14

Energy Audit Applied to Buildings

It is very surprising that when buying a new car, people are very much concerned about economy, but when buying a new home or making a new building (whose lifespan is much longer than a car), energy is of least concern though consumption of energy and its impact on environment is almost equal in both cases.

If we look at the worldwide energy-consumption scenario, in developed countries, energy consumption is slightly higher than the population growth rate, but in developing countries like India, the expected growth in energy-consumption rate is 4.3% compared to the expected population growth rate of 1.3%. Again, the construction-industry growth is 10% in India compared to the world average of 5.2%, which is an alarming rate of energy consumption in the building sector. Commercial buildings are the largest energy consumers after industry and agriculture, and consume more than 20% of the national share. In properly planned energy-efficient buildings, energy saving of 40 to 50% can be achieved and the same for an existing building is 20 to 25% by adopting retrofits and proper maintenance schedules.

When talking of energy efficiency in buildings, there are two major aspects—designing and making an energy-efficient building using ASHRAE or ECBC codes, and following concepts of green buildings or adopting retrofits and maintenance checks to reduce energy consumption of existing buildings.

Green buildings are structures environmentally responsible and resource-efficient throughout a building's lifespan. Starting from design, construction, operation, maintenance, renovation and demolition—all processes are executed for minimum energy consumption and environmental impact.

LEED (Leadership in Environmental and Energy Design) is a USA-based rating programme which assesses buildings against a set of established environmental performance criteria of energy, water usage, material usage, air quality, etc. LEED also provides certification (bronze, silver, gold, or platinum), accreditation, training, and practical resources. To obtain LEED certification, a building has to satisfy certain prerequisites and performance benchmarks. A few Indian buildings certified by LEED are listed in Table 14.1 For a detailed list, refer the website www.igbc.in

Table 14.1 *Some LEED rated buildings in India*

Project name	*Location*	*LEED rating*
One Earth (Suzlon's global headquarter)	Pune	Platinum
Tzed Homes (Biodiversity conservation India Ltd.)	Bengaluru	Platinum
Olympia Technology Park	Chennai	Gold
ITC Green Centre	Gurgaon	Platinum
Rajiv Gandhi International Airport	Hyderabad	Silver

The Government of India has launched *ECBC—Energy Conservation Building Codes*. These are voluntary codes applicable to buildings having a connected load of 500 kW or a contract demand of 600 kVA. These codes state minimum standards for building envelop, equipment, systems, hot-water heating, lighting, motors, etc. This chapter discusses energy-saving potential in new as well as existing buildings. HVAC and lighting are two major sectors where energy savings are possible and they are discussed in Chapters 9 and 13 respectively; hence, detailed discussions on HVAC and lighting are excluded from this chapter.

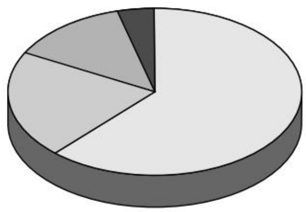


Chart 14.1 *Energy consumption in a commercial building (See color figure)*

❑ 14.1 ENERGY-SAVING MEASURES IN NEW BUILDINGS

As we know, conduction, convection, and radiation are three modes by which heat is transferred from high-temperature atmospheric air to the building envelop. Chart 14.1 shows approximate heat gain by a building by different heat sources. As shown in the chart, the highest amount of heat is poured through glazed walls followed by internal-heat gain and roof-heat gain. Some energy-saving aspects to reduce heat gain and, thereby to reduce energy consumption, are discussed here.

