Review on Modern Photovoltaic Panels – Technologies and Performances

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Abstract. In this article, the authors reviewed the modern technologies for manufacturing transparent, bifacial, flexible panels and other similar solutions. Passive or active cooling solutions, with air or water vapor, or energy storage solutions are analysed. If the passive air cooling of the photovoltaic panel can achieve a reduction of its temperature by only 10 °C, by active cooling, a cooling with over 30 °C can be obtained. These technologies are aimed to improve the energy efficiency of photovoltaic panels. The article presents examples of photovoltaic panels’ own applications, as well as hybrid PV, realizing the cooling of the PV panel and the recovery of the thermal energy in the form of hot air or hot water, with good efficiency.

1. Introduction
The future of solar technology is great, and all society demands can be fulfilled, from heating water to producing electricity. As part of renewable energy technology, the solar energy technology was continuously developed. The most common devices to converts sun energy into electrical or thermal energy are photovoltaic cells (PVs) or solar cells and thermal collectors (TCs) [1, 2].

Several generations of PVs were developed over the last four decades, having the target of a good commercial price and good electrical output efficiency.

First generation of PVs (I-PVs) is mono and polycrystalline silicon solar cells, having a very good efficiency but a high commercial price. The second generation of PVs (II-PVs) is obtained by thin film technologies using as semiconductor materials polycrystalline silicon, cadmium telluride and copper indium disulphide. The II-PVs price is lower, but their characteristics are lower too [3].

The power conversion efficiency and the other photovoltaic characteristics (as energy production, current-voltage characteristics, temperature power coefficient) are not constant. They are affected by the temperature of the environment and by the shading. It is proved that the PVs convert directly 15% to 18% of the solar radiation into electricity [2] and that 1°C temperature increasing will provide 0.14% to 0.47% maximum power decreasing for different commercial types of PVs [4].

The third generation of PVs (III-PVs) is based on semiconducting nano-structured materials which include organic polymer. The III-PVs are cheap and efficient.

The III-PVs technology knows a tremendous development of the new III-PVs materials (as copper indium gallium selenide nanocrystal films, organic/inorganic composites, dyes/TIO2 for Grätzel cells, perovskites, suitable to provide the development of a variety of industrial applications.

Floating solar farms placed on water structures, building integrated photovoltaics (BIPV), solar sheet that integrates thin photovoltaic material in different structures surfaces, photovoltaic dyes that
can develop the solar fabrics with solar filaments embedded into textiles or other materials, or photovoltaic solar noise barriers (PVNB) used on the highways, are only some examples of PVs application developments [5, 6].

In this framework, the aim of the paper is to underline the new photovoltaic panel types and performances under regarding the III-PVs materials. For this purpose, the paper is structured into six chapters including the conclusion. After a brief presentation of the development of PVs technology, in the second chapter are presented the transparent photovoltaic cells, bifacial cells and flexible cells based on the data and examples from the literature. In chapter three and four, using examples from the references, are presented the effect of cooling of the photovoltaic panel efficiency and the hybrid system of thermal and photovoltaic panel, highlighting the performances. In chapter five are shown the experimental results of 60W photovoltaic panel obtained by the authors in the Renewable Energy Lab of Power Engineering Faculty, University Politehnica of Bucharest.

2. New photovoltaic panels construction types

2.1. Transparent photovoltaic cells

The development of transparent and semi-transparent solar cells has begun in the last decades. Based on photovoltaic effect, a photovoltaic cell converts the sunlight into electricity using semiconductor materials. There are more than 20 models of solar cell technologies which depend on materials and methods [7, 8].

The new technology of transparent solar cell has a reasonable efficiency, but it is not enough to compete with silicon solar panels. However, the technology of transparent solar cell (TSC) has a high potential to transform glass surfaces into a solar panel. Researchers are still working to improve efficiency without diminishing transparency.

Transparent photovoltaic cells (TPVs) can turn cities from huge energy consumers into energy producers. If transparent photovoltaic cells were applied to all buildings that have 90% glass on their surface, they have the potential to supply more than 40% of the energy needed for that building [7].

There are about nine technologies for the manufacture of transparent solar panels and they are important due to market demand and their potential applications. These methods are based on the deposition of a thin film of active photovoltaic material on glass. Transparent film was made of small particles with efficiencies of about 7.8% and 8.4% for 6μm and 12μm thick respectively of nanocrystalline films [9].

