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EVALUATION OF ENERGY-EFFICIENT RETROFIT POTENTIAL FOR GOVERNMENT OFFICES IN INDIA

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Abstract

Introduction: High energy consumption by buildings is a great threat to the environment and one of the major causes of climate change. With a population of 1.4 billion people and one of the fastest-growing economies in the world, India is extremely vital for the future of global energy markets. The energy demand for construction activities continues to rise and it is responsible for over one-third of global final energy consumption. Currently, buildings in India account for 35% of total energy consumption and the value is growing by 8% annually. Around 11% of total energy consumption are attributed to the commercial sector. Energy-efficient retrofitting of the built environments created in recent decades is a pressing urban challenge. Presently, most energy-efficient retrofit projects focus mainly on the engineering aspects. In this paper, we evaluate various retrofitting options, such as passive architectural interventions, active technological interventions, or a combination of both, to create the optimum result for the selected building. **Methods:** Based on a literature study and case examples, we identified various energy-efficient retrofit measures, and then examined and evaluated those as applied to the case study of Awas Bhawan (Rajasthan Housing Board Headquarters), Jaipur, India. For the evaluation, we developed a simulation model using EQuest for each energy measure and calculated the resultant energy savings. Then, based on the cost of implementation and the cost of energy saved, we calculated the payback period. Finally, an optimum retrofit solution was formulated with account for the payback period and ease of installation. **Results and discussion:** The detailed analysis of various energy-efficient retrofit measures as applied to the case study indicates that the most feasible options for retrofit resulting in optimum energy savings with short payback periods include passive architecture measures and equipment upgrades.

Keywords

Energy efficiency, energy-efficient retrofitting, energy performance evaluation, public buildings in India.

Introduction

Retrofitting or refurbishment is described as work required to upgrade an aged or deteriorated building (Ma et al., 2012). According to USGBC, green retrofit is defined as “any kind of upgrade of an existing building that is wholly or partially occupied to improve its energy efficiency and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise, all of which is done in a way that is financially beneficial to the owner”. Amongst other advantages, energy-efficient retrofitting results in reduced energy use, cost savings, and higher worker productivity. According to Benson et al. (2011), the most commonly implemented strategies for energy efficiency include improved heating, ventilation, and cooling systems (HVAC), improved insulation, and lighting.

The gravity of India’s energy crisis is evident from the historic blackouts in July 2012 across the country. Currently, buildings account for 35% of total energy consumption and the value is growing by 8% annually (Bureau of Energy Efficiency, 2021). To address the threat of climate change and energy crisis, apart from focusing on the designs of new buildings, attention must also be paid to existing buildings as they are the major consumers of energy. Even then, their replacement rate by the new-build is only around 1.0–3.0% per annum (Ma et al., 2012). Hence, retrofitting public and private buildings, using more energy-efficient products, technologies, and systems, is considered a viable and cost-effective option to reduce energy consumption and environmental degradation. According to the 2016 PIB report, the commercial sector has the potential to achieve 30% energy savings through technology retrofits.

The government also consumes a major portion of

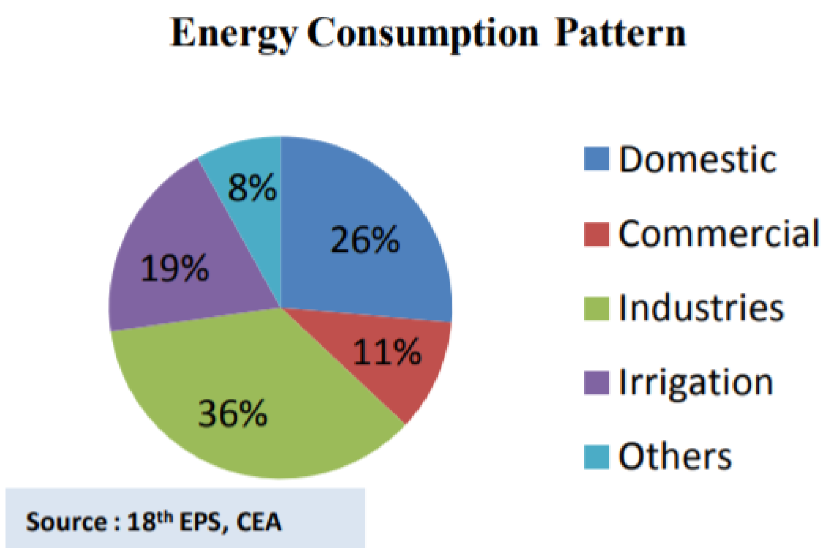


Figure 1. Sector-wise energy consumption pattern in India

energy through its offices, hospitals, railway stations, and other public infrastructure, which have enormous energy-saving potential from proper retrofitting. As can be seen in Fig. 1, commercial buildings account for around 36% of energy consumption in India. Keeping this in mind, BEE (Bureau of Energy Efficiency, Ministry of Power, Government of India) is promoting the implementation of energy efficiency measures in existing buildings through Energy Service Companies (ESCOs), which provide an innovative business model through which the energy-saving potential in an existing building can be captured and the risk faced by the building owner can also be addressed (PIB, 2016). To conserve power, EESL has launched several projects across the country under the BEERP (Buildings Energy Efficiency Retrofit Program). EESL and CPWD have agreed to work on three buildings, namely IP Bhawan, Nirman Bhawan, and Niti Aayog in New Delhi, apart from many other projects across the nation (Energy Division, NITI Aayog, 2015).

Nowadays, there is a great number of building retrofit technologies that are readily available in the market. However, the decision as to which retrofit technology (or measure) should be used for a particular project is a multi-objective optimization problem subject to many constraints and limitations, such as specific building characteristics, total budget available, project target, building services types and efficiency, building fabric, etc. (Ma et al., 2012). The optimal solution is a trade-off among a range of energy-related and non-energy-related factors. A list of possible retrofit options was developed based on a literature study (Dubois et al., 2015; Olander and Siggelsten, 2012; Rey, 2004; Santamouris and Dascalaki, 2002; Upadhyaya et al., 2018), which included both passive and active measures. A detailed analysis of literature (Dascalaki and Santamouris, 2002; Hillebrand et al., 2014; Roper and Pope, 2014; TERI, 2013) and case studies (Abdullah, 2016; NRDC, 2013) helped in developing the methodology for the energy-efficient retrofit study. Each of the retrofit options selected to be implemented in the chosen case study was thoroughly analyzed (Ander, 2016; India Insulation Forum, 2015; Inogate, 2015; Kudarihal and Gupta, 2015; Lunn, 2015; Sudhakaran et al., 2020; TERI, 2021; Walker, 2016). A number of studies were undertaken in the field of energy-efficient retrofit. As per Griego et al. (2015), the use of energy-efficient office equipment and lighting technology and controls can result in over 49% annual energy savings. A case study of Aste and Del Pero (2013) indicated primary energy savings of 40% by improvement of building envelope only, without intervention on HVAC plants, lights or other technical systems. According to Fiaschi et al. (2012), annual energy savings of 4.5% are guaranteed by the installation of PV modules.

To create an efficient scope for retrofit, the unique usage patterns and upgrade opportunities of a project must be examined and evaluated in detail. Energy-efficient design strategies include load reduction, effective use of ambient energy sources, use of efficient equipment and effective control strategies. An integrated design approach is needed to achieve the effective functioning of architectural elements and engineering systems with one another. However, presently, most of the energy-efficient retrofit projects focus mainly on the engineering aspects.

