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Energy Retrofitting of Façade: Curtaining with Building Integrated Photovoltaics

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Abstract

The use of renewable resources helps to reduce dependence of fossil fuels, improve global energy security and tackle environmental problems like climate change. Building integrated Photovoltaics (BIPV) are on the rise as they serve the dual purpose of regulating indoor environment as well as generating electricity. This study presents the analysis of the energy retrofitting of façade with BIPV in the building of Kathmandu Valley. The research focuses on the comparison analysis of placement and type of BIPV in the façade for maximum generation of energy. For this purpose, various type of BIPV were studied and suitable type was used for further calculation. Manual calculation for the sizing of PVs was done for the case building and for the comparison, computer based energy simulation was also carried out using various software i.e. rhino for 3d modelling and grasshopper and ladybug tool for the further analysis of solar radiation and PV. The results illustrates that the placement of BIPV with maximum efficiency in south and east façade of the case building reduces 46.3% of the total consumed units per month. Energy retrofit of façade with BIPV could significantly reduce the monthly bill of the building and can be used as energy mix for the future

Keywords

Building Integrated Photovoltaics, Energy Retrofit, Solar energy, Building facade

1. Introduction

Successful use of renewable energy resources and related technologies can offset a part or entire building's electrical load and thermal energy load [1].

"According to the International Energy Agency's New Policies Scenario, the electricity demand of the world will rise by almost 80 percent during the period of 2012-2040"[2]. The IEA believes that the clean energy revolution is necessary to break the world's dependency on fossil fuels. Today, more than half of the world population lives in city areas and by 2050, it is estimated to nearly double to a total of 6.4 billion. Most of the growth in urban population is expected be in middle and lower-income countries, which have limited capacity to address the new risks emerging and existing risks being intensified by the global urban shift [3]. Such a rebellion would improve global energy security, encourage the continuance of economic growth and help minimize environmental challenges like climate change.

Buildings are among major contributors of greenhouse gases and consuming more than 40% of total primary energy [4]. Façade of the building contains large glass openings, which absorbs solar radiation from the sun, which degrades the indoor air quality. Considering present skills and market scenario, the most promising renewable energy technology to produce electrical energy from buildings is photovoltaics inclination [5]. The use of BIPV is widely recognized for the popularization and acceptance of PV. PV avoids the use of land for energy systems and reduces the cost of capital of the system by providing various purposes for multiple functions of PV components, for instance double use of the outer surface of the building.

Building envelopes to which the BIPV module can be applied mostly depends upon the building façade; with the increase in area of the façade, the building height also increases [6]. PV alleviates the need to use the land for energy systems (double use of the building envelope surfaces), and reduces the capital costs of the systems as it serves several purposes due to the multi-functionality of the PV components [?]. They are becoming "Energy flexible Buildings" by producing, storing, supplying, and consuming energy [7].

The benefits of integrating PV system into national grids are decrease in transmission and distribution line losses, increase in grid resilience, lower generation costs, and reduction in requirements to invest in new utility generation capacity. This will help policy makers in municipal to province level to in different sectors [8].

This technology can be used by the public easily and benefited financially by the government with different incentives and schemes. More energy production will increase energy self-reliance for the public. Solar energy is the source with least negative environmental impact compared to any other energy source. It does not produce greenhouse gases, nor does it pollute the water. As it is renewable source of energy, promotes healthy environment and minimizes the use of non-renewable sources like petroleum products, gas, etc. which ultimately helps the atmosphere to be clean.

2. Methodology

In this research, the study of types of BIPV that can be used in the building of Kathmandu valley was reviewed and energy generation from BIPV retrofitted in the façade of the building was reviewed using research paradigm like post positivism. In addition, the research approach will be inductive research approach as it starts with observations and theories which are proposed later at the end of the research process because of observations and analysis.

To address the key research objectives, this research has used both quantitative and qualitative methods, and also a combination of primary and secondary sources as shown in the figure 1. The qualitative data backs up the quantitative data analysis and results. The study comprises a site survey of case building. The survey was based on direct observations and using questionnaires. The result obtained was triangulated since there is application of the quantitative and qualitative data types in the data analysis.