These methods include:

- **DSSC dye-sensitized solar cells screen printing**. [10]:
  - **Advantages**: low production cost, clean, relatively simple production and design which makes it easy to widely produce; **Disadvantages**: Low reliability;
  - **Polymer solar cell** [11]:
    - **Advantages**: flexibility, low production cost, environmentally friendly; **Disadvantages**: low efficiency, low reliability;
  - **Tandem Semi-transparent Perovskite** [12]:
    - **Advantages**: High efficiency; **Disadvantages**: Low transmission; rapid degradation.
  - **Near-Infrared transparent solar cell** [13]:
    - **Advantages**: organic semiconductor, environmentally friendly; **Disadvantages**: complexity in production - cannot be produced on an industrial scale;
  - **Quantum Dot Solar cell** [14]:
    - **Advantages**: easy production and installation, able to absorb from the infrared region of the light spectrum; **Disadvantages**: low radiation transmission;
  - **Electrophoretic technique** [15]:
    - **Advantages**: good transparency, low production cost; **Disadvantages**: Complicated manufacturing process.
In Table 1 there are compared the characteristics of different TPVs obtained using different methods of photovoltaic thin film deposition. In Table 1 the significance of the characteristics is: $T$, transmission rate percentage of the light through the solar cell; $J_{sc}$, current short circuit in one cm$^2$ active area of the solar cell; $V_{oc}$, voltage open circuit in one cm$^2$ active area of solar cell; $FF$, fill factor which equal to the maximum power divided by the theoretical power; $\eta$, the efficiency percentage of the solar cell [7].

| TPV type                                    | $T$ (%) | $J_{sc}$ (mA/cm$^2$) | $V_{oc}$ (V) | $FF$ | $\eta$ (%) |
|---------------------------------------------|---------|----------------------|--------------|------|-------------|
| Screen printing DSSC [10]                   | 60      | 16.25                | 0.779        | 0.73 | 9.2         |
| Polymer solar cell [11]                     | 66      | 9.3                  | 0.77         | 52.6 | 1.7         |
| Tandem Semi-transparent Perovskite [12]     | 77      | 17.5                 | 1.025        | 0.71 | 12.7        |
| Near-Infrared transparent solar cell [13]   | 55      | 4.7                  | 0.62         | 0.55 | 1.7         |
| Quantum Dot Solar cell [14]                 | 24      | 0.56                 | 18.2         | 0.53 | 5.4         |
| Electrophoretic technique [15]              | 55      | 14.83                | 0.86         | 0.71 | 7.1         |

In conclusion, the transparent solar panels are an option in the future applications of daily life buildings, trains, telephones, car windows, or laptops. However, the process of achieving this technology faces several obstacles from the synthesis of the transparent material to be used, to the design of a new structure and at the same time must maintain a high efficiency.

2.2. Bifacial solar photovoltaics
Bifacial solar photovoltaic panels represent a new technology that increases their electricity production per square meter. Bifacial solar cells simultaneously collect photons that touch the front as well as the back of the solar panel. A study shows that the production of electricity can be increased by 50% by collecting direct radiation and that of the surroundings using solar concentrators [15]. Another advantage of bifacial solar panels is the decrease in temperature in the solar cell and the increase in electricity production due to the absence of the aluminum back of the solar panel.

This technology is expected to grow by 15% of total photovoltaic panels by 2024 [15].

The first substrates for bifacial solar cells were made of monocrystalline silicon more than 40 years ago, giving silicon its leading position as a substrate for long- and medium-term bifacial solar panels. The most important parameter of these panels is the thickness because they directly influence its production costs. Evaluations of the different values of the thickness of the silicon layer were performed, in terms of conversion efficiency, using direct test methods or modeling and simulation. The simulations indicated a minimum decrease in efficiency for a low silicon layer from 200μm to 50μm, thus making it possible to reduce manufacturing costs.

2.2.1. Performance of bifacial solar panels
Improving energy production by using bifacial photovoltaic modules is known to be one of the most promising approaches. Unlike single-sided photovoltaic panels, two-sided ones are designed to absorb solar radiation on both the front and rear surfaces. An overall analysis suggests that bifacial panels may have a 30% better efficiency compared to one side panels [16].

