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Original Article

Energy Performance Evaluation of Detached Residential buildings in a Tier II city in India

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Abstract *- The disproportionate energy use worldwide is causative to a multitude of environmental issues. Electrical energy use in the large footprint of the domestic sector in India needs curtailment. Accordingly, this study analyses the electric energy use of existing plotted residential buildings constructed between 1950-2000 through energy assessment guidelines for categorizing energy performance efficiency. Ten cases of detached plotted residences in a Tier-II city are assessed for energy efficiency based on Eco Niwas Samhita Part-I (ENS Part I) and universal Energy Performance Index (EPI) for annual electrical energy normalized with the area as per the Bureau of Energy Efficiency (BEE) and Green Rating for Integrated Habitat Assessment (GRIHA). An energy audit is conducted for these plotted residential buildings for developing an energy management framework and for shortlisting these buildings for energy-efficient retrofit.*

Keywords — *Building Envelope, Energy efficiency, Energy Performance Index (EPI), Residential buildings, Thermophysical properties.*

I. INTRODUCTION

Buildings need energy for operation and management and for providing thermal and optical comfort to the occupants. The energy performance of buildings can be evaluated at predesign phase and after occupancy with the guidelines and norms developed worldwide and are exclusive to contextual regions and typology. Environmental and economic issues are driving forces for research on reducing energy consumption linked with greenhouse gas emissions in various sectors. Energy efficiency should be the “first fuel”, as stated by Daniel Yergin, and other fuels like coal, natural gas, nuclear and renewables should be ranked after this important new fuel. This statement implies that energy efficiency is the cheapest and most productive method to meet output targets as it focuses on using less to achieve the same results [1]. The expression that can represent energy efficiency is:

Energy Efficiency= Energy Output/Energy Input

This expression indicates that better utilization of energy with minimal energy input will reduce the demand and increase efficiency. The advantage of energy efficiency in buildings is expected to deliver the highest energy reductions most economically. The study on global electricity by McKinsey concluded that the reduction in energy demand without any expenditure is expected to reduce the growth of projected demand to nearly half of the estimates [2]. The International Panel on Climate Change reports that man-made changes in global temperatures will be aggravated, and there is a need to address carbon emissions from cooling and heating buildings [3]. The results of breakthrough research predict that future increases in average global temperatures will put greater pressure on the cooling industry, and this necessitates more efficient systems to reduce greenhouse gas emissions. Besides efficient and environment-friendly cooling systems, energy-efficient building designs can substantially reduce the CO_2 emissions from building energy use at no additional cost by only incorporating the principles of cheapest and most effective fuel is energy efficiency.

II. ENERGY EFFICIENCY IN THE INDIAN CONTEXT

Energy production in India is still ruled by conventional sources such as coal and water-based thermal power plants, with coal constituting 71.87 per cent of the total energy manufacture Central Electricity Authority,2020[4]. Presently India is importing more than 80% of the countries coal for fuel needs because of meagre indigenous reserves, and in the future, energy security may be a major problem at hand. Hence, it is important to take functional actions to reduce energy consumption. With a growing population, the need to fulfil housing demand and to increase access to energy services is critical for good quality of life. The energy services are conducive for fulfilling the basic needs of liveability, such as clean water, transportation, healthcare, sanitation, and communication. Besides economic gains, the efficiency in electricity consumption brings a multitude of environmental advantages like reduction in Greenhouse gas (GHG) emissions by the reduction in emissions from fossil fuel by curtailment in electricity generation.

Fig. 1 Sectoral GHG emissions in India in 2010 and 2030. (Source: McKinsey and World resource Institute)

GHG emissions by electricity production in India were the highest for 2010 as per Fig.1.[5],[6]. When compared to other sectors. Electricity generation and consumption will continue to be number one in GHG emissions through 2030 as per projections statistics. The integration of renewables with energy efficiency will be necessitous to achieving global climate targets [7]. Energy efficiency goals across different sectors further emphasize the significance of building energy efficiency with policies including the Energy Conservation Building Code (ECBC) as per Government of India, 2009 and are crucial for Indian carbon generation reduction [8].

A. Residential Sector Energy Scenario

Residential buildings in India are broadly bifurcated into single or two-family and multiple-family dwelling type units, as shown in Fig.2,[9]. The single- or two-family dwellings may be in the form of row type, semidetached type, or detached from the neighbouring buildings relative to plot size, in consonance with codes and building bye-laws. Such dwellings have independent access used by members of a single-family or two-family setup in plotted development with infrastructure amenities. Detached buildings have space between them and the roofs and walls of the neighbouring buildings on all sides, while semi-detached is separated from the neighbouring building on three sides with open space and attached on one side. Row-type residences have common walls with two adjacent neighbours and have open spaces on two sides, generally front and back. The plotted residential buildings are low rise below 15m height and less number in a particular colony makes them a low-density configuration as well [10].

