Journal of Advances and Scholarly Researches in Allied Education
Vol. 19, Issue No. 6, December-2022, ISSN 2230-7540

A review on the application of Photovoltaic Technology in Building Design for building envelopes

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Abstract - Photovoltaic technology uses sunlight to generate electricity. This technology can be used as a building material for the building envelopes to produce electricity on-site to fulfil the electricity demand required by buildings for various purposes without causing environmental harm. Buildings require roughly 40% of total electricity, with 70% of that used solely for heating, cooling, and lighting, and the remaining 30% used to manage defects, malfunctions, superfluous operations, and electricity loss. Photovoltaic technology can be used to generate electricity as an alternative to nonrenewable fossil fuels. The technology may be integrated into building design to create an adaptable and viable solution for meeting the future need for electricity for zero-emission buildings. It provides an aesthetically pleasing, cost-effective, and technically sound system to harvest solar energy and generate electricity for buildings. The building envelope, form, design, construction material, and construction style all influence the utilization of active and passive solar energy in every structure. Active solar energy can be used to generate electricity using photovoltaic technology. As with Building Applied Photovoltaic (BAPV) and Building Integrated Photovoltaic (BIPV), this technology can be employed in both traditional and new construction methods. This paper aims to give a brief review of applications of photovoltaic technology used in building design, through a systematic literature review to explore how Photovoltaic (PV) technology could be utilized in the future for a variety of commercial and industrial applications.

Keywords - Photovoltaic Technology, Building Design, Building envelope, solar energy, Electricity

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INTRODUCTION

Energy demand is growing worldwide as the population increases and their lifestyle changes. There is an urgency to meet the current demand for energy by enhancement in energy efficiency to address the growing energy consumption. Worldwide the countries are dominated by fossil fuels for energy production and around three-quarter of global greenhouse gas emission is due to the use of fossil fuels and also contributing to air pollution. For this, there is a need to shift towards renewable resources for energy generation from fossil fuels. With the use of those resourcesfor energy productions which are renewable and sustainable, decarbonisation can be done in the coming decades.

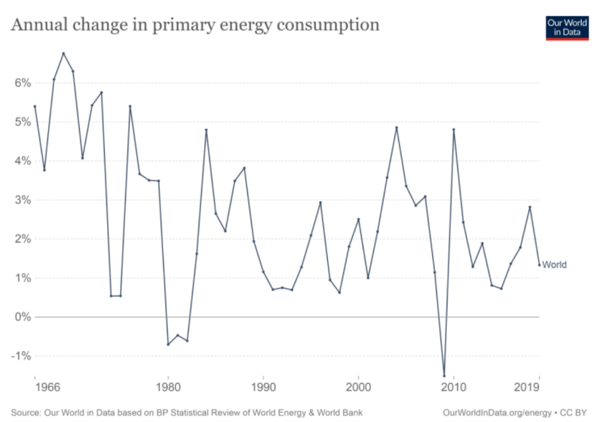

Figure 2https://ourworldindata.org/energy-

production-consumption

The above figure shows an annual change in energy consumption worldwide which increased over the year. There was a fall in energy consumption noticed during the 1980s and 2009. Energy consumption keeps growing globally but it does seem to slow with 1% to 2% per year.

As the population is increasing all over the world, it can be estimated that by 2050 the energy demand will be double. Temperature is increasing subsequently due to which the global warming is also increasing and the weather is becoming extreme and less predictable. Studies show that in most developed countries, about 40% of total electricity is consumed in buildings, of which more than 70% is used only for heat, cooling, and lighting, about 20% of electricity is used in handling faults, malfunctioning and unnecessary operations, and 10% electricity loss. On other hand, in developing countries like India, the major factoris identified as the use of inefficient appliances which contributes for more energy consumption in building. As energy demand is increasing very fast worldwide with rise in population and change in their lifestyle simultaneously. As the lifestyle of the people in India has changed a lot in the last 20-30 years due to which the energy demand has increased extensively and there has been a lot of pressure on the available resources.