In this paper, we evaluate various retrofitting options, such as passive architectural interventions, active technological interventions, or a combination of both, to create the optimum result for the selected building.

The paper aims to identify and evaluate potential retrofitting measures, in terms of energy savings and payback period, to create an optimum energy-efficient solution for the government office building in Jaipur, India.

Methodology

As depicted in Fig. 2, to begin our study, we need to gain an understanding of energy-efficient retrofit practices based on a literature study and case examples. The inferences from the analysis are then applied to the chosen case study. Our goal was to study and implement retrofit measures at Rajasthan Housing Board Headquarters (Awas Bhawan) in Jaipur. Firstly, we conducted a pre-retrofit survey in order to better understand various features, architectural and operational characteristics, concerns of occupants, and building usage. During the pre-retrofit survey, three methods were used to develop an understanding of the actual usage pattern of the building: design analysis using the drawings and technical information provided, physical observation at the site, and interviews with occupants. Based on the information collected, a base case was developed using EQuest software for energy simulation. The building was modeled in its current state. Then, a list of various retrofit options, derived from the literature study, was developed and analyzed as applied to the chosen case study. The retrofit options included both demand-side and supply-side measures like material alterations in wall and roof insulation or windows, the addition of such

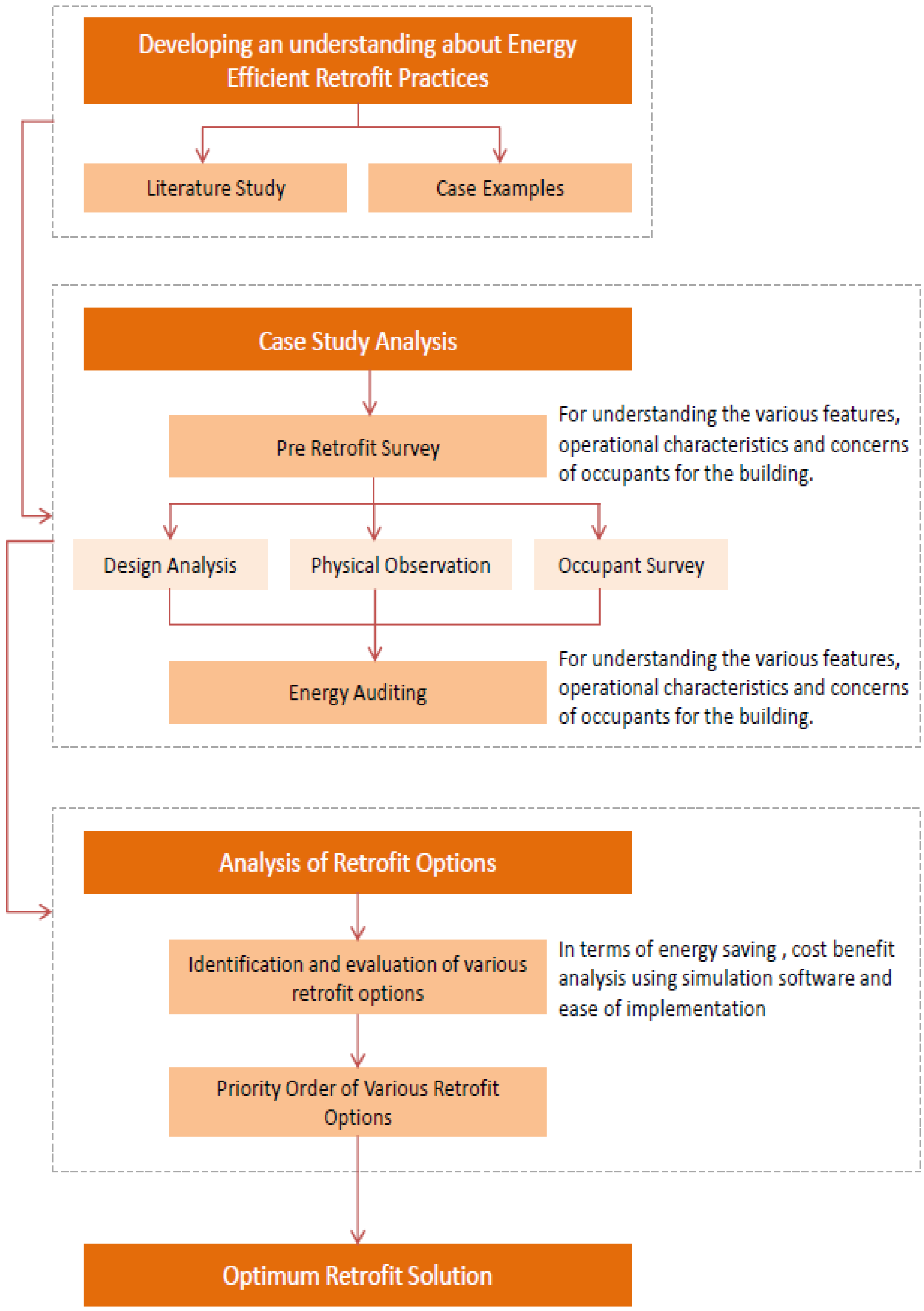


Figure 2. Study methodology

architectural features as sunshades, and equipment upgrade regarding lighting, fans, and solar PVs. All the energy efficiency measures were analyzed in terms of their payback period by comparing the cost of implementation, which was calculated as per a market survey, with the resultant energy savings. Energy savings were determined using the EQuest simulation model for each retrofit option. Based on the payback period and ease of implementation, a priority order was developed for the retrofit options, resulting in the most optimum retrofit solution for the building.

Study and Results

1. Pre-Retrofit Survey

For the analysis, we chose Awas Bhawan (Rajasthan Housing Board Headquarters), Jaipur, Rajasthan, India. The facility has been functional for the last 33 years (since 1984) for 5 days/week, 9 am – 6 pm. It is a four-story structure with an underground basement, an area of 7890 sq. m, and occupancy of around 300 people during working hours. Out of the total area, around 14% are air-conditioned and 65% are centrally air-cooled, thus requiring freshwater.

The average annual energy consumption in the building is 328,250 kWh with the average consumption in summer being 40,000 kWh and in winter — 16,000 kWh. As a result, its Energy Performance Index (EPI) is 42 kWh/sq. m/year.

1.1. Base Case for Energy Simulation

A base model was prepared for “as is” simulation. It has the following characteristics:

1. The building block was made using core and boundary zoning.
2. An evaporative cooling unit of 6750 cfm is provided for each floor, except for the basement and 14% of the area on these floors, which are provided with packaged AC units.
3. The windows are placed with account for the WWR on each face and have sunshades. The windows have the following characteristics: U-Factor — 7.2 W/sq. m·K, SHGC — 0.8, and VLT — 0.76.
4. The walls and the roof have U-factors of 2.01 and 1.376 W/sq. m·K, respectively.
5. The average LPD for the office spaces is 1.1, for the restrooms — 0.9 and for the corridors — 0.5. No dimming devices or sensors are provided with the lighting fixtures.
6. The average equipment power density is 1.25.

