EAI Endorsed Transactions
on Energy Web
Research Article EAI.EU

Evaluating the Environmental Footprint: BPE Framework for Sustainable and Energy-Efficient Residential Buildings in India

Jagadeesh Kasi[1], A K Kaliluthin[2,*] and K Kanmani[3]

[1]Research Scholar, Department of Civil Engineering, School of Infrastructure, B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai
[2]Associate Professor, Department of Civil Engineering, School of Infrastructure,B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai
[3]Assistant Professor (Senior Grade), Department of Civil Engineering, School of Infrastructure, B. S. Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai

Abstract

In the context of enhancing building performance assessment, this study introduces the BPE (Building Performance Evaluation) framework and explores its application through a residential complex in India. An expert evaluation of the questionnaire is carried out to investigate the main element and obstacles to the execution of BPE. The framework, designed to scrutinize five parameters, initially assesses design aspects, including building form, orientation, and aesthetics. Findings reveal that the building design lacks efficient circulation, storage facilities, and satisfactory spatial allocation. Building energy monitoring, essential for comprehensive analysis, faces limitations due to insufficient data availability, emphasizing the need for thorough planning. Thermal comfort analysis, based on temperature and humidity measurements, unveils significant fluctuations beyond comfort thresholds. Expert surveys and occupant feedback further expose reduced utilization of natural ventilation, high air conditioner adoption rates, and adaptive behaviours. The framework's insights prompt opportunities for improvement, yet validation requires broader application across diverse buildings. The study's academic survey emphasizes the importance of integrating BPE in industries with government policies. Field observations highlight challenges in space utilization, material selection, and occupant engagement. This study's findings underscore the BPE-RBPI framework's potential to refine performance assessment, sustainable and energy efficient to foster industry confidence, and drive holistic improvements in India's building sector.

Keywords: Building Performance Evaluation; Residential Building Performance Improvement Framework; Occupant feedback; Building Sector.

Received on 21 May 2023, accepted on 29 September 2023, published on 13 October 2023

doi: 10.4108/ew.4140

*Corresponding author. Email:kalil@crescent.edcuation

1. Introduction

India is the world's third-largest economy and is growing fast, energy consumption almost doubling since 2000. Building accounts for approximately 41% of India's energy consumption [1], and the potential for sustained development and urbanization is large. This possibility was perceived by the building certification boards. The construction of residential buildings in India is mainly developed and the satisfaction of the occupants indicates the actual intention of these buildings. Earlier research consistently explores residential building performance [2], occupant satisfaction [3], air quality [4]. In countries such as the United Kingdom (U.K.), the United States (U.S.), Germany and Australia [5] have enhanced the design and structure of residential buildings. Despite improvements

in the services and buildings framework, a significant gap between forecasts and actual performance was observed in domestic buildings, resulting in higher-than-expected energy use [6]. While there is some evidence of a performance gap in India [7]. It is conjectured that the experience of different countries and India will continue to meet the need for urbanization by offering better domestic buildings.

BPE is one of the methods to address the performance gap, it is a contrast cycle between the forecast and the actual performance of buildings [8]. BPE depends on the investigation and evaluation by experts, occupants, stakeholders with a planned approach to the building life process. The POE covers the performance of the building but is limited to the usability stage, while the BPE also covers the entire lifecycle of the building before and after construction. Since both the POE /BPE made their emergence from the early 1990s in international stages, no proper framework or method is followed worldwide, and still unrecognized or not familiarly used worldwide [9].

The paper is organized as follows. A critical literature review is explored to examine the integration of academic curricula with building performance, and then the basic tools for evaluating building performance in previous research. The BPE frame-work is designed to empower its selection in industry and academics. An academic survey is conducted to understand the obstruction and delivery of BPE in curricula and industries. Finally, the proposed BPE framework is analyzed for a case study building in India, followed by further discussions and findings in the implementation of BPE in India. should briefly place the study in a broad context and highlight why it is important.

