Concise overview of BIPV systems and its future scope

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Abstract. Buildings are considered as a major consumer of electricity. It is said because 40% of the total energy produced is utilized by the buildings. Harnessing the solar energy by means of photovoltaics is seen as a sensible option to meet out the buildings demand either partially or fully. Recent trends have seen BIPV systems as a viable option that not only enhances the aesthetics of the building but at the same time meets out the buildings energy demand. Apart from the aesthetics and electricity production, BIPV, which acts as an integral component of the buildings, reduces solar heat gain at the same time allowing daylight to enter into the building. This paper discusses the different cell technologies used in solar BIPV systems, different types of PV modules used for building integration, orientation and tilt angle optimization of panels, performance analysis with different case studies, cooling methods adopted in this technology and the main barriers that slows down the development of this system. Payback periods is also studied and discussed in this paper.

1. Introduction
40% of the total electricity generated is consumed by the buildings and percentage increases year after year. If buildings could generate enough power to meet out its demand either partially or fully, much of CO2 emission produced could be minimized or eliminated. This is because most of the power generated is by means of non-renewable energy sources like coal and natural gases. Reduction in CO2 emission means lesser greenhouse gas emitted to the atmosphere which in turn helps in reducing global warming [1].

Our Earth receives ample amount of solar irradiance to meet out the global energy demand if all the buildings in our earth is installed with solar PV panels [2]. That said it isn’t that easy to fit all the buildings with solar PV modules at once. Progress can be made step by step and that is where Building integrated Photovoltaics plays an important role. Area is considered as a crucial factor either for constructing a building or for the placement of solar panels. Buildings in urban areas often go with high rise, making the roof area small. Hence most of the outer wall area/ facades exposed with solar radiation can be fitted with solar PV modules. The integration of PV panels onto a building is called as building integrated Photovoltaics. The difference between BIPV and BAPV is that in BIPV the panels will be integrated with the building and in BAPV the PV panels will be fixed onto the building’s roof such as solar roof tops. BIPV not only acts as power producing component but also serves as integral component of the building. The integration can be anywhere from building’s façade to skylights to window shades. Apart from the production and acting as integral component. BIPV helps in reducing the HVAC load of the building. This reduction in load helps in reducing the energy required by the HVAC system thus providing savings and reducing the carbon footprint. Also, the use of semi-transparent modules helps to allow daylighting to enter the building reducing the artificial light requirement [3][4].
Solar PV panels have been seeing a huge price cut year after year, thanks to the extensive research going on with the field. Solar PV panels is majorly used in buildings in order to produce power to meet out its energy demand thereby reducing the reliance on the main grid [5]. Since green buildings and sustainable buildings are coming into the spotlight to help reduce the carbon emissions, solar PV systems are considered to be the go to option for power production due to its easy mounting, less complexity and low mainaintance systems [6]. Many PV manufacturers upon looking into the potential of BIPV have started manufacturing BIPV specific solar PV modules like semi-transparent modules, modules with different color, etc. In this paper we will be discussing the different cell technologies used in BIPV panels along with different BIPV panels available in the market, orientation and tilt angle optimization of solar panels, performance of solar panels along with the factors affecting it. Apart from this, the lifecycle analysis and barriers present in this technology will also been discussed.

2. Photovoltaic Cells and modules
Poly and Mono crystalline silicon PV modules have been used widely for PV applications due to its well established technology and abundant availability of raw material. Polycrystalline panels when compared with monocrystalline are cheap but in terms of efficiency the monocrystalline modules are more efficient by at least 5% in comparison to polycrystalline modules [7]. Both Poly and Mono crystalline modules is enclosed in a rigid aluminum case which is the reason why it is commonly used for BAPV applications.
Thin films are mostly used for BIPV applications. Thin film technology includes amorphous Si, cadmium telluride (CdTe), cadmium indium gallium selenide (CIGS). Thin film cells have lower efficiency when compared to crystalline silicon counter parts [8], however advancement in technology has improved the efficiency of thin film cells up to 23% under laboratory testing [9]. Modern cell technologies include perovskite, dye synthesized and tandem cells, which has a much improved conversion efficiency, ability to capture rays with broader wavelength [10]. Though these technologies have much more benefits compared to thin films and crystalline silicon panels, these are still in research state and is not available for commercial use.