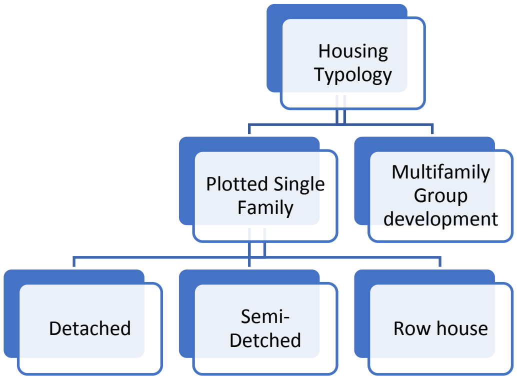

Fig.2 Typology of residential buildings as per Eco-Niwas Samhita-Part I

The occupants of such residences use Mixed Mode ventilation (MM), a combination of natural ventilation and air-conditioning in combined mode used as per thermal comfort requirements by the occupants. In India, maximum residences have individual air conditioner systems, i.e., window air conditioners or split air conditioners, as opposed to central heating or cooling systems used in developed nations. Further, the occupants exercise the right of choice of clothing suitable for the climatic condition to achieve thermal comfort [11]. Electric Energy is generated from fossil fuels, coal, gas, oil, etc. and is consumed in large percentages by households in India. Electricity requirements in residential buildings can be bifurcated into appliances for space conditioning and lighting. In Indian, nearly 80 kWh/m2/ year is used for thermal conditioning and illumination [12].

A majority of building designs do not begin with climate and thermal comfort as the main criteria leading to recurring expenditure of energy to improve the comfort levels in the building [13]. A good combination of the aesthetic and functional design of buildings are no longer factors that make a building acceptable, but the environmentally responsive design has become the third pillar of good design in present times. Whether a building provides thermal comfort or not depends on the heat flux through building envelopes surfaces exposed to the climate. Energy-efficient collaboration in building designs sustains comfortable environmental conditions for human habitation despite the fact it also curtails the cost of energy.

Energy optimization in residential buildings has become a major field of research in the past few decades, with literature published on a variety of aspects of building for quantitative and qualitative scrutinization for efficient management of energy. India is a nation of the developing world, and development in all spheres, including infrastructure and economic growth, is visible. Thus, robust policies, norms, and strategies are required for achieving energy-efficient and sustainable development. The Central Electricity Authority Report illustrates that electric energy use in residential buildings has increased from 75629 GWh (2000-01) to 296219 GWh (2018-19),[14]. About 80% of the total electric energy used in India is generated from coal, oil, and solid biomass, which has increased 50%since 2000[15]. This excessive increase in the use of electricity in the residential sector is attributed to:

1. The Energy Information Administration (EIA) report (2017) documents projections of a higher growth rate in India's commercial sector. Still, the residential sector, which represents more than 70% of the built environment, will remain the highest energy consumer [16]. The key rationale for excessive energy utilization is attributed to the large footprint of residential buildings.
2. The increase in electricity use is also due to an enhancement in demand with a larger number of households connected to electricity supply because of the widespread electrifying mission undertaken since 2012 by the Government of India.
3. In a typical Indian residence, the bifurcation of the total electricity consumed is nearly 28% for lighting, 45% for space conditioning, 13 % for refrigeration, 4% for televisions, and 10% for other appliances in the urban sector [12]. Space conditioning constituting the largest electricity consumption as the main target for energy optimization will account for large savings.
4. With an average annual growth of 3.2% per capita for a household’s disposable income, the increase in the use of electricity consuming appliances and equipment, mainly air conditioners are projected to amplify the energy share of residences from 46% (2015) to 68% (2040), [17].
5. Thermal comfort provider cooling systems are key drivers for increasing electricity requirements in households in India, given ownership of air conditioners has increased by 50% in the last five years [18].
6. The cooling systems increased usage also indicates a lack of satisfaction with the existing temperature and humidity parameters inside the residences.

Thus, the large footprint, wealthy lifestyle, and lack of thermal comfort are the rationale for the outsized share of energy utilization in residential buildings in India. The India Cooling Action Plan (ICAP), as a result, was set up in 2019, formulated by the Bureau of Energy Efficiency’s (BEE’s), as an endeavour for diminution of cooling demand in various sectors by 20% to 25% and cooling energy needs by 25% to 40% by 2037-38. The ICAP implementation necessitates action to cut down energy demand in conformity with the country’s development. Energy conservation and optimization in the Residential sector are required to curtail energy demand and consequent waste generation [19]. Also, restrain is required for unabated use of non–renewable resources such as coal, as a major share of electric energy supplied to residences is from the thermal power plants. Hence the residential sector needs more attention and policy frameworks for energy efficiency if we have to meet the goal of reducing its CO_2 emissions 33‑35% from the 2005 benchmark by 2030 as committed in the Paris Agreement [20].