2. Literature Review

The University of California, through the Center for the Built Environment (CBE), has developed several BPE strategies for HVAC, IEQ, energy monitoring, and occupants' studies [10]. In Australia [11], Japan [12], Holland [13], POE's are utilized to verify the user's satisfaction. A strong relationship between building service and occupant comfort has also been established and the views of clients are being promoted for future improvements. In Brazil [14], a face-to-face interview, plan audit, expert interview, stakeholder meeting, and questionnaire survey was used to calculate the thoughts of the construction and design firms of the end-users. Similarly, in China, Hongkong [15], Singapore [16] the same methodology is applied to IEQ evaluation, questionnaire assessment, and social perception. In the United Kingdom, enterprises such as PROBE (Post-occupancy Review of Building and Engineering), BUS (Building Used Studies) [17] are used to conduct a qualitative and quantitative review, data col-lection, and survey of building performance. A recent BPE is conserved in the UK for domestic residential buildings [18] provides information on plan procedure, energy usage, building service, end-user satisfaction, and maintenance. Apart from the purpose of the BPE analysis, a recent global review [9] indicates that BPE is used by innovation and is the primary phase of adoption.

The IGBC, (Indian Green Building Council), GRIHA (Green Rating for Integrated Habitat Assessment) includes the approaches for new buildings to improve their performance in the energy system, water management, air quality, lighting, etc. The in-tent of the rating system is limited but the introduction of the rating system has not adversely affected the academic curriculum. Industries are required to develop and maintain a role in building performance evaluation, which requires academicians to incorporate industry requirements into the curricula. The All-Indian Council for Technical Education (AICTE) has introduced numerous courses on the environment, sustainable development, green building, the energy efficiency of buildings, climate studies. but all courses are enrolled in elective courses, where students are free to decide on the course selection. BPE has excellent research production in many countries. But in India, it needs to be treated as one of the major entries to increase BPE professionals across the university system.

In this specific context, this research describes the industry BPE framework in the Indian context to assess residential buildings. A proposed survey by experts explores the possibility of executing BPE techniques in academic programs and construction and design firms. The proposed BPE framework is being conducted in a case study building to establish a path for future studies in BPE. The research evaluates two objectives primarily (a) to analyze the scope and encouragement towards BPE in the aca-demic curriculum. (b) the role of occupants and stakeholders and in the context of the BPE.

2.1. View of BPE in India: academics and industries

To plan a customized BPE framework approach for the Indian context, it is crucial to analyze current teaching methods of building performance at universities. The re-search is intended to emphasize that building performance must be recognized by industry and then integrated into school curricula. Civil engineering is a branch closely linked to the building, AICTE [19,20,21] has integrated numerous elective courses curricula such as facility management, energy conservation, green buildings, sustainable cities, and communities. Interestingly, the students show some lack of interest in the courses and are more preferred for the courses of structural and building design. Although the study shows a lack in adopting the BPE method in curricula, there is a moderate number of academic researchers have been published in the application of building performance in India. The literature review shows two sets of studies con-ducted extensively, one of thermal comfort [22,23,24,25,26] consists of spot measurement of Temperature, Relative Humidity, Questionnaire's survey conducted for a time interval to criticize the comfort standards and specifications. Another is the POE [27,28] studies that incorporate occupant comfort following the phases of occupancy. Despite the available techniques, it appears that there is a gap in a defined BPE framework for the review of residential buildings in India.

The BPE framework is developed based on information gathered through the literature review. The BPE-RBPIF consists of research elements to provide its framework in universities and industry. The framework is potentially compared to commonly used BPE methods globally [29].

3. Study Area

The proposed BPE- RBPI framework is tested on a study building. The framework methods are applied to understand the challenges in the implementation of BPE in the Indian context. A residential building in Chennai was selected for the study. The building accommodates 79 dwellings with 6 blocks.

4. Methodology

4.1.Research Method

The current research adopts an exploratory investigation to examine the RBPIF- BPE framework by directing a telephonic call survey to the experts on BPE implementation in academics, trailed by a case study investigation with the proposed framework as a research tool.

The BPE framework is viewed as a business model based on the Deming Cycle, which consists of four stages plan-do-check-act (PDCA) cycle [30]. For continuous improvement with everlasting scope, the Deming cycle is used [30]. The framework (Table.1) includes ‘design review’ through survey and interaction with stakeholders; ‘energy efficiency monitoring’ covering the assessment of energy in the domestic buildings; ‘building thermal comfort’ using data loggers and a proposed adaptative regression model; ‘occupants survey’ using a survey among the occupants to assess the comfort and satisfaction; ‘building service review’ using experts’ opinion for the improvement of the construction and design firms. The case study building was tested to determine the reliability of the BPE framework and will be improved through the research.

