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Potential of Building Integrated Photovoltaics as Building Envelope Material in Europe and its Thermal Analysis using Phase Change Material

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Abstract

Energy decarbonization is one of the main strategies for containing and eliminating greenhouse gases (GHG). The energy sector is regarded as by far the main responsible for the GHG emissions emitted into the atmosphere. In particular, the sector of buildings and construction is also one of the major contributors to environmental degradation due to its high energy demand. Building integrated photovoltaics (BIPV) is a promising technology that can reduce the overall energy consumption of buildings. The purpose of this article is to investigate the potential and contributions of BIPV systems in the European region. The review also aims at investigating the available literature on modeling and simulation techniques used for BIPV optimization. The reviewed modeling and simulation approach used in this paper includes the feasibility analysis of the BIPV system coupled with a heat source pump using TRYNSYS software, and comparative analysis of numerical models of four different BIPV system operational modes. The paper also discusses recent advancements and challenges that come across adopting this technology. Moreover, this paper presents how to manage the temperature rise and improve the thermal performance of BIPV systems using phase change materials. Based on this review we can argue, despite the high potential and available market, BIPV has not widely prevailed in the European region.

Keywords: Building Integrated Photovoltaics (BIPV); building energy materials; urban energy planning; built environment; renewable energy; building energy performance

1. Introduction

For the last two decades, the changing effect in the environment has been a worldwide challenge for many research scholars, environmentalists, policymakers, and many international organizations. The main cause of this change is the consumption of a tremendous amount of fossil fuels, which results in emitting greenhouse gases (GHG) which ultimately pollute the environment and affect the living health beings (Kayani et al., 2020). Growing economies around the world with an increase in their trade and resources are also considered as one of the factors for this rise in GHG emissions (Haseeb et al., 2018), also, in search of better employment people tend to move towards major urban cities, and this urbanization also leads to increase in energy consumption. The energy sector by far is the largest emitter of GHG emissions, and within this energy sector, the production of electricity and heating is the major polluting source. The contributions of world GHG emissions by different sector is shown in Figure 1 (Wang et al., 2022).

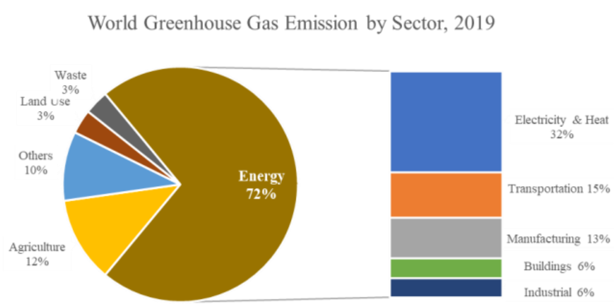

Figure 1 Greenhouse Gas Emissions by sector

Hence, increasing the share of renewable energy sources in the global energy outlook has been the main point of discussion for many nations in the last few decades. Solar energy is a renewable energy source by nature and is also a reliable source producing electrical power, more energy comes out in form of sunlight in a single day than the energy consumed by humans in an entire year. In terms of potential, solar energy surpass all other renewable sources by a big margin (Zhang et al., 2013). With more advancements in technology, the cost of solar PV systems decreased globally by 55% since 2013, which has further increased its usage dramatically (Zhang et al., 2013), and the technology continues to evolve further, especially in the field of Building Integrated Photovoltaics (BIPV). Heating and cooling of buildings account for one-third of energy use globally. The BIPV system not only can generate electricity but can also produce hot air for space heating in some cases (Abdelrazik et al., 2022). In the BIPV system, PV panels are part of the buildings, like windows, facades, roofs, etc, thus there is no need of installing solar panels on rooftops or in the open ground (Rahaman et al., 2022). Making PV modules part of the residential or commercial building will not be just a visual piece, but it will also generate electricity, and it will not require any additional space like other PV systems. It is also interesting to know that this integrated system can reduce the construction and material costs of the building (Rahaman et al., 2022). BIPV systems are well suited to locations that need electricity production but have very limited space (Kumar and Kumar, 2017). The current share of BIPV system in the overall PV industry is growing (Azadian and Radzi., 2013) as of now 80% of BIPV systems has been implemented to building exterior roofs, and rest 20% has been part of building exterior walls. Moreover, the BIPV system of building curtain walls is also on the rise (Tripathy et al., 2017). Due to the high heat-absorbing power of building material, the temperature rise in BIPV systems is higher than in PV systems, and high temperature reduces the energy conversion efficiency of PV systems. Phase Change Materials (PCMs) are capable to offset this reduction in efficiency in BIPV systems. PCMs with their ability to absorb the massive amount of thermal energies within different ranges of temperatures can reduce the temperature of solar cells and increase energy conversion efficiency. Moreover, when used in different approaches, PCMs can also enhance the performance of the building while also reducing GHG emissions (Khaki et al., 2017).