14.1.1 Maximize Use of Natural Energy Flow

HVAC need of the building is directly related to difference between inside and outside temperatures. A well-designed building maximizes natural energy flow, i.e., use of cool air in summer and trapping and storing solar radiation in winter—minimizing the burden of the HVAC system and thereby reducing power consumption. How to maximize use of natural energy flow depends on geographical location and surrounding climate of the building. This is also known as *passive design* of the building. Key elements describing passive design are discussed here:

1. **Orientation of Building** Orienting a building in the proper direction will have passive heating and cooling in all weather and helps reduce energy bills. A building should have minimum exposure in south and west directions to reduce direct heat load from sunrays for Indian latitudes and longitudes falling in hot regions.
2. **Insulation** It reduces heat loss and gain by the building envelop, walls, roof, and floor. Insulation is selected based on several criteria like lifespan, cost, applicable temperature range, weather effect, etc. Some building materials like concrete, brick, etc., serve the purpose of insulation. They also average day and night temperature difference, and thereby increase comfort at reduced energy cost.

3. As shown in Chart 14.2, maximum heat gain in a building is through glazing and windows. Thus, they are designed and located to maximize cool breeze to enter the building in summer and minimize winter winds to enter the building in winter.
4. **Skylights** As mentioned in Chapter 13, use of daylight is the ideal source in terms of quality and energy. People feel healthier when exposed to natural light compared to artificial lights. Some skylight options are shown in Figure 14.1.

