Design and Implementation of a Façade Integrated Photovoltaic (FiPV) System: Conversion of the Faculty of Dentistry Building Facade into a FiPV System at Jamia Millia Islamia University, New Delhi

Dr. Mariam Ahmad[1], Ar. Praveen Sharma[2]

[1]Assistant Professor
Department of Architecture
Jamia Millia Islamia, New Delhi 110025, India.

Abstract:
Building Integrated Photovoltaics (BIPV) is a burgeoning technology, required to deal with the energy crisis the world is facing. The solar radiation is omnipresent and ubiquitous, and has the potential to generate electricity, to meet the need of the urbanized world. In this context the application of photovoltaic (PV) integrated within the built environment becomes very critical. The building façade presents unique opportunities for integrating the photovoltaic technology. The application of PV has been restricted to roof top areas, its potential for façade application hasn't been explored enough. It is possible to utilize the façade area for PV integration and create a more efficient, sustainable and aesthetically satiating façade. According to the Ministry of New and Renewable Energy (MNRE) (India, n.d.), about 5,000 trillion kWh per annum insolation is received on Indian lands with most parts receiving 4-7 kWh per square meter per day. According to the reports The Latest Trends in Photovoltaics Applications, IEA Photovoltaic Power Systems Program (PVPS) (International Energy Agency, 2022) indicated that installed PV capacity at the end of 2020 saved more than 860 million tons of CO2 and it is estimated that the gigatons threshold was reached in 2021.
In this paper an attempt has been made to transform a passive building façade into an energy generating PV façade and assess its potential in generating electricity to meet the building needs. The Faculty of Dentistry Building located in the complex of the Jamia Millia Islamia University, New Delhi has been selected as the base case building. The simulation and analysis are performed with the PVSyst software and the building modelling is done by using the Trimble Sketchup software. The study is limited to the electricity generation through the transformation of façade and it does not include thermal analysis during the research due to its construction technique. The Rain screen cladding system is being used to implement BIPV façade transformation.
The paper is divided into four sections. The first part identifies the most feasible PV technology for façade application. The second part of the paper attempts to identify the most feasible orientation for the application of selected PV technology. This is done by the designing, analyzing three scenario's (a) PV installed on south facade; (b) PV installed on west facade; (c) PV installed on South-West Facade. The third part of the paper is the comparison and analysis of the three cases, thus leading to the identifications of the orientation with high energy generation. The last section of the paper discusses three scenarios in detail.
The transformation of façade was designed and analyzed in terms of the economic feasibility and electricity generation (simulated with the PVsyst software). The viability of economic factor helps any technology to penetrate easily into the market and the analysis on the basis of functionality makes it more workable and adaptable to the stakeholders. The combination of these two studies helps stakeholders to choose PV technology to adopt in the specific user requirements. The installed system capacity of the South Façade, West Façade and South–West façade is 148 kWh, 87.4kWh and 235 kWh respectively. The life cycle analysis has been done to find out the Net Present Value (NPV), Internal Rate of Return (IRR) and Discounted Payback Period (DPP) of the project. Thus, after investigation and evaluation,

it was found that PV façade with south orientation in a composite climatic zone had high potential. The study attempted to transform the passive building facade to an energy generating, smart envelope and feasibility of the designed façade has been supported through a thorough life cycle cost assessment.

Keywords: BIPV, Thin Film Technology, PV Facade, Cadmium Telluride Thin Film, PV Facade Integration.

1. LITERATURE REVIEW

The concept of a world without electricity is unimaginable. There were times of earlier human civilization, where the necessities and needs of common people were being fulfilled without electricity. But present life and its complex functioning require the application of electricity to meet the needs of contemporary human civilization. The major generation of electricity worldwide has been through non-renewable energy sources, causing a lot of pollution and exhaust of harmful greenhouse gases (GHG). These emissions and pollution combined with the fast depletion of non-renewable sources have caused a paradigm shift in the search for better, cleaner and sustainable options of power generation.

The depletion of fossil fuels will lead to complete exhaustion of these resources, oil reserves; coal reserves are going to last till 2050's, gas reserves till 2070's, and uranium ores till 2090's. (Khan, Abas, & Kalair, 2015). The energy crisis the world is facing and the climate change occurring worldwide, have led to the world looking for zero energy, green building strategies and sustainable practices. One very important aspect of these practices is the exploration of renewable energy system. The photovoltaic technology is the corner stone of the renewable energy system.

The omnipresence of solar radiation in excessive amount, throughout the world is one of the key advantages of using photovoltaic technology for energy generation. The photovoltaic technology has undergone a lot of changes leading to improvements in all aspects of the technology. These improvements have been in efficiency, transparency, appearance of PV panels. Thus, leading to better performance in the optical, thermal, and visual properties. With the ongoing research in the field of PV technology, there have been improvements and upgradation in the sustainability and lifespan of the panel. To make the adoptability of PV panels more efficient and feasible, these panels have been categorized into four generations based on technological improvements and upgradations. The First Generation panels are based on the crystalline silicon technology, with lower optical and thermal performance. The Second-Generation panels are based on the thin film technology which has increased the possibilities of integration of the technology with other materials. The previous studies like (Attoye, Aoul, & Hassan, 2017) and (Nagyn, et al., 2016) have demonstrated the applicability of the thin-film technology on building facades. The Third generation PV panels are the improved and upgraded versions of the first- & Second-generation technology. The fourth generation PV technology is still in the study and experimental stage, and are majorly based on the graphene technology.