A simulation and modeling approach is also applied to the BIPV façade system. Experimental and simulation models are developed as part of the ventilated façade system for it to analyze and verify the adequacy of the available simulation tools. The key aspect of a BIPV/PCM façade concept is focused on reducing the peak operating temperatures of the PV modules and affecting action-reaction processes involving heat and mass transfer changes inside the façade elements. Experimental measurements are performed using an outdoor test cell to verify and validate numerical models. The experimental measurements and simulation results are compared for it to provide insight into the consistency between the theoretical results and the experimental data. However, this indicates several limitations that need to be properly identified for further design.

This present study is mainly focused on the recent progress of the BIPV system and the sustainable features it provides to evaluate the electrical and thermal performance of the system while also curbing the GHG emissions produced by the building sector. The rest of the paper is outlined as follows, the second section demonstrates a scenario of the current GHG emissions in Europe, and how this region is making efforts to reduce these growing emissions. In the third section, BIPV architecture, and identification of its suitable selection and location is presented. Section four reviews the role of PCM as the thermal regulator for the BIPV system, the challenges and limitations of the BIPV system, and the summary of the main conclusion are presented in the final section.

2. Solar energy and BIPV ecosystem in Europe

Solar energy is crucial to the shift to renewable energy. This energy source will assist in the achievement of the Europe Union's (EU) climate control aims and lessen its reliance on conventional fuels. Solar PV is the fastest-growing energy source in the EU. In 2020, the PV installed capacity in EU member states grew by 18 GW, accounting for 5.2% of the EU's total electricity output. As a result of the European Green Deal, solar power is now an integral part of Europe's clean energy future. Table 1 presents the Solar PV capacity installed and accumulated in the EU as of the end of 2019 (MW). According to industry estimates, the solar PV sector created around 357,000 jobs in 2020 (Gholami and Røstvik, 2020). A huge solar potential exists compared to the presently PV installed.

capacity in Europe and at the same time segment of integrating PV into the building envelope is emerging (Zanetti et al., 2017).

Table 1. Solar PV capacity installed and accumulated in the EU member states up to 2019 (MW) (Gholami and Røstvik, 2020)

	2018 cumulated	2019 installed	2019 cumulated
Germany	45181.0	3856.0	49016.0
United Kingdom	13118.3	497.7	13616.0
Italy	20107.6	759.0	20864.0
Spain	5239.9	3 992.9	9232.8
France	9617.0	965.6	10575.9
Belgium	3986.5	544.0	4530.5
Holland	4522.0	2 402.0	6924.0
Czech Republic	2075.1	24.9	2100.0
Greece	2645.4	148.4	2793.8
Romania	1385.8	0.0	1317.0
Austria	1437.6	223.0	1660.6
hungry	726.0	653.0	1277.0
Poland	562.0	755.0	1317.0
Bulgaria	1032.7	32.3	1065.0
Denmark	995.0	85.0	1080.0
Sweden	428.0	270.0	698.0
Portugal	667.4	220.0	907.0
Slovenia	221.3	0.7	222.0
Slovakia	472.0	0.0	472.0
Malta	131.3	20.0	150.6
Finland	140.0	75.0	215.0
Cyprus	118.5	10.2	128.7
Luxembourg	130.6	10.0	140.6
Lithuania	82.0	1.0	83.0
Estonia	31.9	75.1	107.0
Ireland	24.2	11.8	36.0
Croatia	67.7	1.3	69.0
Latvia	2.0	1.0	3.0

It is also reported in one article that BIPV can cover electricity demand in various EU member states i.e. from 24% (France) to 40% (Italy) (Gammal et al., 2016). Europe constitutes the largest BIPV installed market (i.e., 42% globally), particularly due to the favorable incentives and available funding given to projects in France, Italy, and Germany. Still, BIPV is considered a niche market, in 2020 the share of BIPV was estimated at merely 3% of the overall global PV market.