Interpretation of data analysis, simulation, and literature review results were discussed along with other dimensions that affected the results in order to achieve the goals of the study. Achieving the goal led to subsequent conclusions.

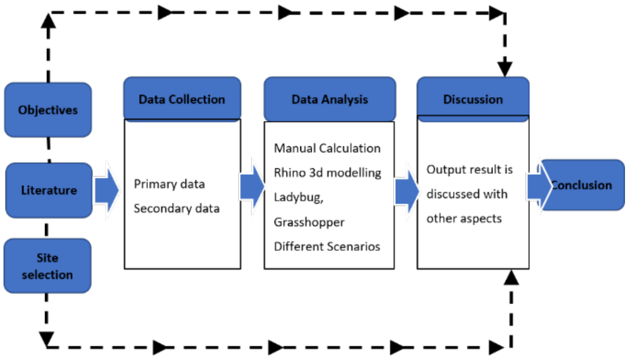

Figure 1: Methodology

3. Literature review

In this research, the study of types of BIPV that can be used in the building of Kathmandu valley was reviewed and energy generation from BIPV retrofitted in the façade of the building was reviewed using research paradigm like post positivism. In addition, the research approach will be inductive research approach as it starts with observations and theories which are proposed later at the end of the research process because of observations and analysis.

3.1 Historical Background

The Sun has been the ultimate source of energy since the beginning of life on Earth. The solar panels were first discovered by Becquerel's discovery in 1839. BIPV's first appearance worldwide was as roof integration in Germany in 1985 [9]. Again, in Germany, the first facade integration took place in 1991. Many countries have already centralized solar energy in their energy policy and have committed to fulfill a significant portion of their energy demand via solar power.

3.2 Energy retrofit and Building integrated Photovoltaics

Energy retrofit involves modifying existing commercial buildings which may improve energy efficiency or decrease the energy demand. In addition, retrofits are often used as opportune time to install distributed generation to a building. Among photovoltaic technologies, building-integrated photovoltaic (BIPV) technology integrates the functions of building exterior materials and photovoltaic (PV) modules into building envelopes.

3.3 Type of Solar Photovoltaics

There are three major types of solar PVs: monocrystalline, polycrystalline and thin-film solar panels. Characteristics for the same are shown in the table 1 below.

Table 1: Major types of Solar PV

Solar panel Type	Material	Efficiency	Cost	Appearance
Mono-crystalline	Pure, single silicon crystal	High (18 % or slightly higher)	Highest	Black or dark blue cells with rounded corners
Poly-crystalline	Silicon fragments	Medium (15-17 %)	High	Blue rectangular cells
Thin-film	Various	Low (11%, but may attain 15%)	Lowest	Black or blue uniform surface

Thin film solar panels can further be classified based on the flexibility, transparency and other characteristics. For the aesthetics purposes also, different experiments are done for new types of solar panels in whole world.

3.4 Benefits of Solar PVs

Continual advancements are being made in solar panel technology that are increasing the efficiency and at the same time lowering the production cost, thus making it even more cost effective. Solar energy can be an alternative in remote areas where it is too expensive to extend the electricity power grid. BIPV is one of the most promising and elegant ways of directly producing on-site electricity from the sun without any environmental harm, pollution, or depletion of natural resources [10].

3.5 Factors affecting performance of PVs

Like everything else that deteriorates when left in the sun, solar panels will also deteriorate from ultra-violet rays. The outdoor performance of a PV module is influenced by many factors. Few of these major factors are: i. Degradation of PV Module ii. Variation in Solar Radiation iii. Module Temperature iv. Fill-Factor v. Parasitic Resistances vi. Shading vii. Soiling viii. PV Module Orientation and Tilt Angle

3.6 Research findings on BIPV

Building shape characteristics were determinant to overall energy results smaller façade-to-roof and larger surface-to-volume ratios were more favorable. Grasshopper/Ladybug enable fast energy and visual simulations with acceptable grade of accuracy and time investment, Rhinoceros BIM [11]. [12] found that significant deviation (to the tune of 50 percent) has been observed between individual panel efficiency and year-round system (array) efficiency. Optimization of the system is more important than efficiency of the PV module. Semi-transparent PV scan effectively save energy, provide cost reduction and also environmental benefits [13].

