सत्यमेव जयते

Ministry of Power
Government of India

Energy-Efficient Retrofit Manuals: Transforming Existing Buildings

Residential

Hot-Dry | Warm-Humid | Temperate | Composite

Building Envelope | Lighting | HVAC | Electrical Appliances

Study by
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India's building sector, accounting for 38% (~208 Mtoe) of total primary energy consumption and 31% (296 TWh) of total electricity use, presents both challenges and opportunities in advancing energy efficiency. While considerable progress has been made in designing energy-efficient new buildings, the potential for retrofitting existing structures remains largely untapped. Retrofitting offers a cost-effective and scalable solution to reduce energy consumption and greenhouse gas emissions, aligning with national sustainability goals. In recognition of this potential, the Bureau of Energy Efficiency (BEE) has developed comprehensive manuals to guide the assessment, planning and implementation of energy-efficient retrofits in both commercial and residential buildings.

The Energy Efficiency Manuals for Existing Buildings mark a significant milestone in this effort, offering a robust framework for integrating modern energy-efficient technologies while addressing structural and operational challenges. This manual incorporates industry best practices and technological innovations, providing practical, actionable guidance for enhancing building energy performance across diverse climatic zones.

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We are deeply grateful to the trainers, stakeholders, and participants in the training programs whose insightful feedback helped in refining this manual, ensuring its practical utility for building owners, designers, and policymakers.

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This manual stands as a testament to collective expertise and a shared commitment to creating sustainable, energy-efficient buildings. It serves as a definitive resource to drive the adoption of retrofitting strategies, fostering a greener, more resilient built environment.

P. Samal.

Pravatanalini Samal)
Director
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Summary of Final Literature Survey Report

INTRODUCTION

The report highlights the significance of retrofitting existing buildings to reduce energy consumption and greenhouse gas emissions. In 2021, buildings accounted for 30% of global final energy consumption and 27% of total energy sector emissions. The study outlines a systematic approach for selecting optimal retrofit measures for Building Envelope, Comfort Systems & Controls, Lighting & Controls, and Electrical & Renewable Energy systems. The objective is to prepare a comparative matrix of retrofit parameters to better understand how to promote energy conservation and sustainability through effective building retrofits.

OVERVIEW

India's energy consumption is rising, making it the third-largest energy user globally. Buildings in India consume about 34% of the energy produced, with HVAC systems accounting for most of the energy used. The report emphasizes retrofitting existing buildings as they currently consume more electricity than new buildings are projected to use over the next 20 years. India's commitment to improving the environment is reflected in its National Action Plan on Climate Change (2008) and its goal to achieve net-zero emissions by 2070. The "Shunya" Labelling Programme promotes Net Zero Energy Buildings (NZEB) and Net Positive Energy Buildings (NPEB).

INTERNATIONAL GUIDELINES

The report reviews various international guidelines for building retrofits to understand critical areas and overcome barriers:

1. **Energy Star Building Upgrade Manual (USA):** Focuses on retro-commissioning, lighting, supplemental load reductions, air distribution systems, and heating and cooling systems.
2. **Major Energy Retrofit Guidelines for Commercial and Institutional Buildings (Canada):** Covers assessing opportunities, energy management planning, implementing major retrofits, and maintaining performance.
3. **Energy Management Good Practice Guide (Australia):** Highlights benefits of energy management, sources of energy data, identifying improvement opportunities, funding support, and continuous improvement systems.
4. **Existing Building Retrofit (Singapore):** Outlines steps for determining baseline, reviewing maintenance and energy procurement, and establishing targets and goals.
5. **ProESCO (Brazil):** Provides guidelines for energy efficiency in public sector buildings, focusing on lighting, motors, compressed air, HVAC, refrigeration, heating, automation, and control systems.
6. **NOM-020-ENER-2011 (Mexico):** Offers guidelines for retrofitting buildings to enhance energy efficiency, including insulation, windows, lighting, HVAC systems, and renewable energy incorporation.

NATIONAL GUIDELINES

India's legislative framework for energy efficiency includes:

- **Energy Conservation Building Code (ECBC) 2017:** Sets minimum energy requirements for commercial buildings.
- **Eco Niwas Samhita (ENS):** Establishes performance requirements for residential buildings.
- **BEE Star Rating for Existing Buildings:** Encourages retrofits to achieve higher energy standards.
- **Perform Achieve and Trade (PAT) for Buildings:** A market-based mechanism to improve energy efficiency in large industries and buildings.
- **Building Energy Efficiency Programme (EESL):** Aims to retrofit 20,000 public and private buildings.

The report concludes by emphasizing the importance of investing in building retrofits to create energy-efficient and decarbonized buildings, thereby supporting India's sustainable development goals and climate action commitments.

Stakeholder Survey Summary

OVERVIEW

The **Final Stakeholder Survey Report** represents a critical step towards enhancing energy efficiency and sustainability in India's building sector. Commissioned by the Bureau of Energy Efficiency and conducted by The Energy and Resources Institute (TERI), this comprehensive survey provides insights into stakeholder expectations and technical requirements essential for developing energy use benchmarking manuals.

SURVEY SCOPE AND OBJECTIVES

1. **Building Aspects:** The survey examined a range of building components, including building envelope design, lighting systems, HVAC systems, service water heating, pumping systems, electrical systems, appliances, and renewable energy integration.
2. **Pan-India Coverage:** The survey covered all Indian states and union territories, capturing diverse regional practices and perspectives to ensure a holistic understanding of the building sector.
3. **Willingness for Retrofits:** It assessed the willingness of building owners and operators to undertake retrofits aimed at improving energy efficiency, providing valuable insights into the feasibility of proposed measures.

METHODOLOGY

For data collection state wise face-to-face interviews were conducted. The sampling strategy involved:

- Targeting all 36 states and UTs.
- Focusing on state capitals and Tier I towns.
- Employing a Proportionate to Population Size (PPS) sampling strategy.
- Utilizing stratified random sampling to maintain randomness.
- Dividing each city into four zones for a balanced selection of domestic and commercial respondents.

Key Findings and Observations

Residential Sector

1. **Awareness and Knowledge:** Respondents displayed varying levels of familiarity with energy efficiency concepts, with around 64% being familiar or very familiar.
2. **Implementation of Energy Efficiency Measures:** The implementation levels varied widely, with over 55% of respondents indicating low levels of implementation.
3. **Energy Audits:** A significant number of homeowners had never conducted an energy audit, highlighting an area for potential improvement.
4. **Importance of Energy Efficiency:** Energy efficiency was considered important by a majority of respondents, though motivations varied.
5. **Actions Taken:** Many homeowners had taken steps to improve energy efficiency, but barriers such as financial constraints and lack of information were noted.
6. **Willingness to Invest:** 60% of respondents were willing to invest in retrofitting measures.
7. **Factors Influencing Investment:** Key factors included potential cost savings, government incentives, and environmental impact.
8. **Importance of ROI and Information:** Most respondents emphasized the importance of understanding the expected ROI and having access to reliable information.

COMMERCIAL SECTOR

1. **Awareness and Interest:** Many commercial buildings lacked load monitoring systems, indicating a need for increased awareness and interest in energy efficiency.
2. **Electricity Bills:** Most respondents reported average monthly electricity bills ranging between ₹20,000 to ₹40,000.
3. **Current Practices:** A variety of energy efficiency practices were implemented, but there was significant room for improvement.

4. **Effectiveness Measurement:** Respondents highlighted the importance of measuring the effectiveness of energy efficiency practices.
5. **Planned Practices:** Many commercial entities planned to implement additional energy efficiency measures in the next 12 months.
6. **Drivers for Planned Practices:** Cost savings and environmental benefits were primary drivers.
7. **Willingness to Invest:** Similar to the residential sector, there was a strong willingness to invest in retrofitting measures.

CONCLUSION

The survey findings highlight the readiness of commercial building owners and operators in India to embrace energy efficiency and retrofitting measures. There is a notable interest in implementing a wide range of energy-saving practices, driven by the potential for cost savings, environmental impact, and improved occupant comfort. Access to information, financial incentives, and clear ROI calculations are seen as key factors influencing investment decisions.

The survey also reveals opportunities for promoting energy efficiency through education and awareness, tailored incentives, and the sharing of successful case studies. A significant number of commercial buildings lack load monitoring systems, indicating a potential lack of awareness and interest in energy efficiency among building owners or operators. While certain measures like energy-efficient lighting are well-adopted, there is room for improvement in load monitoring and HVAC optimization. The emphasis on tangible benefits such as cost savings indicates a business-oriented approach to energy efficiency.

It was observed that despite awareness of benefits, there is a gap in understanding specific features, which could be addressed through targeted education and information dissemination. The survey highlights a need for targeted awareness campaigns to bridge gaps in understanding the benefits of energy efficiency measures. Past retrofitting activities positively influence current willingness to invest, indicating a potential learning curve in recognizing the benefits of such measures over time.

Availability of dedicated funds and government incentives could significantly boost the adoption of energy efficiency practices.

Overview of Retrofits

INTRODUCTION

Retrofitting existing buildings offers significant opportunities for reducing energy consumption and greenhouse gas emissions. Retrofit is considered one of the main approaches to achieving sustainability in the built environment at a relatively low cost and high uptake rates. Although a wide range of retrofit technologies is readily available, methods to identify the most cost-effective retrofit measures for projects are still a significant challenge. The building sector has a relatively large carbon footprint when both direct and indirect emissions are taken into consideration. These guidelines will provide a proven and comprehensive strategy for assessing, planning, maintaining and implementing energy efficiency retrofits in an existing building

RESIDENTIAL BUILDINGS-PRESENT SCENARIO & FUTURE GROWTH

India's energy consumption has been steadily increasing over the years, and India is now the third-largest energy user in the World, after China and the United States . In this context, Out of the total electricity consumed in the building sector, about 33% is used in residential buildings. Electricity consumption in Indian homes has tripled since 2000, as the percentage of households with access to electricity has increased from 55% in 2001 to more than 99% in 2019 .The gross electricity consumption from residential buildings in India is predicted to rise by more than eight times by 2050 . Among various reasons, increased use of decentralized room based air-conditioning units in homes for thermal comfort is an important reason contributing to this rapid increase in the electricity use in residential buildings. The demand for air-conditioning will continue its exponential growth with improvement in household incomes and will become the dominant contributor of GHG emissions nation-wide owing to increased electricity consumption.