The United States (US) ranks second in dominating the BIPV market globally, while Asia has started adapting BIPV projects as well. Table 2 shows the result of the BIPV market analysis by region up to 2020 (Osseweijer et al., 2018), as we can see from the data the growth rate of BIPV for each region has been increasing each year, this is envisaged that the adaptability of BIPV projects in terms of aesthetic and attractiveness is growing along with the decrease in the cost of the project.

Table 2. Compounded Annual Growth Rate (CAGR) of the Global BIPV Market by region up to 2020 (Osseweijer et al., 2018).

Region/Country	2016	2017	2018	2019	2020	CAGR (%)
Asia/Pacific	772	1159	1672	2329	3134	47.8
Europe	1441	2103	2929	3807	4838	39.7
Rest of world	184	263	355	451	561	37.9
USA	675	917	1200	1491	1766	33.0
Canada	86	119	157	190	228	32.6
Japan	268	349	434	520	612	27.5
Total (GW)	3.4	4.9	6.7	8.8	11.1	

3. BIPV Reducing Buildings Energy Consumption in Europe

In 2013, the average annual energy consumption for all types of buildings in EU member states was around 180 kWh/m2. This value may vary from member to member, ranging from 55 kWh/m2 in Malta to 300 kWh/m2 in Estonia, with the latter being notably higher than the EU average. The differences are mainly due to the climatic and weather conditions, and high prices of space heating and air cooling (European Union, 2021). Space heating is the most consumed end-use product in the residential sector accounting for nearly 68%. Water heating and electrical appliances come second, and third with a reasonable contribution of 13% and 12% respectively (European Union, 2021).

Table 3. EU building energy consumption trajectory by 2030 (Gholami et al., 2021)

Year	2012	2020	2030
Energy Consumed by Buildings (kWh/m2/year)	200	160	135

Also, it is pertinent to mention that the Energy Consumption of Building Directives (ECBD) will soon come into effect, which will regulate that all new buildings should follow the zero energy guidelines policy, the objective is to produce as much energy from the building as is consumed (Maduta et al., 2023). The EU committed itself to reducing its building energy consumption by 20% starting from baseline projections (i.e., 200 kWh/m2 in 2012), and the energy reduction target is at least 32.5% by 2030. Table 3 presents the energy consumption data from the baseline year and expected projections until the year 2030 (Gholami et al., 2021). For BIPV to contribute to making zero energy cities in Europe, a business model needs to be implemented where at least three players namely BIPV manufacturers, BIPV installers, and BIPV contractors will play their crucial roles.

Table 4. The average annual geographical and technical potential of BS for BIPV systems in a few selected EU member states (Gholami et al., 2021)

No	Country	BIPV Geographical Potential of BS (kWh/m²)	BIPV Technical Potential of BS (kWh/m²)
1	Austria	792	143
2	Belgium	715	129
3	France	766	138
4	Germany	720	130
5	Italy	999	180
6	Netherlands	714	128
7	Spain	1112	200
8	Sweden	670	121
9	UK	706	127
10	Switzerland	818	147
-	EU Average	806	145

By implementation of this model, BIPV can be seen as a building envelope material option for Building Skin (BS), like wood, brick, or aluminum (Osseweijer el al., 2018). The BS potential can be determined from the average BIPV values from different aspects of the roof area and the location of the building facades. The average annual geographical and technical potential of BS of a few EU member states for BIPV is presented in Table 4. It is also to be noted that the geographical potential of BS is constant, and this constant value varies from location to location depending on average solar irradiation on the solar roof which is spread over different facades with different orientations (Gholami et al., 2021). The value in the table above indicates, if BIPV is used for the entire skin of that building i.e., roof plus façade, the technology can cover the total energy consumed by the building, and if there is an increase in the gross area of the building skin, that increased area also has to be covered by BIPV to supply the additional energy demand of the building. The data in the table also states that on average value BS of any EU building the BIPV technology has the potential in making zero energy cities in the EU.

4. Review of BIPV applications

BIPV system consists of a solar PV module that is integrated into the building envelope replacing conventional materials of the building. The use of the BIPV system has been encouraged by European Strategic Energy Technology (SET) (Kamel and Fung, 2014), and also by ECBD with its guidelines to implement net zero energy building in all EU member states (Yang et al., 2019). This implementation will also be a vital step in reducing energy demand and producing energy generation on-site.

