RESEARCH

PERFORMANCE INDICATORS FOR ENERGY EFFICIENCY RETROFITTING IN MULTIFAMILY RESIDENTIAL BUILDINGS

Chaitali Basu,[1]* Virendra Kumar Paul,[2] and M.G. Matt Syal[3]

ABSTRACT

The energy performance of an existing building is the amount of energy consumed to meet various needs associated with the standardized use of a building and is reflected in one or more indicators known as Building Energy Performance Indicators (EnPIs). These indicators are distributed amongst six main factors influencing energy consumption: climate, building envelope, building services and energy systems, building operation and maintenance, occupants' activities and behaviour, and indoor environmental quality. Any improvement made to either the existing structure or the physical and operational upgrade of a building system that enhances energy performance is considered an energy efficiency retrofit. The main goal of this research is to support the implementation of multifamily residential building energy retrofits through expert knowledge consensus on EnPIs for energy efficiency retrofit planning. The research methodology consists of a comprehensive literature review which has identified 35 EnPIs for assessing performance of existing residential buildings, followed by a ranking questionnaire survey of experts in the built-environment to arrive at a priority listing of indicators based on mean rank. This was followed by concordance analysis and measure of standard deviation. A total of 280 experts were contacted globally for the survey, and 106 completed responses were received resulting in a 37.85% response rate. The respondents were divided into two groups for analysis: academician/researchers and industry practitioners. The primary outcome of the research is a priority listing of EnPIs based on the quantitative data from the knowledge-base of experts from these two groups. It is the outcome of their perceptions of retrofitting factors and corresponding indicators. A retrofit strategy consists of five phases for retrofitting planning in which the second phase comprises an energy audit and performance assessment and diagnostics. This research substantiates the performance assessment process through the identification of EnPIs.

KEYWORDS

energy performance, performance indicators, multifamily residential buildings, energy efficiency, retrofitting

1. Assistant Professor, Department of Building Engineering and Management, School of Planning and Architecture, 6-B, IP Estate, New Delhi-110002, India, and Visiting Scholar, Michigan State University, East Lansing, USA; e-mail chaitali.basu@spa.ac.in (*Corresponding Author)

2. Professor, Department of Building Engineering and Management, School of Planning and Architecture, India

3. Professor, Construction Management Program, School of Planning, Design and Construction, Michigan State University, East Lansing, USA

1. INTRODUCTION

Energy efficiency (EE) means reducing the amount of energy needed to perform a particular task by investing in efficient systems of delivery. Any improvement made to the existing structure or a building system that increases the overall EE is considered as an energy efficiency retrofit. It can be the physical or operational change in a building itself, its energy-consuming equipment, or its occupants' behaviour to reduce the amount of energy needed and convert the building to a lower energy facility (Jafari & Valentin 2017). Retrofits require the replacement and/or upgrade of old building systems with newer energy saving technologies and processes (Syal et al., 2013). Energy retrofitting is argued to be the most feasible and cost-effective method for improving existing buildings' energy efficiency (Jafari & Valentin, 2017).

Inefficient mechanical, electrical, and plumbing equipment in existing buildings can lead to increased cost of utility, furthering inefficiencies, and escalated operational costs, thus, energy efficient retrofits can be one of the most cost-effective measures for controlling operating costs in buildings (Berghorn & Syal, 2016). A large variety of building retrofit technologies and options are available in the market, however, the decision to select retrofit technology or process has to be project specific (Ma et al., 2012). Furthermore, the selection criterion may be a multi-objective optimization problem subject to many constraints and limitations, such as specific building characteristics, total budget available, project target, building services types and efficiency, building fabric, etc. Among the different proposed methodologies for energy assessment of buildings, some focus on energy savings, while others on the overall retrofitting of the whole building site (Luther & Rajagopalan, 2014). For example, in the study by Junghans (2013) a Facilities Energy Efficient (FEE) model is proposed that considers a wide range of parameters such as location, procedures for operation, usage, building's condition, and its current technical standard for building analysis.

In the study by the Institute for Sustainability, UK, (2015) the use of Building Performance Evaluation (BPE) is recommended to be conducted prior to any retrofit or refurbishment project as this helps to establish current 'performance-in-use' of the homes. The study justifies that BPE can reduce the risk of investment in retrofitting by identifying those very specific aspects of buildings that either need retrofitting or can withstand improvements. Another study by the International Energy Agency (IEA, 2013) states that the distinction between the building, and its user related energy consumption patterns cannot be clearly distinguished; therefore, it proposes six main factors influencing energy consumption: climate, building envelope, building services and energy systems, building operation and maintenance, occupants' activities and behaviour, and indoor environmental quality. These factors should be considered in tandem to establish the energy consumption for any building type. This research builds upon the six main factors influencing energy consumption as proposed by IEA (2013).

2. NEED FOR STUDY AND HYPOTHESIS

The energy performance of a building is defined as the amount of energy actually consumed or estimated to meet the different needs associated with a standardized use of a building and is reflected in one or more numeric indicators (Poel et al., 2007). Energy consumption patterns in buildings are linked to the operational, space utilization characteristics, and behaviour of occupants in the space (Hoes et al., 2009). IEA (2013) states that one of the most significant barriers for improving the energy efficiency of buildings is the lack of knowledge about the factors that determine energy use. It recommends that building energy performance is mainly determined by the above mentioned six factors. The latter three factors, related to human behaviour, can have an influence as great as or greater than the former three (Wang et al., 2012). Further, IEA (2013) also states that there is often a significant discrepancy between the designed and real total energy use in buildings. The reasons for this performance gap are generally not understood well, and are often have to do more with the role of human behaviour than the building design. But a distinction between the building-related and the user-related energy consumption cannot be clearly established, which makes it necessary to investigate all six factors together to understand building energy consumption data.

Energy performance indicators can play a critical role in understanding and measuring the impact of the six energy factors. As the factors influencing the energy consumption do not actually indicate the energy consumption patterns of a building, they require other related indicators that can quantitatively or qualitatively measure a buildings performance. These indicators are known as building performance indicators (EnPIs). EnPls are defined as a measure of energy intensity used to assess performance and effectiveness of energy efficiency and energy management efforts (ISO 5000, 2011).

The hypothesis of this research is that energy performance indicators or EnPIs are essential for energy performance assessment criterion for the individual energy performance factors, and also, the aggregate of all the indicators can assess energy performance of an existing residential building. This hypothesis shall be proved or disproved through primary survey.

H_1—EnPIs can assess the energy performance of existing buildings

H_0—EnPIs cannot assess the energy performance of existing buildings

3. NEED FOR FOCUS ON MULTIFAMILY BUILDINGS

The Indian residential sector accounts for approximately 75% of the construction market of India, but has not been the priority for energy efficiency policies (The Economist Intelligence Unit, 2013). While the Energy Conservation Building Code (ECBC) was launched by the Ministry of Power in 2007 to promote energy efficiency in buildings, it was developed to cater to commercial buildings only (beeindia.gov.in, 2018). After 11 years, the Bureau of Energy Efficiency has finally launched ECBC-R, exclusively for the residential sector. The draft version was launched for public comments in February 2018. This interval has caused a lacuna of existing residential buildings that are bereft of any energy saving measures, and thus, there is a huge potential for expanding and adapting existing energy-efficiency policies for the residential segment. Additionally, initiatives such as the launch of "Design Guidelines for Energy-efficient Multi-storey Residential Buildings for Warm-Humid Climates (beepindia.org, 2016), and "Design Guidelines for Energy-efficient Multi-storey Residential Buildings for Composite and Hot-Dry Climates (beeindia.org, 2014)" provide recommendations for energy-efficiency features at the design stage of multi-storey residential buildings. However, these are not applicable for existing constructions.

The multifamily living culture has always been prevalent in India as joint families were the norm in the past wherein multiple related families co-existed in the same residence. As migration from suburbs and villages into cities increased with industrialization and creation of employment in urban areas, it resulted in a shortage of living space that resulted in planned and unplanned growth of high-density residential houses as well as multi-storey high-rise apartment buildings (Md Rian, 2011).

Of the total electricity consumed in the building sector, around 75% is used in residential buildings (ECBC-R, 2017) The residential building stock in urban and suburban areas is mostly shifting toward multifamily residential buildings. It is expected that, with the economics of land and the need for compact cities, multifamily residential buildings will be the dominant housing option to meet the future demands of housing. This is also predicted to be the trend for housing for low-income and the middle-income categories. Therefore, building energy codes for new multifamily buildings are going to be important regulatory measures for energy efficiency in the building sector, but the gap in bringing out such codes has created a stock of existing residential buildings that need immediate attention to assess their energy efficiency potential.

