KEY WORDS:
Building Performance Assessment, Common Tools and Rating Systems in India, Building Performance Evaluation, Instrumentation, Case Study.

Building Performance Assessment and Evaluation of Existing Buildings for Energy Efficiency:
Case Study of Students' Accommodation in a University Campus

Parveen Kumar

Tekton
Volume 1, Issue 1, September 2014
pp. 76 - 95

ABSTRACT

Although there is increasing awareness on integrated design approaches with energy efficient design techniques for designing new buildings, little attention is paid to existing buildings and their energy performance. This paper examines various building performance assessment methods commonly used in India and their merits in identifying energy conservation strategies. Further, Case Study approach has been used to illustrate process of building performance evaluation by tracking performance of existing students' accommodation in a university campus. Various studies have revealed that in absence of tracking of energy consumption and relatively larger footprint and high occupancy of students' accommodation, a higher amount of energy is consumed in them. The paper focuses on establishing integrated approach of monitoring energy consumption, thermal conditions and occupant satisfaction to assess a building's performance and reduce its energy consumption by identifying suitable energy conserving measures.

Parveen Kumar is Associate Professor at Department of Architecture, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonipat and is currently pursuing PhD in Architecture from the same institute in the field of energy efficient design of existing students' accommodation in university campus. His areas of interest include architectural theory, building performance, energy efficiency, urban planning and sustainable development.

gargarch28@gmail.com

Introduction

Significant stock of buildings has been added in India in the last decade riding on fast growth.

This building stock falls under the category of existing buildings and continue to consume energy unabatedly. The United Nations' inter-governmental panel on climate change in its report on "Mitigation of Climate Change" found that the largest energy and carbon savings potential in 2030 will lie in existing buildings through retrofit and renovation (IPCC Fourth Assessment Report, 2013).

The building sector accounts for about 33% of electricity consumption in India with residential sector claiming 25% of energy consumption (ECBC, 2009). Existing buildings with retrofitting measures have a potential of saving energy up to 20 to 25% (CII Report, 2009). Energy efficiency is often referred to as an "invisible resource" — the cheapest, fastest and cleanest way to improve the sustainability of cities (Join, 2014). To reduce energy consumption significantly, there is a need to address energy conservation opportunities in existing buildings by assessing their performance with the aim of low energy and yet comfortable built environments.

This paper aims to examine various building performance assessment methods commonly used in India and their relative merits. This paper further proposes a building performance evaluation methodology for existing buildings. A case study of a University hostel building illustrates this methodology which integrates thermal performance, occupants' survey and energy performance.

Building Performance Assessment (BPA)

Measurement, tracking and monitoring can play a key role in energy management of buildings. A building may appear to be performing well, but it cannot be verified unless its performance is measured and compared to established benchmarks on a regular and continuing basis. The performance of a building might decline over time if not monitored and without an action plan to bring its performance up to the requisite benchmark (ASHRAE, 2012).

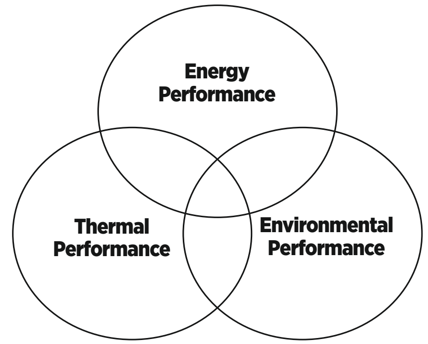

Figure 1 Elements of Building Performance

Building Performance Assessment is the process of monitoring and analyzing facility data on a regular basis to meet energy and performance goals (Greensfelder, 2010). The various elements of building performance include thermal performance, environmental performance and energy performance **(Figure 1)**.Total energy consumption of a building depends on its energy performance based on building envelope, lighting systems and HVAC systems as well as of various equipments used in the building. Rarely do energy audits or energy performance evaluations take into account thermal performance of buildings as well as occupants' comfort and their aspirations as to how the building ought to perform (Brown, 2009). User behaviour and facility management also play an important role in reducing wasteful use of energy in buildings. Assessment of building energy performance is fundamental in making decisions regarding energy efficient design of buildings and in quantifying the impact of energy conservation measures (Hui, 1996).

According to Olsen & Iverson (2006), Building Performance Assessment in existing buildings can lead to the following benefits:

- Improved building performance by using Energy Conservation Measures (ECMs) and climate responsive design features.
- Enhanced thermal and visual comfort of occupants, thus creation of healthier and more productive living spaces.
- Improved facility management and reduced operating cost by monitoring services and life cycle cost analysis.
- Green Rating Certification / Documentation, Energy Code Compliance and reduced carbon footprint.
- Improved decision making process through optimization and comparison of different schemes, options and systems.

Hopfe (2009) also mentions about improved envelope performance through energy studies, determining and optimizing material properties via uncertainty / sensitivity analysis.The study of energy performance for existing buildings is an essential task in energy audits and surveys which aim at optimizing the building operation (CIBSE, 1991).

The energy performance of a building is generally described as Energy Performance Index (EPI) and is defined as total energy consumed in kWh / sq.m. / year. EPI of a building is a resultant sum of several factors, including among others, varying nature of building design, site conditions, zoning, geometry, orientation, selection of materials, shading devices, fenestration distribution, microclimate, and air conditioned / naturally ventilated or mixed mode. Further, it also depends on the way buildings are being used, ease of controls in shading devices / lighting automation, occupant sensors, occupants' background (clothing factor), cultural factors (adaptive opportunities), nature of activities, occupation density, operational schedules etc.

Common Tools and Rating Systems for BPA: An Overview

A wide range of environmental performance design and assessment tools exist providing building design professionals and other project stakeholders with a choice of mechanisms to aid the planning, design, evaluation and management of energy efficient buildings. The United States Department of Energy provides a list of 416 building software tools for evaluating energy efficiency, renewable energy, and sustainability in buildings along with a brief description of salient feature of each tool including expertise required users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact, and availability (DOE, 2009). Energy efficiency of a building is directly related to its thermal performance. Thermal performance is typically calculated for one of two reasons — to size and select mechanical equipment and comfort level as well as to predict the annual energy consumption of a structure (Ziai, 2006).