The need for alternative, efficient, cleaner and sustainable sources of energy have increased the demand for the PV panels in the market. There has been a change in the perception of building, mainly from housing and habitat role to that of incorporating renewable energy systems to generate energy. (Mishra, Ali, Pradhan, Mohapatra, & Singh , 2013). With ideas of Net zero energy buildings, green buildings, the need for integration of PV technology with the built structure has increased and opened new avenues of research within the building integrated photovoltaic technology. BIPV is a field which could help in realizing the goal of zero energy buildings and green building practices, hence leading to increased focus within this segment. When integration of PV technology is considered within the built environment the second-generation i.e. thin film PV technology plays a very catalytic role. The Second-generation PV technology is most preferred by the researchers and stakeholders because of the possibility of integration and application of the PV technology. Thin film photovoltaic technology is very flexible and can be integrated with many materials, especially with the conventional construction materials. With increased efficiency, improved thermal, visual, and optical performance, it not only generates electricity but is capable of replacing the conventional construction materials, enhancing cost effectiveness, and sustainability of construction.

2. METHODOLOGY

The research has been undertaken with an attempt to understand, analyze and evaluate the concept and potential of the BIPV façade, designed in a composite climate. The methodology that has been followed in this paper, is illustrated in figure 1. The first step is the identification of base case building, followed by the study of PV façade through case studies and literature analysis. The third process is the analysis of the PV façade based on climatic consideration of azimuth and tilt angle. The fourth step is the selection of the PV panel and balance of system (BOS). The final step would be the analysis of the selected PV technology on the designed façade.

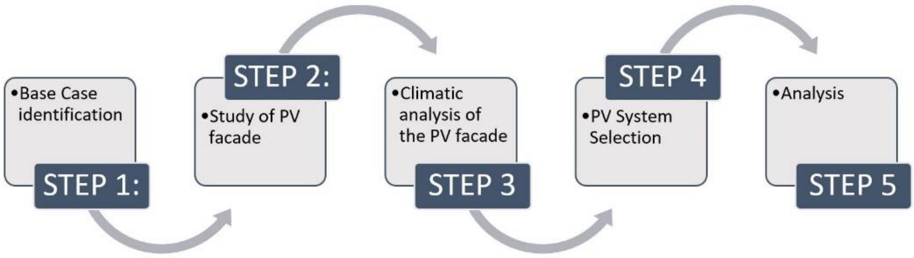


Fig. 1. Methodology of designing a PV façade
Source: Author

The study has tried to transform a passive building façade into an energy generating PV façade and assess its potential in generating electricity to meet the building needs. Hence, the Faculty of Dentistry Building located in the complex of the Jamia Millia Islamia University has been identified for the base case building. The building is located in composite climate and the coordinates of the location are 28.56° N Latitude and 77.28° E., at an altitude of about 207 m. The system will be grid connected. The simulation and analysis are performed with the PVSyst software and the building modelling is done by using the Trimble Sketchup software.

3. CASE STUDIES

The case studies have been conducted to understand the requirement of designing the PV façade. The selection of studies are based on the parameters: (a) understanding the designing of PV façade for the institutional building, (b) study of thin-film technology integrability on the building façade, (c) understanding the relationship of buildings climate and the azimuth and tilt angle of the PV panels integrated on the façade.

a. Case study 01 – Solar Energy Research Institute, Yunnan Normal University

The first study is selected to understand the designing of PV façade for an institutional building. According to the study of (Yunfeng Wang, 2018) and (Wang Yunfeng, 2016), The Solar Energy Research Institute building is an institutional building that is situated in the complex of the Yunnan Normal University which is located in the Kunming, China. It lies in the tropical Climate (Subtropical monsoon climate). It's an institutional building with five floors, thus providing a great opportunity for BIPV façade. The total façade area utilized for integration of the PV panels is 1560 sq. m. (26m x 60M), with a total installed capacity of 120KWp.

The panels are designed and customized according to the needs of the façade. The panels are of mono crystalline silicon wafers, which are designed by sandwiching it with toughened glass. The size of the PV module is 125 mm x 125 mm with a cross section consisting of 6 mm toughened glass + 2.28 mm PVB + 6 mm toughened glass. The design of this module and its technical specification helps to create the possibility of integrating daylighting, transmitting 47% of the daylighting to the interiors. The façade is composed of 64 modules, with PV panels of 1985 mm x 1038 mm dimension. The customized panel has an efficiency of 8.25 %, with a nominal power of 170 Wp. The weight of one panel is 63 Kgs.

In the building there is total 720 Mono-si panels in which there is total 30 Strings and each strings contain 24 modules generating peak power 4080 Wp per string. Around 600 modules are connected with the one inverter and the rest 120 modules are connected with the second inverter.

Fig. 2. Panels on Solar Energy Research Institute, Yunnan Normal University
Source: (Yunfeng Wang, 2018)

It was observed from October 2014 to September 2015, total power generation of the total system was 64.607 MWh. In the month of the September the system generated the minimum amount of electricity which was around 740.2 kWh. Panels were installed at a tilt angle of 85°. These panels are installed 6 meters away from the building because of its tilt angle. Few ventilation blinds are installed to ensure the proper ventilation. Due to the BIPV operation on the façade of the building there is a rise in the building temperature of about 6° C. The increase in temperature helps to keep rooms warm during the winters. During the winters there is higher solar radiation gain on the PV panels due to its tilt angle. The performance ratio of the system in the year 2015 was 64.3 %. The Simple Energy Payback time was 9.38 Years. The Net Present Value (NPV) was RMB 359,347 and the payback was around 15 Years.

b. Case study 02 – Climate Change Research Center, Korea

The Second case study was Climate Change Research center is an Institutional building located in the Gyeo-nasea-dong, Incheon-si, Korea. It was selected to understand the application of different types of panels with different orientations applied as façade for a building. Some of the studies like (Jae Bum Lee, 2013) and (Won Jun Choi, 2019), have stated the need for application of different BiPV technology on different orientations to have a more efficient FiPV system. Hence this building was selected to understand the same. The building had the 3 Floors with basement and the total floor area is 2449 Sq. meter.