III. RESEARCH METHODOLOGY

The methodology adopted for the present research is a case study and data collection by field survey. This study will be useful for categorizing existing plotted residential buildings as per energy efficiency guidelines and Star ratings for certifications in India. Investigating energy efficiency is necessary, be it for a new building or an existing one, as it will not only help in developing frameworks for future energy savings but also guarantee a more comfortable living environment during extreme climatic conditions. Case studies were taken from residential plotted development of detached houses in Jammu, a Tier-II city. The following methodology was adopted:

1. Data collection of annual electricity bills, built-up area, building plan by measurements, building specification, occupancy, and the number of air conditioners used for cooling from plotted Residential buildings for an energy audit.
2. Survey of Occupants' opinion about thermal comfort inside their residences.
3. Assessment of energy performance of residential buildings with ENS Part1 guidelines, BEE and GRIHA.
4. Evaluation of the results of the energy performance assessments in correlation to the occupant’s opinion for thermal comfort condition for a decisive categorization of existing residential buildings as energy-efficient or energy guzzlers for shortlisting existing residences for energy-efficient retrofit.

IV. IDENTIFICATION OF CITY AS CASE STUDY

Jammu city is the winter capital of the union territory of Jammu and Kashmir. This city was selected as it has a large percentage of low-rise plotted residential buildings (Jammu and Kashmir, Housing board Jammu). It is shown under the Cold climatic zone as per National Building Code, but the Jammu region has a climate akin to the composite climate that does not have any season for more than six months.[10] The composite climate of Jammu city is most challenging as some part of the year is hot and humid, some cold and cloudy, some hot and dry, and cold and sunny. It is a zone that experiences more than one season for the entire year and is the most prevalent type of climatic zone in India. The selection of the case study city is for the following reasons:

1. Jammu city is the most populous city with an area of 25% and 50% of the population of the Union Territory and a consequent larger proportion of housing [21]. For sustainable growth, the residential buildings in Jammu need to conserve energy.
2. According to the State Energy Efficiency Index, 2019, this city comes under the aspirant category for energy-saving policies and practices in all sectors [22]. It is a matter of concern that there has been no focused effort for planning and designing of building for energy efficiency in this region, but its neighbouring states and Union territories like

Punjab, Haryana, etc., are doing a commendable job in the field of energy efficiency.

3. The Energy Conservation Act, 2001, enacted by the Govt of India, did not apply to the then state of Jammu and Kashmir. As a result, there has been negligible progress towards energy efficiency in all sectors [23].

4. Jammu city has been subject to immigration since Independence, and again there was a mass migration in 1990, due to unrest in Kashmir valley suddenly increased the need for housing and erratic unplanned development.

5. The expansion of the city is taking place at a fast pace as demand for housing is ever increasing. The residential sector was nearly 70% of the building industry in 1999, 31% for the existing land use survey and 47% for proposed net land use for 2032[21]. In the purview of reverse migration present trend with younger generation preferring to move back to the smaller cities that is Tier II and Tier III cities, Jammu has a great prospect of growth. So, both new and existing residential buildings need to be energy efficient for meeting national energy efficiency goals.

6. There is an acute power crisis in the state of Jammu and Kashmir with long periods of power cuts during extreme summer and winter months. These power cuts are leading to loss of productivity and adverse effect on the health of the occupants. There have often been reports of public outrage in Jammu city over power cuts. The power shortage in summer, monsoons, and winter months and long hours of load shedding from approx. 3 to 6 hours, either intermittent or sometimes at a stretch in has given rise to community running of diesel generators adding to air and noise pollution. Thus, affecting the environment adversely.

7.No detailed typology wise energy audit of electricity usage in buildings, both commercial and residential, has been conducted so far in the union territory of Jammu and Kashmir. So, there is a need to understand the quantity and pattern of energy use and consequently categorize the level of energy performance and evolve energy management policy and intervention accordingly.

TABLE I
ELECTRICITY UNITS BILLED DETAILS FOR 1500 HOUSES

Month 2016	**Units Pumped***	**Units Billed***
April	7.35	4.86
May	13.23	7.69
June	13.23	8.26
July	14.70	9.34
August	13.23	8.26
September	13.23	7.64
October	7.95	4.45
November	6.48	3.91
December	7.98	4.85

*** Lakh unit's kWh (Source: Power Development Authority, Jammu)**

8. In Jammu city, especially during summers and monsoons, there is an increase of nearly 40% of electricity consumption from the rest of the year level, as per data collected in one of the residential colonies of Jammu city in the recent years. This shows a lot of electric energy goes into achieving thermal comfort. The electricity usage variations are shown in Table. I.