Commonly used tools and rating systems for tracking building performance prevalent in India are presented in the following five tables, summarising relevant sections for existing buildings along with their weightage and underlying parameters.

LEED INDIA for Existing Buildings

The LEED (Leadership in Energy and Environmental Design) green building rating system developed by the U.S. Green Building Council is now recognised as an international rating system and followed by more than 24 countries. The LEED rating system has been indigenized by the Indian Green Building Council as LEED-India to suit the national context and priorities for energy efficiency. LEED India has launched 'Green Existing Building O & M Rating System' for enabling existing buildings to be energy efficient and sustainable over the life cycle of the building. Relevant sections for energy efficiency are listed in Table 1.

Site and Facility Management		**18 points**
SF Credit 3.2	Heat island reduction Roof 50%,75%	2,4
SF Credit 5	Building operation and maintenance	2
Energy Efficiency		**30 points**
EE Mandatory requirement 2	Minimum Energy performance EPI Method and Energy simulation	Required
EE Credit 1	Improved energy performance: 10%,12.5%,15%, 17.5%,20%,22.5%,25%	14
EE Credit 2	Onsite renewable energy: 2.5%, 5%, 7.5%,	6
EE Credit 3	Off site renewable energy: 25%, 50%, 75%,	6
EE Credit 4	Energy metering	4
Health and comfort		**14 points**
HC Mandatory requirement 2	Fresh Air ventilation	Required
HC Credit 4	Thermal comfort, indoor temp and RH	2

Table 1 Criteria in LEED - India for energy efficiency
Source: IGBC Green Existing Buildings O&M Rating Systems, Reference guide 2013

Following features are observed:

- It has employed EPI as key performance indicator or energy simulation method and gives credits for lower EPI and promotes on site and off site renewable energy as well as continuous energy metering and monitoring by end use type.

- For comfort and health, it has emphasized surveys to be conducted once in 6 months and monitoring for fresh air ventilation, CO2, comfortable thermal environment at 26_+2 C and 30-70 % RH and conduct occupant survey to show 80% occupants are satisfied.

GRIHA (Green Rating for Integrated Habitat Assessment)

The ministry of new and renewable energy devised GRIHA as national Rating System (developed by TERI - The Energy & Resource Institute). It takes into account provisions of the National Building Code 2005, the ECBC, Energy Conservation Building Code 2007 and local bye-laws. Relevant sections for energy efficiency are listed in **Table 2.**

This system by its qualitative and quantitative assessment criteria, would be able to rate a building on its performance. The rating would be applied to new and existing building stock of varied functions – commercial, institutional, and residential.

Energy Conservation Building Code (ECBC)

The Energy Conservation Building Code (ECBC) was launched by the Bureau of Energy Efficiency (BEE) in May 2007 under the Energy Conservation Act, 2001. It prescribes the specifications for various building components to construct energy efficient new buildings and Energy audits for existing buildings to achieve improved energy performance in existing buildings (Mathur A, 2011). Although voluntary, it provides significant parameters to reduce energy consumption for building envelope, electrical and mechanical equipments, lighting and service hot water heating for various climate zones of the country **(Table 3)**. The code is applicable to building complexes having connected load of 100 kW or greater or a contract demand of 120 kVA or greater or having conditioned area of 1000 sq.m. and above. The code also applies to additions in existing buildings. Two approaches have been defined in ECBC: Prescriptive Approach deals component wise comparison with benchmark with option of trade off. Whereas whole building analysis discusses total performance of system and offers flexibility to designers and compares EPI and unmet hours.

According to the EC Act, compliance with the ECBC has to be expressed in terms of Energy Performance Index (EPI) which is the annual energy consumption per square meter of floor area, and is only possible via Whole Building Performance (WBP) compliance approach. However, the prescriptive compliance approach is relatively easy to implement and enforce. The BEE has developed a Star Rating program for buildings on a scale of 1-5 star scale which is based on the actual EPI of a building **(Table 4)**. The Star Rating program provides public recognition to energy efficient buildings, and creates a 'demand side' pull for such buildings (Seth, 2011).

National Building Code (NBC)
Part 11 of Draft Addendum no: 1 to NBC 2005 (SP: 2007) Approach to Sustainability

Although it is still in draft stage, part 11 provides a comprehensive set of requirements **(Table 5)**. This section is intended to reduce negative impact of buildings on natural environment and emphasises regular monitoring of the building energy consumption along with occupant surveys (BIS, 2012).

Criteria 13	Optimise building design to reduce conventional energy demand	6 mandatory
Criteria 14	Optimise emergy performance of building within specified comfort	12
Criteria 17	Use low energy materials in interiors	4
Criteria 18	Renewable energy utilisation	5 partly mandatory
Criteria 19	Renewable energy base hot water system	3
Criteria 32	Energy audit and validation	Mandatory
Criteria 33	Operation and maintenance protocol for electrical and mechanical equipment	2 Mandatory

Table 2 Criteria in GRIHA for energy efficiency
Source: Introduction to National Rating System – GRIHA, Manual Vol.1,2010

Section 4	Building envelope	Provides prescriptive requirement U and R value for roofs, opaque wall, vertical fenestrations (U value, SHGC, WWR, VLT, Effective aperture and skylights , and envelope performance factor for trade off criteria.
Section 5	HVAC	Provides prescriptive requirement for natural ventilation, thermal comfort as per NBC 2005, or ASHRAE 55,2004 , Minimum equipment efficiency(COP and IPLV) controls , piping and ductwork insulation R value, economizers.
Section 6	Serviced hot water and pumping	Provides mandatory requirement for solar water heating, equipment efficiency, piping insulation, heat recovery
Section 7	Lighting	Provides mandatory requirement for lighting interior as well as exterior for light controls, sensors, LPD, Space controls, exterior lighting building power.
Section 8	Electrical power	Provides mandatory requirement for transformers, energy efficient motors, power factor correction, Electrical metering and monitoring, power distribution systems.
Appendix B	Whole building performance method (WBP)	Uses energy simulation method to compute EPI by modelling proposed design and standard design and applying EEMs by taking in account Weather data metered energy consumption data, Building configuration and its function ,architectural plans and specifications, Operational Schedules, thermal zones, Energy system mechanical, electrical, Building automation system (BAS) documentation Maintenance logs and Metered energy consumption data.

