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IMPROVING ENERGY EFFICIENCY POTENTIAL OF RESIDENTIAL BUILDING OF COMPOSITE CLIMATE IN PUNJAB

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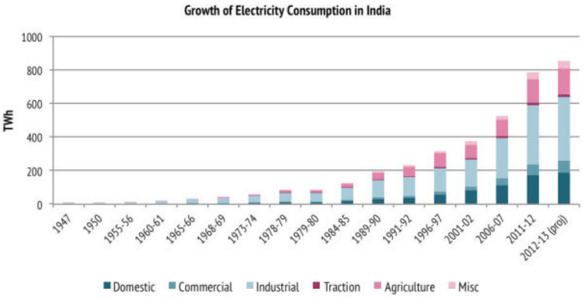
ABSTRACT

India is the second most populous country with a population of 1.3 billion in the world and the third-largest economy, measured by purchasing power parity (PPP). By 2024-25, India has set a target growth rate of 9%, which would place it on a trajectory towards becoming a USD 5 trillion economy, making it the fastest-growing large economy in the world. India's sustained economic growth is placing an enormous demand on its energy resources, energy systems and infrastructure. There are a large number of existing buildings that perform poorly in terms of energy, wasting resources and polluting the environment. In order to overcome big challenges in energy conservation and the reduction in carbon dioxide emissions, promoting the energy efficiency of existing buildings should be of great use. However, user concerns may also be a result of inappropriate use.
This paper aims to provide solution for improving the energy efficiency of existing residential buildings in India. Using data from a typical residential building, an energy model is built and analyzed. Models with different energy saving strategies are then presented to investigate practice and potential solution with regards to energy efficiency and cost. And also calculating the carbon emission produced by the building and evaluating the strategies to lower down the emission. The orientations are also being judged for energy efficient measures.

Key words- Energy Efficiency, Composite climate, EPI, RETV, Carbon emission, Life cycle cost, operational cost, residential sector.

1.0 Introduction:

India coming within the category of developing nations, is growing fast, with a uniform rate every year. With the broading, it has to adjust to the increasing energy demands mainly in the form of electricity. Per Capita Consumption of electricity has increased from 672 kWh in 2007 to 1122 kWh in 2017 according to the report "Growth of Electricity Sector in India from 1947 to 2017" by Ministry of Power, Government of India . The last decade had witnessed a Compound Annual Growth rate (CAGR) of more than 5%. Sector-wise in electricity consumption can be seen from the below figure.



Rising GDP and greater affordability of consumer goods has amplified the purchasing power of Indian consumers resulting in dramatic changes in pattern of energy consumption. Contemporary commercial and residential buildings contain several electrical appliances. This higher penetration of appliances and increased usage lead to a higher Energy Performance Index (EPI) in buildings. However, although the use of energy-consuming appliances is rising, energy consumption due to building envelope characteristics is expected to remain a major element in total energy consumption. A major role that plays in making buildings comfortable both thermally and visually is the building envelope, which consists of external walls, fenestration and roofs, plays a major. When a building does not meet up comfort criteria, occupants reply on mechanical and electrical comfort and lighting systems. Reliance on energy driven systems can only be reduced when the building envelope responds positively to the local climatic context.

A scenario study, commissioned by Global Buildings Performance Network (GBPN) and produced by the Centre for Climate Change and Sustainable Energy Policy (3CSEP) of the Central European University (CEU), estimates that India could easily experience an boost in building energy consumption and CO2 emissions of around 700% by 2050, compared to 2005 levels.

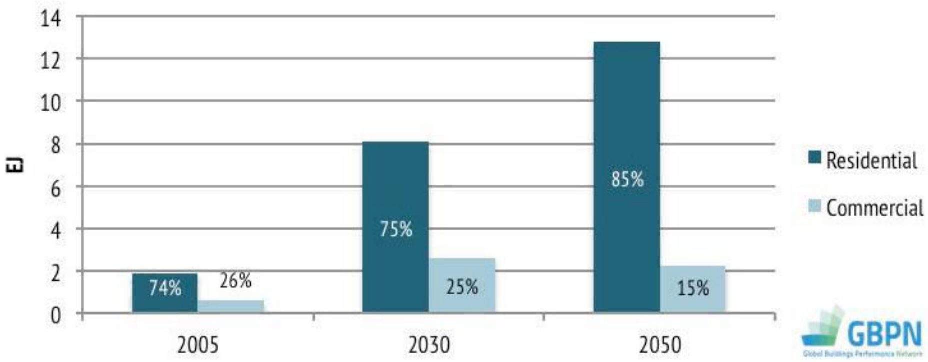


Figure 3: India’s moderate efficiency scenario projected energy consumption of India's buildings in 2030 and 2050; percentages represent the ratio of residential and commercial buildings. Source GBPN (2012).

The learning also indicates that buildings have a “lock-in” period of at least 50-60 years. If energy efficiency measures at the initial construction stage of new residential buildings are not included, then retrofitting these buildings at a later date may not be the best option, economically.

ECBC 2007 has been introduced by BEE on recommended basis but shall be made mandatory in few years and the State Governments shall be responsible for enforcing ECBC through local municipal authorities. Hence, it has to be referred by the architects for designing energy efficient buildings in future.