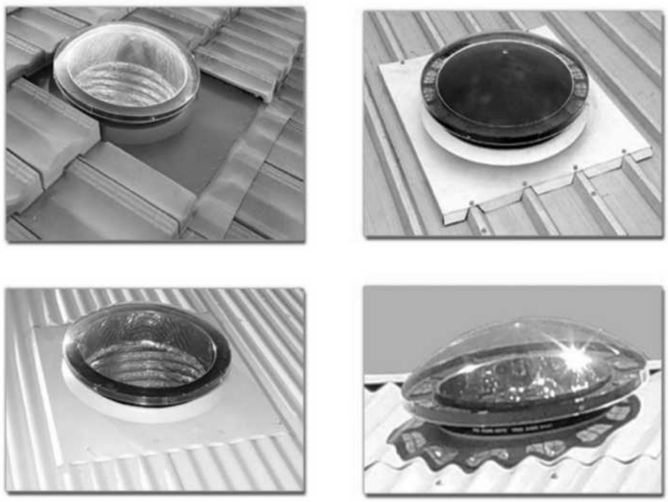


Figure 14.1 *Different fixtures for skylights (See color figure)*

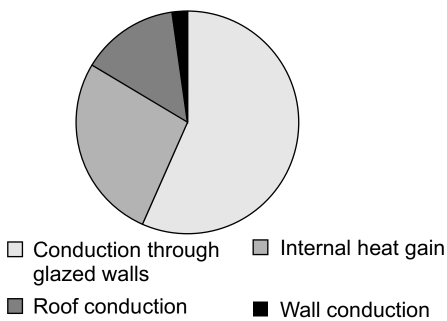
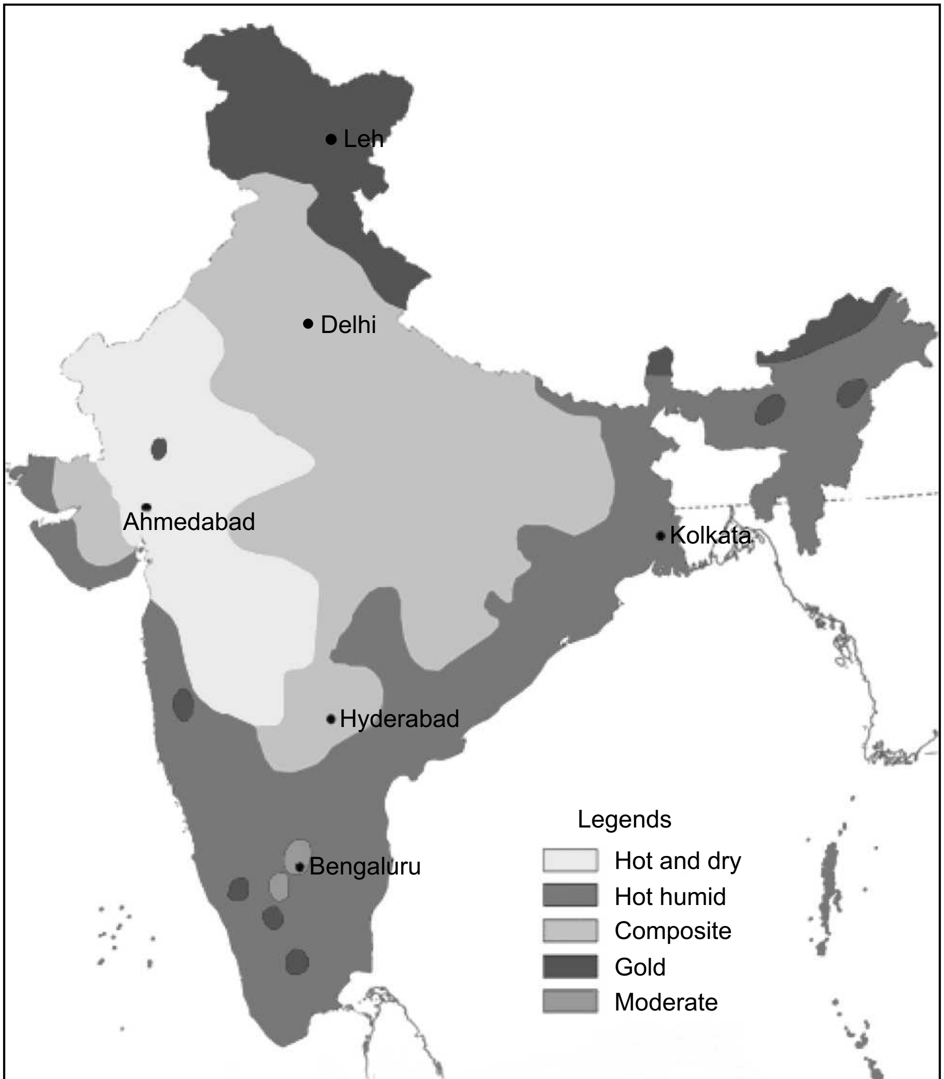


Chart 14.2 *Approximate heat gain in a building premises (See color figure)*

14.1.2 Envelop Heat Gain

The location of a building decides heat gain by its envelop. As our country spreads over a wide geographical span, different states have variations in average atmospheric temperature. Figure 14.2 shows the general atmosphere of a particular location. A summary of advisable indoor conditions are given in Table 14.2. To reduce heat gain through building envelops, some suggestions are given here:

1. Select high-performance glazing with low *U*-value, low shading coefficient, and high visual light transmittance.
2. Use hollow blocks, fly-ash bricks, and autoclaved aerated concrete blocks as insulation bricks to reduce heat ingress.
3. Select and use proper insulation material on sun-facing walls and roofs.
4. Consider window shades, venetian blinds (window blinds), or tree plantations outside the building to reduce direct heat gain.



Map of India showing different climatic zones
(map not to scale)

Figure 14.2 *Different climate zones of India (See color figure)*

14.1.3 Equipment Selection

Use of energy-efficient equipment will reduce power consumption; hence, while selecting an equipment/system consider the following aspects:

1. Use chillers/air conditioners/motors/light fittings/pumps with maximum performance and high star ratings.
2. Use variable-frequency drives for ventilation fans, pumps, etc.
3. Select and locate the cooling tower to perform at its best.
4. Use heat-recovery wheels, heat-pipe-based heat-recovery systems, and economizers in HVAC units.
5. Take maximum advantage of time of day tariff (pumping of water during night hours to reduce daytime electricity consumption).
6. Install wind curtains on all openings.
7. Install occupancy sensors on escalators to avoid continuous running.
8. Adopt building-management system for effective control of equipment.
9. Select and use CFC-free refrigerant in HVAC equipment, which has minimum ozone-depletion potential.