IMPORTANCE ON ENERGY SAVINGS

The residential building sector in India is experiencing unprecedented growth.The floor area is increasing in both rural and urban areas in India, with steeper growth in urban areas. Between 2008 and 2018, the floor area in rural households increased by 25% (from 6.6 billion to 8.3 billion sqm), whereas in urban households, it increased by 61% (from 2.6 billion to 4.2 billion sqm).

In India, Approximately forty per cent of the building stock that will exist in the next twenty years is yet to be built [4]. This demands for higher demand for energy and it is the need of the hour to optimize and mandate building energy demand in existing building stock and future constructions.

Energy conservation and saving is an important factor in mitigating climate change. This reduction and elimination of unnecessary energy use is referred to as energy savings. It can be accomplished by using less energy to perform a given amount of work or by not using energy at all. Energy savings and conservation results in reduction of greenhouse gas emissions (GHG) along with boosting economic growth. Energy savings is one of the simplest ways to help the environment by reducing pollution and utilizing natural energy. Our relentless use of energy, has led to huge increases in supply than in that of demand. Most of which is generated from fossil fuels, resulting in depletion of natural resources. Hence it is important to acknowledge the current scenario by saving energy

CLIMATIC ZONE

As per NBC, for the purpose of design of buildings, the country may be divided into the major climatic zones as given in the below table

CLASSIFICATION OF CLIMATE			
S. No.	**Climatic**	**Mean Monthly Maximum Temperature (°C)**	**Mean Monthly Relative Humidity Percent (%)**
1	Hot - dry	Above 30	Below 55
2	Warm - Humid	Above 30	Above 55
		Above 25	Above 75
3	Temperate	25-30	Below 75
4	Cold	Below 25	All values
5	Composite	A climatic zone that does not have any season for more than six months may be called as composite zone.	

TABLE 1 CLASSIFICATION OF CLIMATE

DETAILED PARAMETERS OF RETROFIT:

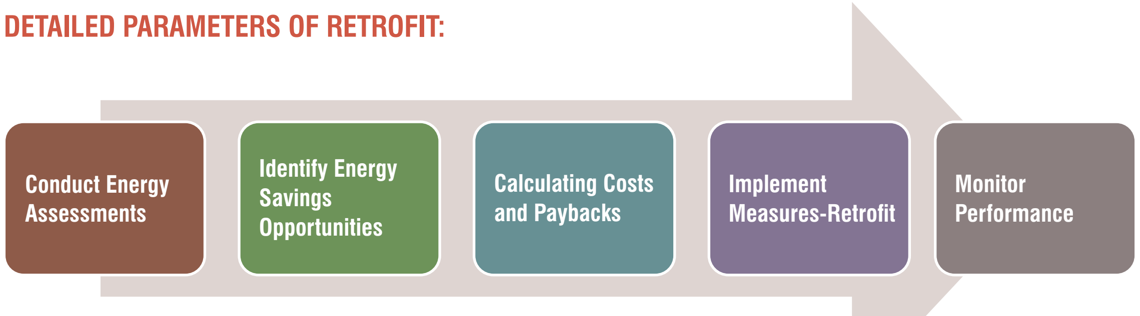


FIGURE 1 PARAMETERS OF RETROFIT

Data Collection

A dedicated staff team is required to initiate any energy management program and audits. One of the key tasks of a building energy audit is the collection of data related to the energy demand of the building and current performance of different building systems. The process of data collection needs to be reliable, repeatable and accurate. While sourcing quality data through desktop data collection becomes a challenge due to a lack of monitoring frameworks in existing facilities, field recordings over a limited period of time might also fail to present the annual performance of buildings accurately. Hence to ensure the precision of the audit, it is recommended to follow a robust mechanism to validate both types of data.

- **Desktop data collection:** At this stage, the facility manager should also convey to the audit team, the facility's level of commitment and the extent to which the management is willing to invest.

Project Details	Building Envelope	Lighting Systems
Location	Architectural Drawings	Lighting Layout
Size	Site Plan and Landscape Plan	Installed lighting typology (CFL, LED, T5 etc.)
Typology	Floor Plans	Wattage of individual lamp type
Number of Buildings	Elevations	Total quantity of lighting fixtures installed
Occupancy	Sections	Usage hours per year
Electrical Systems	Door, Window Schedule	Types of lighting controls installed, if any

TABLE 2 DESKTOP DATA COLLECTION PARAMETERS

- **Field data collection:** Field data collection enables auditors to record and observe the performance of each space and equipment. This activity includes field measurements of the electrical, lighting and HVAC systems, pumping systems, hot water services and helps validate the data collected previously. The information is used to develop both individual system load profile and overall building load profile. The logged data shall be used to verify the exactness of the estimated building total and end-use energy consumption generated by the desktop data collection.

Benchmarking: The next step of building energy audit process is to define the performance of a facility through a calculation matrix. The matrix shall help compare current performance of the facility with similar buildings and help in identifying inefficiently performing area. Occupant comfort (BIS 2005, ASHRAE 55-2010 and CEN Standards EN 15251), Building Envelope (Insulation materials, R-Values, SHGC, VLT), Electrical Systems (IS Codes), Lighting Systems (w.r.t illuminance set by NBC 2016), HVAC Systems (w.r.t ECBC and ASHRAE 90.1), these parameters need to be kept in mind during benchmarking.

Determining Energy Performance Indexes (EPI) and Average Annual Hourly EPI (AAHEPI)

$$\text{EPI,kWh/Annum/m}^2 = \frac{\textit{(Building Energy Consumption)}}{\textit{(Total Builtup Area,m2)}}$$

$$\text{AAHEPI, Wh/h/m}^2 = \frac{\textit{EPI}}{\textit{Operating Hours}}$$

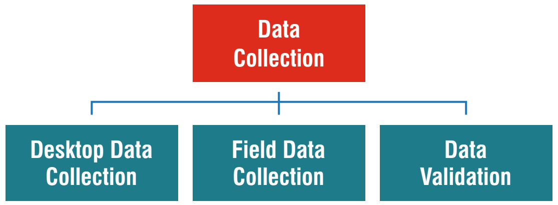


FIGURE 2 DATA COLLECTION

CONDUCT ENERGY ASSESSMENTS

An energy assessment is an essential component of a successful energy management program [9]. This will help to identify the present energy use situation within the building and its energy costs. This assessment helps in developing the energy baseline of the building, for future comparisons of energy use by comparing energy use before and after the program implementation. The energy assessment of the residential buildings can be conducted either by a simple walk through energy assessment or a more detailed energy analysis audit.

The first step in this assessment is to examine energy use and associated costs across systems within the building. The steps are as follows,

1. **Energy Planning** – Assists with identification of building statistics, Building Energy source and use, operation schedules of the building and other necessary information to initiate the assessment.
2. **Questionnaire for the Operations and Maintenance (O&M)** – Understanding the present energy policy and building with Operations and Maintenance (O&M) Staff. This includes questions on Operations Procedures, Building Energy Information, School Condition and Operations, O&M Staff Training.

3. **Walk-Through Assessment Checklist** – Identification of energy saving improvements that can be easily implemented. Walk through Assessment Checklist consists of operation, maintenance and usage procedures of HVAC, lighting, services / amenities, miscellaneous.

   Based on the outcomes from the assessment, the buildings are encouraged to follow the implementation of these measures with a more detailed audit to achieve additional savings. Walk through Assessment can act as a first step to identify existing energy saving opportunities and implement the results followed by a more detailed analysis audit to derive more detailed measures for savings including capital intensive energy saving opportunities [9].

IDENTIFY ENERGY SAVINGS OPPORTUNITIES

- **Educate family members and relatives** on effective energy management practices and raise awareness about the importance of energy conservation and sustainability.
- **Ensure Comprehensive Tracking of Energy Consumption:** Maintain and monitor the energy consumption of the household regularly, fostering awareness and accountability
- **Educate New and Existing Students on the Significance of Energy Management:** Develop educational initiatives targeted at both incoming and current students.
- **Foster a Culture of Continuous Improvement:** Cultivate an environment where ongoing enhancements in energy efficiency are prioritized and embraced throughout the household. Acknowledge and celebrate the exemplary commitment to energy conservation and efficiency.

CALCULATING COSTS AND PAYBACKS

Payback period in capital budgeting refers to the time required to recoup the funds spent in an investment, or to reach the break-even point. Payback period measures the duration of investment to pay for itself or break it even. This also helps identify the savings from the investment. The shorter payback periods are preferable to longer payback periods.

Post assessing the option with technical analysis, capital payback calculations are needed to be performed. This helps choosing best retrofit option as per the user requirement and budgetary constraints. Determining cost effectiveness of large investments over time would require a life cycle cost or monthly flow calculations. This helps to rule out cost intensive interventions with very high payback period. Higher the cost savings ensures the longevity and success of the program/Energy Conservation Measure. Cost savings and payback period can be calculated through the followings ways.

