Original Article
ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research - GRANTHAALAYAH
June 2024 12(6), 41–63

COMPARATIVE EVALUATION OF THE ENERGY PERFORMANCE INDEX OF MODERN URBAN AND TRADITIONAL RURAL HOUSING IN COMPOSITE CLIMATE FOR DEVELOPING PREDICTING MODEL

Dr. Amitava Sarkar [1]

[1] Associate Professor, Department of Architecture, School of Planning and Architecture Vijayawada, Vijayawada, India

Received 29 April 2024
Accepted 03 June 2024
Published 04 July 2024

Corresponding Author
Dr. Amitava Sarkar,
amitava.sarkar3@gmail.com

DOI
10.29121/granthaalayah.v12.i6.2024.5662

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

In this present study Energy Performance Index (EPI) of the traditional rural and modern urban houses located in and around Mandi – Sundernagar town at Himachal Pradesh, India, having composite climate, are assessed based on the household energy consumption data for the year 2021 and 2022. The EPI plays pivotal role as an indicator to assess the energy efficiency of different kind of buildings by setting up a practical holistic benchmark for building designers and other professionals to reduce and optimize the operating energy footprint of the building. Further, the effect and correlation of various influencing factors on the annual household energy consumption and EPI are also analyzed through regression analysis to develop models for the prediction of future trend of household energy consumption pattern. The calculated average EPI value of modern houses is found as 39.24 KWH/m^2/year (range: 29.43 – 50.53 KWH/m^2/year). In contrast, average EPI value of traditional houses is calculated as 7.89 KWH/m^2/year (range: 6.34 – 10.36 KWH/m^2/year). The study shows that the mean total annual energy consumption of modern houses is 5.4 times higher than that of the traditional houses; the mean EPI of modern houses is 5 times higher than that of the traditional houses; and the mean EPI/person of modern houses is 5 times higher than that of the traditional houses in the study area. Linear regression analysis has shown that total annual household energy consumption and EPI can be well predicted by the factors – floor area, annual average household income, and total number of different appliances.

Keywords: Composite Climate, Modern and Traditional Houses, Building Energy Performance Index, Comparative Analysis, Influencing Factors, Prediction Models

1. INTRODUCTION

The domestic sector of India was the second largest user of electricity accounting for 24% in the year 2017-18 MOSPI. (2019) and this phenomenon will continue till 2050 IEA. (2013), BEE (2020-2021) since increase in population will create more demand for built-up areas. As per the report MOSPI. (2019) published by the government of India, in the year 2017-18 the total estimated consumption of electricity increased at the rate of 6.51% and electricity generation increased by

5.71% over the previous year. The increase in demand for electricity by all sectors including domestic will create more pressure on its production capacity. At present in India the major source of electricity is from the thermal power plants (69.25%), followed by the other renewable sources (17.68%), hydro power (11.37%) and nuclear energy (1.70%). By 31st March, 2018, 99.9% of total Indian villages were electrified MOSPI. (2019). This shows that the domestic sectors in both urban and rural areas of India are contributing to the growth of demand for energy. Also, the per-capita energy consumption of the country is also increasing annually MOSPI. (2019). This very crucial aspect and relationship between the population, built-up areas, and energy consumption are acknowledged globally and these are made the part of the 'Energy Indicators for Sustainable Development' formulated by the United Nations Commission on Sustainable Development IAEA. (2005) along with other indicators. Also, recent reports published by the international agencies IEA. (2020), EIA. (2022) indicate that the share of household energy consumption is increasing all over the world although intensity of average annual household energy consumption in India is much lower compared to US, Europe, Japan and many other countries at present. Researchers Espey & Espey (2004) have used macro-level data to assess present household energy consumption and to make projection for the future demand based on that and other scholars Baker et al. (1989), Inoue et al. (2021), Matsumoto et al. (2022) have highlighted the importance and need for finding out the micro-data regarding house-hold level energy consumption to facilitate more realistic and practical forecast for the current and future demand for energy by the domestic sector. The assessment of household level energy consumption data and their relationship with the various factors affecting their energy consumption pattern including the local climatic condition, floor area, number of occupants, household income, usage of home appliances, available sources of energy, etc. will facilitate the projection of probable future household energy consumption pattern. This will further assist in realizing the goal of achieving energy efficiency and thereby reducing the carbon footprint in the housing sector and promoting sustainable development in the region.

Realizing the present and future implications of the scenario in the building sector and by giving due importance various initiatives are taken by India to achieve energy efficiency in the domestic sector. One such primary initiative is the introduction of the 'Energy Conservation Building Code' (ECBC) by the Indian government BEE. (2007), BEE. (2017) with the goal to decrease the total energy intake of the buildings by the end-use depending on their geo-climatic locations and construction systems adopted. Various studies have shown that the major sources of energy consumption in domestic sector by end-use are the need for mechanical cooling in hot areas, heating for cold areas, use of appliances, and artificial lighting. To further the realization of the purpose to achieve self-sufficiency in terms of net energy consumption by the buildings, several studies have been conducted to set-up the bench-marks for residential buildings in different geo-climatic locations of the country in terms of total annual energy consumption (in KWH) per unit built-up area (in m^2) – referred to as Energy Performance Index (EPI) Bhatt et al. (2005), KfW & NHB. (2009), SDC. (2010), GBPN. (2014), BEE. (2014), expressed in the unit KWH/m^2/year. The EPI plays a pivotal role as an indicator to assess the energy efficiency of different kind of buildings and to make them more energy-efficient by proper planning and balance of energy demand and supply. With the changing time the lifestyle of the households is also being changed. The built environment especially the residential buildings are also a manifestation of the aspirations of its owners and users. The ever-increasing energy demand and consequent footprints of the residential architecture is a phenomenon which can be expressed in terms of the EPI indicator. The monthly and annual energy consumption of a residential building is the culminating effect of multiple parameters like its geo-climatic location, architectural design, built-up area, number of occupants, household income, use of mechanical heating and cooling equipment, available daylight autonomy, and use of different home appliances, etc. Hence, setting up of EPI benchmarks for the residential buildings through field survey for different geo-climatic locations provide a basis for the policymakers to project and assess the household energy demand which is to be met by the production side in a sustainable manner. Further, it also provides the architects and building designers to design energy efficient buildings incorporating multiple approaches such as solar passive design, solar active design for the air-conditioned, naturally ventilated, and mixed-use buildings to provide comfortable indoor condition with reduced energy footprint.

In this study the EPI of the modern houses in urban areas and traditional houses in rural areas at Mandi – Sundernagar area in Himachal Pradesh (H.P.), which experiences composite climate like hot summers, wet monsoons, and cold winters as per the National Building Code (NBC) of India BIS. (2016), is investigated. The study area is experiencing rapid urban growth. The composite climate of the study area causes both heat discomfort during summer months and cold discomfort during winter months. Hence, occupants of the modern houses use mechanical cooling during summer months and mechanical heating during winter months to maintain indoor thermal comfort. Whereas the occupants of the traditional houses can able to maintain indoor thermal comfort conditions during winter and summer utilizing the solar passive features such as high thermal mass and large time-lag of the house-constructing. Although, day by day the number of traditional houses is getting diminished because people are constructing their new houses as per the present market forces adopting reinforced cement concrete (RCC) framed construction.

Hence, the main aim of the study is to analyze the EPI of the modern and traditional houses using household energy consumption data based on the monthly electricity bill issued by the State Electricity Board for the years 2021 and 2022. Based on the study, an attempt has been made to observe the monthly and yearly variations in EPI and EPI/person of traditional and modern residential buildings in the study area with different construction methods located in the composite climate zone of India. Also, from the selected literature review factors affecting the domestic EPI and total household power consumption has been identified and their effects and correlations have been analyzed. Further, the details regarding the usage pattern of various home-appliances in the modern and traditional houses of the study area are also presented for having some idea about the lifestyle of the households.