Table 14.2 *Recommendations for different types of weather*

Climate zone	*Recommended building conditions*
Hot and dry	Reduce heat gain by proper orientation. Decrease exposed surface area. Increase thermal mass and resistance. Decrease ventilation during daytime and increase during night time. Increase use of shades with fins and trees. Use light colours on wall exteriors. Use reflective tiles on the roof. Use open-water surfaces, i.e., ponds, fountains, etc., to increase evaporative cooling.
Hot and humid	Reduce heat gain by proper orientation. Decrease exposed surface area. Increase thermal mass and resistance. Increase ventilation during day and night. Increase use of shades with fins and trees. Use light colours on wall exteriors. Use reflective tiles on the roof. Use dehumidifiers and desiccant-based cooling systems to reduce humidity.

(*Contd.*)

(*Contd.*)

Climate zone	*Recommended building conditions*
Composite	Reduce heat gain in summer and loss in winter. Decrease exposed surface area. Increase thermal mass and resistance. Increase ventilation in summer and monsoon and decrease in winter. Increase use of shades with fins and trees. Use light colours on wall exteriors. Use reflective tiles on the roof. Increase humidity in summer and decrease in monsoon.
Cold	Reduce heat loss. Decrease exposed surface area. Increase thermal mass and resistance. Decrease ventilation. Decrease use of shades with fins and trees. Use dark colours on wall exteriors and glass to absorb more solar radiation.
Moderate	Reduce heat gain. Decrease exposed surface area. Increase thermal mass and resistance. Increase ventilation. Increase use of shades with fins and trees. Use light colours on wall exteriors. Use reflective tiles on the roof. Increase humidity in summer and decrease in monsoon.

14.1.4 Insulation

Selection, application, and maintenance of insulation are key factors in energy-efficient buildings. After selecting appropriate insulating material, it is necessary to install it without any cavity or air gap. They need to be protected from sunlight, moisture, wind, and other weather effects.

14.1.5 Cool Roof

Maximum solar radiation is received by the roof of the building as it is continuously exposed to the sun. Heat received by the roof surface is partly absorbed and transmitted to the building and partly reflected back to the environment. Surfaces having more reflectivity will reduce absorption of heat and, thus, the building temperature will reduce. Thus, reflectivity and emissivity of roof material decides the amount of solar radiation received by building.

Roofs covered with reflective coatings are known as *cool roofs*. The benefit of a cool roof is that temperature is 10 to 15ºC lesser than conventional buildings in peak summer. Use of white-coloured china mosaic tiles or white cement tiles also reduces solar radiation received by buildings.

14.1.6 Improving Air-tightness

Air leakage from cracks, holes, walls, ceilings, floors, and openings reduces energy efficiency of conditioned buildings. A building can lose or gain up to one-third of its heat through infiltration or exfiltration. Following measures can be taken to reduce the loss:

1. Installing continuous vapour retarders on walls and ceilings.
2. Blocking holes, cracks, and open surfaces.
3. Proper sealing around windows and doors.
4. Proper sealing around pipeworks and ductworks.

14.1.7 Educate People to Go for Energy-Efficient Buildings

One of the major constraints for not designing and constructing an energy-efficient building is the wrong perception that energy-efficient buildings are more costly. Case studies show there is not a very significant cost difference in conventional buildings and green buildings. On the contrary, over its lifespan, a green building provides lots of benefits to users and the environment. Overall benefits of green buildings are summarized in Table 14.3.

Table 14.3 *Benefits of green buildings*

Benefits of green buildings	*Builder/Developer*	*Employee*	*Owner*
Different identification and image	√	√	√
Saleability of building	√		√
Higher rents	√		√
Higher return on investment	√		√
Higher re sale value	√		√
More work satisfaction and productivity		√	√
Reduction in water consumption			√
Reduction in energy consumption			√

14.1.8 Co-ordination Between Designer and Developer

Lack of coordination has been observed in the Indian construction industry, which ultimately results in fast and nasty designs. Instead of technical designs and software, developers still use rules of thumb in many cases. Awareness and building code mandates may help increase the number of green buildings.