OBJECTIVES

The main goal of this research is to support the implementation of multifamily residential building energy retrofits. This goal is supported by facilitating the energy assessment of this building type with the help of EnPIs. The research objectives to achieve the goal are as follows:

1. Identification of EnPIs for existing multifamily residential buildings for each of the six factors: (i) climate, (ii) building envelope, (iii) building services and energy systems, (iv) building operation and maintenance, (v) occupants' activities and behavior, and (vi) indoor environmental quality. This was achieved through a comprehensive literature review.
2. Expert survey of the EnPIs through a self-administered ranking questionnaire by both professionals and academicians in the built-environment field.
3. Arriving at a priority listing of the EnPIs from the quantitative analysis of responses.
4. Deriving the correlation between the EnPIs to arrive at the final set of indicators vital for the performance assessment of residential buildings.

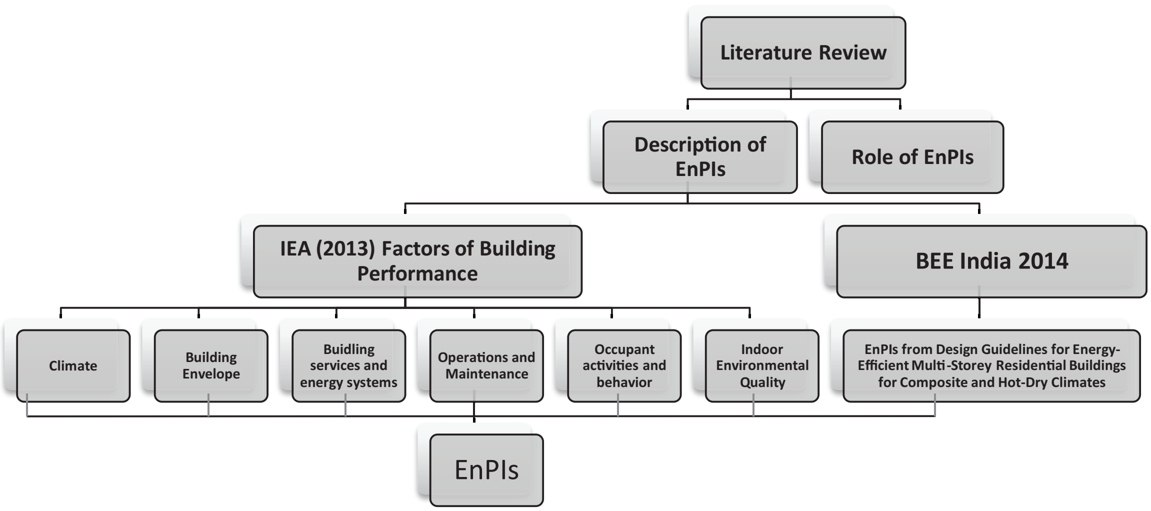
4. LITERATURE REVIEW

A key component of this research was the identification of EnPIs. To accomplish this, a comprehensive literature review was carried out from the existing knowledgebase. Each of the six factors was taken up as individual areas of research, and detailed analysis was carried out to identify corresponding EnPIs. Additionally, the Bureau of Energy Efficiency, the Government of India's Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings for Composite and Hot-Dry Climates' (2014), was also studied in detail to identify performance indicators applicable to Indian multifamily residential units, which were then categorized under the six factors. The structure of literature review is presented in Figure 1.

4.1 Role of EnPIs in Building Performance

The energy performance assessment of buildings has two approaches—performance-based and feature-specific (Wang et al., 2012). The former approach compares quantifiable performance indicators like carbon footprint, energy consumption, and is more precise and also preferable. The latter is based on awarding credits when certain specific features are met like those for green building rating systems.

FIGURE 1. Structure of Literature Review.



Note that there is a difference between energy performance and energy classification. Energy performance is carried out for diagnosing the causes of poor performance of buildings, whereas energy classification only provides overall performance data and does not venture into detailed performance issues. Wang et al. (2012) are of the opinion that development of assessment procedures can be difficult as a quantitative methodology needs to evolve to produce judgment criterion of performance, but current literature are inclined towards quantitative assessment procedures only. IEA (2013) states that gauging the energy performance of existing building stock is relatively easier, as in-use energy can be simply measured rather than feeding parameters into calculation models for new construction. In addition, a performance-based approach takes into account the real behaviour of buildings, reflecting the influence of all six factors that determine energy performance as identified by IEA (2013).

Abel (1994) has distinguished between the 'low energy building' and 'energy efficient building'. While the former is achieved by decreasing the quantity of purchased energy and is highly influenced by occupants, the latter is accomplished via selection of efficient products and their efficient utilization. Olofsson et al. (2004) state that the strategies for identifying and rating both types of buildings is basically defining what has to be conserved and what will be accomplished through that. However, they also argue that evaluating whether one building is more 'low energy' than another is complex and depends on activities being carried out in the building, climate, type of fuel, fabric of the building etc. The decision further becomes more complicated for similar buildings across similar conditions. Alwaer & Clements-Croome (2010) state that a sustainable building is the complex system culmination of three inter-related basics—people (occupants), products (materials, fabric, structure, facilities, equipment, automation and controls, services), and processes (maintenance, performance evaluation, facilities management).

An aim of the indicators is to allow for normalization of energy performance according to the different influencing factors (climate, occupant behaviour, etc.). Additionally, an EnPI 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. Energy performance indicators usually used in the building sector include energy consumption/sq.m, and energy consumption/occupant. ISO

50001 (2011) identifies the following five EnPIs. In the context of a building only the first two would be applicable, while the latter three are indicators for manufacturing industries:

1. energy consumption per time
2. energy consumption per unit of floor area
3. energy consumption per unit of production
4. energy consumption per unit of material consumed
5. energy consumption per unit of material transported

Maldonado (2011) is of the opinion that there are basically two types of EnPIs: Asset EnPI, and Operational Rating EnPI. While the former is based on modelled energy use, the latter is based on measured energy use. Goldstein & Eley (2014) state that a building's energy performance results from the interactions between systems, occupant demands and behaviour, and operation and maintenance (O&M) practices. However, all three are interdependent, thus requiring different variables or indicators. In an example from residential real estate in the Netherlands (Entrop et al., 2009) uses three EnPIs: Energy Performance Coefficient (EPC) for new buildings regulated in 1995, Energy Index Old (EIold) for existing buildings voluntary proposed in 2000, and Energy Index New (EInew) for existing buildings regulated in 2008. The method for determining energy performance for both for existing and new buildings uses the Energy Index (EInew) (Statistical Yearbook of the Netherlands, 2007) that is based on characteristic yearly energy use of a house, total ground surface in sq.m, and total thermal transmission surface in sq.m. In a similar method, indicators applicable for each of the six IEA factors shall be determined.

4.2 Bureau of Energy Efficiency (BEE) Guidelines

Under a bilateral cooperation project-Indo-Swiss Building Energy Efficiency (BEEP) between the Ministry of Power (MoP), Government of India, and the Federal Department of Foreign Affairs (FDFA) of the Swiss Confederation, a manual 'Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings for Composite and Hot-Dry Climates' (2014) was developed in 2009 (beeindia.gov.in, 2015). The objective of the design guidelines was for new residential projects to be energy-efficient. And in order to arrive at an energy performance index (EPI) benchmark to assess new project designs, 732 existing multidwelling residential units in Delhi-NCR (National Capita; Region) were studied for over a year. The study consisted of physical monitoring of space, ambient hygro-thermal conditions, and electricity consumption of space conditioning equipment. Extensive longitudinal data was collected for existing residential units, including assessing the residential units based on the factors by IEA to arrive at design (passive) strategies for energy efficiency for new residential projects.

The EnPIs from this study have been accepted and refined from other literature to arrive at the final listing. In Final Report Annex 53 (IEA, 2013), the factors have been additionally grouped under three levels depending upon the frequency of data monitoring, and complexity of data required;

Level A—Monthly (preferred) or annual (acceptable) energy consumption

Level B—Daily (preferred) or monthly (acceptable) energy consumption

Level C—Daily/hourly energy consumption

Level B can be grouped under Level A, as overlapping data collection frequency. However, Level C requires an extensive set of indicators for data collection as the indicators under the factors can be subjective, and so can the data. Additionally, Level C consists primarily of qualitative data. The indicators as considered in the manual 'Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings for Composite and Hot-Dry Climates' (2004) and are illustrated in Table 1. These have been categorized under the six IEA factors, and also subdivided under numeric indicators, and passive design strategies.

4.3 Climate performance indicators

In 2004, Integrated Environmental Solutions (IES) defined a methodology that uses climate-related data as a benchmark for procedures such as Leadership in Energy and Environmental Design (LEED) and Building Regulations (McLean et al., 2011). Two globally applicable indices were derived from the methodology that are holistic and interactive; they compare climate data from across the world to quantify the climate impact on building energy performance. They

TABLE 1. Factors for considering EnPIs.

