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A review of Building integration of Solar PV Systems

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***Abstract*—Building Integrated Photo Voltaic (BIPV) systems are a promising technology that offer numerous benefits, including energy savings, reduced carbon emissions, and improved aesthetics. However, designing and implementing BIPV systems that are efficient and effective requires careful consideration of several factors. These include high building design, colored PV modules, optimization systems, and policies and regulations. By integrating PV modules into the building's design and using advanced control and monitoring systems to maximize energy generation, BIPV systems can achieve significant energy savings and carbon emission reductions. The deployment of BIPV systems is also influenced by financial incentives and building codes. This review paper, will first discuss the various definitions proposed for different types of energy consumption, followed by the concept of "prosumer." The next section will focus on policies, followed by the different types of technologies for BIPV proposed in the literature, including pioneering countries in the sector. After reviewing the costs of various models and the different optimization techniques proposed in the literature, it will conclude by discussing the various challenges and opportunities of such systems.**

Keywords— BIPV, Building integration PV, Photovoltaic, Optimization, Genetic algorithm.

I. INTRODUCTION

Renewable energy options such as wind and Photo Voltaic (PV) power have the capacity to revolutionize the energy system currently dominated by fossil fuels, and shift it towards a completely sustainable energy system[1]. By balancing economic and social concerns while simultaneously preserving the environment, using clean energy helps to achieve sustainable development goals. [2]. Global energy usage is classified into three main categories: buildings , industry and transportation. Recent figures show that, all three of these sectors equally contribute to overall energy consumption, highlighting the need for a comprehensive approach to energy reform that targets efficiency improvements across all sectors [3].

However, the world's population is growing, and with it comes a greater demand for primary energy and an increase in greenhouse gas emissions, particularly CO2. The sector of building is responsible for 38% of the primary energy used in the world and contributes to around half of emission of greenhouse gas worldwide, with 20% of those emissions coming from building operations[4-5].

Buildings have an enormous energy intensity, and reducing it is vital from both economic and environmental perspectives[6]. Undoubtedly, integrating solar Photo Voltaic (PV) systems is an appealing option for partially meeting the electricity needs of buildings. [7]. The solar energy usage in the construction industry is becoming increasingly popular in many countries[8]. The declining costs of technologies of solar conversion, coupled with the increased PV module efficiency and growing worldwide interest in producing green electricity, make solar energy an increasingly attractive option[9-10].

BIPV (Building Integrated Photo Voltaic) concepts have become more popular in recent times due to several appealing aspects besides energy generation. These include integration into the building envelope without visible attachments, cost reduction compared to retrofitting with PV panels, and improved architectural aesthetics[11].This approach merges architectural design with renewable energy generation, thereby increasing buildings efficiency in terms of energy through the optimization of electrical, thermal, and optical properties of the PV elements [12]. Based on the existing European regulations on performance of energy efficiency in buildings, including Ordinances 2010/31/EU and also 2012/27/EU, respectively [13-14]. The buildings efficiency in energy must be evaluated using a methodology that takes into account various factors, incorporating the structure's thermal characteristics, adequate natural illumination levels, systems for cooling and heating , the use of renewable sources of energy, the addition of passive air conditioning and heating elements, quality of interior air , shading, and architectural design [15].

II. DEFINITIONS

A. NZEB NetZEB PEB

According to the regulations set forth by the European Union, NetZEBs are described as buildings with exceptional performance, which are distinguished by their extremely low energy requirements that are offset by renewable sources-based energy that are generated on-site or in the vicinity of the building [16].

For newly constructed buildings, numerous different terminologies and concepts were proposed in addition to the NetZEB idea. There were also discussions in the literature about how to interpret these significations [17]. Generally, a

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Net Zero Energy Building maintains a null balance of energy over the course of a year, where the energy quantity coming from the utility grid equals the quantity exported back to the utility grid. On the other hand, a Zero Energy Building (ZEBs) is designed to be highly efficient and has a yearly delivered energy that is equal to or lower than the on-site exported energy [18-19]. Positive Energy Buildings PEB, which were first established in France and Denmark, are characterized by generating more renewable energy on-site than the amount used over the course of a year [16].

