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Sustainable Building Solutions: Innovative Strategies And Techniques For Energy Efficiency In Buildings

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Abstract:
The need for power maintains upward thrust, necessitating the generation of massive volumes of electricity. Buildings have undergone modifications to enhance their energy performance and efficiency. Understanding how electricity is utilized in buildings necessitates knowledge of the quantities of energy consumed and the numerous forms of fuels employed. Buildings that may contribute to their energy needs through producing renewable power can lower the quantity of carbon dioxide (CO_2) produced by way of the shape. As a result, to succeed in constructing a sustainable society, buildings will want to be usually superior as generation advances. The idea of integrated green building strategies promotes the protection of more strength-balanced and efficient built environments.
The impact of buildings on the surroundings and people is an element of the sustainable method, which includes distinctive energy supply buildings and smart buildings that use a complete exam of building operations. The study's version specializes in business constructing layout and user adaptability in an energy green industrial environment. Built surroundings this is both functional for the cease consumer and environmentally responsive. The purpose is to construct an overview of the latest consultations on what are the cutting-edge traits accomplished towards making buildings more intelligent, self-sufficient, and more sustainable. However, the effectiveness of these technologies also depends on human behaviour, as around 30% of potential energy savings are lost due to social, cultural, and economic factors. As it is more crucial than ever to use energy more responsibly because of the current global energy crisis, which is causing shortages and excessive prices that are harming businesses, consumers, and entire economies. We can achieve this by making little behavioural and habit adjustments to use less energy during our everyday tasks. Purchasing more energy-efficient products can also help us save energy by lowering our environmental impact and energy costs and also through the technological adaptations. The parameters influencing the strength performance of buildings will be mentioned in studies paper. This paper also addresses the influences that are crucial for improving overall energy efficiency.
Key words- *Energy Efficiency, sustainability, Energy, Built Environment Techniques.*

1. INTRODUCTION-

In today's world, homes and living spaces are closely associated with creating buildings that are as comfortable and convenient as possible globally. The construction industry is expanding rapidly, contributing 30 to 40 percent of the total global primary resources. Currently, buildings rank as the third largest consumers of fossil fuels, following industry and agriculture. The Asia-Link initiative, launched by the European Commission, aims to promote awareness and knowledge about sustainable construction focused on nearly zero energy usage This sustainable construction initiative encourages the incorporation of tested renewable energy technologies into buildings for various purposes, including heating water, regulating temperature, and generating electricity. The energy consumed by buildings is becoming increasingly significant worldwide.
Several European nations have introduced building certifications, such as 'Passive House' in Germany and 'Minenergy' in Switzerland, to recognize standardized low-energy structures [1]. Reports indicate that the building sector in Europe accounts for about 40 to 45 percent of total energy consumption [2], with around two-thirds of this energy being utilized in private residences. Other reports state that in developed nations, buildings contribute to approximately 50 percent of carbon dioxide emissions [3,4]. Therefore, the evaluation of building sustainability is becoming essential for achieving sustainable development, particularly in the construction industry worldwide. The primary objectives of sustainable design include minimizing the depletion of vital resources like energy, water, and raw materials; preventing

environmental damage caused by buildings and infrastructure over their lifecycle; and creating living spaces that ensure safety, productivity, and efficient use of water and solar energy. A tool known as the building environmental assessment system (BEAS) has been proposed by Burdova and Vilcekova and is being implemented in Slovakia for resource conservation [5].

There is significant potential for energy conservation in buildings. Energy-saving measures have been designed for both new constructions and renovations. However, to substantially reduce energy usage in buildings, alongside standard energy-efficiency methods, established renewable energy technologies should be incorporated with passive design elements [6]. Starting in 2020, all new constructions in the European Union will need to adhere to guidelines that promote the development of nearly zero energy buildings, ensuring operational energy savings.