Level of Factor	IEA Factors	EnPIs	Passive Design Strategies
A	Climate	Geographic location	
	Building envelop	Total exposed vertical surface area, cumulative radiation exposure, envelop (wall, glazing), shading, intermediate floor, window-to-floor area ratio, roof area	Typology; tower, liner, liner double loaded corridor
	Building Services and Energy Systems	Appliances (distribution transformer, air-conditioners, ceiling fans, Tubular fluorescent lamps, Electromagnetic and electronic ballasts, storage type electric water heaters/geyser), Other equipment/appliances[1]	
B	Building Operation and Maintenance	main electricity-consuming common services; lighting, water pumping and lifts	
	Indoor Environmental Quality	Set-point, daylighting, ventilation of kitchen	
C	Occupants' Activities and Behaviour	Occupancy profile, load & schedule	

[1]Frost-free (no-frost) refrigerators, Direct cool refrigerators, Pump sets, Domestic LPG stoves, Color televisions *f* Washing machines, Laptop/notebook computers, Office equipment

Source: Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings for Composite and Hot-Dry Climates (beeindia.gov.in, 2015) provide a common ground and simple calculations for comparison of building energy performances and different design strategies. The two indices are:

1. I. Climate Energy Index (CEI)
2. II. Building Energy Index (BEI)

From McLean et al. (2011), CEI indicates the impact of climate on a building's performance for an accepted standard of comfort at a particular geographic location. It is suitable for comparative evaluation of climate globally without considering the building design. The indicator for CEI (Figure 1) is climate data for a location, and the number of hours of building usage, it is calculated at air point and excludes indicators like a building's thermal processes (gains, conduction, infiltration etc.). Hence CEI is independent from factors of building geometry, occupancy load, type of building usage, and service systems of the building. CEI is based on calculations from the psychometric chart. However, as this indicator does not incorporate any other indicator except climate and more specifically the location data, the component on occupant comfort is not taken consideration. Additionally, occupant comfort can be altered by incorporating other indicators which then affect the comfort benchmark in the psychometric chart.

BEI on the other hand has been developed as a holistic performance indicator (McLean et al., 2011). BEI (Figure 2) uses both climate related energy data (from CEI) and also data of non-space conditioning benchmark load for hot water load, equipment load, lighting load and process load. But, like CEI, it also does not consider building morphology or building envelope among major indicators.

For this research, the climate-centric indicators derived from literature shall be as follows: geographic location for local weather conditions, air point and psychometric calculations for standard occupant comfort for a given location, and design airflow. Since a majority of multifamily units in India do not have the provision of central systems, design air-flow (mechanical ventilation) will not be considered. In the majority of occupant comfort studies, relative humidity does not feature as a main indicator, but it is still an important variable to measure, particularly in hot climates like India.

FIGURE 2. Flow Diagram for Calculating CEI (Source: McLean et al., 2011).

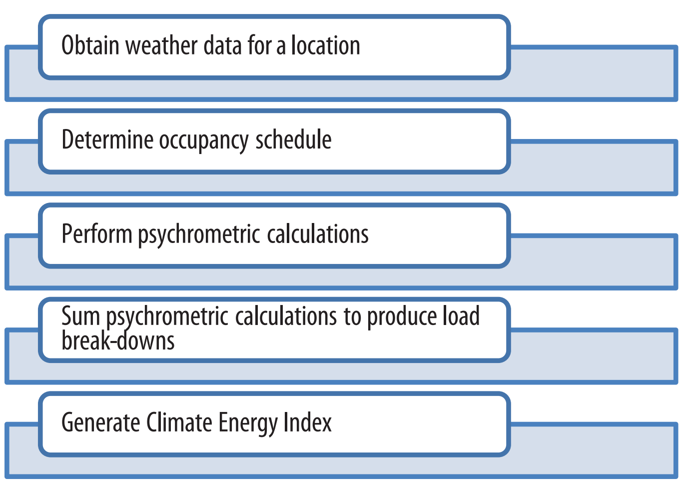
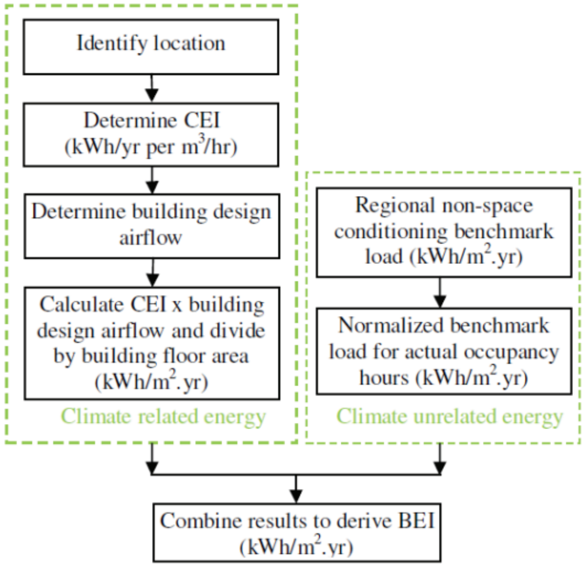


FIGURE 3. Flow Diagram for Calculating BEI (Source: McLean et al., 2011).



4.4 Building envelope performance indicators

In order to consider the geometry of a building for energy performance evaluations, the simple method adopted by energy-related building standards is adopted using numeric indicators that focus on a building's geometric compactness (Heindl & Grilli, 1991: Mahdavi et al., 1996; ÖNORM, 2002). Further, these indicators are derived from the relationship between volume of a built-form and the surface of its enclosure. However, Granadeiro et al. (2013) argue that though geometry can be a tool for ascertaining the energy performance of a building for various design options being considered, it does not necessarily correlate with energy demand for solar gains. Pessenlehner & Mahdavi (2003) also agree that geometric compactness alone cannot be an indicator for energy evaluation. Granadeiro et al. (2013) and Pessenlehner & Mahdavi (2003) modified the geometry factor to overcome these shortfalls and arrived at two indicators; Envelope-Related Energy Demand (ERED) and Design-Performance Space. Inputs to ERED are envelope elements (floor, walls, roofs and windows), U-values of envelope materials, solar heat gain coefficients (SHGC) of windows and site related parameters, concerning temperature and solar irradiation.

Design-Performance Space encompasses numeric indicators for geometry adopted for virtual space which is defined by multiple design and performance dimensions (Mahdavi & Gurtekin, 2002). These dimensions consist of values for design and performance variables. While design variables capture geometric (volume, shape, compactness) and semantic (thermal transmittance of the building enclosure, thermal mass, internal loads), the performance dimension provides for the ranges of values for these specific performance indicators, e.g., energy use, reverberation time in rooms, illuminance levels on working planes etc. Depecker et al. (2001) also created a similar design performance indicator in order to correlate the building design with its energy demand. They argue that while majority of existing design indicators are based on statistical models, their model is a 'forward model' based on a heat transfer concept, which is also used in Portuguese regulation for the energy performance of residential buildings (RCCTE, 2006), and corresponding with international standard ISO 13790 (2008). This comprises an analysis of heat transfer coefficients of structural elements and their U-values.

For this research, the building envelope indicators shall be building typology (multifamily residential in this case), its geometry, design and passive features, if any, geometric compactness, total ground surface around the building, window-wall ratio and roof area, and total exposed vertical surface area. Additionally, the mechanism of heat transfer from Portuguese regulation shall also be considered.

4.5 Building services and energy system's performance indicators

The majority of research and standards available for this performance factor are for commercial buildings which have central heating or cooling systems. The widely used IS/ISO 50001: 2011 Energy Management System is based on energy consumption of an organization as a whole, or of a particular process within the organization. IS/ISO 50001: 2011 recommends that organizations should identify and establish their own energy EnPIs for monitoring and measuring performance, and compare it to a baseline that is applicable for their organization type in IS/ISO 50001: 2011.

For residential buildings, energy consumption is generally for artificial lighting within residential space, space-conditioning equipment, appliances, water pumping, lifts, and exterior lighting. The majority of residential units and complexes in India are not centrally managed, hence, the EnPIs as applicable in IS/ISO 50001: 2011 have to be adapted to suit distinct residential units. In Table 2, an equivalence has been established between EnPIs, from the commercial to residential built-environment.

TABLE 2. Establishing equivalent EnPIs from commercial to residential.

EnPIs for commercial buildings	Equivalent EnPIs for multifamily residential buildings	Levels of data collection
Total energy amount on monthly level	Annual electricity bill, Monthly electricity bill	Level A
Total energy amount on daily and hourly level	Type of occupancy, schedule of occupancy, and usage activities, and behaviour	Level C
Energy use measurement by user type (lighting, air conditioning, satellites, elevators, etc.)	Listing of appliances, and usage pattern through occupancy schedules	Level B
Energy use measurement by system (office system, conference room system, executive office system, computer room system, parking area system, etc.);	Room wise/area wise energy consumption pattern in households, linked to occupancy schedules, and appliance usage schedules.	Level B
Energy use measurement by floor	Unit wise energy consumption pattern in households, linked to occupancy schedules, and appliance usage schedules.	Level A
Energy use measurement by specific machines or subsystems (cooler, heating system, etc.)	Common area energy consumptions	Level B

Source: Adapted from, ISO 50001:2011, Final Report Annex 53 (2013)

4.6 Operation and maintenance (O&M) performance indicators

O&M EnPI is generally based on measured energy use (Goldstein & Eley, 2014) and takes into account the physical characteristics of any building, operation, and maintenance of buildings. For example, in commercial buildings, some offices are increasingly able to demonstrate substantial improvements in energy use based on non-capital measures i.e. only on operational procedures. The green building rating system LEED-EB: O&M uses operational energy rating results from Energy Star to allocate points for energy performance of existing buildings (USGBC, 2014). Energy Star (1999) published an O&M Assessment Report which identifies 11 tasks to be undertaken for assessment as given in Table 3. These have been adapted in the context of residential buildings as O&M EnPIs

4.7 Indoor Environmental Quality (IEQ) performance indicators

Ncube & Riffat (2012) developed an expression, IEQindex, that they derived from the four factors they consider being performance indicators of IEQ for a built-environment. The four factors are Thermal Comfort, Indoor Air quality (IAQ), Acoustic Comfort and Lighting.