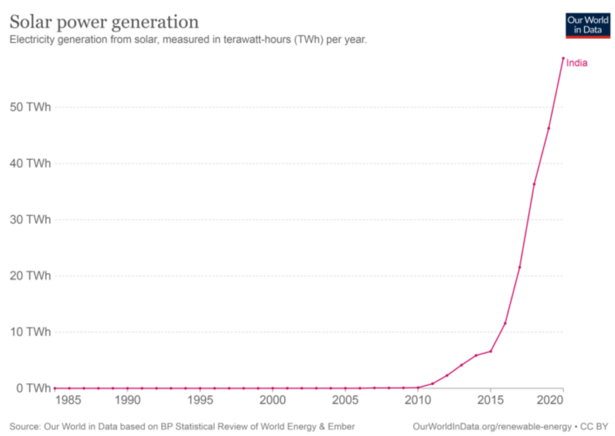

Figure 2, https://ourworldindata.org/energy-production-consumption

Solar generation is relatively a modern renewable energy source and is growing quickly in many countries worldwide like India. India generates around 58.73 terawatt-hours per year of electricity from solar technologiesfrom Grid connected system. The Ministry of New and Renewable Energy (MNRE) initiated Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 targeted 100,000 MW of grid-connected solar power by 2022 under National Solar Mission which was later revised in 2015. India is now at 4th global position for overall installed renewable energy capacity. If this technology is used as an integral part of the building envelopes, it will create a link between demand and supply of electricity onsite.

As we know that the traditional resources like oil, gas, and coal which produce electricity are limited and neither abundant nor everlasting and also play a critical role in creating pollution so we need a technology which is used to produce electricity without changing the ecology and degrading the environment and tackle the problem of environmental pollution. These are the motivating drivers for the innovation of new technology and the best resource for energy production is the sun as solar energy is abundant and everlasting. (By Kehinde Temitope Alade, 2017)

Today new technology photovoltaic is emerging as a viable option. Photovoltaic generate electricity using sunlight which is a renewable resource and PV can also be installed in building to give a new dimension to the energy-conscious design. Photovoltaic is a solid-state device that converts solar energy into electricity that requires no fuel and does not generate any pollutants during its life cycle. In today's stage, photovoltaic's technology can be characterized as follows:

1. Photovoltaic modules have at least 30 years of admissible serviceability which is technically proofed

2. PV technologies have been used in many small and big projects successfully.

3. Photovoltaic is a modular technology that can be utilized for electricity production from milliwatt to megawatt.

4. Photovoltaic technology is viable and cost-effective as well as electricity can be generated by using it in remote sites where it is not feasible to install a conventional power supply system.

5. Photovoltaic technology is universally adopted worldwide.

Photovoltaic modules can be mounted in the building and also used as building envelopes to link the demand and supply of electricity within the site itself. With its use, power plant based electricity can be reduced significantly.

The importance of photovoltaic technology in buildings from the architectural, technical, and financial point of view is as follows

1. No land area is required to install Photovoltaic and can be used in any densely populated area as well,

2. installations of PV does not require any additional infrastructure,

3. generate electricity during day times and fulfil the peak delivery requirements,

4. able to reduce transmission and distribution losses

5. able to replace conventional building materials for building envelopes and used as a viable option which enhances payback considerations,

6. can be able to provide an improved aesthetic appearance to the building in an innovative way,

7. can be integrated with the maintenance, control, and operation of the other installations and systems in the building,

8. Can provide reduced planning costs.

If we talk about photovoltaic in the building context, then photovoltaic should not be viewed only from the point of view of energy production because it acts as a multifunctional element in the building and provides both power and shelter.Solar energy can be found everywhere and especially talking about India, solar irradiance is very high in India which is good for electricity generation.

METHODS AND MATERIALS

To perform a Systematic Literature review, Papers from three databases -Web of Science, Scopus, and Research gate were considered. Total papers were more than 400, which were filtered after removing duplicates and not related to the subject. A total of 66 papers were considered.

Sunlight is an abundant natural resource capable of providing total energy demand and solar power is the conversion of sunlight into electricity. Sunlight converts into electricity in two ways**: Photovoltaic technology (PV) and Concentrating Solar Power system (CSP).** In Photovoltaic technology PV, the sunlight directly converts into electricity.

The PV technology can be used in two ways for building design. The **Building Applied Photovoltaics (BAPV) method comprises superimposing modules onto existing surfaces once construction is finished and The Building Integrated Photovoltaic (BIPV) replaces the use of conventional building materials used for building envelopes**.