This paper discusses four key factors impacting energy efficiency in buildings for sustainable development globally. The first factors pertain to the use of natural sunlight, the design of passive heating and cooling systems, and strategies for rainwater harvesting tailored to the specific climatic conditions of a location. In colder regions, elements such as sunspaces, Trombe walls, air handling units with air-to-air heat exchangers, and proper airtightness with necessary airflow rates are vital components of passive buildings. In hot and arid climates, effective passive cooling strategies include the design of thick walls and cooling roofs through the evaporation of water, unique roof surfaces, earth-water heat exchangers, passive downdraft space cooling, solar refrigeration, and more. In addition, the choice of low energy building materials (like fly ash bricks, fibre reinforced bricks, wood, and stabilized adobe blocks) [6]. is gaining traction, especially in countries such as India, the Middle East, Europe, the USA, and the UK. To build low energy homes that support sustainable development, the embodied energy of the structure must remain low. Furthermore, the focus shifts to conserving operational energy by utilizing energy-efficient equipment, including LED lighting, fans with five-star ratings, as well as refrigeration and air conditioning systems in India. Finally, the use of integrated renewable systems, such as solar water heaters for water heating, small wind turbines, or solar photovoltaic systems for electricity generation on rooftops, is explored in this paper, alongside their economic assessments and environmental impacts [7].

2. Orientation

When it comes to passive solar design in buildings, orientation is the key factor and has been the subject of significant research. The amount of direct sunlight that hits a building's facade is influenced by the azimuth of the wall, which is linked to the building's angle of orientation. [7]. The positioning of the facade also affects other aspects of passive design, like shading [8] and the efficiency of solar elements [9].

Here are the advantages of an ideal building orientation:

- This is a cost-effective strategy that can be incorporated early in the design process.
- It helps to lower energy needs.
- It decreases the dependence on more advanced passive systems.
- It enhances the efficacy of intricate passive methods.
- It boosts natural light levels, lowers the need for artificial lighting, and lessens the internal heating demand within the structure.
- It improves the performance of solar panels.

It is widely accepted that a south-facing orientation is ideal for capturing heat during winter while regulating solar influx in summer [7]. Typically, the longest walls should face south. However, orientation can be analysed to optimize other factors such as total solar intake, building shape, site layout, and yearly energy needs.

2. 1. Orientation and solar Radiation Received

Gupta and Ralegaonkar [10] conducted a study to improve building orientation for various shape factors. Their goal was to reduce solar radiation during summer while maximizing it in winter. They calculated the total energy from this radiation using a specific equation.

$$E = A \times \int_{\omega 1}^{\omega 2} (0.834 \times H) \times \left(cos \frac{i}{\theta z} \right) d\omega \qquad [11]$$

In this equation, A represents the area; H stands for the daily average global radiation on a flat surface; i denotes the incidence angle; d corresponds to the hour angle at dawn or dusk; and Z is the angle from the vertical or angle. The researchers focused on optimizing solar radiation levels during the hottest (June) and coldest (December) months by testing different shape values and adjusting the orientation angle from 0° to 180°. This approach can help determine the best orientation for receiving the least sunlight in summer and the most in winter. They found that the best orientation typically occurs when the longest wall is aligned with the north-south axis.

2. 2. Shape and Orientation

Aksoy and Inalli [12] conducted research on how building orientation impacts the need for heating. They examined three models with various shape factors (1/1, 1/2, and 2/1), both with and without thermal insulation on the exterior. They adjusted the buildings by rotating them 80 degrees, collecting data at intervals of 10 degrees

By integrating shape factor, orientation, and thermal insulation, a heating energy savings rate of as much as 36% can be achieved. They established that for rectangular buildings, the optimal orientation occurred when the longest walls faced south. In square buildings, the peak heating demand was noted when the structure was rotated to an angle of 45 degrees. This demand decreased as the angles approached 0 and 90 degrees, meaning that as one of the building's sides began to point south, the demand went down. For various building shapes without insulation, a heating energy saving rate of 1 to 8 percent was recorded, influenced by the building's orientation.

