Post Occupancy Evaluation to Assess Multifamily Residential Building Energy Performance in India

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Abstract: Post-Occupancy Evaluation (POE) is defined as the process of systematically comparing a building's actual performance measures with explicitly stated performance criteria. POE is widely recognised as being central to addressing the performance gap between design intentions and the actual outcomes of an occupied building. This performance gap is often arising from miscommunication and over-prediction of the building's performance targets in the design stage. This gap also arises due to incorrect methods, tools, and input data for modelling and simulation. Conventionally, the evaluation of housing performance consisted of either physical monitoring or user satisfaction surveys, except that these two do not provide a comprehensive picture. POE is a systematic process for collecting and analyzing occupant feedback. Past research has highlighted occupant's behaviour as a major issue i.e. how occupants operate equipment and how they adjust to the internal conditions that may vary from design assumptions.

The primary goal of this research is to evaluate the application of POE to assess an Indian Green Building Council's (IGBC) Green Homes Certified multifamily residential building in India. The building is in the city of Jaipur, a composite climate zone, and its performance gap was assessed one-year post-occupancy. The methodology comprised of performing energy simulation of three cases on eQuest: a Base-case model based on IGBC Green Homes base-case parameters, as-constructed case based on Green Homes Certification parameters, and as- occupied case based on POE data analysis. The annual energy consumption from the simulation of the three cases is compared to measure the performance gap. The findings indicate a very interesting departure from the general observation of the majority of literature which states a negative 'performance gap' or overutilization between base-case, and as-constructed and as- occupied buildings. In this study, a positive performance gap emerges, i.e. the as-occupied building performs better than the as-constructed. The positive performance gap mainly emerges due to variations in occupancy numbers, and occupancy schedules, equipment usage, equipment power density (EPD), and artificial lighting usage and schedules. These indicate a certain change in urban lifestyles. The concept of positive performance gap is an unexplored area of research in residential sector which indicates the significance of occupant feedback. This study provides a basis to further analyze post-occupancy behavioural studies to understand this positive performance gap.

Keyword: Performance gap, Post-occupancy evaluation, Green Buildings, Green Homes, Occupant feedback Annual energy consumption

Introduction

The primary purpose of a built facility is to meet the needs and expectations of its occupants in a comfortable, healthy, and secure indoor environment. However, over time, the buildings can no longer sustain the changing needs and expectations of its users. As a result, the building's performance has to be enhanced. Post-occupancy evaluation (POE) introduced in the 1960s was to respond to the problems of building performance based on the building's occupant perspective (Preiser, 1989). POE is defined as the process of comparing a building's actual performance measures with its explicitly stated performance criteria (Preiser et al., 1988). National Research Council (1987) states that the results from POE case studies should form the basis for the development of design guidelines for similar facilities in the future. Royal Institute of British Architects (RIBA, 1991) defines POE as the systematic study of in-use buildings that provide architects with an assessment of their design, and owners and users with recommendations on how to get the best out of what they already have.

The primary goal of this research is to evaluate the application of POE to asses an IGBC Green Homes Certified multifamily residential building in the city of Jaipur, India and measure its performance gap one-year post-occupancy. The objectives to achieve the goal are:

- Develop POE survey questionnaire for occupant feedback for the selected case study.
- Analyse data to achieve quantitative inputs from the feedback data for developing energy simulation models.
- Develop energy simulation model in eQuest for three levels of performance comparison;
    - A base-case model based on Green building base-case guidelines
    - As-constructed model based on energy conservation measures and technical interventions of the building
    - As-occupied model based on post-one-year occupant feedback collected from questionnaire survey
    - Analyse the results to understand any performance gap between the three cases

Performance Gap

POE is widely recognized as being central to addressing the performance gap between design intentions and the actual outcomes of an occupied building. Wilde (2014) has identified the performance gaps as miscommunication and over-prediction of the building's performance targets in the design stage. Secondly, the performance gap arises due to incorrect methods, tools, and input data for modelling and simulation (Carbon Trust, 2011). Past research has highlighted that occupant's behaviour is a major issue i.e. how occupants operate equipment and how they adjust to the actual conditions that may vary from design assumptions. There is an immediate need to understand the underlying reasons for the energy performance gap due to occupant's behaviour through the application of POE, and to put in place the mechanisms required to address these.
POE studies are performed on buildings for a variety of reasons such as:
i) solve problems that occur in buildings after occupancy;
ii) correct unforeseen problems in building
use;
iii) fine-tune the building through continued feedback; iv) assess specific building performance aspects; iv) document successes and failures in building performance;
iv) justify new construction or remodel existing buildings; and
v) to specify design guidelines for the improvement of existing facilities, and the design of new ones (Husin et al., 2015; Vischer, 2001).

In order to operate and maintain buildings at an optimal cost, it is important to derive how they deviate from the expectations of their design. Therefore, POE is considered as the measuring tool that can detect underperforming elements of a building (Ozturk et al., 2012; Schwede & Davies, 2008).

There are mainly three approaches for POE; Indicative, Investigative and Diagnostic (Preiser, 1995, Preiser et al., 1988). Indicative POE is a rapid analysis that generally includes quick walkthrough evaluations and structured interviews with key maintenance personnel and end users. Investigative POE is more in-depth analysis that utilizes interviews and questionnaires and usually carried out across a number of buildings of the same or similar typology. Finally, Diagnostic POE focuses on a broad range of technological and human-centric (anthropological) aspects. For this research, Indicative POE has been carried out because a cross-sectional data collection was done at a specific point of time for one case study building.

Performance evaluation and occupant feedback

Performance assessment is conducted to benchmark building energy use by either selecting performance indicators or using Green building rating systems. In a study by Basu et al. (2019), they identified that factors which influence the energy consumption do not actually indicate the energy consumption patterns of a building, and they require other related indicators those can quantitatively indicate a building's performance. These indicators are known as Energy Performance Indicators (EnPIs).

