

# Design and development of a Building Façade Integrated Asymmetric Compound Parabolic Photovoltaic concentrator (BFI-ACP-PV)

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## HIGHLIGHTS

- A Building Façade Integrated PV concentrator was fabricated and characterised.
- Thermal and I-V characteristics of the BFI-ACP-PV/PCM systems are presented.
- The PV electricity efficiency was improved by over 10% when employing PCM.
- Analysis of the electrical power losses for the BFI-ACP-PV system is presented.

## ARTICLE INFO

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## ABSTRACT

Building Integrated PV and Concentrating PV can generate electricity onsite and provide savings in materials and electricity costs, as well as protecting buildings from weather. In this paper, a novel truncated stationary asymmetric compound parabolic photovoltaic concentrator with a geometric concentration ratio of 2.0 has been designed and experimental characterised. The designed system is suitable for building façade application, especially for vertical façade. It has wide acceptance half angles of 0° and 55°, this acceptance angle range enables the concentrator to operate year-round at its geometric gain in most of the UK and EU climatic condition. A comprehensive indoor test was carried out to evaluate the electrical and thermal characterisation of the developed Building Façade Integrated Asymmetric Compound Parabolic Photovoltaic concentrator (BFI-ACP-PV) system, and also the factors that affect the power output of the developed system. The experimental results showed that the developed BFI-ACP-PV system has the potential to increase the power output per unit solar cell area by a factor of 2, when compared with a non-concentrating PV system. Subsequently, a Phase Change Material (PCM) system was integrated to the rear of the BFI-ACP-PV system to moderate the PV temperature rise and maintain good solar to electrical conversion efficiency. It was found out that the electrical conversion efficiency for the BFI-ACP-PV coupled PCM system was increased by over 5% compared with a similar system with no PCM integrated at the rear, when the incident solar radiation intensity was 280 W/m<sup>2</sup>, this value increased by over 10% for an incident solar radiation intensity of 670 W/m<sup>2</sup>.

## 1. Introduction

It is widely accepted that photovoltaic (PV) solar energy has the potential to meet a significant proportion of the world's future energy needs. Low efficiencies with relative high costs comparing with other power generation technologies remain barriers to wide scale adoption of PV. Optical concentrator systems have the potential to increase the solar radiation intensity and efficiency of the solar collector system [1]. The increased solar radiation intensity on the PV system may reduce the system cost, in addition it produces an interesting architectural feature

[2]. However, the output power of silicon based PV systems decrease with increasing PV module temperature. The thermal management of PV systems is therefore important. PV cooling can reduce PV module temperatures and thus increase solar to electrical conversion efficiency, this can be achieved using a range of different approaches, for example adding an air gap/duct to the rear of the PV panel, integrating with low temperature solar thermal collectors and the use of Phase Change Materials (PCM) with appropriate phase transition temperatures [3–7]. Moshfegh and Sandberg [8] used both CFD predictions and experimental measurements as complementary techniques to analyse the

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performance of air flow and heat transfer in an air gap behind PV panels. Brinkworth [9] reported an optimum value of PV air duct design, such that when the  $L/D$  ( $L$  was the length of PV array at the front surface of the duct,  $D$  was the hydraulic depth of the duct) ratio was about 20, the minimum PV temperature was obtained. They also indicated that this value was not significantly affected by the slope of the PV array. Garg and Adhikari [10,11] developed a computational model for predicting the transient performance of a conventional PV-Thermal air heating collector using typical climate data for New Delhi, India. Tripanagnostopoulos et al. [12] investigated the performances of PV stand alone, PV–air thermal collector, and PV–water thermal collector, systems respectively. For these 3 PV systems it was found that there were no significant PV module temperature differences. The electrical efficiency of the air PV-Thermal system increased by 1.6% compared with that of the PV standalone system. An increase of 3.1% was measured for the water PV-Thermal system compared with the PV standalone system. Huang et al. [13] conducted an experimental evaluation of the potential of using PCMs for PV cooling. It was found that RT25 had a better thermal control potential than GR40 for the PV panel tested. They also conducted experimental tests embedding different numbers and types of fins into the PCM to improve the effect heat transfer to the PCM and the thermal management provided to the PV panel. Huang et al. [14] reported the development of a three-dimensional numerical model which they used to simulate a phase change material container linked to a PV system used to control the temperature rise of the PV cells. Hasan et al. [15] integrated 5 different types of PCM with melting temperatures of  $25 \pm 4^\circ\text{C}$  and heat of fusion between 140 and 213 kJ/kg. A maximum temperature reduction of  $18^\circ\text{C}$  was achieved for 30 min while  $10^\circ\text{C}$  temperature reduction was maintained for 5 h at  $1000\text{ W/m}^2$  insolation. Biwole et al. [16] carried out numerical study of combined PV-PCM system. It was found that adding a PCM with a melting temperature of  $26^\circ\text{C}$  on the back of a solar panel can maintain the panel's operating temperature under  $40^\circ\text{C}$  for 80 min under a constant solar radiation of  $1000\text{ W/m}^2$ . Park et al. [17] conducted outdoor test of PV-PCM system and concluded that the optimised melting temperature for PCM was determined to be  $25^\circ\text{C}$ . The electric power generation was increased by 1.0–1.5% compared to that of the conventional PV module. Hasan et al. [18] used Calcium chloride hexahydrate  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  and Eutectic of Capric-Palmitic acid for PV cooling. Browne et al. [19] developed a novel PV/T/PCM system that generates electricity, stores heat and pre-heats water. Moreover, some researches investigated the possibilities of using the waste heat from PV cells, e.g. driving methanol decomposition for combined cycle [20] or acting as heat source for heat pumps [21,22]. A few researchers also attempted to combine concentrating PV and PCM to increase the solar radiation intensity on PV surface and also for PV thermal management. Maiti et al. [23] integrated a PCM with a melting temperature of approximately  $56\text{--}58^\circ\text{C}$  to the rear of a V-trough PV system. During the