![Figure 1. Market of BIPV products][1]
Different PV panels are used for different applications. Panels in BIPV are typically mounted in Buildings façade, roof, windows, skylights and sun shades. Depending upon the application, panels can be transparent, semi-transparent, translucent, colored, framed or flexible. Facades are generally chosen for BIPV application, mainly because of large surface area and the ability to let in more day light to enter into the building by using semi-transparent and transparent panels. However transparent panels do tend to allow solar heat gain which increases the cooling load of the building, hence semi-transparent panels are usually preferred. Apart from semi-transparent panels, coloured panels are gaining popularity due to its sleek integration with the building. Tsai et al [11] develops see through tandem thin film PV panels with eight different colour configurations. These coloured panels although being slightly less efficient than regular panels, can blend easily for BIPV applications due to wide variety of colours and see through functionality. Louis et al [12] explains the importance of white coloured panels, which by default has the tendency to operate at lower temperatures compared to conventional panels thereby having a higher efficiency.

Figure 2. Different PV panels used for Building integration [47].

3. Orientation and tilt angle

Orientation and tilt angle of a panel plays an important role in order to maximize the efficiency of the panels. Panels should be placed such that it gets high amount of solar radiation without any interruption such as shadows. Solar panels usually are placed facing south, if the location is located in northern hemisphere and in north if it is located in southern hemisphere in order to get the maximum solar irradiance [13]. Gindi et al [14] simulates different PV module placement and orientation for an office building. The simulation results showed that tilt angle optimization and orientation of the panels played an vital role in their performance. For the simulated building, south orientated panels with 30° tilt performed better than the other placed panels. Asfour et al [15] simulates different configurations of
solar photovoltaic panels located at Saudi Arabia acting as shading devices. Inclination angle of 0˚, 30˚, 45˚ and 60˚ for both horizontal and vertical placement has been simulated for a 5 storey building. The results shows the maximum power generation and shading potential in horizontal placement with 45˚ inclination while the minimum power generation and shading potential is seen in vertical placement with 0˚ inclination.

Shadings are caused due to nearby building or due to trees or from passing clouds which affects the power generation from the panels. Celik et al [16] explains the effect of shading in PV systems. In this work it can be seen that instead of shifting the panels from one place to another, changing the electrical connection of PV array does the job of improving the system performance in the case of partial shading. Since, in some buildings when there is no space left out to change the location of modules, changing the electrical connection of PV array allows the system to perform better.

4. Performance of BIPV systems

Various factors like panel heating, type of panels, window to wall ratio, etc influence the performance of BIPV systems in order to make the system work in optimum condition.

4.1 System integration

A PV system can be connected to grid or to batteries or to both grid and batteries, these systems are called as on-grid, off-grid and hybrid systems respectively. On-grid systems are highly useful if the building has connection to grid. Off-grid systems are much suitable for buildings that doesn’t have connection to grid, hybrid systems are much suited for system having grid connection but also has frequent power cuts. When it comes to payback period, On-grid system delivers a faster payback [17]. This is because on grid system doesn’t use batteries to store the electricity and hence there isn’t a need to invest on batteries. Also batteries need to be replaced within 5-6 years [18], which increases the overall cost of the system increasing the payback period.

In order for a building to achieve self-sufficiency, PV modules has to be connected with batteries. This increases the overall cost of the system but also decreases the dependency on fossil fuels and increases the reliance on renewables for powering the buildings. Silva et al [19] explains the importance of batteries for a building to improve its self-sufficiency. It can be seen that on an average, without the use of batteries the building self-sufficiency is limited to around 40% hence in order to improve this number, batteries are insisted. Zhang et al [20]. studies the improvement of SSR with respect to different batteries (lead acid, sodium nickel chloride and lithium ion). The results showed that out of the three batteries lithium ion achieved the highest SSR (70%).