Florides et al. [13] and colleagues researched the impact of shape and orientation on buildings as well. They determined that for a square structure, heating demand was minimized when the facade faced each of the four cardinal points. In the case of rectangular buildings, a decrease in heating demand was observed when a smaller part of the surface was positioned toward the east. The authors noted that having the surface oriented to the east significantly raised the heating energy needs.

2. 3. Orientation and Floor Plan

Morrissey et al. [9] discovered that structures with a compact floor plan are less affected by shifts in orientation. In simpler terms, such buildings maintain better thermal efficiency even when their orientation changes, unlike larger buildings (over 200 m2). They found that the area of the floor plan was the key element regarding the ability to adapt to orientation adjustments. Their research involved analysing heating and cooling energy needs derived from a modelling study of 81 various types of residential buildings. They established a statistical relationship between these energy consumption figures and the four most influential factors on the building's thermal efficiency (which are floor plan area, wall-to-floor ratio, total external surface area, and overall window area). The findings indicated that larger residential structures find it harder to achieve satisfactory energy efficiency levels. The houses that were most energy-efficient were less impacted by changes in orientation.

2. 4. Building Orientation and Energy Needs

Research on the best orientation for buildings clearly shows increases in energy savings [14]. Littlefair [15] notes that many resources, including books, user manuals, and guides on passive solar methods, suggest that buildings should ideally face south; however, there is a growing agreement that an orientation of 20° to 30° towards the south is preferable.

Shaviv [16] researched the orientation of a building's glazing surfaces, presenting the outcomes shown in Table above. She found that for optimal energy savings, the primary glazing surface should ideally face south, particularly in regions with warm climates.

3. Energy Conservation in Building

There are four main approaches to decreasing energy use in buildings, ultimately helping to lower CO_2 emissions through energy-saving methods. These approaches include:

a. Designing comfortable passive buildings and strategically orienting them to capture solar energy.
b. Selecting building materials that have low embodied energy for construction.
c. Using energy-efficient household appliances to reduce the operational energy of the building.
d. Implementing renewable energy technologies that are integrated into the building.

3. 1. Passive Building Design

The most environmentally friendly approach is to save as much energy as we can. Passive solar building design contributes to energy-saving initiatives, as the way a building is designed directly affects its energy consumption. Structures that incorporate passive solar design effectively utilize the sun's energy for heating, cooling, and providing natural light without any cost. This approach minimizes the reliance on other energy sources and creates a pleasant indoor atmosphere. Additionally, the principles of passive solar design align well with various architectural styles and can be adapted within existing buildings to achieve net zero energy consumption [17].

3. 1. 1. Principles of Passive Solar Design

Passive solar design brings together various building characteristics to minimize or completely do away with the need for mechanical heating, cooling, and artificial lighting during the day. Designers and constructors carefully consider the path of the sun to lower heating and cooling requirements. While the design does not have to be complicated, it should include understanding solar geometry, window technologies, and the local climate. With a suitable building location, almost any architectural style can incorporate passive solar design [17].

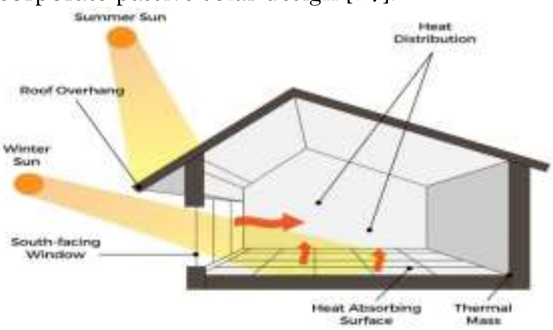

Fig-1. [Pic Ref- https://arka360.com/ros/passive-solar-design/]

The fundamental natural processes used in passive solar energy involve thermal energy movements related to radiation, conduction, and natural convection. When sunlight hits a building, the materials used can either reflect, transmit, or absorb the solar energy (Fig- 1). Moreover, the warmth generated by the sun can induce air movement in controllable ways within designed environments. These fundamental reactions to solar heat led to the thoughtful selection and arrangement of materials and design features that can create heating and cooling effects within a home [18]. Passive solar energy implies that there are no mechanical devices utilized to harness solar energy. Some guidelines must be followed to make the most of solar energy through passive systems. Effective management of building energy can be achieved cleverly using the nearly zero energy building concept [18,19].