Through analysis and energy data, peak demand and Energy Cost Index (ECI) (expressed in ₹ per floor area per year) can be developed [9]. The attractiveness of an energy retrofit investment is typically assessed using one or more of the following three tools:

1. Simple Payback,
2. Net Present Value (NPV) or Internal Rate of Return (IRR)

IMPLEMENT MEASURES-RETROFIT

After analyzing the energy audit and walk through assessment reports, the Energy conservation measures are devised. Each ECM is shortlisted after conducting a payback analysis to understand cost benefits. Implementation of Energy conservation measures requires proper project planning in terms of assigning appropriate timelines, understanding the commitment and involvement mechanism and project finance. The primary goal of the implementing the energy conservation measures is to maximize building operational efficiency along with achieving occupant comfort

MONITOR PERFORMANCE

Regularly monitoring the building's performance is essential, allowing for the introduction of new energy retrofit strategies at set intervals to enhance energy savings. Educating maintenance staff about building efficiency parameters along with financial and non-financial benefits can prove the key measure in the Energy Efficiency in the existing buildings. Collaborative meetings involving the O and M team and other occupants should be held to raise awareness and implement these strategies effectively.

Part -I
Passive Retrofit Solutions

The term 'Passive Retrofit' refers to the practice of using building materials, insulations, windows, walls, building orientation and other simple techniques, reducing the solar heating and cooling of the building. Passive Retrofitting an existing building can be challenging and requires significant work and investment. However, a well-designed passive retrofit building consumes less energy for heating and cooling, reduces carbon emissions, and improves indoor comfort.

Retrofit Plan in stages:

To determine the most suitable retrofit strategy for a building, an initial assessment is required to categorize the project's requirements. Energy retrofit projects can be broadly classified into three categories, **Minor, Major and Deep**

Minor retrofits, ideal as starting point, primarily focus on operational changes. **Major** retrofits encompass a wide range of measures implemented across various building systems, typically resulting in energy savings between 15% and 40%. **Deep** retrofits, on the other hand, are driven less by specific energy-saving targets and more by the desire for significant space modification and optimum utilization of resources. These projects can achieve energy savings exceeding 40%. Prior to developing an Energy Management Plan (EMP), it is essential to establish an energy saving target based on the building assessment findings. These targets can be derived from applicable national energy conservation code, if available.

Building Envelope Retrofit

INTRODUCTION

The building envelope pertains to the structural aspects of a building, which acts as a thermal barrier between the enclosed conditioned space and outside environment through which the thermal energy is transferred. Given the current and anticipated rapid growth in the residential building stock across India and the consequent opportunities as well as the necessity for energy conservation in this sector, the Energy Conservation Code for Residential Buildings is established by the Ministry of Power to establish minimum energy performance standards for residences in India.

CHECKLIST OF ENERGY CONSERVATION MEASURES FOR RESIDENCES (based on climatic zones and building typologies).

All components which separate the spaces inside the building from outside environmental conditions are referred to as the building envelope [8]. The building envelope forms a thermal boundary with the exterior through an integrated system of three-dimensional, multi-layer, multi-material assemblies consisting of the following components:

- Roofing system(s)
- Walling system(s) (Above grade)
- Fenestrations
- Base Floor system(s)
- Below-Grade Walling Systems

Heat always flows from the warmer side of the building envelope to the colder side. Conduction, solar radiation and infiltration are the major parameters of heat flowing through a Building envelope. Radiation is heat flow over a distance from hot to cold, the way the Sun's heat reaches Earth. This causes occupants to use window shades to block excess radiation to maintain thermal and visual comfort.

1. EXTERNAL WALL

- **Envelope Air Tightness**
  - o Ensure the walls are sealed without cracks on external envelope
  - o Sealing small cracks in the envelope improves overall comfort in the space.
- **Retrofit through Building Form and Orientation:** (depending on the availability of space)
  - o Maximize winter solar gain: Concentrate glazing on the south façade to capture low-altitude winter sun.
  - o Minimize heat loss: Reduction in window area on the north façade to prevent excessive heat loss.
  - o Install double glazing with low-emissivity coating to reduce heat loss.
- **Wall Insulation materials**
  - o Ensure proper wall Insulation materials to increase the thermal Mass and minimize heat losses from the envelope.
  - o Enhance overall envelope efficiency by addressing external wall heat gains and losses.
- **High SRI paints**
  - o Apply High reflective coatings to minimize heat absorption from external environment
  - o Reduce the heat gains by reflecting solar radiation and maintains thermal comfort inside building spaces

2. EXTERNAL ROOF

- **Cool Roof**
  - o Apply reflective coatings or install cool roofing materials (Membrane roofings, Clay or Ceramic Tiles, Asphalt Shingles) to minimize heat absorption.
  - o Application of cools roofs reduces the heat gain through roofs by reflecting solar radiation.
- **Vegetated roof**
  - o Implement roof vegetation to improve the air quality and cut down solar radiation on roofs
  - o Reduces the heat gains into the building and mitigate heat island effects.
- **Roof Deck Shading**
  - o Install shaded deck on the terrace to minimize heat absorption.
  - o Reduces direct solar radiation on roof and reduces the solar gains inside the envelope.
- **Roof Insulation materials**
  - o Ensure proper roof insulation materials to increase the thermal mass and minimize heat losses from the roof.
  - o Enhance overall roof efficiency by addressing external roof heat gains and losses

3. FENESTRATION

Heat Transfer through glazing products, encompassing windows, doors, and skylights, share similarities with heat transfer across walls and roofs, primarily occurring through conduction and convection. Analogous to wall assemblies, the U-Factor is employed to quantify the thermal performance of glazing. The Eco-Nivas Samhita emphasizes on three key performance characteristics: U-Factor, Solar Heat Gain Coefficient (SHGC), and Visible Light Transmittance (VLT).

Several areas of building where attention is required to utmost importance:

a) Joint around fenestration and doorframes.

b) Opening at penetration of utility services through roofs, walls and floors.

c) Site-Build Fenestration and Doors.

d) Building assemblies used as ducts.

e) Joints, seams, and penetration of vapor retarders.

f) All other openings in the building envelope.

It is recommended to check junctions between walls and foundations, between walls and building corners, between walls and structural floor/roofs, and between walls and roofs of wall panels.

3.1. VERTICAL FENESTRATION- WINDOWS

- **Fenestration- Air Tightness**
  - o Ensure proper sealing around the Fenestration avoiding infiltration which can increase the cooling load of a space
  - o Reduces the Infiltration and improve thermal comfort without unnecessary drafts inside the space
  - o Reduces the penetration of unwanted particulates, such as dust, into the building.
- **Tinted Films/ Solar Films**
  - o Solar control film can reduce heat gains and UV transmission through glazing system.
  - o Results in cost savings by reducing cooling load and reduction of fading.
- **High performance glazing system- Double and triple glazing (Lower SHGC glazing, Low E coating glazing, Lower U value Glazing)**
  - o Replace single glazing windows with energy efficient glazing and profiles can significantly increase the energy performance of the building.
  - o Improves indoor thermal as the cold radiation from windows will substantially decrease
  - o Reduces cooling load and improve visual and thermal comfort especially for occupants in the perimeter zones.
- **External Shading devices (Fins, Overhangs, Fins Overhangs)**
  - o Implement external solar shading to reduce unwanted solar gains to a building.
  - o Reduces visual discomfort from glare and excess daylight penetration through direct sunlight.
- **Temporary Shading devices (Curtains, Roller Blinds)**
  - o Incorporate Internal blinds to reduce the solar gain to a building, decreasing the heat load with corresponding cost savings.
  - o Reduces unwanted solar gains to a building and visual glare, increasing the thermal and visual comfort of occupants.
- **Automated shading devices**
  - o Upgrade shading devices with Automatic blinds based on solar radiation to minimize heat gains and enhance overall energy efficiency.
  - o Enable remote access and control for homeowners to optimize comfort and efficiency.
- **Internal Light shelfs**
  - o Incorporate external Light shelves to reflect the incoming sunlight upwards to illuminate the ceiling.
  - o Enhances daylight penetration inside the living spaces.
  - o Reduces glare and the need for indoor lighting during day lit hours.
- **Passive daylight penetration- Light pipes**
  - o Incorporate daylight harvesting systems to optimize lighting based on natural light availability.
  - o Improves Daylight penetration and reduces the reliance of artificial lighting during daytime.
- **Light wells**
  - o Incorporating Light well improves the daylight availability in the building.
  - o Reduces the requirement for electric lighting. It also provides social space and a different work setting.
- **Surface Reflectance- Light colored interior walls**
  - o Application of light colored paints on and floors helps in uniform distribution of daylight.
  - o Reduces the requirement for electric lighting helping with minimizing electricity consumption

3.2. HORIZONTAL FENESTRATION-SKY LIGHTING

- **High performance glazing system- Double and triple glazing (Lower SHGC glazing, Low E coating glazing, Lower U value Glazing)**
  - o Replace single glazing windows with energy efficient glazing and profiles can significantly increase the energy performance of the building.
  - o Improves indoor thermal as the cold radiation from windows will substantially decrease
  - o Reduces cooling load and improve visual and thermal comfort especially for occupants in the perimeter zones.
  - o Improves Daylight penetration and reduces the reliance of artificial lighting during daytime.

4. NATURAL VENTILATION

- **Operable panes windows**
  - o Replace sliding windows with operable double pane window system increases the amount of outside air supplied to the building.
  - o Improves the indoor air quality by reducing the dependency on fans and HVAC system
- **Cross ventilation through windows and ventilators**
  - o Introduce cross ventilation through doors, windows and ventilators. This improves the air circulation indoors.
  - o Improves the indoor air quality by reducing the dependency on fans and HVAC system
- **Passive Stack Ventilation (PSV)**
  - o Integrate Stack Ventilation in building envelope to improve ventilation inside spaces ensuring thermal comfort of occupants.
  - o This technique removes unwanted moisture and indoor pollutants from dwellings.

