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SIMULATION AND ANALYSIS OF THE ENERGY CONSUMPTION PATTERN OF AN INSTITUTIONAL BUILDING AS PER ECBC USING EQUEST

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ABSTRACT

Energy Conservation Building Code (ECBC) 2017 helps in achieving energy efficiency in the building sector through their compliance approaches. Bureau of Energy Efficiency (BEE) emphasises all the state government to make it mandatory for all the commercial buildings which are having a connected load of 100kW or greater or a contract demand of 120kW or greater. The study examines the energy-saving potential of a base case building using eQUEST simulation models of an institutional building as per ECBC 2017. The results indicate that energy consumption can be reduced up to 33% as compared to the base case model by applying simple energy-efficient features. The calibrated model is used to find out the payback period by replacing lights and fans with a more efficient one. Thus, it helps in attaining the ECBC benchmark with minimum expenditure that further helps in increasing the future energy-saving potential of energy-efficient buildings.

Disciplinary: Sustainable Energy and Management, Energy Efficient Building, Green and Sustainable Building.

1 INTRODUCTION

Buildings account for 30-40% of total energy use as well as 30% of CO_2 emission all over the world (Ma *et.al.*, 2012). The emerging economy and increasing population in the world from the last two decades, considerably increase energy use (Chaturvedi *et.al.*, 2014). Urbanization in India increases at a rate of nearly 30% (significantly less than developed countries) which also increases electricity consumption to eightfold from 2005-2050 (van Ruijven *et.al.*, 2011).

There is a huge gap between the demand and electricity supply in terms of energy consumption and power generation and from the past few decades, this gap is increasing day by day. Worldwide all the governments and international organizations try to meet out this huge demand for energy in the

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building sector for sustainability. It is estimated that on average a commercial building consumes around 60% of the total electricity for lighting, 32% for space conditioning, and 8% for refrigeration. Although the end-use consumption may vary according to the space cooling requirement, a fully air-conditioned office building consumed about 60% of the total electricity in air conditioning followed by 20% for lighting (IEA, 2011). Building material and building designing play a very significant role in energy consumption. In general energy demand is directly related to the development implies that building efficiency has become more significant in developing countries.

To maintain the consistency in building sector a high degree of regulation is required. Regulatory standards mandated by the government provide a pathway to improve energy efficiency for both building construction material and a variety of electrical appliances. Applying energy conservation measures not only save precious energy but also give financial benefits to the buildings in the coming years. Application of codes is important for newly constructed buildings because it is much convenient and cheaper, also gives long-term benefits to the owner and occupants of building as compared to retrofitting of existing buildings (IEA, 2011). Energy-efficient measures effectively reduce electricity consumption and CO_2 emissions by approximately 40% (Radhi, 2009). A lot of work has been done to reduce energy consumption in buildings by adopting various energy-efficient features (Florides *et.al.*, 2000; Pacheco, 2012; Gratia, 2007; Li, 2008; Castleton, 2010). Researchers use various simulating software to analyze the energy performance of the buildings such as eQUEST, Open Studio, Design Builder, IES-VE, Simergy, EnergyPlus, etc. (Yu and Chow, 2007; Kawamoto, Shimoda and Mizuno 2004; Tavares and Martin, 2007; Kim *et al*., 2012). Bureau of Energy Efficiency (BEE) has approved list of software of the ECBC 2017 user guide to show compliance for whole-building analysis and daylighting.