The study will be beneficial as an attempt to develop an understanding about the intensity of energy consumption pattern in the modern and traditional residences of the Hilly State of Himachal Pradesh, India with composite climate by collecting micro-level data regarding EPI and other related parameters which will assist in taking policy decision regarding the demand and supply of energy in the domestic sector of the State. Based on the analysis linear regression models are developed to predict probable future household energy consumption pattern and their EPI. The following sections present the brief literature review, methodology, results and discussions, and the conclusion of the study. The limitations of the proposed models to predict future EPI and total annual energy consumption are also presented.

2. ENERGY PERFORMANCE INDEX (EPI) – A BRIEF LITERATURE REVIEW

Researchers Gupta et al. (2023), Gupta et al. (2023) have done the study to highlight the significance of prediction models to establish energy benchmark for residential buildings. They have conducted their study based on the data collected from the Indian city of Jaipur with hot and dry climate BIS. (2016). Based on the findings from the regression analysis they have proposed a hybrid prediction model to assess the energy-efficiency and assign rating of residential buildings in Jaipur city and places with similar conditions as per the predicted Building Performance Index (BPI). Researchers have also highlighted the gap and need for developing such models to predict probable annual energy consumption of the residential buildings which will assist the policy makers and energy sector for better utilization of the available resources in the country.

Researchers Ekonomou & Menegaki (2023) have highlighted the need for developing such predictive models and flow-charts adoption of which can help in making the buildings more energy efficient with the present-day context based on the integrative review study of the concerned literature especially by also including the climate change scenario. Other researchers Lianwei & Wen (2021) have also carried out study to find the effect of the contributing factors on energy consumption by the buildings and highlighted that change in geographic locations within the same country can affect the household energy consumption along with other factors like urbanization, climatic, economic, and social factors. They have used the “linear regression – decision tree” method to assess the future trend of urban household energy consumption pattern in China. Other researchers Baltruszewicz et al. (2021), Ding & Peng (2020), Gassar et al. (2019) have also conducted the similar studies recently in Zambia, China, and London respectively to assess the present household energy consumption pattern and the influencing factors such as urbanization, spatial distribution, and socio-economic condition to predict future energy consumption by the domestic sectors through regression analysis.

Researchers Basu et al. (2019) have reported the importance of occupancy schedule and loading as derived from the household behavior, room-sizes, electricity-consuming services, monthly/ annual electricity bills, etc. along with other parameters as important factors affecting the energy-efficiency of buildings based on the result of their study conducted in and around Delhi, the capital of India.

Several studies have been conducted by the researchers and various organizations and institutes to find out the benchmark Energy Performance Index (EPI), which is defined as an index obtained by dividing the annual purchased electricity (in KWH) by the built-up area (in m^2) without including areas under balcony, semi-covered spaces, and common spaces like lifts and lobbies BEE. (2014), of the residential buildings located in different geo-climatic locations of India.

Bhatt et al. (2005) carried out a study in Bangalore city, India with the sample size of eight typical residential buildings in Bangalore. They have evaluated various parameters such as monthly electrical energy consumption, specific energy consumption (SEC) per unit built-up area in KWH/m^2/month and SEC/person, etc. to quantify building energy data for labeling of buildings. They have found SEC for residential buildings ranging 1-3 KWH/m^2/month; the range of energy consumption as 50-250 KWH/month; and range of SEC/person as 300-800 WH/ m^2/person/ month. Further a study-project funded by the Indian government agencies KfW & NHB. (2009) to find out EPI benchmark for Indian domestic sector was conducted in different climatic zones of India including composite climate. A primary survey was conducted with 1000 households, out of which approximately 50% were air-conditioned buildings to establish the EPI benchmark for Indian domestic sector. This project has recommended an average EPI value 49 KWH/m^2/year for residential buildings in composite climate, with minimum EPI value 21 KWH/m^2/year and maximum EPI value 107 KWH/m^2/year. Another collaborative jointly funded project between Swiss Agency for Development and Cooperation (SDC) and Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India SDC. (2010), BEE. (2014) was conducted to establish EPI benchmark for residential buildings in and around Delhi National Capital Region (NCR). The primary survey was conducted with 732 residential flats to collect energy consumption details including usage of household electrical appliances. The survey found mean residential EPI as 48 KWH/ m^2/year with range of 45 - 50 KWH/ m^2/year; mean EPI/person as 15 KWH/ m^2/year with range of 5 - 20 KWH/ m^2/year. It was observed that top floor flats were resulting 10-15% higher EPI values. Also, the survey found average EPI value for each air conditioner (AC) as 30 KWH/ m^2/year with range of 10-40 KWH/ m^2/year. With the similar purpose of establishing a benchmark EPI in another funded project GBPN. (2014) around 201 sample residential units were surveyed in Delhi to collect energy consumption details for the year 2013. The study reported mean residential EPI value as 57 KWH/ m^2/year. As per the Indian national rating system – GRIHA TERI. (2019), the EPI bench-marks values for residential buildings located in composite, hot-dry and warm-humid climate is 70 KWH/ m^2/year, in moderate climate the EPI value is 50 KWH/ m^2/year, and in cold climate the benchmark EPI value is 100 KWH/ m^2/year.

The EPI has been established as an important indicator to assess the energy-efficiency of different building typologies and to make them more energy-efficient by proper planning and balance of energy demand and supply. The literature review shows that the bench-mark EPI values for residential buildings in different climatic locations of India are getting increased over the years. Hence, like in other countries, more study needs to be conducted in different geoclimatic locations of India to find the EPI values of residential buildings to monitor the trends in the energy consumption patterns in the household and their possible reasons to better equip the country to manage the power supply scenario in a sustainable manner. From the above literature review, in this study the effect of the parameters such as (i) covered floor area of the houses; (ii) position of the floor in multi-storey buildings; (iii) number of occupants; (iv) number of bed-rooms in the houses; (v) the various electrical appliances generally used by the household; and (vi) the average annual household income, on the total annual household energy consumption and EPI is calculated and analysed using linear regression analysis to develop a tentative prediction model.

3. METHODOLOGY

The household survey was conducted during the year 2022 in and around the urban and rural areas of Mandi – Sundernagar town (H.P.) with the residential units comprising of 10 typical traditional houses, more than 50 years old, and 30 typical modern houses, which are 5 – 10 years old. The traditional and modern houses were selected through stratified random sampling method representing the older construction methods found in the traditional houses and prevailing construction methods dominated by the market force and current trends in the building sector found in the modern houses. From the household survey report of Mandi area, it was observed that the number of traditional houses is getting diminished as local house-owners are either converting their old houses to new houses or construction new houses on the vacant land by adopting modern construction methods due to the socio-economic reason such as change in life-style, income, and aspirations modulated by the current market force. Hence, to represent the current scenario in the housing sector of the study area a greater number of modern houses (30) and a smaller number of traditional houses (10) are surveyed. The electricity consumption bills were collected for the year 2021 and 2022 during the household survey. Information was collected regarding (i) covered floor area of the houses; (ii) position of the floor in multi-storey buildings; (iii) number of occupants;(iv) number of bed-rooms in the houses; (v) usage pattern of the appliances by the occupants; (vi) list of the electrical appliances generally used by the household, and (vii) average annual household income. The effect and correlation of these factors on the total annual energy consumption and EPI of the houses are calculated and analyzed using multiple linear regression analysis. In case of modern multi-storey urban houses data is presented and analyzed for ground floor and top floor houses with separate electricity meters, whereas single electricity meter was observed in case of two storey traditional houses. Further study will be taken up to assess the EPI of middle floor houses also. The general flow-chart for the study is shown in Figure 1.