EnPls are defined as a measure of energy intensity used to assess the performance and effectiveness of energy efficiency and energy management efforts (ISO 5000, 2011). For multifamily residence, there are 34 identified EnPIs across six factors; i) climate, ii) building envelop, iii) building services and energy systems, iv) building operation and maintenance, v) occupants' activities and behaviour, and vi) indoor environmental quality (Basu et al., 2019). Through a combination of EnPIs based on requirements for a particular building, these can be used to develop the POE survey questionnaire. This study will consider both the Green building rating system and performance indicators to demonstrate the performance assessment process incorporating POE. The EnPIs are presented in Table 1.

Conventionally, the evaluation of housing performance consisted of either physical monitoring or user satisfaction surveys, except that these two do not provide a comprehensive picture because these two are generally not related to each other as they are from different disciplines of building science and social science, respectively (Stevenson, 2009). In order to get a comprehensive picture of the actual performance of a dwelling from both the technical and occupants‘ perspectives, qualitative data collected from occupant feedback needs to be correlated and triangulated against the quantitative data collected by measurement and monitoring of the physical performance of a dwelling (Gupta & Chandiwala, 2010).

Table 1: Energy Performance Indicators (EnPIs) for POE

EnPI related Factors	S.No	Corresponding EnPIs
Climate-centric	1	Geographic location
	2	Orientation of built-form
	3	Air point & psychometric values for a location
	4	Relative humidity
	5	Thermal process or semantics (gains, conduction infiltration etc.)
Building Envelope	1	Building design, typology, and passive features
	2	Compactness factor (ratio of the volume of a built-form and the surface)
	3	Total ground surface
	4	Window-to-floor area ratio, and exposed roof area
	5	Total exposed vertical surface area
	6	Airflow patterns (within a building)
	7	Heat transfer coefficients of elements
Building Services and Energy Systems	1	List of appliances, and usage pattern
	2	Conditioning loads
	3	Monthly electricity bill, and annual electricity bill
	4	Room wise/area wise energy consumption
Operation and Maintenance Building Performance	1	Energy profiling
	2	Identification of user controls, and issues
	3	Appliance Maintenance
	4	Diagnostic plan for the existence of problems, record data
	5	Occupant Feedback & Maintenance Log
	6	Main electricity-consuming common services
Indoor Environmental Quality	1	Thermal comfort; set points
	2	Indoor air quality, airspeed and carbon dioxide concentration
	3	Natural ventilation
	4	Acoustic comfort (sound, noise, peace, silence)
	5	Lighting (Daylighting and artificial lighting)
	6	Visual environment (views)
	7	Room sizes, and layouts
Occupant-centric	1	Occupancy schedule and loading (as derived from behaviour)
	2	Profile of users and their preferences
	3	Perception of occupants (towards their dwelling)
	4	Levels of comfort (as acceptable)
	5	Use of manual and automatic controls
	6	Ways of adapting to thermal comfort

Bordass and Leaman (2005) state that only technological interventions would be insufficient for energy savings without the cooperation of occupant, while (Steemers and Yun, 2009) state that study of occupant behaviour in relation to building performance is still in its emerging phase. Vorger et al. (2014) have developed a stochastic model of occupants in residential buildings which account for households' and occupants' variability in terms of socio-demographic characteristics, schedules, use of electrical appliances, and adaptive behavior which they use with building energy simulation to carry out a series of simulations to develop a statistical distribution of occupant influence on energy performance. Their model integrates an individual's characteristics and correlations with other members and dwelling in general to understand the occupant influence. The model goes on to integrate appliance ownerships with individual characteristics to understand usage and duty cycles. Similarly, artificial lighting usage and occupant action on windows are also factored in the simulation.

These above-noted studies indicate some of the vital occupant behaviours that can be quantitatively factored into energy simulation model to measure the influence of behaviour. While not comprehensive, the major inputs would be occupancy number and schedules, equipment ownership listing and usages, artificial lighting usages, curtain usage (supplementary shading), and window opening schedules. This paper demonstrates the impact of each of these elements individually in order to evaluate how they contribute to the performance gap.

Green rated multifamily residential buildings and performance evaluation

The Green building movement in India started in 2000 with the establishment of the Indian Green Building Council (IGBC) (igbc.in, 2018). IGBC‘s Green Homes was the first rating program, introduced in India in 2011, exclusively for the residential sector. Green buildings claim to improve health and productivity by providing satisfactory and comfortable indoor environments, however, the studies validating this relationship are limited (Gou et al., 2012). IGBC programs are now about 2 decades old, but very few post-occupancy studies have been conducted for multi-family residential buildings.

Beauregard et al. (2011) conducted research on Leadership in Energy and Environmental (LEED) certified homes, and they state that the most efficient method to understand if a home is performing as per its initial intent is to conduct a post-occupancy audit after a home has been lived in for at least one year. This would involve collection and assessment of twelve months of utility bills, re-evaluation of the building envelope, an examination of the current building conditions, and most importantly, feedback from interactions from the occupants. The one-year period ensures that occupants are conversant with the operations of the mechanical systems of their residence and have recalibrated them as per their comfort conditions.

Methodology

Literature study supports the use of POE to understand occupant perception and retrofitting requirements in existing residential buildings, however, there is a gap in POE methodology for assessing retrofitting requirements. While POE assesses the occupant's feedback efficiently, the analysis is limited to a Likehart-scale finding that provides a range of satisfaction and/or dissatisfaction for parameters like comfort temperature, humidity, etc. only. The integration of EnPI-based questionnaire can be beneficial to determine quantitative determinants of satisfaction and/or dissatisfaction. These determinants can be integrated with an energy simulation model to evaluate the performance gap between base-case, as-constructed, and as-occupied case. Therefore, qualitative POE questionnaire was developed based on EnPIs and interview-based surveys were conducted. The results are analysed quantitatively as input parameters for energy model. It is a multi-method questionnaire, and the qualitative responses were converted to quantitative data based on energy simulation requirements in IGBC Green Homes guidelines. The questionnaire for the survey was developed from a previous study on EnPIs (Basu et al., 2019) and presented in Table 2. One of the aims of indicators is to allow for normalization of energy performance according to the different influencing factors (climate, occupant behaviour, etc.). EnPIs may be a simple parameter, a simple ratio or a complex model. Generally, it is a measure of energy use and its efficiency per unit of performance. The physical monitoring data is not within the scope of this research. The methodology is summarised in Figure 1