Table 1. Base case annual energy consumption

Electric Energy Consump-tion (kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh)	Consum-ption,%
Space cooling	3505	5059	11080	15683	20063	20433	17708	18009	16140	13366	8229	4275	153550	14.11%
Ventilation fans	3234	3534	4935	4540	4779	4779	4540	4970	4540	4588	4295	3612	52346	4.81%
Misc. equipment	37869	35735	42441	37936	40917	40714	38139	42441	37936	39393	37665	38140	469326	43.13%
Area lighting	33324	31446	37348	33384	36007	35828	33563	37348	33384	34665	33145	33563	413005	37.95%
Total	77932	75774	95804	91543	101766	101754	93950	102768	92000	92012	83334	79590	1088227	

As per the base case energy simulation results shown in Table 1, the total annual energy consumption in the building is 1,088,227 kWh, where 14.11% are consumed by space cooling, 4.81% — by ventilation fans, 37.95% — by lighting, and 43.13% — by other equipment in the office.

As per the base case simulation, the total electric energy consumption has the following components, as depicted in Fig. 4:

2. Evaluation of Energy Efficiency Measures

2.1. EEM 1 — Wall Insulation

For this case, wall insulation using 50 mm thick XPS (Extruded Polystyrene) boards on the internal face is proposed. The U-Factor for burnt clay brick walls without any insulation is 2.01 W/sq. m·K and the R-Value of XPS insulation is 10.14 BTU. Thus, the resultant U-Factor of the total wall assembly is 0.4303 W/sq. m·K.

As per the energy simulation results shown in Table 2, EEM 1 produces 2.12% energy savings, i.e., 23,027 kWh are saved annually. Better insulation of walls provides energy savings during space cooling and ventilation. The currency used in this paper is the Indian national rupee, denoted as Rs.

The cost calculation for this retrofit measure is as follows:

Area to be insulated = 2204 sq. m. (till the false ceiling) = 23723 sq. ft
Cost of 50 mm XPS insulation = Rs. 50/sq. ft.
Cost for the total area = Rs. 11,86,150
Cost of plaster = Rs. 20/sq. ft
Total cost = 4,74,460
Cost of paint = Rs. 12/sq. ft.
Total cost = 2,84,676

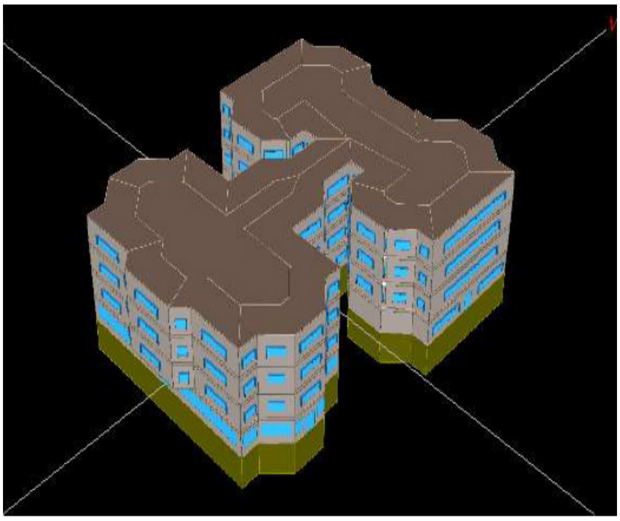


Figure 3. Base case model of Awas Bhawan, Jaipur, India

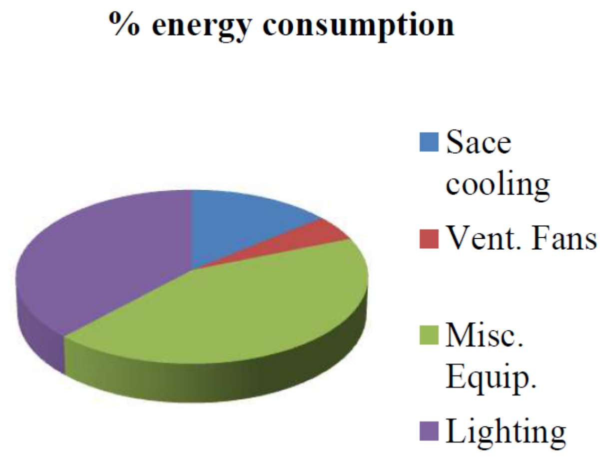


Figure 4. Base case energy consumption breakdown

Table 2. Energy consumption with EEM 1 — 50 mm XPS wall insulation

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.7	4.9	9.8	13.2	16.4	16.7	14.7	15.3	13.8	11.7	7.5	4.4	132.1	132100	21450	13.97%
Ventilation fans	3.4	3.6	4.7	4.3	4.6	4.6	4.4	4.7	4.3	4.4	4.1	3.7	50.8	50800	1546	2.95%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	26	0.01%
Area lighting	33.3	31.5	37.3	33.4	36	35.8	33.6	37.3	33.4	34.7	33.1	33.6	413	413000	5	0%
Total	78.3	75.8	94.2	88.8	97.9	97.8	90.8	99.7	89.4	90.2	82.4	79.9	1065.2	1065200	23027	**2.12%**

Total cost = Rs 19,45,286

Based on Rs. 9/unit cost savings on energy, the payback period for EEM 1 is 9.38 years.

2.2. EEM 2 — Roof Insulation

For this case, roof insulation using 50 mm thick XPS (Extruded Polystyrene) boards is proposed. The U-factor for a normal concrete roof without any insulation is 1.367 W/sq. m·K and the R-Value of XPS insulation is 10.14 BTU. Thus, the resultant U-Factor of the total roof assembly is 0.397 W/sq. m·K.

As per the energy simulation results shown in Table 3, EEM 2 produces 0.39% energy savings, i.e., 4200 kWh are saved annually. Better insulation of the roof provides a very small amount of energy savings during space cooling and ventilation (mainly just in the air-conditioned spaces).

The cost calculation for this retrofit measure is as follows:

Area to be insulated = 5930 sq. ft
Cost of 50 mm XPS insulation = Rs. 50/sq. ft.
Cost for the total area = Rs. 296,500
Cost of roofing = Rs. 60/sq. ft. (75–100 mm thickness)
Total = Rs. 355,800
Total cost = Rs. 652,300

As per the energy simulation results, the cost of energy saved per year is Rs. 37,800. Thus, the payback period for this retrofit measure is 17.26 years.

2.3. EEM 3.1 — Tinted SGUs in Windows

In this case, windows on all the facades are replaced with normal aluminum frame windows with tinted single glass units (SGUs). Such windows have the following characteristics: U-Factor — 6.7 W/sq. m·K, SHGC — 0.6, and VLT — 0.6.

As per the energy simulation results shown in Table 4, EEM 3.1 produces 0.39% energy savings, i.e., 4100 kWh are saved annually. This results in cost savings of Rs. 36,000 per year. The tinted glass panes reduce heat gain, especially due to direct sunlight.

The cost of replacing all the windows with a total area of 7476 sq. ft at Rs. 350/sq. ft will be Rs. 2,616,600.

Therefore, its payback period is 72.68 years.

Table 3. Energy consumption with EEM 2 — 50 mm XPS roof insulation

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	4.2	5	9.3	12.2	15.4	15.8	14.4	15	13.3	11.2	7.3	4.8	127.9	127900	4200	3.18%
Ventilation fans	3.4	3.6	4.7	4.3	4.6	4.6	4.4	4.7	4.3	4.4	4.1	3.7	50.8	50800	0	0%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	33.3	31.5	37.3	33.4	36	35.8	33.6	37.3	33.4	34.7	33.1	33.6	413	413000	0	0%
Total	78.8	75.9	93.7	87.8	96.9	96.9	90.5	99.4	88.9	89.7	82.2	80.3	1061	1061000	4200	**0.39%**

Table 4. Energy consumption with EEM 3.1 — all windows with normal aluminum frame and tinted SGUs

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.8	4.7	9	11.9	15.1	15.5	14	14.7	13.1	10.9	7	4.5	124.2	124200	3700	2.89%
Ventilation fans	3.6	3.6	4.6	4.2	4.5	4.5	4.3	4.6	4.2	4.3	4.1	3.9	50.4	50400	400	0.79%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	33.3	31.5	37.3	33.4	36	35.8	33.6	37.3	33.4	34.7	33.1	33.6	413	413000	0	0%
Total	78.6	75.6	93.3	87.4	96.5	96.5	90	99	88.6	89.3	81.9	80.2	1056.9	1056900	4100	**0.39%**

2.4. EEM 3.2 — DGUs in Windows

In this case, all the existing windows are replaced with normal aluminum frame windows with double glazed units (DGUs). The DGU windows have the following characteristics: U-Factor — 4.65 W/sq. m·K, SHGC — 0.4, and VLT — 0.5.