Even if bifacial photovoltaic modules are a little more expensive, they can produce more electricity and are more suitable for snowy and desert areas compared to one side photovoltaic modules. Therefore, it is believed that replacing conventional panels with this technology can reduce the number of panels needed to produce the same amount of electricity, installation costs, the area covered by them and workforce costs. Because bifacial solar panels absorb direct sunlight and reflected
sunlight from the ground, they can generate 30% more energy by optimizing installation conditions (e.g., height, angle, and direction) without investing extra in other systems.

Figure 1 [16] shows the radiation on both sides of the panel each month, for a 60-cell panel.

![Figure 1](image1.png)

**Figure 1.** Monthly electricity production of single-sided solar panels and 2-sided solar panels per month [16].

It is obvious that bifacial solar panels have a higher efficiency than regular solar panels, so it is expected that in the long run these solar panels will be used in a higher percentage than regular panels.

Even if bifacial solar panels are more expensive, they can pay back their investment over time and be more reliable in the long run.

2.3. Flexible photovoltaic panels

The flexible solar panels can have various uses that cannot be achieved with the help of ordinary solar panels. Their advantage is to be easily mounted on different curved surfaces. From this point of view this technology will be developed for different applications. Also, flexible photovoltaic panels are easy to be manufactured and long lasting than ordinary solar panels.

In Renewable Energy Lab of Power Engineering Faculty, University Politehnica of Bucharest it was tested a flexible solar panel from second generation, FWAVE technology 92W [17], consisting in amorphous silicon (a-Si) applied in a tandem structure layer with thin film plastic. Neighboring cells are connected in series enabling FWAVE module to directly connect to inverters for high reliability.

The flexible panel has 1.8 mm thick.

For three solar irradiation $H(W/m^2)$, simulated with reflectors we test the solar panel, with the results in Figure 2.

![Figure 2](image2.png)

**Figure 2.** Efficiency of FWAVE 92W flexible panel tested in RES Lab from UPB

3. The effect of cooling the panels

The electrical performances of solar cells are improved using cooling systems to recover the energy lost through temperature effect, when the temperature of the photovoltaic panel is increasing.

The cooling strategies for photovoltaic panels are: passive cooling (using air flow between panels and the mounting surface), phase change materials - PCMs [2] (based on storing the heat into material through thermal conductivity) and active cooling (using forced convection of a liquid pumped to remove the heat of the solar panel).

In the last decades it is promoted a method of cooling using the thermal management of heat transfer of a solar panel by using a heat pipe [1].

The air/wind cooling, ice cooling, water cooling or cold-water vapors are some of the methods of cooling solar panels. Of these, we will further present ice, air/wind and water cooling.
3.1. Experimental stand and conditions for ice cooling

The sketch of the experimental stand is presented in Figure 3 [18]. The photovoltaic module is manufactured by a team from China and has an area of 0.1872 m² (0.52m with 0.36m) and a maximum power of 20W. For experiments it was positioned face down to absorb the radiation below from a light source. Ice was used to cool the solar panel, and it was distributed on the back of the panel. [18]. Experimental set-up parameters were maximum power 20W, maximum voltage 17.7V and intensity 1.1A.

The solar radiation was simulated with an electric incandescent lamp with different levels of power: 160W, 300W and 400W. By adjusting the distance and angle of the lamp to the solar panel, the average radiation on the solar panel was maintained at 160W/m², 300W/m² and 400W/m² which were measured with a solar energy meter. Voltage and current were measured with a multi meter. Ice used to cool the solar panel was evenly distributed on the back of the solar panel during cooling tests. During the test, limited melting of the ice was observed, and the ambient temperature was between 24°C and 25°C throughout the tests. Thermocouples were used to measure the ambient temperature.

When the panel is not cooled, the best efficiency is about 4.98%, at the panel surface temperature of 36 ºC, see Figure 3. When the solar panel was cooled the best efficiency was about 7.32%, at the panel surface temperature of 21 ºC. Comparing the results between the cooled solar panel and the uncooled solar panel, at an ambient temperature of 25 ºC, the efficiency increased by 47%. Compared to other published results from other research that increased between 12% and 60%, the value obtained is reasonable.

Figure 4 shows a comparison with other research, of the effects of surface temperature of photovoltaic panels, in electricity production [18].

