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Subject Name: Energy Efficient Practices

Course Offered To: B.Tech 6th Semester Students

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Unit-4
Lighting and Distributed Generation Systems

- Basic Definitions
- Types of different lamps and their features
- Design Considerations for Efficient Lighting
- Energy Efficiency Opportunities in Lighting
- Distributed Generation Systems in Lighting Applications

Lighting plays a crucial role in various applications, including residential, commercial, and industrial sectors. With the advancement in technology, modern lighting solutions focus on energy efficiency, sustainability, and smart control. Distributed Generation (DG) systems complement efficient lighting by ensuring localized power generation, reducing transmission losses, and promoting renewable energy integration.

Role of Lighting in Different Applications

1. Residential Lighting

- Provides illumination for homes, ensuring safety and comfort.
- Enhances aesthetics and ambiance through different lighting designs.
- Smart lighting solutions allow for remote control and automation, reducing energy consumption.
- LED lighting reduces electricity bills and requires minimal maintenance compared to traditional incandescent bulbs.

2. Commercial Lighting

- Essential for offices, retail stores, and public spaces, creating a productive and visually appealing environment.
- Helps in reducing eye strain and improves employee focus and efficiency.
- Implementing energy-efficient lighting solutions lowers operational costs and enhances sustainability.
- Utilization of daylighting techniques and occupancy sensors (Passive IR Sensor) further reduces energy waste.

3. Industrial Lighting

- Plays a key role in manufacturing facilities, warehouses, and processing plants.
- Ensures adequate illumination for precision-based tasks, improving accuracy and safety.
- Industrial lighting systems require high-intensity solutions such as High-Intensity Discharge (HID) lamps or LED high bays.
- Use of automation and IoT-enabled lighting solutions optimizes energy usage and lowers costs.

Basic Definitions

1. Luminous Flux (Lumen)

- Luminous flux is the total visible light emitted by a source.
- It is measured in **lumens (lm)** and represents the brightness of a light source.
- The higher the lumen output, the brighter the light appears.
- **Example:** A 60W incandescent bulb emits around 800 lumens, whereas an equivalent LED might emit the same lumens using only 8W.

2. Illuminance (Lux)

- Illuminance is the amount of light that falls on a surface per unit area.
- It is measured in **lux (lx)**, where 1 lux = 1 lumen per square meter (lm/m^2).
- It determines how well a space is illuminated, which is important in designing lighting for homes, offices, and industrial areas.
- **Example:** A brightly lit office may have around 500 lux, whereas a streetlight might provide 30 lux.

3. Luminous Efficacy (lm/W)

- It represents the efficiency of a light source in converting electrical power into visible light.
- Measured in **lumens per watt (lm/W)**, higher efficacy means better energy efficiency.
- **Example:** Incandescent bulbs have an efficacy of around 10-15 lm/W, while LEDs can exceed 150 lm/W.

4. Color Rendering Index (CRI)

- CRI measures how accurately a light source reveals the colors of objects compared to natural sunlight.
- It is rated on a scale of 0 to 100, where **100 represents perfect color accuracy**.
- **Example:** High CRI lighting (above 80) is used in retail stores and photography, while low CRI lighting may distort colors.

5. Power Factor

- It indicates how effectively electrical power is converted into useful work.
- A power factor of **1 (or close to 1)** means efficient power usage. A lower power factor results in energy losses.
- **Example:** LED drivers and industrial lighting systems aim for a high power factor (above 0.9) to reduce energy wastage.

1. Incandescent Lamps

Working Principle: Incandescent lamps work by passing an electric current through a tungsten filament, which heats up to a high temperature (~2500°C) and emits visible light through incandescence. The filament is enclosed in a glass bulb filled with an inert gas (argon or nitrogen) to prevent oxidation.

Features:

- Low cost and easy to install.
- Short lifespan (~1000 hours).
- Poor energy efficiency (high heat loss).

Incandescent Lamp

2. Fluorescent Lamps (CFLs & Tube Lights)

Working Principle: A **fluorescent lamp** works by utilizing electricity to excite mercury vapor, producing ultraviolet (UV) light, which is then converted into visible light by a phosphor coating inside the lamp. A ballast regulates the current to prevent excessive energy flow.

