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A review of photovoltaic thermal (PV/T) heat utilisation with low temperature desiccant cooling and dehumidification

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ABSTRACT

One of the major obstacles to improving solar thermal cooling technologies is the high operating temperature requirements of most solar thermal cooling systems. This paper reviews recent advances that could reduce the required heat source temperatures for solar desiccant cooling to the range of 50°C–60°C. These approaches include (i) isothermal dehumidification (e.g. two-stage dehumidification or internal cooled dehumidification) and (ii) pre-cooling of the entry air with ambient heat sinks (e.g. indirect evaporative cooling or geothermal exchange). These techniques can potentially leads to a more thermodynamically efficient solution for utilising recovered heat from flat plate photovoltaic thermal (PV/T) collectors for desiccant regeneration.

Analysis of the literature shows that obtainable outlet fluid temperatures from existing PV/T systems nearly match the low temperature desiccant cooling and dehumidification applications. Design and operation factors for achieving sufficiently high outlet fluid temperature in flat plate PV/T collectors include (i) maintaining low mass flow rate per collector area, (ii) addition of a glazed cover and (iii) hydraulic channel diameter optimisation. These factors are reviewed and case studies of complete solar PV/T desiccant cooling are examined.

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1. Introduction

Air conditioning is one of the highest building energy consuming loads in modern society and a key driver of peak demand placing considerable stress on the electricity supply network [1–5]. Vapour compression cooling is the dominant technology for air conditioning. However, there is an ongoing search for a more energy efficient and environmentally friendly alternative to grid powered vapour compression cooling. Given that cooling loads are generally coincident with solar irradiation, solar driven space cooling technologies offer great potential to reduce both energy consumption and peak demand.

Solar cooling technologies have been researched for a number of years. For example, considerable progress has been made via Task 38, 45, 48 and 53 of the International Energy Agency Solar Heating and Cooling Program [6]. Research efforts can be categorized into two categories: (i) conventional vapour compression systems driven by solar photovoltaic (PV) generated electricity and (ii) thermally activated cooling technologies (e.g. absorption chillers) driven by solar thermal collectors.

With continuous cost reductions in PV technology, PV generated electricity prices are moving towards or are already at grid parity to retail electricity prices in some locations [7–9]. Since the coefficient of performance (COP) of electrical vapour compression cooling systems continues to improve, PV powered vapour compression cooling systems could become an attractive option for solar cooling [10].

Solar thermal collectors are a commercially mature technology that converts sunlight into thermal energy. A number of different types of solar collectors exist, including flat plate, evacuated tube and concentrating solar collectors [11], which are suitable for different thermal cooling systems [12–24]. While solar thermal collector efficiency is higher than that of solar PV panels, thermal cooling devices have a lower COP in comparison to conventional compression cooling systems [12]. This leads to larger collector fields when compared to vapour compression systems driven by PV modules. In addition, the cost of thermal cooling devices can be relatively high, particularly for smaller systems [25]. Thus, there is a need to seek alternatives that can improve the competitiveness of solar thermal cooling systems.

Photovoltaic/thermal (PV/T) collectors can potentially deliver a cost effective solution for thermally driven cooling systems because PV/T systems generate both electricity and thermal energy from the incident solar irradiation. In addition, extracting heat from a PV/T module can potentially improve collector efficiency. This additional electrical energy gain, from the cooled PV/T module, can be greater than the energy consumed by parasitic components such as fans or pumps [26] when the PV/T collector is operated under optimal conditions [27]. This should ideally lead to higher overall energy conversion than that of a stand-alone PV module, or of a stand-alone solar thermal collector [28,29].

In the past, researchers have focused on developing PV/T collectors using both flat plate and concentrating collectors with either air or water as the main heat transfer fluid [30–32]. Flat plate PV/T collectors are simpler to install, operate and maintain than the concentrating type [30,31]. They can be easily integrated as part of a building with good aesthetics, leading to improved overall building thermal performance [33,34]. Many studies have already used flat plate PV/T collectors in space heating and hot water heating applications [31]. Given that heat from solar collectors is more readily available in summer, it would be ideal to develop a cogeneration or a tri-generation system that could use the low temperature heat recovered from flat plate PV/T collectors to provide space cooling and electricity simultaneously to a building, rather than just heating.

Various systems that have investigated solar PV/T collectors in different cooling systems are reported in the literature [35–38]. Of the available technologies, PV/T collectors with desiccant cooling show the greatest potential. This is because solar desiccant cooling has the highest COP and lowest operation temperatures when compared with other solar thermal technologies (Table 1).

From an economic point of view, the energy savings obtained from solar desiccant cooling systems can lead to a lower life cycle cost compared to conventional vapour compression, even though their current investment and maintenance costs are still high [25,39–41].

In previous reviews on desiccant dehumidification and cooling applications, high regeneration temperatures were found to be required which is challenging for flat plate PV/T collectors to achieve [42–44]. In limited studies that reported the use of flat plate PV/T collectors for desiccant cooling systems [25,41,45–48], flat plate PV/T collectors were only used for pre-heating the desiccant regeneration air where additional solar thermal air collectors or auxiliary heat sources were needed to achieve higher temperatures. It is inevitable that this would increase the system complexity and cost. Hence, a key question is can flat plate PV/T collectors be the main heat source and provide adequate thermal energy at suitably high temperatures to drive a desiccant cooling application? Methods that (i) keep the desiccant regeneration temperature low and/or (ii) increase the temperature of the waste heat from the solar PV/T collector become critical to enable this application.

Therefore, this review aims to explore the possibility of utilising flat plate PV/T collectors as the main heat source for low temperature desiccant dehumidification and cooling applications. This is achieved by a detailed review of:

- available low temperature desiccant dehumidification and cooling designs and a summary of their operating concept and required heat source temperatures;
- existing flat plate PV/T air and water heating collectors with outlet temperatures that match the desiccant regeneration temperature required for such low temperature dehumidification, and cooling designs and approaches to improve flat plate PV/T collector performance;
- case studies that utilise thermal heat from PV/T collectors in desiccant cooling applications.

Table 1
Performance overview of different solar thermal cooling technologies.

Cooling technology	Operating temperature (°C)	COP	References
Solar thermal absorption	> 72	0.7–0.8	[13,14]
Solar thermal adsorption	> 64	0.4–0.7	[12,16]
Solar ejector	> 70	0.1–0.3	[17,18]
Solar liquid desiccant	> 65	0.6–0.8	[19]
Solar solid desiccant	> 60	0.5–1.1	[12,20]