4.2 PV Cooling methods

PV panel’s efficiency decreases by 0.5% If the temperature of the panel increases by 1˚C beyond its optimum working temperature [21]. In order to make the system work optimally, cooling systems are used. Cooling systems can be categorized into passive and active cooling [22]. Passive cooling doesn’t require any external energy to cool down the system, it rather uses natural ventilation to cool down the system. On the other hand active cooling requires an external energy to operate fans and pumps in order to cool the system. Active cooling is an expensive method and is mainly used in large solar farms and parks. BIPV systems usually utilized passive cooling methods to cool the panels.
Figure 3. Semi-Transparent PV module integrated to the roof of the building with an air duct beneath it [34].

Hamed et al [23], studies the performance of PV panels, placing air channels beneath them. This passive cooling method decreases the panel temperature by around 10°C allowing the panels to work efficiently, improving its power generation by around 5%. Nizetic et al [24], investigated four types of PV cooling namely PCM based cooling, air based cooling, liquid based cooling and radiative cooling. While liquid based cooling performed better than the rest, the LCOE was quite high. On the other hand for air based cooling, the LCOE was quite low, provided its performance was not that poor. PCM based cooling performed slightly better than air cooled but its LCOE was high and the integration of PCM was quite complex. Rounis et al [25], simulates the effectiveness of multiple inlet openings on an BIPV system. In comparison with the double inlet opening system, the multiple inlet system offered a better temperature distribution in the panels while decreasing the temperature of the module by around 10°C. Chivelet et al [26], evaluates the performance a 27kW system having ventilation channels to cool the PV panels. The presence of ventilation channel reduced the panel temperature by 7°C improving its generation. This study also shows that when compared with polymer concrete panel the heat gain in PV panels was much lower (difference of 12°C). Chatzipanagi et al [27], compares building integrated panels (double glazed) with that of building applied panels (ventilated panels). The author uses amorphous silicon and crystalline silicon for both the configurations and the two tilt angle was chosen for the purpose (30˚ and 90˚). From the results it was found that the ventilated amorphous panels place at 90˚ had lower heat gain also the performance was better compared with rest of the case. Amorphous Si performed better in comparison with crystalline Si, this was due to the fact that amorphous Si had better temperature coefficient.

Ioannidis et al [28], upon comparing semi-transparent double skin facades and insulating glazed building integrated PV panels, it was found out that the double skin facades performed better than insulated glazing units mainly due to the presence of ventilation channel. The efficiency of the double skin facades improved 2-9% in comparison with insulated ones depending upon the position of the ventilation channels.

Wajs et al [29], simulates the performance of solar tile under STC. The efficiency of the monocrystalline tile having dimensions 540*540 mm was found to be around 5%. The effect of passive cooling by means of air flow was also determined. In the case of modules without cooling the module efficiency was around 5.2% whereas for case with cooling it was found out to be around 5.6% under same illumination (solar irradiance = 450W/m2). Power output also increased from 8.5W to 10W (solar irradiance = 900W/m2).
Figure 4. Comparison between single and multiple inlet system with different wind speed [25].
Figure 5. Cooling system using vents [25].

Karthick et al [30], studies the effect of PCM based cooling in photovoltaics. In this work sodium sulphate decahydrate is used as pcm material with 0.3% concentration of graphene oxide in order to improve its thermal conductivity. The module with PCM had improvements in efficiency (about 9% increase) as well as overall power output (about 12% increase) compared to modules without PCM. The temperature of the module reduced by 9˚C in comparison with modules without PCM. Yunfeng et al [31], studies the performance of a 120kWp bipv system installed at the solar energy research building located in Kunming, china. The south facing façade consist of 720 semi-transparent monocrys
talline panel having an light transparency of around 50%. Ventilation blinds provided at the top and bottom of the pv wall cools the pv panels during the summer and during winter these vents are kept closed so that the heat generated from pv panels helps to maintain the room temperature higher than the ambient temperature. We can see from the studies that for BIPV systems, passive cooling by means of air vents and ducts provide enough cooling for the panels and at the same time helps to reduce the HVAC loading of the building.

