Assessment of Building Integrated Photovoltaic Panels on Facades of Commercial Buildings with Respect to Energy Conservation Building Code

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Keywords: BIPV Panels, Performance Analysis, Energy Production, Optimal Tilt Angle, Design Builder, Payback Period, BIPV Integration Style.

Abstract: The formulation of the paper considered the need for adapting to renewable resources in fast-growing world. The integration of Building Integrated Photovoltaic (BIPV) panels will minimize the environment damage, climate change, and resource shortages. The BIPV system implemented on the facade is one of the suitable solutions to increase the building performance using the on-site renewable resource with a reduced impact on the surroundings. The methodology introduced in this paper is carried out by using Design Builder software initially, which provides an understanding of the PV energy produced to achieve 3% renewable energy in a modelled commercial building of 20,000 m^2 according to the Energy Conservation Building Code (ECBC) while placed in a moderate climatic zone. This paper aims at studying various approaches to further enhance the energy production of the modelled building after attaining the ECBC minimum requirement. PVGIS system is used to assess parameters such as PV technology used, integration of the panels, system loss, year to year variability, tilt angles of the panels. Further, shadow analysis of the optimal angle to maximize energy production is analysed. A comparative study between the modelled building and the PVGIS system on the panel cost and payback period is conducted. Based on the optimum tilt and azimuth angles, shadow analysis and daylighting analysis is carried out. The paper provides an understanding of the optimal integration style of the BIPV panels on the building facade.

1 INTRODUCTION

The escalating growth of the world and energy use has raised concerns globally on the prolonged exhaustion of energy resources and their destructive environmental impacts. Commercial, residential, and public buildings are presently contributing to 31% of the world's energy demand. Alternatively, fossil fuels are presently in use as the world's most primary energy source. However, the use of fossil fuels has its own disadvantages, such as, environmental destruction, lack of energy, and change in the climate. Hence, the use of alternative energy resources which non-polluting and renewable, is the need of the hour. (lHassanGholami, 2019)

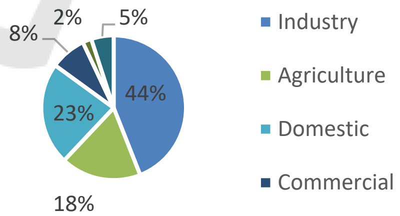

Figure 1: Sector-wise energy consumption (Energy Statistics).

Fig.1. represents the total energy consumption in India in 2015, i.e., 948,328 GWh, in which the highest energy-consuming sector is the industries followed by domestic power consumption. India's combined key energy demand is expected to grow by 2.3 times in the following two decades due to continued economic progress in the building, industrial sectors, and transportation (Joshi, 2018).

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A building to become a zero energy or zero-emission building, the use of non-renewable energy, i.e., solar energy plays a very important role. In this regard, the use of building-integrated photovoltaics (BIPV) can play an important part towards the zero energy or zero-emission building. The BIPV is photovoltaic cells which can be used in building envelopes such as facade or roof. The lifetime of the BIPV system is expected to be 30 years (B.Winnettabc, 2012), however, additional studies indicate the lifetime to be around 50 years. The BIPV system capacity can differ from a limited kilowatt(kW) for a residential building to several megawatts (MW) for a commercial purpose.

The present study focusses on the use and implementation of the BIPV system on improving energy efficiency and consequently enhance the overall building performance according to ECBC (ENERGY CONSERVATION BUILDING CODE, 2017).

1.1 Background and Literature Review

The BIPV products were found in 1990; initially, the rooftop mounted PV panel was installed on metal frames. In the later period, technological developments led to the creation of easier architectural designs that carefully integrates the collection of solar energy into its building design (Hall, 2014).

The BIPV panels are suitable for significant buildings and cities. However, it is quite expensive as compared to the conventional solar system. Yet, the researchers consider the supplementary costs reduced significantly if a revamp or new building envelope is needed anyway. The clients can be benefitted of around ten years of payback time for these additional costs incurred (Bhambhani, 2019).

The vertical integration provides a chance to substitute with solar panels, resulting in reduced energy footprint and delivering a positive ROI (return on investment) on the supplementary investment.

