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Advancements in hybrid photovoltaic-thermal systems: performance evaluations and applications

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Abstract

Due to European Directives the electric and thermal energy needs of new and retrofitted buildings have to be satisfied by increasing percentages of renewable energy. Solar energy and heat pumps are the most promising technologies mainly in residential buildings as they have reached great maturity. PhotoVoltaic / Thermal cogeneration (PV/T) aims to utilize the same area both for producing electricity and heat. As solar cells are sensitive to temperature (their efficiency lowers when temperature increases), heat is beneficially collected. This paper provides a description of the applications of the photovoltaic–thermal systems, such as building integrated PV/T, concentrating PV/T systems and photovoltaic–thermal heat pump systems.

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Keywords: heat pump; hybrid solar system; photovoltaic, PV/T, thermal collector.

1. Introduction

Not all the wavelengths of the incoming irradiation are usefully converted into electricity in PV cells: commercially available single junction PV cells convert between 6 % and 25 % (under optimum operating conditions and depending on the semiconductor material) into electricity, while the rest is dissipated as heat [1]. This is due to the band-gap energy of the semiconductor material. For example, crystalline silicon PV cells can utilize the entire visible spectrum plus some part of the infrared spectrum, but the energy of all the other wavelengths (the far

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infrared and the higher energy radiation) is unusable in order to be converted in electricity and instead is dissipated at the cell as thermal energy. The main drawback is that the PV module can reach temperatures as high as 40 °C above ambient; this causes an increased intrinsic carrier concentration which tends to increase the dark saturation current of the p–n junction. The main effect is the decreasing of the available maximum electrical power, typically 0.2–0.5 % for every 1 °C rise in the PV module temperature for crystalline silicon cells.

Another critical issue for improving performance of PV systems is maintaining a homogeneous low temperature distribution across the string of cells: as the cell efficiency decreases with increasing temperature, the cell having the highest temperature and so producing the least output in series string of cells limits the current and so the electric power produced (current matching).

The well known main idea to face the issues just described is to increase the electrical production of PV by decreasing the normal operating cell temperature by cooling the panel by a liquid (or air). So PhotoVoltaic/Thermal technology (PV/T) aims to utilize the same area both for producing electricity and heat. This also implies to have higher global efficiency with an enhanced use of solar energy ([2] [3]). Different methods can be applied to cool the PV systems depending on the PV technology (solar concentration, type of cells, etc.) and the climate conditions. The main two categories are:

- passive cooling: this refers to technologies used to extract and/or minimize heat absorption from/of the PV panel without additional power consumption. The heat extracted can be dissipated or usefully used. For example, the application of high thermal conductivity metals, such as aluminum and copper, or an array of fins enhances heat transfer to the ambient. Other passive systems are the use of Phase Change Materials (PCM) or the use of heat pipes that are able to transfer heat efficiently through a boiling–condensing process;
- active systems: in this case heat extraction from the PV panel is forced by the utilization of devices such as fans (for air) or pump (for water or other refrigerant liquid). The heat transfer is therefore enhanced with respect to the passive systems even if they consume some energy. These systems may also be used in situations where some additional benefit can be achieved, such as waste heat recovery for domestic water heating. The main application are the PV/T plane o concentrating solar collectors.

PV/T systems are classified into different categories depending on the structure or functionality of the designs. In terms of heat extraction employed, PV/T modules could be classified as air, liquid, heat pipe, phase change materials, and thermoelectric-based types (sections 2 and 3). In terms of the system structure, the modules could be classified as flat-plate, concentrated, building integrated (BIPV), and heat pump-coupled types.

2. PV/T air collectors

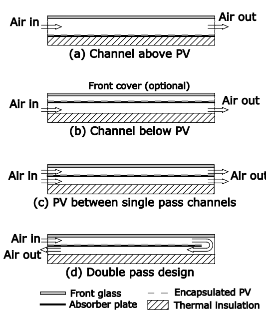

Fig. 1. Different configurations of PV/T air cooled flat plate collectors, with and without glass cover

Air PV/T and ventilated PV façade systems have widely been applied to cool PV cells and to produce low grade thermal energy for space heating in residential applications [4]. No high electrical and thermal efficiency are possible with respect to the water cooled PV/T collectors (section 3) due to the low density and small heat capacity of air. Anyway, they are an economical and useful option when water is limited. Different design concepts have been developed with respect to air flow patterns and to presence of front glazing in order to achieve optimum performance of PV/T modules (Fig. 1).

Fig. 2 depicts two of the four different configurations that were investigated in [5], namely, (1) glass-to-glass PV module with duct, (2) glass-to-glass PV module without duct, (3) glass-to-tedlar PV module with duct, and (4) glass-to-tedlar PV module without duct.

The presence of the duct allows to increase the electrical efficiency, even more with the glass-to-glass PV module type with respect to the glass-to-tedlar type (Fig. 2c). Also air outlet temperature was higher in the case of glass-to-glass because the radiation was transmitted through the back glass. Meanwhile, in the case of glass-to-tedlar the radiation is absorbed by the tedlar layer and conducted away resulting in higher cell temperature.