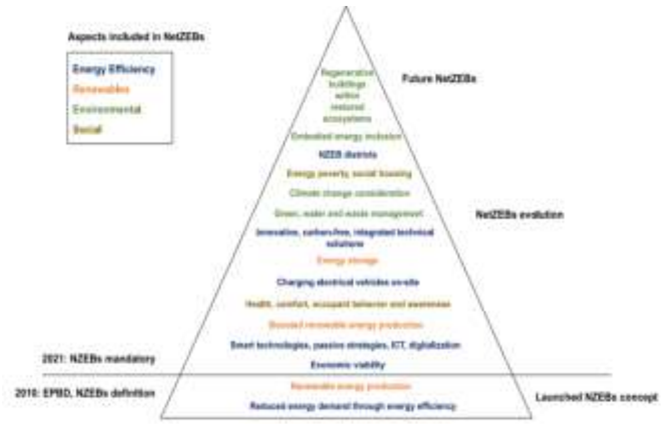

Fig. 1. Evolution of the NZEB concept with aspects [20]

III. Prosumer And Energy Transaction Policies

The importance of sustainable energy extends beyond the protection of the environment, as it is also essential for the growth of economies and societies around the world [21]. The United Nations has created Sustainable Development Goals (SDG) to combat issues such as famines, droughts, wars, plagues, and poverty caused by recent climatic changes and promote sustainability worldwide. One of these goals, SDG 7, is to guarantee inexpensive and green energy access to all [22].

A prosumer is an individual or entity that not only consumes electricity from the grid but also generates their own electricity using solar PV or other renewable sources. They may even be able to sell excess electricity back to the grid depending on the feed-in policy in place [23,24]. In number of countries the Feed in Tariff (FiT) has been a crucial policy in promoting the development of renewable energy-based power integration into the utility grid [25]. The difficulties associated with the FiT approach resulted in the introduction of net billing net metering, which have been recognized as effective tools to promote the adoption of electricity prosumption worldwide [26].

IV. Penetration Of BIPV

Currently, the BIPV idea has been warmly embraced in North America and Europe. Many European nations, including Germany, France, and Italy, have made substantial contributions to the regional expansion of the BIPV industry. In 2014, these three countries alone accounted for 87% of the European market share. Additionally, financial incentives in the form of subsidies on photovoltaic integration from supportive directives by the European Commission are anticipated to aid the market's quick expansion [27]. Based on the Becquerel Institute's 2018 estimates, France now holds the title for the highest installed capacity of BIPV in the world, with 2.7 GWp. This accounts for approximately 27% of the total BIPV capacity installed worldwide. The global BIPV installed capacity in 2018 can be seen in Figure 2 [28].

The commercial segment has become the largest contributor to the BIPV 2020 market share, mainly because more people are becoming aware of green building infrastructure with zero emissions. BIPV installation improves the aesthetic of commercial buildings and dramatically lowers energy usage, which promotes product adoption in this market area [27]. The commercial sector, typically found in densely populated areas, often requires buildings to be designed in a vertical, narrow, and high-rise style [29]. Designers of solar energy face new challenges urban high-rise structures' limited PV roof space panel placement. This has led to an increased interest among researchers to find solutions, including integrating semi-transparent and colored PV in building facades, windows, and walls [30].

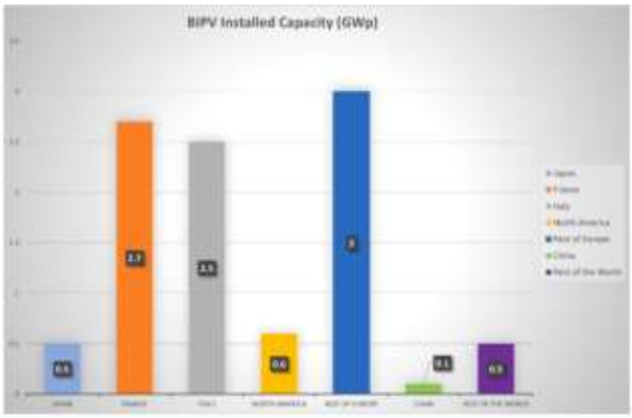

Fig. 2. BIPV estimated capacity gloabllay installed in 2018 [28]

A. Type of BIPVs configurations

BIPVs may be categorized into four broad groups: PV shadings, façades, balconies and roofs integration (as depicted in Figure 3). louvers and lamellas or overhangs are all options for installing PV in shading mode. Applied PVs, continuous or intermittent skylights PVs, and PV tiles are all examples of roof integration. Applications for walls and windows that are (semi)transparent have been considered in the context of façades. When it comes to wall classification, there are four categories based on integration: rain screens, curtain walls, double skin which are non-structural and opaque PV which are structured [16].

