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New Design Arrangement for the PV Roof-Integrated system

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ABSTRACT

This paper introduces a new innovative concept for the PV rooftop design. It is intended to replace the conventional roof tile with a new arrangement using solar collector cartridges. The new cartridge design encapsulates a frameless PV panel and thermal insulation material in a "double E-Shape" section frame, to ease the assembly of the cartridge components. Two design modules solar collector cartridges were proposed to suit the installation arrangement on the roof. Where, in the first design the solar collector cartridges are placed on a pre-prepared rectangular section frame, such that every two adjacent cartridges provide a proper sealing, while the system wiring is arranged to pass through the hollow section frame. The other solar collector cartridge module design is provided with an interlock arrangement. Both modules design will act to limit the heat flow from the rooftop to the building interior space by 60% compared to the conventional roof tile. Rainwater runway channels were provided to ease water flow and cleaning. Air vents were made in the body of the solar collector cartridge to cool the PV panel. The cartridge design module dimension of 0.915 m (L) x 0.790 m (W) x 0.06 m (H). It occupies an area of 0.72 m^2, and less than 15 kg to ease handling, installation, and maintenance. While capable to generate an average daily energy of 1.04 kWh/m^2.

Keywords: Solar Collector Cartridge Rooftop, Building Integrated Photovoltaic (BIPV), Thermal Insulation, Frameless Solar PV Panel.

1. INTRODUCTION

Solar PV panels can be integrated into the building skin allowing electricity generation along with other functions of building material [1, 2]. Besides the advantage of being integrated into the surface of the building, it transforms the building into an energy-generating building. As the building's accounts for 40% of the global energy consumption, the deployment of new renewable energy in buildings and cities plays an important role in saving energy [3]. BIPV act as construction elements in building exterior, roof, and skylight window. The benefits of BIPV have increased cost-effectiveness with the replacement of common building material, electrical, and thermal performance as well as improved architecture and aesthetics [2]. BIPV serves as weather shield protection from heavy rain and heat during summer, act as a thermal insulator to reduce room heat to a comfortable level [4].

The development of BIPV products is at a high growth rate in greater parts of the nation in Europe and created a new work field of employees with a special set of skills and knowledge [5, 6]. BIPV companies such as Tesla, Schott Solar, Sanyo, Sharp and Sun-Tech are working on new products on facades, skylights, and windows. Initiations of the Feed-In-Tariff (FIT) and other government supporting scheme has encouraged public to accept BIPV technology [7, 8, 9].

The BIPV has advanced over the past decade due to global concerns, the rooftop BIPV is the most preferred placement for BIPV modules, due to solar irradiance. However, there's a large façade surface area that needed to be integrated with PV. The progressive development and innovation in BIPV have efficient solutions i.e., reducing production cost, improvement in the integration of building and increase BIPV module efficiency, it mentions that retrofitting and relative ease of installation of BIPVs are very important due to the large area exists in a building [10, 11].

BIPV can deviate into two module types: Facades and Roof-Integrated PV. 80% of the global BIPV market relies on roof-mounted PV and the rest 20% are on the facades [12].

The rooftop of a building is the most unused area/space among other parts of a building. Rooftops and roof pitched are the ideal location for BIPV products [7]. The

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geographic potential of the rooftop solar PV system largely depends upon shadows from the surrounding building. Therefore, to construct a reliable roof solar PV, it is extremely important to estimate the geographical potential of the rooftop PV system [3]. When a BIPV is installed on the rooftop an additional weight must be considered along with the power of the wind. Implementation of solar PV on rooftop initiated by installing the PV independently. A separate frame was designed to hold the solar PV panels and anchoring them to the building rooftop. The PV panels are the most suitable replacement for conventional roof tile. Roof solar collectors are mounted to the buildings like any other materials such as shingles or tiles that can be installed by normal workers [7].

Installing BIPV would avoid energy losses during energy transportation from distributed energy generation. Easy installation, which requires a simple structural and mounting system to hold the solar roof tile made up of aluminium [13].
A recent study on economic analysis on the BIPV system as a replacement for the conventional building skin has stated that the replacement could reimburse all the investment costs and become a source of income for the building [14, 15].