Features:

- Higher efficiency than incandescent lamps.
- Lifespan of 8,000–15,000 hours.
- Requires a ballast to function.
- Contains mercury, requiring proper disposal.

Fluorescent Lamps

3. High-Intensity Discharge (HID) Lamps

Working Principle: HID lamps generate light by creating an electric arc between two electrodes within a gas-filled tube. Metal halide, high-pressure sodium, or mercury vapor gases ionize and emit high-intensity light. A ballast is required to regulate the power supply and ensure a stable arc.

Features:

- Very high luminous efficacy (~75–150 lm/W).
- Long lifespan (10,000–24,000 hours).
- Used for streetlights, stadiums, and industrial lighting.
- Requires a warm-up period to reach full brightness.

High-Intensity Discharge (HID) Lamps

- **Starting the Lamp**:
- When the lamp is switched on, a **ballast** provides a high initial voltage to ignite the gas mixture in the arc tube.
- This high voltage creates an electric arc between the electrodes.
- **Gas Ionization**:
- The electric arc ionizes the gas inside the arc tube (usually a mixture of gases like argon and mercury vapor, along with metal halides in some types).
- Ionization results in free-flowing electrons, allowing the electric current to sustain.
- **Light Emission**:
- The ionized gas emits light as it gets excited by the energy from the electric arc.
- The color and intensity of the light depend on the type of gas and metal halides used in the lamp.
- **Stable Operation**:
- Once the lamp is ignited, the ballast reduces the voltage to maintain a stable arc and consistent light output.

4. Light Emitting Diodes (LEDs)

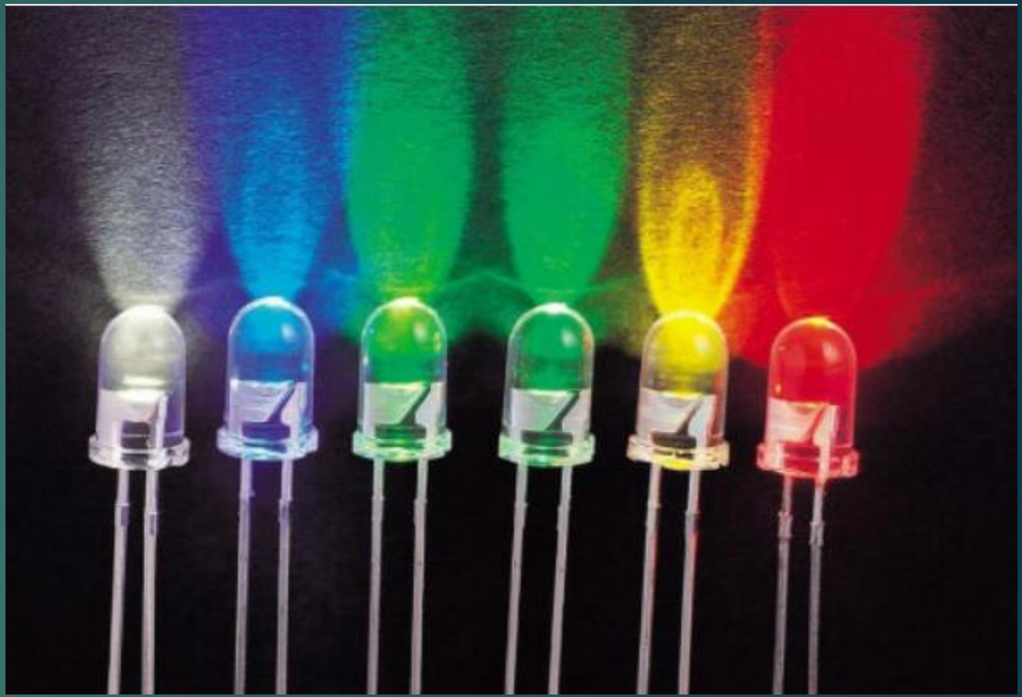
The working of a Light Emitting Diode (LED) is based on a phenomenon called **electroluminescence**, where a material emits light in response to an electric current.