The results from Figure 4 give the variation of efficiency as function of surface temperature Ts. Under non-cooled condition, the best efficiency is about 4.98% which took place at about 36 ºC of surface temperature. With cooled solar PV, the highest efficiency is about 7.32%, which took place at around 21 ºC Ts. Comparing cooled solar panel and non-cooled solar panel, the efficiency increase rate is (7.32%−4.98%)/4.98% = 47%. Other researchers give variation between 12% and 60% [18].

3.2. Water cooling system for a practical application

Based on a 4kW photovoltaic system installed on a house in England, a cooling system can be developed with the following arrangement shown in Figure 5 [18].

A cooling channel fixed under the solar panel can be used. Water is introduced into the system by a pump, and by exchanging heat between the solar panel and the cooling channel, water with a high temperature can be partially or totally stored in a tank (for shower and other household needs) then reach cooling tower fixed in the attic. In the attic where the temperature is lower than the outside temperature, the water can be cooled, in the water tower, naturally by convection or by forced
convection using fans. After that, the water can be pumped back into the cooling channel, and so the cooling tower can lower the water temperature by more than 10 °C during the summer.

The electricity production from these solar panels is shown in Figure 6 [18].

Without the cooling system for the solar panel, the annual electricity production is 1805 kW h. With the cooling system put into operation, the annual electricity production increases up to 2430 kWh, resulting in an increase of about 34%.

Figure 5. Water cooling system in a residential application [18].

Figure 6. Energy production in the practical case for different scenarios of cooling system used [18].

Figure 7. The cost investments amortisation [18].

The amortization of the investment [18] for a 4 kW photovoltaic system, which has an acquisition cost of 6000 euro, based on the average radiation in England, can be estimated at an annual gain of 400 pounds from the solar panel, which results in amortization of the investment in about 15 years. After installing a cooling system together with a water tank as can be seen in Figure 7, if both electricity and hot water production are considered, the cost of the investment can be amortized over 12 years. As the estimated lifespan of a solar system is 20 years, after the investment is amortized, a profit can be made. In conclusion, if the solar panel is cooled, the efficiency can increase significantly. Also, for different radiation values there is an optimal surface temperature of the panel for maximum efficiency. In the experiment of cooling the solar panel with ice on the back of the panel there was an increase in efficiency of 47% and in the case of a photovoltaic panel with water cooling the investment can be recouped in 12 years that mean less than 15 years the recoupment time for a photovoltaic panel without cooling. Obviously, the ice cooling system is more efficient than water cooling for any type of photovoltaic panel.

4. Thermal and photovoltaic hybrid solar systems
Photovoltaic thermal technology (PV/T) refers to a hybrid concept in which thermal energy and electrical energy are produced in the same time. So, a PV panel will convert solar radiation into electricity and a thermal collector will convert thermal energy into heat [19]. In the related literature the PV/T systems use water or air as fluid in the thermal collector and they are briefly described further.

4.1. Hybrid photovoltaic and thermal system for solar energy harvesting and air heating

Moradi et al. [20] review PV/T technology and underline the control parameters and the management of PV/T systems schemes in correlation with the applications. So, the efficiency is the important parameters which must be considered in the design. Also, the geometry of the thermal collector is proper with the application and for residential applications the PV/T with flat plate geometry collector is recommended.

Joshi and Dhole [21] reviewed the published research work on PVT technology in the last decade regarding the theory, mathematical modeling, experimental and numerical results of these systems.

Aldubyan and Chiasson [22] used a PV/T system coupled with a bore hole thermal energy storage (BTES) and the simulation studies shown that the efficiency of the PV/T increased with 4.1% in cold climate and with 4.7% in hot climate. Also, they demonstrate that a ground-coupled heat pump (GCHP) had a synergetic effect and could be used in the system of PV/T with BTES.

Ahmed et al. [23] presented a Trombe photovoltaic wall with direct current fan, and their theoretical and experimental analysis show that the fan is good for raising the indoor temperature and cooling the photovoltaic panel. The Trombe photovoltaic wall has not only the function of generating electricity, space heating and ventilation, but also increases the aesthetics of the building [24].

Sun et al. [24] had considered a photovoltaic Trombe wall (PVTW) in cold weather mounted on the south façade of a building. Using experimental measurements and numerical simulations it was demonstrated that the thermal efficiency of the PVTW was 27% reduced if the results were compared with a Trombe wall. The electric efficiency conversion was 5% reduced as against a PV panel. So, the PV applied on the glazing will reduce the solar heating ability of a Trombe wall.