2. A NEW CONCEPT OF BIPV ROOFTOP DESIGN

This work will introduce a new concept of design to replace the conventional roof tile of a building with a new arrangement of solar collector cartridges (SCC). A house with a conventional roof tile was selected with a roof area of 74m^2. The new SCC design is intended to improve the performance of the roof by providing efficient thermal insulation, and energy-generation replacing the conventional roof tile. Figure 1 illustrates the roof of the landed house provided with tiles and the roof after replacement with the SCCs.

The proposed SCC is structured with a double E-section frame encapsulating frameless PV and insulation sheet, the frame provides ease of assembly by allowing frameless PV and insulation sheet to slide in. The cartridge is designed in a way to ensure ease of handling and fitting on the roof. There're two designs proposed for the SCC based on the placement arrangement on the roof. The proposed design was constructed on SOLIDWORKS student version 2016.

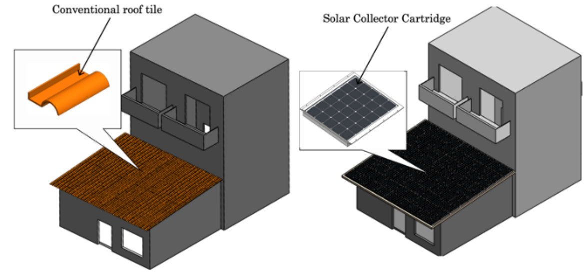

Figure 1: Roof with conventional roof tile and SCC.

i. SOLAR COLLECTOR CARTRIDGE (SCC)

The cartridge is designed to be placed in a prepared frame structure designed to suit the roof. The arrangement should ensure ease of installation, proper thermal insulation, and ensuring water leak proof. Considerations are given primarily for the size and weight of the SCC to ensure ease of handling during installation and maintenance. Figure 2 shows the new SCC module and a sectional view illustrating the dimensions.

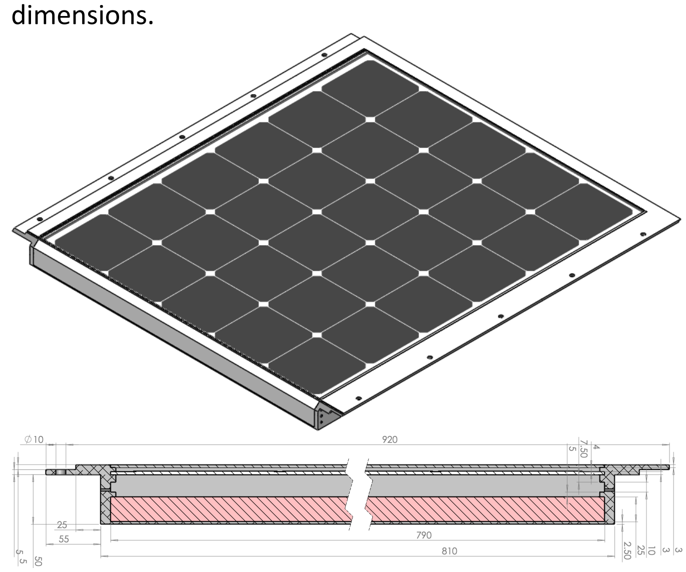

Figure 2: the new SCC module and sectional view with dimensions.

ii. SOLAR COLLECTOR CARTRIDGE (SCC) WITH AN INTERLOCK

The SCC is designed with an interlock arrangement provides a good rigid structure, while at the same time ensure proper thermal insulation and designed with a channel for water passages. Figure 3 shows the SCC with an interlock arrangement and sectional view with the dimensions.

