International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

Solar-Optimized Building Design

Sakshi[1]*, Anushka Jain*[2]*, Sunakshi Shokeen*[3]
[1,2,3]*World University of Design, Sonipat, Haryana, 131029, India.*
Emails: *sakshi.21@wud.ac.in*[1]*, anushkajain.21@wud.ac.in*[2]*, sunakshi.shokeen@wud.ac.in*[3]

Abstract

The aim of this paper is to understand the optimization of solar design, which is an attempt to enhance the building performance through design modifications. The aim of the present study is to evaluate the efficiency of solar panels, with an emphasis on the incorporation of passive solar panels that aid in energy conservation in construction. This study employs a mixed-methods approach. To begin with, the literature review is conducted, and, in particular, the view of previous research is given in an attempt to develop the theoretical background. Afterwards, case studies of solar-optimized buildings are considered in order to see how it worked in practice and what issues arose. Details are provided on the consumption of the material, energy, and the strategies of constructing the design. Upon completion of the case studies and literature review, the findings are then synthesized to offer the guidelines and recommendations on the solar optimized design. Buildings which are designed for maximum utilization of solar energy could incur energy or cost savings of more than 40% in terms of heating and cooling loads. Such optimized designs do not only enhance comfort for the occupants but also minimize the amount carbon dioxide emissions released into the air. On the basis of research, it is crucial to incorporate an optimized solar system in the design phase in order to accomplish long-term environmental goals. This approach boosts overall operational performance, enhances solar energy efficiency, and supports facility sustainability. Solar energy efficiency and sustainable building practices are both capable of being be significantly enhanced with an emphasis on these strategies.

Keywords: *Energy efficiency; Green building standards; Passive solar design; Photovoltaic integration; Sustainability*

1. Introduction

A basic novel approach is to incorporate the, solar enhanced building design in ecological architecture. This strategy packages together innovative ambiance regulation methods with electrical power amounts right from solar light technological innovations in order to minimize the demand for non-renewable powers (IEA, 2020; UNEP, 2017). The need for such innovations arises from the fact that buildings represent the single largest global source of greenhouse gas emissions and addressing them is critical to meeting global energy demand while mitigating climate change (UNEP, 2017). In addition to energy savings, the design of buildings for optimal solar utilization also addresses issues related to heat balance inside both homes and office buildings in order enhance ‘thermal comfort within such indoor environments, thereby contributing towards a decreased Urban Heat Island (UHI) effect very relevant on populated urban areas. The goal of integrating solar technologies with building design is to connect power use and environmental compatibility, harmonizing human necessity with environmental sustainability (IEA, 2020; UNEP, 2017). [1-5]

2. Method

This research presents a methodological approach based on systematic literature review of strategies aimed at boosting the efficiency in energy consumption and environmental quality through building design. Additionally, this research uses case studies of solar-optimized buildings in operation to investigate the practical application and relevance of these strategies within multiple contexts through a comparative analysis. The research effort focuses on using Building Integrated Photovoltaics (BIPV) that layer solar arrays with microalgae air purifiers (IEA, 2020; UNEP, 2017). [6-10]

3. Literature Framework

3.1. Historical Overview

Solar-optimized building design has a rich history that dates back to the Egyptians, Greeks and Romans oriented buildings to the arc of the sun for heating in winter but long eaves provided shade from overheating summer sun. The early passive solar design principles began the development of energy-efficient architecture (just as it was arriving on our contemporary frontier). This changed with the Industrial Revolution, as coal-powered heating and artificial lighting began replacing sun dependent processes at an alarming rate. The oil crises of the 1970s renewed interest in solar design, fusing age-old methods with cutting-edge technologies such as PV panels and Solar thermal arrays. The return to popularity of such features (like the orientation toward solar angles) signaled a new era in sustainable architecture known as passive and active solar design. Today buildings are built incorporating solar oriented design principles as one of the foundational practices in sustainable architecture whereby prioritizing energy efficiency, climate considerations and utilization of natural resources to create a building that is both low environmental impact yet maximizes comfort whilst maintaining functionality. [11-15]