2.0 Need of the Study:

The composite climate zone of India poses building design challenges to architects because of extreme hot, cold, and humid conditions in different periods of the year. As per ECBC User Guide, the characteristics of climate, the thermal requirements in buildings, and their physical manifestations dictate the ECBC requirements for the building envelope. ECBC specifies the parameters which affect the performance of building may not be the best option, economically. Hence the architects are encouraged to use ECBC in the preliminary design stages.
The research is guided by the following questions:

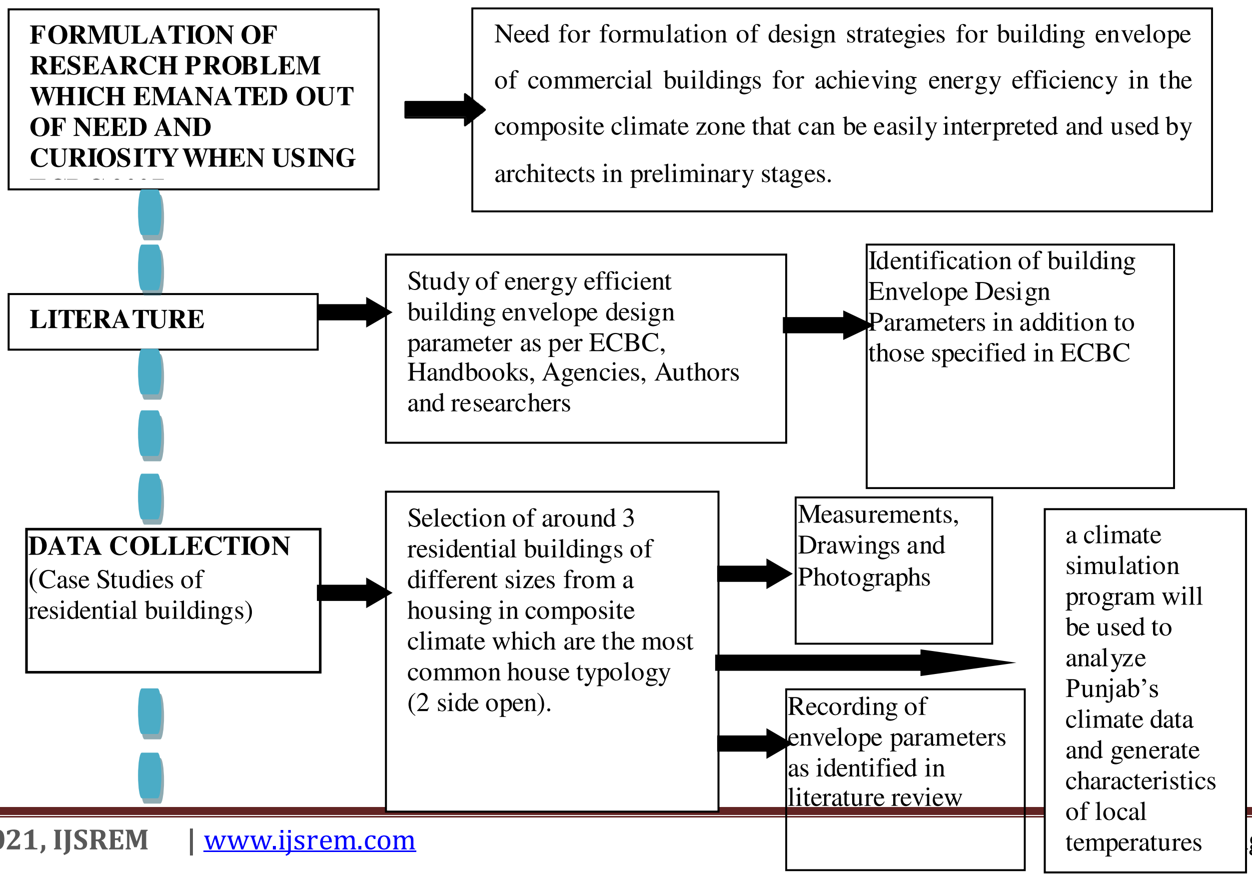
1 Whether architectural design parameters impact energy performance of the building?
2 Whether we can achieve substantial energy efficiency using passive parameters?

The results would provide the Architects with strategies for the design of energy efficient building envelope that can be easily interpreted and used in preliminary stages (w.r.t. residential buildings in the composite climate zone).

3.0 Aim and Objective of the Study:
The aim of this research is to evaluate building performance with respect to energy efficiency potential in residential buildings of composite climate in India.
The objectives of this research are:-

- To understand the energy issues, carbon footprint in residential sector of composite climate from available literature.
- To conduct building envelope configuration studies through case study and building codes.
- To conduct simulation studies on selected cases and calculate the energy performance, RETV, carbon footprint and lifecycle cost of building envelope in various orientations in composite climate.
- To analyze and compare the results to evaluate the energy efficiency potential and validate the results through carbon footprint and RETV.
- To recommend strategies for improvement of energy performance in residential sector.