The factors affecting the function of the panel (MarcoCasini, 2016) are:

(i) Shape and size of the glazing factor
(iii) the distance amongst the PV cells (gradation of transparency)
(ii) technology (monocrystalline and polycrystalline silicon)

Various studies were conducted considering several parameters such as the energy generation, types of material, tilt angles, etc. Biyik et al. (BaverAtlıf, 2017) aimed at increasing the system efficiency considering various factors affecting the BIPV panels such as ambient temperature, the direction of the building and the slope of the PV to get higher power output using simulation tools Energy plus and TRNSYS. YilinLi et al. (Yilin Li a Zhi, 2017) examined the influence of the PV facade's on different tilt angles (30, 45, and 60°) on the surface temperature and PV cell efficiency of the naturally ventilated PV façade. The optimum tilt angle of 30 degrees has the lowest mean surface temp, which provides the optimal performance of elimination of heat from the PV panel. Daniel Tudor Cotfas at el. (Daniel Tudor Cotfas, 2014) provides simple methods to enhance the amount of the electrical energy delivered by the PV panels. Photovoltaic Geographical Information System was used to get calculations based on various materials and angles. The results showed an increase in energy produced without additional costs and materials. AliceBellazzi at el. (Alice Bellazzi, 2018) investigates the energy and thermal performance of a BIPV integrated façade based on different configurations, the global efficiency and the electric production were assessed through a supervising operation of the environmental and energy variables in physical working environments and a mathematical model designed to compare the performance of the system. It was found out that all the parameters were interdependent and depended mainly on climatic variations. A. K. Sharma at el. (Sharma, 2017) provided an understanding of design tool for BIPV systems considering factors such as orientation, location, and panel efficiency and reported that the facade's orientation and the building's location which provided an ideal solution. Grasshopper, Ladybug, and Honeybee are all Rhinoceros 3d plug-ins, were all used to interface Energy Plus and Radiance for the illuminance and calculation for the annual energy computations.

2 DESCRIPTION OF THE METHODS

The fig.2 shows the flow chart of methods followed to assess the BIPV panels-

- The design-builder is initially used to identify the PV energy production (according to ECBC) and the modelled building's active façade area placed in Bangalore (temperate zone-ECBC).
- PVGIS system is used to assess the PV technologies based on the energy production and active area resulted in the Design-Builder (optimum angle, orientation, PV technology, and the cost is identified).

- A comparative study between the Design-Builder and PVGIS system is carried out based on the energy production and payback period.
- Based on the PVGIS result (optimum combination), Google sketch-up is used to illustrate the panels' integration styles on the facade, and shadow analysis is conducted (Location-Bangalore).

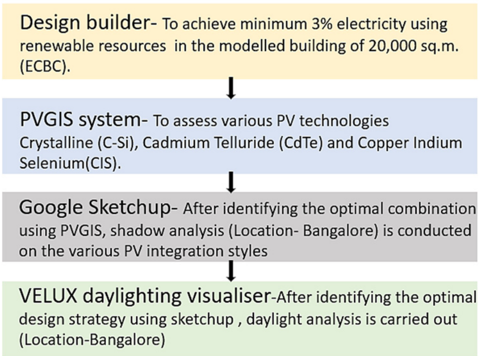

Figure 2: Outline of the methods followed.

2.1 Design Builder

To understand the minimum PV energy produced by a commercial building (according to ECBC) out of the total energy consumption and to identify the active area on the façade.

The design-builder is used to provide minimum PV energy production to reach the ECBC requirement for a 20,000m^2 commercial building considering parameters such as the U value of different elements, WWR ratio, climatic condition, etc. to calculate the EPI of the building.

A commercial building of 20,000 m^2 should have a minimum of 3% of the total power consumption that should be generated using Renewable Energy Generating Zone (REGZ) as per the ECBC. A 10-story building was modelled on Design Builder with a total area of the building to be 20,000 m^2. PV cells were integrated into the south façade of the building. The location of the building was Bangalore (26℃ annual temperature temperate zone). The building was modelled, according to (Mayank Bhatnagar, 2019). Parameters considered are shown in table 1 (ECBC 2017).

Table 1: Parameters followed in the modelled building according to ECBC.