A Trombe wall is a “passive solar design building” obtained with a dark color painted wall and covered with a glass on the outside and having an air gap between the wall and the glaze. During the day the Trombe wall collects the heat which is released indoor at night. In Figure 8 is presented the PVTW of Sun et al. experiments.

![Figure 8. Trombe photovoltaic wall structure [24].](image)

![Figure 9. The PC-PV-Trombe wall structure [25].](image)

Wu et al. [25] used a photocatalytic-photovoltaic Trombe wall (PC-PV-Trombe) to explore, using numerical simulations, the effects of channel height and width on the energetic performances of the...
system. The PC-PV-Trombe is a combination of solar photocatalytic oxidation and solar photovoltaic thermal (PV/T) technology applied to a Trombe wall.

Wu et al. had installed the PC-PV-Trombe wall on the south façade and used a high-transmission glass cover with titanium dioxide as catalytic layer on the inner side. The PV panel was mounted on the insulated wall and the low air on the channel between the glass and the PV panel can be controlled with four flaps. In Figure 9 is presented the structure of PC-PV-Trombe wall.

Under the conditions of solar radiation, ultraviolet light is absorbed by the titanium dioxide layer, and most of the visible and infrared rays are absorbed by the photovoltaic panel. The PV panel converts some of the solar energy into electricity, and the rest is transformed into heat. The air next to the PV panel is heated, reaching from the channel between the panel and the glass to the room where it must achieve thermal comfort. Also, the air flow in the duct removes heat from the photovoltaic panel, which ensures a more efficient operation of the photovoltaic panel and at the same time provides clean and warm air to the room.

The numerical simulation results were not validated by experiments but are interesting that theoretically the PC-PV-Trombe wall has the “highest total efficiency under low solar radiation intensity” [25].

4.2. Hybrid photovoltaic and thermal system for solar energy harvesting and water heating

This system is referring to the integration of a photovoltaic panel and a solar thermal collector of hot water in a single equipment. The solar cell converts solar radiation into electricity with maximum efficiency when the temperature is not very high [21, 26]. Most of the incident solar energy is converted into heat, causing an increase in the working temperature of the cells. By cooling the photovoltaic module with a flow of fluids such as air or water, the efficiency of photovoltaic cells can be improved.

At the same time, the heat uptake by the fluid can be used for heating. Also, hybrid systems offer additional benefits, such as a reduction in thermal voltages and therefore a longer life of the photovoltaic panel and a stabilization of its voltage and current characteristics.

Over the last decade, most research efforts in the hybrid collector system have been done to improve the cost-performance ratio compared to the equivalent use of an individual solar thermal together with a photovoltaic collection system which is mounted in parallel [26].

He et al. [26] constructed and tested a water type hybrid collector using a polycrystalline PV module on a flat box type, aluminum alloy thermal absorber. The conclusion was that the energy saving efficiency was above the PV conventional system.

![Figure 10. Efficiency vs temperature variation in experimental results for the hybrid photovoltaic and thermal system with water heating [26]](image1.png)

![Figure 11. The photovoltaic panel Wellemann Sol14 tested in our RES lab](image2.png)
In Figure 10 are presented the efficiencies in experimental results, [26]. The efficiencies from electric energy, thermal and total energy depend on solar irradiation or on variation of temperature are improved with around 10% by using the hybrid solar photovoltaic system with thermal hot water.

Aste et al. [27] had compared the performance of covered and uncovered PV/T water collectors. An uncovered collector has the absorber in direct contact with the outdoor environment. In this paper the PV/T collectors are different as structures and materials. The uncovered PV/T collectors used a PV panel which integrates five strings of six polycrystalline cells connected in series and placed in a glass-tedlar sandwich. The covered PV/T collector had a microcrystalline PV panel. It was found that the thermal performance of the covered collector is higher than the uncovered collector during the cold season. Regarding the energy efficiency the uncovered water PV/T collector is more effective than the covered one.

Kazem [28] made a comparison between the performance of a conventional PV panel and a water PV/T collector on grid connected. The conclusion was that water-based PV/T collector produces more electric power than the conventional PV panel. The experiments were outdoor in warm weather.

