Different Techniques of Rooftile BIPV System Implementation: Materials and Constructions

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Abstract. Roof integrated systems which are integrating photovoltaic (PV) modules into rooftiles now become a trend of building integrated photovoltaic (BIPV) technology. BIPV refers to PV that are integrated into the building envelope (such as facade or roof) to generate clean and environmental-friendly electricity from the sun radiation. The architectural integration of PV collector modules in new construction makes possible to create glazed surfaces which, besides being an aesthetical and functional innovation, generate electricity, that is allowing the realization of solar control and electric range with consequent energy savings. However, up until now, there have been limited studies that analyzed BIPV from the materials and constructions point of views. This paper aims to expose rooftop BIPV materials that further might be used to replace conventional rooftiles such as terracotta or slate, concrete, plastic, and clay tiles. The flat rooftiles of monocrystalline- and polycrystalline-based BIPV cells are being considered in this paper. Their benefits and drawbacks are also put into account. The parameters that were compared are materials, physical constructions, installations and performances at all weather conditions. All the comparisons of those rooftiles that have been made turned out to meet the modern households’ aesthetical, energy and costs saving.

1. Introduction

As the renewable energy used become trending topic for over two decades, and the non-polluting energy, together with the energy efficiency, are increasing, also zero energy and zero emission buildings are rapidly drawing attention. Due to these circumstances, several buildings in the city are now design to harvest energy from its surroundings. Sun radiation as a clean and friendly-environment energy source is one of the best options. Building integrated photovoltaic (BIPV) systems, where solar cells are integrated within the climate envelopes of buildings and utilizing solar radiation to produce electricity, may represent a powerful and versatile tool for reaching these goals with respect to both aesthetical, economic and technical solutions [1].

According to [2], PV cells may be carried out on sloped roofs, flat roofs, facades and solar shading systems. PV cells could be mounted above or onto the existing or traditional roofing. BIPV systems replace the outer building envelope skin, thus it is also serving simultaneously as both a climate screen and a power source generating electricity [1]. Both studies by Jelle, [1] and [2] reviewed the considered and evaluated aspects of the integration of PV cells into the outer building envelope skin are i) ensuring the air gap underneath the solar cells due to provide air flow; ii) reducing the temperature of the solar cells; iii) inclining the BIPVs, both with respect to existing and new buildings, as the solar cells necessarily need to follow the roof inclination to be integrated solutions; and iv) geographical position...
orientation towards the sun and area coverage; and v) building physical issues, for examples heat and moisture that flow in the building envelope.

Reference [3] reported that BIPV can also bring some other advantages to a building seasonally. For example, in summer, it can help to reduce the heat gain by preventing the envelopes from being directly exposed to solar radiation, thus effectively reducing the indoor cooling load. Additionally, by reserving an air channel between the PV modules and the external envelopes of a building could bring benefit from the air circulation in the channel by decreasing the operating temperature of the PV modules, which provides an effective method to increase the energy efficiency of PV module.

Reference [4] reported that the fundamental raw material that still rules the PV market is silicon. It is the second most common chemical element on earth after oxygen. It is a very hard, grey material that glitters like metal. Naturally it can be found in oxidized form for instance in gravel, sand, clay or quartz. The use of silicon came into focus due to its semiconductor properties.

Rooftile integrated PV module is a trend in BIPV technology. The integration of PV collector modules in new construction, makes possible to create glazed surfaces. This integrated PV into rooftile replaces the conventional rooftiles such as terracotta or slate, concrete, plastic and clay tiles. This paper reviews the silicon-based, namely, monocrystalline and polycrystalline silicon, respectively. Then the model of solar cell and the test to get its energy efficiency. The benefits and drawbacks of those two silicon-based BIPV rooftile solar collector module are also discussed in briefly.

2. Silicon-based BIPV

Silicon is the second most plentiful element in the shell of the earth, right after oxygen. It appears in sand, quartz, stone, rocks, gravel, even in seawater silicon appears in gigantic quantities. The extraction of silicon is less harm to the environment and our planet at all, if the manufacture considered the environmentally friendly processes. Since silicon does not rot, by manufacturing it in a good quality process, this also applies to the other components, such. copper, tin and the high-quality glass. For this reason, the flat-plates of high-purity silicon can generate clean electricity [5].