The building has total 116.2 kWp system installed capacity with three different type of solar panels types i.e., glass to glass, glass to tedlar and amorphous silicon panels. A total of 15 inverters were used to operate all these panels, operating l871 modules and 15 arrays occupying an area of 1177.9 sq. meters. Some of the panels were also provided on the roof top area as well. The total generation of the system is 105267 kWh annually and 8772 kWh monthly average. The building experienced losses in the system and one of the reasons was allocated to breakdown of the thin film PV panels and reduction in efficiency due to the inverters. Despite the losses the system was able to generate around 664.2 kWh surplus amount of energy. The final energy self-sufficiency rate was 0.62%. Accordingly, the building achieved the goal of zero energy building.

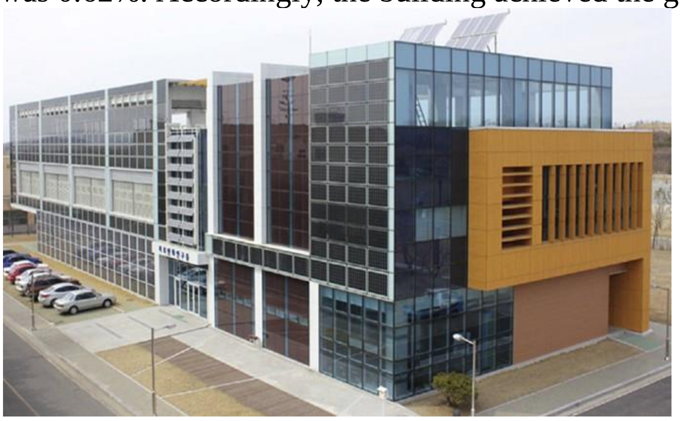


Fig. 3. Panels on Building, Climate Change Research Center
Source: (Jae Bum Lee, 2013)

c. Case study 03 – Industrial Research Institute, Beirut, Lebanon

The third building was selected for understanding and analyzing the transformation of a passive façade into an energy generating façade. The study helps to understand the application of PV overhangs and identifies their feasible tilt angles according to the regions. The Industrial Research Institute is an office building located in the Beirut, Lebanon, lying in the Mediterranean climatic zone. (Talal Salem, 2015). As the southern façade of the building is completely glass, so the PV overhangs were installed in this azimuth so as to generate the required energy.

The total installed capacity of the PV overhangs was17.6 kWp, the monocrystalline silicon PV overhangs covered an area of 111 Sq. meter and the Thin Film PV overhangs covered an area of 176 Sq. meter. The most efficient and feasible tilt angle was found between 20° and 30°. The electricity generated by the PV Overhangs was used to cater to the basic uses thus avoiding transmission & distribution losses. This application was quite feasible as it generated electricity with maximum efficiency without causing occupant discomfort.

Fig. 4. PV Panels Overhangs, Industrial Research Center

Source: (Talal Salem, 2015)

d. Case study 04 – Sodha Bers Complex, Varanasi, India

The fourth building was selected because of its location in the composite climatic zone of India. The Sodha Bers Complex is a residential building located in the Varanasi, India. The building has a basement, and ground plus four floors having a total built-up area of 795 Sq. meter and the total site area is 234 Sq. meter. The total installed capacity of 11.08 kWp is installed on the roof of the building. The PV system is divided in three zones; zone 1, zone 2 and zone 3 with system capacity of 3.6 kWh, 7.2 kWh and 0.28 kWh respectively. The semi-transparent crystalline silicon has been used in the BIPV system and all these panels are installed at a tilt angle of 30°. (Arjun Deo, 2017), (Madhu Sudan, 2016), (Neha Gupta, 2017) and (R.K. Mishra, 2017)

The Pv system installed is quite efficient and economical, having an energy payback time (EPBT) of 19.54 Years. The installed system had no obstruction to daylighting which was easily transferred through the semi-transparent crystalline panel. Hence limiting the need for artificial lighting in the building premises during daytime. The total annual savings are 3675.61 kWh through the application of semi-transparent panels. The increase in the internal building temperature is efficiently managed with the help of wind towers.

Fig. 5. PV Panels on the Building, Sodha Bers Complex

Source: (Arjun Deo, 2017)

e. Comparative Analysis

Table 1. Comparative Analysis of Case studies
Source: Author

S. No.	Name	Solar Energy Research Institute	Climate Change Research Center	Industrial Research Institute	Sodha Bers Complex
1	**Location**	Kunming, China	Korea	Beirut, Lebanon	Varanasi, India
2	**Climate Zone**	Temperate Climate (Subtropical Monsoon Climate)	Temperate Climate (Humid Subtropical Climate)	Mediterranean Climate	Composite Climate
3	**Building Typology**	Institutional Building	Institutional Building	Office Building	Residential Building
4	**Types of Solar Cells**	Monocrystalline silicon	G-G, G-T, Amorphous silicon	Monocrystalline, Polycrystalline and Thin Film	Semi-transparent crystalline silicon
5	**System Capacity**	120 kWp	116.2 kWp	17.6 kWp	11.08 kWp
6	**Tilt Angle**	5°	0°, 30°, 90°	30°	30°
7	**Efficiency**	8.25%	11.65%		9.5%

After studying and analyzing the above case studies we can conclude that the tilt angle and the climatic condition are plays the major role in the BIPV façade design, along with the selection of the panel typology. The system sizing of BIPV is generally smaller in the residential building because of the energy consumption of the building, as compared to institutional buildings where the system capacity is quite high.

4. DESIGNING OF FAÇADE INTEGRATED PHOTOVOLTAIC (FIPV)

a. Selection of base case building and PV technology

The Faculty of Dentistry Building located in the complex of Jamia Millia Islamia University, New Delhi has been identified for the base case building. It has the coordinates aligned with 28.56° N Latitude and 77.28° E. The building lies in the composite climate zone. The building façade is quite interesting as it is a combination of glass and ACP with ribbon windows, providing a good opportunity for PV integration. The FiPV system proposed would be grid connected. One very critical aspect of this building which proves to be quite advantageous to the designing of the PV façade is the large opaque façade towards the south. It was a very crucial design aspect, providing a great opportunity to utilize the maximum solar insolation received in this orientation. Previous studies like (Aaditya & Mani, 2013) (Cheng, Jimenez, & Chie, 2009) have supported the adoption of south orientation for PV integration in the given climatic zone. Another important feature was the presence of large open area on the southern side, thus providing maximum levels of insolation for the south oriented PV façade.