There are a wide variety of BIPV modules are available in the BIPV market, which mainly classified into two classes, namely BIPV modules for roofing systems, which consists of PV modules that are part of the roof structure of the building for the full roof system, and solar tiles, and other is facade BIPV modules which are further classified into cold and warm facades, depending on module containing a ventilated air gap or not (Pearce et al., 2017).

Figure 2. a) BIPV Tiles installed on building roof b) Home-integrated BIPV modules c) Examples of BIPV glazing glasses d) Examples of BIPV foil (Gholami et al., 2021)

Figure 2 depicts different PV modules available in the market (Gholami et al., 2021). Figure 3 below shows the BIPV system application a17pplied to wider known public buildings in Germany (Heinstein et al., 2013). As illustrated in the figures, the BIPV system is also very aesthetic to its viewers and can enhance the building's appearance. Solar cells used in the BIPV modules have transparent or opaque spaces between them, which make the system fit to use for building skylights, windows, and awnings (Gholami et al., 2021).

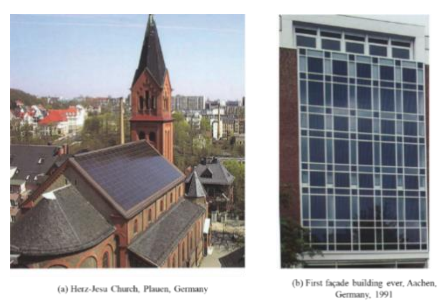

Figure 3. Example of BIPV systems applied to public buildings in Germany (Heinstein et al., 2013)

Thus, the BIPV system not only produces electricity for the building from solar modules but also serves as the envelope of the building material and structure, hence there is no doubt that BIPV is capable to reduce the cost of materials in the overall construction of the building. Figure 4 shows different BIPV applications applied to buildings in European cities as per the requirement of the architecture and design of the building (Heinstein et al., 2013).

Along with many benefits the BIPV system has, the system can get damaged with water immersion into PV modules, hence waterproofing and durability of the BIPV system should be kept in mind before ensuring the architectural design of the building. Meanwhile, further development in this field is now focused on making a design that enables the replacement of PV modules after integrated installation, and not just the extended life of the system.

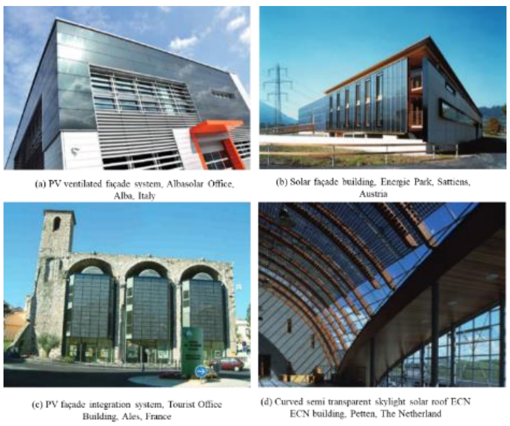

Figure 4. Architectural and design-oriented solar PV integrated buildings in Europe (Heinstein et al., 2013)

5. Modeling and Simulation Approaches to Optimize the BIPV System

Various simulation approaches have been applied to optimize different applications of BIPV systems. In one study, researchers performed the modeling, simulation, and feasibility analysis using the virtual-based TRYNSYS software of the BIPV system in a cold climate in Canada (Kamel and Fung, 2014). The BIPV system of the house was coupled with an air source heat pump (ASHP), and the developed TRYNSYS model was simulated to predict the seasonal performance of the heat pump. The simulation results helped estimate the energy savings and predict the GHG emissions reduction from PV panels, which additionally benefitted in energy cost savings in electricity bills and GHG emission credit of electricity generation from renewable energy resources.

In the study, the TRYNSYS model consisted of individual components, which represented the overall components of the system. There are existing BIPV components available in TRYNSYS libraries. The model was simulated to predict the hourly temperature for the whole year, thermal energy generation, and electricity produced from PV devices. Figure 5 shows the outlet air temperature of the PV systems based on TRYNSYS simulation.