This study used the eQUEST 3.65 version to analyze building performance. eQUEST has been widely used by researchers to find out the impact of various building parameters, such as building envelope shielding, external wall thermal emission external wall thermal insulation, window/wall ratio, and glass type on air conditioner energy consumption in residential buildings. The results show that improvements in envelope shielding and external wall insulation could significantly reduce the cooling load with an energy-savings rate of 11.31% and 11.55%, respectively (Yu et al., 2008). The same software has been used to study the effect of the position and thickness of building facade insulation on the total energy consumption (Yu *et al*., 2008). By applying combined optimization features for insulation on façade, window/wall ratio, efficient glazing and shading devices, a decrease of up to 25.92% was achieved in the total heating and cooling requirement. Other simulation studies have also been performed in Saudi Arabia (Iqbal *et.al.*, 2006.) and sub-tropical Australia (Rahman *et al*., 2010) with geographical conditions similar to India. These studies used a base case building to calibrate their models before simulating the potential savings from different energy conservative measures. A researcher has compared the performance of a conventional building to an ECBC compliance building in India (Manu *et. al*., 2011). The conventional energy auditing process of eQUEST has been used to evaluate the energy-saving potential of three energy retrofit measures. The results show that despite a significant reduction in energy consumption, the energy retrofit measures can also help in achieving a star rating. A similar model has also been used to analyze the energy performance of high-rise buildings (Zhu, 2006; Pan et al., 2007).

1.1 ECBC COMPLIANCE STRATEGY

The energy efficiency means the extent to which the energy consumption per square meter of the floor area of the building measures up to established energy consumption benchmarks for that particular type of building under defined climatic conditions. Building conservation codes and standards were established by the government for various aspects of the building like its structure, electricity, safety, water conservation, etc. by setting minimum criteria so that the building would become more habitable and safe.

BEE in May 2007 with support from the United States Agency for International Development (USAID) launched ECBC 2007 as part of clean energy projects in different states along with the energy efficiency targets. ECBC sets and regulates the minimum energy performance standards from energy-efficient designing to construction of buildings (building envelope, mechanical systems and equipment including heating, ventilating, and air conditioning (HVAC) system, interior and exterior lighting systems, service hot water systems, electrical power, and motors) in terms of energy consumption per m^2 of area. ECBC-compliant buildings deliver 20-25% of energy-savings in different climates when compared with typical buildings (beeindia.gov.in).

In 2017, ECBC 2017, a revised and modified version of ECBC 2007, incorporates advanced technology. It is applicable to the buildings having a connected load of 100kW or greater or a contract demand of 120kW or greater. There are three levels of energy performance standards in the revised code according to the ascending order of efficiency i.e. ECBC, ECBC Plus, and Super ECBC. ECBC (requires 25% less energy than typical building); ECBC+ (requires 35% less energy than typical building); Super ECBC (requires 50% less energy than typical building). Adherence to the minimum energy standard is required to comply with the code while the other two efficiency levels are voluntary in nature and beyond the minimum requirements. The economic performance of ECBC 2017-compliant building varies depending on the type, operational pattern (daytime use or 24h), and location (climate zone) of the building. It also provides climate zone data for major Indian cities. ECBC 2017 prescribes a minimum requirement benchmark for various building structures e.g. for opaque components (wall and roof), fenestration systems (window, skylight), shading, and daylighting (beeindia.gov.in).

The present study performs the energy analysis of an institutional building in the composite climate through the whole-building approach of ECBC using eQUEST software. It is a very simple, highly efficient software that can perform simulation within a few minutes. After the simulation, the base case building was compared with the standard case as per ECBC 2017. Then a proposed case-building model was built after applying some energy-efficient features. The goal of the study is to establish the relative importance of energy-efficient materials in the existing building so that the building can achieve the ECBC benchmark.

2 BASELINE BUILDING MODELING

2.1 BUILDING DESCRIPTION

Along the national highway no. 1 near New Delhi, MV block of D.C.R.U.S.T, Murthal, Sonipat is chosen for further analysis that is an institutional, non-air-conditioned building situated in composite climate. The building information is mentioned in Table1. It is a square-shaped three-story building comprising of lecture halls, faculty rooms, conference halls, and labs. The building's main entrance is from the east direction with a courtyard planning. The front elevation of the building i.e. east façade is made up of single laminated glazing which allows natural and morning glare inside the building. But this also accounts for high heat gain in summers inside the building. The faculty rooms are mostly present in the outer east direction and inside the south and north direction along with the courtyard. Student's lecture halls and labs are facing the south, north, and west directions. Daylighting is very prominent in south-facing lecture halls that benefit the students a lot. The windows are covered with shading devices that block the direct sunlight in summers and allow the direct sunlight in winters to enter inside the room when the sun angle is down. Toilets are present in the west direction.