4.0 Methodology:



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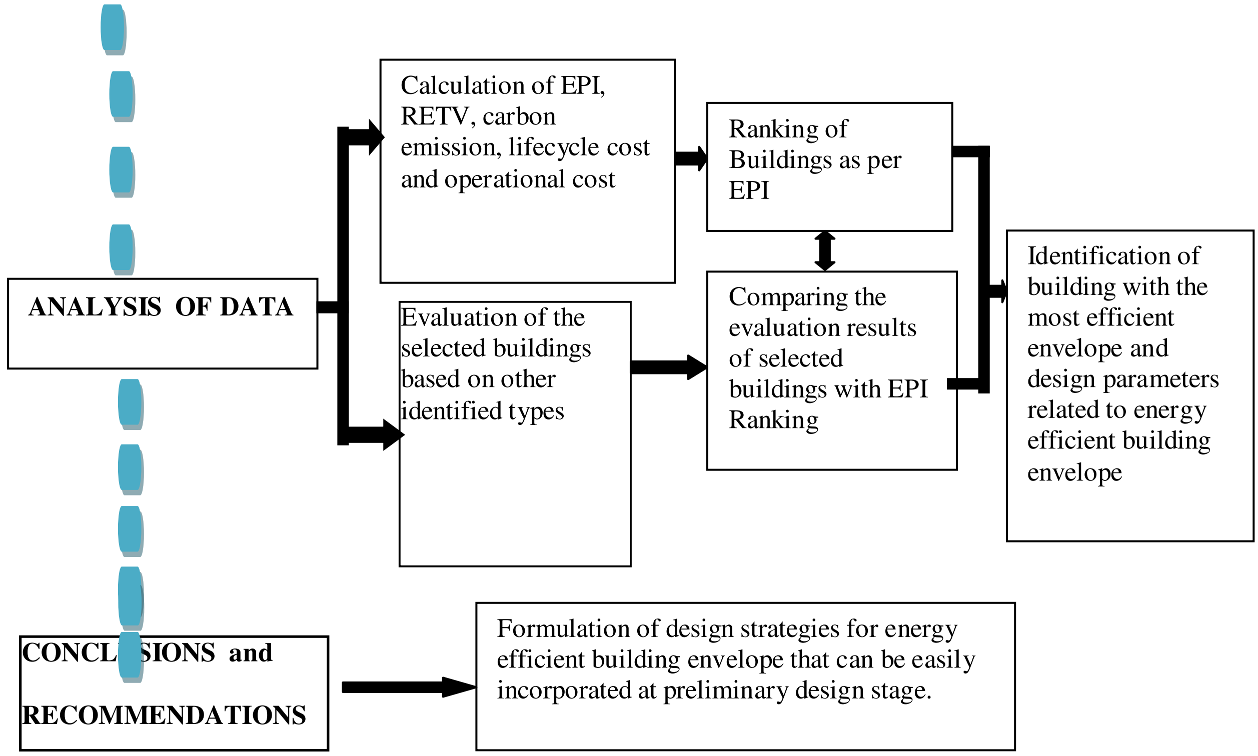


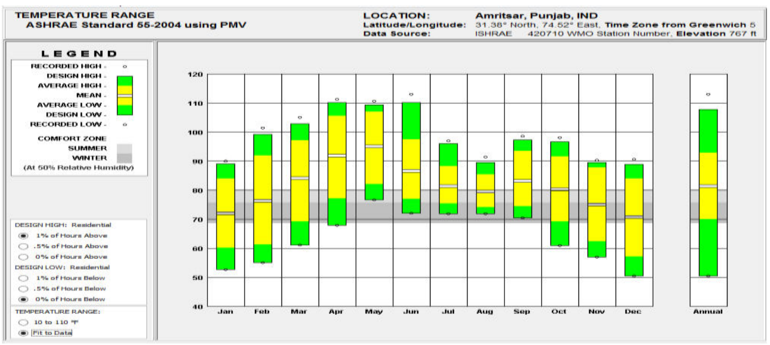
Specifically, four steps will be taken as stated below.

In the **first step** of the study, Climate Consultant, a climate simulation program will be used to analyze Punjab's climate data and generate characteristics of local temperatures. It will also produce a psychometric chart indicating the yearly total hours in the comfort zone and how to increase those hours.

In the **second step**, a reference models will be selected according to the house typologies as mentioned by BEE. The chosen 2-story existing residential building's components, such as the information on its wall, roof, windows, and building service system will be added as basic information for the reference model. Next, an energy simulation program will be used to generate the reference building's energy use within the climate zone of the chosen city. The energy use number generated will then be used as the baseline for further comparison.

In the **third step** of the study, using ECO NIWAS SAMITHA (advance) , an energy simulation program, three different proposed thicknesses of thermal insulation for the walls and roof, two different types of windows, two different rates of energy efficiency for the HVAC will be analyzed within the same climate zone but with different orientation that the reference building occupies. Proposed types are decided among the suggested energy efficient material according to the Energy Conservation Building Code for residence. After analysis, the results will be compared. Based on energy consumption the evaluation of the energy efficiency potential will be done and validation of the results will be done through carbon footprint and RETV.

Lastly, each component recommended in steps 2 and 3 of the study will input into ECONIWAS SAMITHA(advance) , thereby generating the energy usage for the ultimate energy-efficient and cost-efficient residential building model. Through comparing the results with the baseline model's energy usage, the energy savings will be obtained.