The discussion of generating electricity by utilizing sun radiation, the distance from the sun to the earth is between 147-152 million kilometres and this leads to oscillations in the solar constant between 1325-1420 watts/m² (in the long term, if the shape of the earth’s orbit changes - sometimes it deviates more from the circular path, sometimes less). The sun radiates its energy equally strong in all directions. If the average distance from sun to earth is 1367 watts/m², then this also applies to every other square meter that is located on a gigantic sphere with the radius of the earth’s orbit. Then by multiplying the area of this sphere by the sun constant, the sphere has a radius of 150 million kilometers. Additionally, in every square kilometer it provides 1367 watts/m². Overall, this results in a value of gigantic 386 quadrillion watts for the radiance of the sun every second. This amount is a massive power that a power station can possibly generates [5].

Silicon tiles may be applied to make a BIPV roof look very much like a standard tiled roof, while semi-transparent modules may be applied in glass ceilings to create different visual effects [2]. 1367 watts or 1.367 kW/m² are the basis of calculation. An average per year. If a roof with an area of 100m², 13,67kWh of energy per day fall on every m² with 10 hours of sunshine, then in total, this roof has a total energy of 1,367 kWh per day, in the annual average. This is an overall solar rooftile concept that has been developed by a solar rooftile BIPV company in Germany [5].

The crystalline silicon ingots that commonly used to create solar cells from silicon get solar cells and may result in cells with specific thicknesses, sizes and shapes [2] and [4]. Silicon-based PV material technologies can be grouped into three types: monocrystalline silicon (mono-Si), (poly-Si), and thin-film amorphous silicon (a-Si). Table 1 describes the differences of those three silicon-based PV cells.

Utilizing electrical energy without emissions and pollutants, and even completely for free is the aim of every country due to save the environment. This issue can be implemented for the purpose of households ‘needs whereas each house might cover 100% of its own energy needs and also generate energy surplus, which is then fed into the grid.
This section discusses the silicon-based rooftop solar BIPV module, mono-Si and poly-Si, respectively. The discussion details in their materials, configurations and constructions.

### Table 1. Silicon-based solar PV [4] and [6]

| Type of Cells and their criteria | Monocrystalline (Mono-Si) | Polycrystalline (Poly-Si) | Thin-film amorphous silicon (a-Si) |
|---------------------------------|---------------------------|---------------------------|-----------------------------------|
| Physical photo                  |                           |                           |                                   |
| Cell efficiency (at 25 °C, light intensity of 1000W/m², air mass = 1.5) | 16-17%                    | 16-17%                    | 16-17% |
| Module efficiency (%)           | 15-20                     | 11-15                     | 5-7 |
| Temperature coefficient $P_{max}$ [%/°C] (±0.03) | -0.45                     | -0.45                     | -0.21 |
| Characteristic cells            | Shape, size, texture and color (antireflective layer) of the cells | Shape, size, texture and color (antireflective layer) of the cells | Homogeneous surface |
| Characteristic panels           | Arrangement of cells (pattern and translucency), Colors and patterns (background), Colors and types (frame) Glass coating (optical reflection) | Arrangement of cells (pattern and translucency), Colors and patterns (background), Colors and types (frame) Glass coating (optical reflection) | Flexibility: different substrates of the building skin, Optical reflection |

2.1. Monocrystalline silicon BIPV
Materials, configurations and construction
The mono-Si modules are normally of a black or grey colour and have the highest efficiency, but also high prices [7].
The considered mono-Si PV in this study is solar tiles type BIPV 36 cells 100w [8]. This solar roof tiles that has high-efficiency to transform the energy of sunlight into electric energy. Each cell is electrically rated to optimize the behavior of the module. The physical sides (Figure 2) has front-, cell circuit and back-sides. The front-side of the solar tile contains a tempered solar glass with high transmissivity, low reflectivity and low iron content. The cell circuit is laminated using polyvinyl butyral (PVB) as an encapsulant in combination with a tempered glass on both its front and back which provides complete protection and seals against environmental agents and electrical insulation. The back-side of the tile contains tempered glass with low iron content.