Table 1: Building Information.

Building Name	M V Block
Building type	Institutional building (unconditioned)
Floors	G+3
Location	D.C.R.U.S.T, Murthal, Sonipat
Climatic Zone	Composite
Total covered area (FAR)	13048.96 sq.ft
Occupancy type	8 hours
Working days	5 days (Monday-Friday)

2.2 BUILDING BASELINE ENERGY MODELLING

Collective energy consumption data are available on whole-building energy use but there is a lack of detailed breakdown of energy consumption by sub-systems. To recognize the most energy consumption components of the building, the most appropriate way is to develop an energy simulation model to predict the energy performance of the building and the energy conservation potential as per ECBC 2017. A model of the building is created in eQuest, with reference to the steps for calibrated simulation mentioned in ASHARE Guideline 14-2002 (ASHARE, 2002). As a fast and reliable energy simulation tool and the latest version of DOE-2, eQuest has been broadly used in evaluating the energy performance of base case building and predicting the energy-saving potential by simulating the standard case.

2.2.1 3D BUILDING MODEL

A detailed geometric model of the buildings is developed to ensure the reliability of the simulation from the actual building plans and architectural drawings. The three-dimensional (3D) building model is shown in Figure 1.

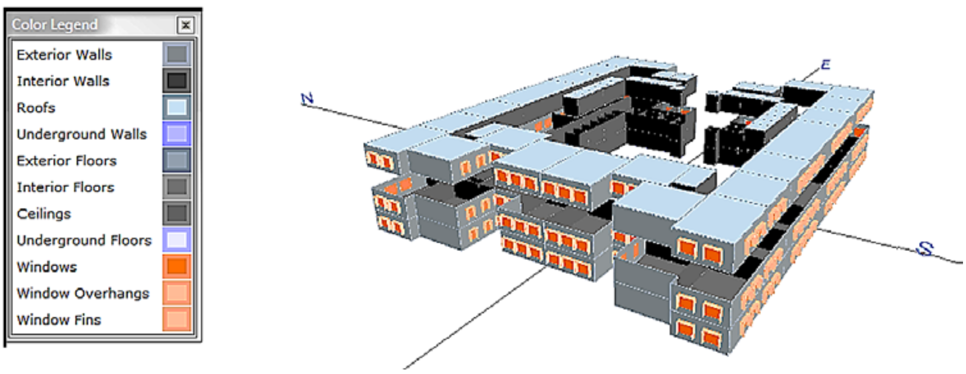


Figure 1: 3D Building model.

2.2.2 BUILDING INPUT VARIABLES

Building construction details i.e. the wall and roof construction material with their U value are given in Table 5. As the building is not equipped with any energy-efficient materials, so it uses all the commonly available building material and construction techniques. But, a cavity wall is given in wall construction details. Internal loads mainly consisting of occupancy schedule, cooling load, lighting loads, and equipment load are calculated manually for each room. As the building is in a composite climate and not using any space heating equipment the gas consumption is excluded from the model. Also, the building working schedule is from 9 am to 5 a.m., external lightning is also excluded from the model. Building energy-intensive lighting consists of 28W T5 tube-lights. Additional equipment load which is taken similar for all the three cases mainly comprises of computers, printers, projectors, lab equipment, lift and water dispenser. Only a few faculty rooms and labs are equipped with ac system, that load is calculated manually and taken collectively as 69 ton.