Table 1: Proposed BPE- RBPI Framework for the Indian Context

	Framework	Plan	Do	Check	Act
1	Design review	Data collection, strategy, building details, and plan of building	Walkthrough survey on review of design building service	Meeting, feedback forms, online/ offline survey, and analysis	Interaction and meeting with stakeholders, designers.
2	Energy efficiency monitoring	Collection of energy usage details and requirements	Forecasting of future energy demand	Energy and electricity load monitoring in individual dwelling and simulation	Energy performance management and action for future development
3	Building thermal comfort	Spot reading for daily indoor temperature measurement	Fixing of data loggers for observing temperature	Integrate the temperature swing and analyze using different models	An adaptative regression model to predict comfort temperature
4	Occupant’s survey	Plan a survey with occupant usage attributes	Walkthrough analysis and occupant responses	Conduct semi-structured interview and integrate the suggested opinions	Correlate the occupant opinion with experts’ responses
5	Building service review	Plan a survey with building performance attributes (BPA)	Walkthrough survey and questionnaire survey conducted through experts	Correlate and integrate the performance attributed review from experts	Action and recommendations to construction and design firms

5. Results and Discussion

5.1. Expert opinion on BPE in academia and industry

The expert survey was conducted to assess the limitations of BPE in academia and industry. The survey questions were mailed, and the expert's opinion is collected via a telephone interview.

The idea of the phone conversation is to get feedback instantly from experts. De-tails of the backgrounds of the academic experts are kept confidential at the request of the experts due to their views on the curricula are discussed in this research. A total of 73 experts (Figure 1) are listed at the start, but due to certain administrative problems and the unavailability of the expert, only 65 expert opinions are collected. The experts are widely distributed in India, over 15 states are included in the survey.