5.0 Analysis and data

According to the American Society of Heating, Refrigerating and Air-Conditioning

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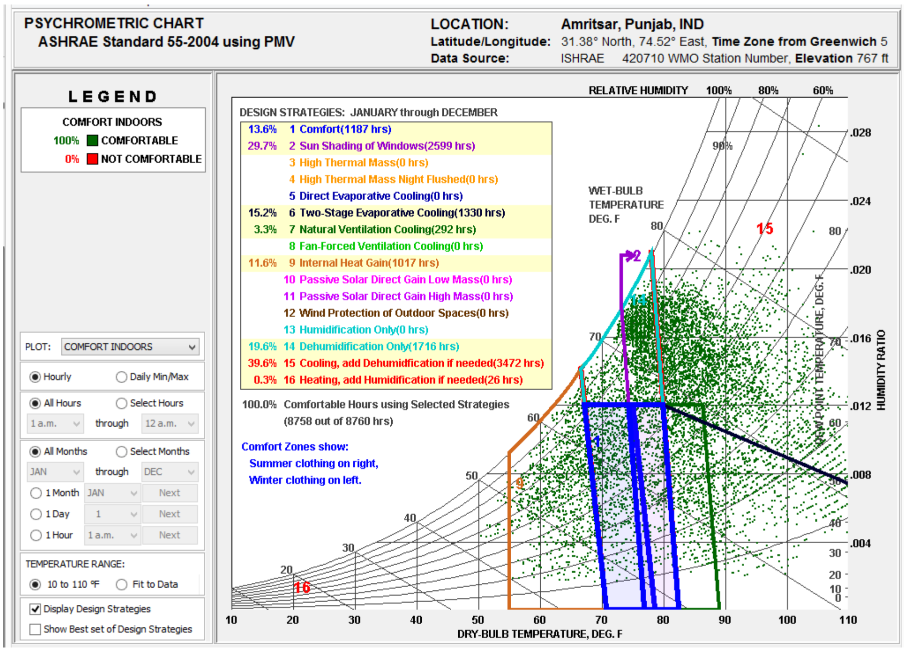
Engineers(ASHRAE) Standard 55, Punjab's comfort temperature zone is 75°F - 80°F in summer and 69°F-75°F in winter (ASHRAE, 2013). In Figure 20, it shows that in Punjab, april ,may,june,july,august, these five months are exclusively cooling needed. Because their highest dry-bulb temperature is 110°F. November febrary,march are the only months for which the average temperature is in the comfort zone. In March, April, September and octuber, more than 50% of the days require cooling in order to feel comfortable.



Comfort Zone

The comfort zone is also referred as the thermal comfort zone. It describes people's perceptions of satisfactory levels for their thermal environment (Ecophon, 2010). The heat exchange between a human body and its surroundings affects the thermal indoor environment. An input of metabolic rate (human activity type) and clothing level (human clothing type) is required to generate a comfort zone. According to ASHRAE Standard 55, the metabolic rate for standing while relaxed is 1.2; for seated, it is 1.0; and for sleeping, it is 0.7. These activities represent the most common human activities in a residential building. This study will use the average of these three rates, which is 1.0, as the metabolic input data. The clothing levels will be 0.5 for typical summer indoor clothing (shorts, light top) and 1.0 for typical winter indoor clothing (long pants, sweater). The psychrometric chart generated using this information is shown in Figure. It indicates that people feel comfortable only 13.6% (1187 hrs) of the year without heating or cooling. Cooling, in particular, is very important in terms of making people feel comfortable. It can increase the number of comfortable hours by 39.6% (3472 hrs). A two stage evaporative cooling can increase comfort by 15.2% (1330hrs) and natural ventilation will increase by 3.3%(292hrs) . Sun shading of windows can increase the number of comfortable hours by 29.7% (2599 hours), and dehumidification can increase the number of comfortable hours by 19.6% (1716 hours). It is easy to see that cooling is the largest factor affecting thermal comfort.

5.1 Reference Model

Basic Information

A typical existing housing in Amritsar, Punjab is used for the reference data. It is an housing with an area of 2 acres, with three types of single family houses. The gross area for unit is 63 m^2,118 m^2,182m^2 . Based on the data collected regarding these typical building. Zones 3023, 3042 and 3065 represent the three different units . The three zones are further being analysed on the basis of type1, type2, type 3. Type 1 include the most efficient construction material according to the u- value and then type 2 and then type 3 according to u-value of the materials.

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Figure 11: layout floor plans of model 3023,3042,3065

Building Envelope

The details of the wall assembly in the existing building. They are very common wall details, found in residential construction throughout Punjab. The exterior wall is 9 inch thick brickwall and has cement and sand on each outer side to level the surface. One layer of paint is applied to the external side of the walls only. The U-value of this exterior wall is 2.1W/m2k. The interior wall is similar to the exterior wall. The roof is 8" reinforced concrete with U- value 3.59 W/m2k . Aluminum-framed windows with normal clear glass , which provide a U-value of 5.5 W/m2k , are very common in India and used throughout. An overhang was used as a shading device without any side fins. The total construction cost for all the three are 9 lakh, 12 lakh and 54 lakh for unit 63 m2,118 m2,182m2 respectively. The energy price in Punjab is rs 8 per unit. The EPI calculated is 69.56, 83.76 and 78.64 (kWh/m² .Year for 63 m2,118m2 and 182m2 respectively.

Cooling System

In India, the most common cooling system used in a residential building is a split-air-handling unit. It comes with two components: one is the indoor air handler, the other is an outdoor heat pump.

Lighting System

Lighting systems are discussed generally in this research. Because LED lighting has the highest energy efficiency of all of the lightings on the market, as its technology develops, prices have continued to drop. In 2018, one 60-watt-equivalent LED light bulb (8.3 watts) was $1.24, very different from its $10 price in 2015 (LEDinside Nicole, 2016). In terms of lighting power density (LPD), for example, using LED lighting in a 100 ft2 family dining area, which would need the equivalent of 30 lumens x 100 = 3000 lumens of light (Submissions, 2018), would mean that four 8.3-watt LED bulbs would be needed (an 8.3-watt LED bulb provides 800 lumens of light). The LPD is thus 4x8.3-watt/100 ft2= 33 w/ft2. The ASHRAE 90.1-2010 standard for that same area is 0.89 w/ft2. Hence using LED lighting makes the lighting 62% more efficient than the ASHRAE standard. The LED lighting is the best choice for improving lighting energy efficiency in both existing and new buildings.The LPD for this research is set as .089w/ft2