The houses selected for case studies were from the oldest planned colonies of Jammu city and more than 20 years old, built between 1956-2000 because of the following reasons:

1. This is the period between the contemporary planned plotted residential development initiation and the energy efficiency norms and guidelines formulation in India by the Energy Conservation Act 2001. The evolution of standards for assessing and improving the energy-efficient performance of buildings by guidelines and certification benchmarks was emphasized after the landmark year in India.

2. Most of the building components have a service expectancy from 20 to 50 after the building is constructed [24]. It was found while researching through the study of various authors that the building envelope is the first one to show signs of degeneration.

3. The selected houses either need repairs or the owners are planning a renovation shortly, especially for the building envelope and overall design changes for increasing space or were not satisfied with the thermal comfort or high electricity bills was a cause of concern.

The aim is to assess buildings' electrical energy efficiency and thermal comfort experienced by occupants through field-survey. The house owners and occupants were contacted based on purposive sampling. Several house owners were contacted for permission for the field survey, house detail, interview, and electricity bills. The response was not very positive as most of them claimed they did not have their electricity bill or were not willing to share. Also, with the pandemic situation, the process of case study and field survey was hampered, and the progress was very slow. The residences were visited, and the occupant's opinions about their areas of concern for thermal comfort was gathered, the houses were measured, and plans were drafted for each of the case studies. The building material details and occupancy was noted, and practices adopted to stay comfortable by occupants were also tabulated.

V. RESIDENTIAL ENERGY ASSESSMENT SYSTEMS IN INDIA

The energy assessment was carried out for the case study residences for evaluation to suitably rate the plotted residential buildings as energy-efficient or inefficient. BEE is a star rating for energy efficiency certification, GRIHA assessment is for energy efficiency under the umbrella of green building rating, and ENS Part 1is for building envelope assessment for energy efficiency. Both Star rating and green building compliance need EPI rating for benchmarking. Building energy efficiency is expressed as a universally accepted index of the EPI and is a benchmarking technique used for rating buildings' energy performance. EPI is calculated as:

$$EPI = \text{annual energy consumption in kWh}/\text{total built} - \text{up area (excluding unconditioned basements)}$$

A. Bureau of Energy Efficiency: The energy efficiency certification system of buildings by BEE is based on a star rating system from 1 to 5 stars, and a greater number of stars means higher energy efficiency of the building. This star rating is based on EPI. The star rating varies as per climate and typology of building and for composite climate is as below;

TABLE II.
STAR RATING AS PER BEE FOR COMPOSITE CLIMATE FOR RESIDENTIAL BUILDINGS

Star Rating Composite	EPI-kWh/m2/year
1-star	$52 < EPI \leq 60$
2-star	$45 < EPI \leq 52$
3-star	$37 < EPI \leq 45$
4-star	$29 < EPI \leq 37$
5-star	$EPI \leq 29$

Source: Bureau of Energy Efficiency, India

However, BEE also segregates the EPI calculations for residential as per conditioned (25% area) as E1 24 ° C as set point and non-conditioned spaces as E2 (75% area) with natural ventilation also at a specified set point suitable for the five different climatic zones of India. The E1and E2 are not taken for this study because the electricity bills collected for a preliminary energy audit for plotted residential buildings do not provide segregated quantification for electricity used for airconditioned areas and non-airconditioned areas. Hence, EPI energy per unit area for the entire house is done for parity between energy rating and green building compliance [25].

***B. GRIHA*:** This is a green building rating system developed by The Energy and Resources Institute (TERI). The absolute energy efficiency constitutes 20 % of the entire rating system with other criteria for compliance, which are sustainable site and planning, solid waste management, health and well-being, materials, and resources. The EPI for compliance of residential building for energy efficiency segment for composite climate by GRIHA is benchmarked at 70 kWh/m2/year [26].

***C. ENS Part 1*:** Eco Niwas Samhita 2018 (Part-I: Building Envelope) was launched in 2018 as a minimum standard for residential building envelope performance for optimizing heat gains in cooling dominated climate zone and heat loss for heating-dominated climate zones. The standards are quantified by the window wall ratio (WWR), window to floor ratio (WFRop) for optimal natural ventilation, and visible light transmittance (VLT) for adequate daylighting and Residential Envelope Transmittance Value (RETV). The RETV calculations are for assessing the thermophysical properties of the entire building envelope for different climatic zones and are calculated by the following equation:[27]

$$RETV_{formula} = \frac{1}{A_{envelope}} \times \left[\left\{ a \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\} + \left\{ b \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\} + \left\{ c \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\} \right]$$

When the thermophysical properties of buildings structure are climate-appropriate, then the buildings will be thermally comfortable for the occupants with less electric energy use requirement for comfort conditioning; hence energy efficiency in such buildings is achieved [9].