Structure of LED:

An LED is made up of a p-n junction diode with two regions: a p-type semiconductor (positive) and an n-type semiconductor (negative). The p-type region has holes (positive charge carriers), while the n-type region has electrons (negative charge carriers).

The materials used in LEDs, such as gallium arsenide or gallium phosphide, determine the color of the light emitted.

Working Principle: When a voltage is applied across the p-n junction, electrons from the n-type region move toward the p-type region, and holes from the p-type region move toward the n-type region. In the active region (the junction between the p-type and n-type), electrons and holes recombine. During recombination, electrons lose energy in the form of photons, producing light. This process is known as electroluminescence.



Light Emitting Diodes

Features:

- High energy efficiency and long lifespan (50,000+ hours).
- Instant illumination with no warm-up time.
- Available in various colors and dimmable versions.
- Low heat generation and mercury-free.

5. Halogen Lamps

The working of a halogen lamp relies on the principle of **incandescence** and involves a chemical process with halogen gas to extend the lamp's lifespan and improve efficiency.

Structure:

A halogen lamp contains a tungsten filament, similar to a traditional incandescent lamp. The filament is enclosed in a quartz envelope rather than glass, as quartz can withstand higher temperatures.

- **The envelope contains a small amount of halogen gas (e.g., iodine or bromine).**

Working Principle:

When electricity flows through the tungsten filament, it heats up and emits light due to incandescence. Over time, tungsten evaporates from the filament and would typically deposit on the inner surface of the bulb. However, in halogen lamps, a chemical reaction occurs between the halogen gas and the evaporated tungsten.

Halogen Lamps

Halogen Cycle:

- The halogen gas reacts with the evaporated tungsten to form tungsten halide.
- Tungsten halide remains in the gas phase at high temperatures and migrates back to the filament.
- The tungsten is redeposited on the filament, reducing the blackening of the bulb and extending its lifespan.
- This cycle allows the filament to operate at higher temperatures, making halogen lamps brighter and more efficient compared to traditional incandescent bulbs.

Features:

•Higher efficiency than standard incandescent bulbs.

•Compact and provides bright white light.

•Short lifespan (~2,000–4,000 hours).

•Produces significant heat.

Design Considerations for Efficient Lighting Systems

- **Light Distribution:** Ensuring uniform illumination to minimize glare and dark spots.
- **Color Temperature Selection:** Choosing appropriate lighting for different environments (e.g., warm light for homes, cool light for offices).
- **Luminance and Brightness Control:** Using dimmers and sensors for energy optimization.
- **Fixture Design:** Selecting energy-efficient fixtures that enhance light output and minimize losses.
- **Integration with Smart Controls:** Utilizing automation and IoT-enabled systems for adaptive lighting.

1. Light Distribution: Ensuring Uniform Illumination to Minimize Glare and Dark Spots

Light distribution refers to the way light spreads within a space to achieve uniform illumination while reducing glare and shadows.