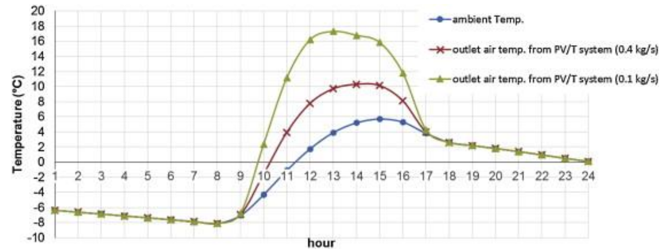

Figure 5. Hourly Validation of Outlet Air Temperature from the PV system (Kamel and Fung, 2014)

Siliang Yang et al., (Yang et al., 2019) in another study performed a comparative analysis of four different types of BIPV building models in a range of climate zones in Australia. The four types of BIPV operational modes include BIPV single skin façade (SSF), non-ventilated BIPV double skin façade (DSF), naturally ventilated BIPV, and fan assisted BIPV. The model was developed in the TRYNSYS simulation tool. In addition to operational modes, two types of PV glazing were applied to the models with different visible light transmittance (VLT). The simulation results showed that naturally ventilated BIPV-DSF with a lower VLT level of 27% maintained better indoor temperature during hot climatic conditions, while non-ventilated BIPV-DSF with a higher VLT level of 37.5% provided more comfortable temperature during cold climate conditions. Moreover, it was found that the thermal insulation of PV glazing had hardly any effect on the indoor temperature of BIPV-DSF. Figure 6 illustrates the numerical model of four different types of BIPV building models, and Figure 7 shows the dynamic model of TRYNSYS containing detailed information on building geometry.

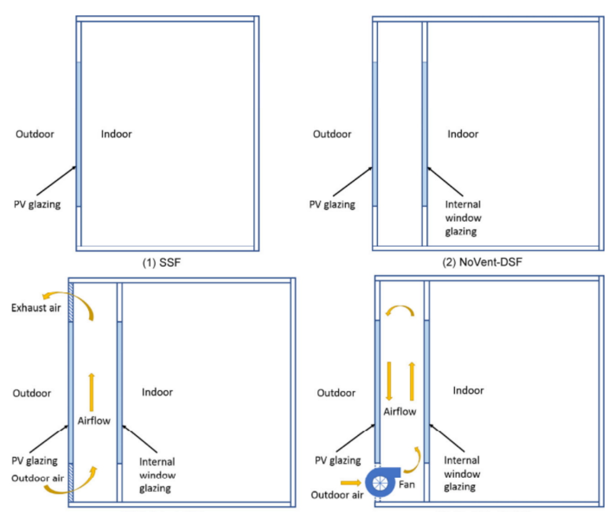

Figure 6. Schematic Diagram of four BIPV Operational Nodes (Yang et al., 2019)

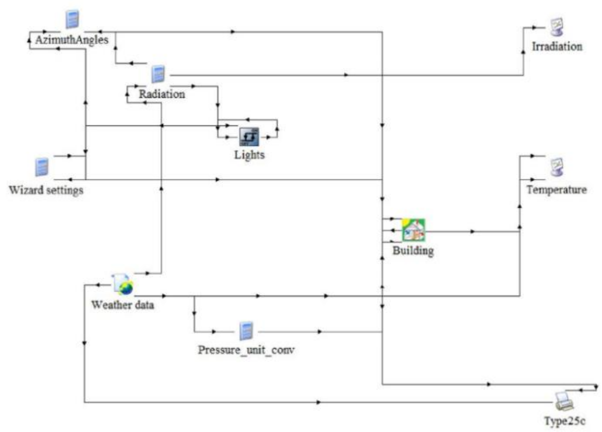

Figure 7. Building Simulation Model in TRYNSYS (Yang et al., 2019)

Figure 8 shows the simulation results and comparison of different PV operational modes in different operative temperatures for Australia.