Building Applied Photovoltaics (BAPV)	Building integrated photovoltaic (BIPV)
superimposing modules onto existing surfaces	replaces the use of conventional building materials
directly affixed to the structures using additional mounting framework and adjustable rails	offers an aesthetical, economical, technical solution to harvest solar radiation
no direct impact on the structure of the building	can be used on the roof, skylights, facades, blinds, and other components of the building envelope
increase the building loads which have an effect on the structure	stronger impact on the indoor atmosphere of the building
not provide water-proofing or wind-shielding to the structure.	are generally translucent or semi-transparent

Although the rapid development of PV technologies around the world has often motivated designers to consider options for mounting solar panels on building facades, using fixed PV modules on the facade is the least effective approach, inhibiting the full use of an integrated system. As a result, researchers are experimenting with adaptive techniques to increase the performance of facade BIPV systems. PV facades are being used as a dynamic building envelope and a climate-adaptive building shell in current research.

Comparison of Different Types 0f PV Modules:

Type of PV	Module Efficiency (%)	Surface area For 1KWP (m2)	Energ payba period
Mono crystalline silicon cell	15-18	7-9	≈ 5 yea
Poly crystalline silicon cell	13-16	8-9	≈ 3 yea
Thin film amorphous silicon cell	6-8	14-20	≈ 2- 4 y
Thin film CIS	8-12	9-11	≈ 1-2 y
Thin film CdTe	9-11	12-17	≈ 1-3 y

RESULT & DISCUSSION

While building-integrated photovoltaics are becoming the backbone of the near-zero-energy construction aim for future, this inevitably places the facades at the core of the energy concerns. To address these 'facade-oriented energy concerns,' developing adaptive modular PV facades and adaptive means of balancing daylighting and shade is a viable option. Adaptive PV facades are a simple way to maximise both solar energy output and solar gain control by installing a smart, dynamic PV integrated shading device on the facade.

Table 1: Comparative summary of PV modules installed in different buildings for electricity generation in different countries

Case Study	Building Type	PV Modules	Solar Structure	Orientation and Tilt angle	Energy Generation (per year)	Reduction on Co2 emission (Tonnes	Remarks
Festo, Noida, India	Office	BIPV	19.52 KW	South facing façade 30 degree tilt	17,106 KW	13.2	Stainless steel frameworks were installed on the south facing façade of the building to mount the panels at the time of construction.
Dell International Services India Pvt Ltd., Bengaluru, India	Office	Thin-film technology	120 KW	45-meter-longvertical solar structure 30 degree tilt	95,159 KW	59.4	India's largest vertical solar farm, produces enough energy to light-up its entire cafeteria and basement parking, 480 modules, 11 storied building wall, Green Building Platinum LEED certification
Future Business Centre - Cambridge	Office	PS-A (100 watts) opaque, PS-C901 Transparent (90 watts) double glazed (DGU)	4.6 KW	57 m sq	3500 kW	3.2	PV glazing for the stairwell curtain walling and the decorative rain screen cladding, sought to attain a high environmental rating, targeting and being awarded BREEAM Excellent.
Discovery Science Center, Santa Ana, California	Institutional	Thin-film technology	20 kW	PV-covered surface of the cube is tilted at 50°	30,000 kW	23	Modules cover the 4,334-ft2 top of the cube. The thin-film modules are treated as an architectural glazing element, produce up to 20 kW of DC electricity at mid-day and 30,000 kWh of electrical energy per year

In the Indian context, there is an unavailability of comprehensive data showcasing a number of photovoltaic projects in the country is one major gap identified. A need is visible for an agency to maintain the record of such projects along with the details of all the manufacturing companies.

PV modules avoid the need of a valuable land resource of at least 4 acres per MWp required for ground-mounted Solar PV. Due to their improved temperature coefficient and low-light operation, thin film CdTe modules have a larger yearly production in the world than crystalline modules. It has a less negative impact on the environment. It provides insulation and result in energy savings in the heating and cooling of buildings. Because of the acoustic isolation, it helps to reduce noise inside the building. It is a weatherproof covering for the structure of the building. It increases the building's aesthetics.

BAPVs are integrated to existing or new PV system on an existing or new building, whereas BIPVs replace the typical building envelope, such as the window, roof, and wall. As a result, BIPV has a stronger impact on the indoor atmosphere of the building. BIPVs are generally translucent or semi-transparent, allowing incident sunshine and solar heat to pass through, directly altering the indoor ambiances. It also has a various features, including the ability to control solar heat gain or loss, reduce daylight glare, and offset the cost of window, roof, or wall materials. BAPVs, on the other hand, make no other contribution to the building environment except the generation of green energy. BIPV tile, foil, and glazing are currently available BIPV products. BIPV foils and tiles are generally used on roofs, whereas BIPV glazings are mostly used in vertical semi-transparent and transparent windows, façades, and walls. Currently, the rooftop-mounted BIPV products accounts for 80%, while the façade-mounted BIPV products accounts for only 20%. Rooftops, which are free of adjacent tall structures or trees, are generally the greatest solutions for harvesting the most energy when pitched at specified elevation angles. Because of their flexibility and light weight, BIPV foil materials are ideally suited for building applications.