An energy audit is conducted by benchmarking techniques such as EPI, the thermophysical performance of building envelope for understanding and analysing various parameters of buildings that impact building energy use. The assessment will aid in the decision for energy-efficient retrofit and shortlisting elements that can be retrofitted suitably. The intention was to collect at least the last three years' data, but not many people were willing to share or did not keep a record of this data. So, the present energy audit is conducted by collecting historical energy data in the form of electricity bills for one year. There is non-availability of sufficient survey data in the public domain pertaining to electricity usage by buildings in the union territory of Jammu & Kashmir currently. The present research is conducted for auditing 10 samples of detached plotted residential buildings for quantifying the use of electric energy and for understanding the need for energy-efficient retrofit if the Energy Performance Index and building envelope (ENS Part 1) shows the energy performance of the buildings as inefficient.

VI. CASE STUDY DETAILS

The data collected by a field survey of the case study detached plotted residences are as follows:

A. General Building Configuration: The plotted residential buildings are made of kiln burnt clay bricks with cement and are one to two floors in height. The majority of residences are either ground floor structures with the room, toilet on the porch, or ground and rooms with a part terrace on the first floor itself**.** The overall condition of the residences is good and is well maintained, with some buildings requiring maintenance in some parts of their facade. The external wall thickness varies from 230 mm thick to 330 mm thick with internal plaster but with or without external plasters, depending on the year of construction and occupants' preference.

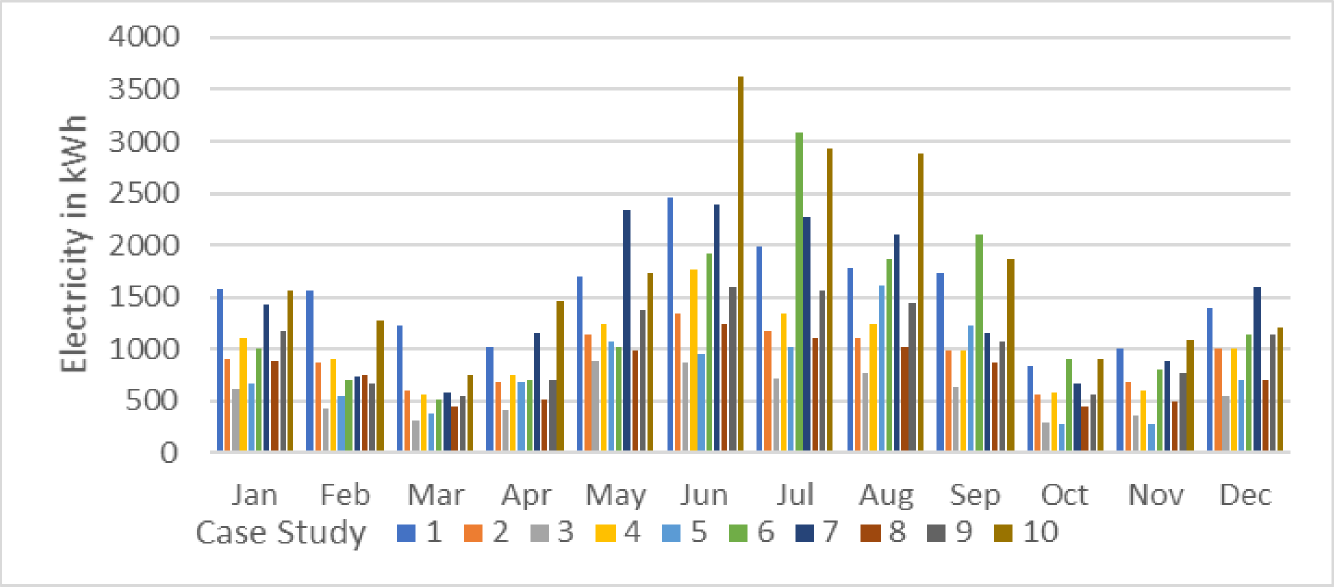

Fig.3 Monthly electric energy used in one year in the 10 Case Study, Detached Residences (Source: Author)

The residences constructed before the 1980s have a 330mm external wall, and ones after the 1980s have a 230mm thick wall as per the case study residences. The internal walls of the residences are 230mm thick and plaster on both sides. The roof has 6mm plaster inside with 120 mm RCC, then 100mm mud phuska and finally 75mm brick tile. All the residences of the case study had single glass windows of 6mm with wooden frames, a 10mm iron grill, and a wire mesh wooden frame inside. The single glass clear windows have high light transmittance VLT=0.76 and also large heat transmittance.