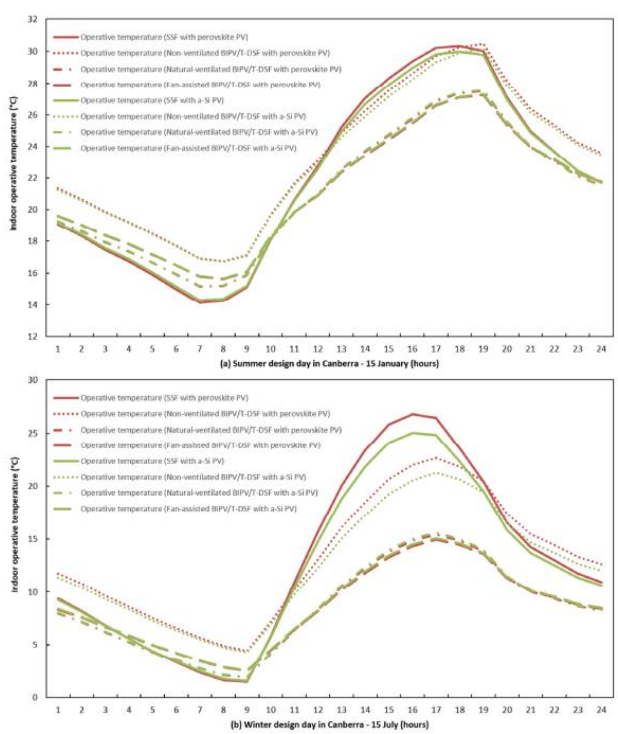

Figure 8. Comparison of different BIPV operational modes during summer and winter in Australia (Yang et al., 2019)

6. Identifying and selecting a location for a BIPV system

There are many technologies of solar cells available in the market, but not all solar cells can be used for building applications. This section will discuss what consideration needs to be taken when choosing a building-integrated PV system. The first and foremost step is the location of the building where an appropriate BIPV system can be implemented. If the building is in a congested area, and there are other buildings sideways, then all the windows and walls of the building are likely to be shaded during the daytime, thus, building an integrated solar wall system might not be a good option in this case, while solar roof system can perform well in this situation.

Similarly, a north-facing PV system is considered more suitable, since it will receive maximum solar irradiation during the daytime. In addition, if the building involves complex architectural designs, then flexible solar modules of thin films can be applied. Also, the surrounding weather and climate conditions of the location are important factors to be considered when selecting a site for BIPV.

The next important step is to investigate the economic feasibility and cost of the project, this investigation includes the analysis of various important parameters which include energy saving, cost-benefit ratio, and also economic payback time of the project, in addition to this life cycle assessment of the project can also be determined to estimate the overall GHG emission generated. The next important step is to investigate the economic feasibility and cost of the project, this investigation includes the analysis of various important parameters which include energy saving, cost-benefit ratio, and also economic payback time of the project, in addition to this life cycle assessment of the project can also be determined to estimate the overall GHG emission generated from the total electrical output of the project, and that can be compared with GHG emission generated of the same electrical output produced from using conventional fuels (Osseweijer et al., 2018).

The selection criteria for the BIPV system are illustrated in figure 9.

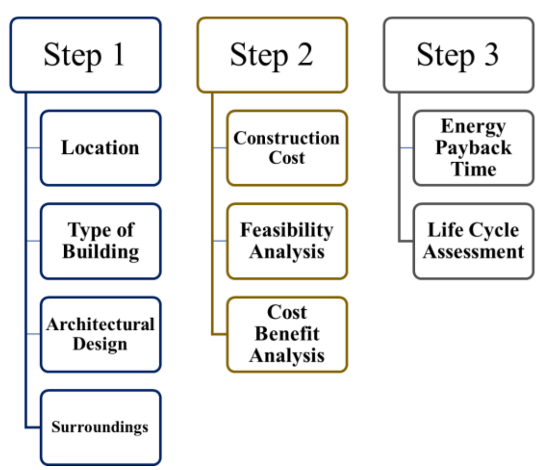

Figure 9. Selection criteria of the BIPV system

7. Thermal regulation of the BIPV system

Out of all the solar irradiation incidents on PV devices, only about 16-20% get converted into electricity, and the remaining transformed into heat, which ultimately increases the temperature of solar cells, and it is a known fact that a rise in temperature of PV solar cells has an adverse effect on solar to electrical energy conversion efficiency, any associated temperature rise in PV panels reduced its efficiency to 0.4-0.5%/K, concerning this, there is also an active similar heat gaining issue with BIPV system, commonly air water or water cooling approach has been followed for heat dissipation, which requires large maintenance while also increasing operating cost, alternatively a duct is also arranged behind the they were used to reduce the peak operating temperature of PV module. Figure 10 (Biyik et al., 2017) below illustrates the internal heat balance mechanism of building façades of both the BIPV system and the BIPV/PCM system.

PCMs can also provide passive energy storage to buildings while being incorporated as solid-state transition PCMs into gypsum wallboard (Pearce et al., 2017). panel which allows airflow from the back of the PV panel, but implementing all these proposed solutions has not produced the desire results.