TABLE 3. Deriving EnPIs from O&M Assessment Report.

O&M Assessment Task	EnPI
Obtain an Understanding of the Building Equipment and Systems	Assessing Building Equipment and Systems
Understand the Building's Energy Use Profile and Identify the Largest Energy Using Equipment	Energy profiling and identification of largest energy using appliances
Identify Known Problematic Control and Operational Problems	Identification of user controls, and issues
Identify the Design and Operational Intent and Control Sequences	Appliance use and control issues
Identify Procedures to Reduce Unnecessary Runtime and Unnecessary Capacity Levels	Occupant schedule and behaviour profiling
Document Identified Equipment Condition Problems	Appliance Maintenance
Identify Changes to Control Parameters, Strategies, Set Points, Sequences or Maintenance Activities that will Optimize Efficiency, Comfort, Operation and Control	Appliance use and control issues
Develop and Implement Diagnostic Testing and Monitoring Plans	Diagnostic plan for existence of problems, record data
Identify Facility Staff Training Needs	Occupant Training Needs
Recommend Equipment Upgrades that may be Cost-Effective	Cost-Effective Equipment Upgrades
Document the Assessment Process and Results	Occupant Feedback & Maintenance Log

Source: Adapted from Operation and Maintenance Assessments Report (1999)

According to Bijarne & Olesen (2007), IEQ quality varies because of design and operation of building systems that control these four factors, and the right balance of both can assist in considerable energy savings while providing thermal comfort. ASHRAE Standard 55[4] for Thermal Environmental Conditions for Human Occupancy (1992), specifies the combination of IEQ and personal factors that produce 'acceptable' thermal conditions (acceptable to >80% of users), however, it also specifies that 'acceptability' can never have a precise definition, and research in this area can only be based on qualitative criterions.

In 2010, the revised ASHRAE Standard 55 included Adaptive Comfort Standard (ACS) which is a range of 'acceptable' temperatures for naturally ventilated houses (Ackerly et al, 2012). There has been research on the IEQ indicators, but the studies concentrated on a single indicator, and its effect on occupants, and not all four factors combined. Examples of such works are visual environment (Galasiu & Veitch, 2006), acoustic environment (Navai & Veitch, 2003), thermal environment (Fanger, 1970) and air quality (Wargocki et al., 2002). In addition, there has been research on non-related indicators of IEQ as well: perceived control, adaptation, expectations and outdoor climate influence evaluation of e.g. the visual environment, room sizes, and room layouts (Veitch, 2001).

In a research by Frontczak et al. (2011), a survey of 645 Danish houses was conducted for identifying the indicators of IEQ. In addition, Frontczak et al. (2011) also studied the non-related indicators and found that a majority of respondents like to have manual control over their indoor environment, especially window opening and solar shading. Thus, non-related factors would also need to be incorporated for IEQ performance, though their degree of influence is subjective. In a comparative study by (Honnekeri, 2014) of a house in Jaipur, India, (naturally ventilated) and one in Alameda, California (mixed-mode), he illustrates four factors of IEQ as being indoor temperature, relative humidity, carbon dioxide concentration, and air speed. All four are synonymous with Thermal Comfort and Indoor Air quality (IAQ), and this study shall consider them as EnPIs.

4.8 Occupant-centric performance indicators

The Institute for Sustainability, UK, (2015) advocates the case for use of Building Performance Evaluation (BPE) to be conducted prior to any retrofit or refurbishment project as that helps to establish current 'performance-in-use' of the homes. Further, they justify that BPE can reduce the risk of investment in retrofitting by identifying those very specific aspects of buildings that either need retrofitting or can withstand improvements. BPE is based on post-occupancy evaluation (PoE) process model by Preiser et al. (1989) in which PoE is viewed as a subset of BPE and is described as the evaluation of buildings' post occupancy for a certain period (Preiser & Vischer, 2005). Further, they describe the challenge of BPE is developing precise measures of occupants' experience of environmental comfort by including more performance criterion than conventionally under consideration.

From 1995 to 1998, the PROBE project (Post-occupancy Review of Buildings and their Engineering) was conducted jointly and was funded by the Building Services Journal (BSJ) and Department of Environment, Transport and the Regions (DETR) under their Partners in Technology programme (PROBE Strategic Review, 1999). PROBE undertook surveys of sixteen

4. ASHRAE Standard 55 is only applicable for naturally ventilated low-rise residential buildings, hence, has significance for residences in India that do not have central cooling building systems, rather mixed-mode cooling i.e. windows with air-conditioners.

recently completed buildings. The project covered three major aspects of building assessments: i) how occupants perceive the building as a whole including its systems, levels of comfort, productivity and well-being, ii) measurement of energy performance of systems and their maintenance requirements, and iii) effects of changes, alterations, replacements to the building and its services for occupants. The overall purpose of this assessment was to have structured insight of actual building performance against 'as-designed' to allow for appropriate design of new buildings that strike the optimal balance between energy efficiency and occupant comfort, (Cohen et. al, 1999).

Innovate UK (previously Technology Strategy Board, UK) conducted the Building Performance Evaluation (BPE) competition in 2010 for performance assessment of both new and refurbished existing housing stocks across the UK; extensive BPE work has already been conducted in the UK to support the zero carbon housings from 2016 onwards. Under funding from this competition, in 2014, Gupta & Kapsali presented their findings from investigations of the effect of occupant behaviour and expectations on energy use and indoor environmental conditions of six case study dwellings across three sustainable housing developments over a period of 1.5 years. Previously, Gupta and Chandiwala (2010) extensively discussed an integrated 'occupant-centered' BPE for large-scale, whole-house, and rapid retrofitting of existing UK housing. Bordass and Leaman (2005) state that technological interventions alone would be insufficient for energy savings without the cooperation of occupants, while (Steemers and Yun, 2009) state that study of occupant behaviour in relation to building performance is still in its emerging phase. Gupta and Chandiwala (2010) further add that application of occupant feedback before retrofitting has also not been critically analyzed. Through their case study projects, they have highlighted how occupant feedback is triangulated against actual physical monitoring and measurement of energy performance of dwellings and can assist in the selection of suitable retrofitting interventions. In Table 4, the tools for occupant feedback, and their outcomes are interrelated with areas of assessment. These shall be considered as EnPIs for this research.

As understood from literature, the occupant-centric indicators are complex and require triangulation with actual physical monitoring data to be considered precise. However, for this study the indicators to be considered as derived from the literature are occupancy schedule and loading as derived from behaviour, the profile of users and their preferences, perception of occupants toward their dwelling as a whole, levels of comfort as acceptable, their ways of adapting to comfort, and maintenance of systems. The maintenance of systems has already been covered under the O&M indicator and thus shall not be duplicated.

5. ROLE OF ENPIS IN RETROFITTING PLANNING

The overall retrofit strategy consists of two parts: i) strategic planning, and tools selection, and ii) major retrofit activities in the whole building (Ma et al., 2012). Further, the strategic plan and tool selection provide requisite information and resources for retrofitting. Ma et al. (2012) propose a strategy that has five phases to retrofit planning in which the second phase consists of an energy audit, performance assessment (and diagnostics). While auditing analyzes building energy data, performance assessment is employed to benchmark building energy use by using selected performance indicators. This research works to identify the building's energy performance indicators that are essential for assessing the building's consumption pattern. This work integrates individual factors considered in different literature and presents a priority listing of

TABLE 4. Measuring occupant-centric building performance: tools, outcomes and corresponding EnPIs.

Tools	Outcomes	EnPI
• Questionnaire surveys • Open-ended semi-structured interviews—occupants • Appliance energy usage questionnaire	• Space and flexibility • Best and worst aspects of the house • Future changes that occupants would like to be incorporated	• how occupants perceive the building as whole including its systems, • levels of comfort, productivity and well-being the building provides • effects of changes, alterations, replacements to the building and its services on its occupants.
• Focus groups • Structured discussion with occupants	• Community/cluster level issues for energy usage, availability	• measurement of energy performance of systems, and their maintenance requirements
• Heating/Cooling schedule diary • Thermal comfort diary • Field observations of user behavior • Occupants' video diaries	• Thermal comfort—scale of comfort recorded through thermal comfort diary • Preferred temperature level • Preferred air quality, air movement, fresh air intake • Preferred day-light levels within the house • Frequent adjustments to heating/cooling • Appliance audit—average daily usage hours • Use of automatic times/ controls	• Schedule and behavior; occupancy loading • Profile and preferences • Ways of adapting to thermal comfort

performance indicators. Additionally, this work also analyses the correlation between indicators which is an important parameter for retrofitting planning decision making for identifying physical upgrades and technical interventions.