As per the simulation results shown in Table 5, EEM 3.2 produces 1.12% energy savings, i.e., 11,900 kWh per year resulting in cost savings of Rs. 106,200. The double glass units provide insulation against heat gain.

The cost of simple aluminum frame DGU windows is Rs. 420/sq. ft. The area of the windows to be replaced is 7476 sq. ft, which makes the total cost of replacement equal to Rs. 3,139,920.

This results in a payback period of 29.57 years.

2.5. EEM 3.3 — Thermal Break Frames

In this case, all the existing windows are replaced with windows having thermal break aluminum frames and double glazed panels. Such assemblies have the following characteristics: U-factor — 3.34 W/sq. m·K, SHGC — 0.4, and VLT — 0.5.

While performing simulation, as depicted in Table 6, we obtain annual energy savings of 1.23% (13,000 kWh), leading to cost savings of Rs. 116,100 per year. The thermal break in frames provides additional resistance against heat gain.

The cost of thermal break frame DGU windows is Rs. 1250/sq. ft, resulting in a total cost of Rs. 9,345,000 for 7476 sq. ft.

As a result, the payback period will be 80.49 years.

2.6. EEM 4 — Fins

In this case, four horizontal fins are provided, having 300 mm width and 50 mm thickness, on the south-east, south-west and south façade fenestrations (Fig. 5), which do not have enough shading.

The construction of such fins costs Rs. 175 per running meter and the total length of the fins to be constructed is 240 m. This will result in a total cost of Rs. 42,000 in case of this retrofit measure.

The fins save around 0.60% (6500 kWh) energy and, therefore, Rs. 58,500 annually. Thus, the cost of construction can be repaid in 1.39 years by savings.

2.7. EEM 5 — Energy-Efficient Lighting Fixtures

In this case, all the existing lighting fixtures (mostly tube lights) are to be replaced with energy-efficient lighting, i.e., LEDs. The use of LEDs results in 25% energy savings for lighting, therefore, the LPD

Table 5. Energy consumption with EEM 3.2 — all windows with normal aluminum frame and DGUs

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.7	4.5	8.4	11.1	14.2	14.6	13.2	13.9	12.3	10.3	6.6	4.3	117.1	117100	10800	8.44%
Ventilation fans	3.5	3.6	4.6	4.2	4.4	4.4	4.2	4.6	4.2	4.2	4	3.8	49.7	49700	1100	2.17%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	33.3	31.5	37.3	33.4	36	35.8	33.6	37.3	33.4	34.7	33.1	33.6	413	413000	0	0%
Total	78.4	75.4	92.7	86.6	95.5	95.5	89.1	98.2	87.8	88.6	81.4	79.9	1049.1	1049100	11900	**1.12%**

Table 6. Energy consumption with EEM 3.3 — all windows with thermal break aluminum frames and DGUs

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.8	4.5	8.4	11	13.9	14.3	12.8	13.6	12.2	10.3	6.7	4.5	116	116000	11900	9.30%
Ventilation fans	3.6	3.6	4.6	4.2	4.4	4.4	4.2	4.5	4.2	4.2	4	3.8	49.7	49700	1100	2.17%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0.00%
Area lighting	33.3	31.5	37.3	33.4	36	35.8	33.6	37.3	33.4	34.7	33.1	33.6	413	413000	0	0.00%
Total	78.6	75.4	92.7	86.5	95.2	95.2	88.7	97.8	87.7	88.6	81.5	80.1	1048	1048000	13000	**1.23%**

Table 7. Energy consumption with EEM 5 — energy-efficient lighting fixtures

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.35	4.12	7.8	10.38	13.45	13.83	12.53	13.2	11.71	9.68	6.13	3.97	110.15	110150	5850	5.04%
Ventilation fans	3.4	3.47	4.55	4.17	4.39	4.39	4.17	4.55	4.16	4.21	4	3.73	49.19	49190	510	1.03%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	24.84	23.44	27.84	24.89	26.84	26.71	25.03	27.85	24.89	25.84	24.71	25.02	307.9	307900	105100	25.45%
Total	69.49	66.83	82.59	77.34	85.58	85.63	79.83	88	78.66	79.13	72.54	70.92	936.54	936540	111460	**10.64%**

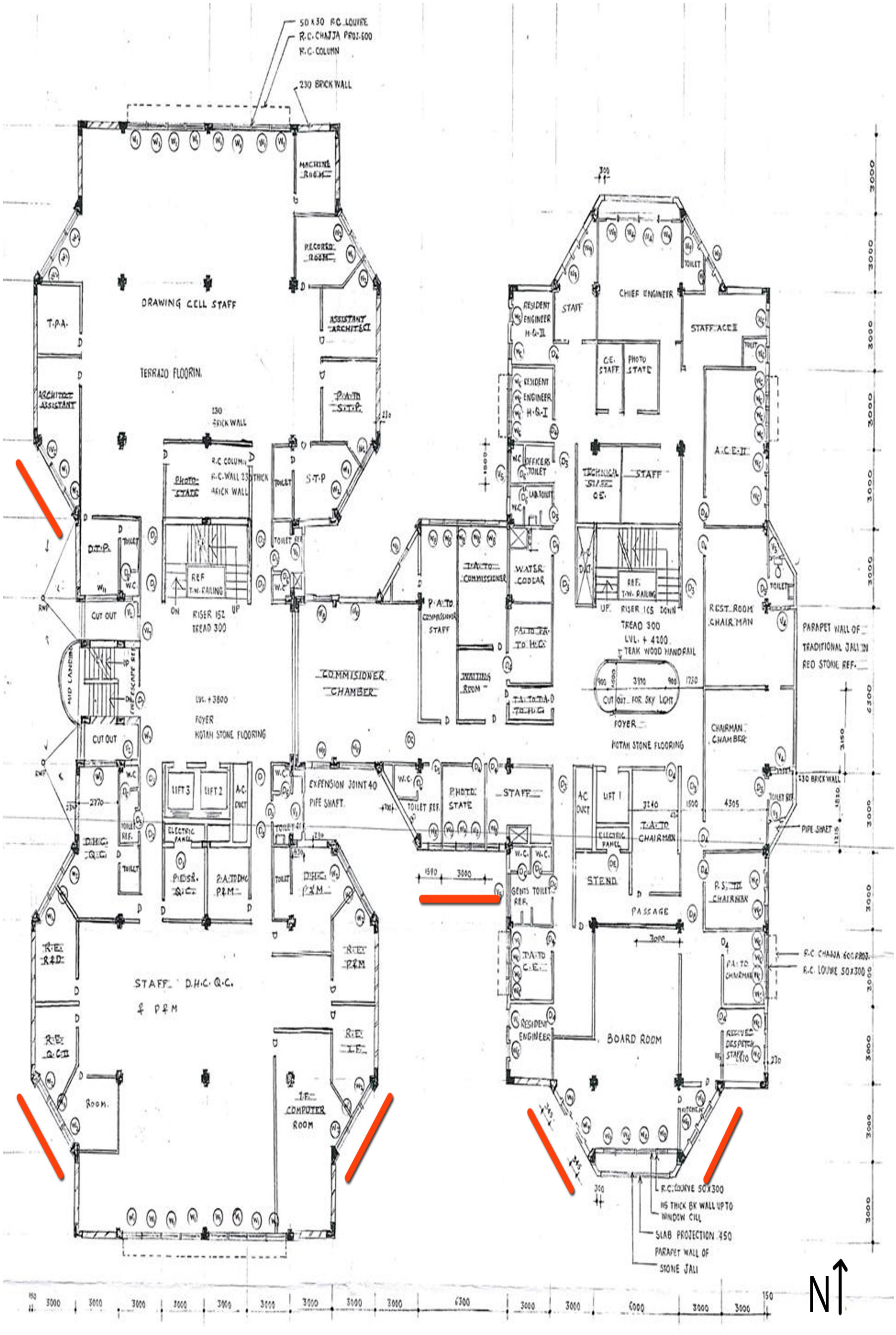
for the office spaces becomes equal 0.825, for the restrooms — 0.675 and for the corridors — 0.375.