Table 3 Criteria in ECBC for energy efficiency. *Source: Energy Conservation Building Code User Guide, 2011*

	Less than 50 % area conditioned			More than 50 % area conditioned		
Star Label	Composite EPI	Warm and humid	Hot and Dry	Composite EPI	Warm and humid	Hot and Dry
1 Star	80-70	85-75	75-65	190-165	200-175	180-155
2 Star	70-60	75-65	65-55	165-140	175-150	155-130
3 Star	60-50	65-55	55-45	140-115	150-125	130-105
4 Star	50-40	55-45	45-35	115-90	125-100	105-80
5 Star	Below 40	Below 45	Below 35	Below 90	Below 100	Below 80

Table 4 BEE Star rating Scheme for buildings for office buildings
Source: Scheme for Bee Star Rating for Office Buildings, BEE, 2009

Section 4	Site Plan, Form and design	Provides guidelines for integrated design approach, building orientation , shading, thermal massing, reduced footprint and reduced volume, building form development plan, natural ventilation, optimum day lighting, building service life, LCA (optional).
Section 6	External landscape lighting design	Provides allowable external LPD, facade lighting, external signage lighting.
Section 7	Building envelope optimisation	Provides guidelines for thermal insulation, thermal mass, cavity, surface texture, roof insulation, surface finish, fenestration design shading, day lit zones, simulation and prescriptive and trade off requirements, RE integration in facade.
Section 8	Materials	Provides guidelines for embodied energy, Life cycle cost, environmental concerns and human health, recycled materials, construction waste management.
Section 11	Building services optimisation	Provides guidelines for mechanical ventilation strategies, passive cooling/ heating techniques, low energy mechanical cooling techniques, HVAC System, Electrical system, Lighting, lifts/escalators, Renewable energy and monitoring, power distribution systems.
Section 13	Commissioning, operation, maintenance and Building performance tracking	Provides guidelines for commissioning and handover, O & M, Building performance Tracking (Measurement and Verification, operator skills and training, Control systems and maintenance

Table 5 Criteria in NBC Part 11 for energy efficiency
Source: Part 11 of Draft Addendum no: 1 to NBC 2005 (SP: 2007) Approach to Sustainability

From the above, Section 13.4 on Building Performance Tracking (Measurement and Verification) clearly spells out techniques of building performance assessment subsequent to commissioning and handover stage of building to the owner. Regular Monitoring of the performance shall be carried out which will provide information whether set environmental performance and targets have been met or not. Attributes of building performance tracking (Measurement and Verification) include the following:

a) Monitoring of technical and energy performance after occupancy, to ensure performance targets during operation of building by energy metering for energy consumption pattern of Lighting (Exterior and Interior), AC, domestic water heating, Renewable Energy systems, water pumping, elevator and plug loads separately by using Energy Management and Control systems (EMCS).

b) Conducting occupant survey annually for first three years of building operation to obtain feedback from users for identifying possible areas of improvement and implementing rectifications accordingly (BIS, 2012).

Analysis of Rating Systems

While each of above cited rating systems is a step in the right direction, the target of achieving energy savings in buildings till date remains a small fraction of the overall potential of the building sector. The success of building energy efficiency standards lies in identifying and defining performance criteria for the given climate, building type and technology (Kabre, 2012). The overview of rating systems reveals that most of the rating systems have a thrust on certification of new buildings and are still in the process of formulating detailed guidelines for existing buildings. Following observations are made with respect to the rating systems:

- The LEED India Green Building Rating System, supported by Confederation of Indian Industry (CII), encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally accepted tools and performance criteria for high performance green buildings. Many developers have constructed buildings with LEED India ratings. LEED is well established and internationally accepted and is the most favoured rating system among the private sector whereas GRIHA, national rating system, developed by TERI and adopted by Ministry of New & Renewable Energy (MNRE) to rate commercial, institutional and residential buildings in India, is based on national environmental concerns, regional climatic conditions and indigenous solutions. Similarly, ECBC compliance systems are also geared towards primarily commercial conditioned buildings. One more difference being that the international codes usually take a hypothetical case for comparison of EPI while GRIHA works with an absolute number, which is easily understood.
- LEED India has prescribed monitoring of buildings for 12 months after commissioning of building. Similarly, the framework of NBC Addendum on Sustainability suggests occupant survey and energy audit of at three years duration whereas BEE star rating systems and ECBC compliance certification

systems are applicable to primarily commercial buildings with sole thrust on EPI. GRIHA building also emphasise O & M of building systems and processes, monitoring and recording of consumption, and occupant health and well-being, but not explicitly.

- The emphasis of LEED rating system is on incorporating high-tech systems to save air-conditioning costs whereas GRIHA has focus on passive solar techniques as a means of optimizing indoor visual and thermal comfort. Passive cooling techniques tend to do away with dependency on the air-conditioning in the first place which is a far more appropriate strategy in our country having chronic shortage of power.
- Use of renewable energy utilisation is given 50 % more weight age in GRIHA as compared to LEED whereas certification of materials used from rapidly renewable sources find weight age in LEED as compared to GRIHA. Proposed NBC draft addendum on sustainability has detailed guidelines on renewable energy and renewable material resources whereas BEE star rated programs and ECBC do not deal with this aspect.
- Water conservation has more contextual relevance in India and finds more emphasis in GRIHA as compared to LEED.

Various rating systems still lack detailed guidelines with respect to building performance assessment aspects. GRIHA has favourable policy as it is suited to the Indian context, laws and energy codes and focuses on reducing energy consumption over project cycle including post construction for new buildings, Use of renewable energy and O & M protocol whereas LEED India has come up with guidelines for existing buildings exclusively to reduce energy consumption and operating cost and emphasise occupants health and comfort. NBC draft addendum on sustainability has not been still been incorporated in practice, but once implemented, will be able to address issues in a more holistic manner.