The next step in designing process of a PV façade was to identify the thin film technology which would be most feasible with respect to: (i) typology of the building, (ii) the climatic zone in which the building is located. The study by (Sharma, 2017) , demonstrated the applicability of thin-film technology on mid-rise and high-rise structures was quite high. The study analyzed the application of Cadmium telluride (CdTe) thin-film

technology on the façade of high-rise structures in Mumbai and found it to be more economical as compared to the crystalline silicon technology. Thus for this research, CdTe thin film panels have been selected for the designing of the BIPV façade. These PV panels are capable of absorbing diffused radiations, hence increasing their applicability on the façade, which does not receive direct irradiations. The study by (Nguyen, Sang, Le, & Vu, 2019) has demonstrated the application of thin film technologies like CIGS (cadmium Indium Gallium and Diselenide) and CdTe on the vertical façade, having a tilt angle of 90 degrees was highly profitable. This study reinforced the idea that CdTe thin-film technology was highly integrable with the façade as it was able to perform at an efficiency of 22.9% without any impedance from increasing temperature.
The efficiency of the cadmium telluride panels that have been selected for this study is around 17-20 % which is highest in the category of the second generation thin film, with a life span of 30 Years. The panels and inverters specifications are mentioned in the table 2.

Table 2. Technical Specifications of the PV panel and Inverter Selected
Source: Solar First and Delta Energy

Name of the panels	First solar 6 CuRe
PV Technology	CdTe
Dimension of the panel	2024mm x 1245mm
Weight of the panel	34.9kg
Area of the panel	2.52 sq. m.
Efficiency of panel	17%-20%
Degradation rate of Panel	0.2%
Inverter used (Model No.)	Delta Energy Solar Inverter (M150_220)
Inverter Nominal Power	15 kWac

The modules for installation on the façade are constructed using the anodized aluminum material with front and back glass which is heat strengthened. The encapsulation of the module is done with a laminated material having edge seal and the adhesive used is silicon.

b. Analysis of Climatic Condition

The shadow analysis was done to understand the irradiation pattern and thus design a PV façade, which would be efficient. A shadow analysis of the building was done using the Trimble Sketchup software. Figures 6 and 7 demonstrate the position of the winter and summer sun respectively. It is quite evident that sun in the summer season because of the higher angle of altitude is over the building. The façade receives very little insolation as the irradiation is significantly low on the front faces. Whereas in the winter season the sun is lower in altitude and hence the façade of the building receives higher insolation due to high levels of irradiation. Moreover, the façade receives diffused radiation during summer months and hence the PV technology selected is quite feasible, as it has higher efficiency with diffused radiation.

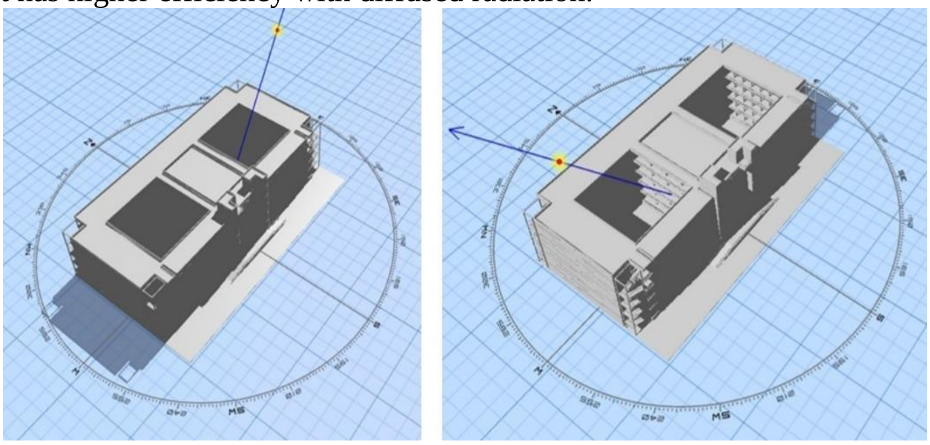


Fig. 6. Shadow Analysis of Building on 21st June 2023, Left Image Depicts the 9:00 AM and Right Image Depicts the 3:00 PM
Source: Author

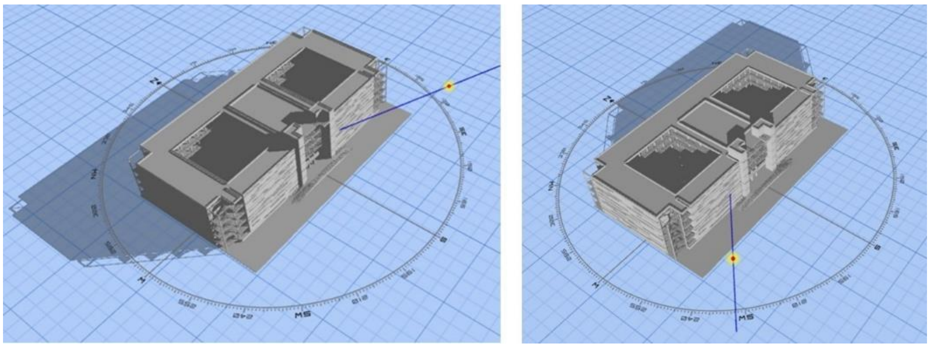


Fig. 7. Shadow Analysis of Building on 21st December 2023, Left Image depicts the 9:00 AM and Right image depicts the 3:00 PM
Source: Author

The Shadow analysis of the façades indicates that maximum insolation levels are available on the southern façade, with irradiation levels reaching 80% of the total received solar hours, see figure 10. The irradiation levels received on the eastern & western facade are 40 – 60 % of total solar hours. This analysis further supports the idea and feasibility of integrating PV technology on the southern façade receiving 80 % solar hour. Thus, increasing the possibility of higher energy generation.