3. 1. 2. Passive Solar Heating

The aim of all passive solar heating systems is to trap the sun's warmth within the building components and release that warmth during times when the sun is not shining. As the building materials absorb heat for future use, the solar energy also helps maintain a comfortable temperature in the space without overheating it. There are two essential components required for passive solar heating:

- Glass facing south in northern areas and the opposite in southern areas.
- Thermal mass that can absorb, store, and distribute heat.

A method of passive solar design that indirectly achieves both cooling and heating is the thermal pond method. This technique uses water contained in beds made of plastic that block ultraviolet rays and are covered with a dark material, placed on top of a roof. Therefore, this system is referred to as a roof pond solar passive heating and cooling system. In warm and mild climates with minimal rainfall, the flat roof acts as a ceiling for the rooms below, helping to regulate temperature for these areas. In colder regions, where warmth is more necessary, pond systems in the attic under sloped roofs are effective. During winter, the sun warms the water, which then radiates heat into the living areas while also storing energy within the water's thermal mass to be released at night [20].

3. 1. 3. Passive Solar Cooling

To maintain a comfortable indoor temperature while using minimal energy, it's important to combine effective insulation, energy-saving windows and doors, natural daylight, shading, and ventilation. Strategies for achieving this encompass the installation of operable windows, wing walls, and thermal chimneys. Natural ventilation can be facilitated by including vents at a building's upper level, allowing warm air to rise and exit through convection. Simultaneously, cooler air can enter through vents located at the lower level. These lower vents should be positioned where trees are planted nearby, as they can offer shading for the cooler air coming in [21].

(I) Ventilation and Operable Windows-

- Install operable windows facing south.
- Casement windows provide optimal airflow. Fully open awning (or hopper) windows; otherwise, the air will go to the ceiling. Awning windows also protect well against rain and function better than double-hung windows.

-When a room features windows only on one side, it is better to choose two windows that are separate, instead of having only one window.

(II) Wing Walls -Wing walls are solid vertical panels situated next to windows that are perpendicular to the wall on the side facing the wind. These walls can increase wind speed naturally because of the pressure variations they create [22].

(III) Thermal Chimney- A thermal chimney makes use of convection currents to pull air out of a structure. By establishing a warm zone with an external outlet for exhaust, air can be pulled inside, effectively ventilating the building. These chimneys can be designed in a narrow shape, resembling a chimney, with a black metal absorber inside behind a glazed front that can reach high temperatures while being insulated away from the building. The top of the chimney must rise above the roof. A rotating metal scoop on top, which opens against the wind, helps heated air to escape without being hindered by the wind patterns. Thermal chimney effects can be integrated into the home design, utilizing open staircases and atriums, enhancing the home's visual appeal.

(IV) Other Ventilation Strategies-

- The openings for the outlets should be a bit bigger than those for the inlets.
- The inlets ought to be placed at lower to medium heights to allow airflow to reach the people inside the room.

The strategy for using passive solar energy to cool buildings focuses on (1) decreasing the heat that comes into a building in the summer and (2) getting rid of unnecessary heat from the inside. The laws of physics are fully utilized in the building's outer design. This approach is more straightforward in new builds. It requires a solid understanding of how heat transfer occurs: through conduction, convective heat movement, and thermal radiation, primarily from sunlight [23].