Methods of Building Process Assessment

Various rating systems and codes in India do not define building performance assessment methodology per se. ASHRAE has outlined in Performance Measurement Protocols for Commercial Buildings: Best Practices Guide, a set of working guidelines by providing tools and techniques for measuring, managing and improving performance of energy and indoor environmental quality for existing building commissioning (EBCx) process (ASHRAE, 2012).

The process entails the following stages:

1) Preparation of Building performance Evaluation plan, interacting with management, seeking due permissions, defining scope and extent and understanding operation and maintenance plan and operational schedules.

2) Collection of building data about building plans, specifications, functional processes, conduct of energy audit to find energy consumption by end use, post occupancy occupant surveys, energy conservation programs already in place and their assessment, monitoring of thermal performance of spaces and spot measurements.

3)Analysis of data to find correlation between energy consumption and thermal comfort.

4) Conductance of performance comparison (benchmarking) to self reference and baseline database.

5) Identification of retrofitting measures, corrective actions.

6) Re-measuring of performance and comparison with past performance or calibration of building model with simulation of building performance.

7) Reporting results and preparing database.

Case Study of a University Hostel

This section discusses a case study to illustrate the process of building performance assessment. The Author has examined students' accommodation (Boys' hostel) in university campus of Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonipat (located on NH1 near Delhi) which lies in composite climatic zone. Due to opening of newer universities and capacity enhancement programmes of existing ones, universities offer themselves as potential candidates for building performance assessment on account of their relatively large building footprint and high energy consumption as well as high user occupancy. Universities can act as forerunners in breaking ground by assessing the performance of their own facilities from energy conservation point of view, to achieve the goals outlined in National mission in sustainable habitat as part of National Action Plan for Climate Change (Kumar, 2013). Although a few studies have been undertaken to study energy consumption pattern of hostels in IITs for achieving energy efficiency, these studies do not take into consideration building envelope's thermal performance, occupant comfort and user behaviour.

Methodology for Building Performance Evaluation (BPE)

The building performance evaluation process adopted in the case study integrates thermal performance, feedback from occupants and energy performance to construe a holistic picture of energy usage. This may lead to suitable corrective decisions to reduce energy consumption, enhanced thermal comfort and occupant satisfaction.

The methodology involves the following steps:

1. Study Area Characteristics in terms of building geometry, functions, building envelope and its characteristics, thermal zones, occupancy schedule and climate analysis.
2. Instrumentation to monitor thermal conditions in different thermal zones
3. Field spot measurements in different seasons and thermal zones
4. Occupant surveys in different seasons and thermal zones
5. Energy metering for individual zones and different end uses
6. Building performance modelling, calibration and validation
7. Identifying retrofitting measures and recommendations of various energy conserving measures through whole building performance simulation to calculate projected EPI.
8. Re-measure performance and compare with past performance.

The above methodology was employed for performance evaluation for the chosen hostel building and is summarised here.

1. Study Area Characteristics

Building Envelope

Each hostel is a three storied structure and consists of two blocks, which are symmetrical to each other, housing 138 rooms each. The blocks have geometry of receding walls and are aligned on due N-S axis, thus the fenestrations open towards West or East. There is a large central courtyard which provides access to individual rooms and also acts as a heat sink for the building **(Figure 2)**. The courtyard is also used for informal activities in summer as well as winter. Each room is day lit, cross ventilated and shaded by deep overhangs provided by balconies and wall fins due to receding geometry **(Figure 3)**.

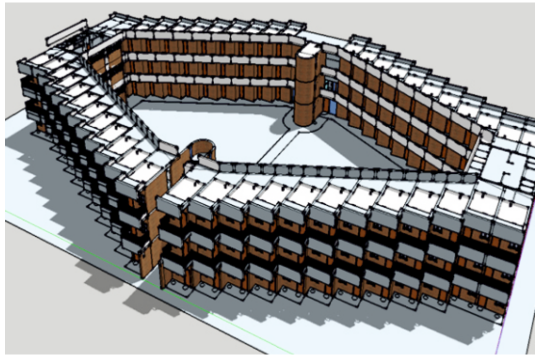

Figure 2 Building geometry of hostels

Figure 3 Views of hostel showing shading pattern

Various parameters of the building envelope related to heat gain are summarised in Table 6. There are 230 mm thick brick walls, plastered on one side. Roofing consists of 150 mm thick Reinforced Concrete slab with 100 mm mud phuska and brick tiles. Internal walls and ceilings are finished in white lime wash, whereas flooring consists of conglomerate IPS flooring in cement concrete. Doors are made with painted wooden frame and ply wood infill and wire mesh shutter. Windows are made with wooden frame and single glazed shutters of 5 mm thick polished plate glass and fly mesh shutters. Windows are shaded by horizontal balcony overhang of 1.37 m and vertical wall of 1.37 m forming a self shading pattern.

Site Climate

Site climate analysis was done by using the software Climate Consultants 5.5 to determine comfort hours during different months in a year. For naturally ventilated buildings, thermal comfort conditions for occupied hours (from 5:00 p.m. to 8:00 a.m.) have been plotted for entire year **(figure 4)**, taking adaptive thermal comfort model of ASHRAE 55-2004 as a basis with 80% occupants' acceptability limits. The results indicate that only 39.1% of total hours are within the comfort zone. Shading analysis of peculiar geometry was done using the Ecotect software to determine percentage of windows shaded in different orientation on different days of year.

2. Instrumentation to Monitor Thermal Conditions

After analysing climatic data of the place in case study, it was observed that data loggers were required to be installed to study real time thermal conditions. Data loggers can be used for various parameters such as Air temperature, Relative humidity, Mean Radiant temperature, Lighting level, Air movement, Air quality, Occupant sensor Data loggers are used to record continuous temp and humidity and lighting conditions.

Data loggers of Onset comp, U.S.A. were used. Data loggers for indoor measurements are generally portable, very small in size (5.8 cm x 7.4 cm x 2.2 cm) and weighing 46 grams.