U value of wall	0.4 W/m2K
U value of roof	0.33 W/ m2K
U value of glass	3 W/m2K
WWR ratio	40%

2.2 Using PVGIS System

PVGIS helps to assess the PV capacity for various patterns and technologies of grid-connected and stand-alone systems. PVGIS system is used to assess Slope angle [°], Yearly PV energy production [kWh], Azimuth angle [°], Yearly in-plane irradiation [kWh/m2], Year-to-year variability [kWh] in Bangalore, which design builder does not provide. Hence after reaching the minimum requirement according to ECBC using design builder and identifying the active area on the façade and PV energy production, further enhancement is carried out by assessing the PV technology.

The assessment is conducted based on three different PV technologies: Crystalline (C-Si), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide(CIS). The efficiency and price per kWh are considered as follows: C-Si: 12-15%, 36.01 INR, CdTe: 6-9% ,22.78 INR and CIS: 7.5-9.5%, 26.46 INR. The lifetime of the BIPV system is expected to be 25 years.

Alternate 1 -The slope angles, i.e., 30°,45°,60°, and 90°, is tested with different azimuth angles (for other PV technology) to understand the optimal orientation and tilt angle for the panel integration.

Alternate 2- The most efficient PV technology (C-Si, CdTe, CIS) is also identified by comparing yearly PV energy production [kWh], Yearly in-plane irradiation [kWh/m2], Year-to-year variability [kWh], and the total loss (%).

Alternate 3 - The PV cost (INR) is calculated for various PV technology.

2.3 Using Google Sketchup

Google SketchUp is a freeware 3D modelling software, used to illustrate various integration of

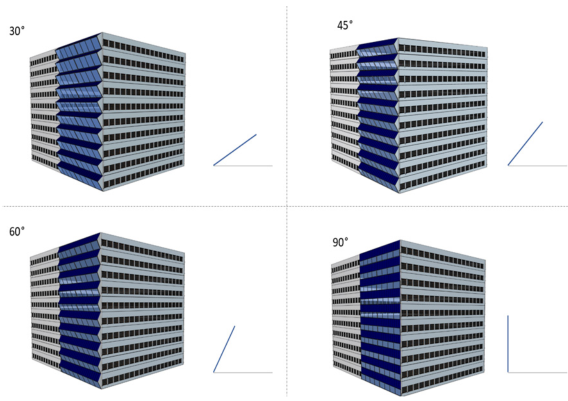

Figure 3: Illustration showing various tilt angles on building façade.

panels on the façade. The same building was used as designed in the design-builder for further assessment.

Alternate 1 – Fig. 3 shows an illustration for the tilt angles integrated on the building facades used in the PVGIS system.

Alternate 2 – Assessing the optimal orientation, tilt angle and yearly PV energy production.

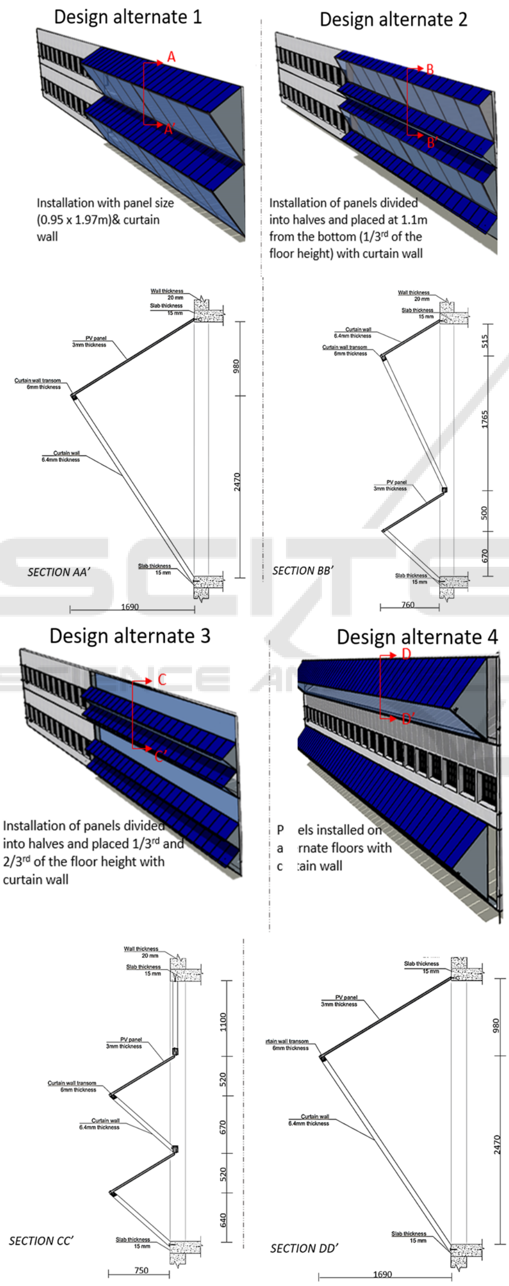

Figure 4: Various integration styles on the building façade with sections.