This modification produces energy savings of 10.64% (111,460 kWh) per year, as depicted in Table 7, resulting in cost savings of Rs. 1,003,140. Apart from savings in terms of direct energy consumption, energy-efficient lighting also provides some savings for cooling and ventilation, as energy-efficient lights dissipate less heat into the environment.

The fixture requirements are determined using

N (lum) = E (avg) x Area / u x d x α

where: u = 0.8; d=0.7. α = 100 lux (corridors)
= 300 lux (offices)
= 500 lux (open spaces).


50 X 30 R.C. LOUVRE
R.C. CHAJJA PROJ. 600
R.C. COLUMN
230 BRICK WALL
MACHINE ROOM
RECORD ROOM
DRAWING CELL STAFF
T.P.A.
ASSISTANT ARCHITECT
TERRAZO FLOORIN
ARCHITECT ASSISTANT
P.A. TO S.T.P.
PHOTO STATE
S.T.P
D.T.P.
CUT OUT
RISER 152
TREAD 300
LVL. + 3600
FOYER
KOTAH STONE FLOORING
COMMISIONER CHAMBER
EXPENSION JOINT 40
PIPE SHAFT
LIFT 3
LIFT 2
ELECTRIC PANEL
D.H.C. Q.C.
P.S. TO D.H.C. P&M
STAFF D.H.C. Q.C. & P&M
R.E. R&D
R.E. P&M
R.E. Q.C.
R.E. I.E.
ROOM
I.E. COMPUTER ROOM
P.A. TO COMMISSIONER STAFF
WATER COOLAR
WAITING ROOM
PHOTO STATE
STAFF
GENTS TOILET
RESIDENT ENGINEER H.G.II
RESIDENT ENGINEER H.G.I
CHIEF ENGINEER
STAFF ACE II
C.E. STAFF
PHOTO STATE
A.C.E. II
TECHNICAL STAFF C.E.
REST ROOM CHAIRMAN
RISER 165
TREAD 300
LVL. + 4200
TEAK WOOD HANDRAIL
CUT OUT FOR SKY LIGHT
FOYER
KOTAH STONE FLOORING
CHAIRMAN CHAMBER
PARAPET WALL OF TRADITIONAL JALI IN RED STONE REF.
230 BRICK WALL
PIPE SHAFT
LIFT 1
P.A. TO CHAIRMAN
STENO
PASSAGE
P.S. TO CHAIRMAN
P.A. TO C.E.
RESIDENT ENGINEER
BOARD ROOM
RECEIVED DESPETCH STAFF
R.C. CHAJJA 600 PROJ.
R.C. LOUVRE 50X300
R.C. LOUVRE 50X300
115 THICK BK WALL UPTO WINDOW CILL
SLAB PROJECTION 450
PARAPET WALL OF STONE JALI
N

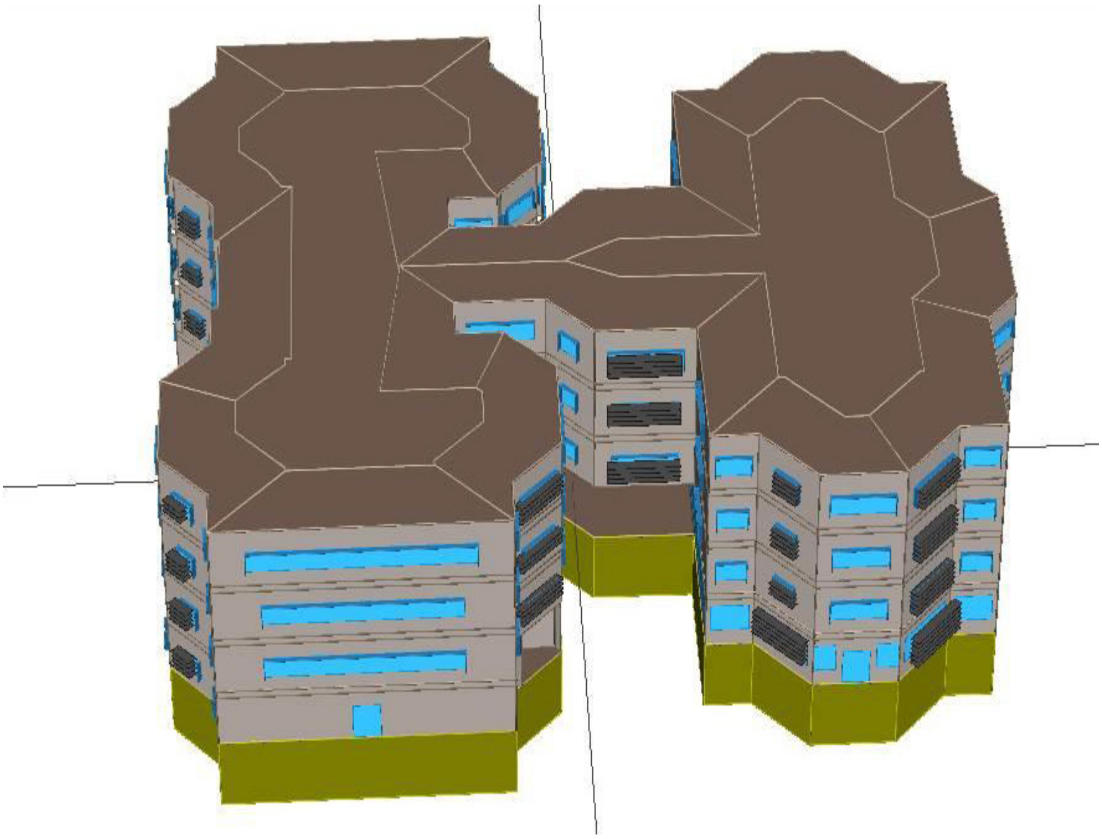


Figure 5. Location of horizontal fins for EEM 4

For cost calculation, 450 pcs. of Philips Sereno (28 W, 3000 lumens) of Rs. 8400 each, 300 pcs. of Power Balance (29.5 W, 3400 lumens) of Rs. 16,000 each and 290 pcs. of Green LED Ultima (10.5 W, 1000 lumens) of Rs. 1500 each are considered. This results in a total cost of Rs. 9,015,000.