Data loggers were launched with the help of PC/ Laptop by using Hobo ware software (BHW –PC for windows) through a USB interface cable to provide recordings of temperature, relative humidity, light intensity at programmable time interval of 10 minutes to find out uncomfortable hours throughout the year in different locations and different orientations. Each data logger was labelled and assigned a particular code in case of multiple data loggers. Twelve data logger were procured for taking measurement of four rooms selected randomly on all three floors to help measure effect of different cardinal directions and room location by floor on thermal comfort. Typical output was obtained as shown **(figure 5).**

Parameter	Units	Quantity in one block	No of blocks	Total
No of living rooms	no	138	2	276
Floor Area of each room	Sq.m.	8.15(2.74 x 2.98)	2	2249.81
Plinth Area	Sq.m.	4107.5	2	8215
Building height	M	10.0 (3 floors)		10
Windows orientation	East or West			
Window to wall Area	%	29 %		
Wall U value	Watt/ m2/K	2.175		
Exposed Wall Area	Sq.m.	14864		
Glass U value	Watt/ m2/K	7.1		
Glass SHGC		0.82		
Visible light transmittance		0.76		
Projection	M	1.37 M at roof level with 0.45 M high suspended fin		
Roof U value	Watt/ m2/K	2.807		
Exposed Roof Area	Sq.m.	8215		
Internal finishes		White wash on walls and ceiling,		
Lighting	Watt/ m2	5		
Air changes per hour		1		
Annual electricity consumption	KWH	161694		

Table 6 Envelope characteristics of the study area

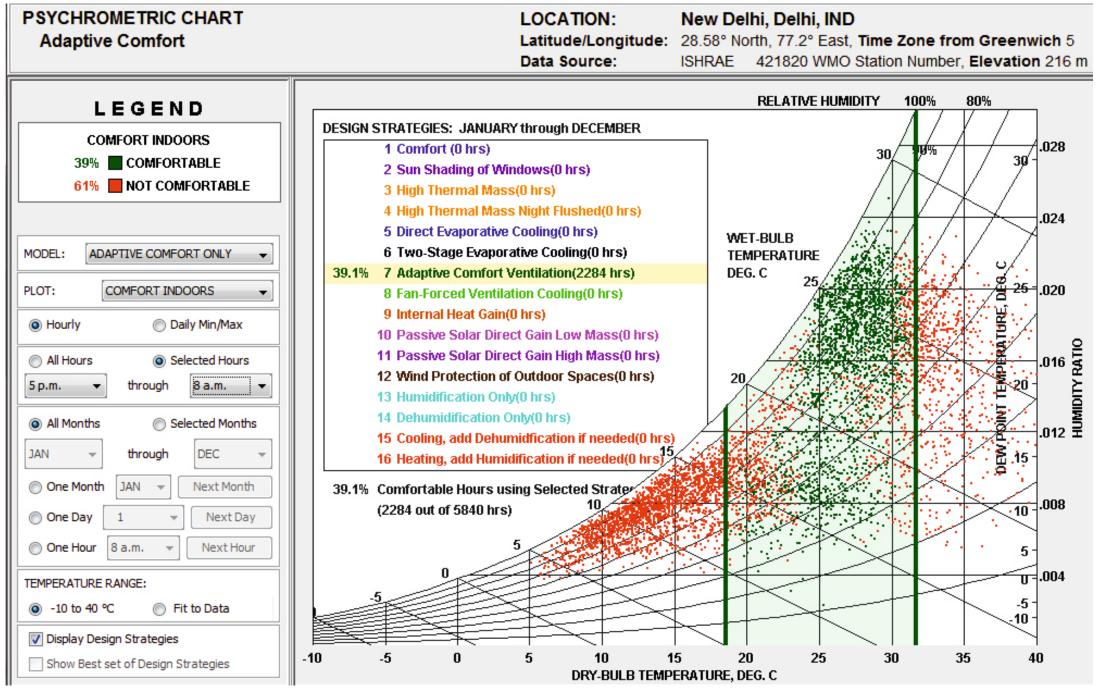

Figure 4: Comfort hours using Adaptive thermal comfort model for occupied hours

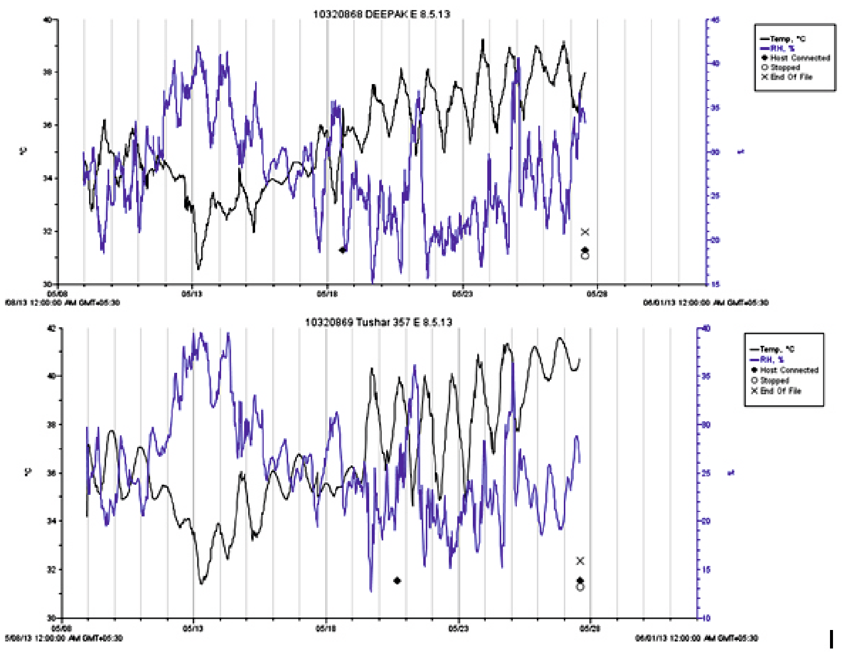

Figure 5: Typical Plot of Temp and Humidity from data loggers (inside)

The output of first part of figure 6 clearly reveals that indoor temperature conditions of room are above 330 C and reaching up to 380 C and RH value ranging from 20 % to 40 %. These values are clearly outside thermal comfort parameters for month of May. Similarly second part of the **Figure 6** shows temperature and RH conditions for hostel room on top floor, clearly revealing temperature difference of 2-30 C and relatively lower percentage of RH by 5 %.This type of plots clearly establish comparative thermal performance of different floors and different orientations.