3 EQUEST SIMULATION DETAILS

The simulation considers the base case i.e. as-built case, the standard case as per ECBC, and the proposed case as per criteria followed by the researcher. Whole Building Performance (WBP) method is used for simulation, that the expected annual energy use of the proposed case must be less than that of the standard case, even though it may not comply with the specific provisions of the prescriptive requirements ECBC 2017. Table 2 gives the input specifications for all three cases.

Table 2: Building Input specification.

Opaque Assembly	Baseline case	Standard case	Proposed case
Ext. Wall assembly	Cement Plaster (25mm.) + Ordinary Brick (100 mm.) + Air Cavity (400 mm.) + Ordinary Brick (100mm.)	Brick wall (230 mm) + Air space resistance+ Brick(230mm) + cement mortar (25mm)	Cement Plaster (25mm.) + Ordinary Brick (230 mm.) + Air Cavity (400 mm.) + Ordinary Brick (115mm.) + Extruded Polystyrene XPS insulation (75mm.) + Clay tile (50mm)
U Value W/m²K	1.25	0.41	0.22
Roof Assembly	100 mm cement plaster + 200 mm RCC slab + 100 mm brick coba	Common brick (230 mm.)+ concrete (75mm) + Plaster 20mm	Common brick (230 mm.)+concrete (75mm)+Plaster 20mm+ polyurethane, expanded (12mm)
U-value (W/m²K)	1.42	0.33	0.19
Glazing U-value(W/m²K) VLT SHGC	Single clear glass 4.2 0.90 0.94		Low-e glass 2.21 28% 0.28
LPD (W/Sqft)	0.248	11.2 W/m^2 or 1.040w/ft^2	0.16
EPD (W/Sqft)	0.605	0.452	0.352
AC load	69 ton	69 ton	69 ton

3.1 BASE CASE BUILDING MODEL

In this study, the base case building is the MV Block, DCRUST, Murthal, Sonipat that does not comply with all mandatory requirements of ECBC 2017. The building is east facing and is made of commonly used construction materials with clear glass windows. Building input specifications with their U value are given in Table 2. Light power density (LPD) and electric power density (EPD) are calculated as per the lightning device and appliances used in each room respectively as shown in Table 3. For lighting, T5 fluorescent tube-lights and simple ceiling fans are used. Additional equipment load of appliances is taken as 0.072 W/ft^2 for each room.

Table 3: LPD and EPD of base case.

LED	7 T5 tubelights (28 W each)= 28 X 7 = 196 watt Area of room = 787.5 sqft = 196/787.5 = 0.248
EPD	6 (70 watt each) = 70 X 6 = 420 watt = 420/787.5 = 0.533 W/Sqft , Additional equipment load = 0.072 W/Sqft, Total EPD = 0.072+ 0.533 = 0.605W/Sqft

3.2 STANDARD CASE BUILDING MODEL (AS PER ECBC 2017)

Standard Building as per ECBC 2017 is a standardized building that has the same building floor area, gross wall area and gross roof area as the proposed building that complies with the mandatory requirements of clause 4.2, 5.2, 6.2 and 7.2 and minimally complies with prescriptive requirements of clause 4.3, 5.3 and 6.3 of ECBC 2017. After simulation of the base case now a standard case is designed to generate a benchmark to judge the existing base case and proposed case. The U value and other parameters as per ECBC 2017 are given in Table 2. LPD used in this case is as per standard of ECBC 2017 and EDP has been calculated by replacing 70W fans with energy-efficient 50W fans, see Table 4. Additional equipment load is the same as it was in the base case.