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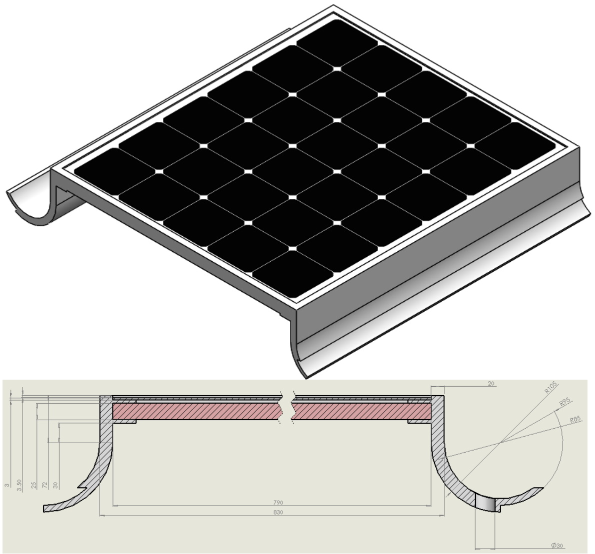

Figure 3: The SCC with an interlock arrangement and sectional view with dimensions.

A part of the initiative on designing the SCC is to replace roof tile and transform the building into an energy-generating building. A new roof with an SCC is designed adopted a frameless solar PV panel and a thermal insulation material to fulfil the requirements. Several aspects are taken into consideration for the replacement of the traditional tile roof. These include weight, size, thermal insulation and leakproof. Moreover, to ease handling, installation, and maintenance the weight is limited to 15 kg.

2.1. SOLAR COLLECTOR CARTRIDGE MODULE DESIGN

The initial stage of designing the SCC is the arrangement of the cartridge on the roof, through providing a frame structure to hold the SCC. The frame is designed to provide support and carry the cartridges. In this design, each independent SCC will be fixed independently on the cartridge frame. The SCC is designed with a "double E shape" section to ensure the smooth sliding of the glass cover, the frameless PV panel, and the thermal insulation sheet into the cartridge frame. Vents were provided beneath the panel across the longitudinal section of the cartridge to enhance the cooling of the PV panel.

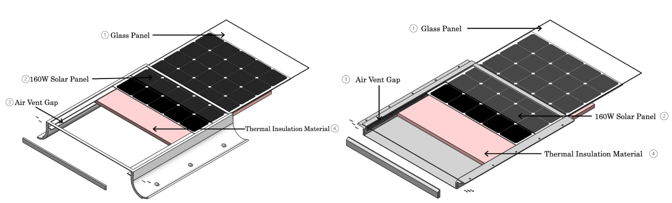

Figure 4: Illustrates the parts of both SCC modules designs and the sliding arrangement.

Figure 4 illustrates the parts of both SCC modules designs and the sliding arrangement. The SCC consists of a glass cover, a frameless PV Panel and thermal insulation material. Between the PV panel and the insulation material, a 10mm space is kept for air ventilation, this would allow an airflow circulation across SCC and improve the performance of the frameless PV panel.

A prepared rectangular frame structure is designed to hold the solar collector cartridges (SCC). The SCC module will be arranged in rows wise on the roof. Figure 5 illustrates the frame for the roof before and after mounting of the SCCs. The selected roof contains 81 SCCs with a surface area of 73.8m^2 and a total output of 13kWp.

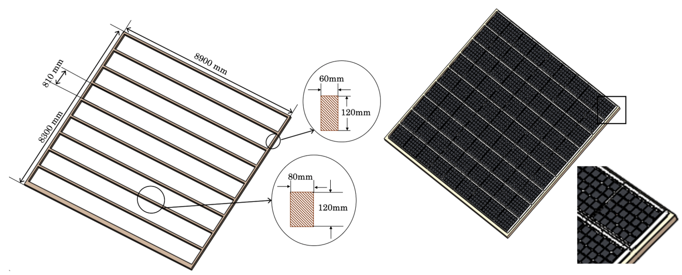

Figure 5: illustrate the before and after the installation of SCC's

2.2. THE SOLAR COLLECTOR CARTRIDGE MODULE WITH INTERLOCK DESIGN

The fundamental concept of SCCs with interlock design is to overlap with the adjacent cartridge to form a rigid roof structure.