Similarly outside weather conditions were monitored with 16 channel data loggers for mounted on the rooftop of the University's Centre of Environment and Energy Studies.

3. Field Spot Measurements in Different Seasons and Thermal Zones

Figure 6: Typical Experimental set up using Anemometer, Lux meter, thermo couple for Globe temperature and Data logger for spot measurements.

Spot measurements were obtained to measure the globe temperature and air velocity to find out thermal comfort. These were conducted four times in the year, each time for a week identified as representative of each season and

Figure 7: Anemometer to measure air speed

student occupancy profile **(Figure 6)**. Spot measurements were recorded typically for different rooms in different directions and as well as on different floors for a week continuously at different durations of time to assess thermal comfort conditions. Typical Experimental set up consisted of Anemometer, Lux Meter, Thermo Couple for Globe temperature and Hygrometer **(Figure 7)**. The output of the instrumentation in the form of Air temperature, Globe temperature, Air speed, Relative humidity, Clothing valve, Metabolic

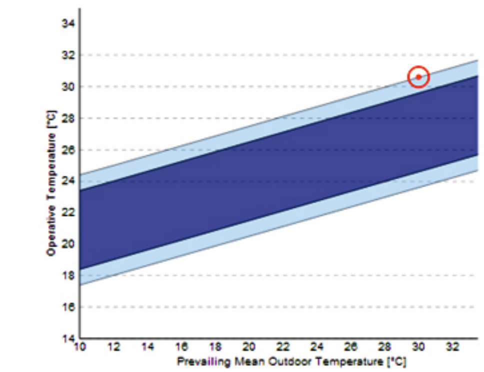

Figure 8: Results of thermal conditions from spot measurement for August month

rate was plotted with help of web based tool (Centre for Built Environment CBE thermal comfort tool) to find indoor thermal comfort conditions and comfort hours using adaptive comfort model **(Figure 8)**.

Month	Mean monthly outdoor temp. °C	Air temp °C	Mean Radiant Temp °C	Relative Humidity %	Air speed m/s	Clothing Value	Metabolic rate	PMV	PPD %	Comfort Compliance As per Adaptive Sensation as per PMV model
May 2013	32.6	31.8	32.9	42	0.3	0.4	1.0	1.23	37	No, Slightly warm
Aug 2013	29.4	30.3	30.2	75	0.3	0.4	1.0	0.79	18	Yes, Slightly warm
Dec 2013	16.8	18.3	17.8	60	0.1	1	1	-1.33	42	No, Slightly cool
Feb 2014	17	16.3	16.2	62	0.1	1	1	-1.83	68	No, Cool

Table 7: Results of thermal comfort conditions for different months using CBE thermal comfort tool for study period

Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
3	2	1	0	-1	-2	-3

Table 8 Thermal comfort measured on Thermal sensation scale as defined in ASHRAE. *Source: ASHRAE 55, 2012*

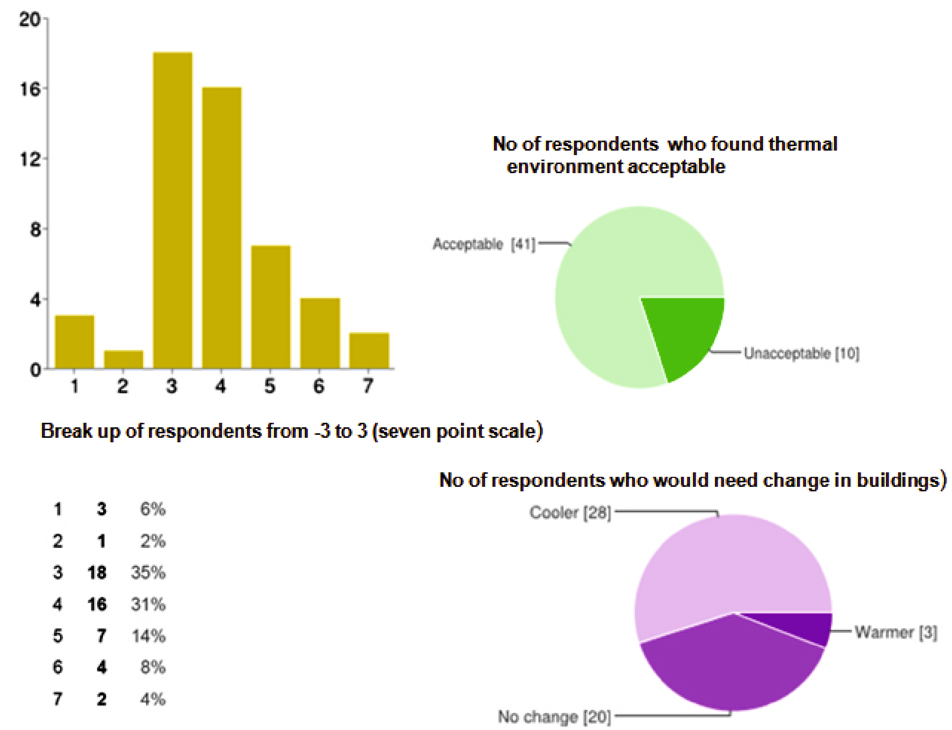

Figure 09: Results of occupant surveys for August month

Results of thermal comfort conditions for study period in different months using CBE thermal comfort tool are summarised in **Table 7**. Spot measurements were carried 5-6 times a day for a week identified as representative of each season and student occupancy profile. Results clearly indicate that thermal conditions are not comfortable except for the month of August.