4. Research Context

Bhat- Bhateni is considered as one of the leading supermarket and departmental store chain spreading in Kathmandu valley as well as in major cities around the country. Bhat-Bhateni is one of Nepal's most trusted and famous brand. Public-oriented bhatbhateni building contains a large variety of products used in people's daily use. The building is identical and architectural uniformity maintained providing typical façade color, material, fenestration designs and plane geometry. Bhatbhateni supermarket and departmental

Figure 2: Bhatbhateni east façade (Anamnagar)

store depend mainly on electricity, HVAC system, and refrigeration. It is necessary to carry out the energy calculation from BIPV from the façade by simulation through different soft wares for energy savings.

As BIPV will be used for the electricity generation, total energy consumption units of the building is very necessary for the energy simulation of the façade. These units will later be used in the simulation process in Ladybug. To calculate the number of solar panels from the equations provided, these units are equally important. It is found that July- August have the maximum consumption units as shown in the figure 3 above. Major load present are HVAC load, equipment loads, lightings and electricity loads.

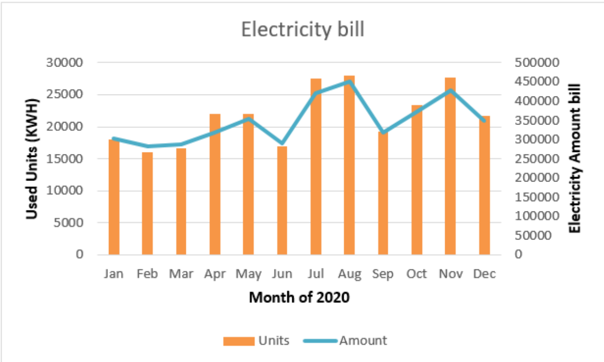

Figure 3: Electricity bill of the year 2020

5. Modelling and Simulation

Energy modelling was performed to calculate the solar radiation radiated on the building envelope. To calculate the type, size, and orientation of the solar PV, this simulation is important. First, the model was

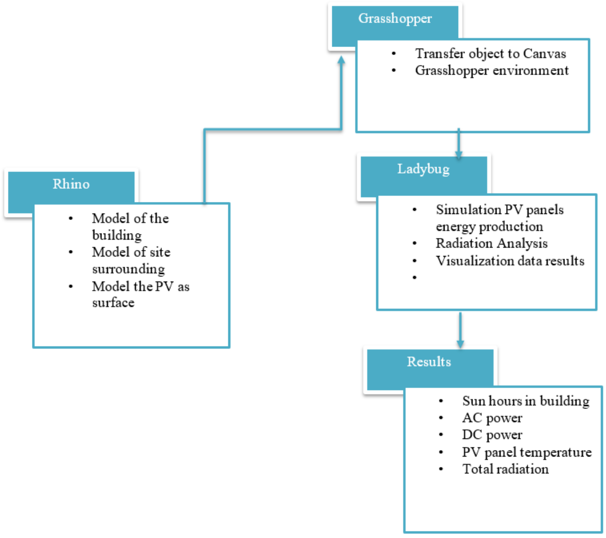

Figure 4: Flow chart for the simulation

modelled in the rhino were used. Grasshopper provides the environment canvas for the building modelled in rhino, which the plugin tool, but it alone cannot perform the necessary simulation for BIPV, so Ladybug plugin for grasshopper is used further for energy simulation as shown in the above figure 4. Ladybug is used for energy simulation that relies on several Energy Plus validated models with the climate file Energy Plus Weather file (EPW) of the target location.

5.1 Scenario Cases

For the simulation process, six scenarios were developed regarding the type, efficiency,orientation, placement and tilt angle as presented in the table 2.