Similarly, a frame structure with a hollow rectangular sectional with the dimensions of 80mm by 120mm is used to hold the solar collector cartridge with interlock in place. Figure 6 illustrates the frame before and after mounting the solar collector cartridge with interlock.

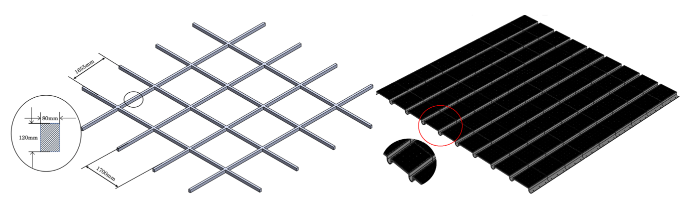

Figure 6: the frame before and after mounting the solar collector cartridge with interlock.

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2.3. SELECTION OF SOLAR PV PANEL

Most of the solar PV panel manufacturing companies designs with a durable aluminium frame to protect the PV module from the harsh environment. The weight and the surface area are limited to ease handling selecting a suitable frameless PV panel (XXR-SF-160) module is selected of 160Wp with an area of 0.73m^2.

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2.4. SELECTION OF THERMAL INSULATION MATERIAL

Besides the energy generation, the SCC is also designed to limit the heat flow to the building space via the roof. Therefore, a Polyurethane foam (PUP) thermal insulation material thickness of 25mm with thermal conductivity of 0.027 W/m K was selected. Consideration was given to the operating temperature to ensure safe working and performance [17, 18].

3. RESULTS AND ANALYSIS

This work focuses on the further development of BIPV, through a new concept of BIPV rooftop design using solar collector cartridges. Two innovative module designs were introduced. The roof will offer an efficient way for energy production with the implementation of the SCC integrated to the roof, while will limit the heat flow from the top of the roof to the room space.

3.1. ANALYSIS OF HEAT TRANSFER

In a conventional roof building, heat is transferred to the building space through the conventional roof tiles or ceramic tiles, due to the temperature differences. Such heat flow will influence the thermal comfort in the occupied space.

3.2. CALCULATIONS OF HEAT TRANSFER

To determine the heat transfer from the roof to the indoor with implementation of the SCC is represented by the thermal resistance circuit given in figure 7. The outdoor and indoor temperatures were taken for the location as 37 ^oC and 25 ^oC.

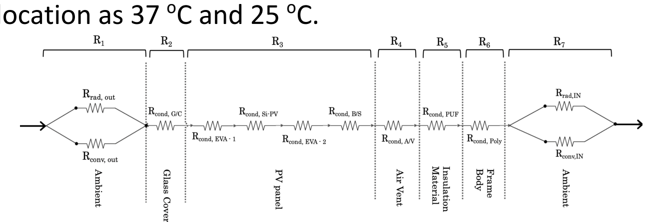

Figure 7: The SCC- roof thermal circuit diagram.

Similarly, the heat transfer from the conventional roof tile, the same procedure should be followed.

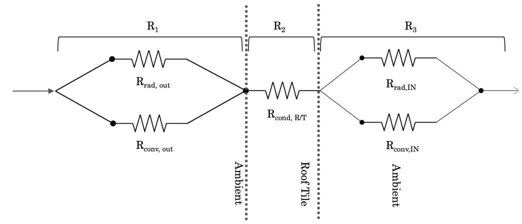

Figure 8: Thermal resistance circuit diagram of the conventional roof tile.

3.3. The SCC ENERGY GENERATION

Implementing both of SCC module designs on the selected roof area of 74m^2 can host 81 solar collector cartridges. Each SCC is provided with (XXR-SF-Sunpower-160W) PV panels. Helioscope software was used to calculate the monthly and annual energy generation for the selected location 6.75840 N and 79.9500^0 E.

The daily average energy harvested from the roof of 74m^2 with PV panel surface area of 58.53m^2 is 60.75kWh. Figure 9 shows the monthly daily average energy production.