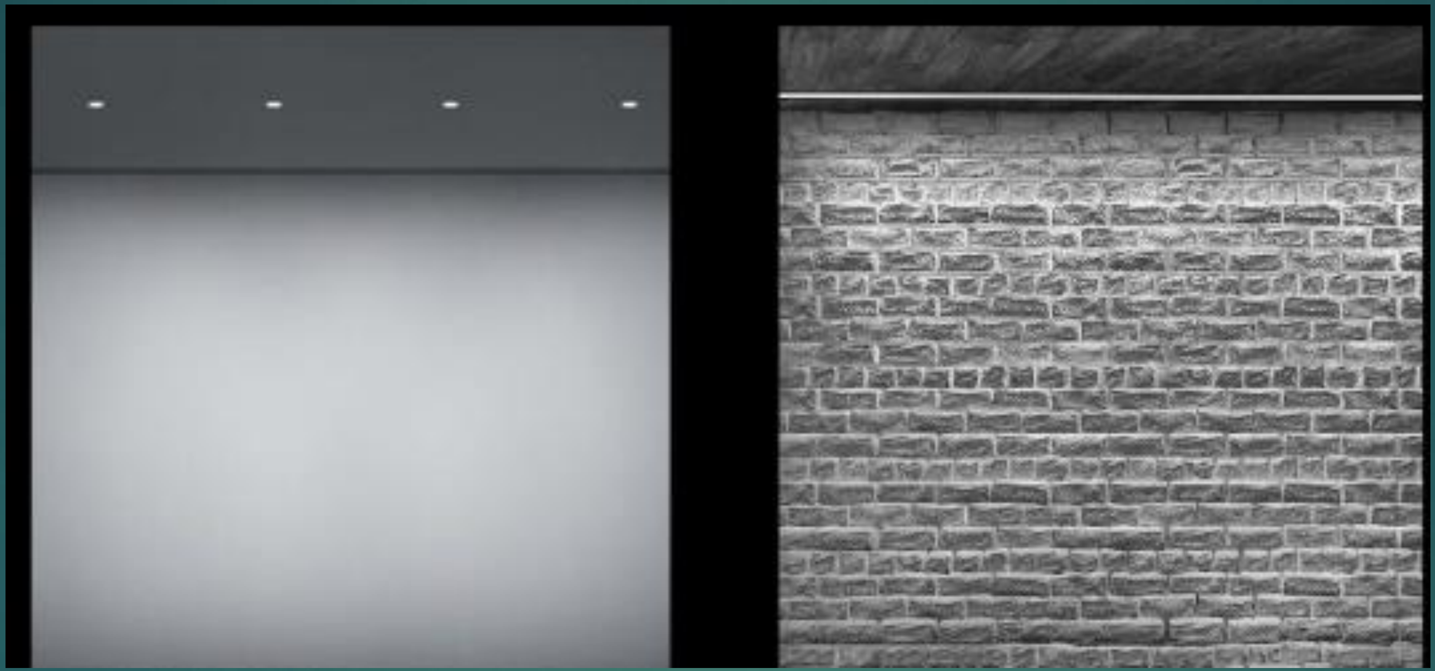
•**Importance:** Uneven lighting can cause discomfort, eye strain, and inefficient use of energy.

•**Techniques for Optimal Distribution:**

- **Use of Diffusers and Reflectors:** Helps spread light evenly, avoiding harsh spots and shadows.
- **Zonal Lighting:** Different areas require different lighting intensities based on their function. Ex- Living room requires ambient lighting (<500 lux), kitchen requires bright lighting (<200 lux).
- **Proper Spacing of Fixtures:** Proper spacing of light fixtures is crucial to achieve uniform illumination, minimizing shadows, and creating a visually balanced space. Fixtures placed too close together can result in excessive brightness and wasted energy. Fixtures placed too far apart can lead to uneven lighting and shadows. The distance between fixtures is typically equal to **1 to 1.5 times the height of the ceiling**. Pathway lights are usually placed **6-10 feet apart** to ensure safe navigation while maintaining a natural look.
- **Wall Washing and Grazing Techniques:** Enhances aesthetics while maintaining uniform light coverage.

Wall washing: Wall washing is a technique where light is evenly distributed across a wall, creating a smooth, uniform glow. The aim is to reduce shadows and emphasize the flatness of the wall.

Wall grazing: Wall grazing is a technique where light is focused closely on a wall to highlight its texture and depth. Unlike wall washing, grazing intentionally emphasizes shadows created by the wall's surface.



Wall Washing

Wall Grazing

2. Color Temperature Selection: Choosing Appropriate Lighting for Different Environments

Color temperature, measured in Kelvin (K), defines whether the light appears warm, neutral, or cool.

Categories of Color Temperature:

(A) Warm Light (Below 3000 K)

Characteristics: Produces a yellowish or reddish hue, similar to candlelight or early morning sunlight.

Applications:

- Living rooms and bedrooms for a cozy and relaxing atmosphere.
- Restaurants and cafes for an inviting ambiance.

Examples: Incandescent bulbs and warm-tone LEDs.