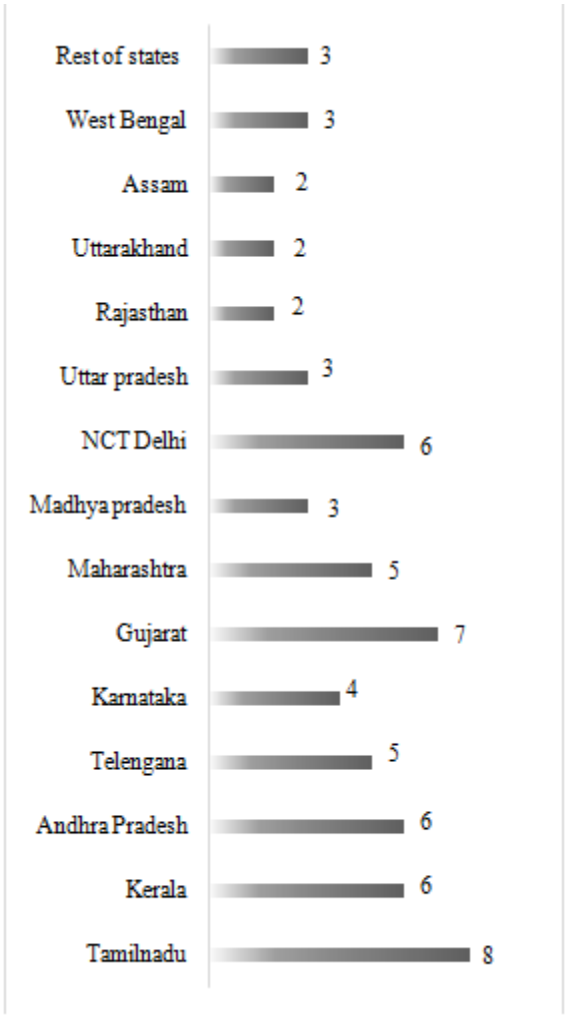

Figure 1: Distribution of Experts among the States in India

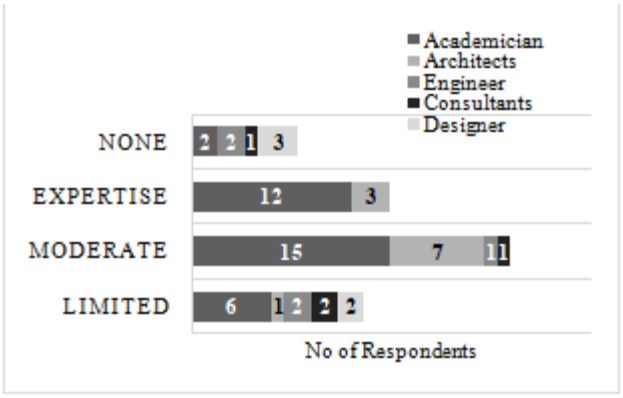

Figure 2: Respondents Knowledge Level in BPE

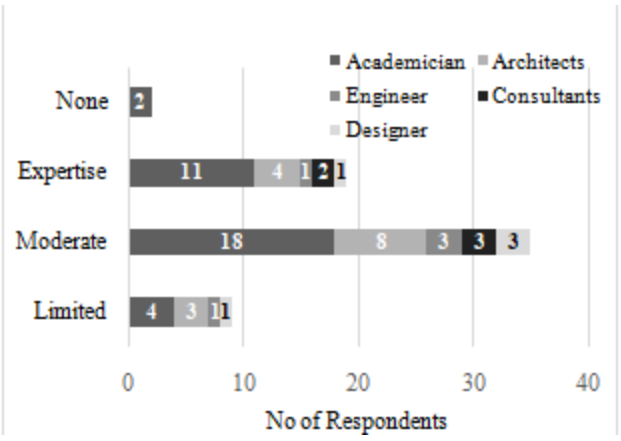

Figure 3: Experience of Respondents

Most of the respondents are from an academic background with good industrial exposure. Approximately 65 percent of experts have academic and industrial expertise. The respondent's knowledge level in BPE (Figure 2) was assessed using a scale as follows; Limited (L- High awareness about BPE but not practiced), Moderate (M- practiced at least one project in BPE), Expertise (practiced more than 3 projects in BPE) and None (No Awareness about BPE). Responses indicate that designers have a limited level of familiarity with BPE. Architects possess adequate knowledge of BPE.

The experience of the respondents (Figure 3) is collected, scale as follows; Limited (1-2 years of experience), Moderate (2-10 years of experience), Expertise (more than 10 years of experience), and None (0 years of experience). This indicates that a greater number of respondents have over 10 years of work experience. The most expert with more BPE knowledge have an academic and industrial background. The limitation of the survey is the size of the sample, but the survey is meant to provide the opinion about the BPE framework. Sampling data are retained with high quality and accuracy.

The expert study provides an overview of the introduction of BPE into the Indian context. Most experts have agreed that BPE is the future and is much needed to build a suitable framework in India. The respondents added further points about the implementation of BPE in India: for better energy management, improved design, and building services, effectiveness in design, and awareness of sustainable and cli-mate-oriented buildings.

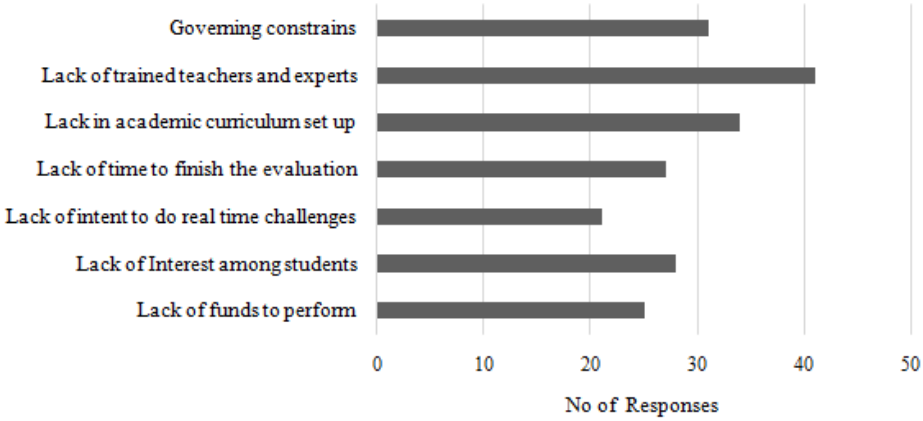

Figure 4: Difficulties to Implant BPE in Academic Curricula

Most experts commented on considering a primary course on BPE in undergraduate programs. The difficulties in implanting the BPE in academic curricula (Figure 4) show a lack of trained experts and teachers in academia to promote the BPE. Also, lack of academic structure and governance constraints is viewed as a challenge by many ex-perts. The survey has a different set of questions for the people in academia, on the further discussion the faculty are not satisfied with the dissertation work provided in the curricula. The lack of literature thesis in the courses leads to a lack of knowledge in research and industrial orientation in BPE.