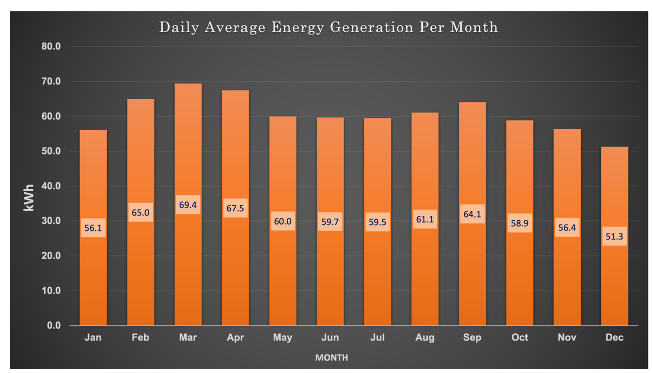

Figure 9: Monthly daily average energy production.

According to the report obtained from helioscope states that an average of 1,840kwh/m^2 solar irradiance and 22,155.6kwh of energy produced annually. System losses due to shade and constrained DC output contains no significant impact on irradiance and energy respectively. Yet the system contains losses due to the irradiance reflection off the module surface and soiling(e.g.: surface dust) and energy loss due to the mismatch of total energy and inverter.

3.4. FINANCIAL PERFORMANCE OF SCC

The total estimated cost of a single unit of a solar collector cartridge (SCC) with a surface area of 0.72m^2 is 136.02$ (188.92$/m^2). Tesla solar roof cost around 221.21$/m^2 [25, 26]

Table 1: The SCC components estimated cost and weight

Component	Weight (kg)	Cost ($)
Glass	3.60	7.32
PV panel (XXR-SF-Sunpower-160W)	2.46	96.00
Insulation material (PUF-25mm)	0.58	2.70
Polyamide – Nylon 6/6 30% Glass fibre – Frame material	7.80	30.00
Total	14.44	136.02

⁎Costing of all components made in U.S Dollars.

Additional expenditures such as installation, inverter, wiring, and logistic costs were not taken into consideration in both scenarios. Therefore, there's a possibility of reducing the cost if other expenditures were minimized to reduce the payback period of the project. With a large-scale the unit cost per square meter would be reduced significantly.

4. CONCLUSION & DISCUSSION

A new innovative concept solar collector cartridge roof top module was developed, to offer a supportive energy generation for residential or and commercial buildings. The main findings of this study as follows:

- A new concept of BIPV arrangement was produced, through proposing two different solar collector cartridge modules with a new arrangement of mounting the SCC on the roof, that is with and without interlock.
- Both designs are constructed to ensure ease of installation, handling, and maintenance. For both designs the weigh is around 15kg and occupy an area of 0.72m^2.
- An easy assembly of the SCC components, through the smooth sliding in double E section frame for the glass cover, frameless PV panel and the insulation materials.
- A Polyurethane foam (PUF) insulation material was used to enhance the performance of the roof to limit the heat flow to the occupied space in the house.
- The heat flow from the roof top to building space is limited to 60% compared to the conventional roof tile.
- A 10 mm air vent was provided under the frameless PV panel to enhance cooling and improve its efficiency.
- The SCC model will generate about 1.038 kWh/m^2 of energy, taking into consideration of all possible losses in the system.
- The estimated cost and maximum peak power of the SCC module are 188.92$/m^2, 222.2W/m^2 respectively. While for Tesla roof tile are 221.21$/m^2, 54.63W/m^2 respectively.
- This new innovative design will encourage public and state-owned buildings towards adopting the new concept BIPV arrangement. At the mean time improving the roof performance and while making this part of the building to generate energy leading to the building energy performance towards nZEB.

Such a design concept has a greater potential in replacing the conventional building material soon. With the support of the government and private firms, such a product could motivate the public to move towards green energy by adding the benefit of having low thermal comfort. The SCC not only could potentially replace the rooftop but also the façade with a little bit of further development to the product. The SCC weighs 14.44kg and this could be further reduced by making the side body parts hollow, therefore the weight has the possibility of reducing weight. When looking at the economic point of view, the product cost more than a conventional roof tile but the SCC could also generate an income for the installer by connecting to the national grid.

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