Case Study and POE Methodology

The selected case building is in Jaipur, India, and is rated under IGBC Green Homes as Gold Certified. This project is identified for its unique characteristics required for POE: i) a stand- alone multifamily apartment and not part of housing society that are generally certified under IGBC Green Townships, ii) the building had been occupied for one year, a requirement for POE, iii) even in housing societies with larger number of multifamily buildings, retrofitting is still a bespoke activity, and thus this selection can be justified by the fact that the process is replicable and standardised, iv) in India, Green Ratings are voluntary, and are often limited to high-end residential buildings only, v) the POE of a certified Green Building accorded the opportunity to compare three cases for performance gap, base-case as per IGBC Green Homes standard, as-constructed case, and as-occupied case. To validate the findings, energy simulation is conducted using the eQuest software platform (www.doe2.com).

The case study is an eight storied multifamily residential building. Each floor has three, 4-bedroom units with a super built-up area of approximately 500 sq.m. Each unit has one servant room also. Of the 24-units, only 21 were occupied since past one year. The common amenities include two shared lifts and one service lift apart from two separate staircases. The layout plan of a typical floor is provided in Figure 2, and a blown-up layout of one unit is provided in Figure 3. The building is IGBC Green Homes Gold rated. The questionnaire survey was conducted amongst the 21occupied units of the building (3 were unoccupied at the time of the survey). The data collected is converted to energy simulation inputs as per IGBC guidelines, and the three cases are simulated in eQuest. The methodology comprised of performing energy simulation of three cases on eQuest; i) a base-case model on IGBC Green Homes parameters, ii) as-constructed case based on IGB Green Homes Gold certification energy interventions, and iii) as-occupied case based on POE data analysis. The annual energy consumption from the simulation of the three cases is compared to measure the performance gap.

Table 2. POE Survey Questionnaire Themes

EnPI	POE survey themes
Geographic location	What is the geographic location of your permanent dwelling (city)?
Orientation of built-form	What is the orientation of your residence?
List of appliances, and usage pattern	Please select the appliances/plug loads present in your dwelling, and their units. (selection list) Indicate their approximate usage time /per day
Monthly electricity bill, and annual electricity bill	What is the average monthly (average of one year) electricity bill of your residence? (provide a range) Would you say that the monthly bill is in tune with your/your family's usage of electricity in the form of lighting and appliances?
Conditioning loads Room wise/area wise energy consumption Energy profiling	Is there central cooling and heating in the residence? If yes, what is the total load? If window/split units, which rooms are conditioned, and what are the tonnage (size) of air conditioning? Do you use heaters in winters? If yes, how many, and what is the wattage? Duration of usage/ per day for air conditioner and heater.
Identification of user controls, and issues Diagnostic plan for the existence of problems, record data	How often do you service your appliances? (list of appliances) Do you keep records of appliance maintenance schedules, maintenance and repair costs, repair records etc.

Appliance Maintenance	
Main electricity-consuming common services	Do you have electricity-consuming common services (like lifts etc) that you share with other occupants?
Thermal comfort; set points	In summer's what is the minimum comfortable set-point of your air conditioning?
Levels of comfort (as acceptable)	In winters what is your maximum comfortable set-point of your heater?
Natural ventilation	How satisfied are you with the air quality in your home? When do you generally open the windows of your dwelling? Duration for which the windows are kept open. Time of the day for which the windows are kept open.
Acoustic comfort (sound, noise, peace, silence)	How satisfied are you with the acoustics (noise levels) of your home?
Lighting (Daylighting and artificial lighting)	Which rooms are adequately daylit? What is the duration of usage of artificial lights? What is the time of usage?
Visual environment (views)	Do you keep curtains drawn? Mainly which orientation? Duration for which the curtains are kept closed? Time of the day for which the curtains are kept closed? Any glare or overheating due to which the curtains are drawn?
Occupancy schedule and loading (as derived from behaviour)	What are the maximum and minimum occupancy slots of your residence? (list of 4-hour time-slots)
Profile of users and their preferences	How many people in the categories below occupy your dwelling? (list of different categories e.g. students, stay-at-home etc.) Gender of occupants Age groups of the occupants

Perception of occupants (towards their dwelling)	How satisfied are you with the following in reference to different aspects of your dwelling? (list of aspects e.g. orientation, humidity in summer, ventilation etc.) When you experience thermal discomfort (temperature and humidity), which of the following would you say are the most responsible? How satisfied are you with the following regarding your dwelling's design?
Use of manual and automatic controls	Any automation involved in air conditioning or heating or artificial lighting? Which type?
Ways of adapting to thermal comfort	How would you describe your personal habits in relation to your dwelling? When you experience thermal discomfort (temperature and humidity), which of the following would you say are the most responsible?