14.1.9 HVAC Sizing and Number of Lightings

It is observed that most buildings have oversized air-conditioning plants installed and same is the case in lighting. It is also observed that highest or lowest temperatures just exist for 2 to 5% of the days of a year; hence, selection of an HVAC system should be based on actual requirement, rather than future expansion plans or thumb rules. Similarly, excessive lighting should be discouraged, as it adds load on the HVAC system and energy bill.

As per IGBC codes, installed chillers and air conditioners of a building should meet the following performance values to meet requirements of a green building.

Table 14.4 *Minimum power consumption of chiller units as per IGBC codes*

Type of chiller	*Capacity (ton)*	*Minimum COP*	*Minimum IPLV*
Air-cooled chiller	Less than 150	2.90	3.16
Air-cooled chiller	More than 150	3.05	3.32
Centrifugal water-cooled	Less than 150	5.80	6.09
Centrifugal water-cooled	150 ton to 300 tons	5.80	6.17
Centrifugal water-cooled	More than 300	6.3	6.61
Reciprocating, water-cooled	All sizes	4.2	5.05
Rotary, screw, and scroll compressor, water-cooled	More than 150	4.7	5.49

Table 14.5 *Minimum power consumption of AC units as per IGBC codes*

Cooling capacity (kW)	*Maximum power consumption (kW)*			
	Unitary AC	*Package AC*		*Split AC*
		Water-cooled	*Air-cooled*	
1.7	1.1	3.75	4.75	–
2.6	1.4	6.00	7.00	–
3.5	1.6	9.00	10.0	1.7
4.4	2.0	11.5	13.5	–
5.2	2.4	17.0	20.0	2.6
7.0	3.2	–	–	3.4
8.7	4.25	–	–	4.5
10.5	5.2	–	–	5.4

14.1.10 Efficient Use of Water

Reduced use of water has direct impact on the environment and indirect impact on energy saving. A building design should utilize the groundwater table and reduce municipal-water demand through effective management of rainwater. Providing a rainwater harvesting system will capture run-off water from the roof area.

Select water-efficient (low flow rate) plumbing and irrigation fixtures. Promote use of an onsite water-treatment system to treat wastewater generated in the building. Treated wastewater or rainwater can be used for flushing toilets.

14.1.11 Adopt Solar Water Heating

A solar water-heating system has a collector area and storage tank. The *collector* is made of an insulated box having an array of water pipes attached to black-painted metal sheets. The collector box might have a glass or plastic cover to retain solar energy. Solar water heating can be of passive or active type. In passive systems, circulation of water is gravity-assisted and, hence, does not require pump. A tank connected with a collector stores hot water. The schematic of passive and active solar water-heating systems are shown in Figure 14.3. In an active solar water-heating system, a pump circulates water from the storage tank. Up to 90% of energy saving is possible with solar water-heating system and, hence, solar water heating is an essential part of an energy-efficient building. Calculate total hot water requirement of the building at the design stage and install solar panels at the initial stage of the building.