3.2. Theoretical Framework

The concept of sustainable building design has matured in the realm of Sustainable Development that concentrates on sun hours as an energetically free option (Cooper, 2011). Given that this information is a required base of knowledge in the design realm when it comes to proper techniques that will help students tap into solar power naturally and keep from burdening their external environment (Cooper, 2011). Passive Solar Design takes advantage of natural energy systems intrinsic to building elements and responses; Active Solar design requires mechanical, such as photovoltaic panels are used for capturing sunlight or converting it (Asdrubali et al., 2015). These passive solar properties also meet a key sustainable development objective: Pollutant minimization, mainly created through human interventions with better building performance.

3.3. Types of Solar Technologies

The solar systems are one of the significant technologies in the modern building design for energy saving and sustainability (IRENA, 2019). The primary technology is Photovoltaics (PV), which produce electricity by converting sunlight into direct current using semiconductor materials directly, such as silicones and germanium in 2013. PV technology has advanced to the point that PV cells can be incorporated into building elements like facades and roofs — a concept known as Building Integrated Photovoltaics (BIPV) — where it replaces conventional construction materials by performing one or more functions typically associated with those material of their original use, but in this case are used for capturing solar energy while at work without impairing structural integrity or reliability IRENA, 2019. Despite the great attentions paid to BIPV, its exit from concept demonstration stage has been encumbered for a long time because of increased costs and conversion losses as well compared with conventional grid connected PV systems (Zhao & Yang, 2017). This shows the need for more research to make BIPV technologies cheaper and faster.

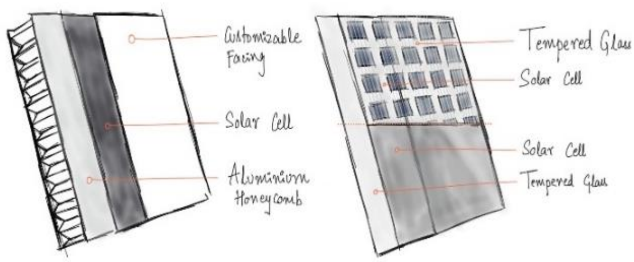

Figure 1 Solar Cladding and Solar Cell - Sketch of Solarclad and Solar Cell, Adapted From an Original Image by Archdaily (2021)

Companies like Mitrex and Tesla are leading the way, introducing solar technology to building aesthetic design processes by creating new solutions that maintain technical specifications. These include solutions for building cladding, glass and facades and BIPV (Building Integrated Photovoltaic) that can all generate clean renewable electricity from the exterior of buildings by substituting normal materials with

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

SolarClad & SolarWall's sunlight harvesting automation technology (Mitrex, 2021) as presented by Figure 1. On the other hand, Tesla has products such as the Solar Roof and Solar Glass which are intended to be a replacement for traditional roofing with solar tiles and glass with SolaRail (Tesla, 2021) that provides almost invisible low-profile rail mounting solution of panel-style modules (Tesla, 2020). Additionally, the Solar Cladding and solar cells technologies shown great importance in present building designs. The main differentiation point however, is rather Tesla marketing its products towards building design compatibility, rooftop collection and energy independence with Powerwall storage solutions in order to break the "The grid" whereas Mitrex focuses on flexibility/design integration. Anyhow, they play an important role in reducing carbon footprints and retrofitting new constructions sustainably (Mitrex, 2021; Tesla, 2021). [16-18]