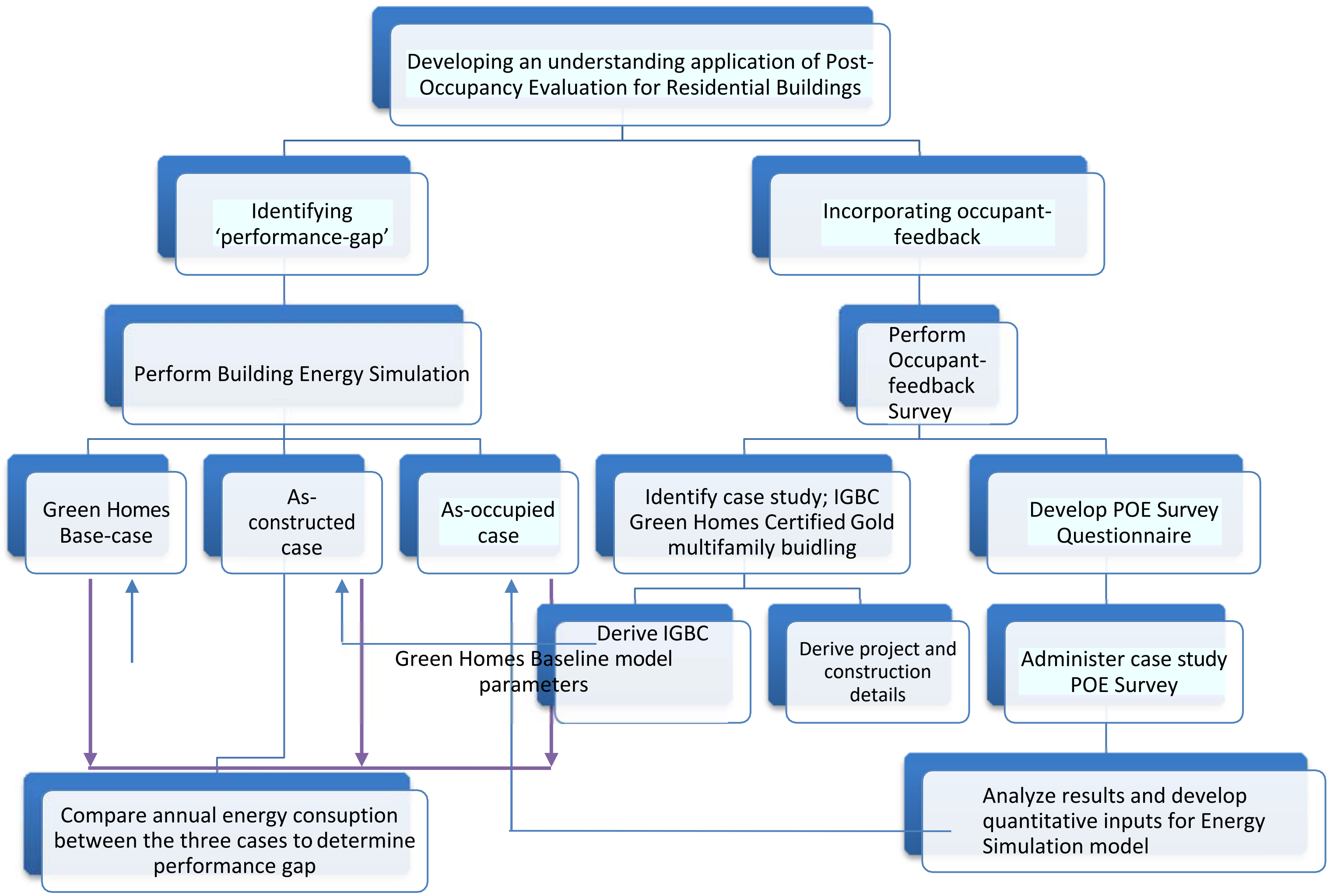

Figure 1: Research Methodology for POE application

Figure 2: Typical layout plan of a floor of case study

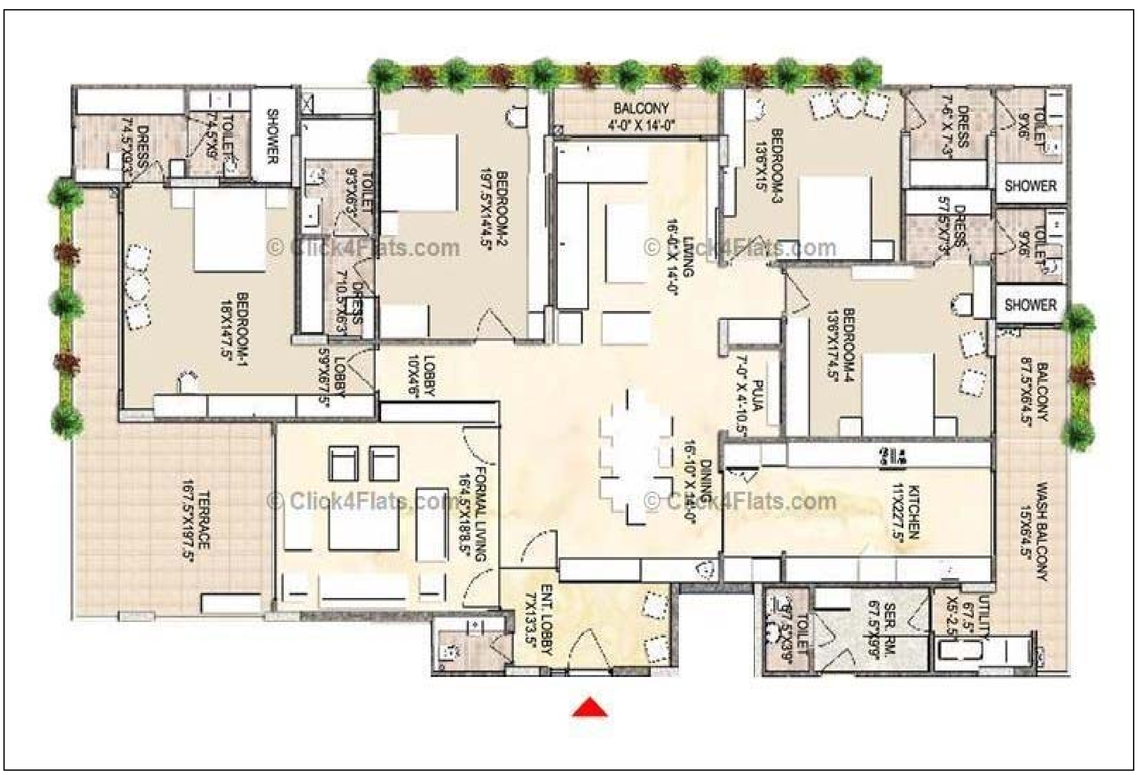

Figure 3: Blown-up layout plan of a unit

Quantitative Derivation from Questionnaire Survey

The survey was analysed to derive POE quantitative parameters such as: occupancy numbers, equipment and lighting usage and schedules, occupancy schedules, and curtain usage (for consideration in shading), air-condition usage, and average comfort set-points.