Segregation of Measures

BASED ON THE CAPITAL COST INVOLVEMENT ALL THE MEASURES WILL BE SEGREGATED INTO NO COST, LOW COST, MID COST AND CAPITAL-INTENSIVE COST ECMS

Efficient Building retrofit material selection and planning demands a nuanced understanding of Thermal and visual comfort. Hence these Energy Conservation Measures (ECMs) are categorized by their capital cost implications. This comprehensive segregation into No Cost, Low Cost, Mid Cost, and Capital-Intensive Cost tiers ensures stakeholders can make informed decisions balancing financial constraints and sustainability objectives. The following detailed breakdown offers extensive insights into the implementation strategies and considerations for each category:

I. NO-COST AND LOW COST ECMS:

1. OCCUPANT BEHAVIOR

- **Description:** Conducting awareness programs to promote energy-efficient practices.
- **Implementation Strategies:** Encouraging active participation from occupants is crucial for the success of behavioral changes. Building managers can facilitate engagement through surveys, feedback sessions, and collaborative initiatives. By involving occupants in the decision-making process and encouraging them to share energy-saving ideas, a sense of shared responsibility is fostered. Occupant engagement extends beyond theoretical understanding to practical implementation. Through interactive workshops, occupants can learn about the energy consumption patterns of common appliances, the impact of lighting on overall energy use, and the potential for behavioral changes to contribute to substantial savings.

FIGURE 3 OCCUPANT BEHAVIOR

2. OPERATION AND MAINTENANCE

- **Description:** Conduct periodic maintenance for optimal functioning of energy integrated shadings devices and controls.
- **Implementation Strategies:** Regular cleaning and maintenance of glazing and envelope is essential for maximizing efficiency. Accumulated dirt, dust, and debris on fixtures can significantly reduce their efficiency, leading to increased energy consumption. Cleaning efforts should extend beyond visible surfaces to include lamp covers, reflectors, and diffusers. This attention to detail not only enhances energy efficiency but also contributes to a visually appealing and well-maintained building environment.

FIGURE 4 OPERATION AND MAINTENANCE

3. COOL ROOFS AND WALLS

- **Description:** Application of High SRI paints on roof and walls to reduce the solar heat gains through roof
- **Implementation Strategies:** Reflective paints or 'cool paints' can be used to reduce the amount of solar heat transmitted to the building. Upgrade roof and wall materials with high albedo materials to reduce heat gains. White or light colored materials, green roof and 'cool paints' all can considerably reduce heat gains into the building and mitigate heat island effects

FIGURE 5 COOL ROOFS

4. VEGETATED ROOF

- **Description:** Incorporate vegetated roofs and potted plants in the roof to reduce the external heat loads.
- **Implementation Strategies:** Upgrade roof with vegetation to reduce heat gains and improve the air quality of the space. This can considerably reduce heat gains into the building and mitigate heat island effects. This also acts as insulation and for a co-benefit of water collection.

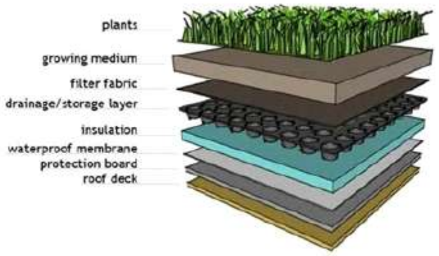


FIGURE 6 VEGETATED ROOF

5. FENESTRATION AIR TIGHTNESS

- **Description:** Ensure airtightness in Fenestration to optimize energy efficiency without additional costs without causing increase in cooling loads.
- **Implementation Strategies:** Unwanted infiltration can increase the amount of unconditioned air into a space; thereby increasing the cooling requirements. Infiltration can also decrease thermal comfort, and introduce unwanted particulates, such as dust, into the building.

FIGURE 7 FENESTRATION AIR TIGHTNESS

6. TINTED FILMS/ SOLAR FILMS

- **Description:** Application of a colored or a solar film over the glazing prevents the solar gains through glazing
- **Implementation Strategies:** Solar control film can reduce heat gains and UV transmission. This results in cost savings by reducing cooling load and reduction of fading and other side effects due to UV exposure.

FIGURE 8 TINTED FILMS/ SOLAR FILMS

7. TEMPORARY SHADING DEVICES

- **Description:** Install indoor shading devices to reduce excess daylight and heat gains through fenestration.
- **Implementation Strategies:** Internal shading devices like curtains and manually operated blinds reduces the solar gain to a building, decreasing the heat load with corresponding cost savings .It also prevents excess daylighting into a building which causes visual discomfort and glare, therefore increasing the thermal and visual comfort of occupants.

FIGURE 9 TEMPORARY SHADING DEVICES

8. Light color paint-interior walls

- **Description:** Upgrading the interior walls with light color paint increases the uniform light distribution inside the space.
- **Implementation Strategies:** Light color paint helps in distribution of light and illumination inside the spaces It also helps in reflecting the light when it falls on surface

FIGURE10 LIGHT COLOR PAINT-INTERIOR WALLS

II. MID COST ECMS:

1. ENVELOPE AIR TIGHTNESS

- **Description:** Incorporate adequate sealing for building envelope to protect it from infiltration.
- **Implementation Strategies:** Infiltration is a form of convection in which heat flows via air movement. When the infiltration of the space is higher occupants feel cold when the door is open on a winter day, and why caulking small cracks around windows improves comfort. Unwanted infiltration can increase the amount of unconditioned air into a space; thereby increasing the cooling requirements. Infiltration can also decrease thermal comfort, and introduce unwanted particulates, such as dust, into the building.

FIGURE 11 ENVELOPE AIR TIGHTNESS

2. ROOF DECK SHADING

- **Description:** Install a roof deck shading on terrace to eliminate the solar radiation on the roof.
- **Implementation Strategies:** Roof deck shading can be used to reduce unwanted solar gains to a building. It cuts down the global horizontal radiation of roof surface and acts as an air gap by reducing the heat load on the roof surface.

FIGURE 12 ROOF DECK SHADING

3. EXTERNAL SHADING DEVICES

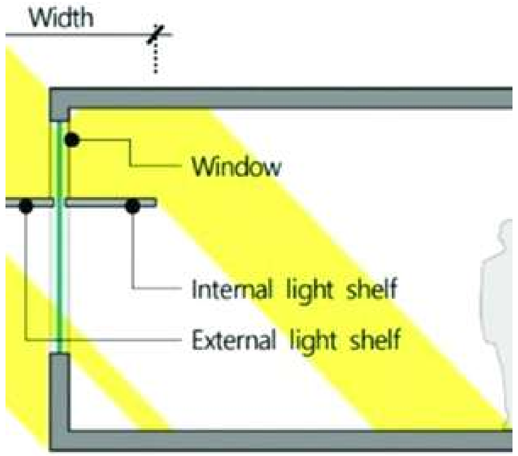
- **Description:** Install external shading devices based on the location and the solar analysis to reduce the solar radiation
- **Implementation Strategies:** External solar shading can be used to reduce unwanted solar gains to a building. It cuts down the global horizontal radiation of roof surface.

FIGURE 13 ROOF DECK SHADING

FIGURE 14 INTERNAL AND EXTERNAL LIGHT SHELF

4. INTERNAL AND EXTERNAL LIGHT SHELF

- **Description:** Implement Light shelf to enhance the daylighting inside the building and to reduce the dependency on artificial lighting during daytime
- **Implementation Strategies:** External Light shelves can be used to reflect the incoming sunlight upwards to illuminate the ceiling. The reflected light will have little solar heat content, and can reduce the need for indoor lighting. It is also useful for reducing glare. Daylight penetration can be enhanced through the use of internal light shelves and changing the ceiling profile to bounce light further into the space.



III. CAPITAL INTENSIVE ECMS:

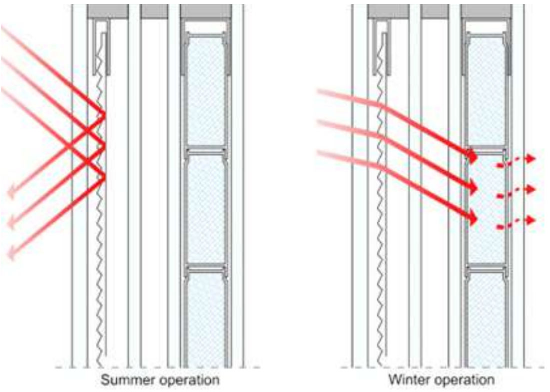
1. WALL AND ROOF INSULATION MATERIALS

- **Description:** Upgrade adequate wall and roof insulation to shield the building from external heat gains.
- **Implementation Strategies:** Insulating the building envelope helps with retaining warmth in the winter and cool air in the summer, in turn reducing the need for excessive cooling. It also provides protection against weather-induced degradation and physical deterioration, increasing the overall durability of the building. This can be done by adding an air gap in the wall construction or another insulation layer balanced with the provision of cool surfaces.

FIGURE 15 WALL AND ROOF INSULATION MATERIAL

2. HIGH PERFORMANCE GLAZING SYSTEM

- **Description:** Upgrade the existing single pane glass with double and triple glazing to reduce the external heat gains through the fenestration.
- **Implementation Strategies:** Incorporating Lower SHGC glazing, Low E coating glazing and Lower U value Glazing contribute to the reduced heat gains through the fenestration resulting in minimized use of artificial light consumption. This reduces cooling load on HVAC system and improves visual and thermal comfort especially for occupants in the perimeter zones.



