BUS\textsuperscript{1} [24] results and FM interview, the exterior and interiors of the building are considered well designed and facilities are overall satisfactory; however, lack of meeting rooms and storage space, open plan office noise, and lack of control over temperature were noted as issues. Variation in use between ‘as-built’ and ‘in-use’ include: most the spaces on second and third floors of the buildings are unoccupied and are being used to store unwanted things; balconies are used to house split AC units to cool the newly designed occupancy of the fourth floor; and improper wiring, unnecessary spotlights, broken window shade controls, water leakage in the false ceiling, lack of storage at the workspace were noted at the time of walkthrough survey. Overall, the design review process proved to be challenging as much of the core team responsible for the coordination of the certification process had left or retired and even the plans received from the FM consultants did not represent the current state of in-use.

4.2. Energy assessment
The building received two Energy Efficiency credits for Minimum Energy Performance (mandatory minimum) for projecting a 10\% reduction in total energy consumption beyond the design baseline of 817,000 kWh. The PV system’s capacity goes beyond the 7.5\% that was required to gain the maximum credits for on-site renewables. Though grid connected, all PV electricity generated is consumed by the building. The building also gained two credits for purchasing 273.5 MW of off-site renewable energy.

The following energy analysis considers energy data for the year covering 1 April 2017 – 31 March 2018 as this is the extent of data available to the researcher for PV generation. Though the data for grid and diesel consumption span from January 2017 – June 2018, there is a gap in the data wherein the monthly totals for March – May 2018 are missing. March 2018 is therefore proportionally estimated from March 2017. Overall, the building is not performing as well as expected; it is also consuming more energy than it did in 2015 (pre-certification). Based on current consumption, in relation to the design baseline, the building would not qualify for the Minimum Energy Performance credits to achieve certification. The total EPG is +6\%; however, the renewable system is performing better than predicted: EPG = -21\%. Overall, this lowers the net EPG to +3\%. Table 2 shows the results for the as-designed and as-built energy consumption and generation.

|                          | Pre-certification (2015) | As-designed | In-use |
|--------------------------|--------------------------|-------------|--------|
| Total energy use (kWh/yr)| 734,424                  | 735,125     | 779,789|
| Renewable generation (kWh/yr)| 115,760               | 115,856\textsuperscript{a} | 140,671|
| Net energy use (kWh/yr)  | 618,664                  | 619,269     | 639,118|
| Net energy use/m\textsuperscript{2} (kWh/m\textsuperscript{2}/yr)\textsuperscript{b} | 79.3                   | 79.4        | 81.9 |

\textsuperscript{a}Given as percentage of total energy use (15.76\%) based on historic performance.

\textsuperscript{b}Energy Performance Index.

Figure 1 shows the case study building’s energy performance index (EPI) in relation to relevant Indian benchmarks [25, 26]. The building is performing better than other green buildings and the Indian Energy Conservation Building Code (ECBC) office building benchmark for the hot & dry climate.

\textsuperscript{1} The Building Use Studies (BUS) methodology obtains feedback data on building performance through a self-completion occupant questionnaire; the results can be compared against a national benchmark database. The questionnaire prompts the respondents to comment on the building’s image and layout, comfort, and daily use of the building features.
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Figure 1. Annual energy data for building (1 April 2017 – 31 March 2018) with benchmarks.

There is a strong correlation ($r = 0.68$) between total energy consumption and total degree days [27]. Total energy consumption proportionally tracks degree days from April – October 2017. However, despite the low degree days for the months of November 17 – February 18, more energy is consumed in these months than would be expected. Part of this is attributed to the continuous ventilation and fixed windows in the building. The reported lack of handover provided to the current FM onsite could also contribute to higher than expected energy consumption, especially during the winter months. During the previous change in FM, no handover was provided to the current FM. This resulted in lack of awareness of the extent of BMS monitoring, including air handling unit temperature monitoring.

4.3. Indoor environment

The acceptable operative temperature range for offices in summer is 24.5°C +/- 2.5°C according to the ISHRAE standard [28]. Figure 2 shows the temperature measurements for four spaces during the monitoring period. As operative temperature was not observed, dry bulb temperature is used here as a proxy. Based on the temperature data alone, the comfort temperatures in the spaces of the building are well-managed though not consistent from floor to floor. The 4th floor office has the most occupied hours (80%) within 0.5 degrees of the target temperature. The ground floor is well within acceptable range but could experiment with scaling back on the cooling a little to reduce energy consumption. RH is not as well managed as temperature. The 4th floor office also has the smallest percentage of hours (1%) over 70% RH; however, the 1st floor open office has 60% of occupied hours over 70% RH. This should be reviewed and monitored as it could increase formaldehyde and microbial concentrations in the air, leading to health problems or allergic reactions.