IGBC Green Homes considers the occupancy to be calculated as 2 persons each in the first two bedrooms, thereafter, 1 person each in additional bedrooms. This building has 4 bedrooms and 1 servants' room, therefore, occupancy per unit is 7. Therefore, for 24 units, the base case stands at 168 people, but POE survey shows occupancy as 94 people only (Table 3) leading to an average of 4 persons in each unit as per POE. The occupancy comparison in different time slots is presented in Figure 4.

Table 3: POE Occupancy

Floor	*Unit 1*	*Unit 2*	*Unit 3*
1st	4	3	3
2nd	8	2	5
3rd	3	4	0
4th	6	4	3
5th	4	3	2
6th	2	5	0
7th	8	7	5
8th	0	7	6
Total	**35**	**35**	**24**
Total in building	**94**		

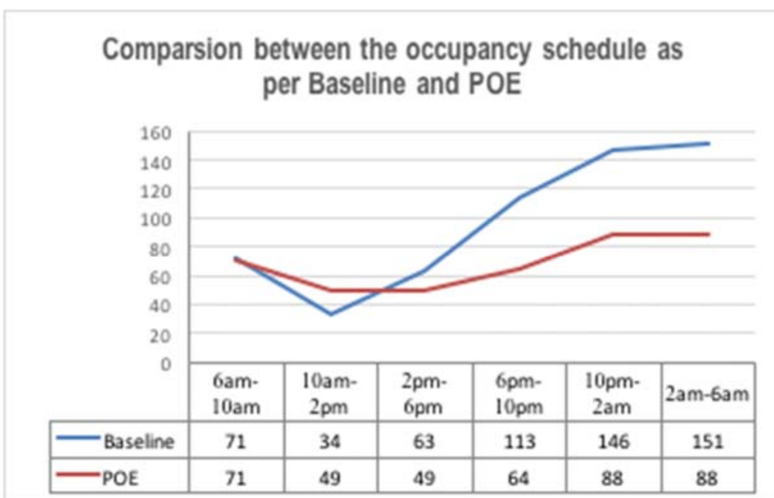

Figure 4: Comparison between Base-case occupancy schedule and POE schedule

The major points of difference between as-constructed and as-occupied starts from the occupancy schedules, and equipment usage schedules. It is evident that equipment usage presumed under base- case case vastly differs from actual equipment loads in a dwelling. This is from the occupancy load and schedules which generally do not consider stay-at-home people including older people and full- time servants. This leads to variation in equipment usages and effects lighting and air-conditioning usages. The difference between base-case and POE occupancy schedules, lighting usage schedules (Lighting Power Density/LPD), equipment usage schedules (Equipment Power Density/EPD) are presented in Figures 5-8 respectively.