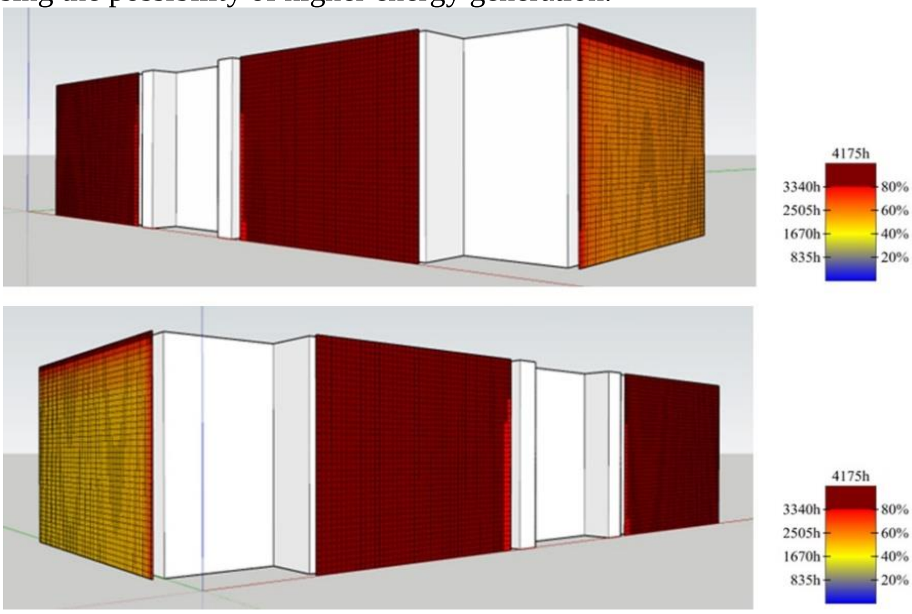


Fig. 8. Solar Hour Analysis of (Top Diagram) East and south façade, (Bottom Diagram) South and West Façade
Source: Author

A wind Rose diagram was prepared to understand the pattern of airflow circulation around the building. This diagram helps to understand the major air flow directions, as it would be an important criterion for heat dissipation caused due to photovoltaic effect of the PV technology. The Wind rose diagram shown in figure 11 shows that the predominant wind direction is NW to SE and WNW to ESE. Another very important determinant while integrating the PV panels on the façade is the speed of wind, which might cause lateral force on the panels. If the wind speed is very high, it might lead to the integrity issue of the PV panel mounted in the facade has been identified in the study by (Ahmad & Zia, 2022). The maximum wind speed as is seen in the figure 9 is 8 meter per second, thus indicating that the panel's integrity remains intact and hence they are safe to be mounted on the facade.