Figure 1

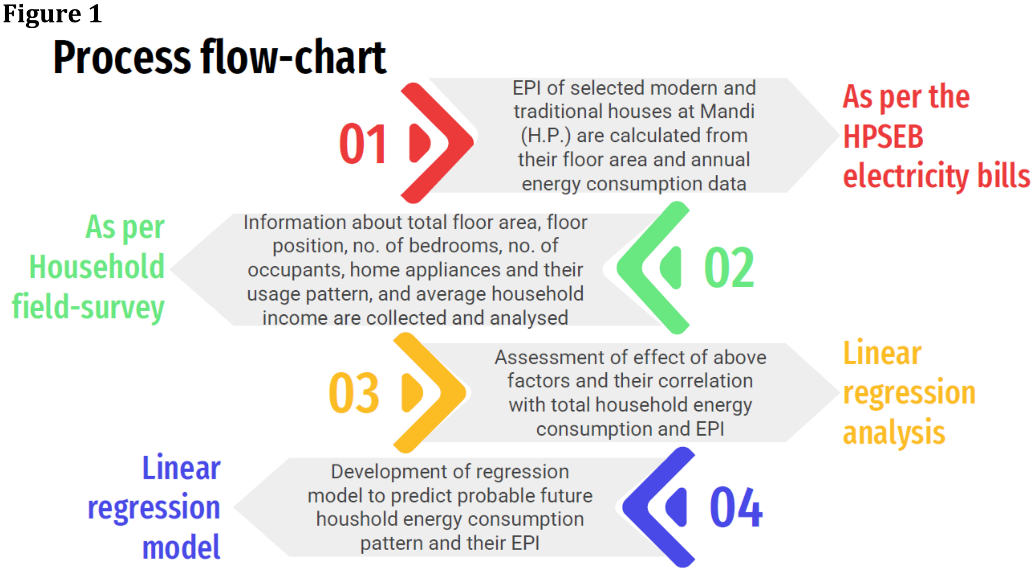

Figure 1 Flow-Chart of the Methodology for the Study

At first stage, information was collected regarding total floor area (in m^2) of the houses and total annual energy consumption (in KWH) as per the electricity bills of the selected modern and traditional houses. Then by dividing annual energy consumption of the houses with the corresponding floor area, the EPI (in KWH/m^2/year) of the selected houses are calculated. Then EPI/person is also calculated by dividing the EPI of the houses with corresponding number of occupants. The above data for modern and traditional houses are tabulated, compared and analyzed. At next stage, information collected from the household survey about total floor area, floor position, number of bedrooms, number of occupants, home appliances and their usage pattern, and average household income of the selected houses are tabulated and analyzed. Next, assessment of effect of above factors and their correlation with total household energy consumption and EPI is done using linear regression analysis. The details of the household appliances and the usage pattern of theses appliances observed during the study are also tabulated. Then, from the analysis in the study regression model is developed to predict probable future household energy consumption pattern and their EPI.

3.1. STUDY AREA LOCATION WITH CLIMATE

The study area (latitude 31.32º N, longitude 76.53º E, altitude 850 meters above MSL) experiences hot summers with maximum temperature reaching 40ºC (mean high 34.2ºC) in the months of May-June, cold winters with minimum temperature 3ºC (mean low 2.7ºC) in the months of December-February, monsoon with average annual rainfall of more than 1400mm predominantly in the months of July-September IMD. (2022). Mandi - Sundernagar (H.P.) area receives good amount of solar radiation with intensity ranging between 3.45 KWH/m^2/day (in January) and 7.42 KWH/m^2/day (in May – June) ISHRAE. (2017), which signifies potential for use of roof-top and on-site/ off-site solar photo voltaic panels to generate electricity from renewable sources and can contribute to achieve and sustain energy efficiency of the buildings including domestic sector. As per the climate classification map for India given in the NBC BIS. (2016), the study area falls in the region with composite climatic condition.

3.2. TYPOLOGY OF HOUSES SURVEYED

In this study the sample size consists of 30 modern houses and 10 traditional houses due to resource constraints. Further study will be done with larger sample size committing more resources. The architectural characteristics of the selected traditional rural and modern urban houses from Mandi – Sundernagar area are given in Table 1. The external and internal views of the few selected traditional and modern houses are shown in Figure 2 and Figure 3 respectively. At present the prevalent construction practices in the study area is being modulated by the present day market forces and the buildings appear similar in its planning and aesthetics as any other modern buildings seen in the plain areas of the country with warm, hot, composite, and other climatic conditions. In the study area the modern dwellings predominantly are on plotted development with individual houses and apartments of one to three storey heights. The people in rural areas are also adopting modern construction practices due to market force and other socio-economic reasons. The transformation in rural housing is taking place as per the aspirations of the people and number of existing traditional construction is getting reduced. The surveyed houses are selected from the prevailing types of housing pattern observed in the study area.

Table 1

Table 1 Details of Selected Houses

Attributes	Traditional houses	Modern houses
No. of units	10 nos.	30 nos.
Age of construction	More than 50 years	5 – 10 years
Floor area	60 – 112 m^2	70 – 140 m^2
No. of storeys	Typically 2	2 - 3

Wall	Thickness 45cm; sun-dried mud brick with stones plinth and mud/ cement plaster	Thickness 23cm; burnt bricks, cement plaster, paints/ tiles
Floor	Timber joists, Timber planks, layers of mud-cow-dung finish	10 – 11.5cm thick (RCC) slab with tiling or marble flooring
Roof	Pitched roof, attick, slate roofing on timber rafters; ceiling of timber joists and timber planks	10 - 11.5cm thick RCC slab with 6cm screedg and water-proofing on top
Windows and doors	Small size windows few in number, only on east-facing walls, with solid timber shutter; Solid timber doors	Large glazed windows with timber/aluminium frame more in number placed on all sides; Solid timber doors
Floor height	2.1 – 2.4 meter	3.1 meter
*U-value of wall (thermal transmittance)	1.35 W/m²K	2.13 W/m²K
*U-value of roof (thermal transmittance)	1.7 W/m²K	3.35 W/m²K
*U-value of windows (thermal transmittance)	4.83 W/m²K	5.23 W/m²K
*Time-lag of wall	8-10 hours	4-5 hours
*Time-lag of roof	8-10 hours	4-5 hours

Source BIS, 1978; Koenigsberger et al, 2013

Figure 2

Figure 2 External and Internal Views of Traditional Houses at Mandi (H.P.)

Figure3

Figure 3 External and Internal Views of Modern Houses at Mandi (H.P.)

4. RESULTS AND DISCUSSION

4.1. ENERGY PERFORMANCE INDEX (EPI) OF HOUSES IN THE STUDY AREA

One of the main purposes of the study was to find out and compare the Energy Performance Index (EPI) of the traditional and modern houses located in and around Mandi – Sundernagar (H.P.) town and also to find out the correlation of EPI and total annual energy consumption with the other factors such as floor area of the building, number of bed rooms, number of occupants, average annual household income, and total number of appliances used by households, etc. Therefore, during the household survey of the residential units comprising of 10 traditional rural houses and 30 modern urban houses, the electricity consumption bills were collected for the year 2021 and 2022 for the analysis. The findings from the analysis are discussed in the following paragraphs.