Table 2: Scenario cases

Cases	Description
Scenario 1	Mono- crystalline BIPV in South facade
Scenario 1a	With efficiency 15%
Scenario 1b	With efficiency 20%
Scenario 2	Mono- crystalline BIPV in South and East facade
Scenario 2a	With efficiency 15%
Scenario 2b	With efficiency 20%
Scenario 3	BIPV in segments in South and East facade
Scenario 3a	30^0 Tilt angle
Scenario 3b	60^0 Tilt angle

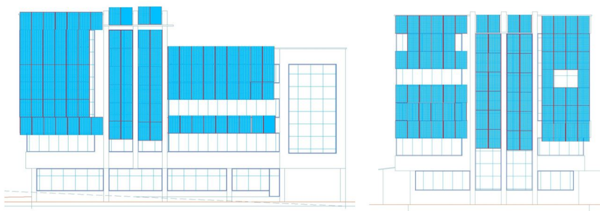

Figure 5: Placement of calculated BIPV in the east and south facade of case building

Figure 6 shows the logical sequence of the ladybug for the scenario cases developed, the process was same for all the cases but the input parameters are different. As the building was already modelled in rhino, BIPV were placed in façade of the building in the grasshopper with ladybug plugin. Besides PV modules' characteristics simulation required other attributes, like PV surface tilt angle, PV surface azimuth angle, mounting configuration of the modules and the percentage of area of active modules (percentage of the module's area excluding module framing and gaps between cells). These parameters are different for different scenario depicted in table 2.

6. Analysis and Results

6.1 Results from Manual Calculation

With the average units per month i.e. 20,000 kWh, calculation for the sizing of PV panels, batteries and inverter were done. As 100 percent was much higher, only 60 percent was taken into consideration. For the calculation, 500w solar pv with 19.5 percent efficiency from Pi-energy solar technology was used. The results from the calculation are 223 solar panels,70 kAh battery and 173 KVA inverter. BIPVs from the calculattion were curtained in the east and south facade as shown in the figure 5.

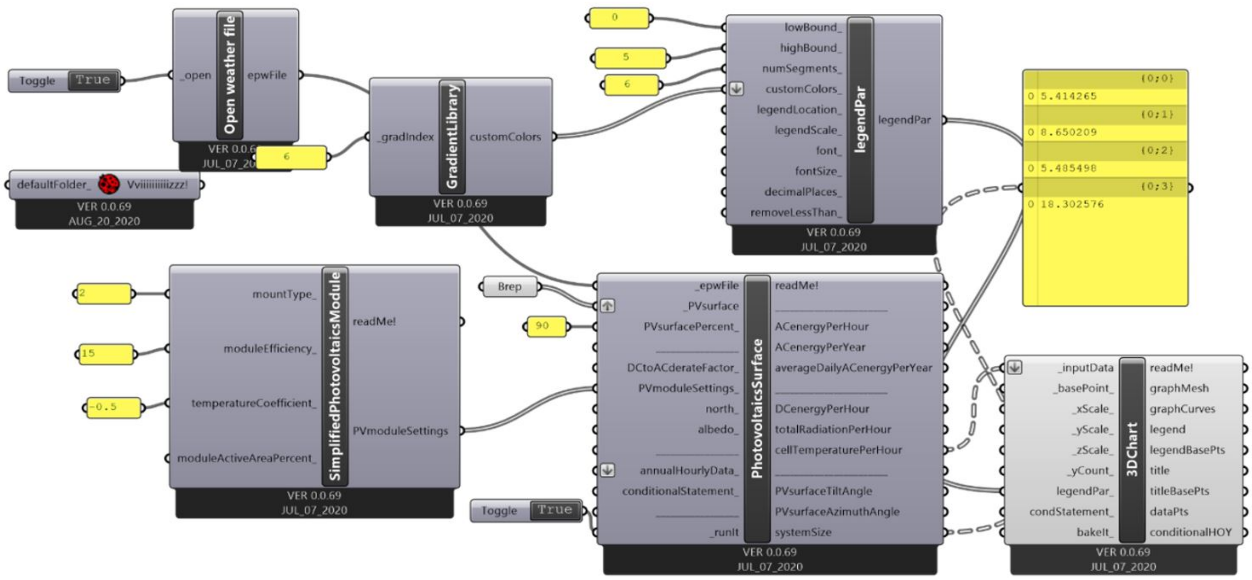

Figure 6: Logical sequence of ladybug with solar PV setting with different parameters