The double skin wall integration may be divided into two types. One category is the ventilated façade that is positioned near the wall and expands the building's thermal barrier up to 30 cm away from the existing wall. The second method of integration involves using heat dispersion, increasing daylighting, and allowing enough area for maintenance of walls over greater lengths of up to 1.0 m. With PV Curtain Walls, the conventional glazing system of façade is swapped out with PV glass with the right amount of transmittance, enabling it to produce energy, offer internal illumination, and provide shaded circumstances [16].

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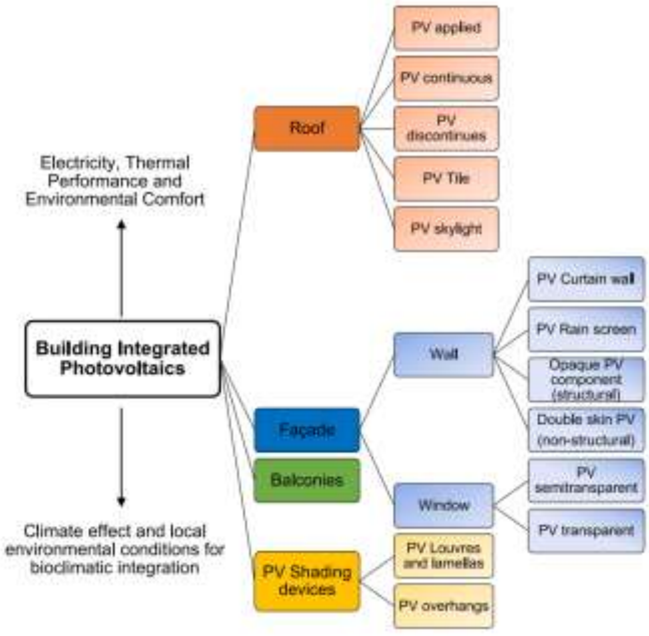

Fig. 3. Building integration design and appliaction based categories of BIPV [16]

B. BIPV on high-rise buildings

In today's big cities, high-rise buildings are seen as necessary and offer various benefits to the country. In addition to providing a good ratio of rentable floor surface per area of land , high-rise buildings have become in some countries a symbol of economic advancement. Szolomocki categorized current and future building shapes into four categories: extruder, rotor, twister/tordos, and free form. The extruder type has the same cross section for the entire height of the building. Rotor-shaped buildings are similar to extruders, but their shape resembles a drill bit. Tordos or twister buildings have a solid, twisted form with an identical "twister" façade on each level. Finally, the free-form configuration is a blend of straightforward geometrical elements, such as lines, solids and surfaces. According to Szolomocki, these shapes represent the trend in building shapes for current and future generations [29-31]. Implementing BIPV system into the building envelope could be a significant challenge, given the current trends in building shapes. As the available roof area is often limited, it may be necessary to utilize the façade area with the purpose of achieving optimal energy output [29].

From a technical perspective, BIPV applications on the façade of tall buildings have promising potential, according to the research conducted by Hoseinzadeh on the energy efficiency of BIPV in a tall building situated in Tehran [32]. Regarding the EN 50583-1:2016 standard, the BIPV module should not only serve as a traditional material for building but also perform extra functions such as structural stability, thermal barrier properties, weather and fire protection, and more. Therefore, integrating BIPV into a building envelope provides the building with multiple capabilities, including on-site energy production, self-consumption, and solar shading, which can help cool down the building interior, thanks to the silicone-based solar PV module [33].

C. BIPV technology

The "Frame of Horizon 2020 projects Dem4BIPV and PVSITES" report included a survey that focused on finding solutions to increase the interest in BIPV. The survey revealed the following factors that have the most significant impact on driving BIPV interest [28]:

- Reduced component prices for PV systems,
- System improvements that boost competitiveness,
- Enhanced BIPV product customization choices and easthetic,
- Variety of product manufacturers that stimulate competition,
- Growing regulatory exigencies to improve building sustainability.

[34] states that significant research has been conducted in previous years to increase the performance of BIPV systems, focusing on both the PV cell and its system levels. The BIPV system is divided into three groups by Biyik: PV technology, market names and application type. Several studies highlight the significance of aesthetic of the structure design, stating that function, aesthetics, technology, and cost, are more significant than large integration [29]. Lu and Law conducted a study demonstrating that reduction of the heat obtained from windows can be linked to the utilization of semi-transparent technologies of BIPV by approximately 65%, thereby lowering energy consumption required for cooling [35]. Another study on semi-transparent technologies of BIPV conducted by Joseph showed that for windows the use of semi-transparent result in energy savings ranging from 11% to 19% [36].