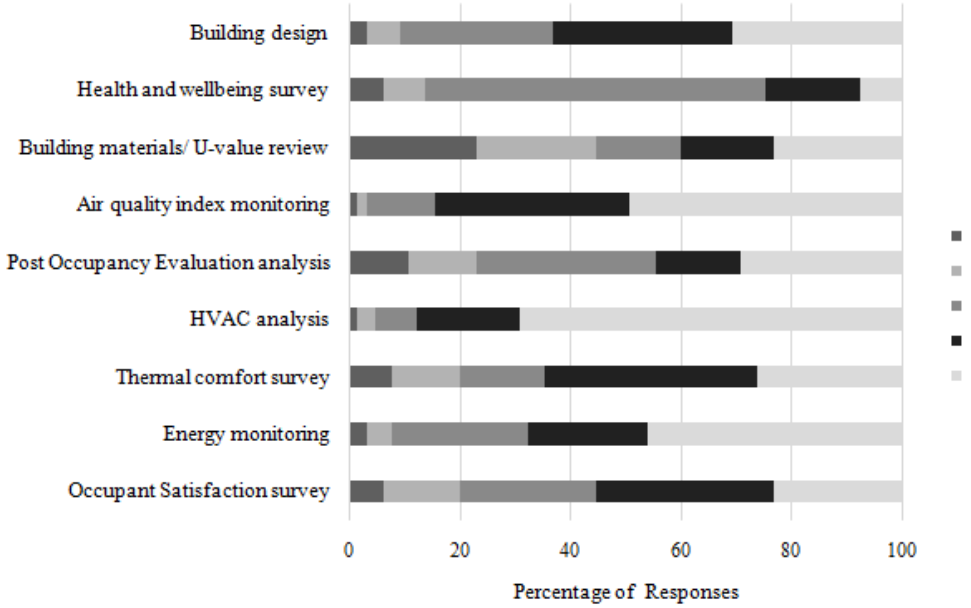

Figure 5: BPE Methods and Their Level of Importance

The level of importance of various BPE methods (Figure 5) are collected through a 1-5 scale of 1- NI (Not Important), 2- LI (Low Important), 3- MI (Moderately Important), 4- HI (Highly Important), 5- VHI (Very Highly Important). The responses reflect the importance of thermal comfort studies, HVAC analysis, and the occupant satisfaction survey. This shows that academia is having more facilities and laboratories for design and testing concepts but lacks BPE equipment. The main purpose of the survey of aca-demic experts is to identify obstacles to the adoption of the EPB. In the expert's opinion, the barriers are listed: lack of experts to perform experiments, lack of time to per-form tasks, lack of availability of funds to purchase equipment, lack of interest from stakeholders, and motivation. Most experts said the lack of policies from stakeholders and industry to promote BPE, which is considered a major impediment among the obstacles.

The BPE- RBPI Framework was applied in a case study residential building as a research tool. All five parameters are applied over the building. The design review is the

parameter applied first as a research tool to check the reliability of the framework. The building consists of 7 blocks with four-story in each block, the design aspects com-prise the building form and orientation. Moreover, the design of the building looks aesthetic and the plan verification showing more unused spaces and dissatisfaction towards the storage facility in the design. The inadequate circulation and spaces are overlooked from the design review.

Building energy monitoring required a full-year analysis of energy meter reading and its fluctuation. Since the facility management team in the study building are unable to furnish the details, it's quite limited to carry out the monitoring. Overall, the energy monitoring is required to be planned well before the selection of the case study building. The daily relative humidity, indoor and outdoor temperature (Figure 6) is measured to calculate the thermal comfort of the building. The temperature fluctuation is higher comparing with the standard comfort temperature. Also, the building serves a mixed-mode of ventilation, and more occupants are interested to have an artificial cooling system in dwellings.