B. Occupants' perceptions and practices for thermal comfort: The occupants are extremely uncomfortable with the fan in the summer inside the house as the temperatures soar above 40°C outside during these seasons. The occupants experience discomfort during monsoon as well, with temperatures reaching 38°C and humidity above 70 %. They resort to the use of air-conditioners for thermal comfort in the rooms that are occupied for most of the time in the day and night and during summers and monsoon. The occupants prefer to stay in conditioned areas and feel their movement within the house is restricted because of the heat inside the house. They usually operate the air conditioners varying from 18°C- 22°C. According to the occupants, they reduce the temperature of air conditioners when it becomes very hot because they feel the appliance seems to be ineffective in increasing the comfort level inside the room. During winters from November mid or so, it becomes very cold, so the occupants use heaters, radiators, air conditioners as heat pumps in the rooms, and this continues till the end of February. The frequent power cuts cause extreme discomfort, though they have inverters to run fans. Overall, the occupants They are not very satisfied with the thermal conditions of their residence.

VII. EVALUATION FOR STAR RATING AND GRIHA

The data of electricity use for the 10 detached houses are presented in the form of a graph in Figure 3. The annual data of each of the case studies are shown in different colours, and the highest energy use is observed in the summer temperatures above 40°C and monsoon months when the temperatures are more than 38°C and humidity more than 60% in all the case studies.

TABLE IV. EPI ANALYSIS TABLE FOR CASE STUDIES

	Area m^2	Annual electric energy kWh	No. of Per#	Energy per capita	EPI*	Star Rating
I	360	18254	7	2608	50	2
II	300	11018	5	3672	36	4
III	238	6796	2	3398	28	5
IV	212	12081	3	3020	57	1
V	238	9372	3	3124	39	3
VI	435	15776	5	3115	36	4
VII	391	17310	5	3462	44	3
VII	345	8551	3	2850	25	5
IX	312	12631	5	3157	40	3
X	408	21279	8	2360	52	1

(Source: Author)

During the winter months of December, January and February, there is an increase in electricity usage but marginal. The maximum electricity is used in Case Study 10 from June to August, and the least energy is used in Case study 5 every month as well as annually. The data collected from the case study residences was first evaluated by the benchmarking point-based Star rating of BEE and GRIHA for composite climate, as shown in Table IV.

A. Analysis

The EPI of 10 case study residences is below 70 kWh/m2/year, and it makes all the cases complaint about GRIHA, green building certification. As per Table IV, all the detached residences are star rated between 1 to 5 stars and thus suitable for certification. So, the residential buildings evaluated as per electric energy normalized with the area are energy efficient.

TABLE V. TABLE OF COMPARISON OF AVERAGE PER CAPITA ENERGY USE.

Average	No. of Person	Built-up Area in m2	Annual Electric Energy kWh	Per capita Electric Energy kWh
*Data as per research	4	106	3755	938
Present case studies	5	306	11960	3025

* “Technical Report, 2014 by GBPN” [28]

Correlating the occupant's perception of thermal comfort, it seems paradoxical that these residences are energy efficient and not at all thermally comfortable. The occupants have to consistently use active conditioning appliances for staying comfortable and are very uncomfortable during power cuts. Also, as per calculations, the annual per capita energy for occupants of these residences is higher in comparison with the national average in Table V. confirms the same.

According to the report by the Ministry of Power, the per capita electricity usage was 1,181 kWh in the year 2018-19 India. In the Jammu district in the year 2019-20, the per capita consumption was 1146 kWh annually [29]. But the annual average per capita energy consumption for the case study residences is 3025 kWh and is much higher than the national average. Further considering the worldwide per capita consumption was 3,130 kWh in 2014, according to data listed by the World Bank, the energy per capita for these case study residences is at power with the global consumption.

Hence, the need to evaluate these case studies with other parameters on which electrical energy use depends besides the area of the residential building.

B. Findings and Inferences of EPI Application

a) The average electricity consumption for one year for all the 10-case studies shows maximum electricity consumption in June, July, and August. The sudden increase in electric use is observed from May and drops after September. The annual baseload is approximately 4798 kWh in March and October, when temperature and humidity are within the comfort zone, as shown in Fig.4. This graph shows that on an average 35 per cent increase in electricity consumption from the baseload in June.

b) The assessment of case studies reflects that for the majority of residences, the EPI is star rated as per BEE and compliant as per GRIHA green building rating system. The results are graphically represented in Fig.5 are the actual energy used in comparison with the energy required to be star rated between 1-Star and 5-Star. The graph below reiterates the fact that the units of electricity consumed by the detached plotted residences show energy-efficient performance. However, W. Bracke et al. found that the disadvantage of the current area-normalized energy use index is that it invariably tends to reprimand buildings with a small area for reasons that energy use does not increase linearly with floor area, and secondly, this index decreases as the built-up area increases [30]. This is tricky as the same building comes under an efficient operation if the area is increased with the same kWh of electric energy used, and if the area is reduced with the same pattern of energy use, it becomes inefficient and an energy guzzler.