5. Experimental studies on a 60W photovoltaic panel in RES Laboratory

In this experiment made in Renewable Energy Sources Lab of Power Engineering Faculty, it was used a 60W Wellemann Sol14 photovoltaic panel from first generation, a light source of 500 W, a cooling fan, multimeters for measuring voltage and current, anemometer for air current speed and pyranometer for solar radiation. Also, it was used a battery to store the electricity produced, and a small consumer. In Figure 11 were transposed the catalogue characteristics of the photovoltaic panel used in the experiment.

The graphs in Figure 12 show the electric power as a function of voltage for radiation of 200W/m$^2$ and 400W/m$^2$ for wind speeds of 1m/s, 2m/s and 3.3m/s.

| Nr. | H (W/m²) | Air speed (m/s) | Pel [W] | Increase of power (%) |
|-----|----------|----------------|--------|----------------------|
| 1   | 200      | 0              | 9.49   | 0                    |
| 2   | 3.3      | 0              | 9.83   | 3.625                |
| 3   | 2        | 2              | 9.78   | 3.008                |
| 4   | 1        | 1              | 9.73   | 2.504                |
| 5   | 400      | 0              | 22.95  | 0                    |
| 6   | 3.3      | 3.3            | 24.30  | 5.882                |
| 7   | 2        | 2              | 24.00  | 4.575                |
| 8   | 1        | 1              | 23.70  | 3.268                |

Table 2. Parameters measured on the photovoltaic panel in the study case without and with cooling

Figure 12. Air cooling effect of the 60W photovoltaic panel, at 400W/m$^2$ (a) and 200W/m$^2$ (b) for the same air speeds (wind speeds), tested in RES lab.
In conclusion, if the panels are cooled their efficiency increases and a higher production of electricity is obtained. For the radiation of 200 W/m² the power increase with 3.6% when the panels were cooled with a wind speed of 3.3 m/s and for the radiation of 400 W/m² the power increase was about 5.8% at the same wind speed.

This proves that the cooling of the PV panels has a significant impact on its performance, and hybrid solar systems can be considered as an alternative of heating system.

6. Conclusions
Following this study, some conclusions can be highlighted:
• PV technologies are still in developing and progress even there are obstacles in maintaining high efficiency. In this context the transparent solar panels would be used as sources of electricity and heating for different applications.
• Bifacial (double-sided) photovoltaic solar panels have a higher efficiency than conventional PV panels and are expected to increase the electricity production per square meter.
• The properties of flexible solar panels implemented in a flexible substrate are recommended them to be used on different types of surfaces regardless of their shape.
• The experiment developed in the Renewable Energy Laboratory of Power Engineering Faculty University Politehnica of Bucharest, proved that if the panels are cooled, their efficiency increases, and a higher production of electricity is obtained. So, for irradiation of 200 W/m² the increase in cooling power was 3.6% with a wind speed of 3.3 m/s and for irradiation of 400 W/m², the increase in power was about 5.8% at the same speed of wind.
• Hybrid solar photovoltaic - thermal systems resulting in hot air or hot water are more effective than the conventional PV panels.