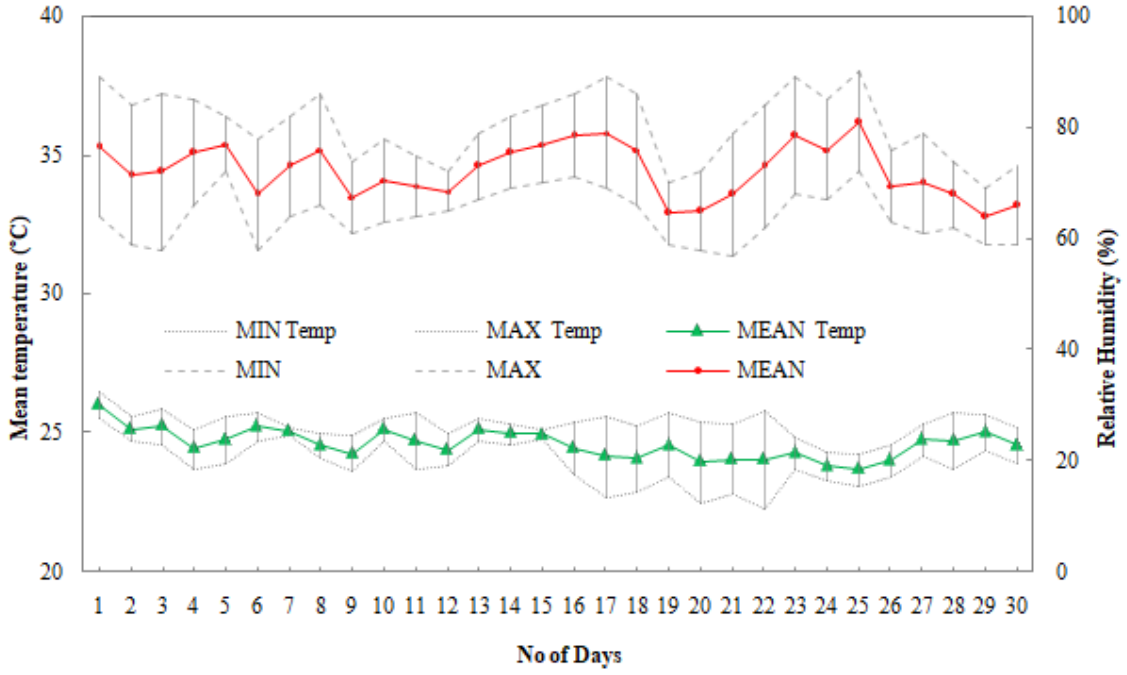

Figure 6: The Mean Temperature and Relative Humidity of the Case Study Building

The investigation shows an average Indoor temperature of 29ºC during day time. A marginal variation of indoor temperature is measured in the selected zones of a building. This reveals the lack of cross ventilation in the building. The occupant survey was done with the occupants and the building service review was conducted with the experts. The survey shows the usage of natural ventilation in dwellings is reduced. The buildings are operated in a mixed-mode purpose. Air conditioning units have a direct relationship with energy efficiency because of their operating cost and maintenance. Nearly 90% of housing units use at least one air conditioning unit, regardless of room orientation. The use of alternating current appliances is seen here as an additional adaptive behavior of the occupants. The framework provides insight about the case study building to make it better, more study to be carried out with more sample buildings to validate the findings.

6. Summary and Conclusion

The expert survey reveals the perception and participation of academics in implementing BPE courses in the curricula. The civil engineering and architectural sec-tors integrate some courses into BPE. The building industry must encourage the aca-demic community to incorporate courses into the BPE, based on government policy. The lesson learned from conducting the BPE study identifies a suitable method for conducting future RBPIF studies in the Indian context.

The learning started from the field study and walk-through survey shows that modification in the utilization of spaces based on occupants needs, this arises questions over the trust of users who don't imply their need in the study building. Also, the freedom in the selection of material, changes in plan, change in the green corridor, change in spaces makes it difficult to evaluate with building drawings and documents. Almost many of the occupants are less interested to participate in the survey, this makes the quality of sampling limited. To improve this aspect, it is required to give knowledge about building performance about the occupants through interviews and videos. The user's opinion about the perception and enjoyment in the building is collected

from the occupant's real experience and the occupants are highly encouraged to participate in the survey.

This study attempts exploratory research to establish a BPE-RBPI framework for the Indian context, to assess the performance of residential buildings through a building survey and an academic survey. The survey indicates the lack of people ready to assess the building's performance. As a vital test for its selection, suggesting that pre-pared people are desirable as well as the framework. The case study investigation of the BPE approach provides insight about the method and utilization of building studies for better understanding, more details are required regarding the building and occupant engagement.