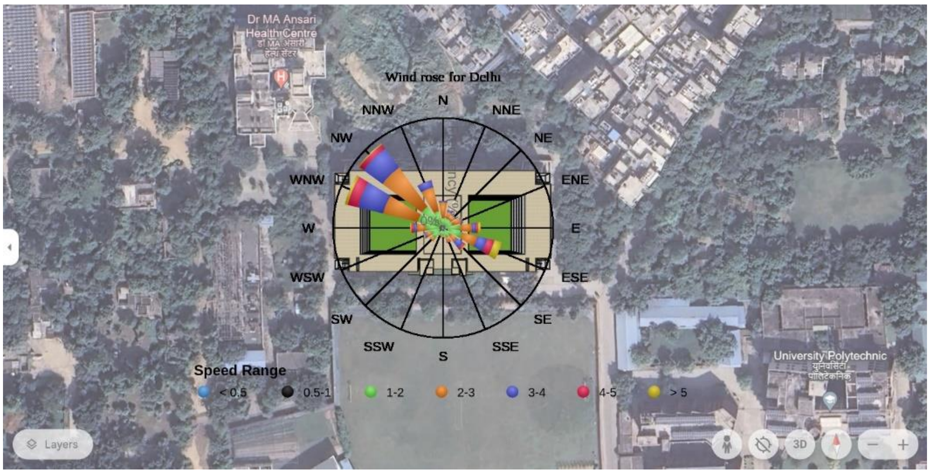


Fig. 9. Wind rose Diagram
Source: Author

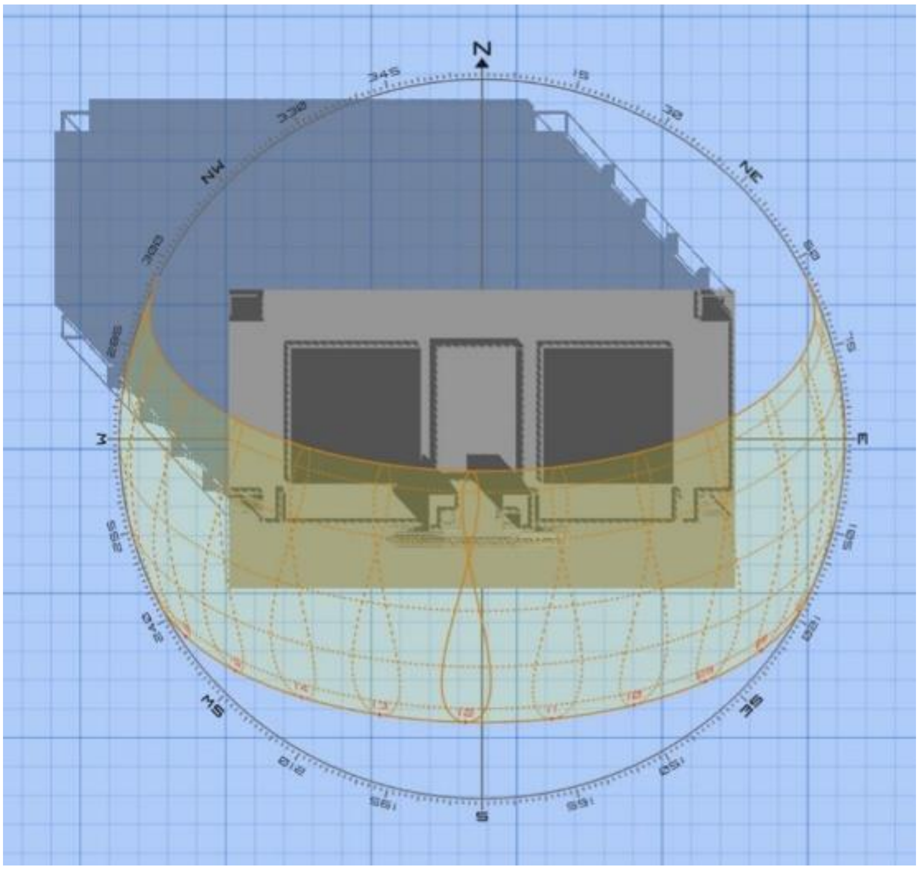


Fig. 10. Sun Path Diagram
Source: Author

c. Designing of the façade

The faculty of dentistry building has an existing façade (figure 11) with cladding of aluminum composite panels (ACP) all around and horizontal ribbon windows, provided for daylight and ventilation purpose. The outer shell of the base case building is constructed with a brick wall with RCC slab projecting out at each level. The ACP is applied on top of the brick wall cladding system. This kind of the system is also known as the Rain screen cladding system.

Fig. 11. Top Image: Existing southern façade of the Faculty of Dentistry Building, Bottom Image: Transformed Southern PV façade of the Faculty of Dentistry Building
Source: Author

The aim of this study was to transform the passive façade of the building into an energy generating, sustainable façade, which enhances the functionality of the building. Hence, the building was quite suitable as the Aluminum composite panels provided an opportunity for replacing them with innovative, energy-efficient material. The major role of these Aluminum Composite panels is to provide a nice aesthetic appeal and at the same time protect the structure from the external environment. The role of protection from the external environment and creating aesthetically satiating façade could also be achieved with the integration of photovoltaic technology (i.e. CdTe panels). Apart from this secondary role, it would also be able to generate electricity and provide an adaptive façade, without creating any conflict (i.e. simultaneously acting as façade and generating energy) as has been indicated in the study (Ahmad & Zia, Design Strategies for Façade integrated Photovoltaic Technology (FiPV), 2022).

Fig. 12. Left Image: Existing Western façade of the Faculty of Dentistry Building,
Right Image: Transformed Western façade of the Faculty of Dentistry Building
Source: Author

The transformation of the façade had to be carried out with the limitation of not changing the functionality of internal spaces. The existing façade had ribbon windows to allow ventilation and daylighting. The new transformed façade was to replace the ribbon windows with a new cross-sectional window, wherein the existing windows were extruded and mounted with PV panels and the protruding part was opened for ventilation (figure 13). This cross-section further increases the area for the application of PV panels hence increasing the energy generation.

Fig. 13. New Cross Section of the Windows
Source: Author

Three scenarios were analyzed by providing CdTe PV panels instead of ACP on the façade. The three scenarios were designed by replacing the ribbon windows and ACP cladding with CdTe Panels on the (i) southern façade, (ii) western façade, (iii) south and western façade together.

5. RESULT

a. System Performance

The study parameters taken for conducting the simulation on PVSyst are shown below in table 3 along with the result of the three design scenarios. Table 3 highlights the main results after simulation, and this forms the basis of conducting life cycle cost assessment to work out the feasibility of the three design scenarios. For the purpose of conducting life cycle cost assessment the life of the project was taken as 30 years, inflation rate was considered to be 6.7% and discount rate was taken as 6.75%. The fixed feed in tariff rate for Delhi was taken as 8.00 INR per kWh.

Table 3. Parameter of study and result of three design scenarios
Source: Author

Scenarios	**Scenario 01**	**Scenario 02**	**Scenario 03**
Application	BIPV Applied on South	BIPV Applied on West	BIPV Applied on South & West
Building Image with PV Installation			
System Capacity	148 kWh	87.4 kWh	235 kWh
PV Technology	CdTe	CdTe	CdTe
No. of PV modules	308	182	490
Module area	776 Sq. m.	459 Sq. m.	1235 Sq. m.
No. of Inverter	10	6	16
Pnom Ratio	0.99	0.971	0.98
Annual Generation	101427 kWh	50379 kWh	147381 kWh
Performance Ratio	67.1 %	65.81 %	64.73 %
Specific Production	686 kWh/kWp/Year	577 kWh/kWp/Year	627 kWh/kWp/Year
Degradation Rate	0.2 % Annually	0.2 % Annually	0.2 % Annually
Total CO2 Saved	2848.1 tCO2	1414.6 tCO2	4138.5 tCO2

As is evident from table 3, the first case i.e., scenario 1 is the most feasible option. The energy production as well as the performance ratio of the system is also quite high as compared to the other two scenarios. Primarily this is attributed to the higher solar hours received on the southern façade, and larger surface area for the integration of CdTe panels.

b. Parameter for the Life Cycle Cost Assessment

The analysis of BIPV façade is incomplete without the economic evaluation of the system installed. The economic feasibility analysis is one of the major enablers for increasing the uptake of this technology within the realm of building construction. Previous studies like (Gholami & Rostvik, Economic analysis of BIPV systems as a building envelope material for building skins in Europe, 2020), (Gholami, Rostovik, & Muller, Holistic economic analysis of building integrated photovoltaics (BIPV) system: Case studies evaluation, 2019), (Sorgato, Schneider, & Ruther, 2017) have demonstrated that the economic feasibility conducted through life cycle cost assessment was a very powerful tool to understanding the viability and feasibility of integrating PV technology within the building envelope. Hence in this study the feasibility of the PV façade was established with the help of life cycle cost assessment.