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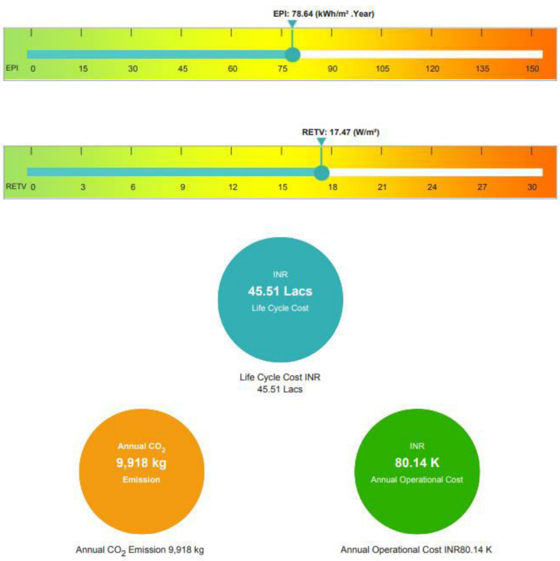
Plug Loads

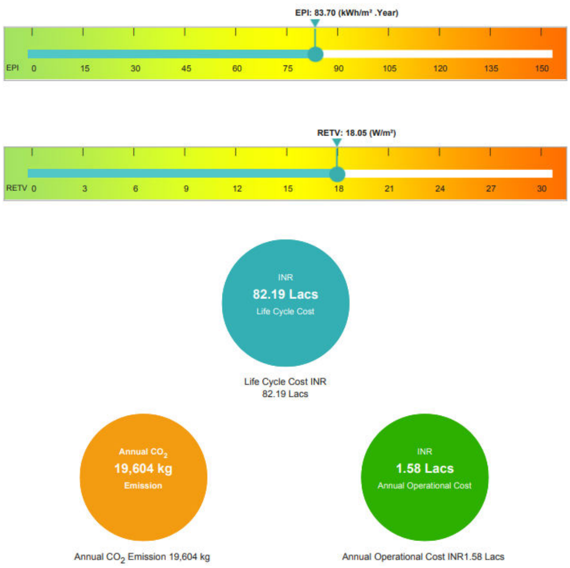
Plug loads are the energy that used by equipment that is plugged into an outlet, excluding general lighting, heating, cooling, water heating, or ventilation. Plug loads devices vary by household and location. In terms of common ones in Indian household, refrigerators, washing machines, televisions, computers, and kitchen ventilation are most likely seen in an average indian family. With acceleration of urbanization and rising income in Indian households, ownership of appliances is expected to increase. According to the visual survey of housing all the houses owned refrigerator, washing machine, TV and some basic kitchen appliances. In addition, kitchen ventilation becomes necessary for cleaner and healthier life due to Indian cooking habits. Therefore, these five types of plus load devices will be included in reference model. Each type of appliances has various models with different wattages. The typical wattages that most common models of these five plug load devices may pull in an average five-person Indian household is studied. In the reference model the unit of 63 m2,118 m2,182m2 consumes 1200, 1800, 2150 watts. Therefore, it will be set as the reference point of plug loads in reference model. This research intends to improve energy efficiency of existing residential buildings in Punjab. It is true that as buildings become more energy efficient, the impact of plug loads become more apparent. Hence, it is strongly recommended that each household pay attention to the BEE STAR RATING on the bodies of appliances and purchase as highest level as they can afford to live an energy saving life. In addition, it is suggested that residents care about plug loads and keep no-cost energy-saving habits, such as turning appliances all off instead of leaving them active modes However, it is impossible to require residents to use or not to use specific models of appliances. Therefore, in this research the plug loads will be considered as only a basic component in the analysis.

5.2 Reference Model Energy Usage

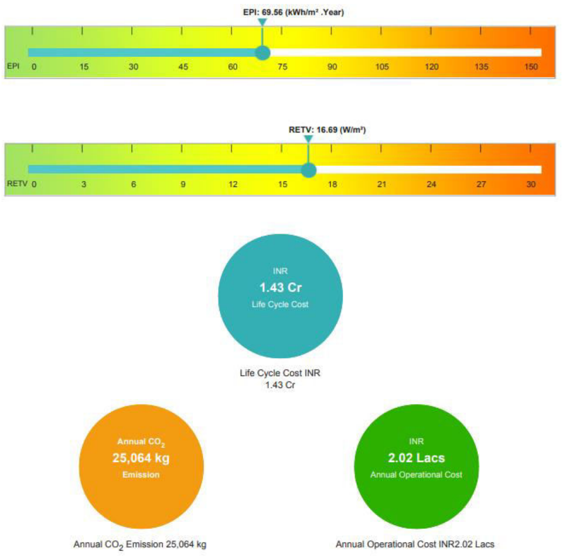
The reference model annual EPI 69.56, 83.76 and 78.64 (kWh/m² .Year), as shown in Figure . The energy cost is rs 8 per unit. The cooling-on set point is 24°c. with COP of 3.2.And the RETV (Residential Envelope Transmittance Value) is 16.69,18.05, 17.47 which make it thermally uncomfortable and make it rely more on mechanical cooling.



Reference model 3023 having EPI 78.64 (kWh/m² .Year), RETV of 17.47 (w/m2),annual carbon emission of 9918kg and with annual operating cost of 80.14 k and life cycle cost of 45.51lacs.



Reference model 3042 having EPI 83.70 (kWh/m² .Year), RETV of 18.05 (w/m2),annual carbon emission of 19,604kg and with annual operating cost of 1.58 lacs and life cycle cost of 82.19 lacs.