4.3 Window to wall ratio and packing factor

Another important factor to look into is window to wall ratio and packing factor. WWR is the ratio of window area to wall area. WWR decides the amount of natural daylight to enter into the building. Higher the ratio, higher will be amount of solar gain. WWR has a direct effect on buildings energy consumption. Choosing the optimum WWR will lead to lower energy consumption that is spent on lighting systems and HVAC systems [32].

Figure 6. Walls having WWR of 19% and 33% [33].
Cannavale et al [33], studies the performance of semi-transparent perovskite solar cells with two window to wall ratio (19% & 32%) configurations. Both the configurations showed better useful daylight illuminance when compared with clear glass and solar control films. Daylight glare probability was also seen less in perovskite cell. Cell Efficiency, when compared with amorphous silicon semi-transparent cells was more over the same but daylight transmittance was much higher around 42% in perovskite cells compared to 7% for silicon cells.

Packing factor is the ratio of total area of the solar cell by total area of the module. Lower the packing factor, higher will be the chances of daylight entering the building and lower will be the electricity production. Higher the packing factor lower will be the chances of daylight entering the building and higher will be the electricity production. Vats et al [34], studies the performance of semi-transparent module with varying packing. In terms of packing factor, the module with the least packing factor (42%) had the highest electrical efficiency due to lower cell temperature but increased the room temperature due to higher solar gain. The optimum cell coverage ratio in this study was found out to be 62%. Hence WWR and packing factor should be selected carefully depending upon the requirements.

| PV modules | Packing factor | 0.42 | 0.62 | 0.83 |
|------------|----------------|------|------|------|
| θ (°C)     | θ (°C)         | θ (%)| θ (%)| θ (%)|
| n-Si       | 13.0           | 13.0 | 13.0 | 13.0 |
| p-Si       | 12.0           | 12.0 | 12.0 | 12.0 |
| e-Si       | 10.0           | 10.0 | 10.0 | 10.0 |
| CdTe       | 8.7            | 8.7  | 8.7  | 8.7  |
| GaSb       | 7.7            | 7.7  | 7.7  | 7.7  |
| HIT        | 6.5            | 6.5  | 6.5  | 6.5  |

Table 1. Effect of packing factor for different PV Modules W.R.T module temperature (Tc), Module Efficiency (η) and room temperature (Tr) [34].

4.4 Barriers in BIPV system

Although BIPV technology is having a whole lot of advantages and gaining a good amount of attention thanks to its sleek integration and promotion of green buildings, it still has a long way to become a matured technology. Since many countries are just getting their hands on with solar PV technology [35], BIPV’s couldn’t take the spotlight and its development is held back.

Prieto et al [36], analyses the barriers present in BIPV field which limits the development of this technology. In this study various engineers and research people were consulted to determine the factors influencing the development of BIPV technology. It was found out that the main barriers responsible for the underdevelopment was the economics of the system which includes cost of the system and lack of government incentives. The next barrier was the product itself i.e. unavailability of modules, inefficient modules etc. other than these barriers lack of knowledge or awareness of this technology also limited its development.

Benedicto et al [37], discusses the importance of BIPV systems in office buildings and points out the major constraints which affect the development of these systems. Despite some cities receiving good solar insolation, due to lack of awareness and government support, BIPV systems weren’t thrown to the limelight.
Shukla et al [38]. discusses the potential of BIPV in India along with the barriers present in this technology. The authors explain the various government policies present in India for solar PV systems. The main barriers pointed out were lack of awareness in BIPV systems for both residents and also for technicians, lack of government support and lack of research in this technology.

| MAIN CATEGORIES | DESCRIPTION OF THE BARRIERS |
|-----------------|-----------------------------|
| INTEREST        | Lack of interest in solar design by architects and clients/developers |
| ECONOMY         | Not economically justifiable and lack of governmental incentives |
| KNOWLEDGE       | Lack of sufficient technical knowledge by architect, by client/developer and by consultant |
| INFORMATION     | Lack of architecturally oriented literature about these technologies and useful data for architects in product datasheets |
| PRODUCT         | Lack of products suitable for quality building integration and complementary building components |
| PROCESS         | Lack of tools that support design and sizing of systems / Technology is considered too late in the design process (insufficient time and resources) |

Table 2. Main barriers present in BIPV system [36].