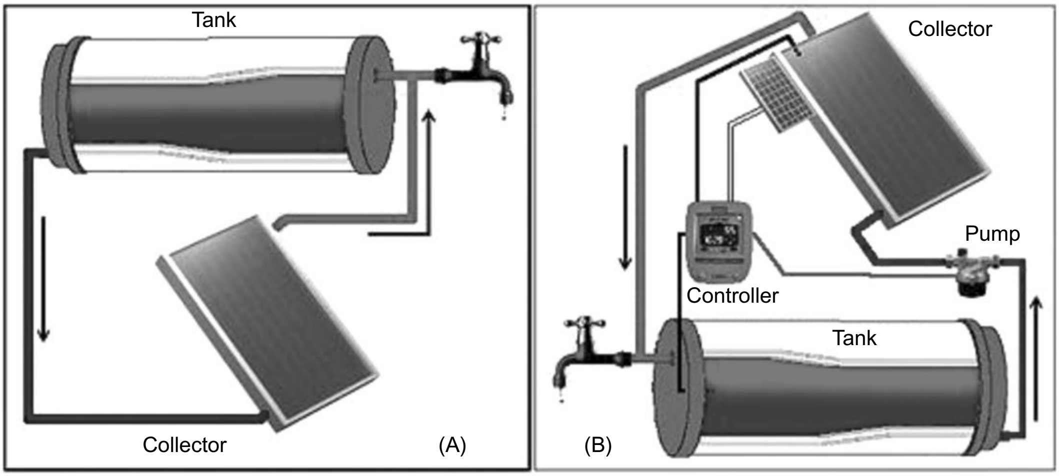


Figure 14.3 *Passive and active solar water-heating systems*

14.1.12 Promote Use of Decentralized Power Plants

Distributed generation, or decentralized power plants, are small-capacity generators using many sources of energy. These plants have excellent economics of scale and if run with green fuel, they have positive impact on the environment. A biofuel-based or non-edible-oil-based decentralized power plant is an option of utility power and reduces dependence on fossil fuels.

14.1.13 Energy-saving Measures in Existing Buildings

Fear of rapid depletion of exhaustible energy sources, global warming, climate change, and mushroom growth in the construction industry are reasons for conducting energy audits of existing buildings. Ancient buildings were designed and constructed in harmony with nature; so in a way they are energy-efficient, but buildings constructed in the last 50 years are potential candidates for energy efficiency. Conducting an audit of an existing building is a multiphase task, including data collection, analysis, identifying opportunities, planning, and then implementing. The list of information to be collected by an audit team is listed below:

1. Building plan and HVAC layout.
2. Energy cost and tariff data.
3. Type of chiller, capacity, and operating pattern.
4. Details of fan, pump, pipework, ductwork, etc.

5. Occupancy with respect to time and day.
6. Various equipment and systems installed.
7. Type and numbers of luminaries and their control mechanisms.
8. Power distribution and transformer details.
9. Details of lift, escalators, and their operating hours.
10. Other sources of energy if used like gas, diesel, etc.

After obtaining the above data, the energy-audit team will compare the same with design and historical data. Major deviations in current data, design data, and historical data for a particular system or equipment are an indication of abnormality. The following parameters can be assessed to compare data:

1. COP or IPLV of the HVAC system.
2. Motor, pump, fan efficiency, and load pattern.
3. Piping-system frictional losses.
4. Luminous efficacy.
5. Heat loss from hot water or steam lines.
6. Boiler, compressor, heat-pump efficiency if they exist in the building.

Follow this principle for data collection: "Do not estimate what you can calculate and do not calculate what you can measure." It is also critical to decide the points of data collection. Follow technical guidance given in respective chapters to collect the data of an HVAC system, lightings, pumps, motors, etc., to have accurate data. The next task after data collection is analyzing. At this junction of time, the audit team will screen and spot the parameters for which qualitative and quantitative deviations in trends are observed. These points are sources of energy-management opportunities, now onward noted as EMO.

After identifying EMO, an auditor will perform financial analysis like payback period, net present-value calculations, etc., for suggested changes. If required, lifecycle cost assessment will be carried out for a particular EMO. It should be noted that the EMO should not downgrade the quality of service or working environment, e.g., increasing room temperature will save energy but creates uncomfortable working conditions for residents or employees. The EMO should also consider previous audit recommendation or due maintenance, if any, which is followed by implementation. The Energy Utilization Factor (EUI) is a platform to compare energy consumptions of different buildings of similar nature.

$$\text{EUI} = \frac{\text{Annual energy consumption}}{\text{Gross floor area}} \tag{14.1}$$

Collect the energy-consumption data in the following format.

Table 14.6 *Data sheet*

Month	*kWh*	*KVA*	*PF*	*kW*	*Energy charges*	*Demand charges*	*Total cost*	*Diesel or gas charges*
January								
February								
March								

April
May
June
July
August
September
October
November
December

If a building uses gas or diesel as a secondary form of energy, add their monthly consumptions. Using Equation (14.1), calculate the Energy Performance Index (EPI) of the building. Gross floor area is taken in m^2; hence, EPI is calculated in kWh/annum/m^2.