3. 2. Embodied Energy in Buildings

A key objective in the construction industry is to create structures that have minimal effects on the environment. A major concern is the energy consumed, as the construction of buildings requires a vast amount of energy [24]. Therefore, it is crucial to explore materials with low embodied energy that can help decrease energy usage during building processes. Embodied energy refers to the total energy used across all steps involved in building production, starting from sourcing natural resources to delivering the finished product. This includes mining, manufacturing materials and tools, transportation, and administrative activities [25].

Energy in buildings can be divided into two categories: (1) energy needed for maintaining a building throughout its lifespan and (2) the embodied energy that is used in the creation of the structure with building materials [26]. Understanding both types of energy consumption is essential for grasping the energy requirements of buildings. Currently, the embodied energy from building materials accounts for roughly 15% to 20% of the total energy a building uses over a span of 50 years. Homeowners play a significant role in the materials chosen, having the power to select those with low embodied energy, thereby reducing fossil fuel energy consumption during their production [27]. Utilizing materials with low embodied energy can significantly lower energy use in buildings and lessen the environmental effects associated with construction.

The construction sector ranks among the largest in terms of workforce and the volume of materials manufactured, such as cement, bricks, and steel. The gap between the demand and supply for residential buildings continues to rise yearly. Cement (over 75 million tonnes yearly), steel (over 10 million tonnes yearly), and bricks (over 70 billion yearly) are the primary materials consumed in India's construction industry. Reducing the use of traditional materials by adopting alternative options, methods, and techniques can lead to significant energy savings and decreased CO_2 emissions [26]. The current trend is towards using materials that require substantial energy, like aluminium, steel, and glass. Consequently, it is advisable to limit the use of these metals to help keep energy levels in buildings lower. Various materials are available for constructing masonry walls.

Exploring alternative materials with low embodied energy is essential. Five types of building blocks—burnt clay brick, stone, hollow concrete block, steam-cured mud block and soil-cement block, —were analysed for their embodied - energy. The findings revealed that stone blocks do not require thermal energy, while burnt clay bricks use the highest amount of energy among the options examined. The block made from soil and cement has 6% cement in it and is the most efficient in terms of energy use. It uses just 23. 5% of the energy that burnt clay bricks require. Soil-cement blocks and hollow concrete blocks, which have

7-8% cement, exhibit similar values for embodied energy, approximately 30% of the energy used by burnt clay bricks [28].

Table 1: Embodied primary energy of building materials [28]

Ranking	Building Material	Primary Energy Input (MJ/kg)
Very high energy	Aluminium	200-250
	Plastics	50-100
	Copper	100+
	Stainless steel	100
High energy	Steel	20-60
	Lead, Zinc	25+
	Glass	12-25
	Cement	5-8
	Plaster board	8-10
Medium energy	Lime	3-5
	Clay bricks and tiles	2-7
	Gypsum plaster	1-4
	Concrete In situ	0.8-1.5
	Blocks	0.8-3.5
	Precast	1.5-8
	Sand-lime brick	0.8-1.2
	Timber (sawn)	0.1-5
Low energy	Sand, aggregate	<0.5
	Flyash, RHA,	<0.5
	volcanic ash Soil	<0.5
	Adobe	<0.2

The analysis of the energy embodied in different building materials shows that burnt clay brick masonry has an energy content of 2141 MJ/m3. In contrast, soil- cement block masonry uses only 1/3 of the energy that burnt clay brick masonry requires, while concrete masonry block contains around 40 to 45% of the energy needed for burnt clay brick masonry. When stabilized mud blocks are used as filler in solid reinforced cement roof or floor slabs, the energy content reduces by 20%. Masonry vault roofs are more efficient in energy use than solid reinforced concrete slabs. Among the various roofing types, tile roofs have the least energy content. A research project compared three different types of buildings: a multi-storey building, a traditional two-storey load-bearing brick construction, and another two-storey structure using different building methods. [25,26] It was observed that the multi-storey RC framed building had the highest embodied energy at 421 GJ (equivalent to 21 tonnes of coal) for a 100 m2 area. A load-bearing masonry structure made from burnt clay bricks combined with an RC slab has 30% less embodied energy in comparison to the RC framed building. Incorporating energy-efficient alternative construction methods can lead to significant reductions in the embodied energy of structures. Load-bearing soil-cement block masonry and SMB filler slabs showed a 62% reduction in embodied energy against the RC framed building and a 45% decrease compared to burnt clay brick masonry with an RC solid slab [26].