Majority of the studies pointed out the possible barriers that affects the development of BIPV technology is cost of the system itself [39] and lack of awareness among the people. Although BIPV systems has so much of positive sides lack of awareness and support from government makes the development of this technology quite slow [40].

4.5 Life time analysis and payback period

Any product manufactured will be consisting of different materials and parts combined together to form a single usable product. Life time analysis of a product relates to the analysis of costs associated for manufacturing along with the energy spent in order to produce a product [41]. The life of a solar panel begins with excavation of raw materials, segregation of raw materials, transportation of raw materials, manufacturing of solar cells, fabrication of solar panel, transportation and installation of solar panel, commissioning of solar panels, decommissioning of solar panels, recycling of materials [42].
Payback period can be classified as economic payback period and energy payback period. Economic payback period is the duration within which a product pays back the amount invested upon it. The payback period involving energy is called as Energy payback period. Energy payback period is the duration within which the product repays the overall energy spent on it (excavation, transportation, manufacturing, etc.) the Energy payback period is usually a shorter period where the panels pays back within 6 months – 2 years depending upon the type of the panel and the amount of radiation it receives it. Economic Payback period is usually high ranging from 5-10 years depending upon the type of panels, location, type of integration, electricity tariff, etc [43].

In case of BIPV, the payback period is slightly longer than conventional BAPV. It is because the cost of materials used for BIPV is quite high when compared to BAPV [44]. Perez et al [45]. discusses energy payback of BIPV plant in new York. It was observed that this plant despite having a low performance ratio (63%) compared to other plants (usually 80%) due to west orientation, the energy payback period was around 3.8 years, for comparison the typical façade system didn’t have any payback periods as it didn’t produce electricity. Similarly Huang et al [46]. finds out that the energy payback periods of silicon based panels will be around 3-7 years.

5. Conclusion

BIPV systems opens a wide range of possibilities for solar PV systems both in terms of productivity and aesthetics. Conventional BAPV systems like roof tops are limited only to roof area whereas with BIPV most of the buildings surface area can be integrated with photovoltaics without compromising the aesthetics of the building. With the emergence of green and sustainable buildings, the potential of BIPV’s can further be unlocked. That said due to barriers like lack of knowledge, awareness in this technology and lack of support from the government, the pace of growth is still slow and can be fastened up eventually when provided with suitable schemes and incentives.

As far as the future is concerned, keeping in mind the actions taken by the nations worldwide to reduce the dependency of fossil fuels on behalf of climate change, BIPV systems can help in boosting the development of green and sustainable buildings. With PV manufactures and building architects seeing a potential in BIPV system, the future is said to be very much secured for BIPV systems.

Abbreviations

| Abbreviation | Definition                  |
|--------------|-----------------------------|
| a-Si         | Amorphous Silicon           |
| BAPV         | Building Applied Photovoltaics |
| BIPV         | Building Integrated Photovoltaics |
| CdTe         | Cadmium Telluride           |
| c-Si         | Crystalline Silicon         |
| CO2          | Carbon dioxide              |
| DSSC         | Dye Sensitized Solar Cell   |
| μc-Si        | Microcrystalline Silicon    |
| OPV          | Organic Photovoltaic        |
| HVAC         | Heating, Ventilation, and Air Conditioning |
| PCM          | Phase Change Material       |
| PV           | Photovoltaic                |
| Si           | Silicon                     |
| WWR          | Window to Wall Ratio        |

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Conflict of interest

The authors do not have any sort of conflict of interests.

References

[1] Darkwah, Williams Kweku & Odum, Bismark & Addae, Maxwell & Koomson, Desmond & Kwakye Danso, Benjamin & Oti-Mensah, Ewurabena & Asenso, Theophilus & Buanya, Beryl. (2018). Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. Journal of Scientific Research and Reports. 17. 1-9. 10.9734/JSRR/2017/39630.

[2] Shaikh, Mohd Rizwan & Shaikh, Sirajuddin & Waghmare, Santosh & Labade, Suvarna & Tekale, Anil. (2017). A Review Paper on Electricity Generation from Solar Energy. International Journal for Research in Applied Science and Engineering Technology. 887. 10.22214/ijraset.2017.9272.