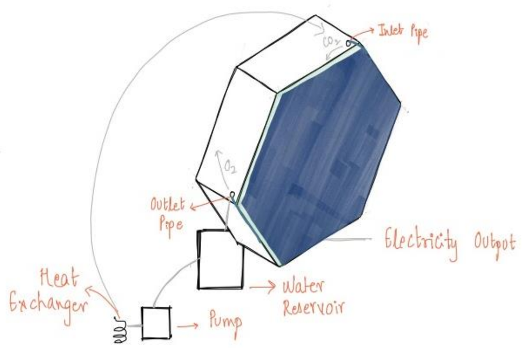

Figure 2 Operational Working of the BIPV Panel

The term BIPV has been used to describe the range of Organic Photovoltaic (OPV) integrated facades developed combined with microalgae in hexagonal water filled modules, which create electricity while purifying air and running a sustainable mutual ecosystem on site. The OPV cells which are obtained from flexible organic semiconductors harvest solar energy and generate electricity. At the same time, microalgae absorb CO2 and exude oxygen through photosynthesis to create a better air quality (Gagnon & McCabe, 2018) as illustrated in Figure 2. The encased water-loop pipes are filled with nutrient-rich water, creating the ultimate breeding ground for healthy algae to grow. With a modular design, the modular panels can be easily integrated and built over curved surfaces leading to excellent aesthetics in combination with high performance. A sustainable and aesthetically unique means of creating energy efficient & low impact building façades, this innovative system (Gagnon & McCabe, 2018).

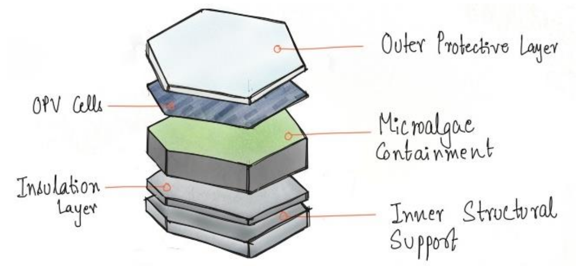

Figure 3 Component Layers of BIPV Panel

Compared to Solar Thermal Systems — these are systems that work by capturing the suns energy into usable heat in a residential scenario. Solar water heating systems are especially attractive in areas where alternative energy sources also use similar temperature inputs for other reasons (Duffie & Beckman, 2013). Solar Thermal Systems are the perfect stand-alone units for heating living spaces, making it optionally even more attractive than TCAM this is due to its efficiency. Moreover, these systems can combine the two solar energy sources — Solar Thermal and Photovoltaic into an Integrated System that makes use of all possible sunlight to deliver not only electricity generation but also heating applications (IRENA, 2019). By this, optimal solar utilization for building needs is guaranteed (IRENA, 2019). (Refer Figure 3)

3.4. Design Strategies for Solar Optimization

Utilization of solar optimization design strategies would significantly increase the value of these technologies. The Sun emits not only light but also long-wave radiation, both of which consume in Passive Solar Design, a built environment concept that optimizes the use of traditional energy sources to heat/illuminate buildings (and may even resolve cooling), without mechanistic help required. The orientation of buildings for the consumption of solar energy is important in Passive Solar design. This has to do with the configuration of windows and walls in relation to solar rays — helping them penetrate

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

optimally during winter but also providing a shade for summer sun. By using thermal mass materials and efficiently insulating the house, energy efficiency is improved additionally by capturing heat throughout the day for release during night time. An effective application of this is illustrated in Figure 4, where the concept depicts how morning and afternoon sunlight with ventilation can contribute to natural heating/cooling (as opposed to mechanical means) of a building. It includes the orientation of building for maximum sunlight, thermal mass materials to absorb heat during day and release it at night as well as shade devices that control solar gains and losses (Heschong Kats 1999;). Whilst Passive Solar Design is relatively simple, it can also reduce our base building demand for mechanical heating and cooling thus driving down energy consumption (Kats 2003). In contrast, Active Solar Energy Systems do not depend on a Passive Solar Design in the same way but are comprised of special mechanical equipment such as solar panels for generating electricity generally and water heaters that collect heat from sunlight. The sufficiency of the layout in this area comprises a suitable slope and rooftop orientation, capable to seize maximum incident solar rays (IEA, 2020). Moreover, there must be a carefully thought-out application and number of active solar systems within the building limit for preserving both performance as well as aesthetic agreement (IEA 2020).