Further enhancement of the suitable combination is carried out by integrating various design strategies on the façade (fig. 4), conducting shadow analysis by modelling a similar building modelled in Design builder (3.1.). The shadow analysis is carried throughout the day when the sky is clear. The shadow cast is measured (%), and an optimal design strategy is identified.

2.4 Using VELUX (Badri Mohapatra, 2018)

VELUX Daylight Visualizer is a specialized lighting simulation tool for the assessment of daylight requirements in buildings. It is intended to boost the use of daylight and help professionals by assuming and documenting daylight factor and the appearance of an area before reaching the building design. The daylighting analysis is conducted on a building with 40% WWR according to ECBC 2017.

Alternate 1 - The design integration styles (fig. 4) modelled in Google SketchUp for the optimal combination identified using PVGIS are further assessed for daylighting (after results achieved from 2.2.).

The building modelled in Google Sketchup is simulated in VELUX, in Bangalore (12.9716°N,77.5946°E) at 15:00 IST with the integrated design style on the southern side.

3 RESULTS & ANALYSIS

3.1 Using Design Builder to Achieve ECBC Minimum Requirements: (2.1)

The amount of energy consumption in the modelled building of 20,000 sq.m. resulted in 46,80,000 kWh in the commercial building. Hence the EPI was calculated to be:

$$EPI = \frac{\text{Annual energy consumption in kWh}}{\text{Total built-up area}}$$

$$= \frac{46{,}80{,}000}{20{,}000} = 234 \text{ kWh/m}^2\text{-yr}$$

The above calculated EPI index produced is for a 24h operating commercial building modelled in a temperate zone.

The photovoltaic power generated is 89,076.537 kWh, with a power conversion loss of 4,453.83 kWh providing efficiency of renewable energy efficiency of 4.27 %. To achieve 3% renewable energy of the total power consumption of the building (ECBC), a comparative calculation is carried out based on the modelled building; 59,453.91 kWh (59.45MW/h) of photovoltaic power is generated (includes power conversion loss). The active photovoltaic area calculated is 450 m^2 on the southern façade.

3.2 Using PVGIS System (2.2)

Table 2 was formulated based on the outputs produced by the PVGIS system. Each slope angle is tested with different azimuth angles to identify the optimal orientation for the panel integration. The assessment also finds out the optimal tilt angle of the panel when integrated in Bangalore. The most efficient PV technology is further identified by comparing yearly PV energy production(kWh), Yearly PV energy production [kWh], Yearly in-plane irradiation [kWh/m2], Year-to-year variability [kWh], and the total loss (%).

Table 2. shows the data collected for PV technologies- C-Si, CdTe, CIS. Each technology is assessed based on each tilt angle (30°,45°,60°, and 90°); each tilt angle is placed in different azimuth angles (N/180°, NW/135°, NE/-135°, W/90°, SE/-45°, S/0°, SW/45°, E/-90°) for the various PV technology.

Table 2: Comparison of PV technologies based on energy production, system loss, electricity cost, variability.