This work is limited to the identification of performance indicators; however, it recommends future research in their applicability to retrofit planning. Additionally, the other phases of strategic planning should also be studied at a micro-level.

6. SUMMARY OF LITERATURE REVIEW

A significant part of this research was to undertake a comprehensive literature review in order to derive the EnPIs. The summary of all literature reviewed and their relation to EnPIs is presented in Table 5. In total 34 sources were studied extensively to derive the EnPIs, and their significance in retrofit planning, highlighted in Table 6.

TABLE 5. Summary of Literature Review.

Factors influencing energy performance (IEA, 2013)	Corresponding Indicators EnPIs	Author/Reference
Climate	Geographic location	beeindia.com (2014) McLean et al. (2011)
	Orientation of built-form	
	Air point & psychometric values for a location	
	Relative humidity	
	Thermal process or semantics (gains, conduction infiltration etc.)	
Building envelop	Building design, typology, and passive features	beeindia.com (2014) Heindl & Grilli (1991) Mahdavi et al. (1996) ÖNORM (2002) Granadeiro et al. (2013) Pessenlehner & Mahdavi (2003) Mahdavi & Gurtekin, 2002 Depecker et al. (2001) RCCTE (2006) ISO 13790 (2008)
	Compactness factor (ratio of volume of a built-form and the surface)	
	Total ground surface	
	Window-to-floor area ratio, and exposed roof area	
	Total exposed vertical surface area	
	Airflow patterns (within building)	
	Heat transfer coefficients of elements	
Building Services and Energy Systems	List of appliances, and usage pattern	beeindia.com (2014) IS/ISO 50001: 2011 Energy Management System
	Conditioning loads	
	Monthly electricity bill, and annual electricity bill	
	Room wise/area wise energy consumption	
Building Operation and Maintenance	Energy profiling	beeindia.com (2014) Goldstein & Eley (2014) USGBC (2014) Energy Star (1999)
	Identification of user controls, and issues	
	Appliance Maintenance	
	Diagnostic plan for existence of problems, record data	
	Occupant Feedback & Maintenance Log	
	Main electricity-consuming common services	

(Continues)

TABLE 5. *(Cont.)*

Factors influencing energy performance (IEA, 2013)	Corresponding Indicators EnPIs	Author/Reference
Indoor Environmental Quality	Thermal comfort; set points	beeindia.com (2014) Ncube & Riffat (2012) Bijarne & Olesen (2007) ASHRAE Standard 55 (1992/2010) Ackerly et al. (2012) Galasiu & Veitch (2006) Navai & Veitch (2003) Fanger (1970) Wargocki et al.(2002) Veitch (2001) Frontczak et al. (2011) Honnekeri (2014)
	Indoor air quality, air speed and carbon dioxide concentration	
	Natural ventilation	
	Acoustic comfort (sound, noise, peace, silence)	
	Lighting (Daylighting and artificial lighting)	
	Visual environment (views)	
	Room sizes, and layouts	
Occupants' Activities and Behaviour	Occupancy schedule and loading (as derived from behaviour)	beeindia.com (2014) Institute for Sustainability, UK (2015) Preiser et al. (1989) PROBE Strategic Review (1999) Cohen et. al. (1999) Gupta & Kapsali (2014) Gupta and Chandiwala (2010) Bordass and Leaman (2005) Steemers and Yun (2009)
	Profile of users and their preferences	
	Perception of occupants (towards their dwelling)	
	Levels of comfort (as acceptable)	
	Use of manual and automatic controls	
	Ways of adapting to thermal comfort	

7. METHODOLOGY

In order to achieve the four objectives of this research, a two-stage methodology was adopted: i) comprehensive literature review to identify energy performance indicators (EnPIs) for the six factors, and ii) a primary survey amongst architects, energy analysts, climate change policy specialists etc. in the field of energy efficiency of the built-environment, particularly with experience of retrofitting.

The findings from the comprehensive literature review are summarised and presented in Table 6. The second stage of the research was to develop a questionnaire for survey validation, and prioritizing the set of indicators identified as per ranking derived from a mean rank of survey responses. The EnPIs would be prioritised though a ranking questionnaire wherein the factors are ranked based on the views of experts of what constitutes a holistic built-environment that is both thermally comfortable for occupants and also energy efficient. The six factors were ranked separately, and then the 34-EnPIs under each factor were ranked.

TABLE 6. EnPIs and their significance in retrofit planning.

Factor	S.No	Corresponding Indicator; Ranking parameters for experts	Significance for Retrofit Planning
Climate-centric	1	Geographic location	will ascertain climate type, temperature, airflow and humidity of the location. Additionally, this would also identify the direction of building in relation to sun.
	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.)	identify air tightness factor which depends upon age of dwelling
Building Envelope	1	Building design, typology, and passive features	heat gains will depend upon orientation will define features that provides comfort to occupants will identify the internal layout of units
	2	Compactness factor (ratio of volume of a built-form and the surface)	the overall volume of building
	3	Total ground surface	These are project specific data that would need to be taken from existing design, or measured on site through inspection. Additionally, airflow has to be simulated in plan based on air speed of location, and actual design of dwelling.
	4	Window-to-floor area ratio, and exposed roof area	
	5	Total exposed vertical surface area	
	6	Airflow patterns (within building)	
	7	Heat transfer coefficients of elements	The heat transfer coefficient or U-values of structural elements can be made available by knowledge of materials used.
Building Services and Energy Systems	1	List of appliances, and usage pattern	will provide a basic idea of the appliance usage of the dwelling, room-wise schedule of usage based on occupancy patterns of the dwelling. This can be followed-up with physical monitoring to understand if performance is as per design and usage.
	2	Conditioning loads	
	3	Monthly electricity bill, and annual electricity bill	
	4	Room wise/area wise energy consumption	

(Continues)

TABLE 6. *(Cont.)*

Factor	S.No	Corresponding Indicator; Ranking parameters for experts	Significance for Retrofit Planning
Operation and Maintenance Building Performance	1	Energy profiling	
	2	Identification of user controls, and issues	appliance usage schedule
	3	Appliance Maintenance	appliance maintenance log
	4	Diagnostic plan for existence of problems, record data	
	5	Occupant Feedback & Maintenance Log	
	6	Main electricity-consuming common services	if common shared electricity load, then major grievance
Indoor Environmental Quality	1	Thermal comfort; set points	temperature set point, and range of variance across the day, and for different seasons
	2	Indoor air quality, air speed and carbon dioxide concentration	major issues with air quality, and window opening schedule across the day, and for different seasons
	3	Natural ventilation	
	4	Acoustic comfort (sound, noise, peace, silence)	issues with sounds/noise in the dwelling, and major times of disturbances
	5	Lighting (Daylighting and artificial lighting)	room-wise issues with levels of daylighting, glare, and usage pattern of artificial lighting across the day
	6	Visual environment (views)	rooms with direct view, and further need for views
	7	Room sizes, and layouts	compactness of dwelling, and issues with room sizes
Occupant-centric	1	Occupancy schedule and loading (as derived from behaviour)	occupancy schedule, linked with appliance usage
	2	Profile of users and their preferences	Demographic; gender, age and major occupation of all occupants
	3	Perception of occupants (towards their dwelling)	overall satisfaction and productivity in quantifiable parameters
	4	Levels of comfort (as acceptable)	
	5	Use of manual and automatic controls	occupant behaviour across the day, and seasons in quantifiable parameters
	6	Ways of adapting to thermal comfort	

This research adopted non-probability sampling for data collection and purposive or judgemental sampling (Saunders et al., 2009). Respondents were individually emailed the questionnaire survey based on their professional background in energy efficiency for the built environment. Selections were made with the view that the sample was informative regarding the subject of research (Neuman 2005) i.e. heterogeneous sampling (Patton, 2002) was attempted by focusing on the respondents who have knowledge of energy efficiency and retrofitting. A shortfall of this sampling is that it cannot be considered to be statistically representative of the total population as sample sizes are generally small because the researcher has to know the respondents in order to approach them for the survey. However, such sampling technique presents an interesting perspective that this small sample may have vastly different views based on the diversity of respondents and patterns may emerge out of the data that are unique (Patton, 2002).

The analysis of the different respondent sets would yield either of the following two results: the experts will have a strong consensus regarding the parameters as being important for assessing retrofitting potential. This will imply that that retrofitting planning can follow a generic template based on the EnPIs, but if consensus among experts is not reached, it would mean retrofitting can be said to be a bespoke exercise that varies amongst built-environment typologies, then, building performance evaluation has a vital role in assessing the built environment before planning.