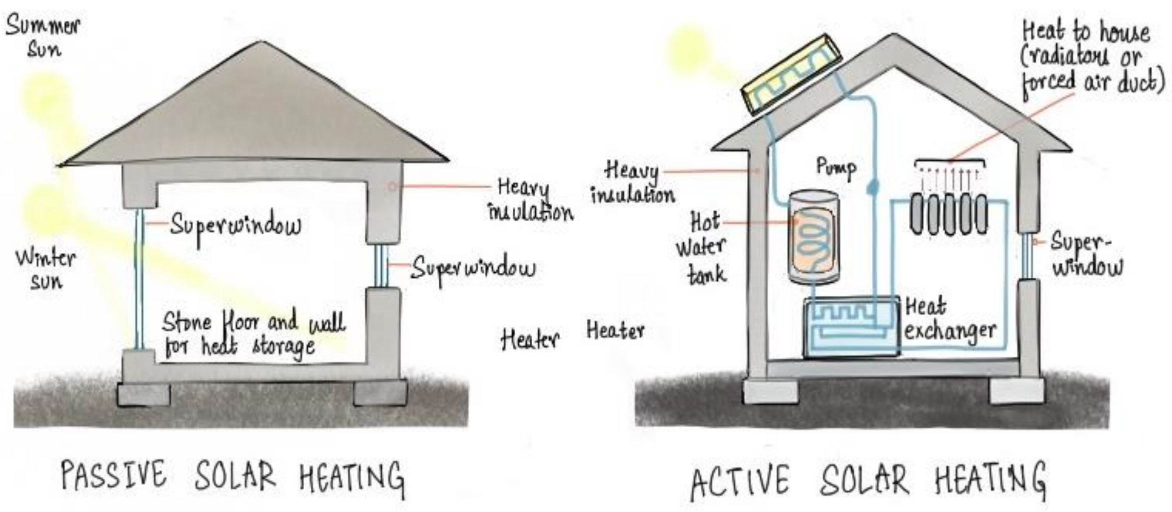

Figure 4 **Passive and Active Solar Design Sketch of Passive and Active Solar Design Adapted From an Original Image by Slideshare (2014)**

BIPV: Bio-Integrated Photovoltaic (BIPV) Panel is a multi-stack system engineered to produce energy and cleanse the air. A transparent, durable outer layer protects the internal components from environmental threats and also lets sunlight to pass through the tempered glass that cover Organic Photovoltaic (OPV) cells which convert light into electrical energy (Gagnon & McCabe, 2018). CO2 comes on Both Sides — by the water in adjacent layered modules, where microalgae consume carbon dioxide and produce oxygen with its photosynthesis activity that helps to purify air. Between the frame and the inner support is an insulation layer which maintains thermal efficiency, so that a solid panel (comprising aluminium/ wood laminate) can be structurally self-supporting but only weighs between five to seven hundred kilos allowing it to attach securely onto any building structure being developed (Gagnon & McCabe, 2018).

3.5. Case Studies and Examples

For additional examples and case studies regarding how solar energy can help building sustainability, for instance consider Modhera Solar Village, Gujarat, India or the Bullitt Center Seattle (IRENA 2019;

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

Sorrell 2015). Well, in fact —these examples not only illustrate the advances made technologically but also showcase applications of solar-optimized building designs to socio-economic lifestyle settings. Modhera is a village where agriculture being the primary occupation, now have Solar Plant. However, this made Modhera one of those solar farms that work a little better and it cut drastically its dependence on fossil fueled costlier power (IRENA 2019). It is an example of how the use of scaling solar power can improve villages make independent while their bills. It shows how targeted government policies and subsidies can make a real difference to uptake of solar tech in perennially underserved areas. The Bullitt Center in Seattle is a downtown location photovoltaic success. The Bullitt Center, complements a commitment to solar by promoting the use of photovoltaics in city places (Sorrell 2015). It represents a pivot in the energy landscape of cities away from historical carbon practices — urban scale self-sufficiency. The Bullitt Center is an ultimate demonstration project for integrated building strategies; its solar orientation would be just one part of the sustainable project; it also includes rainwater harvesting and net-zero energy technique.