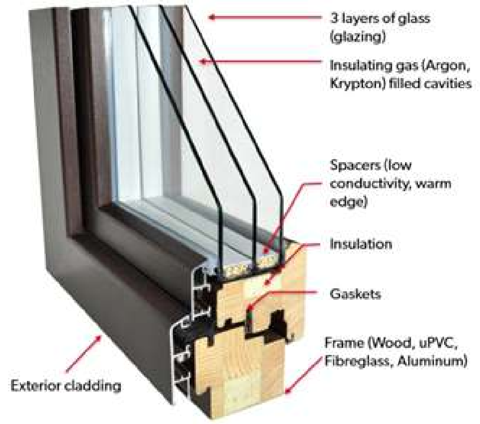


FIGURE 16 HIGH PERFORMANCE GLAZING SYSTEM

3. LIGHT PIPES

- **Description:** Implement of light pipes or advanced daylight harvesting systems for effective use of daylight and optimize energy consumption
- **Implementation Strategies:** A daylight pipe is a tube used for transmitting daylight to an internal space. These can be used as an alternative to electric lighting, and offer better heat insulation properties than skylights and windows, as well as reduced running costs .These systems use sensors and controls to modulate artificial lighting based on the availability of natural daylight. By dynamically adjusting lighting levels in response to changing daylight conditions, daylight harvesting systems optimize energy consumption and provide a seamless integration of natural and artificial light.

FIGURE 17 LIGHT PIPES

4. AUTOMATED SHADING DEVICES

- **Description:** Integrate Automated shading devices to optimize the daylight and glare through Fenestration
- **Implementation Strategies:** To complement daylight harvesting, automated shading systems can be integrated to control glare and optimize daylight utilization. These systems adjust the positioning of blinds or shades based on the sun's position, preventing excessive glare while allowing for the maximum use of available natural light. This dual approach enhances occupant comfort and energy efficiency.
- Automatic blinds can be programmed to close when the level of solar radiation reaches a threshold and to open when conditions become more favorable for daylighting and outside view.

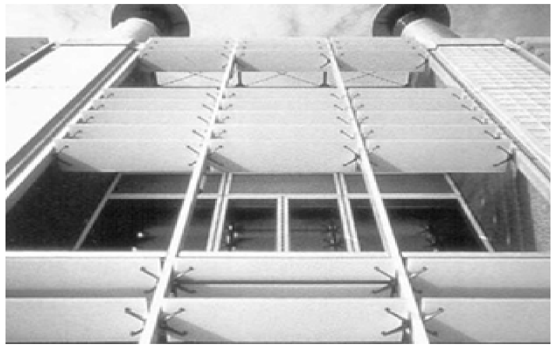


FIGURE 18 AUTOMATED SHADING DEVICES

5. LIGHT WELLS

- **Description:** Integrate light wells to optimize daylight utilization.
- **Implementation Strategies:** Capital intensive ECMs include retrofit of light wells and small courtyards in the buildings spaces to maximize daylight utilization and natural ventilation while minimizing energy consumption. Upgrading the envelope with light wells ensures uniform illuminance levels across neighboring spaces of the light wells contributing to both energy efficiency and the visual comfort of occupants. An atrium brings daylight into deep open spaces, reducing the requirement for electric lighting. Atria also provide social space and a different work setting. However, consideration must be given to potential heat gain.

FIGURE 19 LIGHT WELLS

6. OPERABLE PANES WINDOWS

- **Description:** Replacement of sliding windows with openable windows to ensure natural ventilation into building
- **Implementation Strategies:** Capital intensive ECMs include retrofit of windows in case of sliding doors to improve the air circulation and to extend the natural ventilation into the building spaces .

FIGURE 20 OPERABLE PANES WINDOWS

7. PASSIVE STACK VENTILATION (PSV)

- **Description:** A passive cooling technique driven by natural wind with thermally generated pressure. Passive stack ventilation (PSV) is an effective means of naturally ventilating tall buildings working on a combination of the natural stack effect, and the effect of wind passing over the roof of the dwelling.
- **Implementation Strategies:** The ventilation systems uses the ducts connected from the ceiling of the rooms to extract air to outdoor by a combination of the natural stack effect and the pressure effects of wind passing over the roof of the building.

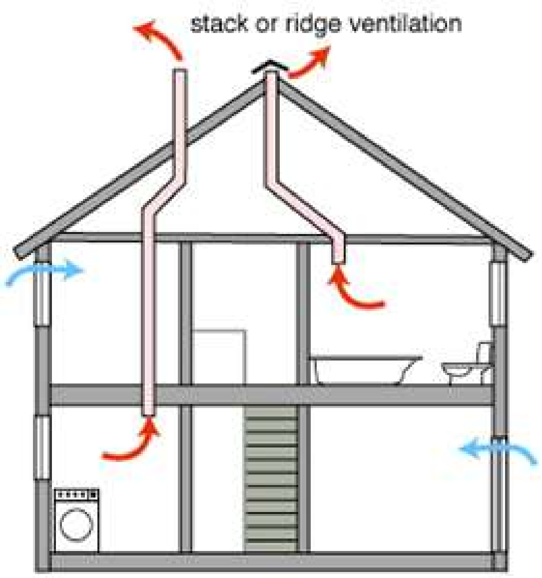


FIGURE 21 PASSIVE STACK VENTILATION

8. CROSS VENTILATION THROUGH WINDOWS AND VENTILATORS

- **Description:** Integrate cross ventilation in building envelope to improve ventilation inside spaces ensuring thermal comfort of occupants.
- **Implementation Strategies:** To complement with operable windows usage of ventilators inside living space s allows hot air built up inside the space to rise up maximizing thermal comfort of occupant comfort corresponding natural ventilation. This dual approach enhances occupant comfort and energy efficiency. The use of natural ventilation increases the amount of outside air supplied to the building, which improves the indoor air quality.

CONCLUSION:

This elaborate segregation of ECMs based on capital cost involvement serves as a comprehensive guide for stakeholders involved in Envelope retrofit projects in the Indian context. By delving into intricate details of implementation strategies and considerations, decision-makers can strategically plan and execute retrofits that not only align with budgetary constraints but also contribute to long-term sustainability objectives. This approach ensures a balanced and effective implementation of energy-efficient Envelope retrofits with thermal and visual comfort, tailored to the unique challenges and opportunities presented by the diverse landscape of India.

Matrix of ECMs (based on cost)

	No cost and Low-Cost ECMs:	Mid-Cost ECMs	Capital-Intensive ECMs
Types of Retrofit	**Existing Building Commissioning**	**Standard Retrofit**	**Deep Retrofit**
Energy Savings	Up to **25%** Energy Savings	**25-45%** Energy Savings	Over **45%** energy savings
Benefits of each type	Can be achieved with minimal risk and capital outlay by improving building operation and maintenance procedure	Component level replacement levels of existing equipment for improved energy efficiency.	An integrated whole building approach is used for energy savings. For example, combination of building envelope upgrade with lighting and mechanical system upgrade.
External Wall	High SRI paints	Envelope Air Tightness	Wall Insulation materials
Roof	Cool Roof- Vegetated roof, High SRI paints	Roof Deck Shading	Insulation materials
Fenestration- **• Control of Heat Gain**	Air Tightness Tinted Films/ Solar Films Temporary Shading devices	External Shading devices	High performance glazing system Automated shading devices
Fenestration **• Daylight improvement**	• Light color paint-interior walls	Internal and External Light shelf	Light pipes Light Wells
Skylight			High performance glazing system/Double Glazing
Natural Ventilation			• Operable panes windows • Cross ventilation through windows and ventilators • Passive Stack Ventilation

Part -II
Active Retrofit Solutions

The term 'Active Retrofit' refers to the practice of incorporating advanced technologies and systems to improve the energy efficiency of a building. This includes the installation of energy-efficient HVAC systems, smart lighting, renewable energy sources like solar panels, and energy management systems that optimize energy use. Active Retrofitting often requires significant work and investment, but it can drastically reduce energy consumption, lower carbon emissions, and enhance occupant comfort. A well-executed active retrofit can transform an existing building into a high-performance, sustainable facility.

Lighting Retrofit

Lighting retrofits in existing residential buildings play a crucial role in enhancing energy efficiency and reducing operational costs. Good lighting in a building provides sufficient light in the right place. This enables the occupants to see easily and in comfort allowing them to perform their work efficiently without strain or fatigue. Artificial lighting contributes to about 14% of the total primary energy use of a standard residential building [8] This section provides a comprehensive set of technical guidelines for implementing effective lighting retrofits in residential buildings across India. The focus is on maximizing energy savings, optimizing lighting quality, and ensuring long-term sustainability. Lighting, constituting a substantial portion of a building's energy consumption, becomes a pivotal area for targeted enhancements. The process of retrofitting lighting systems involves the upgrade or replacement of existing fixtures, controls, and technologies to enhance energy efficiency, reduce operational costs, and foster a more sustainable built environment. Residential Buildings can achieve potential savings of 30% to 60% with occupant behavior and lighting controls

For Lighting Retrofit

I. NO COST ECMs

No-cost ECMs for lighting retrofits are rooted in the fundamental principle of altering occupant behavior, optimizing operational practices, and implementing proactive maintenance strategies. These measures not only contribute to immediate energy savings but also establish a foundation for a sustainable and energy-efficient lighting environment in the long term.

Let us explore each dimension of these measures in detail.

1. BEHAVIORAL CHANGES:

a) **Energy Awareness Programs:** Creating a culture of responsibility and mindfulness among building occupants is a cornerstone of no-cost ECMs. Energy awareness programs play a pivotal role in educating occupants about the importance of energy conservation. Through workshops, seminars, and informative campaigns, building managers can instill a sense of ownership and responsibility for energy-efficient practices. A well-designed awareness program should address the environmental impact of energy consumption, the financial benefits of energy savings, and practical tips for reducing energy use. Regular communication channels, such as newsletters, posters, and digital displays, serve as constant reminders, reinforcing the importance of energy conservation.

b) **Active Occupant Engagement:** Encouraging active participation from occupants is crucial for the success of behavioral changes. Building managers can facilitate engagement through surveys, feedback sessions, and collaborative initiatives. By involving occupants in the decision-making process and encouraging them to share energy-saving ideas, a sense of shared responsibility is fostered. Occupant engagement extends beyond theoretical understanding to practical implementation. Through interactive workshops, occupants can learn about the energy consumption patterns of common appliances, the impact of lighting on overall energy use, and the potential for behavioral changes to contribute to substantial savings.

c) **Monitoring and Feedback Systems:** Implementing monitoring and feedback systems provides real-time information on energy consumption. This transparency allows occupants to visualize the impact of their behavior on energy use. Web-based platforms, mobile applications, or even simple energy dashboards in common areas can display real-time energy data, fostering a sense of accountability among building occupants. The integration of monitoring and feedback systems enables occupants to track their progress in reducing energy consumption. Recognition programs and incentives can further motivate individuals and teams to actively participate in energy conservation initiatives.