Table 4: LPD and EPD of standard case

LED	As per ECBC 2017, Building Area Method: (University and School– 11.2W/m^2 or 1.040w/ft^2
EPD	6 (50 watt each) = 50 X 6 = 300 watt = 300/787.5 = 0.380 W/Sqft, Additional equipment load = 0.072 W/Sqft, Total EPD = 0.452 W/Sqft

3.3 PROPOSED CASE MODEL

The proposed building is consistent with the actual design of the building and complies with additional Energy Efficiency Measures (EEM) like insulation on wall and roof, low-e glass in glazing, and energy-efficient lights and fans that can be implemented in the existing building. These features decrease the U value and provide thermal comfort to the occupants. LPD and EDP can be further decreased by using highly efficient lights and fans respectively as shown in table 5. For, e.g. T5 28W tube-light is replaced with 18 W LED light and 70W fan is further replaced by 32W energy-efficient fan.

Table 5: LPD and EPD of the proposed case

LED	T5 Tube lights, 18 watt each, 18 X 7 = 126 watt, Area of each room = 787.5 sqft, = 126/787.5 = 0.16 W/Sqft
EPD	6 Fans, 32 watt each, 32 X 6 = 192 watt, Area of each room = 787.5 sqft, = 192/787.5 = 0.243 W/Sqft, Additional equipment load = 0.072 W/Sqft, Total EPD = 0.315 W/Sqft

4 RESULT AND DISCUSSION

The whole building energy simulation approach has been adopted to analyze building energy simulation. The study proves the efficiency and significance of efficient materials and appliances in ECBC with their payback period. The results are analyzed based on the electric energy consumption pattern of the three cases for the whole year. EPI ratio as prescribed by ECBC is one of the important criteria to understand the ECBC compliance approach. Also, the efficiency of various types of lights and fans has been characterized. Later, their LPD and EPD have been compared with energy consumption through simulation.

4.1 ENERGY CONSUMPTION PATTERN

The proposed case is developed by only changing the building envelope details (i.e. insulation on wall and roof), the use of low-e glass, and the use of energy-efficient lights and fans. Other parameters like cooling load and additional equipment load remain the same in all the three cases. Energy consumption pattern of the three models i.e. base case, standard case, and the proposed case that has been evaluated through simulation for the whole year as given below in Table 6.

4.2 EPI RATIO

The other criteria of comparison among the three cases are the EPI and the EPI ratio. The EPI of a building is the energy consumption of the building divided by its total built-up area and the EPI ratio is calculated by the EPI of the Proposed Building to the EPI of the Standard building.

EPI for Base case = 390180/ 13048.96 = 29.90

EPI for Standard Case = 563510/ 13048.96 =43.18

EPI for Proposed Case = 258810/ 13048.96 = 19.83

EPI ratio for proposed case = Proposed case EPI / Standard case EPI = 19.83/43.18 = 0.45

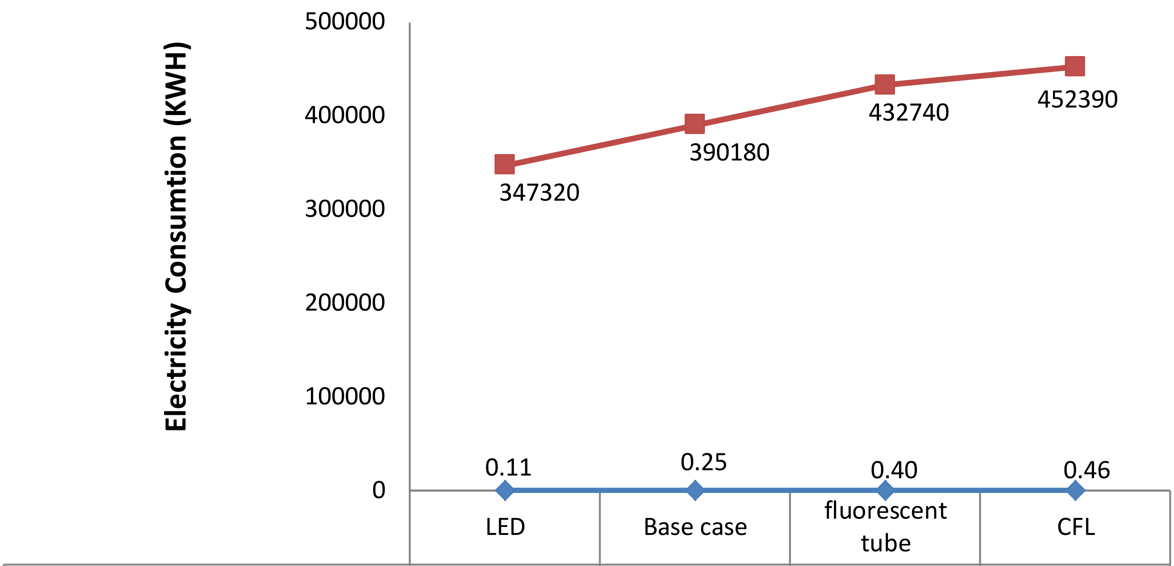
Thus the proposed project will be super ECBC (as per ECBC shown in Table 6).