D. Colored PV

To achieve the goal of having buildings with net zero energy consumption, numerous parties choose to incorporate renewable energy technology into their structures. This is particularly evident in Europe, where the Efficiency in Energy Directive 2018/2020 mandates that the Renewable Energy Sector (RES) must reach a target of 32% by 2030 [37]. Many are aware that a significant portion of European buildings consist of historic structures. In the optic to achieve the energy efficiency goals set by the EU, it's necessary to improve all existing buildings, including those of historical significance. However, there's a concern that implementing BIPV may diminish the architectural value of these historic buildings [29].

Fig. 4. PV cells as element of building patterns [38]

Considerable research has been conducted thus far to address the aesthetic concerns of PV technology, with colored PV emerging as a popular solution. Colored PV was developed to provide a means of camouflaging or integrating PV modules with a building's appearance. For instance, the PV modules can be manufactured to mimic the same pattern or color as the original building material, effectively concealing them from view. Utilizing colored PV

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in a creative fashion has the potential to increase social acceptance of incorporating building-integrated photovoltaics (BIPV) into existing historic buildings. [39].

Several varieties of colored PV are currently accessible on the market [30], including: Solar cells equipped with an anti-reflection coating. PV-active layers that are colored and/or semi-transparent. Special solar filters in the form of coatings, layers or interlayers with different colors or patterns. Encapsulant films made of colored polymers. Front glass altered via the use of coating, printing, or other finishing processes.

The choice of colored PV is determined by the desired aesthetic appearance and the location of the building where the PV module will be installed. The newest colored PV technology uses a printing digital ceramic on the PV glass's front, which provides a way to hide the solar cell produced by crystalline silicon. Nevertheless, on the front glass any printing will reduce light transmission, thereby affecting module efficiency, despite being a technology that harnesses solar energy [29].

E. Colored PV module sensitivity analysis

In [43] To determine the best colored photovoltaic (PV) module for integrating with a building, a sensitivity analysis was performed. Four different types of colored PV modules were examined in the analysis. The PV layout was created using PVSyst and an inverter was incorporated to create a complete Building Integrated PV (BIPV) system, the design of the PV layout using 1418 square meters on the building rooftop was also discussed. To provide a benchmark for comparison purposes, a conventional PV module type was also included in the study. The total annual production of the conventional PV module was significantly greater than that of all the colored PV modules considered in the analysis, with a production of 435,105 kWh/year. Nonetheless, the conventional PV module will serve as a reference point for evaluating how well the colored PV modules perform in comparison. Without the traditional Silk Plus PV module included, the colored Silk Pro module is the one giving the highest production of energy, with an annual total production of 326,101 kWh/year [29].

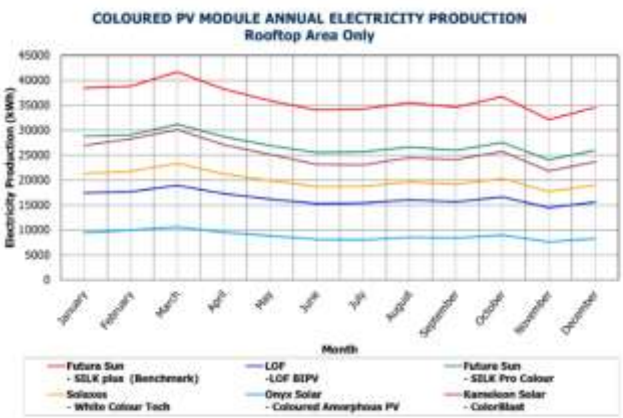

Fig. 5. Colored PV module annual electricity production [29]

F. Façade PV module tilting angle sensitivity analysis

In this study conducted by [29], to determine the best angle for tilting PV modules on the east and west sides of a building an analysis based on the sensitivity has been performed. The methodology described above was used, and the analysis was conducted using the colored Sun Silk Pro Futura, which is based on research findings. Like the colored PV module analysis on sensitivity, the optimal angle was chosen based on the highest production of energy by year. The study found that the best angles for both facades were 50 and 60 degrees, with production of energy annually of 201,236 kWh/Yr and 200,979 kWh/Yr for the façade east-facing oriented. As there was negligeable difference in yearly energy output between these two angles, more analysis of the ratio of performance is required to establish the ideal angle [29].