The findings from the analysis of household-survey data are calculated and tabulated under the parameters House No., EPI, Floor area, Total annual energy consumption, No. of bedrooms, No. of occupants, EPI/person, and Annual household income and presented in Annexure 1 regarding the traditional houses and in Annexure 2 regarding the modern houses. The EPI (in KWH/m^2/Year) of the selected houses is calculated by dividing their annual energy consumption (in KWH) with the respective floor area (in m^2) and further EPI/person (in KWH/m^2/person/Year) is calculated by dividing the EPI of the houses with number of occupants.

It was observed from the details in Annexure 1 that the covered floor area of traditional houses ranges from 70-112 m^2, total annual energy consumption ranges from 450 – 1160 KWH, with an average value of 735.15 KWH, number of bedrooms ranges from two to three, and household size ranges from four to five. Further, the EPI of the traditional houses is calculated as ranging from 6.34 – 10.36 KWH/m^2/Year, with an average EPI value of 7.89 KWH/m^2/Year, and EPI/person as ranging from 1.54 – 2.08 KWH/m^2/person/Year, with an average EPI/person value of 1.79 KWH/m^2/person/Year. In the case of modern houses referring the details in Annexure 2, it was found that floor area ranges from 70-140 m^2, total annual energy consumption ranges from 2300 – 6600 KWH, with an average value of 3956 KWH, number of bedrooms ranges from two to four, and household size ranges from four to six. Further, the EPI of the modern houses is calculated as ranging from 29.43 – 50.53 KWH/m^2/Year, with an average EPI value of 39.24 KWH/m^2/Year, and the EPI/person as ranging from 5.48 – 12.63 KWH/m^2/person/Year, with an average EPI/person value of 8.84 KWH/m^2/person/Year. For the top floor modern houses total annual energy consumption ranges from 2450 – 6600 KWH and the EPI value ranges from 34.04 - 50.53 kWh/m^2/year, with an average EPI value of 41.68 KWH/m^2/Year, whereas for the ground floor modern houses total annual energy consumption ranges from 2300 – 6500 KWH and the EPI value ranges from 29.43 - 46.43 kWh/m^2/year, with an average EPI value of 36.80 KWH/m^2/Year.

The analysis shows that the mean total annual energy consumption of modern houses is 5.4 times higher than that of the traditional houses; the mean EPI of modern houses is 5 times higher than that of the traditional houses; and the mean EPI/person of modern houses is 5 times higher than that of the traditional houses in the study area. This is primarily due to the construction methods and materials used in the traditional houses such as 45 cm thick walling with sun-dried mud-bricks having lower U-value and high thermal lag, low ceiling height and flooring of timber planks and layers of mud-cow-dung finish and pitched roof with attick (Table 1), providing good thermal insulation against heat loss in winters and heat gain in summers, and less opening area, which reduce the need for mechanical cooling and heating during summers and winters respectively Sarkar & Bose (2015), Sarkar & Bose (2016), and the lifestyle of the occupants, usage pattern and less use of electrical home appliances when compared to the modern houses (Table 1). Further, it is found that the mean EPI value of the top floor modern houses is about 13% more than that of the ground floor modern houses, mainly due to the exposure of the roofs of top floors and single storey buildings to the hot outdoor conditions causing overheating during summers.

It is found that the average annual household income of the traditional rural houses ranging from Rs.4.5 – 6.5 lacs with a mean value of Rs.5.6 lacs; the source of their income is from shops, government and public sector job, IT/ private company/industry job, armed forces, teaching, service industry, agriculture and animal husbandry, and pension. Almost all the households possess agricultural land and many of them still do the cultivation along with their other profession. They still practice the traditional socio-cultural rituals as their lifestyle, whereas, the average annual household income of the modern urban houses ranging from Rs.7 – 14 lacs with a mean value of Rs.11.27 lacs. Their source of income is primarily from their own commercial establishments, transport industry and other trading business, government and public sector job, IT/ private company/industry job, armed forces, teaching in higher education institution, cash crops, and pension, etc. They are more exposed to the current urban lifestyle and use more electronic gadgets and other home appliances for their comfort and socio-economic requirements which results into more power consumption and more demand on the supply chain.

4.2. DETAILS AND USAGE PATTERN OF THE HOUSEHOLD APPLIANCES

The details about the availability of electrical home appliances found during the physical surveys in the selected modern and traditional houses of the study area is given in Annexure 3. It is observed that the electrical home appliances that are being used in the traditional rural houses include refrigerator, TV, Radio, CD player/ sound-system, room-heater, mixer-grinder, washing machine (in few cases), computer/ laptop. Whereas, the home appliances found being used in the modern urban houses include refrigerator, TV, Radio, CD player/ sound-system, microwave-oven, room-heater, water-heater, mixer-grinder, electric cooker, washing machine, few cases of air conditioner (AC) and computer/ laptop. In four modern houses (house no. 7, 8, 22 and 25) single split AC was installed in the bedrooms which is being operated mainly during hot summer days as reported by the occupants. It can be seen from the Annexure 1, that the EPI values of these houses with AC installed is relatively higher than others. This also highlights the trend and attitude of occupants of modern houses to install AC which may further increase the demand and load on energy production and supply. It is evident from the Annexure 3 that in the modern urban houses more electrical appliances are being used when compared to the traditional rural houses.

During the household survey, attempts were also being made to collect information regarding the usage pattern of the electrical appliances generally used by the households. The average usage pattern of these household appliances observed from the survey is given in Table 2. It is found that the intensity and propensity of using the home appliances are relatively less compared to their usage in modern houses. Although the occupants of the traditional houses are using modern appliances and equipment like computers, laptop, smart phones, etc. by doing required additional wiring in their traditional houses to meet their educational, business, and occupational need. During the survey of the houses, it was observed that the traditional houses had minimal electrical wiring system. Most of those traditional houses were not even using fans for cooling also due to the reasons discussed above such as thick high thermal mass wall, timber-mud flooring, pitched roof with attic, etc. It is apparent that due to change in lifestyle, rapid urbanization, exposure to advertisements, economic opportunity, and with increase in family income households in both urban and rural areas are using more electrical appliances and this trend will continue in coming days due to the prevailing market force and aspirations of households which may be further influenced by the surrounding local, national, and global socio-economic condition MOEF (2023). As a consequence, the total energy consumption and demand for electrical energy by the housing sector will be increasing to operate all those household electrical appliances.

Table 2

Table 2 Average Usage Time of Household Appliances Found During Survey

Appliances	Units of Usages	Average usage value
Radio	Hours/ day	6
TV	Hours/ day	4
CD Player/ Sound System	Hours/ day	4
Computers/ Laptop	Hours/ day	4.5
Refrigerator	Hours/ day	24
Electric cooker/oven, Microwave, Toaster	Minutes/ day	30
Geyser/ Electric water heater	Hours/ day	1 (when needed)
Electric heaters	Hours/ day	5 (during winters)
Air conditioning (cooler)	Hours/ day	5 (during summers)
Washing machine	Minutes/ day	45 (when needed)

4.3. COMPARISON OF MONTHLY ENERGY CONSUMPTION IN TRADITIONAL AND MODERN HOUSES

Table 3 and Figure 4 present the comparative analysis of monthly and annual energy consumption details and EPI of modern and traditional houses found in the study area with composite climate. It is evident from Table 3 and Figure 4 that in the modern houses monthly energy consumptions are higher than the traditional houses especially during winter and summer months. This is due to the construction practice of the traditional houses with thick high thermal capacity wall, mud-timber flooring, pitched roof with slate roofing and attic, less opening – all of which provide better capacitive insulation against heat gain in summer and heat loss in winter to maintain indoor thermal comfort condition. Further, there are a smaller number of electrical appliances being used in the traditional houses when compared to the modern houses. The occupants of the traditional houses are found more dynamic while interacting with outdoor spaces since they utilize the outdoor spaces as per the seasonal and temporal condition prevailing. During summer months they utilize the indoor shaded spaces and during winter months they carry out many activities under sunny condition. However, indoor daylight condition is found less in the traditional houses due to few small openings. But transformation is also taking place in the traditional houses due to change in lifestyle, rapid urbanization, and with increase in family income and to fulfill their socio-economic aspirations.