Based on these calculations, EEM 5 has a payback period of 8.9 years.

2.8. EEM 6 — Use of Sensors

2.8.1. EEM 6.1 — Use of Daylight Sensors

Generally, the daylit area is 25% of the total area. With the use of daylight sensors, 10% of lighting power consumption can be reduced in those areas. Hence, with daylight sensors, the LPD for the office spaces becomes equal 0.80, for the restrooms — 0.658 and for the corridors — 0.366.

The use of daylight sensors produces total energy savings of 0.85% (8000 kWh), as depicted in Table 8, and cost savings of Rs. 72,000 per year. The reduction in direct energy consumption due to lighting also results in reduced heat load.

2.8.2. EEM 6.2 — Use of Occupancy Sensors

Generally, the area controlled by occupancy

Table 8. Energy consumption with EEM 6.1 — daylight sensors

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.31	4.08	7.75	10.33	13.42	13.8	12.52	13.16	11.69	9.65	6.09	3.93	109.73	109730	420	0.38%
Ventilation fans	3.37	3.46	4.55	4.17	4.39	4.39	4.17	4.56	4.17	4.21	3.99	3.71	49.14	49140	50	0.10%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	24.24	22.87	27.16	24.28	26.19	26.05	24.41	27.16	24.28	25.21	24.11	24.41	300.37	300370	7530	2.45%
Total	68.82	66.21	81.86	76.68	84.9	84.94	79.2	87.28	78.04	78.47	71.89	70.25	928.54	928540	8000	**0.85%**

Table 9. Energy consumption with EEM 6.2 — occupancy sensors

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	3.24	4.02	7.67	10.25	13.35	13.74	12.44	13.1	11.62	9.57	6.02	3.86	108.88	108880	850	0.77%
Ventilation fans	3.35	3.44	4.54	4.16	4.38	4.38	4.17	4.57	4.16	4.21	3.99	3.69	49.04	49040	100	0.20%
Misc. equipment	37.9	35.8	42.4	37.9	40.9	40.7	38.1	42.4	37.9	39.4	37.7	38.2	469.3	469300	0	0%
Area lighting	23.02	21.73	25.8	23.07	24.88	24.75	23.19	25.8	23.07	23.95	22.9	23.19	285.35	285350	15020	5.00%
Total	67.51	64.99	80.41	75.38	83.51	83.57	77.9	85.87	76.75	77.13	70.61	68.94	912.57	912570	15970	**1.72%**

sensors is 75% of the total area. With the use of occupancy sensors, 10% of lighting power consumption can be reduced in those areas. Hence, with occupancy sensors, the LPD for the office spaces becomes equal 0.763, for the restrooms — 0.624 and for the corridors — 0.347.

The application of occupancy sensors ensures 1.72% (15970 kWh) energy savings, as depicted in Table 9, and Rs. 143,730 cost savings annually. The reduction in lighting load also results in the reduction of heat load thus produced.

The cost of combined daylight and occupancy sensors is Rs. 1500 each. In the building, 325 pcs. of such sensors shall be used, resulting in a total cost of Rs. 487,000.

Based on total energy savings ensured by both

Table 10. Energy consumption with EEM 7 — BEE 5 star rated fans

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	2.98	3.79	7.34	9.91	13.08	13.48	12.22	12.83	11.35	9.25	5.73	3.59	105.55	105550	3330	3.06%
Ventilation fans	3.23	3.36	4.52	4.15	4.37	4.37	4.15	4.55	4.15	4.22	3.96	3.59	48.62	48620	420	0.86%
Misc. equipment	33.17	31.3	37.18	33.23	35.84	35.67	33.42	37.18	33.23	34.51	32.99	33.41	411.13	411130	58170	12.40%
Area lighting	23.02	21.73	25.8	23.07	24.88	24.75	23.19	25.8	23.07	23.95	22.9	23.19	285.35	285350	0	0%
Total	62.4	60.18	74.84	70.36	78.17	78.27	72.98	80.36	71.8	71.93	65.58	63.78	850.65	850650	61920	**6.79%**

Table 11. Energy consumption with EEM 8 — VFD in the central evaporative cooler

Electric energy consumption (kWh x 1000)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh x 1000)	Total (kWh)	Savings	Savings, %
Space cooling	2.98	3.69	7.24	9.81	12.98	13.48	12.2	12.83	11.35	9.15	5.73	3.59	105.03	105030	520	0.49%
Ventilation fans	1.93	1.96	2.52	2.35	2.37	2.37	2.35	2.45	2.35	2.3	2.16	2.09	27.2	27200	21420	44.06%
Misc. equipment	33.17	31.3	37.18	33.23	35.84	35.67	33.41	37.18	33.23	34.51	32.99	33.41	411.12	411120	10	0%
Area lighting	23.02	21.73	25.8	23.07	24.88	24.75	23.19	25.8	23.07	23.95	22.9	23.19	285.35	285350	0	0%
Total	61.1	58.68	72.74	68.46	76.07	76.27	71.15	78.26	70	69.91	63.78	62.28	828.7	828700	21950	**2.58%**

daylight and occupancy sensors, the cost of their application can be repaid in 2.26 years.

2.9. EEM 7 — Energy-Efficient Fans

In this case, all the existing fans are replaced with BEE 5 star rated fans. Normal fans operate at 75 W, 0.3 kWh whereas 5 star rated fans operate at 50 W, 0.2 kWh.

This results in annual energy savings of 6.79%, i.e., 61,920 kWh, as depicted in Table 10. Such energy savings reduce the electricity costs by Rs. 557,280.

Each BEE 5 star rated fan costs Rs. 2000, therefore, to install 130 such fans, Rs. 260,000 will be required.

Based on the above calculations, the payback period for energy-efficient fans will be 0.47 years.

2.10. EEM 8 — Variable Frequency Drive

In this case, a variable frequency drive (VFD) is used in the central evaporative cooler. A constant speed drive operates only at 100% load, whereas a VFD can operate at variable speed in case of different power loads, thereby reducing power consumption according to the needs.

The VFD use leads to energy savings of 2.58% (21,950 kWh) per year as shown in Table 11, resulting in a reduction of energy costs by Rs. 197,550.

The VFD cost for nine fans of 3000 cfm, 9 kW is Rs. 60,000. Thus, the initial cost can be repaid in 0.30 years by the savings produced.

2.11. EEM 9 — Solar PVs

In this case, a 50 kW Solar PV system has to be installed for supply-side management. A 50 kW system will require a 500 sq. m area (total roof area — 1500 sq. m) and will generate 66,000 units per year, resulting in cost savings of Rs. 59,400.

The initial installation cost of the system will be Rs. 6,800,000 and the initial maintenance cost will be Rs. 272,000 with an increment of Rs. 13,600/year. Thus, its payback period will be around 11.45 years.

3. Comparative Analysis

To evaluate the different EEMs, we offer a matrix (Table 12), based on which the EEMs are prioritized according to the payback period and ease of installation, where the score of 10 is the most difficult and the score of 1 is the easiest.

The results from the comparative matrix (Table 12) are presented in Fig. 6.