4. Occupant Surveys

Post occupancy evaluation survey was conducted using a questionnaire while doing the spot measurements. This was to assess occupants' thermal conditions, assess energy leaks and typical user's behaviour and thermal sensation votes as per ASHRAE scale shown as 7 point scale ranging from hot to cold **(Table 8).**

Sampling

Proportional stratified random sampling method was used for a total population of 1104 and target population of 138.The selection of the sample was based on variables, namely orientation and floor wise stay of residents. The sample comprises 44 residents for Winter season and 63 residents for Spring (May) seasons. 52 residents for Summer (August) season and 46 for Fall (December) season.

The survey was conducted through online as well as offline questionnaire and included information on background of the occupant, thermal comfort vote, thermal comfort sensation vote as per ASHRAE- 55 adaptive comfort guide, occupancy schedule, clothing pattern, metabolic activity, occupants adaptive controls energy related behaviour etc.

Survey Results

Analysis of questionnaire reveals that in the month of August, 80% subjects (occupants) are comfortable within range of -1 to 1 at thermal sensation scale. 80% of occupants have found thermal environment acceptable, but 55% wanted the indoors to be cooler **(figure 9)**. Similarly for month of May (Summer month), 50 % subjects (occupants) are found to be comfortable within range of -1 to +1 at thermal sensation scale, whereas 59 % of occupants have found thermal environment unacceptable and 79% wanted the indoors to be cooler.

For winter season, the occupant survey results were found contrary to thermal comfort analysis using spot measurements. For month of December, 81 % subjects (occupants) are found to be comfortable within range of -1 to +1 at thermal sensation scale, whereas 85 % of occupants have found thermal environment acceptable and 43% wanted the indoors to be relatively warmer. Similarly for month of February, 84% subjects (occupants) are found to be comfortable within range of -1 to +1 at thermal sensation scale, whereas 93 % of occupants have found thermal environment acceptable and 36% wanted the indoors to be cooler.

Results from occupant surveys reveal that thermal comfort levels as defined in ASHRAE adaptive model cannot be taken at the face value as subjects were found to be comfortable. Several other factors such as acclimatisation of occupants, climatic zone, cultural context, age and occupation, flexibility in clothing and metabolic activities in hostel buildings, adaptive controls to use fans, operate windows, terraces etc can also contribute towards spatial conditions to be more acceptable in terms of thermal comfort. Results from Occupant surveys indicate realistically the performance of building and can be used to harness passive solar design strategies for achieving comfortable low energy buildings rather than using mechanical ventilation methods.

5. Energy Metering for Individual Zones and Different End Uses

Figure 10: Electric metering to determine end use and total energy consumption at room level

Energy metering by end use was carried out by providing for separate electricity meters for lighting and plug loads for each group of six rooms at a common distribution board point and readings were taken for the entire year as shown **(figure10).** This is one of the important metrics which helped in calibrating existing building simulation model. In addition, electric utility bills were collected for past three years and analysed to understand energy consumption patterns over different months. Results from metering of 24 rooms (out of 132 rooms) yield information regarding total energy consumed per room and also break up of energy by end use. Energy consumed in the rooms was calculated to be having Energy Performance Index (EPI) of 28 Kwh per sq.m.

6.Building Performance Modelling, Calibration and Validation

Data thus collated was used to generate a model of the existing building for simulation of its performance as illustrated **(figure 11)**. In case of existing buildings, 'as is' model reflecting real time performance taking in to account occupants profile, thermal zones and energy consumption is created. This process is known as calibration of model. Such a

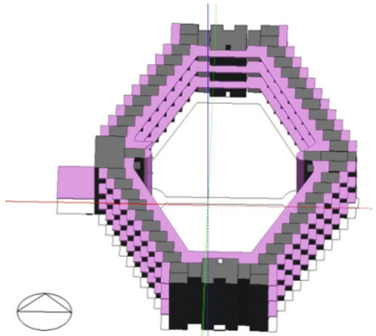

Figure 11: Model of hostel in design builder software

calibrated model can be simulated in building performance software such as Design Builder, eQuest, Energy Plus, IES or Econirman Building. Various input parameters of the case study are modelled in design builder software. Energy consumed in calibrated model reflected an EPI of 29.51 Kwh/sqm with lighting 5.35 Kwh/sqm, fans 15.03 Kwh/sqm, plug loads 9.13 Kwh/sqm. This is in very close proximity to the actual EPI of the building. Other important parameters related to thermal comfort are as shown in **figure 12.** This shows total number of discomfort hours as 4303.6 or 64% of the total occupied hours which is again in line with ASHRAE 55-2004, but do not match with comfort levels expressed by occupants in occupants survey.

7. Identifying Retrofitting Measures and Recommendations

Effect of various possible energy efficiency measures can be studied in the simulated

model. Different energy conserving measures (ECM) can be applied to assess effects of each parameter. Various combinations of various ECMs can be studied to arrive at optimised solution by studying subsequent effect of each ECM with respect to its efficacy as well as cost

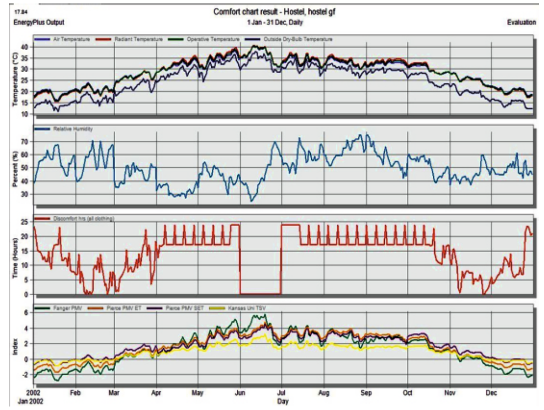

Figure 12: Comfort conditions output in simulated model

evolved. By trials of parametric analysis of different ECMs, one can reduce EPI (Energy Performance Index) of the building and at the same time bring it within ASHRAE adaptive thermal comfort standards.

Different ECMs such as improved roof insulation, wall insulation, WWR, glass design, shading devices, efficient lighting and fans, lighting controls, automation in window operations can enhance thermal comfort. Also the results can be used as a database for comparing effects of various design strategies such as orientation, geometry of building, building envelope characteristics, sustainable materials, shading devices etc. to assess comfort levels and energy consumed in buildings for extensions in existing buildings as well as new projects. Building performance evaluation of existing buildings in a particular geographical locality can be used to set or compare benchmarks for energy performance index in different locations.