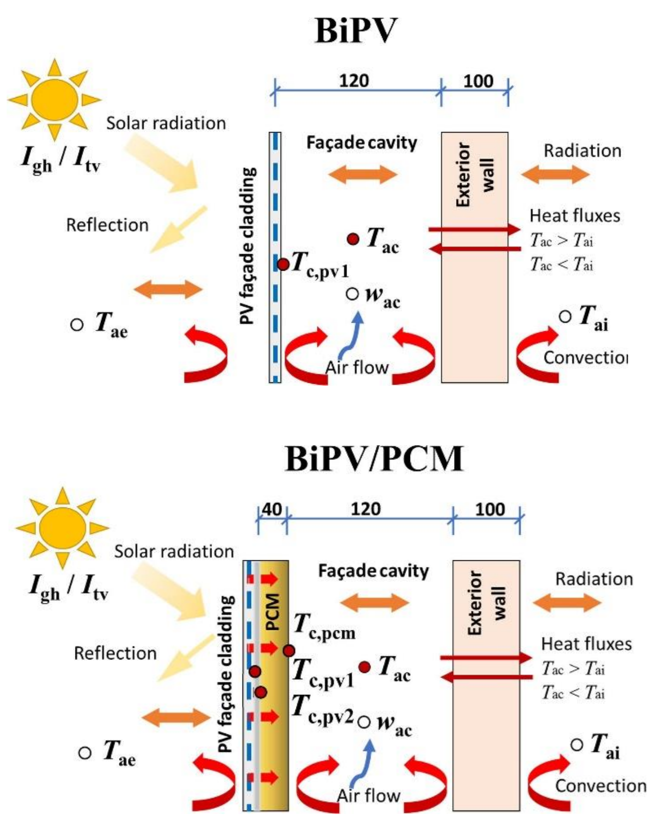

Figure 10. Heat Balance Mechanism of BIPV System and BIPV/PCM System (Biyik et al., 2017)

Another innovative method for temperature control of electronics includes the use of phase change materials (PCMs). This application of using PCM on the rear side of PV module cladding was developed as part of building facades, as PCMs can absorb a large amount of energy at a constant phase transition temperature. There are various studies have already taken place on the use of PCMs as heat dissipation materials, Ismail et al. presented the experimental and numerical studies of glazing filled with different thicknesses of PCMs. Solar-aided latent heat storage systems and their thermal performance have been studied by Esen (Biyik et al., 2017), also the problems occurring in solid-liquid phase change and its probable solutions via numerical technique have been studied by Dincer and Rocen (Crawford et al., 2006).

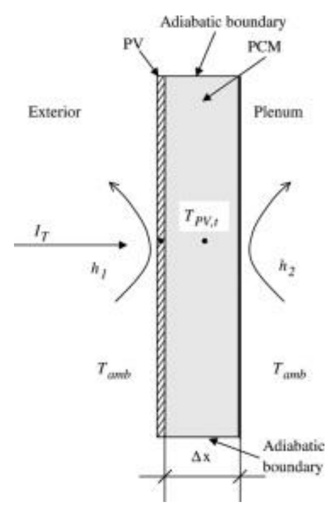

Figure 11. Heat Transfer system in PCM system (Pearce et al., 2017)

After all these studies, incorporating solid-liquid PCM for thermal regulation of Building Integrated PV is still a novel approach for controlling building temperature, and it is also proven in various studies that under good ambient conditions a PCM-supported BIPV system may enable the PV module to operate at good solar to electrical efficiency. This system also comes with the additional benefit that all the stored heat in the PCM can be released and provide heating building during the night. A schematic diagram of heat transfer using PCM is presented in figure 11 (Pearce et al., 2017). PCMs that have been used in BIPV applications are available commercially, and they also have a phase change melt temperature close to PV characterization and testing temperature of 25°C. The most common PCM is RT25, which is paraffin wax, i.e., long chain saturated hydrocarbons, the other common PCM is GR40, which is granulated in nature and is a mixture of both paraffin waxes and inorganic material. Both PCMs contained in an aluminum container are regarded as non-toxic, they are also chemically inert and do not have any adverse impacts on human health or the environment. Thermochemical properties of PCM (RT25, and GR40) and aluminum are presented in Table 5 (Peng et al., 2011; Ravyts et al., 2019; Crawford et al., 2006).