Table 6: Comparative analysis between the three cases

Case	Base Case	Standard Case	Proposed Case
Energy consumption (kWh*1000)	390.18	563.51	258.81
LPD (W/Sq. ft.)	0.248	1.040	0.160
EPD (W/Sq. ft.)	0.605	0.452	0.315

4.3 EFFECT OF LPD ON ELECTRICITY CONSUMPTION

The energy consumption by lighting systems accounts for a large proportion of building energy consumption. Different types of lights are used to find the most efficient lighting system by calculating its payback period and the results show that LPD will directly affect energy consumption. Based on the simulation result, captured the relationship between the annual energy consumption and lighting power density of the various lighting system is shown in Figure 2. The analysis of energy consumption per year by the different types of lights is mentioned in Table 7.



	LED	Base case	fluorescent tube	CFL
Electricity Consumption (KWH)	347320	390180	432740	452390
Light Power Density (W/m²)	0.11	0.25	0.40	0.46

Figure 2: Relationship between LPD & Electricity consumption

As per the results, if T5 tube-lights are replaced by LED lights, the demand for the energy reduces to 13.14 kW and the energy consumption reduces to 25,680 kWh/year. By considering the cost of one unit as ₹10 per kWh, one can save ₹256,800 per year with a payback period of 0.6 years.

Table 7: Effect on demand and energy consumption by changing replacing system

Lamp type	Power per lamp (W)	No. of lamp	Operational schedule (no. of hours per year)	Demand (No. of lamp * power per lamp/1000) (kW)	Energy (Demand*operational hour) (kWh/year)
T5 tubelight	28	868	1952	24.30	44,434
CFL	18	1860	1952	33.48	65,353
LED	18	620	1952	11.16	21,754
Fluorescent tubelight	40	992	1952	39.68	77,455

4.4 EFFECT OF EPD ON ELECTRICITY CONSUMPTION

The study finds the relationship between the EPD and electric energy consumption of the building by only changing the efficiency of fans, rest all loads remain the same. Figure 3 shows the relationship and Table 8 depicts the demand and energy analysis by merely changing the fans of the building.