Table 3

Table 3 Comparison of Energy Consumption and EPI in Modern and Traditional Houses

Months	Modern House no-5 Ground floor	Traditional House no-6	Modern House no-9 top floor	Traditional House no-8	Modern House no-10 Ground floor	Traditional House no-9	Modern House no-16 Top floor	Traditional House no-10
January	320	50	650	75	600	75	280	120
February	310	50	560	74	500	74	200	110
March	250	30	300	77	300	77	140	95
April	270	30	350	80	350	80	150	90
May	280	40	500	90	380	95	230	95

June	270	30	430	90	370	90	230	90
July	250	40	410	85	350	85	220	90
August	230	30	370	84	330	84	190	90
September	240	40	350	85	320	90	180	90
October	220	30	350	80	300	80	180	80
November	230	30	430	75	400	75	210	80
December	280	50	500	75	500	75	240	110
Annual energy consumption in KWH	3150	450	5200	970	4700	980	2450	1140
Floor area in m^2	105	70	112	112	112	105	70	112
EPI in KWH/m^2/Year	30	6.43	46.43	8.66	41.96	9.33	35	10.18
Number of occupants	4	4	4	5	4	5	4	5
EPI/person in KWH/m^2/person / Year	7.5	1.61	11.61	1.73	10.49	1.87	8.75	2.04
Number of electrical appliances	12	6	13	8	12	8	12	8

Figure 4

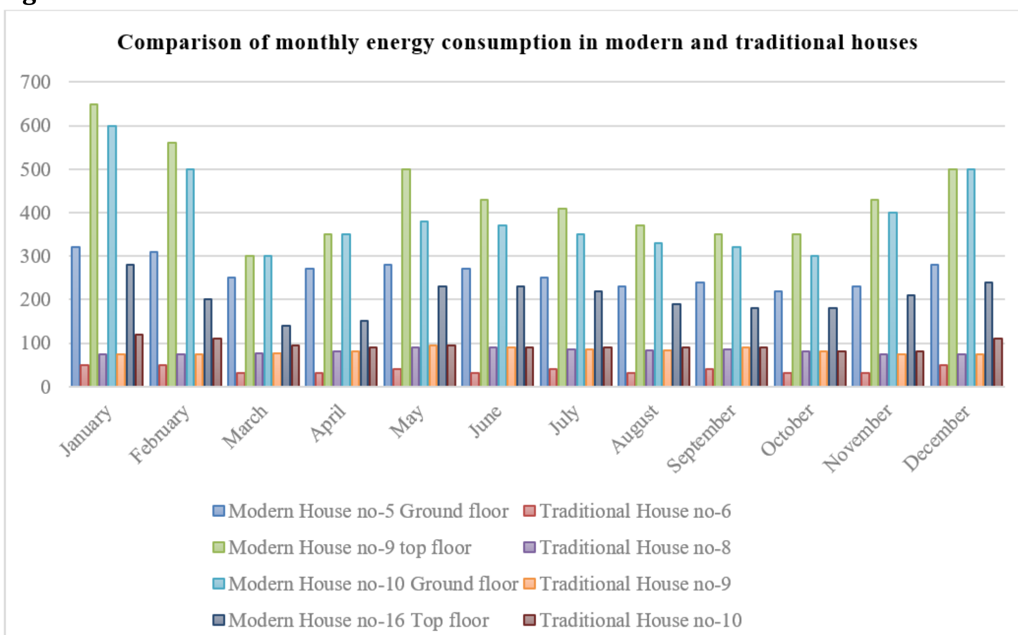

Figure 4 Comparison of Energy Consumption in Modern and Traditional Houses

4.4. FACTORS AFFECTING ANNUAL ENERGY CONSUMPTION AND EPI OF THE HOUSES

The multiple linear regression analysis has been done by using IBM® SPSS® Statistics (2022) tool to find out the correlation of different determinant factors such as total floor area, number of bed rooms, average annual household income, number of occupants, and number of different and total appliances, considered as independent variables, on the dependent variables 'total annual energy consumption' and EPI of the selected 10 traditional house and 30 modern houses at Mandi – Sundernagar (H.P.) town with composite climate. The data regarding the various parameters mentioned above are collected for the years 2021 and 2022, hence the number of datasets used in the statistical analysis is 80 (N=80). One set of linear regression analysis is done keeping the parameter EPI as dependent variable to develop a model for forecasting probable EPI of the residential buildings in the study area located in the hilly region with composite climate and other similar locations. The other linear regression model is developed keeping the parameter 'total annual energy consumption' as dependent variable to forecast the probable total annual energy consumption of the buildings located in the study area and other similar conditions. In the multiple linear regression analysis, the independent variables – number of TV, freeze, sound-system, and heater, which were found used in all the houses, considered as constants and they are not used as determinant factors in the regression models. Although number of these appliances are included in the variable 'total no of appliances' which has shown significant correlation with the parameters 'total annual energy consumption' and EPI values of the residential buildings.

Based on the regression analysis, the dependent variable 'total annual energy consumption' has shown strong correlation with the parameter 'average annual household income' (Pearson correlation coefficient, r = 0.930) which signifies that the increase in average household income will enhance the purchasing power of the households resulting into purchase and use of more electrical home appliances and equipment causing the increasing energy footprint of the residential buildings causing more demand on the power sector. Similarly, 'total annual energy consumption' has shown good correlation with factors – floor area of houses (r = 0.641), mixer-grinder (r = 0.473), computer/ laptop (r = 0.817), cooker (r = 0.817), microwave-oven (r = 0.817), geyser (r = 0.817), washing machine (r = 0.622), and total number of appliances (r = 0.813). The correlation between number of AC and total annual energy consumption (r = 0.210) is found low mostly due to the reason that houses with AC is less in number among the samples selected, nevertheless it has shown positive correlation with the total annual energy consumption. The correlation of total annual energy consumption with the parameters number of bedroom (r = 0.194) and number of occupants (r = 0.069) is found weak and that with number of radio (r = -0.597) is found having negative correlation which indicates that if the number of radios increases the total energy consumption may decrease. Further, the regression analysis has shown that the annual household income has good correlation with floor area (r = 0.740), computer/ laptop (r = 0.738), cooker (r = 0.738), oven (r = 0.738), geyser (r = 0.738), washing machine (r = 0.564) and total number of appliances (r = 0.686).

Similarly, the dependent variable - EPI has shown good correlation with average annual household income (r = 0.756), mixer-grinder (r = 0.529), washing-machine (r = 0.704), and strong correlation with computer/ laptop (r = 0.946), electric cooker (r = 0.946), microwave oven (r = 0.946), geyser (r = 0.946), total number of appliances (r = 0.958), which signifies that increasing intensity of using electrical home appliances will cause increasing the benchmark EPI value of residential buildings. The correlation of EPI with number of AC (r = 0.295) and floor area (r = 0.266) is moderate but indicates that the increase in number of AC will impact EPI. Further, the EPI shows weak correlation with number of occupants (r = 0.047) and negative correlation with number of bedroom (r = -0.159) and number of radio (r = -0.599), which signifies that as the number of bedrooms and number of radios increase the EPI of the houses may decrease.