2. OPERATIONAL ADJUSTMENTS:

a) **Fine-tuning Lighting System Settings:** Regularly reviewing and adjusting lighting system settings are a proactive measure that requires minimal effort but yields significant benefits. Fine-tuning involves optimizing light levels based on occupancy patterns and the specific requirements of different areas within the building. For example, areas with ample natural light may require lower artificial illumination levels. By periodically assessing and adjusting lighting system settings, building managers can ensure that the lighting environment remains conducive to tasks and activities while avoiding unnecessary energy expenditure. This practice also addresses the changing needs of occupants and spaces over time.

3. MAINTENANCE PRACTICES:

a) **Proactive Maintenance Schedule:** Proactive maintenance practices are integral to the longevity and efficiency of lighting systems. Establishing a proactive maintenance schedule involves routine inspections of lighting fixtures and controls. Regular assessments identify potential issues before they escalate, preventing unnecessary energy loss and extending the life of the lighting system. A comprehensive maintenance schedule includes visual inspections, electrical testing, and assessments of control systems. By addressing issues promptly, building managers can ensure that the lighting system operates optimally, delivering the intended illuminance levels without unnecessary energy waste.

b) **Cleaning Fixtures and Reflectors:** Regular cleaning of fixtures and reflectors is essential for maximizing light output. Accumulated dirt, dust, and debris on fixtures can significantly reduce their efficiency, leading to increased energy consumption to achieve desired illuminance levels. Scheduled cleaning routines ensure that fixtures maintain their effectiveness over time. Cleaning efforts should extend beyond visible surfaces to include lamp covers, reflectors, and diffusers. This attention to detail not only enhances energy efficiency but also contributes to a visually appealing and well-maintained lighting environment.

c) **Addressing Issues Promptly:** Proactive maintenance practices also involve addressing issues promptly when they arise. Rapid response to malfunctioning fixtures, controls, or wiring prevents prolonged periods of energy waste and ensures uninterrupted lighting service. Establishing clear communication channels for reporting issues, along with a responsive maintenance team, is crucial. This proactive approach not only contributes to energy savings but also enhances occupant satisfaction by maintaining a reliable and efficient lighting infrastructure.

II. LOW COST ECMS

Low-cost Energy Conservation Measures (ECMs) for lighting retrofits present an opportunity to enhance efficiency without substantial financial investment. This section explores various low-cost ECMs, spanning LED lamp replacements, occupancy sensors, plug load controls, and other strategies designed to achieve tangible energy savings while maintaining budgetary considerations.

1. LED Lamp Replacement:

a) **High-Efficiency LED Lamps:** The cornerstone of low-cost lighting retrofits is the replacement of traditional incandescent and CFL lamps with high-efficiency LED alternatives. LED lamps offer superior energy efficiency, longer lifespans, and enhanced lighting quality. This simple yet impactful swap reduces energy consumption and maintenance costs, while also contributing to a reduction in the carbon footprint of the building.

b) **Lumen Output Considerations:** When implementing LED lamp replacements, careful consideration of lumen output is crucial. Opting for LED lamps with a high lumen output ensures that the desired illuminance levels are maintained while still achieving energy savings. This strategic selection enhances both visual comfort and overall lighting efficiency.

FIGURE 22 LED LAMP REPLACEMENTS

1. OCCUPANCY SENSORS:

a) **Automated Lighting Control:** Integrating occupancy sensors into lighting systems is a cost-effective way to ensure that lights are only active in areas when and where they are needed. These sensors detect movement and occupancy, automatically turning lights on when a space is in use and off when it is vacant. This real-time responsiveness not only reduces energy waste but also aligns lighting with the actual needs of building occupants.

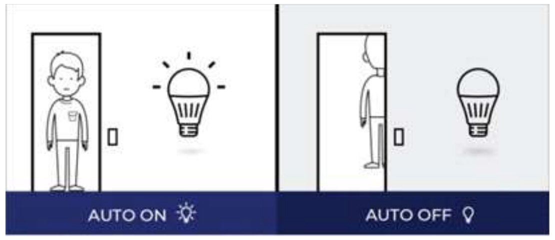


FIGURE 23 OCCUPANCY SENSORS

III. MID COST ECMs

Mid-cost ECMs for lighting retrofits occupy a crucial position in the spectrum of energy efficiency strategies. While low-cost measures offer immediate benefits, mid-cost solutions introduce a layer of sophistication, incorporating advanced technologies that contribute to both energy savings and enhanced lighting quality. This section delves into the details of mid-cost ECMs, emphasizing their significance in achieving sustainable and efficient lighting systems within residential buildings.

1. SMART LIGHTING CONTROLS:

a) **Time-of-Day Controls:** Smart lighting controls include time-of-day controls that enable the automation of lighting adjustments based on specific time periods. This ensures that lighting levels are optimized throughout the day, aligning with occupancy patterns and external lighting conditions. Time-of-day controls contribute to energy savings by avoiding unnecessary illumination during periods of low activity

FIGURE 24 ToD CONTROLS

2. TASK LIGHTING INTEGRATION:

a) **Adjustable Fixtures:** Task lighting solutions often involve the use of adjustable fixtures that can be easily repositioned to suit changing task requirements. The flexibility of these fixtures ensures that lighting can be directed precisely where it is needed, reducing the need for overall ambient lighting and minimizing energy consumption.

FIGURE 25 TASK LIGHTING

3. ADVANCED LIGHTING FIXTURES:

a) **High-Efficiency Luminaires:** Mid-cost ECMs include the replacement of outdated fixtures with high-efficiency luminaires. These fixtures are designed to maximize light output while minimizing energy consumption. Upgrading to advanced lighting fixtures ensures uniform illuminance levels across spaces, contributing to both energy efficiency and the visual comfort of occupants.

b) **Fixture Placement Optimization:** Optimizing the placement of lighting fixtures is another mid-cost strategy. Strategic placement considers the layout of spaces and the intended use of each area, ensuring that lighting is distributed efficiently. Proper fixture placement enhances lighting uniformity and reduces the need for excessive illumination, contributing to energy savings.

IV. CAPITAL-INTENSIVE COST ECMS

Capital-intensive cost ECMs emerge as transformative solutions that address not only immediate energy savings but also long-term sustainability goals. These measures, while requiring a substantial upfront investment, introduce cutting-edge technologies and advanced strategies and energy-conscious practices.

1. FULL FIXTURE REPLACEMENT:

a) **Modern, Energy-Efficient Fixtures:** One of the core capital-intensive ECMs involves the complete replacement of existing lighting fixtures with modern, energy-efficient alternatives. These fixtures, often based on LED technology, offer higher efficacy, longer lifespans, and improved lighting quality. Full fixture replacements not only contribute to substantial energy savings but also align with sustainability goals by reducing the overall environmental impact of lighting systems.

b) **Compatibility with Advanced Controls:** When undertaking full fixture replacements, it is essential to ensure compatibility with advanced lighting controls. This integration allows for enhanced control over lighting levels, color temperatures, and other parameters. The compatibility ensures that the investment in modern fixtures is maximized through comprehensive control and customization capabilities.

2. DAYLIGHT HARVESTING SYSTEMS:

a) **Automated Shading Systems:** Automated shading systems can be integrated to control glare and optimize daylight utilization. These systems adjust the positioning of blinds or shades based on the sun's position, preventing excessive glare while allowing for the maximum use of available natural light. This dual approach enhances occupant comfort and energy efficiency.

FIGURE 26 AUTOMATED SHADING SYSTEMS

3. ADVANCED LIGHTING CONTROLS INTEGRATION:

a) **Color-Tunable Lighting:** Capital-intensive ECMs involve the integration of color-tunable lighting controls. This technology allows for the adjustment of color temperature, mimicking natural daylight variations throughout the day. Color-tunable lighting not only enhances visual comfort but also has potential benefits for occupant well-being and productivity by supporting circadian rhythms.

b) **Adaptive Lighting Systems:** The adoption of adaptive lighting systems represents a transformative strategy. These systems use sensors, occupancy data, and machine learning algorithms to adapt lighting conditions based on user preferences, occupancy patterns, and environmental factors. Adaptive lighting enhances energy efficiency by providing personalized illumination, responding in real-time to changing needs.

4. BUILDING INTEGRATED SOLAR PHOTOVOLTAIC:

- **Description:** The term “building integrated photovoltaics” is applied to any application of photovoltaics mounted on or withing a building envelope. Additionally, it refers to projects where the photovoltaics are used to enhance the design concept of a building and where there is consideration of integration at physical, environmental and aesthetic levels. This technology enables the integration of PV on or withing roofs, glazing, skylight and shading devices.
- **Implementations:** Building Integrated Photovoltaics (BIPV) offers a dual-purpose approach to energy conservation and retrofitting by seamlessly integrating photovoltaic modules into the building envelope. This innovative strategy not only generates clean electricity but also enhances the building's aesthetic appeal and potentially improves its thermal performance. Exploring available government incentives, subsidies, and regulations to optimize the BIPV project's financial viability and compliance.

V. CLIMATIC ZONES AND BUILDING TYPOLOGIES CONSIDERATIONS

I. REGIONAL CLIMATE ADAPTATION:

- Consider climate-specific measures such as heat management in warm climates and thermal insulation in colder regions.
- Optimize lighting controls based on daylight availability variations in different regions.