Life cycle cost assessment is a very wide and inclusive technique. It encompasses the assessment of economic, social and environmental cost to establish the feasibility of a system. The study has incorporated the parameters which are shown in table 4 for conducting Life cycle cost assessment.

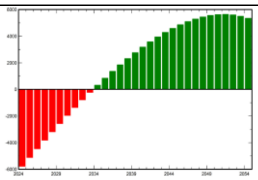
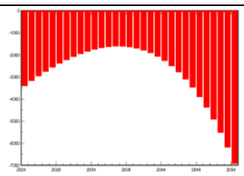
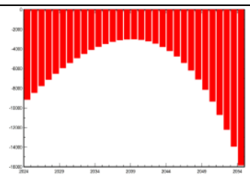
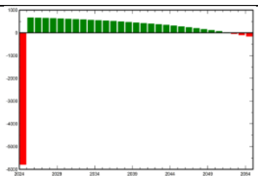
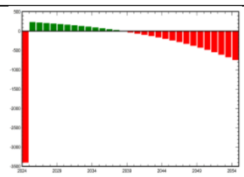
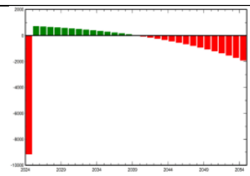
Table 4. Study Parameters for conducting life cycle cost assessment
Source: Author

INSTALLATION COST			
S. No.	**Particulars**		**Cost (in INR / Wp)**
1	PV Modules	FS-6480 A – C	12
2		Support for Modules	4
3		Solar Inverter M15A-220	7.5
4	Other Components	Accessories, Fastener	0.1
5		Wiring	1.8
6		Combiner Box	0.4
7		Monitoring system	0.5
8		Surge Arrester	0.1
9		Installation of modules	9
10		Installation of inverters	1.5
11		Transport	1.5
12		Grid Connection	0.1
OPERATING COST			
S. No.	**Particulars**	**Cost (in INR / Wp)**	
1	Maintenance	Provision for inverter repair	0.5
2		Salaries	0.1
3		Repairs	0.1
4		Cleaning	0.2
5		Security Fund	0.1

c. Life Cycle Cost Assessment (LCCA)

The result of LCCA for three different scenarios are shown in table 5. The cash flow of scenarios 2 and 3 are negative, implying cash outflow is more than cash inflow. The internal rate of return for scenario is positive 7.74% whereas for the other two scenarios it is zero. Similarly, the return on investment is negative for scenario 2 and 3.

Table 5. Result of LCCA for the three scenarios
Source: Author

Scenarios	**Scenario 01**	**Scenario 02**	**Scenario 03**
Cumulative Cashflow (kINR)			
Yearly Net Profit (kINR)			

Installation Cost	57,87,936 INR	33,98,304 INR	91,49,280 INR
Operating Cost	4,41,117.32 INR / Year	5,21,320.47 INR / Year	14,03,555.1 INR / Year
Total Produced Energy	102 MWh / Year	50.4 MWh / Year	148 MWh / Year
Cost of Produced Energy	7.672 INR / kWh	12.888 INR / kWh	11.863 INR / kWh
Payback Period	17.6 Years	Unprofitable	Unprofitable
Net Present Value (NPV)	4,24,314.02 INR	(-31,38,661.4) INR	(-72,51,567.91) INR
Internal Rate of Return (IRR)	7.74 %	0 %	0 %
Return on Investment (ROI)	7.3 %	-92.4 %	-79.3 %
Total Generated Emission	278.62 tCO2	164.7 tCO2	443.32 tCO2
Total CO2 Saved	2848.1 tCO2	1414.6 tCO2	4138.5 tCO2
Grid Lifecycle Emission	936 gCO2 / kWh	936 gCO2 / kWh	936 gCO2 / kWh

When considering the payback period of scenario 1 it is 17.5years which is approximately half the life of investment. When compared with the other two scenarios it is profitable, as is seen that the payback period for scenario 1 and 2 exceeds the life of BIPV system. Similarly, the Net Present Value (NPV) of scenarios 2 and 3 are negative, (31,38,661.4) INR and (72,54,567.91) INR respectively. One very important finding of LCCA was that in case of scenario 1the Internal rate of return, which is 7.74% is greater that the discount rate and inflation rate. Thus, it can be concluded that scenario 1 is the most feasible option for generation of PV façade as compared to scenario 2 and 3.

6. ANALYSIS & DISCUSSION

In this paper the feasibility of the integrating CdTe panels on the façade of an institutional building has been discussed. The analysis was done on the basis of (i) PV system performance, (ii) Economic feasibility analysis. The PV system performance identified the best-case scenario, based on the energy generation, performance ratios, efficiency of the designed system. For understanding the economic feasibility of the designed PV façade, a LCCA was conducted. The LCCA was an important tool to calculate the profitability of the designed system. It was found that payback period for Southern PV façade was 17.6 years, which reduced to 13 years if simple payback period calculation was undertaken. The "Internal Rate of return" was around 7.3% in southern PV façade, which was greater than the discount rate of 6.75%, along with a positive "Internal Rate of Return". These results indicate that the system generates profit in its entire life cycle. Whereas the other two design options of integrating PV on the western façade and southern and western both facades were non-feasible as is seen in table 5.