(B) Neutral or Cool White Light (3000 K - 5000 K)

Characteristics: Mimics midday sunlight and provides a balanced, neutral appearance.

Applications:

- Offices and retail spaces for a clean and professional look.
- Kitchens and bathrooms where clarity is essential.

Examples: Fluorescent lights and white LEDs.

(C) Daylight or Cold Light (Above 5000 K)

Characteristics: Produces a bluish-white tone, resembling daylight on a clear day.

Applications:

- Industrial and outdoor spaces for better visibility.
- Hospitals and laboratories where high precision is required.

Examples: High-output LEDs and specialized daylight lamps.

3. Luminance and Brightness Control: Using Dimmers and Sensors for Energy Optimization

Luminance refers to the perceived brightness, which needs to be controlled based on occupancy and ambient lighting conditions.

Methods for Controlling Brightness:

Dimmers: Adjust light intensity to reduce energy consumption and enhance user comfort.

Motion Sensors: Detect occupancy and turn lights on/off accordingly, minimizing wastage.

Daylight Sensors (Photocells): Automatically adjust artificial lighting based on natural light availability.

4. Fixture Design: Selecting Energy-Efficient Fixtures That Enhance Light Output and Minimize Losses

Light fixtures impact overall efficiency by directing and diffusing light effectively.

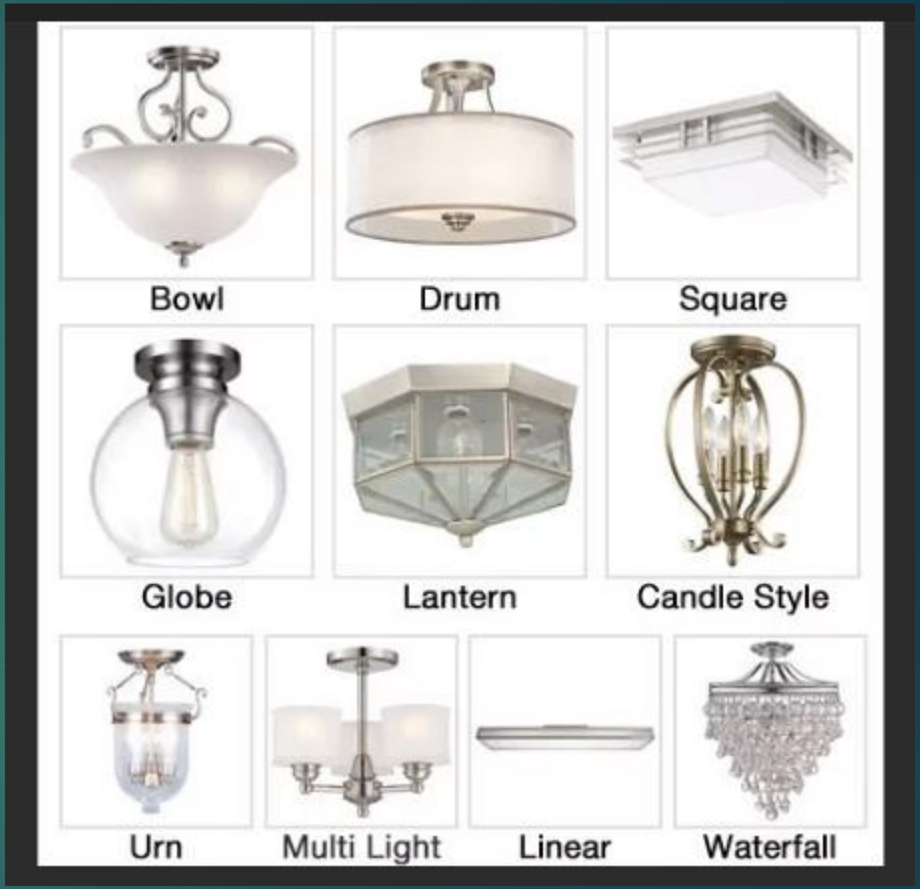
Key Considerations in Fixture Design:

Energy-Efficient LEDs: Consume less power and have a longer lifespan compared to traditional bulbs.