II. ENERGY MODELING:

- Utilize energy modeling tools to simulate the impact of ECMs based on the specific climatic conditions and building characteristics.
- Optimize lighting retrofit strategies to align with the overall energy performance goals.

III. LIGHTING QUALITY ENHANCEMENTS:

- Invest in fixtures with improved color rendering and uniformity to enhance occupant comfort.
- Consider glare reduction measures to improve overall lighting quality.

HVAC Retrofit

INTRODUCTION

In the dynamic landscape of building management, the role of HVAC systems (Heating, Ventilation, and Air Conditioning) has become pivotal in shaping energy-efficient practices. HVAC retrofitting, characterized by strategic upgrades and modernization of climate control systems, has emerged as a cornerstone in the journey towards sustainability within the built environment. This introduction serves as a gateway to comprehensively explore the nuances of HVAC retrofitting in India, traversing through regulatory compliance, industry trends, the pressing need for energy savings, meticulous checklists of Energy Conservation Measures (ECMs), and the transformative potential of technological innovations.

SIGNIFICANCE OF HVAC RETROFITTING

As the world increasingly grapples with the challenges posed by climate change, the significance of retrofitting existing HVAC systems comes to the forefront. The energy consumed by Air-conditioner and cooling systems in residential buildings constitutes a substantial portion of the overall consumption. Retrofitting offers a strategic avenue to enhance the efficiency of these systems, thereby reducing operational costs, mitigating environmental impact, and aligning with global sustainability objectives.

CHECKLIST OF ECMs (Common Measures for All Zones and Typologies)

Achieving optimal energy efficiency in HVAC systems during retrofits requires a meticulous approach, considering the diverse climatic zones and building typologies across India. This comprehensive checklist outlines essential Energy Conservation Measures (ECMs), categorized based on climatic considerations and specific building types, ensuring a customized and effective strategy for HVAC retrofit projects in the Indian context

I. REGULAR HVAC SYSTEM MAINTENANCE:

- Establish a routine maintenance schedule to ensure the ongoing efficiency and longevity of HVAC systems.
- Conduct periodic inspections, filter replacements, and system optimization.

II. OCCUPANT AWARENESS PROGRAMS:

- Implement programs to raise awareness among occupants about energy-efficient practices.
- Foster a culture of energy conservation through education and engagement..

Segregation of Measures

Efficient HVAC retrofit planning demands a nuanced understanding of Energy Conservation Measures (ECMs) categorized by their capital cost implications. This comprehensive segregation into No Cost, Low Cost, Mid Cost, and Capital-Intensive Cost tiers ensures stakeholders can make informed decisions balancing financial constraints and sustainability objectives. The following detailed breakdown offers extensive insights into the implementation strategies and considerations for each category:

I. NO-COST ECMs:

1. AIR FILTER MAINTENANCE:

FIGURE 27 AIR FILTER MAINTENANCE

- **Description:** Establishing a proactive air filter maintenance schedule.
- **Implementation Strategies:**
  - Employing real-time monitoring systems to track filter health and schedule replacements.
  - Introducing predictive maintenance tools that use data analytics to forecast optimal replacement times.
  - Conducting regular training for maintenance staff to enhance filter replacement efficiency.

2. BEHAVIORAL CHANGES:

- **Description:** Conducting awareness programs to promote energy-efficient practices.
- **Implementation Strategies:**
  - Developing interactive campaigns utilizing multimedia channels to engage building occupants.
  - Introducing incentive programs for energy conservation.
  - Establishing a continuous feedback loop for occupants to share energy-saving suggestions.

3. OPTIMIZED HVAC SYSTEM SETTINGS:

- **Description:** Adjusting temperature setpoints and ventilation rates to optimize energy efficiency without additional costs.
- **Implementation Strategies:**
  - Conducting periodic energy audits to identify optimal setpoints and control parameters.
  - Utilizing predictive analytics tools for continuous system optimization.
  - Implementing a proactive maintenance schedule to ensure controls operate optimally.

II. LOW-COST ECMs:

1. PROGRAMMABLE THERMOSTATS:

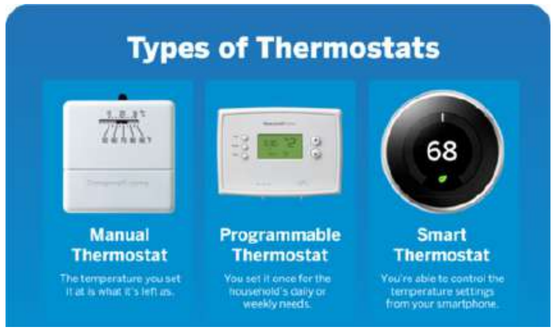


FIGURE 28 PROGRAMMABLE THERMOSTATS

- **Description:** Upgrading to programmable thermostats for better control and scheduling.
- **Implementation Strategies:**
  - Deploying smart thermostats that can be remotely controlled and programmed.
  - Integrating thermostats with occupancy sensors for adaptive temperature control.
  - Conducting training sessions for building occupants to maximize thermostat usage.

III. MID-COST ECMs:

1. ENERGY STAR-RATED APPLIANCES:

- Replace old appliances with Energy Star-rated models for improved efficiency.
- Capital-intensive due to the need to replace existing appliances, but significant energy savings and environmental benefits over their lifecycle.

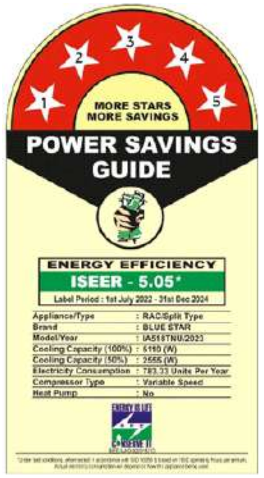


FIGURE 29 INSTALLING STAR RATED APPLIANCES

2. SMART APPLIANCES:

- Integrate smart technologies for automated control and energy optimization.
- Higher initial cost, but the automation capabilities contribute to precise energy management, leading to long-term operational efficiency and energy savings.

FIGURE 30 INTEGRATE SMART CONTROLS AND AUTOMATION

IV. CAPITAL-INTENSIVE COST ECMS:

1. HIGH-EFFICIENCY HVAC SYSTEMS:

FIGURE 31
INSTALLING HIGH-EFFICIENT HVAC SYSTEM

- **Description:** Complete replacement or major upgrade to high-efficiency HVAC equipment.
- **Implementation Strategies:**
  - Conducting a comprehensive lifecycle cost analysis to justify the long-term benefits.
  - Exploring innovative financing models, such as performance-based contracting.
  - Collaborating with manufacturers and suppliers to customize systems based on building needs.

2. VARIABLE REFRIGERANT FLOW (VRF) CONTROLS:

FIGURE 32 VARIABLE AIR VOLUME (VRF) CONTROLS

- **Description:** Installing VRF controls to optimize airflow and enhance zoning capabilities. VRF can be used to replace split Air conditioners in a household or residence where the requirement of split Air conditioners is more than three individual units.
- **Implementation Strategies:**
  - Conducting a detailed HVAC system assessment to identify zones suitable for VRF controls.
  - Integrating real-time monitoring systems to adjust VRF settings dynamically.
  - Implementing control algorithms that consider occupancy, temperature, and airflow requirements.

3. SMART METERS:

FIGURE 33 INTEGRATING SMART ENERGY METERS

- Integrate smart meters for real-time monitoring and effective load management.
- Considerable upfront investment, providing detailed insights into energy usage patterns for informed decision-making and long-term efficiency gains

4. RENEWABLE ENERGY INTEGRATION:.

FIGURE 34 RENEWABLE ENERGY INTEGRATION

- **Description:** Incorporating renewable energy sources, such as solar panels, to power HVAC systems.
- **Implementation Strategies:**
  - Conducting feasibility studies and energy modeling to optimize renewable energy system sizing.
  - Exploring government incentives, grants, and subsidies to offset initial capital costs.
  - Integrating smart grid technologies for efficient energy distribution and storage.

CONCLUSION:

This elaborate segregation of ECMs based on capital cost involvement serves as a comprehensive guide for stakeholders involved in HVAC retrofit projects in the Indian context. By delving into intricate details of implementation strategies and considerations, decision-makers can strategically plan and execute retrofits that not only align with budgetary constraints but also contribute to long-term sustainability objectives. This holistic approach ensures a balanced and effective implementation of energy-efficient HVAC retrofits, tailored to the unique challenges and opportunities presented by the diverse landscape of India.

Retrofit Case Study

GPRA RESIDENTIAL COMPLEX, EAST KIDWAI NAGAR, NEW DELHI

Location	East Kidwai Nagar, New Delhi-11023
Site Area	2,76,045.65 sq.m
Built-up Area	5,62,217.36 sq.m.

The following strategies were adopted to reduce the building impact on the natural environment:

PASSIVE DESIGN STRATEGIES.

1. Envelope
   - China mosaic tiles were applied to all exposed roof surfaces to reflect heat and lower indoor temperatures, contributing to overall thermal comfort.

ACTIVE DESIGN STRATEGIES.

2. Energy
   - **Occupancy sensors** were installed to automatically control lighting and reduce energy wastage.
   - **LED fixtures** were used throughout the building to improve energy efficiency and lower electricity consumption.
   - Electrical equipment with a minimum BEE 3-Star rating was selected to ensure optimal energy performance.
   - Timers for external lighting were installed to regulate usage and prevent unnecessary energy consumption
3. Renewable Energy
   - A 940 kWp on-grid solar rooftop plant was installed to generate clean energy and reduce reliance on conventional power sources.
   - A biogas plant was set up to convert organic waste into usable energy, promoting sustainability and waste management.
   - Solar-powered streetlights were installed to provide outdoor lighting while minimizing electricity consumption from non-renewable sources.