❑ 14.2 WATER AUDIT

Water management is a systematic approach of identifying, measuring, monitoring and reducing water consumption by various activities. Like energy audit, water audit is also a part of energy assessment of an existing building. It is an assessment of the capacity of total water produced by the governing authority and actual quantity of water distributed throughout the assessment area (e.g., town, municipal corporation area, township, etc.) The difference between the two is known as *nonrevenue water* or *unaccounted water*. A water audit also gives qualitative and quantitative analyses of water consumption. Advantages of a water audit are listed below:

1. It encourages social responsibility by identifying wasteful use of water.
2. It promotes water conservation and thereby reduces cost of water distribution and pumping.

Water-audit Methodology

Like an energy audit, the method to carry out a water audit depends upon many parameters like water source, population, type of use, climatic condition, source of wastewater generation, legal requirements, distribution network, etc., and, hence, an audit method is a tailor-made method applicable to a particular end user. However, general guidelines are given here for carrying out a water audit.

► ***Part A: Planning and Preparation*** It includes data collection and preparation of site sketch. Prepare a flow chart of the water-distribution system. If bulk water meters are available on the water-distribution network, collect water-flow rate data and if not available, measure the same with an ultrasonic water-flow meter.

► ***Part B: Verification*** Verify the mapped water-distribution system with the existing water-supply system for piping layout, valves, connections, etc. Verify that water meters are available or can be installed at major supply points, tube-well supply to the main line, reservoir supply line, etc.

► ***Part C: Data Collection*** Collect the data of water flow at major inlet points, data of population density, number of operating hours and per capita consumption or per ton consumption, raw water plant, demineralization plant, reverse osmosis plant, wastewater plant, etc. Collect the data of operating details of various pumps in each stream and operating hours. Also, collect water-quality details at all key points. In case of any breakdown or scheduled maintenance occurring in history, collect the data for the same.

► ***Part D: Analysis*** The information collected will be consolidated and used to prepare overall and streamwise water balance, and the location where unaccounted water flow occurs will be identified. Measure pressure drops in the pipe-distribution network. Further analysis is carried out to classify the water consumed, wasted, and lost in terms of finance and submitted in the form of a water-audit report which has key identifications like:

1. Locations that need immediate action to repair leak.
2. Locations that need water losses closely monitored.
3. Estimation of water-pumping cost and suggestions to reduce it by efficient use of pump or taking advantage of time of day tariff.

❑ 14.3 HOW TO AUDIT YOUR HOME?

Audit of a single-family a residence is fairly simple. It starts with gathering information of the building envelop, and past electricity and gas bills. List the number of plugged equipment at your home. In an air-conditioned house, inspect insulation and seals for windows and doors, and the integrity of ducts.

From past energy bills, analyze the consumption and identify patterns or anomalies.

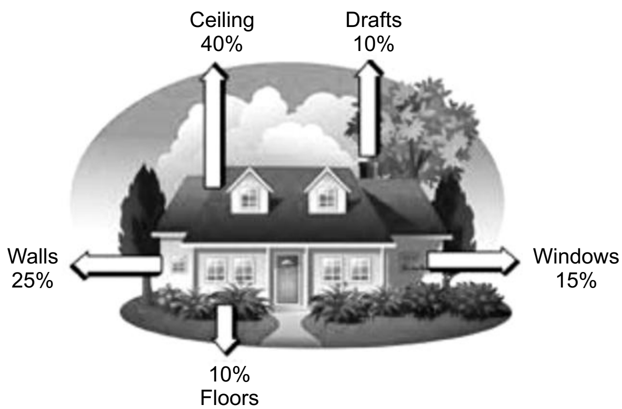


Figure 14.4 *Energy saving from different parts of a building*

Identify potential energy-saving opportunities from the analysis, e.g., performance deviation in the air-conditioning system, adding insulation, service requirement of hot-water system, adding double-pane windows or window shading, retrofitting lighting systems, retrofitting with more efficient STAR rated equipment, etc. ECSs are suggested with cost benefit and simple payback analysis.