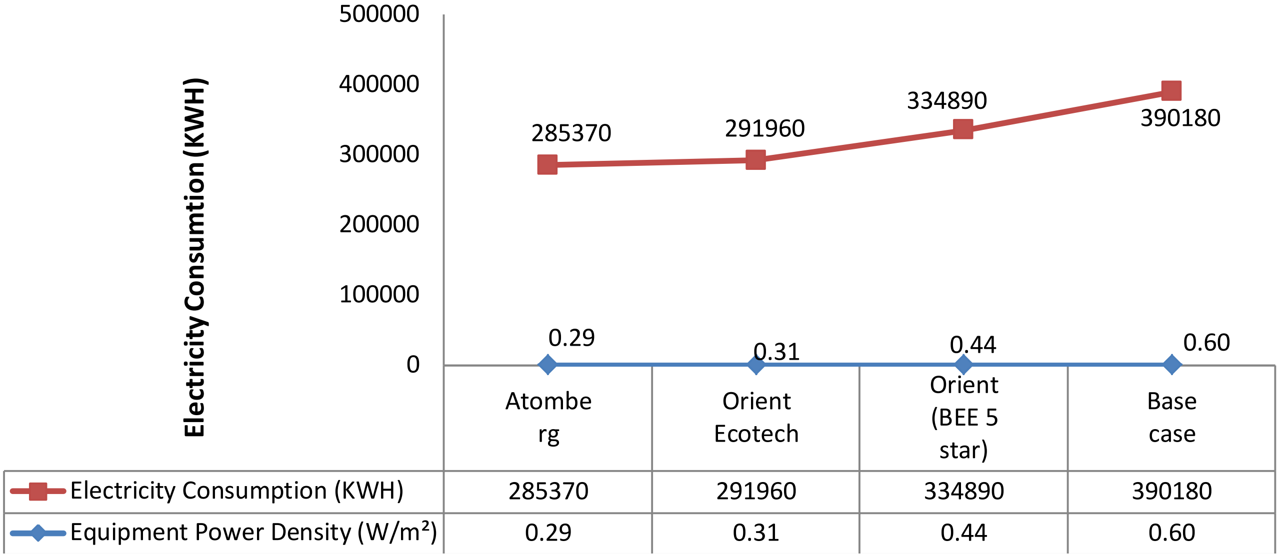


Figure 3: Relationship between EPD & electricity consumption.

Table 8: Effect on demand and energy consumption by replacing fans

Fan type	Power per fan (W)	No. of fan	Operational schedule (no. of hours per year)	Demand (No. of fan * power per lamp/1000) (kW)	Energy (Demand*operational hour) (kWh/year)
Usha fans	70	720	1952	50.4	98381
5star orient fan	48	720	1952	34.56	67461
Orient ecotech	32	720	1952	23.04	44974
Atomberg Renesa	28	720	1952	20.16	39352

As per the result, if Usha fans are replaced by Atomberg Renesa 28W fans, the demand for the energy reduces to 30.24 kW per fan and the energy consumption reduces to 59,029 kWh/year. By considering the cost of one unit as ₹10 rupees per kWh, one can save ₹5,90,290 per year with a payback period of 4.45 years.

5 CONCLUSION

Energy simulation of the base case and its comparison with ECBC benchmark shows that by applying easy retrofit solutions a building can achieve a significant reduction in energy consumption and resource demand and hence easily achieve ECBC rating. Since the old existing buildings like the base case building consumes a lot of energy due to lack of energy-efficient features and need renovation after some time. We utilized the control variables method to analyze the influence of insulation, efficient glazing, LPD, and EPD on building energy consumption. Simulation program, eQUEST is used for the analysis. From this study, the simulation results show that the energy consumption in the base case model is low as compared to the standard case due to the very high-energy requirement for lighting in the standard case.

Use of insulation in the wall and roof of the proposed case and low-e glazing helps in decreasing the space energy demand of the proposed case. Also, thermal lag is high in the proposed case so ventilation fan demand is also less. Results clearly show that the energy demand in the standard case is higher than the other cases due to less efficient standard for lighting i.e. 305230KWh. An energy reduction of 33% is achieved by implementing minimum ECBC standards; hence there is a scope for further improvement of an existing building retrofit.

Lights and fans' efficiency has a direct impact on building energy consumption, and the influence is bigger by estimating its payback period. The payback period for replacing lights is 0.6 years and the payback period for replacing efficient fans is 4.45 years.

These strategies can be easily applicable to old government schools and college buildings that need retrofitting due to occupant discomfort. Although various works have been done so far in the current building energy design and saving process but still varies according to the design and orientation of the existing buildings that need continuous research. This paper just aims to keep lower the retrofitting area with minimal expenditure.

6 AVAILABILITY OF DATA AND MATERIAL

Information can be made available by contacting the corresponding author.

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