Figure 2. Temperatures (9 July – 3 August 2018).

Figure 3 shows the indoor air quality (IAQ) measurements taken in four offices during the period 10 July – 6 August 2018. Each office was measured for six days at a time, sequentially with the same device. Note: 1FOC = first floor open centre office, 4FOB = fourth floor open back office, CF = closed front office. ISHRAE (2016) thresholds are shown in the graphs for PM2.5 and CO₂. For these graphs the lower band indicates the Class A threshold: aspirational and the upper band indicates the Class C.
threshold: marginally acceptable. Though mean PM2.5 concentrations in the offices are below the ISHRAE Class A threshold, two offices have maximum values which have reached unacceptable levels. A total of 13% of occupied hours combined in these spaces had CO2 concentrations between the Class B: acceptable and Class C: marginally acceptable levels. 3% of occupied hours were beyond marginally acceptable. Most of these hours were experienced at the end of the workday in the fourth-floor open office. This corresponds with the BUS findings where occupants rated the air quality as fresh; better than the BUS mean.

![Figure 3. Office IAQ measurements and ISHRAE standard thresholds.](image)

4.4. Occupant survey
According to BUS survey results, the design, the building’s image to visitors, whether the building meets the user’s needs and effectiveness of the use of the space were considered satisfactory. Overall lighting is considered satisfactory. In addition, the respondents considered there to be enough natural light on the scale toward ‘too much’; however, there is little to no issue with glare in the building. Measurements showed higher than required levels of daylight with exception of ground floor and some deeper, central areas of open floor plan offices. In these areas the daylight factor was consistently below 2% due to internal partitions. Control over lighting is considered good, though no better than the BUS benchmark mean. Overall comfort is rated moderately high for both summer and winter. In both seasons the temperature is perceived to be on the cooler side, cooler in winter, and the air is considered neither too dry nor too humid, somewhat still, and fresh & odourless. Though comfort and temperatures are considered satisfactory, the respondents feel that they have little control over cooling or ventilation. Productivity at work is perceived to have increased because of the environmental conditions in the building and occupants feel healthier when in the building.

5. Discussion
Though there is generally a lack of procedure to ensure that the design intent of green buildings is realized, this certification process was special in that a year of pre-certification energy data were available with which to compare projection calculations. This was because the building was certified as an existing building. However, no performance evaluation follow-up was officially performed after the certification process. Though the building is performing worse than it did in 2015 there could be external environmental factors, occupancy shifts, etc. that contributed to this. This is a clear case of a Platinum rating that was not dependent on energy performance but a significant list of other green building features to qualify for certification. This raises two questions: (1) Is a 10% reduction on baseline sufficient to earn a platinum rating knowing that there is often an EPG? (2) As the building in-use is only performing at a 5% reduction on the baseline can it still be considered a Platinum rated building? Recommendations to improve performance include low cost options such as awareness campaigns
addressing energy-related use of the building among occupants and high cost options such as, consider operable windows and or trickle vents to reduce the need for mechanical ventilation in the winter months, mixed-mode ventilation and or night-purging. It was also recommended that the BMS system be commissioned on regular basis and that meetings are held to discuss the findings of the BMS system amongst facility and building management to improve performance.

The learnings from this study will be used to improve the I-BPE process. When assessing an existing building after much time has passed, lack of access to design intent data can occur. Knowing beforehand that these issues exist would require more time to survey the building and systems in order to develop an idea of the difference between as-designed and in-use. Another lesson learned is that monitoring devices that are dependent on Wi-Fi connection or outlet connection can suffer interruptions during power outages which happen often. This suggests the need to consider, as an option, battery driven logging equipment with built-in storage accessible by Bluetooth. Coordination with management in the building helped increase the return rate of BUS responses. Selling the concept to the building owner/management is essential to success. Delivering recommendations for improvement can help in this regard.

6. Conclusion

This study shows the process of testing the I-BPE methodology on a Platinum-certified green office building in the hot and dry climate of India. The field study was carried out for 30 days which included spot measurements, data monitoring, walkthroughs and occupant surveys. The field study offers a template for replication of BPE and benchmarking data for green residential buildings in India. The next step in the Learn-BPE project involves testing the I-BPE approach on several other case studies implemented by students using a programme developed for this purpose. The I-BPE case studies intend to demonstrate actual performance of certified green buildings in India, publish the data, and continually provide a testing platform for refinement of the I-BPE framework for application in India. Finally, the I-BPE case studies are also intended to build trust in the industry by strengthening the relationship between the industry professionals and researchers in academia.

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