Table 12. Comparative matrix

	EEM	Energy Saved (kWh)	Initial Cost (Rs.)	Annual Savings (Rs.)	Payback Period (yrs)	Ease of Installation	Priority
1	Wall insulation	23,027	1,944,630	207,243	9.38	7	II
2	Roof insulation	4200	652,300	37,800	17.26	7	III
3.1	Normal Al frame windows with tinted SGUs	4100	2,616,600	36,000	72.68	8	-
3.2	Normal Al frame windows with DGUs	11,900	3,139,920	106,200	29.57	8	III
3.3	Windows having Al frames with thermal breaks and DGUs	13,000	9,345,000	116,100	80.49	8	-
4	Additional shading devices	6500	42,000	58,500	1.39	5	I
5	Energy-efficient lighting fixtures	111,460	9,015,000	1,003,140	8.99	3	II
6.1	Daylight sensors	8000	487,000	72,000	2.26	3	I
6.2	Occupancy sensors	15,970		143,730			
7	BEE 5 star rated fans	61,920	260,000	557,280	0.47	2	I
8	VFD in central evaporative coolers	21,950	60,000	197,550	0.30	3	I
9	Solar panels	66,000	6,800,000	594,000	11.45	2	II

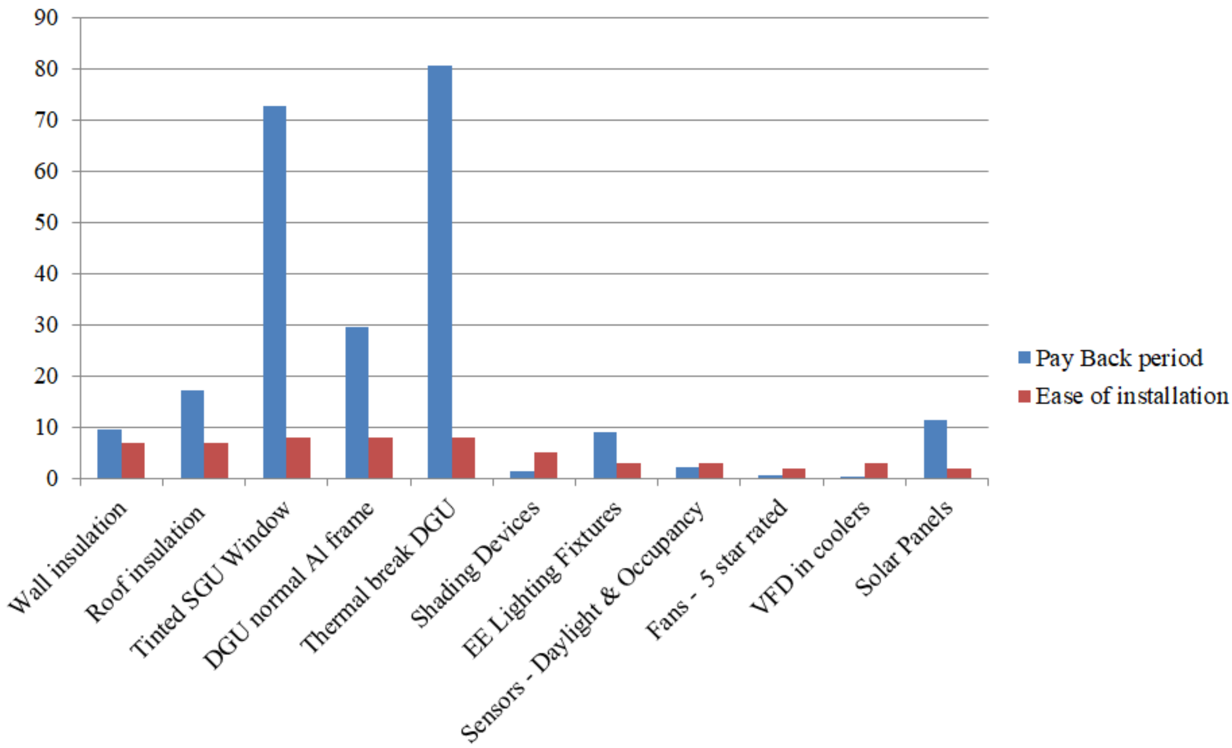


Figure 6. Comparative graph

4. Optimum Retrofit Solution

Using the ESCO route, with 70% given to the ESCO for repayment, the optimum retrofit plan is as shown in Table 13.

Repayment will only be through 70% of cost savings, i.e., Rs. 720,342. Therefore, the payback period will be 1.18 years.

Results

We conducted this detailed survey and analysis of the case study building of Awas Bhawan, Jaipur to identify the target areas and responsive retrofit measures for each of them. Each of the energy efficiency measures was simulated using EQuest to calculate the corresponding amount of energy saved. These measures were further compared and evaluated in terms of their cost, savings generated, and ease of implementation, to develop an optimum retrofit plan for the chosen building, using the ESCO route. In order to do that, 70% savings are used for ESCO repayment, whereas the remaining 30% are kept with the office.

Based on the results, it is observed that energy savings due to wall insulation are around 2% and due to roof insulation — around 0.4%. Approx. 0.4% of energy can be saved when all the window panes are replaced with tinted glass panes, approx. 1.2% of energy can be saved using double glazed panes with aluminum frames instead of the existing windows, and approx. 1.3% of energy can be saved by replacing the existing windows with double glazed

Table 13. Optimum retrofit plan with the ESCO repayment route

No.	EEM	Energy Saved (kWh)	Initial Cost	Annual Savings (Rs. 9/unit)	Payback Period (yrs)
1	Daylight sensors	7970	Rs. 487,000	Rs. 71,730	2.26
2	Occupancy sensors	15,970		Rs. 143,730	
3	5 star rated fans	61,950	Rs. 260,000	Rs. 557,550	0.47
4	VFD in central evaporative coolers	21,950	Rs. 60,000	Rs. 197,550	0.30
5	Shading devices	6500	Rs. 42,000	Rs. 58,500	1.39
	TOTAL	114,340	Rs. 849,000	Rs. 1,029,060	1.18

units with thermal break aluminum frames. The use of fins on the south-west and south-east faces results in energy savings of 0.60%. Replacing the existing lighting fixtures with energy-efficient fixtures can save around 10% of energy. Besides, 0.85% of energy can be saved by using daylight sensors and around 1.7% — by using occupancy sensors. The use of BEE 5 star rated fans can save around 6% of energy. Around 2.5% of energy can be saved by using VFD in central evaporative coolers.

It is seen that though energy-efficient lighting fixtures and solar panels produce the maximum energy savings in terms of the volume and payback period, the most optimum solutions are provided by VFD in central evaporative coolers and BEE 5 star rated fans with the approx. 0.4-year payback period in contrast to the 10-year payback period for lighting and solar panels.

Thus, the choice of EEMs to be undertaken, apart from depending on the amount of energy saved, mainly depends on the availability of financing, payback period, and building characteristics ensuring the ease of installation.

Recommendations

Having analyzed the results of the study, we give the following recommendations for energy-efficient retrofitting**:**

- Low-cost options can also be utilized to get similar results in case of budget constraints (e.g., the use of reflective films on glass panes).
- Government subsidies on energy-efficient lightings, fans and solar PVs can be very helpful in the case of such projects.
- Apart from the implementation of retrofit measures, proper maintenance is also very critical for the proper functioning of the elements according to the design. This can be achieved using BMS.
- Architectural design in terms of the orientation, size and placement of openings as well as the use of spaces is very significant for energy efficiency in buildings. No retrofit measures can fully compensate for that. Hence, prevention is better than cure.
- Presently, most of the energy-efficient products available in the market are intended for new construction, whereas the maximum amount of energy is consumed by existing buildings. Thus, the development of new products given retrofitting is urgently needed.