Reference model 3065 having EPI 69.56 (kWh/m² .Year), RETV of 16.69 (w/m2),annual carbon emission of 25064kg and with annual operating cost of 2.02 lacs and life cycle cost of 1.43cr.

The HVAC system, making it the largest consumer of energy in the reference model as the need for cooling and dehumidification is 60% to be in comfort zone in composite climate as per Ashrea climate data. Reducing the HVAC's energy use will have the largest impact on the total energy consumption in the reference model.

There are two strategies that could be used to reduce the HVAC's energy use:
Insulating the thermal envelope well in order to reduce the energy loss.
Using high-performance HVAC equipment to use less energy to generate the same amount of heating and cooling.
These two strategies will be compared in the following section.

According to the U- value three types of categories of energy efficient types are made i.e.
Type 1 (most efficient),
Type2 (more efficient) a nd
Type3 (efficient) and
Baseline(which is the most common construction seen).
The following are the materials included in different TYPES:

Categories	Materials	U-Value(w/m^{2}k)
TYPE 1	**Wall**: Fly ash brick cavity wall (internal heavy mass) & both side plaster and Polyurethane	0.20
	Roof: Underdeck Polyurethane Insulation	0.22
	Fenestrations: Triple glazing	1.3
	HVAC: 5 Star	
TYPE 2	**Wall**: Brick Wall - Cavity Wall (both side heavy) & both sides plaster with Glass fiber & mineral fiber	0.27
	Roof: Underdeck Glass Fiber and Mineral Fiber Insulation	0.30
	Fenestrations: Double glazing	3
	HVAC: 4 Star	

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TYPE 3	**Wall**: Autoclaved aerated concrete (AAC) block wall with plaster on both sides **Roof**: Overdeck Expanded polystyrene (thermocole) (EPS) Insulation **Fenestrations**: Double glazing **HVAC**: 3 star	0.70 0.35 3
BASELINE	**Wall**: brickwall 9" thick with cement plaster on both sides **Roof**: R.C.C. **Fenestrations**: Double glazing **HVAC**: 3 star	2.13 3.59 3

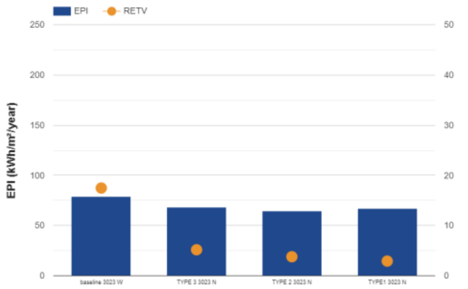
Now as all the types are simulated according to the 8 orientations:
North, South, West, East, Northeast, Northwest, Southeast, Southwest

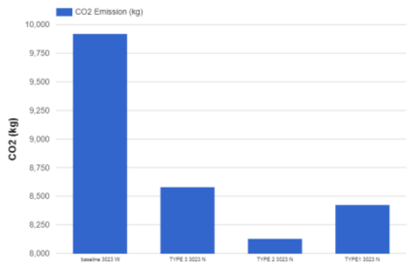
5.3 Result

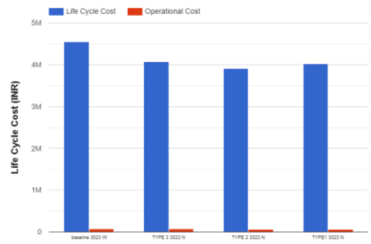
And the results achieved are graphically represented which shows the best orientation in terms of energy efficiency , RETV(residential envelope transmittance value), Carbon emission and Life cycle cost of the building.
The comparative graph of various types with baseline shows how we can improve energy efficiency of the building.

Parameters (3023)	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)
Baseline	12.48	75.95	9580	4430367	77414.4
type 3	5.17	68.02	8579	4071935	69325.5
type 2	3.79	64.45	8129	3910881	65690.9
type 1	2.91	66.83	8428	4017991	68108.1

Table 2: Comparison between the types of model 3023







3042	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)
baseline	18.05	83.69	19604	82 lacs	1.5 lac
type 3	5.14	75.83	17763	75 lacs	1.4 lacs
type 2	3.59	73.15	17134	73 lacs	1.3 lac
type 1	3.14	69.3	16231	70 lacs	1.3 lacs

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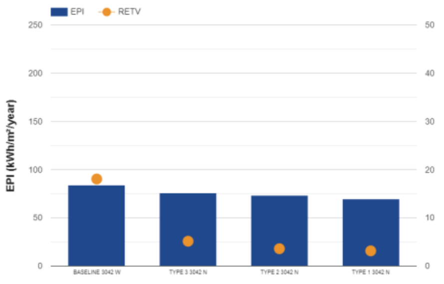
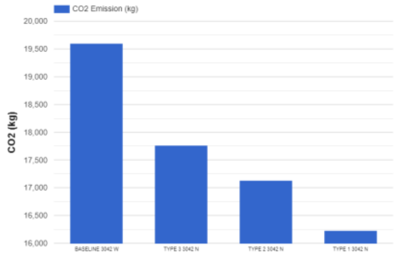
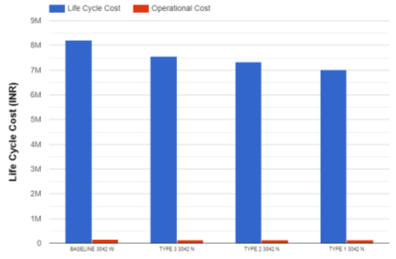
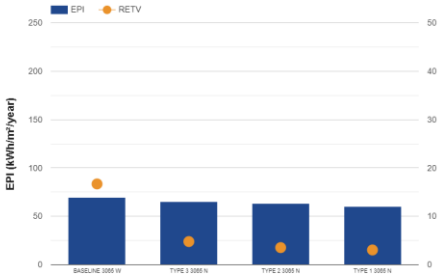
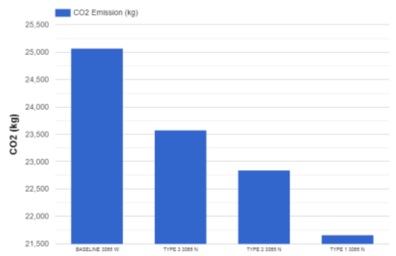