8. DATA ANALYSIS AND FINDINGS

The survey received 106 valid answers out of 280 experts who were contacted for response. This is a 37.85% response rate which is acceptable for statistical analysis. The expertise of 106 respondents can be summarized as per Figure 4. The analysis was conducted on an overall count of 106; also the respondents were divided into two groups: industry practitioners and academicians/researchers. However, while the industry category has sufficient respondents (94) for statistical analysis, the academic category (12) data is not large enough for analysis.

For analysis two sets of tests were performed: Kendall's Concordance and Kruskal-Wallis H test. Kendall's W is known as the Kendall's Coefficient of Concordance (spss-tutorials.com/spss-kendalls-condordance-coefficient-w/, 2018). Further, it is an estimate of the variance of the row sums of ranks divided by the maximum possible value the variance can take; this occurs when all variables are in total agreement. Hence $0 \leq W \leq 1$, 1 representing perfect concordance.

FIGURE 4. Expertise of Respondents.

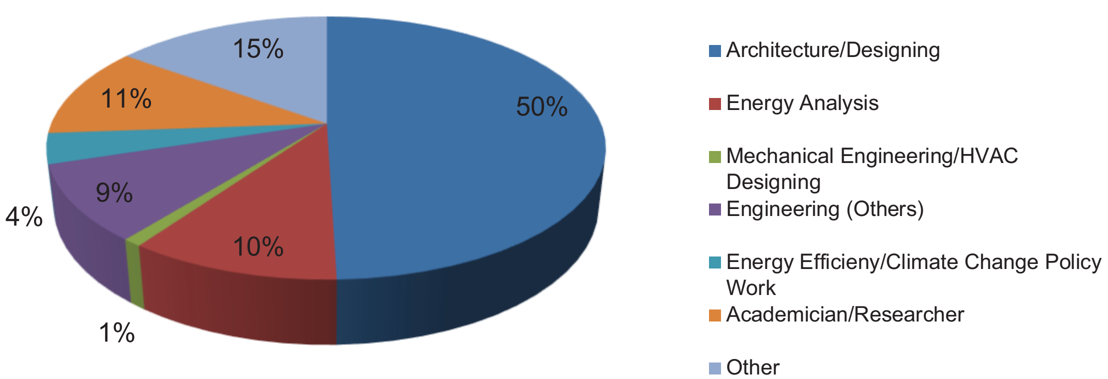
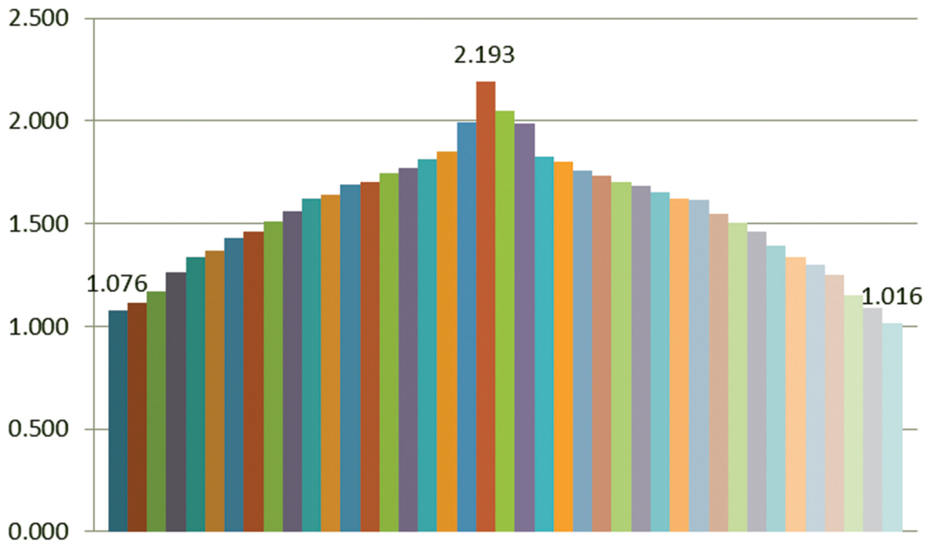


FIGURE 5. Variance analysis results for all respondents.



The test of W suggests a way of testing an argument for the significance of the contributions of individual variables to the overall concordance to determine which of the individual variables are concordant with one or several other variables in the group. In order to determine the significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable, the Kruskal-Wallis H test is conducted statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php, 2018). Ranking questions are analysed by rank-based nonparametric test and is considered the nonparametric alternative to the one-way ANOVA.[5]

The median from the Kruskal-Wallis H test for all respondents is 2.193, and for the industry practitioners is 2.189, thus a difference of only .004. Therefore, there is negligible variance between the two groups. The median and variance for all respondents is presented in Figure 5 and industry practitioners are presented in Figure 6.

Kendall's Concordance test results show low levels of agreement among the respondents. The test result for the two groups—all respondents and industry practitioners—is presented in Table 7. While for the first group of all respondents, the Kendall's W is 0.345, for the industry practitioners it is 0.292, and in both cases, it shows that there is low disagreement between experts as to which factors and EnPIs are to be considered for building performance evaluation for retrofit planning. This low level of consensus may be attributed to noting from the literature review that a holistic approach for considering all six factors and their corresponding indicators for the purpose of building performance has not been explored. Moreover, previous studies have concentrated on the factors individually

The factors and the EnPIs have been prioritised based on Mean Rank. This step was again repeated for all respondents and industry practitioners. The results are presented in Table 8. The rankings are consistent in both groups with the occupant-centric factor ranking as the

5. ANOVA test is a way to find out if survey or experiment results are significant (http://www.statisticshowto.com/probability-and-statistics/hypothesis-testing/anova/, 2018).

FIGURE 6. Variance analysis results for industry practitioners.

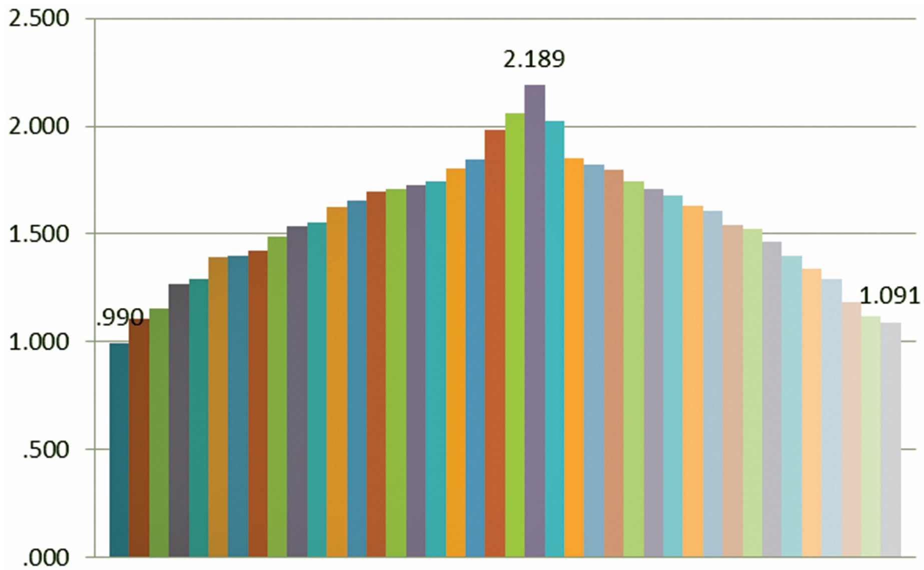


TABLE 7. Kendall's Concordance Test Results.

Test Statistics	All respondents	Industry practitioners
N	106	94
Kendall's W[a]	.345	.292
Chi-Square	1497.930	1098.377
df	41	40
Asymp. Sig.	.000	.000

[a] Kendall's Coefficient of Concordance

most important for retrofit planning. Current literature also places significant emphasis on understanding the occupant behaviour and energy consumption patterns in both residential and commercial buildings.

The EnPIs were also ranked following a similar methodology, and the rankings are presented in Table 9. There was a difference in ranks of 8 EnPIs. While all respondents ranked occupancy schedule and loading (as derived from behaviour) from occupant-centric factor as the most significant, industry practitioners ranked room sizes and layouts from the indoor environmental quality factor as most vital for retrofit planning. Similar variations in ranks can be seen across thermal comfort, set points and relative humidity, levels of comfort (as acceptable), thermal process or semantics (gains, conduction infiltration etc.), ways of adapting to thermal comfort, and occupant feedback and maintenance log.

The Mean Ranks for the EnPIs across the six factors were separately analysed to derive the most significant EnPI across each category. While the ranks remained same for both the groups, there was slight variance in Mean Ranks only. The results are presented in Table 10.

TABLE 8. Mean Rank of Factors.

Factors	Mean Rank (All respondents)	Ranking	Mean Rank (Industry practitioners)	Ranking
Occupant-centric	4.67	1	4.77	1
Operation and Maintenance Building Performance	3.93	2	3.98	2
Indoor Environmental Quality	3.63	3	3.66	3
Building Services and Energy Systems	3.39	4	3.36	4
Building Envelope factors	2.79	5	2.71	5
Climate-centric factors	2.58	6	2.52	6

TABLE 9. Mean Ranks of EnPIs.