Conclusion

To develop an optimum energy-efficient retrofit strategy, both active and passive methods need to be considered and evaluated. Though the payback period serves as a great tool to assess the feasibility of various retrofit options, ease of installation, period of disruption in regular activities also need to be kept in mind while taking decisions regarding the optimum solution. The detailed analysis of various energy-efficient retrofit measures regarding the case study indicates that to achieve the best results, it is not necessary to go for difficult and expensive options, which might become unfeasible, keeping in mind the monetary perspective and ease of installation. The study reveals that the most feasible options for retrofit, resulting in optimum energy savings with short payback periods, include passive architecture measures like shading devices, equipment upgrade using energy-efficient fans, daylight and occupancy sensors, VFD in central air cooling, followed by such measures as the use of energy-efficient lighting fixtures and solar panels. The study shows that measures like insulation, window alteration using DGUs and thermal break aluminum frames seem to be lucrative at the first instance but are difficult to undertake since they are characterized by long periods of disruption, high costs, and large payback periods. With a payback period of only 1.18 years and high ease of installation, the optimum retrofit solution with passive façade alteration and selective equipment upgrade turns out to be the most feasible option for government offices in India and can be applied to other such buildings, especially in the composite region.

References

Abdullah, A. (2016). Sustainable and energy-efficient commercial retrofit: Case study of Perkins+Will Atlanta Office. *Perkins+Will Research Journal*, Vol. 08.01, pp. 48–66.

Ander, G. D. (2016). *Daylighting. WBDG Whole Building Design Guide.* [online] Available at: https://www.wbdg.org/resources/daylighting [Date accessed: 25.02.2020].

Aste, N. and Del Pero, C. (2013). Energy retrofit of commercial buildings: case study and applied methodology. *Energy Efficiency,* Vol. 6, Issue 2, pp. 407–423. DOI: 10.1007/s12053–012-9168–4.

Bureau of Energy Efficiency (2021). *Energy benchmarks for commercial buildings.* [online] Available at: https://beeindia.gov.in/sites/default/files/Flyer_22nd%20Jan.pdf [Date accessed: 19.05.2021].

Dascalaki, E. and Santamouris, M. (2002). On the potential of retrofitting scenarios for offices. *Building and Environment,* Vol. 37, Issue 6, pp. 557–567. DOI: 10.1016/S0360–1323(02)00002–1.

Dubois, M.-C., Bisegna, F., Gentile, N., Knoop, M., Matusiak, B., Osterhaus, W. and Tetri, E. (2015). Retrofitting the electric lighting and daylighting systems to reduce energy use in buildings: A literature review. *Energy Research Journal,* Vol. 6, Issue 1, pp. 25–41. DOI: 10.3844/erjsp.2015.25.41.

Energy Division, NITI Aayog (2015). *Energy efficiency interventions at NITI Aayog.* [online] Available at: https://niti.gov.in/sites/default/files/energy/Energy-Efficiency-Interventions-at-NITI.pdf [Date accessed: 02.09.2020].

Fiaschi, D., Bandinelli, R. and Conti, S. (2012). A case study for energy issues of public buildings and utilities in a small municipality: Investigation of possible improvements and integration with renewables. *Applied Energy,* Vol. 97, pp. 101–114. DOI: 10.1016/j.apenergy.2012.03.008.

Griego, D., Krarti, M. and Hernandez-Guerrero, A. (2015). Energy efficiency optimization of new and existing office buildings in Guanajuato, Mexico. *Sustainable Cities and Society,* Vol. 17, p. 132–140. DOI: 10.1016/j.scs.2015.04.008.

Hillebrand, G., Arends, G., Streblow, R., Madlener, R. and Müller, D. (2014). *Evaluation tool and retrofit matrix for office buildings.* E. ON Energy Research Center Series, Vol. 4, Issue 4. Aachen: RWTH Aachen University, 78 p.

India Insulation Forum (2015). *Thermal insulation of buildings. Stakeholder Awareness & Applicator Training.*

Inogate (2015). *Energy efficient lighting technologies, standards and potential savings.* [online] Available at: http://www.inogate.org/documents/1_Technologies__standards__potential_2015–12-15.pdf [Date accessed: 15.03.2021].

Kudarihal, C. S. and Gupta, M. (2015). Artificial lighting systems for energy efficiency. *Lighting India*, Vol. 10, No. 3, pp. 22–25.

Lunn, M. (2015). *Achieving energy efficiency through integrated lighting controls.* White Paper WP525001EN. [online] Available at: https://www.cooperlighting.com/s/lighting-stories/pdf/integrated-lighting-controls-wp525001en.pdf [Date accessed: 15.06.2020].

Ma, Z., Cooper, P., Daly, D. and Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. Energy and Buildings, Vol. 55, pp. 889–902. DOI: 10.1016/j.enbuild.2012.08.018.

NRDC (2013). *Saving money and energy: Case study of the energy-efficiency retrofit of the Godrej Bhavan building in Mumbai.* [online] Available at: https://www.nrdc.org/sites/default/files/energy-retrofit-godrej-bhavan-CS.pdf [Date accessed: 10.08.2020].

Olander, S. and Siggelsten, S. (2012). *Energy-efficient measures when retrofitting the existing building stock.* [online] Available at: http://www.co2olbricks.de/fileadmin/Redaktion/Dokumente/Publications/WP4-OP09_SE_Measures_Retrofitting.pdf [Date accessed: 18.09.2020].

Rey, E. (2004). Office building retrofitting strategies: multicriteria approach of an architectural and technical issue. *Energy and Buildings,* Vol. 36, Issue 4, pp. 367–372. DOI: 10.1016/j.enbuild.2004.01.015.

Roper, K. O. and Pope, B. (2014). Creating a framework for the successful implementation of energy retrofit projects. *Journal of Facilities Management,* Vol. 12, Issue 1, pp. 38–55. DOI: 10.1108/JFM-05–2013-0028.

Santamouris, M. and Dascalaki, E. (2002). Passive retrofitting of office buildings to improve their energy performance and indoor environment: the OFFICE project. *Building and Environment,* Vol. 37, Issue 6, pp. 575–578. DOI: 10.1016/S0360–1323(02)00004–5.

Sudhakaran, P., Joshi, B., Singh, G., Kumar, M. and Ansari, S. (2020). Performance simulation and validation of climate adaptive dynamic facades in campus buildings. *International Journal of Advanced Science and Technology,* Vol. 29, No. 6, pp. 4721–4736.

TERI (2013). *Roadmap for Incorporating energy efficiency retrofits in existing buildings.* [online] Available at: http://cbs.teriin.org/pdf/Energy_Efficiency_Retrofits_in_Existing_Buildings.pdf [Date accessed: 31.06.2020].

TERI (2021). *Window design for day lighting, ventilation and to reduce solar heat gains.* [online] Available at: https://silo.tips/download/chapter-3-window-design-for-day-lighting-ventilation-and-to [Date accessed: 19.05.2021].

Upadhyaya, V., Sudhakaran, P., Shukla, A. K., Kumar, S. and Joshi, B. (2018). Application of small-scale renewable energy techniques in traditional buildings of Jaipur. *International Journal of Civil Engineering and Technology,* Vol. 9, Issue 2, pp. 627–643.

Walker, A. (2016). *Natural ventilation. WBDG Whole Building Design Guide.* [online] Available at: https://www.wbdg.org/resources/natural-ventilation [Date accessed: 15.06.2020].