C-Si

Slope angle [°]	Azimuth angle [°]		Yearly PV energy production [kWh]	Yearly in-plane irradiation [kWh/m²]:	Year-to-year variability [kWh]	Total loss [%]:	PV electricity cost [per kWh]
30	180	N	1232.57	1697.76	24.38	-27.4	43.49
	135	NW	1292.66	1777.75	23.7	-27.29	41.73
	-135	NE	1311.5	1795.79	30.59	-26.97	40.87
	90	W	1405.89	1937.86	28.54	-27.45	38.13
	-45	SE	1514.54	2082.83	37.96	-27.28	35.39
	0	S	1542.83	2123.37	36.35	-27.34	34.74
	45	SW	1495.82	2064.56	33.15	-27.55	35.83
	-90	E	1443.53	1987.51	29.91	-27.37	37.13
45	180	N	994.07	1388.30	19.20	-28.4	53.92
	135	NW	1115.66	1538.9	18.64	-27.5	48.05
	-135	NE	1139.53	1561.53	28.33	-27.02	47.04
	90	W	1284.07	1771.31	26.03	-27.51	41.56
	-45	SE	1411.99	1940.98	36.95	-27.25	37.96
	0	S	1439.09	1978.28	34.94	-27.26	37.24
	45	SW	1386.99	1915.87	31.41	-27.61	38.64
	-90	E	1328.95	1827.95	26.37	-27.3	40.33
60	180	N	766.95	1075.42	14.60	-28.68	69.89
	135	NW	918.41	1274.65	14.04	-27.95	58.36
	-135	NE	942.49	1297.63	25.09	-27.37	56.87
	90	W	1127.85	1556.25	23.37	-27.53	47.53
	-45	SE	1251.73	1718.24	34.22	-27.15	42.82
	0	S	1260.46	1736.13	31.97	-27.4	42.52
	45	SW	1213..82	1681.89	36.03	-27.83	44.16
	-90	E	1175.52	1614.4	22.42	-27.19	45.60
90	180	N	370.74	559.23	6.41	-33.71	144.59
	135	NW	519.27	747.94	9.73	-30.57	103.23
	-135	NE	546.96	777.36	9.70	-29.64	98.00
	90	W	731.79	1023.77	21.33	-28.52	73.25
	-45	SE	796.16	1107.91	18.86	-28.14	67.33
	0	S	716.48	1012.67	25.06	-29.25	74.81
	45	SW	764.12	1074.71	25.84	-28.9	70.15
	-90	E	777.14	1073.08	15.05	-27.58	68.97

CdTe

Slope angle [°]	Azimuth angle [°]		Yearly PV energy production [kWh]	Yearly in-plane irradiation [kWh/m²]:	Year-to-year variability [kWh]	Total loss [%]:	PV electricity cost [per kWh]
30	180	N	1212.29	1697.76	24.69	-28.6	27.97
	135	NW	1275.41	1777.75	23.95	-28.26	26.59
	-135	NE	1292.9	1795.79	31.12	-28	26.21
	90	W	1393.85	1937.86	29.06	-28.07	24.33
	-45	SE	1503.83	2082.83	38.89	-27.8	22.55
	0	S	1532.82	2123.37	37.4	-27.81	22.12
	45	SW	1486.28	20064.56	34.02	-28.01	22.81
	-90	E	1417.06	1962.80	36.97	-27.80	23.93
45	180	N	966.16	1388.3	19.42	-30.41	35.10
	135	NW	1091.63	1538.9	18.69	-29.06	31.06
	-135	NE	1113.76	1561.53	28.73	-28.67	30.44
	90	W	1269.33	1773.41	26.90	-28.42	26.71
	-45	SE	1397.8	1943.09	37.45	-28.06	24.26
	0	S	1424.54	1980.17	36.29	-28.06	23.80
	45	SW	1374.26	1917.56	32.85	-28.33	24.67
	-90	E	1299.17	1805.81	35.45	-28.06	26.10
60	180	N	733.2	1077	14.02	-31.92	46.25
	135	NW	889.45	1276.77	14.06	-30.34	38.12
	-135	NE	915.46	1305.51	23.23	-29.88	37.04
	90	W	1108.72	1561.06	23.96	-28.98	30.67
	-45	SE	1231.39	1723.10	34.68	-28.54	27.53
	0	S	1235.78	1738.54	33.73	-28.92	27.44
	45	SW	1203.8	1693.36	30.22	-28.91	28.16
	-90	E	1143.13	1599.13	33.19	-28.52	29.66
90	180	N	325.65	553.96	5.87	-41.21	104.14
	135	NW	481.59	748.62	8.58	-35.67	70.42
	-135	NE	494.83	761.6	14.71	-35.03	68.53
	90	W	700.87	1026.42	16.05	-31.72	48.38
	-45	SE	760.26	1109.85	23.45	-31.50	44.60
	0	S	684.44	1026.77	21.96	-33.34	49.54
	45	SW	735.57	1084.32	20.25	-32.16	46.14
	-90	E	735.49	1064.93	24.57	-30.94	46.10