indoor tests, when PCM integrated, the PV temperature could be maintained at  $65\text{--}68^\circ\text{C}$  for 3 h whereas in its absence the temperature rose beyond  $90^\circ\text{C}$  within 15 min under an irradiation of  $2300\text{ W/m}^2$ . Emam et al. [24] [25] numerically investigated the thermal performance of a parabolic trough combined PCM system. Su et al. [26] investigated the cooling effect of phase change material (PCM) for a tracking-integrated concentrating photovoltaic-thermal (CPV-T) system. There is a potentially 10% increase of the electrical power output when compared with similar concentrating system with water cooling. Sharma et al. [27] experimentally investigated the effect of using PCM with a melting temperature of  $42^\circ\text{C}$  on a Building-Integrated concentrated PV. An increase in relative electrical efficiency by 7.7% with PCM incorporation at solar radiation intensity of  $1000\text{ W/m}^2$  was observed. Although the designed Concentrated PV system is more suitable for vertical façade, the system was tested under horizontal location. The effect of nature convection on heat transfer within the PCM under melting stage would be difficult to be evaluated. Then, Sharma et al. [28] proposed to incorporate micro-fins, Phase Change Material and Nanomaterial Enhanced PCM for Building-Integrated Concentrated PV. It was found out that the integration of PCM demonstrated a temperature reduction of  $10^\circ\text{C}$ , when compared with the system without the PCM. In addition, there are some other development in novel building integrated concentrating PV window systems, the developed systems can be used for electricity generation and also daylight control recently [29–31].

This paper presents work aimed at developing a novel stationary concentrating PV façade system, which can minimise the use of PV systems while maintaining good solar energy capture and electrical conversion efficiency. Meanwhile, a Phase Change Material (PCM) system was integrated to the rear of the concentrating PV system to moderate the temperature rise of the PV. The developed concentrating PV combined PCM system therefore can be used for electricity generation and also store the excessive heat in daytime and potentially for later use. A low concentration non-imaging air filled truncated non-tracking Building Integrated Asymmetric Compound Parabolic Photovoltaic Concentrator (BFI-ACP-PV) system, which has a geometric concentration ratio of 2.0 and acceptance half angles of  $0^\circ$  and  $55^\circ$ , has been designed and experimentally studied. This developed stationary BFI-ACP-PV system can operate year-round at its geometric gain in most of the UK and EU climatic condition. A comprehensive characterisation of the developed BFI-ACP-PV/PCM and its counterpart non-concentrating PV were investigated under indoor environmental conditions. Both electricity and thermal behaviour were evaluated under various solar radiation intensities. The temperature dependency of solar to electrical conversion efficiency was also conducted. Finally, the power loss of the BFI-ACP-PV system was also analysed. A schematic illustration showing the cross section of the reflector profiles, illustrating the truncation made is shown in Fig. 1.

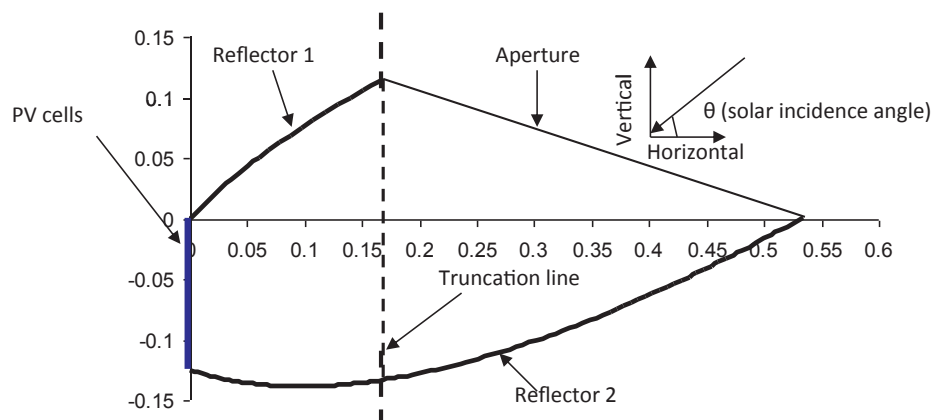


Fig. 1. BFI-ACP-PV system with acceptance-half angle of  $0^\circ$  and  $55^\circ$ , all dimensions in metres.

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