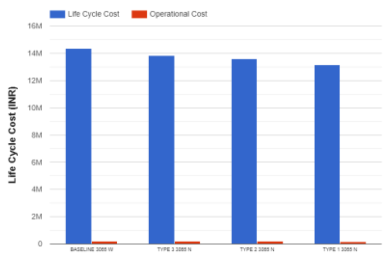




3065	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)
baseline	16.69	69.56	25064	1.4 cr	2 lacs
type 3	4.77	65.42	23574	1.38 cr	1.9lacs
type 2	3.52	63.38	22840	1.35 cr	1.8 lac
type 1	3.04	60.11	21661	1.31 cr	1.7 lacs







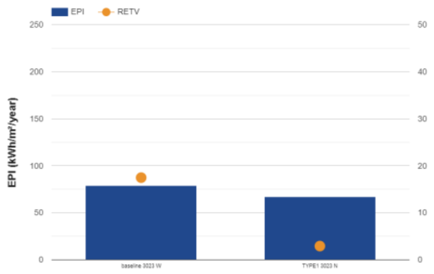
6.0 Summary & Conclusion

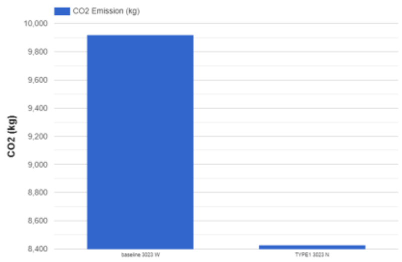
Urbanization in India has been evolving rapidly. The increasing building stock contributes India to become the one of largest energy consumer in residential buildings in the world. It has made India the biggest carbon dioxide emitter (Global Carbon Atlas, 2017). Moreover, it has brought environmental problems such as smog, global warming. Following developed countries' lead, India's government has implemented policies about the energy efficiency of residential buildings. This research aims to propose most cost-efficient solutions to improving energy efficiency in residential buildings in Punjab. It seeks to suggest a direction that can be taken as a reference when constructing residential buildings in northern regions. Especially, this research investigates to remove inefficient cooling system as the heat source in summer in Punjab , in order to reduce coal consumption and carbon dioxide emission. In this research, reference model is located in Amritsar , the most representative city of Punjab . Four steps have been taken to propose the ultimate cost-efficient and energy-efficient residential building model. Firstly, it runs Climate Consultant to simulate and collect climate data of reference model. Secondly, it uses Energy plus software to simulate existing residential buildings of 3 different sizes and orienting in all the 8 direction. Thirdly, with eco niwas samitha software simulating, it with proposed active and passive strategies that are inspired by literature review. It finds an optimal solution, which is installing type 1 materials on the exterior wall, roof, upgrading the existing windows, and using an energy efficiency rating cooling system results in the ultimate model which is highly energy efficient. The results are summarized as below in Table 7.
Lastly, it presents the ultimate cost-efficient and energy-efficient residential building model.

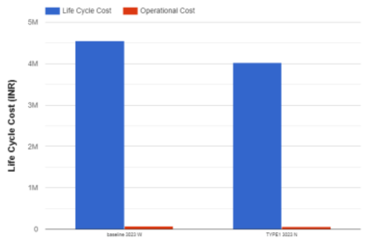
6.1 The Ultimate Energy-Efficient Residential Building Model.
The energy consumption of the building when using all of the recommended elements is 64.45 Kwh / m²/ year for 82m2 which was 78.64 Kwh / m²/ year with baseline measures that means annually with type 1 the energy consumption will be 5480kwh/m2 and with baseline its 6227kwh/m2 i.e. there is a saving of around Rs 800 per month. So around 12% reduction in EPI with the type I energy efficient measures. And 90% reduction in RETV

which makes building thermally more comfortable. The carbon emission is around 90 % less as compared to baseline measures and there is 15% saving in the life cycle cost which is calculated for 25 years.

3023	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)
baseline	17.47	78.64	9918	45 lacs	80148
type 1	3.79	64.45	8129	39 lacs	65690

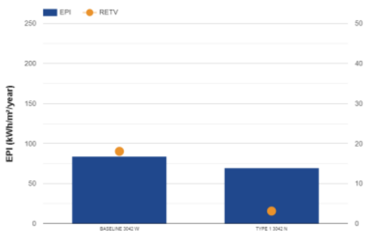


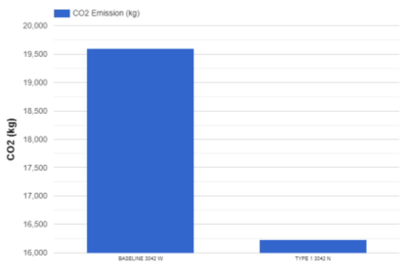


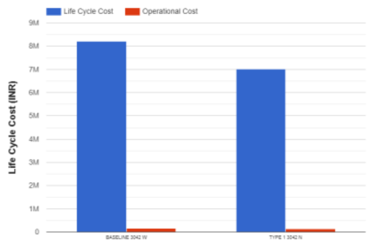


The energy consumption of the building when using all of the recommended elements is 69.3 Kwh / m²/ year for 118m2 which was 83.69 Kwh / m²/ year with baseline measures that means annually with type 1 the energy consumption will be 8177kwh/m2 and with baseline its 9876kwh/m2 i.e. there is a saving of around Rs 1200 per month. So around 12% reduction in EPI with the type I energy efficient measures. And 90% reduction in RETV which makes building thermally more comfortable. The carbon emission is around 90 % less as compared to baseline measures and there is 18% saving in the life cycle cost which is calculated for 25 years.