Optical Design: Properly designed reflectors enhance light output while reducing wastage.

Heat Management: Well-ventilated fixtures dissipate heat efficiently, prolonging lamp life and reducing energy losses.

Material Selection: High-quality materials, such as aluminum reflectors, improve light efficiency and durability.



Different fixture designs

5. Integration with Smart Controls: Utilizing Automation and IoT-Enabled Systems for Adaptive Lighting

Smart lighting systems integrate automation and Internet of Things (IoT) technology to optimize energy consumption and user convenience.

Advantages of Smart Lighting:

- **Energy Savings:** Automated lighting adjustments reduce unnecessary power consumption.
- **Personalization:** Allows users to customize brightness and color settings for different activities.
- **Remote Control & Scheduling:** Lights can be controlled via mobile apps, voice assistants, or pre-programmed schedules.
- **Integration with Building Management Systems (BMS):** Enhances efficiency by coordinating lighting with HVAC and security systems.

Example: Philips Hue, Wyze Bulb.
Features: These bulbs can change color, brightness, and schedules via smartphone apps or voice assistants like Alexa or Google Assistant.

Philips Hue

Energy Efficiency in Lighting

Lighting is the basic requirement of any facility and it impacts the day-to-day activities of the people. This accounts a considerable amount of total energy consumption in domestic, commercial and industrial installations.

In industries, energy consumption for lighting constitutes only a small component of the total energy consumed, which is nearly 2-5 percent of total energy consumption. It accounts for 50 to 90 percent in the domestic sector and it may go up to 20-40 percent in case of commercial /building sectors, information technology complexes, and hotels.

So it becomes an important area wherein energy to be conserved, especially in the domestic sector. Lighting efficiency solutions therefore play a key role in energy saving opportunities.

1. **Re-lamping with Energy-Efficient Lights**

Energy efficient lamps can deliver the same amount of lighting with greater energy saving at low cost, when compared with conventional lamps. Traditional incandescent lamps consume a lot of energy to produce light in which 90 percent of consumed energy is given off as heat and also they consume more energy, typically 3-5 times more than the actual amount to produce light.

Energy efficient lamps overcome these problems by offering many more advantages than incandescent lamps. The two most popular choices of energy efficient light bulbs include CFLs (compact fluorescent lamp) and LED (light emitting diode) lamps.

Use high-intensity fluorescent lights instead of metal halide lamps for industrial and commercial spaces

Comparison of Incandescent, CFL , LED and Halogen lamps

Features	LED	CFL	Incandescent	Halogen
Light Bulb Comparison				
Rated Avg. Life	50,000	10,000	750-1000	2,000
Life Span	Vastly Longer	Long	Low	Medium
Watts	6-18	3-120	3-500	5-500
Cost to Operate	Lowest	Low	High	Medium
Energy Consumption	Lowest	Low	Medium	Medium
Lumens per Watt	45-75	60	15	25
Color Temp. (K)	2700-5000	2700-6500	2700	3000

2. Improving Lighting Controls

Lighting can be controlled with the use of various sensors to allow the operation of lamps whenever they are needed. These sensors detect the presence of humans, motion, timing or occupancy and based on the sensor output, it switches the lamps ON and OFF.

- Types of these controls include infrared sensors, automatic timers, motion sensors, and dimmers.
- Photo sensors monitor the daylight conditions and accordingly send the signals to main controller to turn the lamps automatically off at dawn and on at dusk. This type of lighting control is commonly used with street lighting and outdoor lighting.
- Street lighting is another major area of energy conservation as it contributes considerable power consumption especially in the highways. Centralized control systems are most commonly used in street light control.
- The popular centralized control is the SCADA (supervisory control and data acquisition) system which ensures remote control of operation of street lights from a central location.

Motion Sensor LED Lights

3. Replacing of Existing Fixtures and Ballasts

Replacing energy inefficient accessories with new energy efficient fixtures and ballast gives superior energy savings, longevity, and reliability.

The main function of a luminaire or lighting fixture is to distribute, direct and diffuse light.

Some fixtures can absorb more than half of the illumination emitted the bulb that reduces the efficiency of the lighting.