6.2 Radiation Analysis

To identify the most suitable façade for photovoltaic integration, the irradiation analysis was used which can be seen in the figure 7. Radiation analysis for the 21st June and in 21st December was done as it is the longest and shortest day throughout the year. It is found that maximum solar radiation is on roof and then in south and east façade. Due to the space limitation and functional space on roof, BIPV on south and east façade is preferred here as it gains more sunlight than other orientation of the building.

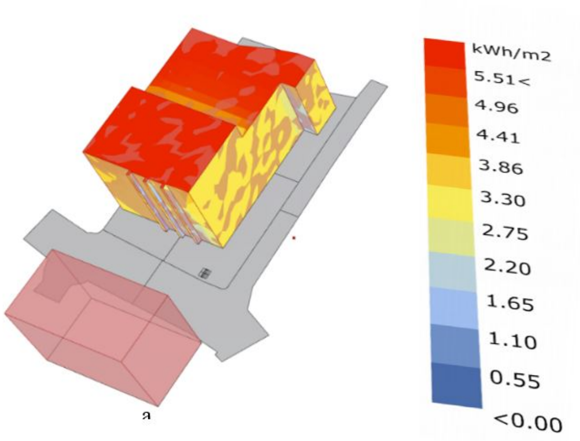

Figure 7: Radiation on building on 21 June

6.3 Results and Comparison of Scenario cases

6.3.1 Yearly AC Output

It is the AC power output for each hour during a year measured in kWh. In the figure 8, it can be depicted that the maximum AC generation for a year is for scenario 2b that is the BIPV used in both south and east façade with 20 percent efficiency and the least can be seen in the scenario 1a, i.e., the BIPV in south façade with 15 percent efficiency.

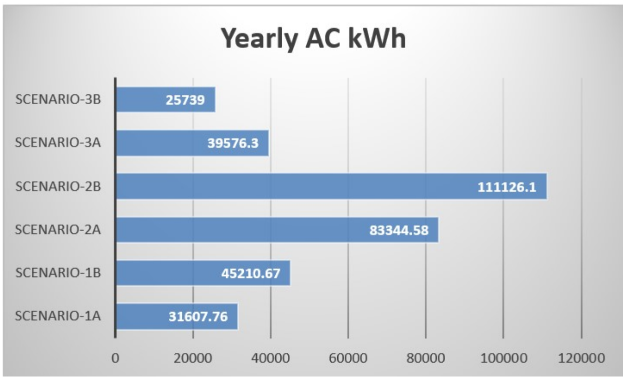

Figure 8: Comparison of yearly AC energy output of different scenarios

6.3.2 Daily Average AC energy output

It is the average daily AC power output per day for a whole year measured in kWh /day. As the AC power for a year is maximum in scenario 2b, so the average daily AC is also same presented in the figure 9.

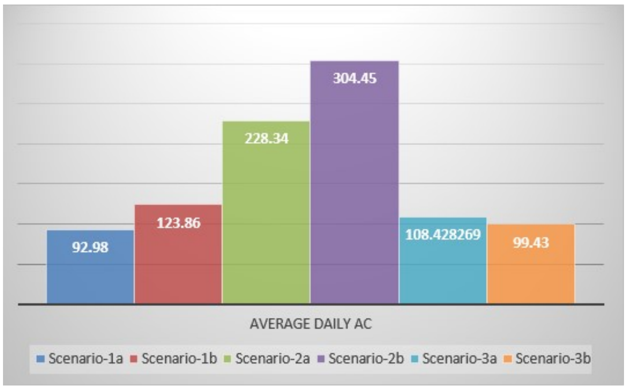

Figure 9: Comparison of daily AC energy output of different scenarios

6.3.3 DC System Sizing

It is the DC rating of the PV system measured in kW. The DC system sizing of the solar panel is also maximum for scenario 2, as the area of BIPV is more in this scenario as presented in the figure 10.