CIS

Slope angle [°]	Azimuth angle [°]		Yearly PV energy production [kWh]	Yearly in-plane irradiation [kWh/m²]:	Year-to-year variability [kWh]	Total loss [%]:	PV electricity cost [per kWh]
30	180	N	1157.58	1710.19	22.43	-32.31	34.02
	135	NW	1215.19	1788.68	23.06	-32.06	33.01
	-135	NE	1232.25	1807.8	27.90	-31.84	31.96
	90	W	1323.46	1947.29	28.13	-32.04	29.75
	-45	SE	1425	2092.34	36.04	-31.89	27.63
	0	S	1451.76	2132.03	35.46	-31.91	27.12
	45	SW	1408.4	2073.26	32.54	-32.07	27.96
	-90	E	1345.57	1973.23	30.53	-31.81	29.26
45	180	N	930.78	1402.74	15.35	-33.65	42.31
	135	NW	1040.35	1543.37	16.65	-32.59	37.85
	-135	NE	1065.41	1569.9	24.44	-32.14	36.96
	90	W	1202.89	1773.24	23.99	-32.16	32.70
	-45	SE	1320.63	1944.48	33.47	-32.08	29.82
	0	S	1346.72	1978.75	34.69	-31.94	29.24
	45	SW	1299.59	1916.31	31.93	-32.18	30.30
	-90	E	1232.27	1812.32	30.94	-32.01	31.96
60	180	N	712.31	1086.23	14.09	-34.42	55.29
	135	NW	851.8	1280	14.21	-33.45	46.23
	-135	NE	879.19	1309.63	19.78	-32.87	44.79
	90	W	1053.99	1558.51	21.68	-32.37	37.36
	-45	SE	1169.05	1722.33	31.03	-32.12	33.68
	0	S	1168.08	1729.55	32.96	-32.46	33.71
	45	SW	1140.98	1687.92	29.49	-32.4	34.51
	-90	E	1088.50	1598.73	30.07	-31.91	36.18
90	180	N	332.29	555.18	6.36	-40.15	118.52
	135	NW	474.86	749.76	7.95	-36.66	82.93
	-135	NE	491.25	768.22	11.83	-36.05	80.16
	90	W	675.14	1021.76	16.67	-33.92	58.33
	-45	SE	733.62	1107.55	20.76	-33.76	53.68
	0	S	662.75	1020.99	21.93	-35.09	59.42
	45	SW	714.71	1084.95	19.07	-34.13	57.27
	-90	E	715.41	1071.48	18.05	-33.23	55.05

Analysis: PV technology- Crystalline Silicon produces maximum yearly PV energy production while compared to CdTe and CIS.

Orientation- The South and South-East provide maximum yearly PV energy production (kWh) due to high yearly in-plane irradiation (kWh/m^2) and low system loss (%).

Optimal angle-The optimal angle is identified to be 30 degrees with the highest annual PV energy production (kWh).

Cost- The crystalline technology is the costliest while compared to the CdTe and CIS technology but has higher PV energy production and reduced system loss.

- Summary of the above tabulated form (table 2) is shown in fig. 5 and 6

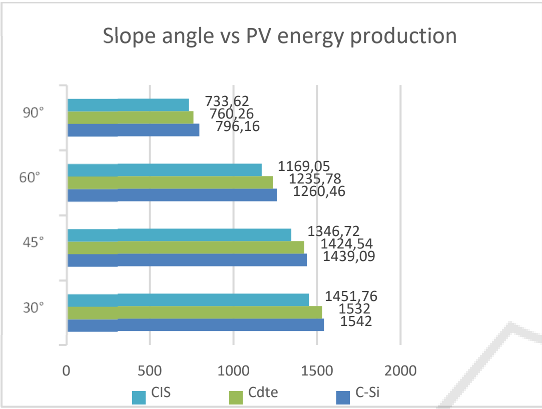

Figure 5: Graph showing a comparison between PV technology, yearly energy production (kWh) and the PV tilt angle.

The crystalline silicon PV technology has the highest yearly PV energy production with an optimum tilt angle of 30° followed by 45°,60° and 90°. The second highest PV energy is produced by the CdTe technology with an optimum angle of 30° and CIS has the least energy production comparatively (fig.5).