The insights from this analysis provide valuable guidance for choosing energy-efficient building technologies that can substantially lower the overall embodied energy of buildings. Although the findings are relevant to conditions in India, they may also be applicable to many other developing countries that follow similar construction methods. Adobe houses made with adobe, cow dung, and other materials that require little energy led to significantly lower CO2 emissions when compared to concrete or brick constructions. According to the embodied energy analysis, the payback time for energy in a mud house is 18 years [29]. The embodied energy per square meter for a reinforced concrete building is recorded at

3702. 3 MJ/m2, which is noticeably higher than that of a mud house at 2298. 8 MJ/m2 [29]. The potential annual savings for heating and cooling energy in a mud house were calculated as 1481 kWh/year and 1813 kWh/year, respectively, for the composite climate of New Delhi. As a result, the total reduction in CO2 emissions from both heating and cooling energy savings was found to be 5. 2 metric tons annually. The potential annual carbon credit from a mud house was estimated at €52. Similar results were found in different climatic zones within India. The reduction of CO2 emissions due to the renovation of a mud house with an area of about 94 m2 compared to an RCC structure house reached 58 metric tons. The carbon credits earned amounted to €580 from the reduction of CO2 emissions when constructing a mud house rather than an RCC building, based on a rate of €10 per metric ton of CO2 mitigated. Therefore, the overall embodied energy in a building can be greatly decreased by using energy-efficient or alternative materials that have low embodied energy [29].

3. 3. Renewable Energy Technologies Integrated into Buildings

Renewable energy comes from natural processes that are always being replenished. Various forms of renewable energy originate directly from the sun or from heat found deep within the earth. This term also includes the heat and electricity produced from resources like solar, wind, ocean, hydropower, biomass, geothermal sources, as well as biofuels and hydrogen made from renewable resources [30]. Included in renewable energy technologies are solar energy, wind energy, hydroelectric power, micro-hydro systems, biomass, and biofuels [31]. As per the global status report from 2007, around 18% of the world's final energy consumption in 2006 was produced from renewable sources, with 13% coming from conventional biomass like wood burning. The second largest renewables source was hydropower, which accounted for 3%, and hot water and heating contributed 1. 3%. [32] Together, modern technologies such as geothermal, wind, solar, and ocean energy made up about 0. 8% of final energy use. Thus, the potential for using these technologies is large and surpasses all other readily accessible sources [33].

A considerable portion of the energy needed for heating and electricity in buildings can be efficiently met with solar thermal collectors and photovoltaic systems. In the upcoming years, other renewable energy sources like wind turbines, biomass, and hydrogen produced solely from renewable sources can also be utilized, reducing dependency on traditional energy forms. Both renewable energy sources and nuclear energy serve as alternatives to mitigate the greenhouse effect. Out of these options, only renewable energy sources are sustainable and environmentally friendly, available almost uniformly around the world, easily accessible to everyone with minimal market trust and ownership investment, and importantly, are inexhaustible [34].

Renewable energy technologies offer numerous advantages, including energy supply sustainability and security, creation of more jobs, and a longer lifespan for energy systems. Although the costs of solar energy systems remain relatively high, they align with both European and international agreements. This is because solar technology is particularly environmentally friendly for buildings and urban settings. Additionally, this technology plays a crucial role in the economies of many countries since it has the potential to replace costly and imported traditional energy forms such as oil, gas, coal, and nuclear fuel. Solar Energy Systems can harmoniously fit onto buildings to satisfy heating, cooling, electricity, and lighting demands. The exteriors and both flat and sloped roofs of residences, hotels, sports centres, and other structures provide excellent surfaces for expanding the installation of solar thermal collectors and photovoltaic panels.