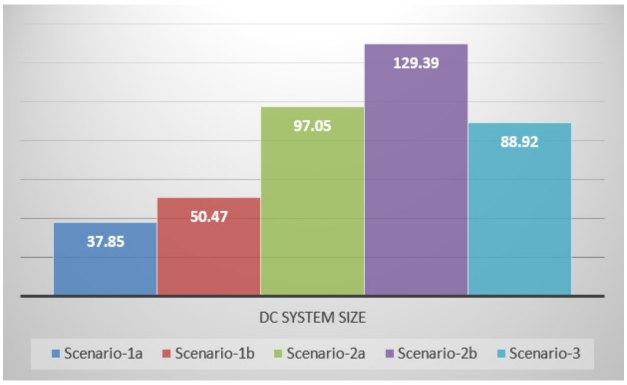

Figure 10: Comparison of DC system size of different scenarios

6.3.4 Comparison of DC system size of solar panel with surface area

In the table 3, comparing DC system size with that of surface area placed in the façade of the building, maximum can be seen in scenario 1b with 20 % efficiency PV panels in the south façade and minimum in the scenario 1a with 15 percent efficiency PVs.

6.3.5 Comparison of Yearly AC output of solar panel with surface area:

By comparison of yearly AC output of Solar PVs with the surface area shown in table 3, it can be depicted that scenario 1b gives maximum i.e. 13.5 kWh/sq.ft. and scenario 3a showed the poor performance with just 5.52 kWh/sq.ft

Table 3: Comparison of results of different scenario cases

Parameter	Unit	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 3b
DC system size	kW	38.75	50.47	97.05	129.39	88.92	88.92
Area	sq.ft	3349.02	3349.02	8586.43	8586.43	7164.778	7164.778
System size/ area	kW/ sq.ft.	0.011	0.015	0.011	0.015	0.012	0.012
Yearly AC	kWh	31607.76	45210.67	83344.58	111126.1	39576.30	25739
Yearly AC/ area	kWh/ sq.ft.	9.43	13.50	9.70	12.94	5.52	3.59
Monthly energy	kWh	2633.98	3767.55	6945.38	9260.50	3298.02	2144.917
Energy by BIPV	%	13.17	18.83	34.72	46.3	16.49	10.72

6.3.6 Comparison of Yearly AC output of solar panel with building energy consumption:

By comparison of yearly AC output of Solar PVs with energy consumption, from the table 3 can be seen that 46.3%of total energy consumption of the building and scenario 3b with the thin-film with 60-degree tilt angle showed poor performance.

7. Findings and Discussions

This research was done with the aim to provide an appropriate BIPV to Bhatbhateni building at Anamnagar so that it can tackle future crisis. The energy consumption of the building was studied and energy modelling was performed to visualize parameters. The energy consumption charges for the summer season is double than that of the winter season. The building is dependent fully upon mechanical and artificial system for operation.

Different findings were obtained for the six scenarios developed earlier. The outputs obtained were, AC energy generated for a year, total yearly AC energy output, and daily average AC energy output for a year, hourly DC energy output of the PV array for a year, hourly total solar irradiation, hourly cell temperature for a year, and system size. The findings recommend that maximum energy generation from BIPV used in both south and east façade of the building PV efficiency 20%, temperature coefficient -0.5 was found in scenario 2b when compared with other scenario developed during the simulation process. In addition, scenario 1b was considered good with the comparison of yearly AC output with the surface area. From the financial analysis, it can be depicted that the minimum payback period for the BIPVs were of scenarios 1a and 2b with 3.6 and 3.8 years respectively.

From the comparison of manual calculation to that of the simulated results, it can be depicted that the area of solar PV is less than simulated results. Also, manual calculation gave more energy generation than that of scenario2b which was considered good from the simulation process. This can be due to the consideration of solar radiation in the building in the simulation process in different time, month and year from the EPW file loaded in ladybug software. In manual calculation no such factors were considered. Also, the placement of the solar panel impacts the power generation as in the simulation process, the surrounding were also present and BIPV were placed in the building façade.