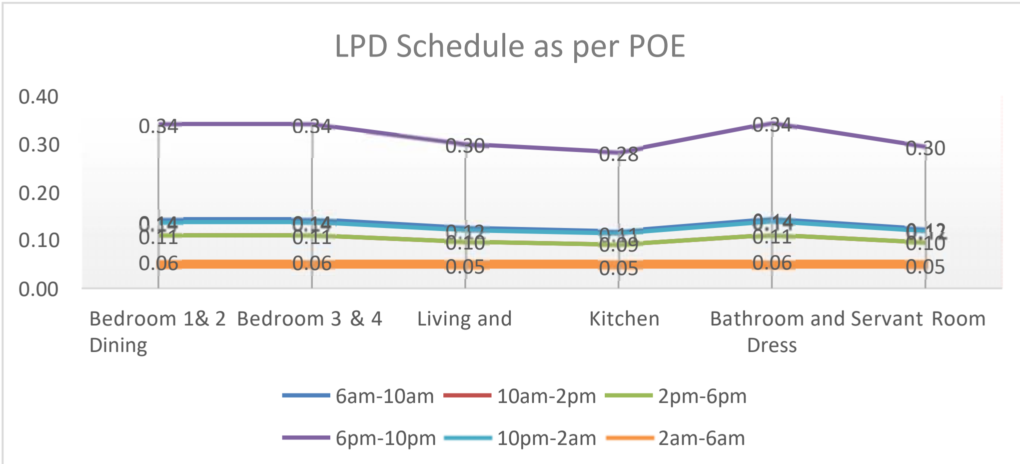

Figure 5: LPD Schedule as per POE

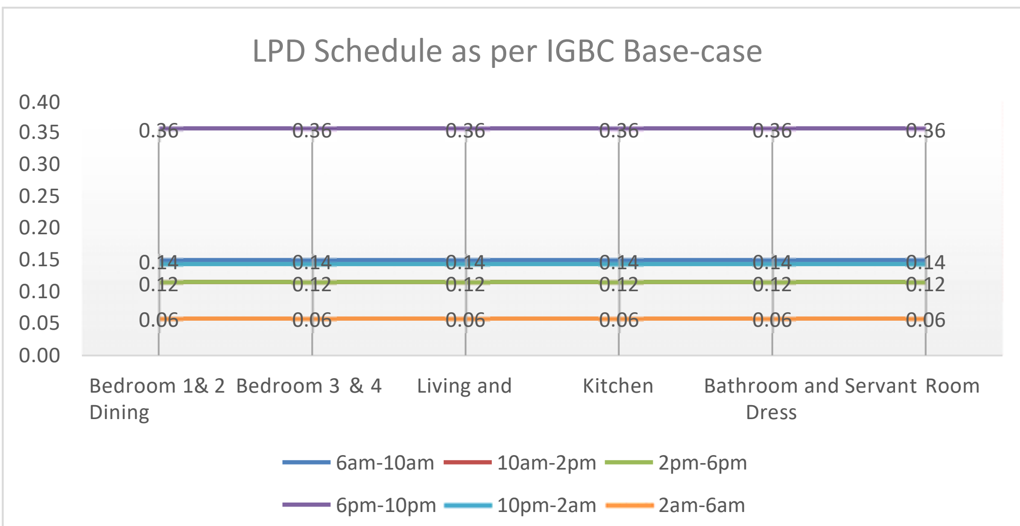

Figure 6: LPD Schedule as per IGBC Base-case

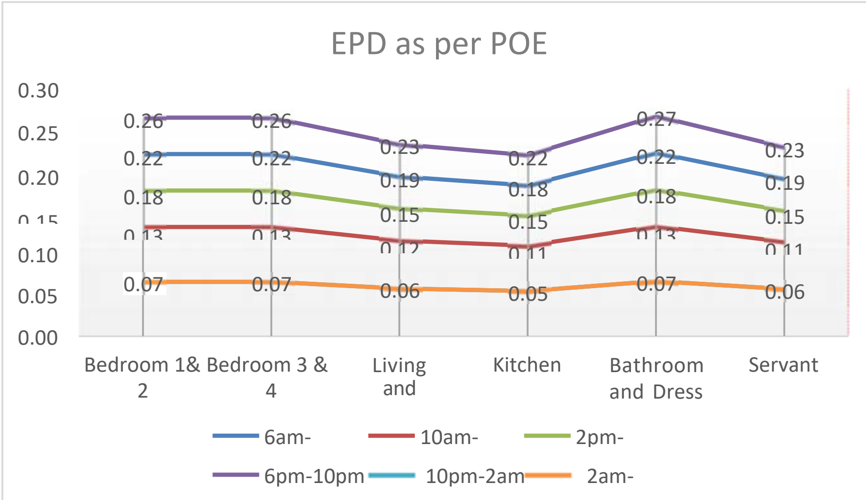

Figure 7: EPD as per POE

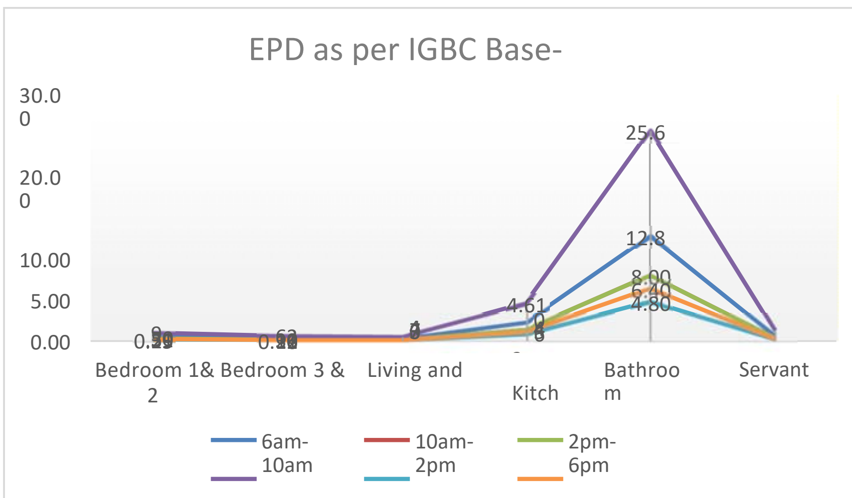

Figure 8: EPD as per Base-case

Base-case, As-constructed Green Certified, and As-occupied cases for simulation

With the data from POE analysis, inputs for the three simulation models were compiled. These inputs were compiled under three categories: i) building construction specifications, ii) occupancy patterns, and equipment load density, and iii) lighting power density, and HVAC loads. The inputs used for the energy simulation of the three cases are presented in Table 4.

Table 4: Energy Simulation Inputs for Three Cases

Inputs for the simulation model	Base-case	As-constructed	As-occupied
Source of information	From IGBC Green Homes Rating System Version 2 Annexures I- III (2012)	From the Green building parameters adopted by the project.	From the POE survey conducted amongst the residents.
Climate	Composite	Composite	Composite
Orientation	The base-case energy performance is the average of the performance with original orientation and after rotating the entire building 90, 180, 270 degrees. The building is modelled so that it does not shade itself.	As per design (in Figure 16-17)	As per design (in Figure 16-17)
Opaque assemblies	The U-Value for Exterior walls is 0.44Btu/hr-sqft^{0}F	The exterior wall is made up of 9‖ fly-ash brick, with 20mm cement plaster on both sides. Its U-Value is 0.1323 Btu/hr-sqft^{0}F	-same as-constructed-
Fenestration	The U-Value for Fenestration is 1.0032 Btu/hr-sqft^{0}F and its Solar Coefficient (SC) is 0.413. No shades or overhangs are modelled.	There is a Double Glazed Unit (clear 6mm glass + 12mm air gap + clear 6mm glass) fenestration with a U- Value of 0.33 Btu/hr- sq.ft0F and a Solar Coefficient of 0.32. The overhangs (balconies) are modelled as per the actual design.	-same as-constructed-