References
[1] Du Y 2017 Advanced thermal management of a solar cell by a nano-coated heat pipe plate: A thermal assessment, Energy Conversion and Management 134 70–76
[2] Browne M C, Quigley D, Hard H R, Gilligan S, Ribeiro N C C, Almeida N and McCormack S J 2016 Assessing the thermal performance of phase change material in a photovoltaic/thermal system Energy Procedia 91 113–121
[3] Lubon W, Pelka G, Marszalek K and Malek A 2017 Performance analysis of crystalline silicon and CIGS photovoltaic modules in outdoor measurement Ecol Chem Eng S 24(4) 539-549
[4] Cotfas D T, Cotfas P A and Machidon O M 2018 Study of Temperature Coefficients for Parameters of Photovoltaic Cells Hindawi International Journal of Photoenergy 5945602
[5] Lupu A G, Homutescu V M, Balanescu D T and Popescu A 2018 A review of solar photovoltaic systems cooling technologies IOP Conf. Series: Materials Science and Engineering 444
[6] Mather R R and Wilson J I B 2017 Fabrication of Photovoltaic Textiles Coatings 7(63) doi:10.3390/coatings7050063
[7] Husain A A F, HasanW Z W, Shafie S, Hamidon M N and Pandey S S 2018 A review of transparent solar photovoltaic technologies Renewable and Sustainable Energy Reviews 94 779-791
[8] Gangopadhyay U, Jana S and Das S 2013 State of Art of Solar Photovoltaic Technology Hindawi Pub. Co., Conference Papers in Energy 764132
[9] Hore S, Vetter C, Kern R, Smit H and Hinsch A 2006 Influence of scattering layers on efficiencies of dye-sensitized solar cells Solar Energy Materials and Solar Cells 90 1176–88
[10] Seigo I, Peter C, Pascal C, Khaja N M, Paul L P, Chy T P and Michael G 2007 Fabrication of screen-printing pastes from TiO2 powders for dye-sensitised solar cells. Prog Photovolt ResAppl 15(7) 603–12
[11] Chen K S, Salinas J F, Yip H L, Huo L, Hou J and Jen A K 2012 Semitransparent polymer solar cells with 6% PCE, 25% average visible transmittance and a colour rendering index close to 100 for power generating window applications Energy Environ Sci 5(11) 9551-57
[12] Bailie C D, Christoforo M G, Mailoa J P, Bowring A R, Unger E L, Nguyen W H et al. 2014 Semitransparent perovskite solar cells for tandems with silicon and CIGS Energy Environ Sci 8(3) 956–63
[13] Lunt R R and Bulovic V 2011 Transparent near-infrared organic photovoltaic solar cells for window and energy-scavenging applications Appl Phys Lett 98 113305
[14] Zhang X, Hägglund C, Johansson M B, Sveinbjörnsson K and Johansson E M J 2016 Fine tuned nanolayered metal/metal oxide electrode for semitransparent colloidal quantum dot solar cells. Adv Funct Mater
[15] Guerrero-Lemus R, Vega R, Taehyeon K, Amy K and Shephard L E 2016 Bifacial solar photovoltaics–A technology review Renewable and Sustainable Energy Reviews 60 1533-49
[16] Park H, Chang S, Park S and Kim W K 2019 Outdoor Performance Test of Bifacial n-Type Silicon Photovoltaic Modules Sustainability 11 6234
[17] FWAVE Solar Modules 92W https://www.fwave.co.jp/en/ Accessed in july 2020.
[18] Peng Z, Herfatmanesh M R and Liu Y 2017 Cooled solar PV panels for output energy efficiency optimization Energy Conversion and Management 150 949-955
[19] Romero R L, Sánchez R J, Guerrero D M, Molina F J L and Álvarez D S 2018 Mitigating energy poverty: potential contributions of combining PV and building thermal mass storage in low income households Energy Convers Manage 173 65–80
[20] Moradi K, Ebadian M A and Lin C X 2013 A review of PV/T technologies: Effects of control parameters International Journal of Heat and Mass Transfer 64 483–500
[21] Joshi S S and Dhoble A S 2018 PhotovoltaicThermal systems (PVT):Technology review and future trends Renewable and Sustainable Energy Reviews 92 848–882
[22] Aldubyan M and Chiasson A 2017 Thermal Study of Hybrid Photovoltaic-Thermal (PVT) Solar Collectors Combine with Borehole Thermal Energy Storage Systems 4th Int. Conf. on Power and Energy Systems engineering CPESE 2017 Energy Procedia 141 102-108
[23] Ahmed O K, Hamada K I and Salih A M 2011 Enhancement of the performance of Photovoltaic/Trombe wall system using the porous medium: experimental and theoretical study Energy 171 14–26
[24] Sun W, Ji J, Luo C and He W 2011 Performance of PV-Trombe wall in winter correlated with south façade design Appl Energy 88(1) 224–31
[25] Wu S-Y, Xu L and Xiao L 2020 Performance study of a novel multi-functional Trombe wall with air purification, photovoltaic, heating and ventilation Energy Conversion and Management 203 112229
[26] He W, Chow T-T, Ji J, Lu J, Pei G and Chan L-S 2006 Hybrid photovoltaic and thermal solar-collector designed for natural circulation of water Applied Energy 83(3) 199-210
[27] Aste N, Del Pero C and Leonforte F 2017 Water PVT collectors performance comparison The 8th Int. Conf. on Applied Energy – ICAE 2016 Energy Procedia 105 961-66
[28] Kazem H A 2019 Evaluation and analysis of water-based photovoltaic/thermal (PV/T) system Case Studies in Thermal Engineering 13 100401