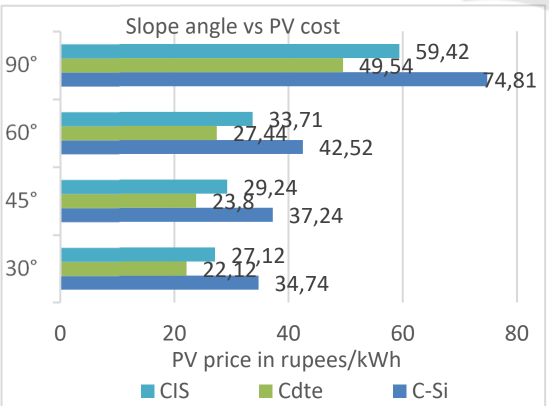

Figure 6: Graph showing a comparison between PV technology, price in INR and the PV tilt angle.

The crystalline silicon PV technology is the costliest technology i.e. 34.74 INR/kWh, followed by CdTe - 22.12 INR/kWh and CIS-27.12 INR/kWh while integrated at an optimum angle of 30° (fig.6).

3.3 Comparing Modelled Building in Design Builder with PVGIS System

The modelled building (Design builder) 's total energy production is 46,80,000 kWh, integrated on the southern façade. A comparison between the modelled building and the results achieved in the PVGIS system is carried out to provide an understanding with respect to the PV technology, yearly PV energy production, and the cost incurred.

The comparison is carried on based on the most suitable factors identified in Table 2, i.e., optimal tilt angle 30 degrees is considered, and a comparison is conducted for all the PV technologies (C-Si, CdTe & CIS) based on the energy production, cost, etc.

The direct solar heat gain is noted to be five hours per day i.e., 13:00 -18:00 IST, i.e., 5h x 365 = 1825h/year. The PV energy produced is 59,453.9 kWh/year by the modelled building; 38.8 kWp is produced in Bangalore when installed on the Southern side.

kWp x PV energy production = total energy generated by the system,

Using the above formula, yearly PV energy production is calculated considering the PV energy production for C-Si:1542.83 kWh, CdTe:1532.82 kWh & CIS:1451.76kWh and the peak performance to be 38.8kWp.

Table 3: Yearly PV energy production and panel cost.

PV technology	Yearly PV energy production (kWh)	Panel cost (INR)
C-Si	59,861.80	20,79,598.93
CdTe	59,473.41	13,15,551.83
CIS	56,328.28	15,27,622.95

Table 3-Considering the PV price based on the PV technology (fig.6) i.e. C-Si -34.74 INR/kWh, Cdte-22.12 INR/kWh and CIS-27.12 INR/kWh while integrated at an optimum angle of 30°,the panel cost is calculated for the yearly PV energy production (kWh).

3.3.1 Payback Period

The amount of energy consumption resulted in 46,80,000 kWh in the commercial building with 59,453.9 kWh of PV energy produced yearly (3.1). Considering C- Si PV technology from table 3 yearly PV energy production results in 59,861.80 kWh with BIPV panel cost of 20,79,598.93 INR (table 3). The lifetime of the system is expected to be 25 years according to the PVGIS tool. The cost per kWh electricity in India is 5.43 INR (Jaganmohan, 2020), for 59,861.80 kWh of PV energy produced would result in savings equivalent to 3,25,049.57 INR annually. Hence the payback period for the PV panel cost is 6.4 years, the system is expected to function with profit for the remaining 18.6 years (The system losses projected consists of all the losses in the system due to which the power distributed to the electricity grid could be lesser than the power generated by the PV modules. There are numerous reasons for this loss, as the loss in the cables, dirt (snow at times) on the modules, power inverters, etc. Over the years the modules tend to lose their power over time, so the average yearly output over the system's lifetime will be a few percent lesser than the output in the initial years which has been considered 14% in table 2).

Similarly, the payback period for the CdTe technology with 59,473.41 kWh PV energy and panel cost 13,15,551.83 INR, the electricity cost per annum is equivalent to 3,22,940.61 INR yearly the payback period will be 4.1 years and CIS technology with 56,328.28 kWh PV energy and panel cost 15,27,622.95, the electricity cost per annum is equivalent to 1,94,332.56 INR yearly the payback period will be 7.9 years.

3.4 Design Consideration for Maximum Energy Production using Google Sketchup(2.3)

The design considerations are analyzed based on the optimum angle, i.e., 30 degrees installed on the southern façade (table 2). Various integration styles on the façade are carried on. A shadow analysis is carried out for panels integrated on the S façade in Bangalore using Google Sketchup.