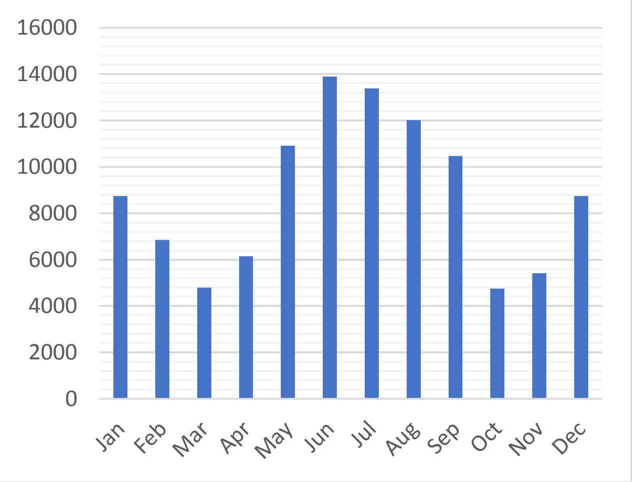

Fig. 4 Average electricity consumption by the case study plotted residences in one year (Source: Author)

Thus, this benchmarking technique may not reflect the true picture and will hamper the proper implementation of energy efficiency policies, especially in detached residences.

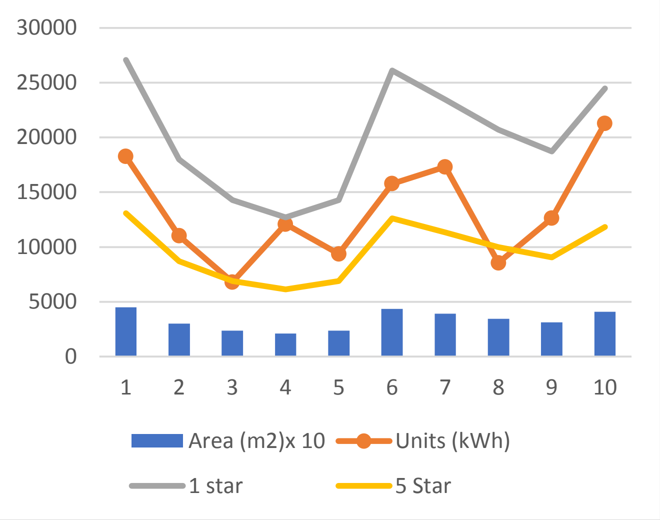

Fig. 5 Electric energy normalized per unit area for a star rating and the electric energy used by the case studies (Source: Author)

VIII. EVALUATION OF THE BUILDING ENVELOPE THERMAL PERFORMANCE

The energy assessment for the building envelope is calculated for the case study residence as per ENS Part 1 in this section. The value of thermal transmittance, the U values and solar heat gain coefficient (SHGC) is calculated as per data collected from the residences for electric energy evaluation is given in Table VI.

TABLE VI. CONSTRUCTION MATERIAL U -VALUE FOR WALLS, ROOF AND WINDOWS AND SHGC VALUE (SOURCE: ECBC 2017)

Existing building Material	U value
Roof	
Cement Plaster+ 130 RCC+100mm mud Phuska+75mm Brick tile	1.81 W/m2K
Wall	
Internal Cement Plaster+230mm brick wall	1.96 W/(m2·K)
Internal Cement Plaster+230mm brick wall+ External Cement Plaster	
Internal Cement Plaster+330mm brick wall	1.543 W/(m2·K)
Internal Cement Plaster+330mm brick wall+ External Cement Plaster	1.237 W/(m2·K)
Existing Glass	
6mm clear glass	U value = 7.1 W/m^{2}K
	SHGC: 0.81

The values for calculation are taken from ECBC 2017[31]. This calculation is used for RETV calculations for building envelopes except for the roof. The Formula for RETV is shown in section 4. The ten residences are evaluated again as per ENS Part 1 guidelines for energy efficiency. The RETV Values for the ground floor and first floor are calculated separately as the layout of both the floors is different in most cases. The parameters for building envelope energy performance are given in Table VI.

IX. DISCUSSION

The RETV values and Uroof are much higher than the benchmark value of 15W/m^2 and 12 W/m²K, respectively, as per the prescriptive guidelines of ENS Part 1 for the composite climate. Figure 6 shows that the RETV calculation for the ground floor of the residences is much higher than the first-floor cases. The higher RETV values in the case studies are mainly due to the high window wall ratio high, U values of walls and high SHGC of glass in the windows. The first floor of Case Study 5 has a calculated RETV that is lower than the maximum prescribed value as per guidelines and is thus energy efficient. Thus, the roof and walls of the case study residences are not of suitable thermophysical properties as a protective barrier for composite climate and permit a considerable amount of transmittance of heat and cold from existing external climatic conditions to the interiors of the residences.