The multiple linear regression analysis shows that the dependent variable - total annual energy consumption of the houses is influenced by the factors such as total number of appliances, number of occupants, building floor area, number of AC, mixer-grinder, radio, washing-machine, Geyser, number of bedroom, and annual household income. The analysis has shown that the dependent variable - total annual energy consumption (X) can be well predicted by the factors – floor area (B1), annual average household income (B2), mixer-grinder (B3), washing machine (B4), total number of appliances (B5) and can be expressed by the Equation 1.

$$X = 33.972B1 + 159.361B2 - 956.531B3 - 1003.087B4 + 681.253B5 - 6760.496$$

(The coefficient of determination, $R^2 = 0.957$, Confidence level = 95%)

Equation 1

In the above regression equation, the positive and negative coefficients indicate how much the dependent variable is expected to increase or decrease respectively when that independent variable increases or decreases by one unit, holding all other independent variables constant. The variables in the equation will use the same units in which they are measured in Freund & Wilson (2003). The statistical details of the regression model as per Equation 1 are shown in Table 4.

Table 4

Table 4 Statistical Details of the Regression Model with Total Annual Energy Consumption and its Predictors

Model Summary[b]	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.978[a]	.957	.950	382.50378

a. Predictors: (Constant), Total number of appliances, Number of occupants, Floor area, Number of bedrooms, Number of AC, Mixer, Radio, Washing machine, Geyser, Average annual household income

b. b. Dependent Variable: Total annual energy consumption

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	222976311.640988	10	22297631.164099	152.400807	.000[b]
	Residual	10095330.746512	69	146309.141254		
	Total	233071642.387500	79			

a. Dependent Variable: Total annual energy consumption

b. Predictors: (Constant), Total number of appliances, Number of occupants, Floor area, Number of bedrooms, Number of AC, Mixer, Radio, Washing machine, Geyser, Average annual household income

Similarly, the other linear regression analysis has shown that the dependent variable – Energy Performance Index (EPI) of the houses can be well predicted by the factors – annual average household income (C1) and total number of appliances (C2) and can be expressed by the Equation 2. The statistical details of the regression model as per Equation 2 are shown in Table 5.

$$EPI = 1.120C1 + 5.813C2 - 33.014$$ ($R^2 = 0.951$, Confidence level = 95%)

Equation 2

Table 5

Table 5 Statistical Details of the Regression Model with EPI and its Predictors

Model Summary[b]	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.975[a]	.951	.943	3.435033

a. Predictors: (Constant), Total number of appliances, Number of occupants, Floor area, Number of bedrooms, Number of AC, Mixer, Radio, Washing machine, Geyser, Average annual household income

b. Dependent Variable: EPI

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15668.394677	10	1566.839468	132.789159	.000[b]
	Residual	814.162272	69	11.799453		
	Total	16482.556949	79			

a. Dependent Variable: EPI

b. Predictors: (Constant), Total number of appliances, Number of occupants, Floor area, Number of bedrooms, Number of AC, Mixer, Radio, Washing machine, Geyser, Average annual household income

Simplistic prediction models are being developed through multiple regression analysis to predict the probable annual energy consumption and EPI value for residential buildings located in similar geoclimatic conditions through Equation 1 and Equation 2 respectively which shows good coefficient of determination (R^2) values. The proposed simplistic regression model also signifies the total household energy consumption and EPI values of residential buildings will be affected by the factors such as household income which will affect their affordability to use more electrical appliances resulting into higher consumption of energy. The proposed model should be further improved with larger dataset to be collected from the study area by conducting systematic household survey with necessary resources. Also, the model indicates that, since households are anyway going to use the available electrical appliances due to the fulfilling their household, educational, occupational, and recreational pursuit, the energy-efficiency labelling program like star-rating of electrical appliances BEE. (2017) should be carried on with timely updates to reduce the quantity of operational energy and associated carbon footprint of the domestic sector in India.

5. CONCLUSION

In India domestic sector consumes significant amount of electricity during pre-construction stage, construction stage, operation stage, and end-of-life/ demolition/ recovery/ recycle stage. In recent times household electricity consumptions are also increasing due to increase in total built-up area for housing, and change in life-style, education, economic and social condition in the country. The demand for more energy by the domestic sector is further accentuated by the process of rapid urbanization happening in our country due to economic liberalization and other associated factors which is causing the transformation of rural housing character to urban housing. The several studies and facts are showing that this phenomenon will continue in the coming decades. The demand for more energy by the domestic sector also puts more pressure on the supply side and results into more emission and increasing carbon footprint which may harm the environment.

Recent studies have shown the importance of collecting micro-level household energy consumption data from different geo-climatic location to enable more precise prediction regarding future energy consumption and demand by the residential sector. An attempt has been made in the present investigation to find out the EPI values of the traditional rural and modern urban houses in and around Mandi - Sundernagar (H.P.) area with 'composite' climatic condition through physical appraisal of the selected houses and by collecting information regarding the actual total annual energy consumption data as per the electricity bills. The present study has collected, analyzed and presented information regarding micro-level urban and rural household energy consumption data of a hilly state of India and other associated details regarding the various types and number of appliances used by the households and their usage pattern. The findings of the study have brought out the fact about the implication on monthly and annual energy consumption of residential buildings with traditional and modern construction methods.

- The calculated average EPI value of modern houses is found as 39.24 KWH/m^2/year (range: 29.43 – 50.53 KWH/m^2/year). In contrast, average EPI value of traditional houses is calculated as 7.89 KWH/m^2/year (range: 6.34 – 10.36 KWH/m^2/year), which is very much lower than the EPI values of modern houses. The study shows that the mean total annual energy consumption of modern houses is 5.4 times higher than that of the traditional houses; the mean EPI of modern houses is 5 times higher than that of the traditional houses; and the mean EPI/person of modern houses is 5 times higher than that of the traditional houses in the study area. This also indicates that traditional houses have much lesser energy footprint and carbon footprint in terms of operational energy when compared to the modern houses. Number of electrical appliances being used in the traditional houses are found lesser compared to the modern houses.
- The study has proposed simplistic empirical models through regression analysis to predict probable total annual energy consumption and Energy Performance Index (EPI) for the residential buildings located in the study area with composite climate which may be applicable to other similar condition with the help of predictor parameters. However, the present study is constrained with relatively small sample size due to available resource required to carry out survey with larger samples. Hence, in future more such studies should be carried out to develop empirical model for realistic future projection regarding household energy consumption in urban and rural areas and to find out an optimum holistic EPI bench-mark values for different building typologies in different geo-climatic regions of the country considering the emerging scenarios, which will benefit the professionals, experts related to the building industry to incorporate and integrate necessary strategies during conceptualization and construction of the building projects.
- Further, this type of studies will assist the concerned policy makers and other concerned authorities to assess the present and future energy demand to take suitable measures regarding production and supply of electricity and to make the home appliances more energy-efficient which will benefit the society and country by saving and optimum use of natural resources and by investing more on renewable green energy sources like

solar, wind, biomass, which is also a commitment given by the Indian government as one of its initiatives to make the country resilient against the local and global climate change phenomena.

6. DECLARATIONS

- The author has no relevant financial or non-financial interests to disclose.
- The author has no competing interests to declare that are relevant to the content of this article.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

BEE, Annual Report (2020-2021). Bureau of Energy Efficiency, Ministry of Power, Government of India, New Delhi.

BEE. (2007). Energy Conservation Building Code 2007. Bureau of Energy Efficiency, Ministry of Power, Government of India, New Delhi.

BEE. (2014). Chapter 2: Survey and Monitoring of Electricity Consumption, Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings (Composite and Hot-Dry Climates). Bureau of Energy Efficiency, Ministry of Power, Government of India, New Delhi.