3.6. Challenges and Limitations

There are a lot of benefits to solar-centric design, however there still exist numerous obstacles that stand in the way of its mainstream adoption. The design difficulties are largely due to the need for challenging alterations of existing structural and electrical systems when retrofitting old solar technology in buildings (Zhao & Yang, 2017). The same is true of solar systems; local weather and siting constraints will influence how effective a system can be (Tobin & Radhakrishnan, 2016). Furthermore, large upfront capital costs at early stages of development are a key economic factor which has contraindicated other technologies like the SolarLeaf that use algae (Zhao & Yang, 2017). In addition, up-to-date building codes and standards continue to trail new technology for this industry making it challenging on getting the latest solar installations integrated (Tobin & Radhakrishnan, 2016). Tackling these technical, economic and regulatory hurdles head-on is what it will take to truly shift the paradigm towards solar-informed building design.

3.7. Environmental and Economic Impacts

The solar oriented designs have environmental benefits as well, with the decrease in greenhouse gas emissions by shifting away from non-renewable fossil fuels and into renewable energy sources for power generation aiding the mitigation of climate change (UNEP, 2017). Solar technologies can reduce your energy costs over the years which in turn guarantee local and grid system stability (IEA, 2020), employment opportunities generated by an up-and-coming renewable industry. These and other impacts need in part to be incorporated into a full evaluation of the effectiveness of solar-optimized building designs as well as intended trajectories (IRENA, 2019). This underscores the need to scale-up renewables for future of electricity consumption in addition to making climate objectives as indicated by Figure 5 (IRENA, 2019).

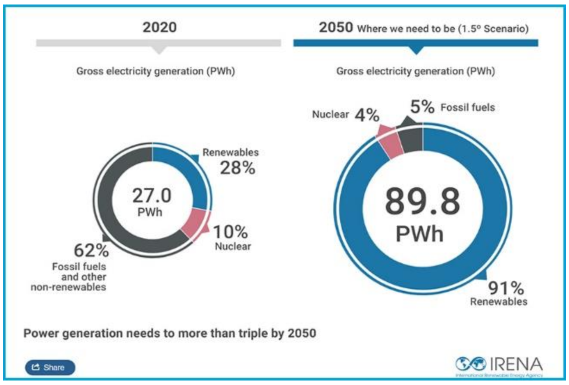

Figure 5 Global Electricity Generation by Energy Source, As Depicted By Irena (2021).

3.8. Gaps in the Literature

This continued heavy reliance on accommodating solar-optimized design in the literature points to an area of research that is not yet fully exploited. We simply need many years of long-term performance data before we can truly understand how durable these technologies are and what they will mean for operations (Gagnon & McCabe, 2018). More importantly, the general cost-benefit of solar systems under different economic conditions remains unclear due to a shortage in ongoing research that evaluates their overall long-term value (Zhao & Yang, 2017) Socio-cultural acceptability Studies have found that

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

the acceptance of solar-integrated buildings varied in different regions (especially developing countries where awareness and affordability were significant barriers) but strangely, it was not quantified. Looking into these factors might yield important lessons learned regarding worldwide application of solar-optimized designs. Additional studies are also needed to investigate the human factors in solar-optimized buildings, including how people behave within and appreciate such settings. In addition, adopting new or custom technologies will require policy adaptation since current building codes and regulations may not support the assimilation of advanced solar technology (Tobin, 2016). So, plugging these gaps is key to establishing the business case for solar-optimized design moving forward (Sorrell, 2015).

Conclusion

This research paper examined the potential of solar-optimized building design through bio-integrated photovoltaics with a specific focus on algae panels. Despite traditional photovoltaic systems being the most realistic option for electricity generation, they seem to ignore many other more important environmental influences such as air quality or urban heat island phenomena (Asdrubali et al., 2015). On the contrary, bioactive integrated photovoltaics present a mutualistic benefit: generating renewable energy which also helps clean up carbon air by absorbing CO_2 and releasing O_2 (Gagnon & McCabe, 2018). This support to the simultaneity between buildings able of generating energy and could be regenerated for future use. The development of algae-based building photovoltaics is considered an innovative solution in sustainable architecture as they address challenges such as energy usage, urban contamination and sustainability (Mitrex, 2020). We must ensure that technologies capable of yield positive effects for energy and environment are combined, thereby enabling city environments to become more sustainable (Tesla, 2020).