Exterior roofs	The U-Value for Roof Construction is 0.2114 Btu/hr-sqft^{0}F and its roof reflectance is 0.3	The Roof slab is made up of RCC with 50mm XPS over deck insulation. Its U-value is 0.074 Btu/hr-sqft0F. There is white china tiles mosaic on the roof, giving a roof reflectance of 0.45.	-same as-constructed-
HVAC	Packaged Variable Volume Variable Temperature (VRV System) type Air side HVAC system, with Fan Power of 0.000246 kW/cfm. COP = 3.28 Heating = electric	Packaged Variable Volume Variable Temperature (VRV System) type Air side HVAC system, with Fan Power of 0.0003 kW/cfm. COP = 3.33 Heating = electric	-same as-constructed-
Equipment Power Density (W/sq.ft)	Bedroom 1-4 = 1.29 Dinning & living = 0.72 Kitchen = 8.70 Toilet & dress = 2.67 Servant room = 1.90	Bedroom 1-4 = 1.24 Dinning & living = 0.67 Kitchen = 8.75 Toilet & dress = 2.37 Servant room = 1.67	Bedroom 1-2 = 1.24 Bedroom 3-4 = 0.78 Dinning & living = 0.67 Kitchen = 5.81 Toilet & dress = 2.37 Servant room = 1.67
Lighting Power Density (W/sq.ft)	Bedroom, Dinning & living, Kitchen, Toilet & dressing, servant room = 0.5 Common areas and staircases= 0.4	Bedroom, Toilet and dress= 0.44 Dinning & living = 0.39 Kitchen = 0.37 Servant room = 0.38 Common lobby = 0.21 Staircase = 0.19	Bedroom, Toilet and dress= 0.44 Dinning & living = 0.39 Kitchen = 0.37 Servant room = 0.38 Common lobby = 0.21 Staircase = 0.19
Total exterior lighting load	5 Kwh	3.29 Kwh	3.29 Kwh
HVAC temp. set point (ºC).	Cooling set point = 26 Heating set point = 20	Cooling set point = 26 Heating set point = 20	Cooling set point = 22 Heating set point = 12

Results and Findings

Based on the data from the simulation cases from Table 4, the following 6 corrections were made to the as-constructed case to arrive at the as-occupied case. These were:

- Temperature change
- Occupancy change
- Occupancy schedule change
- Equipment usage change
- Equipment Load Density (EPD)
- Lighting power change (LPD)

With the inputs for the simulation collated, the three cases were simulated, and results are provided as follows: as-designed (base-case) - Table 5, as-constructed with Green building features - Table 6, and as-occupied with inputs from the survey results - Table 7.

Table 5: Base-case Energy Consumptions Results

(Note: The results shown in Tables 5-7 are in 1000 KWH (kilowatt hour x1000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of total energy consumption
Space Cool	21.4	26.7	50.9	75.1	95.8	95.7	87.6	82.8	77.1	65.5	41.7	22.4	**742.8**	38.17%
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Space Heat	11.2	6	0.2	0	0	0	0	0	0	0	1.3	10	**28.7**	1.47%
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Vent. Fans	35.2	31.8	35.2	34	35.2	34.1	35.2	35.2	34	35.2	34	35.2	**414.1**	21.28%
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Ext. Usage	2.1	2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	**25.1**	1.29%
Misc. Equip.	51.6	46.6	51.5	49.9	51.6	49.9	51.6	51.6	49.9	51.6	49.9	51.6	**607.1**	31.20%
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Area Lights	10.9	9.8	10.9	10.5	10.9	10.5	10.9	10.9	10.5	10.9	10.5	10.9	**128.3**	6.59%
Total	**132.4**	**122.9**	**150.8**	**171.6**	**195.6**	**192.3**	**187.4**	**182.6**	**173.6**	**165.3**	**139.5**	**132.2**	**1946.1**	

Table 6: As-constructed Energy Consumptions Results

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of total energy consumption
Space Cool	19.9	23	40.6	56.2	72.3	73.4	69.8	66.8	61	51.8	34.3	21.1	**590.2**	36.20%
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Space Heat	2.6	1.2	0	0	0	0	0	0	0	0	0.1	2.1	**6**	0.37%
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Vent. Fans	27	24.4	27	26.1	27	26.1	27	27	26.1	27	26.1	27	**317.5**	19.47%
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Ext. Usage	1.7	1.5	1.7	1.6	1.7	1.6	1.7	1.7	1.6	1.7	1.6	1.7	**19.7**	1.21%
Misc. Equip.	49.7	44.9	49.7	48.1	49.7	48.1	49.7	49.7	48.1	49.7	48.1	49.7	**585.4**	35.90%
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0%
Area Lights	9.5	8.6	9.5	9.2	9.5	9.2	9.5	9.5	9.2	9.5	9.2	9.5	**111.8**	6.86%
Total	**110.4**	**103.6**	**128.5**	**141.2**	**160.2**	**158.4**	**157.7**	**154.7**	**146**	**139.7**	**119.4**	**111.1**	**1630.6**	

Table 7: As-occupied Energy Consumptions Results

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	% of total energy consumption
Space Cool	19.2	22.2	38.9	53.8	68.8	69.6	65.8	62.9	57.7	49.2	32.8	20.2	**561.1**	36.42%
Space Heat	2	0	0	0	0	0	0	0	0	0	0	1.8	**3.8**	0.25%
Vent. Fans	27	24.4	27	26.1	27	26.1	27	27	26.1	27	26.1	27	**317.5**	20.61%
Ext. Usage	1.7	1.5	1.7	1.6	1.7	1.6	1.7	1.7	1.6	1.7	1.6	1.7	**19.7**	1.28%
Misc. Equip.	46.1	41.7	46.1	44.6	46.1	44.6	46.1	46.1	44.6	46.1	44.6	46.1	**542.9**	35.24%
Area Lights	8.1	7.3	8.1	7.8	8.1	7.8	8.1	8.1	7.8	8.1	7.8	8.1	**95.5**	6.20%
Total	**104.1**	**97.1**	**121.8**	**133.9**	**151.7**	**149.7**	**148.7**	**145.8**	**137.8**	**132.1**	**112.9**	**104.9**	**1540.5**	

As per the simulation result for the base-case, the annual energy consumption was 19,46,100 kWh, for the as-constructed case, it was 16,30,600 kWh, and finally for the as-occupied case, it was 15,40,500 kWh. Thus, there is a positive performance gap of 48.7% between the base-case and as- occupied, and yet again, a positive performance gap of 4.6% between as-constructed and as-occupied.

This is a very interesting departure from the general observation because the literature generally points towards a negative ‗performance gap' or overutilization between as-designed, and as- built and occupied buildings. In this case, the multifamily Green building is actually performing better than anticipated. The major reasons for this are the under-occupancy, a variation of the occupancy schedules, less than anticipated equipment power density, a variation in equipment usage schedules, and a variation of the lighting usage schedules which is lower than predicted. This also brings out the behavioural pattern of occupants which points to positive 'performance gap' or underutilization. Overall there is a 4.6% better performance of the occupied Green Building over the predicted energy savings from energy simulation of the energy saving measures applied in the building. The most important observation is the inclusion of occupant-feedback regarding their occupancy number, occupancy schedule, equipment power density, and artificial lighting usage schedule. Thus, through the actual data of occupancy, the savings are better than predicted energy saving measures. The breakup of the positive 'performance gap' is summarized in Table 8.