- The higher efficiency fixtures can emit more light and hence one can save energy and money. Such fixtures consist of reflectors to direct the light in a desired direction.

- All discharge lamps require a ballast for achieving required operation. Conventional magnetic type ballasts cause power losses which is typically 15 percent of the lamp wattage. It also can raise fixture temperature during operation. So the proper ballast must be chosen to reduce ballast losses, fixture temperature and system wattage.

- In today's market, many electronic types of ballast are available which can save 20 to 30 percent energy consumption over standard ballasts.

Luminaire or lighting fixture

4. **Leverage Natural Light**:
Maximizing the use of natural sunlight in building design is an effective way to enhance energy efficiency and reduce reliance on artificial lighting.

Here's how this approach can be implemented in detail:

Orientation of the Building: Positioning the building to face the sun's path ensures optimal sunlight exposure throughout the day. In tropical regions like India, it's best to consider shading to avoid overheating.

Window Placement: Strategically place windows to allow sunlight to penetrate deeper into rooms. South-facing windows in the Northern Hemisphere (like India) provide consistent daylight.

Skylights: Integrate skylights into roofs to illuminate spaces with natural light. Diffused skylights help avoid harsh glare.

Leverage of Natural Light

Distributed Generation System

Distributed Generation refers to small-scale energy production systems located close to the point of energy use. By generating power locally, DG systems minimize energy losses during transmission and distribution, significantly improving overall efficiency.

Key contributions include:

- Reduction in reliance on centralized power plants.
- Lower grid congestion and improved reliability.
- Support for renewable energy integration.

Role of Distributed Generation (DG) in Energy Efficiency

1. Localized Power Generation
2. Integration of Renewable Energy Sources
3. Hybrid Systems with Battery Storage
4. Demand-Side Management

1. **Localized power generation:** Localized power generation involves producing electricity near the consumption point, reducing the dependency on distant centralized power plants.

Impact on Efficiency:

•**Minimized Transmission Losses**: Traditional grid systems lose energy as electricity travels long distances. With DG, power is generated close to the user, eliminating these losses.

•**Reduced Stress on Grids**: By decentralizing power production, localized generation reduces the strain on existing power infrastructure.

•**Example**: In rural areas, microgrids powered by solar or wind can supply energy directly to communities without relying on extensive transmission lines.

2. Integration of Renewable Energy Sources

DG systems often integrate renewable energy technologies such as:

(a) Solar Photovoltaic (PV): Converts sunlight into electricity, suitable for residential and commercial applications.

(b) Wind Turbines: Generates power from wind, commonly used in windy regions.

(c) Biomass Generators: Use organic materials like agricultural waste for energy production.
(d) Micro-Hydro Systems: Harness water flow from small streams or rivers to generate electricity.

Benefits:

- Provides clean, sustainable electricity.
- Reduces greenhouse gas emissions.
- Promotes energy independence for local communities.

Example: A community solar project powering homes and street lighting in remote areas with no grid access.

3. Hybrid Systems with Battery Storage:

Hybrid systems combine renewable energy sources (e.g., solar or wind) with energy storage technologies, like batteries, to ensure a consistent power supply. Batteries store excess energy produced during peak generation times. Stored energy is used during periods of low generation or high demand, ensuring uninterrupted supply.

Applications:

- Essential for lighting systems during power outages.
- Provides reliable energy for hospitals, schools, and other critical facilities.

Example: A solar-battery hybrid system that powers a village, ensuring lights stay on even during cloudy days or at night.

4. **Demand side management:**

Demand-Side Management (DSM) involves optimizing energy consumption by aligning demand with the available supply.

Role in Energy Efficiency:

- DG systems are integrated with smart lighting solutions that automatically adjust based on occupancy or time of day, reducing wastage.
- Reduces peak demand on the grid by using local energy sources during high-demand periods.

Examples:

- Motion-sensor-controlled lighting systems in public spaces powered by local solar panels.
- Time-scheduled lighting in commercial buildings to balance energy use and reduce unnecessary consumption.

Thank You