Shadow analysis: It is observed that the integrated panels receive direct solar heat gain from 13:00 to 18:00 IST. Partial shadow is casted from 13:00 -14:30 IST (14:30 – 18:00 IST no shadow is observed). Assuming that the shadow casted is solely by the overlying panels (integration style).

Table 4: Shadow overcast on various integration style.

Integration style	Overcast at 13:00 (in %)	Overcast at 14:00 (in%)
1	0.67	0.24
2	0.59	0.23
3	0.56	0.21
4	0.34	0.00

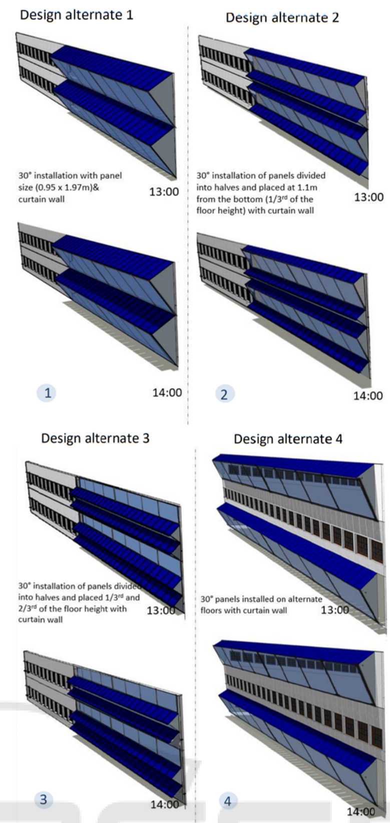

Figure 7: Illustration showing various styles 30-degree PV panels can be integrated on the façade.

The table 4 shows the percentage of shadow casted on the panels based on the integration style. Design alternate 4 is identified to be the most suitable integration style with minimal shadow casted i.e., 0.34% which will lead to increased energy production due to increased direct solar heat gain. Followed by design alternate 3 design alternate 2 and design alternate 1.

3.5 Daylight Simulation using VELUX (2.4)

The daylight simulation carried out for the design integration style modelled in Google Sketchup.

The Daylighting Factor (DF) is the ratio of the light level inside the structure to the light level outside the structure. It is defined as: DF = (Ei/Eo) x 100%. The designate alternate 1,2,3 and 4 have 1%,0.79%,0.76% and 1.35% daylighting factor ranging from 2.62-3.00.The daylighting factor ranging from 2.62-3.00 design alternate four is identified to be the most efficient, followed by design alternate 1, design alternate two, and design alternate

3. The daylighting factor assessment is restricted to the region with BIPV panels.

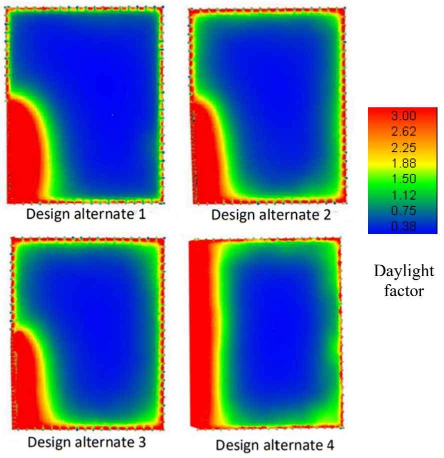

Figure 8: Daylighting analysis conducted on various design integration styles.

4 CONCLUSIONS

This study examined the ways to improve PV energy production when integrated on a building façade. It identifies the optimal combinations to be integrated on the building façade to rigorously increase the PV energy production. The analysis of adopting BIPV panels in projects based on the optimal tilt angle, orientation, payback period, integration style, etc. The study conducted could be helpful to the practitioners in the industry to understand the working and advantages of the system and ways to integrate the panels to generate maximum energy production in Bangalore. A similar methodology can be followed to study the performance of BIPV panels in various parts of the world. The optimal PV technology identified in this study is crystalline silicon with annual energy production of 59,861.80 kWh in a 20,000 sq.m. commercial building, integrated at an optimal angle of 30 degrees on the southern façade for maximum solar heat gain and has a payback period of 6.4 years. Further analysis can be done in various places by following similar methodology to enhance energy production using BIPV panels installed on the façade and the large spectrum of PV technology can be assessed by conducting on-site or laboratory experiments, since using software tools have limited access to assess various PV technology.

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