Table 5. Thermochemical properties of PCM (RT25, and GR40) and aluminum

Property	PCM		Container
	RT25 (Liquid)	GR40 (Solid)	Aluminium
Density (Kg/m³)			
Solid	785	710	2675
Liquid	749	N/A	N/A
Specific Heat (J/m³/K)			
Solid	1,413,000	1,065,000	2,415,525
Liquid	17,97,000		N/A
Thermal Conductivity (W/m/K			
Solid	0.19	0.15	211
Liquid	0.18	N/A	N/A
Melting Temperature	26.6	43	N/A
Latent Heat of Fusion (J/Kg)	232,000	82,000	N/A
Kinematic Viscosity (mm²/s)	2.4	N/A	N/A
Flash Point (°C)	164	187	N/A
Volume Expansion (/K)	0.001	Almost None	2.34×10^{-5}

8. Challenges in adapting a BIPV system

Till now, one of the bigger challenges of any PV system is its low energy conversion efficiency. Currently, the solar-to-electrical conversion efficiency is approximately 25%, and that is also reported at a laboratory scale, the actual efficiency of modules operating commercially is even lower, and it would eventually take time to be more competitive in the future. Thus, BIPV operating with PV modules having lower efficiency extends economical payback time and leads to lower investment in this technology.

Solar power is the main energy source in BIPV systems, and its optimum availability is the major question, hence it would be challenging to select the best PV modules for BIPV systems in regions where solar insolation is low.

The main purpose of the BIPV system is to generate electricity using PV modules while also maintaining the level of integration of the system to act as building envelopes like walls, roofs, skylights, etc. However, due to complicated structures, and different mounting design variations, the total cost of the BIPV system is itself very high, also, conventional building materials can solve many problems associated with building very easily, while in particular, BIPV not effective when dealing with any damaged system of the building (Crawford et al., 2006).

The temperature rise of PV panels is a major concern, and sometimes the temperature of the solar cell may reach up to 70°C, proper ventilation and implementing PCMs can reduce the heat and increase the electrical performance.

The lifetime of the BIPV system is also one of the greatest challenges. Usually, PV modules are manufactured to provide the output power for 10-20 years, whereas any building is constructed for over 50 years. Hence replacement of the BIPV system with another new BIPV system is a big challenge.

Due to their lack of knowledge and understanding of the system, architects, engineers, and installers face structural issues while designing and installing PV systems into the building envelope. Designers also face the challenge of the extra load of the BIPV system, which might damage the roof or any construction part of the building.

The majority of countries have pledged at the United Nations (UN) climate summits to reduce their overall GHG emissions, still, fossil fuel companies in those countries have a dominant influence, and the vast majority of power plants run on conventional fuels. Countries have developed policies to spur the growth of the renewable energy sector, attention has been paid to renewable energy technologies like solar PV, solar thermal, and concentrated solar power, rather than to solar BIPV systems.

9. Conclusion

Despite its wider applications across the world, very limited attention has been given to BIPV in the European region, but it was also revealed there is a huge potential for this technology in EU member countries. Also, we covered how BIPV can be regarded as the sustainable and environmentally friendly solution in reducing building overall energy consumption and making zero energy cities in EU states. Based on the review and advancement of the BIPV system, the following concluding remarks can be made.

- Despite having a considerable amount of solar potential, many EU nations are behind in harnessing solar power and adapting new solar technologies.
- Unlike conventional solar PV systems, the BIPV system takes no additional space on the installation site and can be integrated with the building façade or any other building envelope.
- To obtain maximum benefits from the BIPV system, a proper selection procedure should be followed.
- The temperature rise of solar cells is a big issue, which can be offset by introducing PCMs. However, PCMs or other devices for reducing cell temperature add to the cost of

the system.

- One of the bigger challenges that the PV industry is facing is the lower energy conversion efficiency, and efficiency gets further lower, and electrical losses get higher when the inverter and batteries are connected to the system, where batteries for the energy storage system, still take up the major chunk of the total cost of the BIPV system. New materials for solar cells along with highly efficient PCMs for cooling measures can improve efficiency.
- Investors are more interested in investing in other solar technologies like solar thermal and concentrated solar power, they believe BIPV is not the preferred technology, hence public awareness is important so that the socioeconomic benefits of the system can be examined.

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