Results and Discussion

The power-generation characteristics of the new algal PV systems embedded on building facades for addressing urban environmental problems are depicted. These panels remove CO_2 while at the same time emitting O_2, and they generate energy (Sorrell, 2015). These panels are less efficient than conventional silicon-based solar PV, which have energy conversion efficiencies of 15-20% (Duffie & Beckman, 2013). Or highly polluted urban sprawls having high PM, CO_2 with a benefit by algal panels in cleaning the air not would be (Tobin & Radhakrishnan, 2016; IRENA, 2019). Compared to more advanced solar technologies like thin-film, for example; the efficiency rate is considerably lower and they are of higher installation cost but algae panels remain unique from an environmental perspective as well as with regards on energy (IRENA, 2019). Although they are less efficient, thin-film solar cells must be made on a larger "per-cell" surface area than more traditional panels to provide an equivalent amount of energy. Conversely, solar cladding tends to be less efficient and costlier than other options although are more attractive within the look of a building (Zhao & Yang, 2017). The dual functionality of energy generation and air purification in the algae panels make them an attractive component for solar-optimized building design, further so with possible improvements through technological advancements as well as from economies of scale (Sorrell, 2015). Bio-integrated photovoltaic, also known as BIPV panels are a novel advancement in solar energy technology that integrates biological systems into regular PV cells. Unlike conventional solar panels, which convert only sunlight into electricity, BIPV has the advantage of utilizing living organisms in their development (Gagnon & McCabe, 2018) or structural components could be designed as bio-receptive with environment-specific benefits such as air purification and bioluminescence. Installed in or on building façades, roofs, and windows BIPV converts sunlight into electricity with the added benefit of directly integrating electrical energy generation where it is needed while simultaneously providing a new use for existing installations. The design details for the Living Solar Façade can be found in Figure 4. The above sketch describes how BIPVs are set out in a building's facade, showing the broad architectural concept and performance of this system. They may be applied to both fresh builds and can be retrofitted into current buildings, with adaptable designs in

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

different shapes and sizes ensuring they contribute towards enhancing aesthetics while promoting sustainable practices (Mitrex, 2020). BIPV panels are composed of durable building materials with various finishes and tint options, while additionally reducing carbon emissions and increasing air quality in green buildings. While the photovoltaic cells and biological components need to undergo regular maintenance for them all to work properly, they still have a lifespan roughly equivalent of that of standard solar panels (Tesla, 2020).

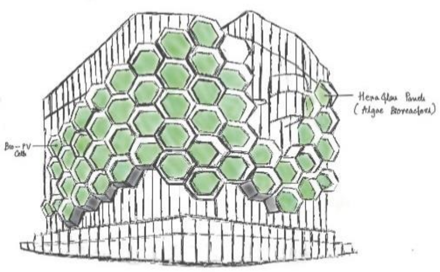

Figure 6 Living Solar Façade Design with BIPV Panel

The Living Solar Façade is an innovative example of sustainable building design that embeds bio-integrated photovoltaics (BIPV) alongside hexagonal panels featuring algae illustrated in figure 6. Another feature of this wall is that it does not only generate electrical and thermal energy, which are produced by the organic photovoltaic cell embedded in its cells but also help to clean our polluted air absorbing CO2 building atmosphere), releasing O2 into formation — Photosynthesis (Gagnon & McCabe, 2018). The curve of the panels improves light exposure, which increases both energy production and photosynthesis (Mitrex 2020). In effect, the Living Solar Façade makes it possible to harness and purify air via an archetype of a building facade becoming both energy-producing surface as well as smog-eating chimney—a new marker in constructing more sustainable/healthier urban environment (Tesla 2020).