Factor	Energy Performance Indicators (EnPIs)	Mean Rank (All respondents)	Ranking	Mean Rank (Industry practitioners)	Ranking
OC	Occupancy schedule and loading (as derived from behavior)	27.74	1	27.40	2
IEQ	Room sizes, and layouts	27.60	2	27.48	1
BE	Heat transfer coefficients of elements	26.85	3	26.56	3
IEQ	Lighting (Daylighting and artificial lighting)	26.17	4	26.36	4
IEQ	Thermal comfort; set points	25.60	5	25.39	6
CC	Relative humidity	25.59	6	25.62	5
O&M	Main electricity-consuming common services	25.02	7	25.05	7
BE	Building design, typology, and passive features	23.96	8	23.73	8
CC	Air point & psychometric values for a location	22.17	9	22.19	9
BE	Total exposed vertical surface area	21.49	10	21.63	10
BE	Airflow patterns (within building)	21.12	11	21.19	11
IEQ	Levels of comfort (as acceptable)	20.54	12	19.99	14
CC	Thermal process or semantics (gains, conduction infiltration etc.)	20.32	13	20.88	12

TABLE 9. *(Cont.)*

Factor	Energy Performance Indicators (EnPIs)	Mean Rank (All respondents)	Ranking	Mean Rank (Industry practitioners)	Ranking
OC	Ways of adapting to thermal comfort	19.97	14	19.93	15
O&M	Occupant Feedback & Maintenance Log	19.95	15	20.05	13
O&M	Diagnostic plan for existence of problems, record data	19.55	16	19.37	16
O&M	Appliance Maintenance	18.70	17	18.34	17
IEQ	Visual environment (views)	17.38	18	17.44	18
OC	Perception of occupants (towards their dwelling)	16.56	19	16.68	19
BSES	Monthly electricity bill, and annual electricity bill	15.03	20	14.98	21
O&M	Energy profiling	14.81	21	15.14	20
IEQ	Natural ventilation	14.70	22	14.78	22
O&M	Identification of user controls, and issues	14.49	23	14.78	23
BE	Window-to-floor area ratio, and exposed roof area	14.25	24	14.28	24
CC	Geographic location	14.00	25	13.61	25
CC	Orientation of built-form	13.24	26	13.29	26
OC	Use of manual and automatic controls	12.77	27	12.64	29
OC	Profile of users and their preferences	12.44	28	12.99	27
IEQ	Indoor air quality, air speed and carbon dioxide concentration	12.41	29	12.83	28
IEQ	Acoustic comfort (sound, noise, peace, silence)	12.12	30	11.82	30
BSES	List of appliances, and usage pattern	11.82	31	11.67	31
BE	Total ground surface	11.78	32	11.64	32
IEQ	Room wise/area wise energy consumption	11.28	33	11.43	33
BSES	Conditioning loads	10.01	34	10.06	34
BE	Compactness factor (ratio of volume of a built-form and the surface)	8.58	35	8.77	35

CC: Climate-centric, BE: Building Envelope, BSES: Building Services and Energy Systems, O&M: Operation and Maintenance Building Performance, IEQ: Indoor Environmental Quality, OC: Occupant-centric

TABLE 10. Mean Ranks across EnPIs.

Factor	EnPIs	Highest Mean Rank (All respondents)	Highest Mean Rank (Industry practitioners)
Climate-centric	Relative humidity	3.86	3.84
Building Envelope	Heat transfer coefficients of elements	5.83	5.77
Building Services and Energy Systems	Monthly electricity bill, and annual electricity bill	3.03	3.02
Operation and Maintenance Building Performance	Main electricity-consuming common services	4.6	3.86
Indoor Environmental Quality	Room sizes, and layouts	5.58	5.56
Occupant-centric	Occupancy schedule and loading (as derived from behaviour)	5.12	5.08

9. SUMMARY AND CONCLUSIONS

The primary purpose of the research was to determine if retrofit planning can be standardized by determining the energy factors and their corresponding performance indicators that are relevant for planning for energy efficient retrofitting of multifamily residential buildings. A literature review was conducted to identify the relevant factors and EnPIs globally considered for building performance evaluation that determine retrofitting. The basis of the study was the background work done by IEA (2013), wherein six factors were considered. This research had the retrofitting consultants or sustainability consultants as the primary stakeholders to benefit from this prioritised listing and to enable them to perform holistic building performance before planning.

This research further populated the factors by identifying corresponding indicators and determining the outcomes from the indicators. In total for the six factors, 35-EnPIs were identified. Then a ranking questionnaire was developed and circulated amongst experts from the built-environment that received 106-valid responses. A notable fact from the data analysis was that the Kendall's Coefficient of Concordance was low for the responses indicating that experts had a low-level of concordance or agreement over the factors and corresponding indicators identified for retrofit planning. Thus, this study can be furthered by expanding both set of factors and EnPIs, for example, post occupancy evaluation and occupant feedback, technical interventions and their energy saving analysis, and their payback period analysis. Additionally, the study was independent of Green Building certification parameters, which can be proposed as a future extension of this study, and those may be considered as factors. A primary reason for the low levels of agreement can be that researchers have previously not clustered factors and corresponding indicators, rather concentrated on the study of individual factors for detailed analysis; thus, perceptions have varied in terms what experts deem significant for retrofitting.

The results from data analysis identified the EnPI occupancy schedule and loading (as derived from behaviour) as the most significant for retrofit planning by all respondents but industry practitioners ranked room sizes and layouts as most significant. Occupant-centric factors have been identified as the most significant factor for retrofitting by all respondents, including industry practitioners. However, Indoor Environmental Quality ranked fourth, while room sizes and layouts have been ranked as most significant by industry practitioners. The current trend of literature is veering towards understanding the nuances of occupant behaviour in both residential and commercial (office) spaces and integrating the variations into energy modelling/simulation to determine energy gurgling behaviour. While literature from the USA, UK and other EU countries have largely concentrated on occupant behaviour in standalone houses, Indian housing typology and occupancy leans more towards multifamily dwellings, and this presents a challenge due to the larger variance of occupant type, demographics, equipment and lighting loading and usage schedules etc. Moreover, this varies geographically based on climatic conditions. The results also identify the occupant-centric factor and indicator as significant, thus supporting literature.

The overall goal of this research was to support retrofit planning, and this work achieved this through integration of distinct performance indicators or EnPIs under various energy influencing factors into a single priority listing for ease of reference. Retrofitting strategic planning requires a building performance to be undertaken, and with a ready reference of EnPIs, the process is simplified and a holistic outlook of a building's performance can be attained. This can ease the burden for experts involved with retrofit planning.

The work performed in this research on the identification and prioritization of EnPIs can also serve as the basis for future research on investigating further phases of retrofit planning at a micro-level to arrive at a more detailed database and knowledgebase for energy efficiency retrofitting projects. Such efforts will contribute towards the critical area of promoting energy retrofitting of existing buildings worldwide.

10. ACKNOWLEDGEMENT

The funding for this research was received under the Building Energy Efficiency Higher & Advanced Network (BHAVAN) Fellowship from the Indo-US Science and Technology Forum (IUSSTF), and Department of Science and Technology (DST), Government of India. The opinions and findings expressed here, however, are those of the authors alone, and are not necessarily the views or positions of the IUSSTF and DST.

11. REFERENCES

1. Abel E. (1994). Low-energy buildings, Energy and Buildings, Vol. 21, pp. 169–174.
2. Ackerly, K, G. Brager, E. Arens (2012). Data Collection Methods for Assessing Adaptive Comfort in Mixed Mode Buildings and Personal Comfort Systems. Center for the Built Environment, UC Berkeley.
3. Alwaer, H., and D. J. Clements-Croome, (2010). "Key Performance Indicators (KPIs) and Priority Settings in Using the Mutli-Attribute Approach for Assessing Sustainable Intelligent Buildings." Building and Environment 45 (4): 799–807.
4. B. Bordass, A. Leaman (2005). Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques. Building Research & Information, 33 (4) pp. 347–352
5. Bureau of Energy Efficiency (2014). Design Guidelines For Energy-Efficient Multi-Storey Residential Buildings—Composite And Hot-Dry Climates. Ministry of Power, Government of India. Available online [http://beepindia.org/group/group-design-guidelines-energy-efficient-multi-storey-residential-buildings-composite-and-hot].