Structures can be planned using bioclimatic architecture to reduce energy requirements and lessen their environmental footprint. This can be achieved through the use of advanced insulation materials and specialized glass options, like smart windows, which effectively minimize heat loss in winter and lower cooling energy needs in summer. Because of this, energy savings in buildings, particularly new constructions, may exceed 50% compared to traditional buildings, making it a common practice in construction for the built environment [34].

The addition of devices and solar energy systems can increase costs and must be aligned with the building's design and surrounding area. Solar energy solutions are often chosen for their visual appeal as well, helping to eliminate the drawbacks associated with diesel-powered systems for heating and electricity, such as smoke and chimneys. It is crucial to implement these systems in a way that complements the local environment and landscape, which requires thorough planning and careful environmental studies.

Utilizing solar energy systems for sustainable development can lead to innovative buildings that incorporate bioclimatic elements focused on energy conservation. Since buildings account for approximately 35% of final energy use and around 40% of greenhouse gas emissions, it is believed that energy savings can reach 60% when solar energy solutions are employed for both heating and cooling. Additionally, the European Commission has introduced a new directive mandating energy efficiency in newly built structures. Thus, integrating renewable energy systems into well-designed buildings can enhance living standards [35].

The following types of solar energy systems integrated into buildings are being used globally:
(I) Flat Plate Thermosyphon Units (FPTU) and Integrated Collector Storage (ICS)
(II) Solar Collectors featuring Coloured Absorbers
(III) Solar Collectors equipped with Booster Reflectors
(IV) Unglazed Solar Collectors
(V) Hybrid Photovoltaic/Thermal (PV/T) Systems.

4. Innovative Strategies and Techniques

4. 1 High-efficiency Insulation Material-

Another significant field of progress is in high-efficiency insulation materials, which include vacuum-insulated panels, aerogels, and phase-change materials. These products significantly lessen heat loss, keeping indoor temperatures steady with little need for heating or cooling. Standard insulation typically allows heat to escape, but these advanced materials form nearly unbreakable barriers that enhance energy retention. The potential energy savings from these systems is around 15 to 20 percent, and when paired with airtight building methods, they become even more efficient. Nonetheless, the higher costs of these advanced materials may hinder widespread use, especially in affordable housing markets [36]. Therefore, incorporating these technologies into building regulations and offering government subsidies could encourage broader use.

4. 2 Smart HVAC systems

Smart HVAC systems for heating, ventilation, and air conditioning represent another significant advancement in energy management for buildings. Often driven by artificial intelligence and machine learning, these systems can foresee and adjust to changes in occupancy, weather patterns, and indoor air quality needs. By continually optimizing their performance, smart HVAC systems can cut energy use by as much as 30 percent. Additionally, the use of building automation systems—which manage lighting, HVAC, and other utilities—greatly enhances energy efficiency [37]. These systems allow for real-time tracking and remote management, which is especially beneficial for large commercial buildings. Although investing in these technologies and infrastructure requires an initial outlay, the long-term savings on utility costs and improved comfort make them worthwhile for both new builds and renovations.

4. 3 LED and Smart Lighting Innovations

These play a crucial role in creating sustainable lighting solutions. LED lights consume up to 80 percent less energy than traditional incandescent bulbs and have a much longer lifespan. When paired with motion sensors, daylight harvesting techniques, and programmable settings, smart lighting adjusts to user habits and the availability of natural light, minimizing waste. These technologies are quite cost-effective and can be utilized in homes, businesses, and industrial environments [38]. They are considered a straightforward and accessible step towards energy-efficient buildings and are often the first action taken for sustainability improvements.