[3] Young Tae Chae, Jeehwan Kim, Hongsik Park, Byungha Shin, Building energy performance evaluation of building integrated photovoltaic (BIPV) window with semi-transparent solar cells, Applied Energy, Volume 129, 2014, Pages 217-227, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2014.04.106.

[4] Sung Lok Do, Minjae Shin, Juan-Carlos Baltazar, Jonghun Kim, Energy benefits from semi-transparent BIPV window and daylight-dimming systems for IECC code-compliance residential buildings in hot and humid climates, Solar Energy, Volume 155, 2017, Pages 291-303, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2017.06.039.

[5] Arvind Chel, Geetanjali Kaushik, Renewable energy technologies for sustainable development of energy efficient building, Alexandria Engineering Journal, Volume 57, Issue 2, 2018, Pages 655-669, ISSN 1110-0168, https://doi.org/10.1016/j.aej.2017.02.027.

[6] Reda Hassanien Emam Hassanien, Ming Li, Fang Yin, The integration of semi-transparent photovoltaics on greenhouse roof for energy and plant production, Renewable Energy, Volume 121, 2018, Pages 377-388, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2018.01.044.

[7] Taşçıoğlu, Ayşegül & Taşkın, Onur & Vardar, Ali. (2016). A Power Case Study for Monocrystalline and Polycrystalline Solar Panels in Bursa City, Turkey. International Journal of Photoenergy. 2016. 1-7. 10.1155/2016/7324138.

[8] Aghaei, Mohammadreza. (2012). A Review on Comparison between Traditional Silicon Solar Cells and Thin-Film CdTe Solar Cells.

[9] T. Kato, J. Wu, Y. Hirai, H. Sugimoto and V. Bermudez, "Record Efficiency for Thin-Film Polycrystalline Solar Cells Up to 22.9% Achieved by Cs-Treated Cu(In,Ga)(Se,S)2," in IEEE Journal of Photovoltaics, vol. 9, no. 1, pp. 325-330, Jan. 2019, doi: 10.1109/JPHOTOV.2018.2882206.

[10] Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, A comprehensive review on design of building integrated photovoltaic system, Energy and Buildings, Volume 128, 2016, Pages 99-110, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2016.06.077

[11] Chin-Yi Tsai, Chin-Yao Tsai, "Development of Tandem Amorphous/Microcrystalline Silicon Thin-Film Large-Area See-Through Color Solar Panels with Reflective Layer and 4-Step Laser Scribing for Building-Integrated Photovoltaic Applications", Journal of Nanomaterials, vol. 2014, Article ID 809261, 9 pages, 2014. https://doi.org/10.1155/2014/809261.
[12] Scartezzini, Jean-Louis & HEINSTEIN, Patrick & Perret-Aebi, Laure-Emmanuelle & PALOU, Jordi & Cattaneo, Gianluca & Li, Heng-Yu & MUSSOLINO, Vincenzo & SANSONNENS, Laurent & Ballif, Christophe. (2015). Energy harvesting and passive cooling: A new BIPV perspective opened by white solar modules.

[13] Joannes I. Laveyne, Dimitar Bozalakov, Greet Van Eetvelde, Lieven Vandevelde,"Impact of Solar Panel Orientation on the Integration of Solar Energy in Low-Voltage Distribution Grids", International Journal of Photoenergy, vol. 2020, Article ID 2412780, 13 pages, 2020. https://doi.org/10.1155/2020/2412780.

[14] Salwa El Gindi, Ahmed Reda Abdin, Ayman Hassan, Building integrated Photovoltaic Retrofitting in office buildings, Energy Procedia, Volume 115, 2017, Pages 239-252, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.05.022.

[15] Asfour, Omar. (2018). Solar and Shading Potential of Different Configurations of Building Integrated Photovoltaics Used as Shading Devices Considering Hot Climatic Conditions. Sustainability. 10. 4373. 10.3390/su10124373.s

[16] Berk Celik, Engin Karatepe, Santiago Silvestre, Nuri Gokmen, Aissa Chouder, Analysis of spatial fixed PV arrays configurations to maximize energy harvesting in BIPV applications, Renewable Energy, Volume 75, 2015, Pages 534-540, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2014.10.041.