8. Re-measure performance and compare with past performance

There is a need to reassess the actual performance of building continuously throughout the life span of building or project cycle of building for understanding effect of retrofitting measures applied to the building. Regular conduct of occupant surveys also plays a key role to assess occupants' thermal comfort conditions and satisfaction level. Measuring, metering and monitoring are three key principles to keep track of building performance and ensuring continuous performance level of building up to desired level otherwise building performance may decline due to aging or improper operation and maintenance.

Conclusion

In the field, there is a dearth of quantified data on thermal performance, occupant comfort and satisfaction level in relation to energy consumption even for newly designed or existing energy efficient green buildings. There is a great potential to save energy by assessment of building performance of existing stock of buildings by taking into account their energy consumption pattern by end use, conducting energy audits and carrying out field measurements of thermal comfort conditions and conducting occupant surveys during different seasons in naturally ventilated building in composite climate. There is a need to streamline discipline of building performance assessment objectively by monitoring, metering and measuring after the building is commissioned and handed over to owners. Database thus obtained can be used to benchmark its performance, develop baseline data for such typology of buildings in different climatic, cultural and location context. Further, there is also a need to suggest a framework to integrate thermal performance, energy performance and feedback from occupant's surveys to construe holistic picture of performance evaluation of building in order to help take suitable corrective decisions to reduce energy consumption and enhanced thermal comfort and occupant satisfaction. Thus building performance assessment of existing buildings can not only lead to reduce energy consumption significantly, but also reduce operating cost and reduce carbon foot print as well – a step towards a goal of sustainability. ■

Acknowledgments

This research paper is based on research being conducted by the author as part of PhD under supervision of Prof. (Dr.) Jyoti Pandey Sharma at Department of Architecture, Deenbandhu Chhotu Ram University of Science & Technology, Murthal. The author thankfully acknowledges the support of the University management in granting facilities as well as permissions to conduct experimental set up in students' accommodations of the university. The author is thankful to Sh. Anurag Bajpai, Dr. Jyotirmay Mathur, Sh. Pardeep Kumar and Dr. Vishal Garg for helpful discussions.

References

ASHRAE. (2012). *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide.* Retrieved February 21,2014, from www.ashrae.org

Brown, Z.B. (2009). *Occupant comfort and engagement in green buildings: Examining the effects of knowledge, feedback and workplace culture,* PhD thesis. Retrieved May 6, 2014, from pics.uvic.ca/sites/default/files/uploads/.../brown_thesis_2009

CIBSE, (1991). *CIBSE Application Manual AM5:1991. Energy Audits and Surveys,* London: The Chartered Institution of Building Services Engineers.

CII Report. (2009). *Energy Efficiency in Building Design and Construction.* Retrieved May 31, 2014 from imcosm-india.com/.../5%20Energy%20Efficiency%20In%20Building%...

Department of Energy Building Tools. (2009). *Tools Directory.* New Delhi. Retrieved May 22,2014 from http://www.eere.energy.gov/ buildings /tools _directory/ 2009.

ECBC. (2009). *Energy Conservation Building Code User Guide.* New Delhi: Bureau of Energy Efficiency.

Bureau of Indian Standards. (2012). *Preliminary Draft Amendment No 1 to National Building Code of India 2005(SP:2007).*

Greensfelder, E. (2010). *Building Performance Tracking in Large Commercial Buildings: Tools and Strategies.* California: California Energy Commission

Hopfe, C.J., (2009). Uncertainty and Sensitivity Analysis in Building Performance Simulation for Decision Support and Design Optimization. Duitsland. Retrieved April,12, 2014 from alexandria.tue.nl/extra2/200911580.pdf

Hui, C. M. (1996). *Energy Performance of Air-conditioned Buildings in Hong Kong.* PhD Thesis. City University of Hong Kong, Retrieved April 22,2014 from web.hku.hk/~cmhui/thesis/cGEp2.pdf

IGBC. (2013). *Building Environmental Assessment Method.* Retrieved April 22,2014 from www.igbc.ie/c5/download/Reports/2013_IGBC_BEAM_Full_report.pdf

IPCC Fourth Assessment Report. (2013). *Residential and commercial buildings, Climate Change 2007.* Cambridge University Press. Retrieved April 28,2014 from www.ipcc.ch/.../publications_ipcc_fourth_assessment_report_wg3_repor...

Join, C. (2014). Efficient Roofs for Efficient Buildings?: Building Blocks for Energy Efficient Cities in India. Retrieved April 28,2014 from sustainablecitiescollective.com/.../efficient-roofs-efficient-buildings-build...

Kabre, C.(Ed.).(2012). Building Energy Efficiency Standards in India. National conference on Energy efficient design of buildings and cities. Murthal: DCR University.

Kumar, P. (2013). Monitoring thermal performance of Students' accommodation in university campuses for energy efficiency. National Conference in Advancements in Sustainable Practices and Innovations Renewable Energy ASPIRE-2013. Bhatinda: Giani Zail Singh –PTU Campus.

Mathur, A. (2011). United Nation Development Program /Global Environmental Facility Project Document : Energy Efficiency Improvements In Buildings,
Retrieved April 28,2014 from www.undp.org/.../india/.../energy_efficiency_improvements_in_commer...

Olsen, E. & Iversen, M. (2006). Overview of simulation: presentation for engineers. International Building Performance Simulation Association - USA .Simbuild 2006. MIT Cambridge. Retrieved April 19,2014 from www.ibpsa.us/publications.shtml

Seth, S. (2011), BEE Star Rating for Buildings- an initiative to promote energy efficiency in buildings. *Renewable energy, Akshay Urja*, April 2011. Retrieved February 12, 2014 from www.mnre.gov.in/...2011/.../BEE%20Star%20rating%20for%20building

Ziai, N.(2006). Measuring Building Performance Energy Efficiency Software Tools, Retrieved April 6,2014 from extension.ucdavis.edu/unit/greenbuilding.../measure_bldg_perf.pdf