3042	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)
baseline	18.05	83.69	19604	82 lacs	1.5 lac
type 1	3.14	69.3	16231	70 lacs	1.3 lacs







The energy consumption of the building when using all of the recommended elements is 60.11 Kwh / m²/ year for 182m2 which was 69.56 Kwh / m²/ year with baseline measures that means annually with type 1 the energy consumption will be 10940kwh/m2 and with baseline its 12659kwh/m2 i.e. there is a saving of Rs 1200 per month. So around 12% reduction in EPI with the type I energy efficient measures. And 90% reduction in RETV which makes building thermally more comfortable. The carbon emission is around 90 % less as compared to baseline measures and there is 18% saving in the life cycle cost which is calculated for 25 years.

3065	RETV(W/m2)	EPI(kWh/m2/year)	CARBON EMISSON(KG)	LIFECYCLE COST(INR)	OPERATIONAL COST(INR)

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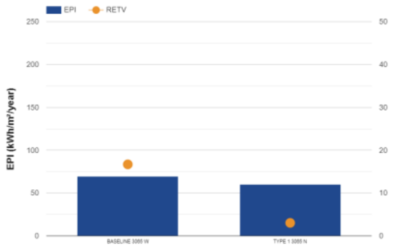
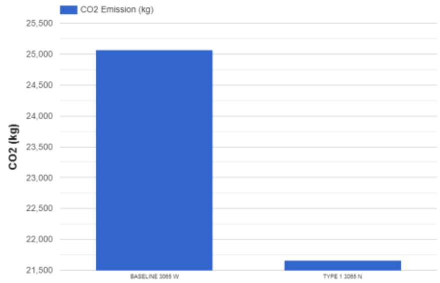
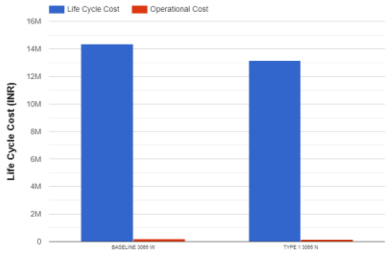
baseline	16.69	69.56	25064	1.4 cr	2 lacs
type 1	3.04	60.11	21661	1.31 cr	1.7 lacs







Although it is difficult to define a high-performance energy efficient residential building as using EPI around 60 kwh/m²/ year of energy, on top of ensuring residents' consistent comfort all year round, this result represents a significant energy efficiency improvement without relying on the cooling system. It can be achieved more by using energy efficient lighting and equipment which would save more energy.More importantly, it reduces its annual energy cost from 20k to 30k.

7.0 Application of Results

As one of the largest building construction market in the world, India in recent years has paid great attention to establishing policies, updating regulations, and upgrading rating systems for energy- efficient buildings to provide guidance for new construction. Booming industry and transport push up CO2 emissions and harm air quality. When it comes to Indian residents' higher and higher expectations in terms of living environments and quality of life, new construction can mostly meet their needs. However, it is also important to consider the energy concept from preliminary stage. Thus, whether examining the situation from the vantage point of the Indian government's determination or the Indian residents' rising expectations, improving energy efficiency potential of residential buildings' is urgent.

The public and private sectors have an obligation to work together to implement energy-saving strategies and solutions. Therefore, this research has aimed to make a contribution to this meaningful and high-priority mission, providing these findings to lighten the burden of all of society slightly. By collecting data from an existing residential buildings in Punjab , the reference models was built to represent the most common residential buildings in northern India . Through applying different types of passive and active strategies, the ultimate building model was simulated, improving both energy efficiency and cost efficiency. Hence, this research can be used with confidence as a reference as well as a guideline for constructing other residential buildings. In particular, in order to make it economically feasible to improve the energy performance of the large stock of residential buildings, this research has taken cost under careful consideration. Thus, improving residential buildings can be achieved at a rapid pace, boosting the possibility of reducing the carbon footprint of India.

8.0 Area for Further Research

Since this research was conducted based on single family residence of Punjab, India. India is set to more than double its building space over the next two decades, with 70% of new construction happening in urban areas. Its large population, rapid urbanization, and a large number of existing residential buildings become the dominant factors for the need of high rise building with multifamily. Therefore, the reference data may be applicable to residential high rise buildings in Punjab. In the future, high rise residential buildings should be investigated in terms of improving their energy efficiency and maximizing their potential in order for them to serve the local residents well. In addition, this research is not an endpoint but rather a small beginning step in the improvement of residential buildings. It is meant to encourage more discussion and research, intensifying the effort to improve the energy performances of residential buildings in order to provide a better living for people. Last, but not least, this research should be updated as scientifically and technologically innovative methods and strategies are introduced. Thus, this line of research can keep analyzing and providing better solutions for improving the energy-efficiency of the residential buildings in India.

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