[17] Ghazali, Syafii. (2016). Performance and Energy Saving Analysis of Grid Connected Photovoltaic in West Sumatera. International Journal of Power Electronics and Drive Systems (IJPEDS). 7. 1348. 10.11591/ijpeds.v7.i4.pp1348-1354.

[18] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil, H. El-Sherif, Enhancing the performance of photovoltaic panels by water cooling, Ain Shams Engineering Journal, Volume 4, Issue 4, 2013, Pages 869-877, ISSN 2090-4479, https://doi.org/10.1016/j.asej.2013.03.005.

[19] Grubišić-Čabo, Filip & Nizetic, Sandro & Tina, Giuseppe. (2016). Photovoltaic panels: A review of the cooling techniques. Transactions of FAMENA. 40. 63-74.

[20] Tareq Abu Hamed, Aiman Alshare, Hossam El-Khalil, Passive cooling of building-integrated photovoltaics in desert conditions: Experiment and modeling, Energy, Volume 170, 2019, Pages 131-138, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2018.12.153.

[21] S. Nižetić, A.M. Papadopoulos, E. Giama, Comprehensive analysis and general economic-environmental evaluation of cooling techniques for photovoltaic panels, Part I: Passive cooling techniques, Energy Conversion and Management, Volume 149, 2017, Pages 334-354, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2017.07.022.

[22] Efstratios Dimitrios Rouinis, Andreas K. Athienitis, Theodore Stathopoulos, Multiple-inlet Building Integrated Photovoltaic/Thermal system modelling under varying wind and temperature conditions, Solar Energy, Volume 139, 2016, Pages 157-170, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2016.09.023.

[23] Martín-Chivelet, N.; Gutiérrez, J.C.; Alonso-Abella, M.; Chenlo, F.; Cuenca, J. Building Retrofit with Photovoltaics: Construction and Performance of a BIPV Ventilated Façade. Energies 2018, 11, 1719.
[27] Anatoli Chatzipanagi, Francesco Frontini, Alessandro Virtuani, BIPV-temp: A demonstrative Building Integrated Photovoltaic installation, Applied Energy, Volume 173, 2016, Pages 1-12, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2016.03.097.

[28] Ioannidis, Zisis & Kapsis, Konstantinos & Buonomano, Annamaria & Athienitis, Andreas & Rounis, Eleftherios & Stathopoulos, Ted. (2017). Study on the Energy Performance of Semi-Transparent PV Façades Under Continental Climate. 1-12. 10.18086/swc.2017.12.04.

[29] J. Wajs, A. Golabek, R. Bochniak, Photovoltaic Roof Tiles: The Influence of Heat Recovery on Overall Performance, Energies. 12 (2019) 4097.

[30] Karthick, A. & Manokar, A. & Pasupathi, Manoj & Manoj Kumar, Nallapaneni & Chopra, Shauhrat & Ghosh, Aritra. (2020). Investigation of Inorganic Phase Change Material for a Semi-Transparent Photovoltaic (STPV) Module. Energies. 13. 3582. 10.3390/en13143582.

[31] Yunfeng Wang, Ming Li, Reda Hassanien Emam Hassanien, Xun Ma, Guoliang Li, "Grid-Connected Semitransparent Building-Integrated Photovoltaic System: The Comprehensive Case Study of the 120 kWp Plant in Kunming, China", International Journal of Photoenergy, vol. 2018, Article ID 6510487, 13 pages, 2018.https://doi.org/10.1155/2018/6510487.

[32] Shaeri, J.; Habibi, A.; Yaghoubi, M.; Chokhachian, A. The Optimum Window-to-Wall Ratio in Office Buildings for Hot–Humid, Hot–Dry, and Cold Climates in Iran. Environments 2019, 6, 45.

[33] Alessandro Cannavale, Maximilian Hö rantner, Giles E. Eperon, Hen ry J. Snaith, Francesco Fiorito, Ulbald o Ayr, Francesco Martellotta, Building integration of semitransparent perovskite-based solar cells: Energy performance and visual comfort assessment, Applied Energy, Volume 194, 2017, Pages 94-107, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2017.03.011.