The junction boxes with IP65, are made from high temperature resistant plastics and containing terminals, connection terminals and protection diodes (by-pass). These tiles are supplied with symmetric lengths of cable, with a diameter of copper section of 4 mm and an extremely low contact resistance, all designed to achieve the minimum voltage drop losses.

2.2. Polycrystalline silicon BIPV
Materials, configurations and construction
The poly-Si modules have a blue colour deriving from small crystals and are cheaper but yield lower efficiencies [7].

The considered poly-Si PV in this study is solar tiles type BIPV 36 cells 100w modules that cells are made of several crystals of high purity silicon to transform the energy of sunlight into electric energy. Each cell is electrically rated to optimize the behaviour of the module. Figure 3 illustrates the front-, cells, and back-side of the module. The front of the module contains a tempered solar glass with high transmissivity, low reflectivity and low iron content. The cell circuit is laminated using EVA (Ethylene-Vinyl Acetate) as an encapsulant in combination with a tempered glass on its front and a tempered glass with low iron content on the backside.

The junction boxes with IP67, are made from high-temperature resistant plastics and containing terminals, connection terminals and protection diodes (by-pass). These modules are supplied with symmetric lengths of cable, with a diameter of copper section of 4 mm and an extremely low contact resistance, all designed to achieve the minimum voltage drop losses.
3. Test method
According to [9], the evaluation of BIPV involve several properties, for example solar cell current and voltage (1), maximum power (2), efficiency (3) and the effect of temperature on cell efficiency are as follow.

\[ I = I_p - I_0 \left[ \exp \left( \frac{q(V + IR_s)}{AKT} \right) - 1 \right] - \left( \frac{V + IR_s}{R_sh} \right) \]  

where \( I_p \) is the photocurrent, \( R_s \) is the series resistance, \( R_sh \) is the shunt resistance, \( A \) is the diode ideality factor, and \( I_0 \) is the diode saturation current.

\[ P_m = V_{m} I_{m} = (FF) V_{oc} I_{sc} \]  

where FF is the fill factor, \( m \) refers to maximum power point of the I-V curve, \( V_{oc} \) is the open circuit voltage, and \( I_{sc} \) is the short circuit current.

\[ \eta = \frac{V_{m} I_{m}}{A G} \]  

where \( A \) is PV module area, and \( G \) is the irradiance.

The effect of temperature on cell efficiency can be deduced from the relation of (4).

\[ \eta_c = \eta_{ref}(1 - \beta_{ref}(T_c - T_{ref})) \]  

where \( \eta_{ref} \) is the module efficiency at reference conditions, \( \beta_{ref} \) is the temperature coefficient, \( T_{ref} \) is the reference temperature, and \( T_c \) is the cell/module temperature.

The values reported by solar cell manufacturers are mainly obtained according to standard test conditions (STC, irradiance 1000 W/m², temperature of PV cell 25°C, solar radiation distribution AM
1.5) or nominal operating cell temperature (NOCT, irradiance 800 W/m², ambient air temperature 20°C) [2]. By using the equations (1)-(3), and modeling them using MATLAB platform, then the output power (Wp/m²), and transparency of mono-Si, poly-Si rooftop and a-Si solar BIPV, respectively are illustrated in Figure 4.

![Transparency Vs Output Power](image)

Figure 4. Mono-Si and poly-Si output power versus their module transparency.

Thus, it can be stated that the more transparent the mono-Si, poly-Si and a-Si modules, the more the output power increased, since the more sun radiation has been absorbed through the modules.

4. Conclusion
The persistent research and development of both PV and BIPV materials such as mono-Si, poly-Si, and a-Si on their construction technologies perspective then generate better sun radiation and result clean and environmentally friendly electricity. Additionally, better BIPV solutions with respect to increased solar cell efficiency, reduced production costs improved building integration problems.

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