BEE. (2017). Energy Conservation Building Code.

BIS. (2004). Indian Standard - Guide for Heat Insulation of Non-Industrial Buildings (First Revision) IS: 3792-1978. Bureau of Indian Standards, New Delhi.

BIS. (2016). National Building Code of India 2016 SP 7: 2016. Bureau of Indian Standards, New Delhi.

Baker, P., Blundell, R., & Micklewright, J. (1989). Modelling Household Energy Expenditures using Micro-Data. Econ J, 99(397), 720–738. https://doi.org/10.2307/2233767

Baltruszewicz, M., Steinberger, J.K., Owen, A., Brand-Correa, L.I., & Paavola, J. (2021). Final Energy Footprints in Zambia: Investigating Links between Household Consumption, Collective Provision, and Well-Being. Energ. Res. Soc. Sci., 73 (6), 101960. https://doi.org/10.1016/j.erss.2021.101960

Basu, C., Paul, V.K., & Matt Syal, M.G. (2019). Performance Indicators for Energy Efficiency Retrofitting in Multifamily Residential Buildings. Journal of Green Building, 14(2), 109-136. https://doi.org/10.3992/1943-4618.14.2.109

Bhatt, M.S., Rajkumar, N., Jothhibasu, S., Sudhirkumar, R., Pandian, G., & Nair, K.R.C. (2005). Commercial and Residential Building Energy Labeling. Journal of Scientific & Industrial Research, 64(1), 30-34.

Census of India. (2011).

Ding, Y.X. & Peng, S. (2020). Study on the Spatial Distribution and Influencing Factors of Household Energy Consumption in China. [J]. Resource Development Market, 36(04), 366–370.

EIA. (2022, October 6).

Ekonomou, G. & Menegaki, A.N. (2023). The Role of the Energy Use in Buildings in Front of Climate Change: Reviewing a System's Challenging Future. Energies, 16, 6308. https://doi.org/10.3390/en16176308

Espey, J.A. & Espey, M. (2004). Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities. J Agric Appl Econ, 36(1), 65–81.

Freund, R.J. & Wilson, W.J. (2003). Statistical Methods (2nd Ed.). Academic Press.

GBPN. (2014). Residential Buildings in India: Energy Use Projections and Savings Potentials. Global Building Performance Network, Paris.

Gassar, A., Yun, G.Y., & Kim, S. (2019). Data-Driven Approach to Prediction of Residential Energy Consumption at Urban Scales in London. [J]. Energy, 187(11). https://doi:10.1016/j.energy.2019.115973

Gupta, G., Mathur, S., Mathur, J., & Nayak, B.K. (2023). Blending of Energy Benchmarks Models for Residential Buildings. Energy and Buildings, 292. https://doi.org/10.1016/j.enbuild.2023.113195

Gupta, G., Mathur, S., Mathur, J., & Nayak, B.K. (2023). Comparison of Energy-Efficiency Benchmarking Methodologies for Residential Buildings. Energy and Buildings, 285. https://doi.org/10.1016/j.enbuild.2023.112920

IAEA. (2005). Energy Indicators for Sustainable Development: Guidelines and Methodologies. International Atomic Energy Agency, Austria.

IEA. (2013). Technology Roadmap: Energy Efficient Building Envelopes. International Energy Agency, France.

IEA. (2020). Key World Energy Statistics. International Energy Agency, France.

IMD. (2022). Climatological Tables of Observatories in India 1991-2020. India Meteorological Department, Ministry of Earth Sciences, Government of India, New Delhi.

ISHRAE. (2017). Indian Weather Data 2017. Indian Society of Heating, Refrigerating and Air Conditioning Engineers, India.

Inoue, N., Matsumoto, S., & Mayumi, K. (2021). Household Energy Consumption Pattern Changes in an Aging Society. The Case of Japan between 1989 and 2014 in Retrospect. Int J Econ Policy Stud. https://doi.org/10.1007/s42495-021-00069-y

KfW & NHB. (2009). Consulting Services for the Design of a "Promotional Programme for Energy Efficient New Residential Housing in India" Through the National Housing Bank (NHB). Kreditanstalt für Wiederaufbau & National Housing Bank, New Delhi.

Koenigsberger, O.H., Ingersoll, T.G., Mayhew, A. & Szokolay, S.V. (2013). Manual of Tropical Housing and Building – Climatic Design. Universities Press (India) Private Limited, Delhi, India.

Lianwei, Z. & Wen, X. (2021). Urban Household Energy Consumption Forecasting Based on Energy Price Impact Mechanism. Front. Energy Res. 9. https://doi.org/10.3389/fenrg.2021.802697

MOSPI. (2019). Energy Statistics 2019. Central Statistics Office, New Delhi.

Matsumoto, S., Mizobuchi, K., & Managi, S. (2022). Household Energy Consumption. Environmental Economics and Policy Studies. 24, 1–5. https://doi.org/10.1007/s10018-021-00331-9

SDC. (2010). A Report on Baseline Scenario of Energy Performance of Residential Buildings in Composite Climate of India. Swiss Agency for Development and Cooperation.

Sarkar, A., & Bose, S. (2015). Thermal Performance Design Criteria for Bioclimatic Architecture in Himachal Pradesh. Current Science, 109(9), 1590-1600. https://doi.org/10.18520/cs%2Fv109%2Fi9%2F1590-1600

Sarkar, A., & Bose, S. (2016). Exploring Impact of Opaque Building Envelope Components on Thermal and Energy Performance of Houses in Lower Western Himalayans for Optimal Selection. Journal of Building Engineering, 7, 170-182. https://doi.org/10.1016/j.jobe.2016.06.009

TERI. (2019). GRIHA Reference Guide Version-2019-Vol-1 for green building design and certification, The Energy and Resources Institute, Ministry of New and Renewable Energy, Government of India, New Delhi.

ANNEXURE

Annexure 1

Annexure 1 Energy Performance Index (EPI) Details of the Selected Traditional Houses

Traditional houses				Year-2021			
House No.	EPI (KWH/m²/ Year)	Floor area (m²)	Total annual energy consumption (KWH)	No. of bedrooms	No. of occupants	EPI/person (KWH/m²/ person/Year)	Annual household income (Rs. in lakhs)
1	8.06	90	725	3	4	2.01	6.00
2	8.33	90	750	3	4	2.08	6.00
3	7.00	80	560	3	4	1.75	6.00
4	6.38	80	510	3	4	1.59	5.00
5	7.20	82	590	3	4	1.80	5.00
6	6.86	70	480	2	4	1.71	4.80
7	7.72	92	710	3	5	1.54	4.50
8	8.48	112	950	4	5	1.70	6.50
9	9.24	105	970	4	5	1.85	6.00
10	10.36	112	1160	4	5	2.07	6.20
Traditional houses				Year-2022			
1	8.09	90	728	3	4	2.02	6.00
2	7.67	90	690	3	4	1.92	6.00
3	6.38	80	510	3	4	1.59	6.00
4	6.88	80	550	3	4	1.72	5.00
5	6.34	82	520	3	4	1.59	5.00
6	6.43	70	450	2	4	1.61	4.80
7	8.26	92	760	3	5	1.65	4.50
8	8.66	112	970	4	5	1.73	6.50
9	9.33	105	980	4	5	1.87	6.00
10	10.18	112	1140	4	5	2.04	6.20