V. Economic analysis

A. Battery cost

To compare battery costs, power capacity ($/kW) and energy capacity ($/kWh) are commonly used metrics. Nevertheless, the best measure to employ may vary depending on the application and battery size. Customers with high peaks in their power usage may need more power capacity (kW), but not necessarily a larger amount of energy discharge (kWh). Conversely, customers with stable power usage may need more energy discharge according to their power capacity. Consequently, customers with high peak load profiles may seek to reduce expenses of power used ($/kW), while those with flat load profiles may seek to reduce expenses in proportion to the capacity of energy ($/kWh) [40].

Numerous research studies have documented the expenses associated with domestic energy system of storage, with a particular focus on lithium-ion batteries, which are the most widely used technology for residential energy storage. These studies frequently use €500/kWh (~$600/kWh) as their baseline cost for hardware of battery [41-43]. The hardware costs of batteries decreased by approximately 50% per year between 2014 and 2016. The installation expenses, however, remained mostly the same [44,45]. Fares and Webber [46] report that installed costs for batteries range from $700 to $1800/kWh. Comparing several costs of battery hypotheses across different studies can be difficult since each study uses different techniques and system size hypotheses. Nevertheless, based on the literature, the typical estimate for the cost of installation falls within the range of $700 to $1500 per kilowatt-hour [47].

B. Load control cost

Devices for the control of loads make use of home appliances that are commonly owned by residential customers. As a result, the additional costs of implementing load control are relatively low when compared to the cost of batteries. The supplementary expenses usually involve incorporating extra hardware to household appliances and acquiring any necessary software for configuring the system. As an illustration, a smart thermostat has the potential to convert the thermal mass of a residence into an energy storage mechanism, all while avoiding the need to replace

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the using heating and air conditioning infrastructure. The supplementary expense would solely consist of the price for acquiring the thermostat hardware and installation, which is generally only a few hundred dollars as opposed to thousands. [47-49].

C. Empirical result discussion

Although the literature on solar devices spans diverse geographic settings and research methodologies, there are at minimum three common discoveries [47]:

- Solar plus devices add value to PV systems, resulting in financial benefits for PV system owners across various technologies, regions, and rate structures. However, these benefits may vary significantly due to differences in technology expenses, rate structures, and energy consumption patterns.
- Considering the current cost of batteries, load control devices are a more economical solution. Nonetheless, batteries provide greater versatility and are more efficient in boosting self-use and backup power. Consequently, the implementation of batteries may surpass initial predictions derived solely from solar plus analysis in the short term.
- A reduction in compensation rates for exporting energy to the grid reduces the worth of solar plus, but concurrently amplifies the added value of solar plus in comparison to a standalone photovoltaic (PV) system. In spite of optimal design strategies for solar plus systems, there is still the possibility of excess output of PV being sold to the utility grid. The devaluation of grid export rates lessens the monetary benefits that customers receive from both solar plus and standalone PV systems. However, solar plus technology can mitigate the unfavorable economic effects of declining grid export rates by amplifying self-consumption.

VI. BIPV Optimization approaches

Authors have employed objective optimization techniques to explore how modifying system parameters and limiting performance degradation could enhance BIPV performance. Algorithms for optimization compared to an analysis based on basic parameters, may examine a wider range of possible solutions and also generate trade-off solutions among the desired goals [50]. To improve PV in louver system configuration, Taveres and colleagues used Evolutionary Optimization of Multi-Objective, which depended on a Genetic Algorithm (GA). Measurements of the energy need, daylighting levels and PV generation were used to the evaluation [50]. Gao and colleagues [51] employed the same algorithm to achieve an equilibrium a way to balance daylight transmissions and solar heat uptake in PV overhangs. The Non-dominated Sorting Genetic Algorithm II (NSGA-II) by Ref. [52] was another approach used to assess BIPV and viable (adjusting costs and PV energy) rooftop designs during the early design level.

Figure 10 illustrates a common process for optimizing a BIPV system with adjustable parameters. This process includes a) input data parameters of data input such as climate geometry and operational schedules, b) a simulator that conducts thermal, electrical and daylight analyses, and c) an optimizer that utilizes single or multi-objective algorithms [16].