7. CONCLUSION

The emphasis on renewable energy system, along with the directives of MNRE (Ministry of New and Renewable Energy), and India's commitment to reducing the dependency on fossil fuel, has led to the quest for alternatives to fuel the urban network of cities. The building stock in the urban network is quite important in terms of energy expenditure. The possibility of the façade of these buildings to act as energy generators hasn't been exploited to its full potential. This study is aimed at understanding the potential of façade being transformed into an energy generator by integrating the renewable energy system. Thus, understanding its capability to reduce the dependence on conventional sources of energy and create a more sustainable option. The study has demonstrated that the feasibility of adoption of PV façade (southern orientation) in the composite climate is quite high. Further strengthening the concept of transforming a passive building façade into an active energy generator. Simultaneously reducing GHG emissions and creating a more sustainable design. An important finding of this study is the identification of parameters for deciding the adoption of PV façade. These two parameters are the solar hours received on the façade and the shadow analysis. These two parameters along with the major criteria of building typology and PV technology to be adopted in addition to other design parameters to determine the adoptability of PV facades.

REFERENCES:

1. Ahmad, M., & Zia, H. (2022, January). Architectural integration of photovoltaics in the building façade: a framework for architects' design process. Int. J. Renewable Energy Technology, 13, 84-100. Inderscience.
2. Ahmad, M., & Zia, H. (2022). Design Strategies for Façade integrated Photovoltaic Technology (FiPV). ICCAUA2022 Conference full paper proceedings book, Alanya HEP University, Alanya, Turkey (pp. 173-180). Alanya: Alanya HEP University.
3. Arjun Deo, G. M. (2017). A thermal periodic theory and experimental validation of building integrated semi-transparent photovoltaic thermal (BiSPVT) system. Solar Energy, Elsevier, 1021-1032.
4. Attoye, D. E., Aoul, K. A., & Hassan, A. (2017). A REVIEW ON BUILDING INTEGRATED PHOTOVOLTAIC FACADE CUSTOMIZATION POTENTIALS. Sustainability 2017, 9(12), 2287(Climate Change Mitigation and Adaptation - ZEMCH 2016). doi:10.3390
5. Cheng, C. L., Jimenez, C. S., & Chie, M. (2009). Research of BIPV optimal tilted angle, use of latitude concept for south orientated plans. Renewable Energy, 1644–1650.
6. Gholami, H., & Rostvik, H. N. (2020, August 1). Economic analysis of BIPV systems as a building envelope material for building skins in Europe. Energy 204.
7. Gholami, H., Rostovik, H. N., & Muller, D. (2019). Holistic economic analysis of building integrated photovoltaics (BIPV) system: Case studies evaluation. Energy and Building (203).
8. India, G. o. (n.d.). Ministry of New and Renewable Energy. Retrieved from mnre.gov.in: https://mnre.gov.in/solar-overview/
9. International Energy Agency. (2022, September). Retrieved from iea.org: https://www.iea.org/reports/approximately-100-million-households-rely-on-rooftop-solar-pv-by-2030
10. Jae Bum Lee, J. W. (2013). An empirical study of performance characteristics of BIPV (Building Integrated Photovoltaic) system for the realization of zero energy building. Energy, Elsevier, 25-34.
11. Khan, N., Abas, N., & Kalair, A. (2015). Earthy, solaris and atmospheric energy sources. International Journal of Renewable Energy Technology, 6(1). doi:10.1504/IJRET.2015.067515
12. Madhu Sudan, G. T. (2016). Daylighting and energy performance of a building for composite climate: An experimental study. Alexandria Engineering Journal, Elsevier.
13. Mishra, S. P., Ali, S. M., Pradhan, A., Mohapatra, P., & Singh , V. (2013). Increasing energy efficiency in India by the use of green building. International Journal of Renewable Energy Technology, 4(4). doi:10.1504/IJRET.2013.058140
14. Nagyn, Z., Svatozarevic, B., Jayathissa, P., Begle, M., Hofer, J., Lydon, G., . . . Schlueter, A. (2016). ADAPTIVE SOLAR FACADES: FROM CONCONCEPTS TO PROTOTYPES. Frontiers of Architectural Research, 5(2), 143-156.
15. Neha Gupta, G. T. (2017). Energy Matrices of Building Integrated Photovoltaic Thermal Systems: Case Study. Journal of Architectural Engineering.
16. Nguyen, L. D., Sang, D. N., Le, N. T., & Vu, N. H. (2019). Facade Integrated Phtovoltaic systems: Potential Applications for Commercial Building in Vietnam. International Conference on System Science and Engineering (ICSSE) 2019 (pp. 219-223). Dong HOi City, Queang Binh Province, Vietnam: IEEE.

17. R.K. Mishra, S. T. (2017). Unit cost analysis for sodha Bers Complex (SBC): An Energy Efficient Building. Thermal Science and Engieering Progress.
18. Sharma, A. K. (2017). Solar PV Facade for High-rise Buildings in Mumbai. International Journal of Civil Engineering Research., 8, number 1, 15-32.
19. Sorgato, M., Schneider, K., & Ruther, R. (2017). Technical and Economic Evaluation of thin film CdTe Building Integerated Photovoltaic replacing Facade and Rooftop Materials in office buildings in a warm and sunny Climate. Renewable Energy.
20. Talal Salem, E. K. (2015). Analysis of Building-Integrated Photovoltaic Systems: A Case study of commercial Buildings under Mediterranean Climate. Procedia Engineering, Science Direct, 538-545.
21. Wang Yunfeng, R. H. (2016). An experimental study of building thermal environment in building integrated photovoltaic (BIPV) installation. Bulgarian Chemical Communication, Volume 48, Special Issue E, 158-164.
22. Won Jun Choi, H. J.-W.-k.-B. (2019). Power Generation Performance of Building-Integrated Photovoltaic systems in a Zero Energy Building. energies, MDPI.
23. Yunfeng Wang, M. L. (2018). Grid-Connected Semitransparent Building-Integrated Photovoltaic System: The Comprehensive Case Study of the 120 kWp Plant in Kunming, China. Hindawi International Journal of Photoenergy, Volume 2018, Article ID 6510487, 13 Pages.