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OPTICAL DESIGN OPTIMIZATION OF A TUBULAR CPC-PVT COLLECTOR

Summary

This study is an optical investigation of a novel concentrating PVT module, which has been designed for building integration. A tubular model is proposed, consisting of a compound parabolic concentrator and a vertical PVT unit to provide a unique modular design for easy installation and operation in both residential and commercial sectors. An optimisation process is presented to achieve the maximum solar absorption through the various dimensions of the receiver area. For this aim, a series of optical simulations is carried out in Tonatiuh software, modelling the optical elements and adopting Monte Carlo Ray Tracing techniques. Results revealed that for the given dimensions of the tubular module, a receiver unit of 80 mm height could maximise solar absorption, bringing the highest electrical yields while further increases in PVT height diminish the solar reflection and power generation.

Keywords: CPC, PVT, Optical optimisation, Ray Tracing, Building integration

1. Introduction

The dissemination of the energy recovery concept has formed the concept of Photovoltaic and Thermal (PVT) energy harvesting technology. What directed the scientists toward this novel technology was the composition of terrestrial solar radiation, which consists of 43% IR, 48% VIS and 9% UV rays [1], where most of PV cells use a small fraction of the received energy and the remaining portion is wasted to heat on the surface of a simple PV system. Therefore, a PVT module is a new configuration of a solar system that is formatted based on a combination of PV cells with a thermal collector, and it will be capable to convert solar radiation into electricity and heat simultaneously. In a PVT module, PV cells are fixed to a heat exchanger with either air or water as a cooling medium. As a result, the PVT modules convert more solar energy per area than a corresponding combination of separate PV modules and solar thermal collectors and therefore cause a reduction in manufacturing and installation costs. PVT, as a sustainable technology, can play a major role in achieving sustainable development goals. In recent years, countries are taking serious steps towards the implementation of PVT systems to meet their domestic needs utilizing more renewable energy from a given area, especially in places with space limitations for both PV and thermal collector installation. Like other technologies, PVT display some opportunities and limitations for the producers and end-users which must be addressed in any energy transition plan. One of the merits comes from this technology is the aesthetic advantage compared to conventional thermal collectors with robust designs. The other enticing feature is the interesting niche market which can be formed from both utility or autonomous systems [2]. On the other hand, there is still low industrial involvement in PVT mass production, and the overall public knowledge needs to be improved by recent developments.

The cogeneration of electricity and heat in a PVT module, using similar structural and concentrating components, boosts the overall efficiency of the system. It also provides better finance for electricity conversion in comparison to power generation in a conventional PV system [3]. Currently, the application of concentrating PVT (CPVT) modules is limited in scale and the most common systems consist of components of considerable size, such as solar towers, parabolic trough concentrators (PTCs), compound parabolic concentrators (CPCs), parabolic dish concentrators (PDCs) and large Fresnel reflectors with two-axis tracking systems. Building-integrated CPVT systems can be installed either on the building façade or rooftop. Single-axis tracking designs are more suitable for building integration [4]. Similar to high-concentration systems, PTCs are typically installed on flat roofs and are ideally hidden from view. In such a system, a solar tracker is accomplished via rotating the entire concentrator/receiver on a single axis. Linear Fresnel reflectors (LFRs) present a variety of options depending upon the technology desired: two-axis tracking, sun-tracking by moving mirrors or PV receiver. In this configuration, the receiver stands still, and solar tracking is achieved via rotating the individual mirrors. In this way, total movement is minimized that facilitates the building incorporation of such systems. Linear Fresnel lenses meet the expectations regarding architectural integration. These systems can distinguish the beam from diffuse solar radiation, making them attractive for controlling illumination in building interiors. Fresnel lenses are preferred because they combine a concentrating element with an optically transparent window or cover in a single unit. This study focuses on the application of CPCs with PVT technology to offer unique flexibility for solar concentration despite the module tilt angle. CPC represents non-imaging concentrators, which are capable of collecting all available radiation - both beam and diffuse - and directing it to the receiver. As a result, they do not have such strict requirements for the incidence angle as the parabolic troughs have, which makes them attractive from the point of view of system simplicity and flexibility. Therefore, this study proposes a tubular design of these modules that provides modularity and flexibility, allowing multiple units to be installed on building structures such as roofs and walls, supplying the required levels of thermal and electrical power as needed. This layout provides hybrid energy management within the built environment, using renewable energy sources to reduce heating and electricity costs, particularly during peak sunlight hours. Moreover, stored thermal energy allows for consistent climate control, maintaining optimal conditions for plant growth regardless of external weather changes. As a result, the modular nature of each PVT tubular panel enables easy customization and scalability. Residential and commercial buildings can install as many or as few modules as needed, which makes it possible to tailor the system precisely to the size and energy requirements of the sector demand. This research is situated within the design framework of the module, aiming to optimize its design by incorporating optical simulations of its components to size them appropriately based on the maximum energy-generation targets.