Conversely, designing and assessing BIPV systems involves scrutinizing factors that cannot be solely measured through explicit values, such as PV power or cooling/ heating loads. Multiple authors have utilized various decision making analysis using a multi-criteria (MCDA) techniques or a blend of them to choose and optimize in buildings PV systems. For instance, Stamatakis et al. [53] used the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method to research in the Mediterranean area the best BIPV system for office structures. In Refs. [54,55], the VIKOR (VlseKriterijumskaOptimizcija I KaompromisnoResenje) technique was used to find the best way to integrate PV into a tall residential building. This was accomplished by taking into consideration aesthetic standards, web polls, and qualitative interviews. Ref [56] Uses neural network to predict the output power from a building-integrated bifacial solar PV system that has an improved roof surface Albedo.

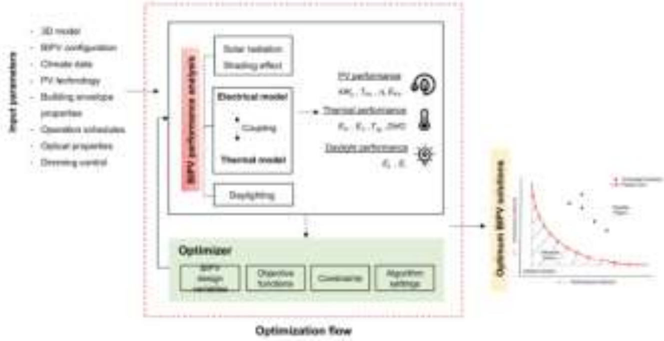

Fig. 6. Standard process for optimizing a BIPV system with variable parameters [16]

VII. Challenges and opportunities

The previous section of this paper reviewed and discussed studies on the integration of various types of PV modules in buildings. The findings suggest that using these systems, especially in buildings, has the potential to substantially decrease the usage of fossil fuels and the release of greenhouse gases. Therefore, it is recommended that policies be put in place to encourage builders to incorporate these systems in their upcoming projects. Offering incentives can increase the attractiveness of using these systems. Since economic feasibility is crucial for large-scale deployment of these systems, it is important to focus on developing more effectiveness and cost savings systems. Additional research and development efforts are necessary for the advancement of PV-integrated and heat HPs. The introduction of new, more efficient systems and reduced construction cost will promote advancements in related technologies. Buildings that are heated and cooled by HPs can incorporate PV systems by utilizing surplus power generated during low cooling or heating load hours. By integrating PV panels associated with HPs installed in buildings, surplus power can be used for other electrical appliances or sold to the grid. To enhance the cost-effectiveness of these systems, a PV/T (Photovoltaic/Thermal) system that uses water as a cooling

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agent for the PV modules can be utilized to generate a portion of the necessary domestic hot water [57].

Although there are many opportunities for developing PV with heat power in buildings, there are also several challenges to be addressed. Most of the buildings that currently exist do not utilize HPs for the purposes of cooling and heating, which presents a noteworthy hindrance to the widespread expansion of PV coupled with HPs. Another obstacle that arises in the advancement of PV coupled HPs is the comparatively lower performance of PV cells, which can result in insufficient power generation to meet the heating or cooling load requirements of HPs. It is necessary to have enough space available to install PV cells with appropriate capacity to fully supply the power needed by HPs. In addition, the intermittent nature of solar energy can cause fluctuations in power generation, such as during cloudy hours, which may require the use of other systems or connection to the grid. In addition, PV modules alone are not sufficient to provide power during night hours, making them ineffective without the use of storage units or connection to the grid, which can increase the overall system cost. Furthermore, the evolution of PV coupled HPs in the residential sector is hindered by a lack of social awareness and acceptance of the benefits of these systems, as highlighted in a study by [58]. To promote the development of these systems, increasing awareness of their benefits is suggested [57].

VIII. Conclusion

The use of building-integrated photovoltaic (BIPV) systems shows great potential to meet the growing energy demands of the building sector and to decrease greenhouse gas emissions. Various types of PV modules have been developed and integrated into buildings, ranging from transparent to colored and flexible modules. The integration of PV modules with the existing buildings can also help to utilize surplus generated power during low cooling or heating loads or sell it to the grid. However, there are still some challenges in developing BIPV systems, such as the intermittency of solar energy, the relatively low efficiency of PV cells, and the lack of social awareness of the benefits of BIPV systems. To overcome these challenges, it is necessary to develop more efficient and cost-effective systems, integrate them with storage units or the grid, and increase public awareness of their benefits. Policymakers and building constructors should also incentivize the utilization of these systems in the upcoming building projects to achieve a sustainable future.

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