Due to the additional adaptive components (trackers, actuators, additional supporting structure), the embodied environmental impact of a dynamic BIPV solution is around 50% more than a static one, resulting in higher life cycle impacts. When the multi-functionality of the system is taken into account, such as savings from adaptive shade to the building's heating, cooling, and lighting demands, the embodied environmental impact can be offset, making adaptive solar facades a viable BIPV option. An adaptable solar facade may save 56 percent of total energy compared to no shade and 25 percent compared to fixed louvers.

CONCLUSION

If Solar PV Facades are employed in buildings, there is the potential for significant financial savings as well as a decrease in GHG emissions. The results with CdTe modules show that Thin Film technology is an excellent solution for Solar PV Facades.

The building facade serves as a boundary/mediator in which various technologies can be integrated to perform a variety of purposes. The increasing demand for sustainability considerations in contemporary design is undoubtedly contributing to the transformation of the building envelope, or façade, from a passive barrier to a rational, active, and adaptive layer between the internal and outdoor environments. As a result, adaptive facades are gaining popularity to meet a various needs, including energy conservation and harvesting, environmental impact mitigation, and so on. By combining qualities of these facades, they expect to enhance building performance and meet a wider range of needs. Adaptive photovoltaic (PV) facades, for example, strive to modify the various functions, generate electricity, increase daylight use, and improve the facade's energy performance by lowering heating and cooling loads. An adaptive PV façade is a photovoltaic system installed on the facade that combines the advantages of adjustable shading with integrated sun tracking.

REFERENCES

1. Bansal, N. K. and Goel, S. (2000) 'Integration of photovoltaic technology in cafeteria building, at Indian Institute of Technology, New Delhi', *Renewable Energy*, 19(1–2), pp. 65–70. doi: 10.1016/S0960-1481(99)00017-8.
2. Bhargava, B. (2001) 'Overview of photovoltaic technologies in India', *Solar Energy Materials and Solar Cells*, 67(1–4), pp. 639–646. doi: 10.1016/S0927-0248(00)00336-6.
3. Gangopadhyay, U., Jana, S. and Das, S. (2013) 'State of Art of Solar Photovoltaic Technology', *Conference Papers in Energy*, 2013, pp. 1–9. doi: 10.1155/2013/764132.
4. IRENA (2019) *Future of solar photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper)*, *International Renewable Energy Agency*. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf.
5. Irizarry, A. A., Colucci, J. A. and O'Neill, E. (2014) 'Chapter 5 Solar Photovoltaics', *Achievable Renewable Energy Targets*, pp. 1–96. Available at: https://www.uprm.edu/aret/docs/Ch_5_PV_systems.pdf.
6. Orhon, A. (2016) 'A review on adaptive photovoltaic facades', *Solar TR2016 International Solar Conference & Exhibition*, (September), pp. 463–470.
7. Ortega, E., Aranguren, G. and Jimeno, J. C. (2021a) 'Photovoltaic modules transient response analysis and correction under a fast characterization system', *Solar Energy*, 221(March), pp. 232–242. doi: 10.1016/j.solener.2021.03.032.
8. Ortega, E., Aranguren, G. and Jimeno, J. C. (2021b) 'Photovoltaic modules transient response analysis and correction under a fast characterization system', *Solar Energy*, 221(May), pp. 232–242. doi: 10.1016/j.solener.2021.03.032.
9. Reddy, P. *et al.* (2020) 'Status of BIPV and BAPV system for less energy-hungry building in India-a review', *Applied Sciences (Switzerland)*, 10(7), pp. 1–24. doi: 10.3390/app10072337.
10. Sick, F. and Erge, T. (1996) 'Photovoltaics in buildings - a design handbook for architects and engineers', p. 280.
11. Singh, U. P. *et al.* (2013) 'International Conference on Solar Energy Photovoltaics', *Conference Papers in Energy*, 2013(33), pp. 1–1. doi: 10.1155/2013/917045.
12. Yan, X. *et al.* (2021) 'Strategies to increase the transient active power of photovoltaic units during low voltage ride through', *Energies*, 14(17). doi: 10.3390/en14175236.

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