6. INDO-SWISS BUILDING ENERGY EFFICIENCY PROJECT (BEEP) (2016).
7. Efficiency (2016). Design Guidelines for Energy-efficient Multi-storey Residential Buildings for Warm-Humid Climates. Available online [http://beepindia.org/resouces-year-wise].
8. Berghorn, G, Syal, M (2016). Risk framework for Energy performance contracting Building Retrofits. Journal of Green Building. Vol. 11, No. 2 (Spring 2016) pp. 93–115.
9. Centraal Bureau voor de Statistiek (English: Statistics Netherlands), Statistisch jaarboek 2007 (English: Statistical yearbook of the Netherlands 2007), ISBN 978-90-357-1586-8, 2007 (in Dutch).
10. Cohen, R., P. Ruyssevelt, M. Standeven, W. Bordass, and A. Leaman (1999). Building Intelligence in Use: Lessons from the Probe Project. Usable Buildings Trust, London, UK.
11. Entrop, A.G., Brouwers, H.J.H., Reinders, A.H.M.E., (2010). Evaluation of energy performance indicators and financial aspects of energy saving techniques in residential real estate. Energy and Buildings. Vol. 42, pp. 618–629.
12. Fanger, P.O., 1973. Assessment of man's thermal comfort in practice. British journal of industrial medicine. Vol. 30, No. 4, pp. 313–324.
13. Energy Conservation Code for Residential Buildings (ECBC-R) (2017). Bureau of Energy Efficiency. Ministry of Power. Available online [https://beeindia.gov.in/sites/default/files/Residential%20Code_Building%20Envelope_Draft_rev4.pdf]
14. Frontczak, M., Andersen, R.V., Wargocki, P., (2012). Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing. Build Environ. Vol. 50, pp.56–64.
15. Galasiu, A. D., Veitch, J.A., (2006). Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review. Energy and Buildings. Vol. 38, pp. 728–742.
16. Goldstein, D.B. & Eley, C, (2014). A classification of building energy performance indices. Energy Efficiency. Volume 7, Issue 2, pp 353–375.
17. Gupta, R., and Kapsali, M. (2014): How effective are 'close to zero' carbon new dwellings in reducing actual energy demand: Insights from UK. PLEA, Ahmedabad. (30th International PLEA Conference 16–18 December 2014, CEPT University, Ahmedabad).
18. Gupta, R., Chandiwala, S, (2010). Integrating an occupant-centred building performance evaluation approach to achieve whole-house and low-carbon retrofitting of UK homes. Proceedings of Conference: Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK.
19. Heindl, W., Grilli, P.V. 1991. On Establishing Standards for the Overall Heat Transfer Coefficient of Buildings, CIB-W67-Workshop 1991, Vienna.
20. Hoes, P., Hensen, J.L.M., Loomans, M.G.L.C., Vries, B. de & Bourgeois, D. (2009). User behavior in whole building simulation. Energy and Buildings 41(3): 295–302.
21. Honnekeri, A, Brager, G, Manu, S, Rawal, R, (2014). Occupant Feedback in Energy-Conscious and 'Business as Usual' Buildings in India. In 30th International Plea Conference. Ahmedabad, 16–18 December. Ahmedabad: CEPT University. 1–9.
22. International Energy Agency Programme on Energy in Buildings and Communities (2013). Total energy use in buildings. Analysis and evaluation methods. Final Report Annex 53.
23. ISO (2008). ISO 13790:2008—Energy performance of buildings—Calculation of energy use for space heating and cooling. TC 163 Thermal performance and energy use in the built environment
24. ISO (2011). SO 50001:2011. Energy management systems—Requirements with guidance for use.
25. Jafari, A, Valentin, V (2017). Sustainable Impact of Building Energy Retrofit Measures. Journal of Green Building. Vol. 12, No. 3 (Summer 2017) pp. 69–84.
26. Junghans, A, (2013), Decision support model for energy-efficient improvement of entire building stocks, Facilities, Vol. 31 No. 3/4, 2013 pp. 173–184.
27. Laerd Statistics (2018). Kruskal-Wallis H Test using SPSS Statistics. Available online [https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php]
28. Luther, M.B, Rajagopalan, P (2014). Defining and Developing an Energy Retrofitting Approach. Journal of Green Building. Vol. 9, No. 3 (Summer 2014) pp. 151–162.
29. Ncube M, Riffat S. Developing an indoor environment quality tool for assessment of mechanically ventilated office buildings in the UK—A preliminary study. Building and Environment 2012;53:26–33.
30. Ma, Z.J., Cooper, P., Daly, D., Ledo, L., Existing building retrofits: Methodology and state-of-the-art. Energy and Buildings, 55; 2012: 889–902 http://dx.doi.org/10.1016/j.enbuild.2012.08.018.

31. Mahdavi, A., Brahme, R., Mathew, P. 1996. The "LEK"-Concept and its Applicability for the Energy Analysis of Comercial Buildings, Building and Environment, 31(5). pp. 409–415.
32. Mahdavi, A., Gurtekin, B. (2002). Adventures in the design-performance space. European Meetings on Cybernetics and Systems Research Conference 2002, Vienna, 2–5 April, 2002.
33. Maldonado E. (2011). Implementing the energy performance in buildings directive, Brussels, Belgium, The European Union, EA-30–11–026-EN-C, 2011.
34. McLean, D., Roderick, Y., Quincey, R. and McEwan, D., (2011). Climate energy index and building energy index: New indices to assess and benchmark building energy performance. In Proceedings of the Building Simulation 12th Conference of International Building Performance Simulation Association, Sydney, Australia (Vol. 1416, p. 792799).
35. Md Rian, I (2011). Multicultural Flexible Housing: Addressing the Need and Scope of Flexible Housing in Cosmopolitan Indian Cities. 5th International Conference & Workshop On Built Environment In Developing Countries, Penang. Available online [https://www.researchgate.net/publication/235754363_Multicultural_Flexible_Housing_Addressing_the_Need_and_Scope_of_Flexible_Housing_In_Cosmopolitan_Indian_Cities]
36. Navai, M., Veitch, J. A., (2003). Acoustic satisfaction in open-plan offices: review and recommendations.
37. Newman, W.L. (2005). Social research methods: Qualitative and quantitative approaches. (6th ed). Boston, MA: Allyn & Bacon.
38. O&M Assessments—Enhancing Energy-Efficient Building Operation Best Practices In Operation And Maintenance (1999). Prepared With Funding From The U.S. EPA And U.S. DOE.
39. O&M Assessments—Enhancing Energy-Efficient Building Operation Best Practices In Operation And Maintenance (1999). Prepared with Funding from The U.S. EPA And U.S. DOE.
40. Olofsson, T., Meier, A., Lamberts, R, (2004). Rating the energy performance of buildings. Int. J. Low Energy Sustain. Build. 3, 1–18.
41. ÖNORM 2002. ÖNORM B 8110-1: Wärmeschutz im Hochbau—Anforderungen an den Wärmeschutz und Nachweisverfahren, Österreichisches Normungsinstitut, Wien, 29. Januar 2002.
42. Pessenlehner, W, A, Mahdavi, (2003). Building Morphology, Transparence, and Energy Performance. In Eighth International IBPSA Conference. Eindhoven, August 11–14. Ahmedabad: Heriot Watt Research Home. 1025–1032.
43. Poel, B, van Cruchten, G, A. Balaras, C, (2007). Energy performance assessment of existing dwellings. Energy and Buildings, 39, 393–403.
44. Preiser, W.F.E. (ed.) (1989). Building Evaluation. Plenum, New York, USA.
45. Preiser, W.F.E., and Vischer, J.C. (eds.) (2005). Assessing Building Performance, Elsevier, Oxford, United Kingdom.
46. Probe Strategic Review (1999), Report 3: Occupant Surveys. Building Use Studies Ltd, William Bordass Associates, ESD.
47. RCCTE 2006. Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE), (Thermal Buildings Regulation, in Portuguese). Decree-Law n. º 80/06, of April 4 th, 2006.
48. SPSS Tutorials (2018). SPSS—Kendall's Condordance Coefficient W. Available online [https://www.spss-tutorials.com/spss-kendalls-condordance-coefficient-w/].
49. Steemers, K. and Yun, G. Y. (2009). Household energy consumption: a study of the role of occupants. Building Research & Information, 37(5–6): 625–637.
50. Syal, M., Duah, D., Samuel, S., Mazor, M., Mo, Y., and Cyr, T. (2014). Information framework for intelligent decision support system for home energy retrofits. Journal of Construction Engineering and Management. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000773.
51. The Economist Intelligence Unit (2013). Achieving scale in energy-efficient buildings in India: A view from the construction and real estate sectors. Available online [http://www.gbpn.org/reports/achieving-scale-energy-efficient-buildings-india-view-construction-and-real-estate-sectors].
52. United States Green Building Council (2013). LEED Reference Guide for Building Operations and Maintenance. Available online [http://in.usgbc.org/resources/leed-reference-guide-building-operations-and-maintenance].
53. V. Granadeiro, C. João, L. Vítor, D. José (2013). Envelope-related energy demand: a design indicator of energy performance for residential buildings in early design stages Energy Buildings pp. 215–223.

54. Veitch J.A and Newsham G.R., (2000). Preferred Luminous Conditions in Open Plan Offices: Research and Recommendtions, Journal of Lighting Research and Technology, pp. 199–212.
55. Wang, S., Yan, C., Xiao, F, (2012). Quantitative energy performance assessment methods for existing buildings. Energy and Buildings, 55(2012), pp. 873–888.
56. Wargocki P, Sundell J, Bischoff W, (2002). Ventilation and health in nonindustrial environments. Report from a European Multidisciplinary Scientific Consensus Meeting. Clima 2000/Napoli 2001 World Congress, Napoli (I), 15–18 September 2001. Indoor Air.