The analysis was also carried out for individual POE data to have a distinct understanding of the influence of each of the 6 corrections. The annual energy consumption for the 6 POE data are compared against the base-case and as-constructed energy consumptions and presented in Table 9.

Table 8: Energy Performance Gap Analysis

Energy Consumption kWh *1000	Base-case	As-Constructed (Green Rated)	As-occupied (with POE data)	% difference (A-B)*100/A	% difference (A-C)*100/A	%difference (B-C)*100/B
	A	B	C			
Space Cooling	742.8	590.2	561.1	20.5%	24.5%	4.9%
Space Heating	28.7	6	3.8	79.1%	86.8%	36.7%
Ventilation Fans	414.1	317.5	317.5	23.3%	23.3%	0.0%
Exterior Usage	25.1	19.7	19.7	21.5%	21.5%	0.0%
Miscellaneous Usage (plug loads)	607.1	585.4	542.9	3.6%	10.6%	7.3%
Area lights	128.3	111.8	95.5	12.9%	25.6%	14.6%
Total	**1946.1**	**1045.2**	**997.6**	**46.3%**	**48.7%**	**4.6%**

Table 9: POE case wise energy consumption for 6 Corrections

POE cases	Base-case energy consumption kWh *1000	As-constructed energy consumption kWh *1000	As-occupied energy consumption kWh *1000
Temperature change	1946.1	1630.6	1624.8
Occupancy change	1946.1	1630.6	1617.3
Occupancy schedule change	1946.1	1630.6	1636.5
Equipment usage change	1946.1	1630.6	1659.5
Equipment Load Density (EPD)	1946.1	1630.6	1552.4
Lighting power change (LPD)	1946.1	1630.6	1608.7

The change in EPD results in an overall positive _performance gap‛ of 4.80% (underutilization) when compared to the as-constructed case. As per the results of the survey, instead of 5, only 3 television sets are used (1 in Living Area, Bed Room 1, Bedroom 2 each). As a result, the EPD for Bedroom 3 & 4 is reduced. Also, 1 out of the 2 refrigerators provided, and the dishwasher are not used, thereby changing the EPD for kitchen also goes down.

As per IGBC Green Homes Rating System-Version 2 (2012), the base-case occupancy calculations are based on the first 2 bedrooms having 2 occupants each, and the other bedrooms having 1 occupant each. Thus, the base-case total stands at 168 occupants in 24 dwellings averaging 7 occupants per dwelling, however, in actual, there is an average of 4 residents in each unit, thus the savings from occupancy number. Additionally, the actual occupancy schedule varies because of stay- at-home people, and students returning home by afternoon. However, this causes higher equipment usage. This presents a uniform occupancy schedule, and corresponding energy consumption, rather than peaks and non-peaks of energy consumption over the day. The day time consumption of artificial lights is reduced as all the spaces in the units have adequate daylight.

As shown in Table 9, the individual impact of occupant behaviour from POE feedback indicates positive performance gap in 5 out of the 6 cases, and thus an overall positive performance gap. The individual case studies are an essential component to identify wherein the performance gaps are positive and wherein are they negative. This is because while in total the gap may be positive, but individually one or more POE case may indicate otherwise. This is useful for undertaking retrofitting, where behaviour or schedule may be the cause of overutilization, and no up gradation may be required to achieve energy efficiency.

Summary and Conclusions

The analysis shows an energy ‘performance gap' in buildings between the Green building base-case and as-constructed and as-occupied. Generally, the influence of occupants and their behaviour is ignored at the time of the simulation. The inclusion of occupant related parameters into design performance evaluation makes for more realistic predictions about the energy performance of a building. Post Occupancy Evaluation (POE) is a useful tool for getting the occupant feedback, in terms of actual occupancy numbers, occupancy schedules and other related schedules like equipment usage and equipment load density, and lighting usage schedule. Additionally, POE also provides accurate information regarding the comfort temperatures adopted by the occupant, and thus the set- points of energy simulation models are calibrated towards more realistic scenarios.

POE is an emerging area of research in the residential sector in India, especially for multifamily residential buildings. It is challenging because the occupancy type, number, schedules, etc. vary considerably, even on the same floor. However, multifamily residential buildings form a major portion of the residential sector in India; hence it's essential to evaluate their performance in terms of user experience, and effect on the environment. Literature points towards an existing ‘performance gap' which is generally negative, i.e. the as-designed and as-constructed buildings perform poorly as compared to an as-occupied buildings. This research studied the application of POE to evaluate the _performance gap' and found that the as-occupied buildings perform better than anticipated, leading to a positive ‘performance gap’.

The main reason for this positive ‘performance gap’ is due to the occupancy which is approximately 30% less than anticipated which leads to lower utilization of many types of equipment. Additionally, some equipment such as, dishwasher, microwave, second refrigerator, and television are not utilised in actual which is connected to occupant behaviour patterns.

Several interesting observations emerge from this study, the primary one being a revision of occupancy rates during the design process for a more realistic comparison between the base-cases and the proposed design cases. The comfort temperatures also require more realistic inputs based on further research on the geographic location-wise study of occupant comfort set-points. This study was limited to a comparison of results from energy simulation; however, the literature recommends triangulation of data between simulation and actual physical monitoring and auditing.

Finally, POE not only helps us in understanding the performance of present buildings, but it also creates a knowledge base for the design of future buildings. This study has been instrumental in identifying the positive ‘performance gap' that emerges out of POE study data being used to correct simulation inputs. The study will provide a basis for further investigation into this positive performance gap of buildings to refine POE methodologies for residential buildings.

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