References

[1]. International Energy Agency (IEA). (2020). Renewables 2020: Analysis and forecast to 2025. IEA. Retrieved from https://www.iea.org/reports/renewables-2020.

[2]. Kumar, V., & Kumar, S. (2024). Enhancing Solar Photovoltaic Cell Efficiency: A Comparative Analysis of Advanced Materials and Manufacturing Techniques. International Research Journal on Advanced Engineering Hub (IRJAEH), 2(05), 1303-1310. https://doi.org/10.47392/IRJAEH.2024.0180

[3]. Saranedaran, M. S., Kumar, M. M. N., Krishna, M. R. H., & Kumari, M. P. S. (2024). Sun Charge: Transforming Solar Streetlights into EV Power Hubs. International Research Journal on Advanced Engineering Hub (IRJAEH), 2(06), 1809-1815. https://doi.org/10.47392/IRJAEH.2024.0248

[4]. Karthick, U. (2024). Solar Sustainability: Redefining Waste Management in Renewable Energy. International Research Journal on Advanced Engineering Hub (IRJAEH), 2(01), 42-49. https://doi.org/10.47392/IRJAEH.2024.0006.i1

[5]. Arunbabu, R., Ajaykarthik, R. T., Babu, F., & Raju, Y. M. (2024). Automatic Street Light Control Using IoT and Solar Energy. International Research Journal on Advanced Engineering Hub (IRJAEH), 2(03), 672-676. https://doi.org/10.47392/IRJAEH.2024.0097

[6]. United Nations Environment Programme (UNEP). (2017). Towards a zero-emission, efficient, and resilient buildings and construction sector: Global Status Report 2017. UNEP. Retrieved from https://www.unep.org/resources/report/global-status-report-2017.

[7]. U.S. Energy Information Administration (EIA). (2021). International Energy Outlook 2021. EIA. Retrieved from https://www.eia.gov/outlooks/ieo/.

[8]. Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional photovoltaic technologies. Energy and

International Research Journal on Advanced Engineering and Management
https://goldncloudpublications.com
https://doi.org/10.47392/IRJAEM.2024.0437
e ISSN: 2584-2854
Volume: 02
Issue: 09 September 2024
Page No: 2956-2963

Buildings, 93, 133-145. doi: 10.1016/j.enbuild.2015.02.038.
[9]. Cooper, I. (2011). Sustainable building design: Principles and practice. Wiley-Blackwell.
[10]. Gagnon, S., & McCabe, M. (2018). Bio-PV technologies: An overview and future trends. Renewable and Sustainable Energy Reviews, 82, 16-31. doi: 10.1016/j.rser.2017.09.050.
[11]. Heschong, L. (1979). Daylighting in Architecture: A New Approach. MIT Press.
[12]. International Renewable Energy Agency (IRENA). (2019). Renewable Power Generation Costs in 2019. IRENA. Retrieved from https://www.irena.org/publications/2019/Jun/Renewable-Power-Generation-Costs-in-2019.
[13]. Zhao, X., & Yang, X. (2017). Review of the costs and benefits of Building Integrated Photovoltaics (BIPV) technology. Renewable Energy, 101, 434-445. doi: 10.1016/j.renene.2016.09.041.
[14]. Mitrex. (2021). SolarClad & SolarWall: Innovative Solar Solutions. Mitrex. Retrieved from https://www.mitrex.com/.
[15]. Tesla. (2021). Solar Roof & Solar Glass. Tesla. Retrieved from https://www.tesla.com/solarpanels.
[16]. Duffie, J. A., & Beckman, W. A. (2013). Solar Engineering of Thermal Processes. John Wiley & Sons. ISBN: 978-1118094248.
[17]. Sorrell, S. (2015). Explaining Sociotechnical Transitions: A Critical Realist Perspective. Routledge. ISBN: 978-1138927660.
[18]. Tobin, P., & Radhakrishnan, K. (2016). Advances in Solar Energy Technology and Policy. Wiley.