Annexure 2

Annexure 2 Energy Performance Index (EPI) Details of the Selected Modern Houses

Modern houses	Year-2021							
Floor	House No.	EPI (KWH/m² / Year)	Floor area (m²)	Total annual energy consumption (KWH)	No. of bedrooms	No. of occupants	EPI/person (KWH/m²/ person/ Year)	Annual household income (Rs. in lakhs)
Top	1	39.29	70	2750	2	4	9.82	7.20
Ground	2	39.00	70	2730	2	4	9.75	7.20

Ground	3	32.45	94	3050	3	4	8.11	10.00
Top	4	34.04	94	3200	3	5	6.81	9.00
Ground	5	29.43	105	3090	3	4	7.36	12.00
Ground	6	40.71	70	2850	2	4	10.18	7.00
Top	7	50.53	94	4750	3	4	12.63	10.00
Top	8	49.47	95	4700	3	4	12.37	11.00
Top	9	46.43	112	5200	3	4	11.61	12.00
Ground	10	45.54	112	5100	3	4	11.38	14.00
Ground	11	46.43	140	6500	4	4	11.61	16.00
Top	12	47.14	140	6600	4	4	11.79	17.00
Ground	13	39.29	140	5500	4	4	9.82	16.50
Top	14	43.62	94	4100	3	5	8.72	11.00
Ground	15	32.98	94	3100	3	6	5.50	11.00
Top	16	35.71	70	2500	2	4	8.93	9.00
Ground	17	32.86	70	2300	2	5	6.57	9.50
Ground	18	36.57	105	3840	3	6	6.10	11.00
Ground	19	36.00	100	3600	3	4	9.00	10.00
Top	20	37.00	100	3700	3	6	6.17	10.50
Ground	21	36.67	90	3300	3	4	9.17	10.00
Top	22	40.00	80	3200	2	4	10.00	9.00
Top	23	42.50	80	3400	2	5	8.50	9.00
Top	24	45.63	80	3650	2	5	9.13	11.00
Top	25	46.92	130	6100	4	6	7.82	14.00
Top	26	43.33	120	5200	3	5	8.67	14.00
Top	27	40.42	120	4850	3	4	10.10	12.50
Ground	28	34.17	120	4100	3	5	6.83	13.00
Ground	29	34.55	110	3800	3	4	8.64	13.50
Ground	30	35.24	105	3700	3	6	5.87	11.00
Modern houses	**Year-2022**							
Floor	**House No.**	**EPI (KWH/m² / Year)**	**Floor area (m²)**	**Total annual energy consumption (KWH)**	**No. of bedrooms**	**No. of occupants**	**EPI/person (KWH/m²/ person/ Year)**	**Annual household income (Rs. in lakhs)**
Top	1	40.00	70	2800	2	4	10.00	7.20
Ground	2	37.86	70	2650	2	4	9.46	7.20
Ground	3	32.98	94	3100	3	4	8.24	10.00
Top	4	34.57	94	3250	3	5	6.91	9.00
Ground	5	30.00	105	3150	3	4	7.50	12.00
Ground	6	41.43	70	2900	2	4	10.36	7.00
Top	7	50.53	94	4750	3	4	12.63	10.00
Top	8	48.95	95	4650	3	4	12.24	11.00
Top	9	46.43	112	5200	3	4	11.61	12.00
Ground	10	41.96	112	4700	3	4	10.49	14.00
Ground	11	46.43	140	6500	4	4	11.61	16.00
Top	12	42.14	140	5900	4	4	10.54	17.00
Ground	13	41.07	140	5750	4	4	10.27	16.50
Top	14	35.64	94	3350	3	5	7.13	11.00
Ground	15	37.23	94	3500	3	6	6.21	11.00
Top	16	35.00	70	2450	2	4	8.75	9.00

Ground	17	37.14	70	2600	2	5	7.43	9.50
Ground	18	35.71	105	3750	3	6	5.95	11.00
Ground	19	36.00	100	3600	3	4	9.00	10.00
Top	20	35.40	100	3540	3	6	5.90	10.50
Ground	21	34.44	90	3100	3	4	8.61	10.00
Top	22	40.63	80	3250	2	4	10.16	9.00
Top	23	39.38	80	3150	2	5	7.88	9.00
Top	24	36.25	80	2900	2	5	7.25	11.00
Top	25	43.08	130	5600	4	6	7.18	14.00
Top	26	43.75	120	5250	3	5	8.75	14.00
Top	27	36.67	120	4400	3	4	9.17	12.50
Ground	28	36.00	120	4320	3	5	7.20	13.00
Ground	29	30.91	110	3400	3	4	7.73	13.50
Ground	30	32.86	105	3450	3	6	5.48	11.00

Annexure 3

Annexure 3 Details of Electrical Appliances Found in the Houses Selected

House No.	Radio	TV	Fridge	Mixer-grinder	Computer/ Laptop	Electric cooker	Microwave-oven	CD-Player/ Sound-system	Geyser/ Water heater	Washing machine	Electric heater	Air-conditioner	Total no. of home appliances
Modern houses													
1	0	1	1	1	2	1	1	1	2	1	1	0	12
2	1	1	1	1	2	1	1	1	2	1	1	0	13
3	0	1	1	1	2	1	1	1	2	1	1	0	12
4	0	1	1	1	2	1	1	1	2	1	1	0	12
5	0	1	1	1	2	1	1	1	2	1	1	0	12
6	1	1	1	1	2	1	1	1	2	1	1	0	13
7	1	1	1	1	2	1	1	1	2	1	1	1	14
8	1	1	1	1	2	1	1	1	2	1	1	1	14
9	1	1	1	1	2	1	1	1	2	1	1	0	13
10	0	1	1	1	2	1	1	1	2	1	1	0	12
11	0	1	1	1	2	1	1	1	2	1	1	0	12
12	0	1	1	1	2	1	1	1	2	1	1	0	12
13	0	1	1	1	2	1	1	1	2	1	1	0	12
14	0	1	1	1	2	1	1	1	2	1	1	0	12
15	0	1	1	1	2	1	1	1	2	1	1	0	12
16	0	1	1	1	2	1	1	1	2	1	1	0	12
17	0	1	1	1	2	1	1	1	2	1	1	0	12
18	0	1	1	1	2	1	1	1	2	1	1	0	12
19	0	1	1	1	2	1	1	1	2	1	1	0	12
20	0	1	1	1	2	1	1	1	2	1	1	0	12
21	0	1	1	1	2	1	1	1	2	1	1	0	12
22	0	1	1	1	2	1	1	1	2	1	1	1	13
23	0	1	1	1	2	1	1	1	2	1	1	0	12
24	0	1	1	1	2	1	1	1	2	1	1	0	12

25	0	1	1	1	2	1	1	1	2	1	1	1	13
26	0	1	1	1	2	1	1	1	2	1	1	0	12
27	0	1	1	1	2	1	1	1	2	1	1	0	12
28	0	1	1	1	2	1	1	1	2	1	1	0	12
29	0	1	1	1	2	1	1	1	2	1	1	0	12
30	0	1	1	1	2	1	1	1	2	1	1	0	12
Traditional houses													
1	1	1	1	1	1	0	0	1	0	0	1	0	7
2	1	1	1	0	1	0	0	1	0	0	1	0	6
3	1	1	1	0	1	0	0	1	0	0	1	0	6
4	1	1	1	0	1	0	0	1	0	1	1	0	7
5	1	1	1	1	1	0	0	1	0	0	1	0	7
6	1	1	1	0	1	0	0	1	0	0	1	0	6
7	1	1	1	1	1	0	0	1	0	0	1	0	7
8	1	1	1	1	1	0	0	1	0	1	1	0	8
9	1	1	1	1	1	0	0	1	0	1	1	0	8
10	1	1	1	1	1	0	0	1	0	1	1	0	8