4. 4 Intelligent Building Technologies

Intelligent buildings make use of automation, sensors, and IoT technology to enhance energy efficiency. Their features include occupancy sensors, automated shading systems, advanced HVAC controls, and energy tracking dashboards. AI technology can now modify indoor temperatures driven by current data, resulting in energy savings of up to 20%.

4. 5 Eco-Friendly Materials and Circular Building Practices

Choosing materials with low embodied carbon—like bamboo, recycled steel, and bio-based insulation—helps to decrease a building's emissions over its entire lifespan. Additionally, modular construction enables the reuse of components, supporting circular practices in the construction industry.

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4.6 Building Automation Systems (BAS)

Building Automation Systems also known as BAS, are networks that combine hardware and software to oversee and manage the mechanical, electrical, and electromechanical functions within a building [34]. The importance of these systems is growing in the realm of sustainable construction, as they help to maximize energy efficiency, enhance indoor air quality, and improve comfort for users. By linking different building services, such as heating, ventilation, air conditioning, lighting, security, and fire safety, BAS ensures that all elements operate smoothly and effectively [40].

4.6.1 Main Characteristics of BAS for Energy Efficiency:

- HVAC Management: BAS can change temperature settings in response to how many people are present and the weather outside, which helps to lower energy waste while keeping comfort levels.
- Lighting Management: Smart lighting systems that use motion detectors and daylight sensors can greatly cut down on electricity use by dimming or turning off lights when spaces are empty or when there is enough natural light [40].
- Instant Monitoring and Reporting: BAS offers immediate information on energy use, enabling facility managers to spot problems and make necessary adjustments quickly.
- Scheduling and Zoning: These systems can be set to operate only during times when spaces are in use and can divide buildings into different zones for more precise energy distribution based on particular requirements.

4.6.2 Advantages:

- Improved Efficiency: Centralized management makes oversight easier and lowers the chance of operational mistakes.
- Financial Savings: Lower energy usage translates to considerable savings over time.
- User Comfort: Customized settings for climate and lighting lead to improved productivity and overall well-being [37].
- Growth Potential: Contemporary BAS solutions can connect with Internet of Things devices and artificial intelligence systems, allowing for expansion and preparation for the future.

Table 2- Energy saviny

Strategy	Energy Saving (%)	Implementation Cost	Maintenance	Suitability (Urban vs Rural)
Passive Solar Design	25%	Medium	Low	Urban & Rural
High-Performance Insulation	20%	Medium	Low	Urban
Smart HVAC Systems	30%	High	Medium	Urban
LED & Smart Lighting	15%	Low	Low	Urban & Rural
Renewable Energy Integration	40%	High	Medium	Rural & Suburban
Green Roofs & Walls	18%	High	High	Urban
Building Automation Systems	35%	High	Medium	Urban

5. CONCLUSIONS

Today's buildings use a lot of energy for construction, operation, and maintenance. Due to the global energy crisis, it is important to develop effective strategies for energy conservation in buildings. There are various methods to lessen the dependence on traditional energy sources like fossil fuels. New buildings can incorporate solar passive design elements based on their location, orientation, and climate. For example, using a Trombe wall for heating in a honey storage facility has proven effective in winter. Additionally, good daylighting design can reduce the need for artificial lighting during the day, thereby lowering overall energy consumption and CO_2 emissions, which supports sustainable development.

Using locally sourced building materials with low embodied energy can also help reduce energy needed for construction and lower CO_2 emissions. It is important to minimize the energy required for building operation from fossil fuels, thus encouraging the use of renewable energy technologies. Buildings that are fully powered by renewable energy systems are considered highly energy-efficient or zero-emission green buildings. A comparison of the economic viability of various renewable energy technologies supports their adoption over traditional energy sources.
Sustainable building solutions are critical for reducing the environmental footprint of the construction sector. By adopting a holistic approach that includes passive design, smart technologies, sustainable materials, and supportive policies, the building industry can lead the way in energy efficiency. As the global community shifts toward carbon neutrality, integrating these innovative strategies will be essential to achieving long-term sustainability goals.

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