[34] Kanchan Vats, Vivek Tomar, G.N. Tiwari, Effect of packing factor on the performance of a building integrated semitransparent photovoltaic thermal (BISPV) system with air duct, Energy and Buildings, Volume 53, 2012, Pages 159-165, ISSN 0378-7778, https://doi.org/10.1016/j.enbuild.2012.07.004.

[35] Rafaela A. Agathokleous, Soteris A. Kalogirou, Status, barriers and perspectives of building integrated photovoltaic systems, Energy, Volume 191, 2020, 116471, ISSN0360-5442, https://doi.org/10.1016/j.energy.2019.116471.

[36] Prieto, Alejandro & Knaack, Ulrich & Auer, Thomas & Klein, Tillmann. (2017). Solar façades - Main barriers for widespread façade integration of solar technologies. Journal of Facade Design and Engineering (JFDE). 5. 51-62. 10.7480/jfde.2017.1.1398.

[37] Benedetto Joseph, Tatiana Pogrebnyaya, Baraka Kichonge, "Semitransparent Building-Integrated Photovoltaic: Review on Energy Performance, Challenges, and Future Potential", International Journal of Photoenergy, vol. 2019, Article ID 5214150, 17pages, 2019. https://doi.org/10.1155/2019/5214150.

[38] Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, Rizalman Mamat, Solar PV and BIPV system: Barrier, challenges and policy recommendation in India, Renewable and Sustainable Energy Reviews, Volume 82, Part 3, 2018, Pages 3314-3322, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2017.10.013.

[39] Yujie Lu, Ruidong Chang, Veronika Shabunko, Amy Tan Lay Yee, The implementation of building-integrated photovoltaics in Singapore: drivers versus barriers, Energy, Volume 168, 2019, Pages 400-408, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2018.11.099.

[40] Farshad Azadian, M.A.M. Radzi, A general approach toward building integrated photovoltaic systems and its implementation barriers: A review, Renewable and Sustainable Energy Reviews, Volume 22, 2013, Pages 527-538, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2013.01.056.

[41] Zhang, Tiantian & Wang, Meng & Yang, Hongxing. (2018). A Review of the Energy Performance and Life-Cycle Assessment of Building-Integrated Photovoltaic (BIPV) Systems. Energies. 11. 3157. 10.3390/en11113157.
[42] Poh Khai Ng, Nalanie Mithraratne, Lifetime performance of semi-transparent building-integrated photovoltaic (BIPV) glazing systems in the tropics, Renewable and Sustainable Energy Reviews, Volume 31, 2014, Pages 736-745, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2013.12.044.

[43] Emami Razavi, Seyed & Jahangir, mh & Mousavi, Soroush. (2019). A Review Study About Photovoltaic Systems and the Energy Payback Time Calculation for Selected Modules. 6. 40-52.

[44] Yun-Wu Wu, Ming-Hui D. Wen, Li-Ming Young & I-Ting Hsu (2018) LCA-Based Economic Benefit Analysis for Building Integrated Photovoltaic (BIPV) Façades: A Case Study in Taiwan, International Journal of Green Energy, 15:1, 8-12, DOI: 10.1080/15435075.2016.1251924.

[45] Perez, M.J.R., Fthenakis, V., Kim, H.-C. and Pereira, A.O. (2012), Façade–integrated photovoltaics: a life cycle and performance assessment case study. Prog. Photovolt: Res. Appl., 20: 975-990. doi:10.1002/pip.1167.

[46] Dikai Huang, Tai Yu, Study on Energy Payback Time of Building Integrated Photovoltaic System, Procedia Engineering, Volume 205, 2017, Pages 1087-1092, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2017.10.174.

[47] Reddy, P.; Gupta, M.V.N.S.; Nundy, S.; Karthick, A.; Ghosh, A. Status of BIPV and BAPV System for Less Energy-Hungry Building in India—A Review. Appl. Sci. 2020, 10, 2337.

[48] Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, Recent advancement in BIPV product technologies: A review, Energy and Buildings, Volume 140, 2017, Pages 188-195, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2017.02.015.