Thermal comfort analysis, based on temperature and humidity measurements, unveils significant fluctuations beyond comfort thresholds. While the building employs mixed-mode ventilation, occupants show a preference for artificial cooling. Indoor temperature discrepancies indicate insufficient cross-ventilation. Expert surveys and occupant feedback further expose reduced utilization of natural ventilation, high air conditioner adoption rates, and adaptive behaviours. The framework's insights prompt opportunities for improvement, yet validation requires broader application across di-verse buildings. The study's academic survey emphasizes the importance of integrating Building Performance Evaluation (BPE) courses into educational curricula, aligning with government policies. Field observations highlight challenges in space utilization, material selection, and occupant engagement. User participation constraints necessitate innovative data collection strategies. The paper advocates for enhancing building performance professionals through training programs and aligning policy and education for effective BPE implementation. This study's findings underscore the BPE-RBPI framework's potential to refine performance assessment, foster industry confidence, and drive holistic improvements in India's building sector.

The BPE-RBPIF was evaluated in a study building to refine fundamental techniques and activities to lead further analysis of BPE in India. The RBPIF approach is expected to help build the confidence of construction and design firms by avoiding the vulnerability of BPE's liability risk. It is necessary to motivate academicians with limited knowledge in BPE to attend a workshop, a training program to develop their skills in building performance assessment. Government policy and education programs aligned incoherence to support the BPE. Policymakers need to focus their attention on cities to improve the implementation of the BPE-RBPI framework. Overall, to enable BPE in India, the critical point is to develop more professionals, and it includes both strategy and market changes as driver.

Declarations

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgements.

I would like to place my special thanks to my research supervisor Dr. A K Kaliluthin, Associate Professor, Department of Civil Engineering, School of Infrastructure, B.S. Abdur Rahman Crescent Institute of Science and Technology for his cooperation, guidance and support throughout this research work.

References

[1] Dos Santos, A.L.T.; Villa, S. B.; Garcia, G. M.; Leão, C. R. Incorporation of post-occupancy evaluation in building information modeling: a case study in Brazil. *Architectural Engineering and Design Management*, **2023**, 1-19. [Cross Ref]

[2] Tham, K.W.; Wargocki, P.; Tan, Y.F. Indoor environmental quality, occupant perception, prevalence of sick building syndrome symptoms, and sick leave in a Green Mark Platinum-rated versus a non-Green Mark-rated building: A case study. *Science and Technology for the Built Environment***2015**, 21, 35–44. [Cross Ref]

[3] Alborz, N.; Berardi, U. A post occupancy evaluation framework for LEED certified US higher education residence halls. Procedia Eng. **2015**, 118, 19–27. [Cross Ref]

[4] Gupta, R.; Gregg, M. Empirical evaluation of the energy and environmental performance of a sustainably-designed but under-utilized institutional building in the UK. *Energy and Building***2016**, 128, 68–80. [Cross Ref]

[5] Tannor, O.; Appau, W.M.; Attakora-Amaniampong, E. A post-occupancy evaluation of in-house facilities management service quality and user satisfaction in multi-tenanted office buildings in Ghana. *Facilities***2023**, Vol. ahead-of-print No. ahead-of-print. [Cross Ref]

[6] Leaman, A.; Stevenson, F.; Bordass, B. Building evaluation: practice and principles. *Build. Res. Inf.***2010**, 38, 564–577. [Cross Ref]

[7] Sabapathy, A.; Ragavan, S.K.; Vijendra, M.; Nataraja, A.G. Energy efficiency benchmarks and the performance of LEED rated buildings for Information Technology facilities in Bangalore, India. Energy Build. 2010, 42, 2206–2212.