❑ 14.4 GENERAL ENERGY-SAVING TIPS APPLICABLE TO NEW AS WELL AS EXISTING BUILDINGS

1. Use solar control glass to restrict solar radiation to pour through glazing. They permit light and restrict radiation from entering the building and, thereby keep the building-temperature low.
2. Keep high-heat-generation processes away from the building or use exhaust/ventilation fans for them.
3. Some locations have a big difference in day and night temperatures. It is advisable to use high thermal mass material (concrete, bricks, tiles, etc.) in such locations, as they are able to keep the building warm during winter nights and cold during summer days.
4. Replace outdated thermostats with programmable ones.
5. Rather than using an air conditioner, install ceiling fans, as in many cases, air movement is sufficient for comfort conditions.
6. CFLs consume less power and have long life compared to incandescent bulbs; hence, replace them.
7. Maintain and clean lamps for best performance.
8. Reduce the number of lamps in nonworking areas or use low-wattage bulbs.
9. Use low-flow faucets and showerheads to save water in bathrooms and kitchens.
10. Avoid acrylic paints or wallpaper, instead use natural paints or low Volatile Organic Compound (VOC) paints.
11. Use indoor plants as they add oxygen to the atmosphere and eliminate harmful volatile organic compounds.
12. Use on-demand hot-water heaters instead of storage-type hot-water heaters.
13. Use low Solar Heat-Gain Coefficient (SHGC) material. SHGC is a measure of solar heat gain from window glass. An SHGC of 0.3 indicates that the window allows 30% of solar radiation to pass across the window glass.
14. Encourage the use of electric vehicles in township, campus, etc., and provide electric-vehicle-charging facility.
15. Promote use of solar, wind, biogas, and biomass energy to reduce burden on the utility.
16. Encourage continuous monitoring of energy performance. Use different meters for external lighting, water pumping, and HVAC. Measurement and verification is simpler if segregated data are available.
17. In case of residential and hospital buildings, segregate waste (dry, wet, paper, plastic, metal, glass, surgical, etc.) before sending them to landfills. Also, collect batteries, lamps, and e-waste separately. Identify the scope of recycling green waste in the campus.
18. Encourage use of salvaged building materials and products instead of virgin material.

Descriptive Questions

Q-1 What is a green building?

Q-2 Give building recommendations for different climate zones of Indian states.

Q-3 Suggest energy-saving measures in a building.

Q-4 Explain water audit.

Short-Answer Questions

Q-1 What is passive design of a building?

Q-2 How can you reduce heat gain through a building envelop?

Q-3 What is cool roof?

Q-4 How can you ensure air-tightness in building?

Q-5 What are efficient ways to use water in a building?

Q-6 Define "Energy Performance Index".

Q-7 What is solar-heat-gain coefficient?

Fill in the Blanks

Q-1 LEED stands for ____.

Q-2 ____ is the largest source of heat gain in a building.

Q-3 Roofs covered with reflective coatings are known as ____________________.

Q-4 Temperature of a cool roof is _________________ lesser than a conventional building in peak summer.

Multiple-Choice Questions

Q-1 Which of the following helps reduce heat gain in a building envelop?

(a) Use of hollow blocks (b) Use of fly-ash bricks

(c) Use of aerated concrete blocks (d) All of the above

Q-2 Which of the following helps reduce direct heat gain in a building?

(a) Window shades (b) Venetian blinds

(c) Tree plantation (d) All of the above

Answers

Fill in the Blanks

1. Leadership in environment and energy design
2. Glazed walls and windows
3. Cool roof
4. 10 to 15°C

Multiple-Choice Questions

1. (d) **2.** (d)