8. Conclusion/Recommendation

The main objective of this research is to find out the possibility of BIPV in the façade of the commercial building of Kathmandu that has been achieved by the calculation and simulation results of different scenario cases. The energy generated by BIPVs is mainly dictated by daily average AC and yearly AC output placed in the building facade. Basically, performance of the solar PVs mainly depend upon the orientation, tilt angle, shading, placement, solar radiation from the sun, etc. which should be taken into consideration while placing these BIPVs.

The comparison between different scenario cases concluded that the BIPV with 20% efficiency retrofitted in both south and east façade can give maximum power output. Hence, energy retrofit with BIPV in the existing façade of the building can reduce the dependency in fossil fuel that ultimately helps in the reduction of GHGs that creates clean environment. BIPV can also be used as the mix energy with other resources.

BIPVs can play a significant role in buildings in tapping the solar energy potential especially in country like Nepal where there is a good amount of sunshine throughout the year. Use of BIPVs in the buildings helps in reducing the use of fossil fuels which are non-renewables. As these are clean source and energy efficient, use of BIPVs should be encouraged. Some recommendation on further studies such as orientation as the above study have not done research on all the orientation, building types, climate to the impact of the BIPVs.

References

[1] Gayathri Aaditya and Monto Mani. Integration of photovoltaics in buildings. 2017.

[2] Sabri Çiftçi, Mehmet Solak, and Melih Kuncan. Powered by the sun: designing and analyzing technical and economic aspects of a school sustained by photovoltaics. *Journal of Mechatronics and Artificial Intelligence in Engineering*, 1(1):21–32, 2020.

[3] Ahmed Abdalla, Alaa El'eshy, and Ahmed Eltantawy. "life energy architecture" crowd farms as human power plants (main entrance for mansoura university "el-baron gate"). *Energy Procedia*, 115:272–289, 2017.

[4] Ann Florini. The international energy agency in global energy governance. *Global Policy*, 2:40–50, 2011.

[5] Sara Freitas and Miguel Centeno Brito. Solar façades for future cities. *Renewable energy focus*, 31:73–79, 2019.

[6] Somil Yadav and SK Panda. Thermal performance of bipv system by considering periodic nature of insolation and optimum tilt-angle of pv panel. *Renewable Energy*, 150:136–146, 2020.

[7] Marco Lovati, Graziano Salvalai, Giulia Fratus, Laura Maturi, Rossano Albatici, and David Moser. New method for the early design of bipv with electric storage: A case study in northern italy. *Sustainable Cities and Society*, 48:101400, 2019.

[8] KN Nwaigwe, P Mutabilwa, and E Dintwa. An overview of solar power (pv systems) integration into electricity grids. *Materials Science for Energy Technologies*, 2(3):629–633, 2019.

[9] Manfred Hegger, Matthias Fuchs, Thomas Stark, and Martin Zeumer. Picture credits. In *Energy Manual*, pages 272–275. Birkhäuser, 2012.

[10] Guillermo Quesada, Daniel Rousse, Yvan Dutil, Messaoud Badache, and Stéphane Hallé. A comprehensive review of solar facades. opaque solar facades. *Renewable and Sustainable Energy Reviews*, 16(5):2820–2832, 2012.

[11] Jader de Sousa Freitas, Joára Cronemberger, Raí Mariano Soares, and Cláudia Naves David Amorim. Modeling and assessing bipv envelopes using parametric rhinoceros plugins grasshopper and ladybug. *Renewable Energy*, 160:1468–1479, 2020.

[12] Gayathri Aaditya, Rohit Pillai, and Monto Mani. An insight into real-time performance assessment of a building integrated photovoltaic (bipv) installation in bangalore (india). *Energy for Sustainable Development*, 17(5):431–437, 2013.

[13] Nikolaos Skandalos and Dimitris Karamanis. Pv glazing technologies. *Renewable and Sustainable Energy Reviews*, 49:306–322, 2015.