[8] Preiser, W.F. Building performance assessment - from POE to BPE, a personal perspective. *Archit. Sci. Rev.***2005**, 48, 201–204. [Cross Ref]

[9] Li, P.; Froese, T.M.; Brager, G. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Building and Environment***2018**, 133, 187–202. [Cross Ref]

[10] Maslova, S.; Burgess, G. Delivering human-centred housing: understanding the role of post-occupancy evaluation and customer feedback in traditional and innovative social housebuilding in England. *Construction Management and Economics***2023**, 41(4), 277-292. [Cross Ref]

[11] Carthey, J. Post occupancy evaluation: Development of a standardized methodology for Australian health projects. *Int. J. Constr. Manag.***2006**, 6, 57–74. [Cross Ref]
[12] Agee, P.; Gao, X.; Paige, F.; McCoy, A.; Kleiner, B. A human-centred approach to smart housing. *Building research & information***2021** 49(1), 84-99. [Cross Ref]
[13] Engelen, L.; Held, F. Understanding the office: Using ecological momentary assessment to measure activities, posture, social interactions, mood, and work performance at the workplace. *Buildings***2019**, *9*(2), 54. [Cross Ref]
[14] Göçer, Ö.; Candido, C.; Thomas, L.; Göçer, K. Differences in occupants' satisfaction and perceived productivity in high-and low-performance offices. *Buildings***2019**, *9*(9), 199. [Cross Ref]
[15] Lee, M.C.; Mui, K.W.; Wong, L.T.; Chan, W.Y.; Lee, E.W.; Cheung, C.T. Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms. *Build. Environ.***2012**, 49, 238–244. [Cross Ref]
[16] Wong, N.H.; Jan, W.L. Total building performance evaluation of academic institution in Singapore. *Build. Environ.***2003**, 38, 161–176. [Cross Ref]
[17] Durosaiye, I.O.; Hadjri, K.; Liyanage, C.L. A critique of post-occupancy evaluation in the UK. *J Hous and the Built Environ* , **2019**, 34, 345–352. [Cross Ref]
[18] Rasheed, E.O.; Khoshbakht, M.; Baird, G. Does the number of occupants in an office influence individual perceptions of comfort and productivity?—new evidence from 5000 office workers. *Buildings*, **2019**, *9*(3), 73. [Cross Ref]
[19] AICTE. Model curriculum for postgraduate degree courses in engineering & technology Vol. I. Delhi, 2018a.
[20] Al Mughairi, M.; Beach, T.; Rezgui, Y. Post-occupancy evaluation for enhancing building performance and automation deployment. *Journal of Building Engineering***2023**, 107388. [Cross Ref]
[21] Elsayed, M.; Pelsmakers, S.; Pistore, L.; Castaño-Rosa, R.; Romagnoni, P. Post-occupancy evaluation in residential buildings: A systematic literature review of current practices in the EU. *Building and Environment***2023**,110307. [Cross Ref]
[22] Indraganti, M. Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India. *Appl. Energy***2010**, 87, 866–883. [Cross Ref]
[23] Indraganti, M. Using the adaptive model of thermal comfort for obtaining indoor neutral temperature: findings from a field study in Hyderabad, India. *Build. Environ.* **2010**, 45, 519–536. [Cross Ref]
[24] Kumar, S.; Mathur, J.; Mathur, S.; Singh, M.K.; Loftness, V. An adaptive approach to define thermal comfort zones on psychrometric chart for naturally ventilated buildings in composite climate of India. *Build. Environ.* **2016**, 109, 135–153. [Cross Ref]
[25] Dhaka, S.; Mathur, J. Quantification of thermal adaptation in air-conditioned buildings of composite climate, India. *Build. Environ.***2017**, 112, 296–307. [Cross Ref]
[26] Manu, S.; Shukla, Y.; Rawal, R.; Thomas, L.E.; De Dear, R. Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC). *Build. Environ.***2016**, 98, 55–70. [Cross Ref]
[27] Bhanware, P.; Jaboyedoff, P.; Chetia, S.; Maithel, S.; Reddy, B. Case study of an energy efficient commercial building: Validating design intent and energy simulation results with monitored performance data. *Inspire* (Jaipur: India), **2017**.
[28] Thomas, L.E. Combating overheating: mixed-mode conditioning for workplace comfort. *Build. Res. Inf.***2017**, 45, 176–194. [Cross Ref]
[29] Gupta, R.; Gregg, M.; Passmore, S.; Stevens, G. Intent and outcomes from the Retrofit for the Future programme: key lessons. *Build. Res. Inf.***2015**, 43, 435–451. [Cross Ref]
[30] Othman, A.A.; Elsaay, H. A learning-based framework adopting post occupancy evaluation for improving the performance of architectural design firms. *J. Eng. Des. Technol.*, **2018**. [Cross Ref]