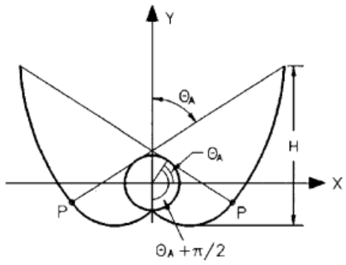

Fig. 1: Fully developed CPC diagram.

2. Methodology

CPC have some specific operational features that make them complex in design. Details of a compound parabolic concentrator were studied by McIntire [5]. The two key elements in the design of CPC collector are the tubular absorber radius and acceptance angle. In the present work, the outer diameter of the absorber is 8 cm. According to the optimisation procedures in pretests, the acceptance half-angle of 30 ° was selected to operate without sun tracking for 4 hours. The size of the CPC model was determined using proper equations (see Fig.2a). A truncation was done to fit into a 40-cm-diameter tubular module, see in Fig. 2b. Moreover, in order to maximize the solar energy exploitation and for the sake of simplicity in module design and manufacturing, the PVT element was designed in a flat plate configuration. This will result in the installation of two vertical PV cells on the two illuminated sides, with a heat exchanger embedded in a sandwich configuration between the two PVs. However, this study concentrates only on the optical components and only considers glass, reflectors and the PV modules.

To optimise the PVT element dimensions, a series of optical simulations was carried out in Tonatiuh software, modelling the tubular module as shown in Fig. 2c. A number of PVT heights were investigated, and the amount of energy absorbed for electricity generation was computed in this study.

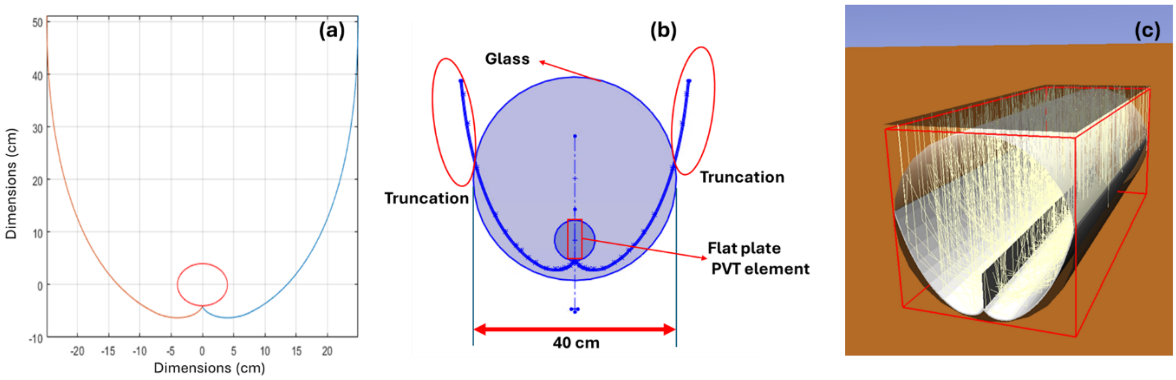

Fig. 2: Design and simulation of the CPC-PVT; (a) CPC diagram, (b) truncation of CPC, (c) physical domain.

3. Results and discussions

Heights from 60mm to 130mm, with steps of 10mm in between, were studied. To compare them an indicator called Radiation to Shading Index (RSI) was developed, defined as the average radiation on the two receiver sides, divided by the shaded surface projected on the ground by the PV panels themselves. The reflector is considered transparent to the radiation. Integrating the RSI in the interval 0°-30° incident angle, the optimum working range, we obtain the values shown in the plot in figure (3). The 70mm and 80mm geometry have the same performance, but as the 80mm one produces more energy overall, due to an increased surface area, this last geometry was chosen as the optimum one.

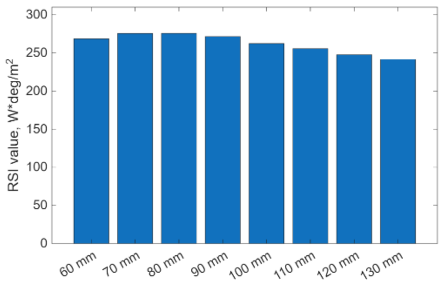

Fig. 3: Values of RSI integrated in the interval 0°-30° incident angle, compared.

4. References

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