Best Practices for overall improvement of the site

4. **Water Management**
   - **Low-flow faucets with aerators** were used to reduce water consumption without compromising functionality.
   - **Cumulative water consumption was reduced by 65%** through efficient water management strategies.
   - **Sprinkler irrigation systems** were installed to ensure efficient water distribution and minimize wastage.

BEST PRACTICES

5. **Site Parameters:**
   - The site provides **easy access to essential services**, including a grocery store, pharmacy, park, restaurant, and EV charging stations, promoting convenience and sustainability.
   - Approximately **4,980 trees were planted and preserved** within the site to enhance greenery and reducing Urban Heat Island effect

PALLADIO, TATHAWADE, PUNE


Location	Tathawade, Pune
Climate	Warm & Humid
Rating	GRIHA - 4 Star
Energy Performance Index	27.53 KWh/m2/year
Site Area	15994.32 m2
Built-Up Area	14223.61 m2
Client	Vilas Javdekar Eco Developers Pvt. Ltd.

PASSIVE DESIGN STRATEGIES.

1. **Envelope**
   - **Shading devices**, such as curtains and blinds combined with appropriate glazing, were incorporated to reduce direct solar heat gain by approximately **45%**.
   - **Heat-reflective paint** was applied to the roof to minimize solar heat absorption, resulting in a temperature reduction of around **1.5°C**.

ACTIVE DESIGN STRATEGIES

2. **Lighting**
   - **LED fixtures** were installed throughout the building, ensuring energy conservation while maintaining the recommended **lux levels as per NBC 2005**.

RENEWABLE ENERGY

3. **Solar hot water system**
   - A **solar hot water system** was installed to meet **100% of the project's hot water requirements**, thereby reducing energy consumption from non-renewable sources..

5 MASTERS' RESIDENCES, NEAR FOOTHOUSE, DOON SCHOOL

Location	Dehradun, Uttarakhand
Climate	Composite
Rating	GRIHA 4 Star
Site Area	614.05 Sq.m
Built-Up Area	190.15 Sq.m
Client	Doon School

PASSIVE DESIGN STRATEGIES

1. Materials

- Use of low-VOC and lead free paints helps in maintaining good indoor air quality.
- The shading devices like curtains and films of the residence reduces the direct incident heat penetration by about 60% of direct heat gain inside the building.

ACTIVE DESIGN STRATEGIES

2. Lighting

- The use of LED fixtures for lighting design resulted in Lighting power density of 2.29 W/sq. and thermal efficiency of the project is 399.73 sq.ft./TR (37.14 sqm/TR).
- All fans and geysers installed in the building are BEE 5-star and BEE 4-star rated, respectively.

BEST PRACTICES

- Almost 60% of the total open area on site is soft paved and/or shaded under trees.
- Dense vegetation around the residences helps in moderating the micro-climate.
- At the campus, level, dedicated resting areas and toilets are provided for the service staff.
- Each residence has an organic kitchen garden.

GRATITUDE ECOVILLA

Location	Puducherry, Tamil Nadu
Climate	Warm and Humid
Site Area	306.10 Sq.m
Built-Up Area	474.00 Sq.m
Client	Mr. Prabodh Doshi and Mrs. Roma Doshi
Renewable Energy Integrated Design Team	Ms. Trupti Doshi (Auroma Architecture)

PASSIVE DESIGN STRATEGIES

1. Walls

- Low VOC and lead-free paints have been used to maintain good indoor air quality.
- The use of appropriate glazing for windows and internal shading devices resulted in92.86% of the total living area is day-lit.

ACTIVE DESIGN STRATEGIES

2. Lighting

- The use of LED fixtures for lighting design resulted in Lighting power density of LPD of the project is 3.22 W/m2 which is lower than the ECBC specified limit of 7.50 W/m2 for residential buildings.

3. Appliances

- All fans installed in the building are BEE 5-star rated.

BEST PRACTICES

- Basic amenities such as grocery store, ATM, park, pharmacy restaurant, community center, school and place of worship are in close proximity to the site.
- Dedicated toilet and resting room were provided for service staff in the project.
- Reclaimed wood has been used in the project interiors.
- Environmental awareness signages have been displayed at various locations.

PAVNA RESIDENCE

Location	Aligarh, Uttar Pradesh
Climate	Composite
Site Area	9,012 sq.m.
Built-Up Area	27.53 KWh/m2/year
Site Area	2,406 sq.m.
Client	Ms. Aasha Jain and Ms. Priya Jain
Renewable Energy	1.4 kWp Panel and 150 lpd capacity of solar water heater

PASSIVE DESIGN STRATEGIES

1. Building Envelope

- **Low-VOC and lead-free paints** were used to maintain good indoor air quality and promote occupant well-being.

ACTIVE DESIGN STRATEGIES

2. Lighting

- The **Lighting Power Density (LPD) of the project is 6.02 W/sqm**, which is lower than the **ECBC-specified limit of 7.5 W/sqm** for multifamily buildings, ensuring energy efficiency.

3. HVAC and Appliances

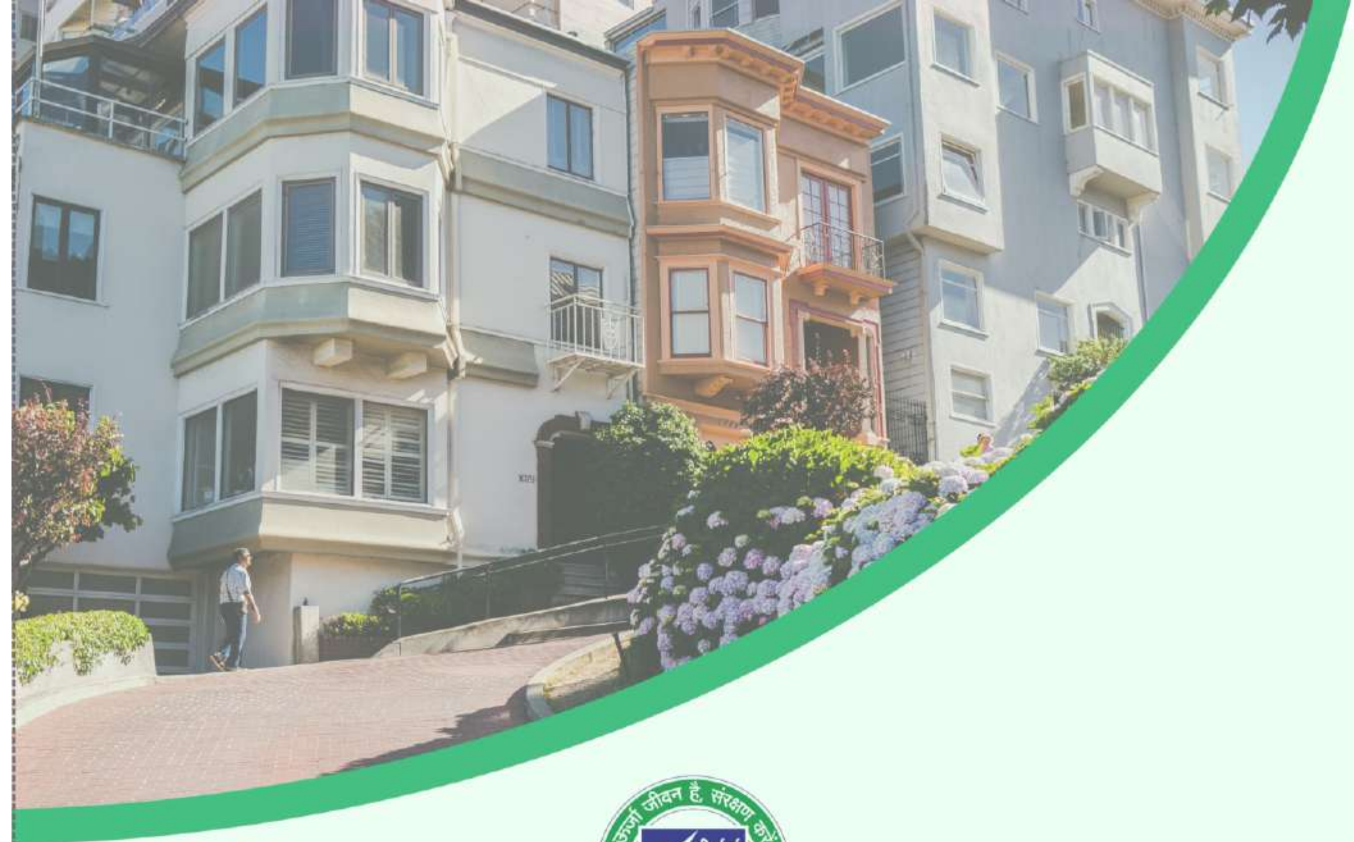
- All **fans and geysers** comply with **BEE 5-star efficiency ratings**, reducing energy consumption.
- A **VRF (Variable Refrigerant Flow) system** was installed to optimize heating and cooling performance.
- **Automatic controls** were implemented for all electrical fixtures to enhance energy savings.

RENEWABLE ENERGY

- **Solar photovoltaic panels** with a capacity of **1.4 kWp** were installed to generate clean energy.
- A **solar water heater with a 150 LPD (liters per day) capacity** was installed in the villa to reduce reliance on conventional water heating systems.

BEST PRACTICES

- **Dedicated toilets and resting rooms** were provided on-site for service staff to ensure their comfort and well-being.
- **Green building features** were prominently displayed to raise awareness about environmental sustainability.
- **Electric vehicle (EV) charging points** were installed to encourage the use of eco-friendly transportation.



Bureau of Energy Efficiency

BEE is statutory body under the Ministry of Power. It assists in developing policies and strategies with the primary objective of reducing energy intensity of the Indian economy. BEE co-ordinates with designated consumers, designated agencies and other organizations to identify and utilize the existing resources and infrastructure performing the functions assigned to it under the Energy Conservation Act.

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