The WFRop is for ventilation, and in all the cases, this ratio value is more than the minimum as per ENS Part 1, which reflects that the residences should have good ventilation. But for good and effective ventilation, the positioning of the windows also has to be appropriate in relation to the direction of air movement, and larger openings are not the only criteria. In most cases, the WWR was more than the minimum required as per the guideline's values, and the glass for the windows needs to be of lower VLT for energy efficiency. The VLT of glass has to be lower with higher WWR for blocking the free ingress of heat and cold inside the house, depending on the climate. Though the high value of VTL is good for daylight transmittance and hence reduces the requirement of artificial light. But existing windows have a single glass with a high VLT of 0.76, thus making the windows assembly inefficient. The value of 0.27 is found to be appropriate for composite climate as ENS Part 1. The value larger WWR creates overheating of the interiors of the buildings with the single glass as the VLT is very high, which implies that with the light transmittance, the heat transmittance is also high.

X. INFERENCES

The results of the calculation based on the Eco Niwas Samhita code show that the building envelope of the 10-case study detached residences do not have appropriate thermophysical properties as per the code are not efficient and not compliant with the values for the composite climate.

TABLE VII. THE CALCULATION FOR ENERGY PERFORMANCE OF BUILDING ENVELOPE AS PER ECO NIWAS SAMHITA PART–I (SOURCE: AUTHOR)

Building Envelope Composite Climate	Residential envelope transmittance value (RETV)		Thermal transmittance of roof (Uroof)		Minimum openable window-to-floor area ratio (WFRop)		Window/wall ratio (Minimum)		Min VLT	
Case Study	15 W/m^2 K		1.2 W/m^{2}K.		12.50		0.0-0.30		0.27	
	G.F.	F.F.	G.F.	F.F.	G.F.	F.F.	G.F.	F.F.	G.F.	F.F.
I	21	22	1.8	1.8	26.50	13.80	0.87	0.79	0.11	0.11
II	18	22	1.8	1.8	11.50	19.80	0.59	0.75	0.13	0.11
III	16	19	1.8	1.8	9.90	16.70	0.46	0.76	0.16	0.11
IV	24	17	1.8	1.8	8.70	9.00	0.45	0.24	0.16	0.27
V	18	13	1.8	1.8	15.40	14.20	0.81	0.36	0.11	0.20
VI	21	24	1.8	1.8	12.60	12.80	0.81	0.36	0.11	0.20
VII	27	18	1.8	1.8	13.80	6.90	0.86	0.31	0.11	0.20
VII	25	23	1.8	1.8	13.90	13.70	0.84	0.70	0.11	0.11
IX	20	18	1.8	1.8	12.00	8.30	0.85	0.34	0.11	0.20
X	23	22	1.8	1.8	10.70	6.80	0.52	0.37	0.13	0.20

It also supports the occupant's opinion of thermal comfort. Further elaborating that the houses are not thermally comfortable for the occupants and hence need for disproportionate use of conditioning appliances for comfort throughout the summer, monsoons, and winter seasons. Further, this also explains the high energy use per residence and capita when compared to the national average. As per TERI, typical energy load consumption for a building where HVAC (Heating, Ventilation, and Air Conditioning) constitutes more than 50% of the total load with certain variations in percentage in some cases is mainly dependent upon the design aspects of buildings, especially typology and building envelope. So, the building envelope is a major determinant for energy consumption in buildings [32]. These residences are energy guzzlers and do not provide the requisite thermal comfort to the occupants. So, to increase the electrical energy efficiency and comfort level in the residences building envelope needs to be retrofitted. Thus, the existing residences are not energy efficient as rated based on EPI- electric energy normalized per unit area by the BEE and GRIHA.

XI. CONCLUSION

Excess energy use has a multitude of negative impacts on the environment and hence liveability. Building performance assessment is essential for the curtailment of energy use in the building sector. The current EPI calculated is the above-stated guidelines, with the area of the building as the main determinant for energy efficiency quantification does not provide a detailed and clear understanding of the energy performance of the residences. Whereas analysis ENS Part 1 quantifies the values of inefficient building envelope elements -walls, roof, and windows of the case study residences. Based on these results, it can be concluded that retrofit of the building envelope has the potential for improving the energy performance of these buildings. The current guidelines point-based benchmarking consider the climate of the place and building envelope for rating buildings in India but the other four building performance indicators such as building energy systems, operation and maintenance, Occupant activities and behaviour, and Indoor environmental quality are not taken into consideration [33]. The energy performance index for existing or new buildings, besides considering built-up areas, must include other suitable building performance indicators contextually. It has to take into consideration the parameters which impact energy consumption in buildings and viable parameters for retrofitting for energy efficiency. The current assessment approach needs to be revamped for a more holistic approach to the assessment of energy efficiency, and hence consequently, more effective measures can be taken for curtailment of energy expended wherever needed. Thus, developing guidelines and star ratings that are more robust and insightful are required to meet energy optimization goals.

The future work can be to develop an energy assessments tool and more all-inclusive benchmarking for better rating systems for plotted residential building energy-efficient certification.

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