THERMOSIPHONIC HYBRID PV/T SOLAR SYSTEMS

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ABSTRACT

Thermosiphon solar water heaters and Photovoltaic (PV) devices are well known solar systems that provide heat and electricity, respectively. In this work, these two systems are combined into a hybrid Photovoltaic/Thermal (PV/T) solar system which can simultaneously provide electricity and heat, thus achieving a higher conversion rate of the absorbed solar radiation than standard PV modules. When properly designed, PV/T systems can extract heat from PV modules which can be used to heat water or air. By doing so the operating temperature of PV modules is reduced, which is beneficial, as it keeps their electrical efficiency at a sufficient level. In this paper, the design considerations and experimental results of a thermosiphonic hybrid PV/T solar system are presented. The electrical and thermal energy output for a pc-Si PV/T module type under the climatic conditions of Patras are presented.

INTRODUCTION

Commercial photovoltaic (PV) convert, depending on the type of PV cells, 5%-15% of the incoming solar radiation into electricity. The rest are losses and most of them are converted into heat. PV modules and heat extraction units mounted together constitute the hybrid photovoltaic thermal (PV/T) solar collectors (Fig.1, left), which convert the absorbed solar radiation into electricity and heat simultaneously. Thus, solar radiation increases the temperature of PV modules, resulting in a reduction of their electrical efficiency, their installation on flat building roofs however, permit their natural cooling. In the facades and tilted roofs, cooling of PV rear surface is achieved with circulating water of lower temperature than that of PV modules, so as to keep the PV electrical efficiency at a satisfactory level. In PV/T collectors there is a conflict between their electrical and thermal performance. The electrical performance is higher for lower PV operating temperatures. On the other hand, the thermal performance should provide a heat removal fluid (water or air) at highest possible temperature in order to adapt more effectively into solar thermal applications, but this results to the PV electrical efficiency drop. The additional thermal output that is produced from PV/T systems makes them cost effective compared to separate PV and thermal units, provided that they cover together the same total aperture surface area as that of PV/T collectors.

An extensive study on water [1- 4] and air [1, 5-7] heat extraction from PV modules has been performed at the University of Patras where hybrid PV/T prototypes have been investigated. Performance improvements carried out aimed to overcome some limitations in efficient system operation and to make these new solar energy devices more attractive for various applications. The initial cost of water type PV/T systems (PVT/WATER) is higher than that of air type PV/T systems (PVT/AIR) and can be effectively used all seasons, mainly in low latitude countries, as water from mains is usually under 20^{o}C. The PVT/WATER systems can be installed both on horizontal or tilted roof (Fig. 1, right) of buildings, or on their facades, depending on building architecture.

The work done by the Cyprus University of Technology concerns mainly the modeling and simulation of PV/T systems for a variety of applications [1,2,8].

In this paper we briefly present the design and performance of thermosiphon hybrid PVT/WATER systems. The systems have been designed and tested outdoors in order to record their electrical and thermal performance. These PV/T collectors can provide hot water and electricity in domestic, agriculture and industrial sectors. Regarding small size PVT/WATER systems they can be applied to one family houses, multiflat residential buildings, small hotels, and other similar applications. These devices can be used alternatively to the thermosiphonic and the ICS solar water heaters, mainly in stand-alone and mini-grid application of photovoltaics. To increase system energy output the application of booster diffuse reflectors is also studied [1,2,5,6,7], which increase the solar radiation on PV module aperture surface and overcome the reduction of the electrical output due to the optical losses from the extra glazing used.

Some aspects and results regarding plain types of glazed and unglazed PVT/WATER collectors, as well as a combination of them with water storage tank in a natural (thermosiphonic) flow, give a performance figure of this new water heating system, for laboratory scale unit operation. Based on these results, we aim to develop an improved system, so as to achieve a system of practical value.

PV/T DESIGN AND OPERATION

Hybrid PV/T solar water heaters can be effectively used for domestic water, space heating and other similar applications, contributing also to the reduction of the electrical consumption of buildings. The investigated PVT/WATER models consist of silicon PV modules and the heat extraction unit is a metallic sheet with pipes for the water circulation. Water is flowing in the pipes in order to avoid the direct contact of water with the PV rear surface (Fig.1, left). This heat exchanger element is in thermal contact with the PV module rear surface. The whole unit is thermally insulated at the back and the edges to reduce heat loses to the ambient.

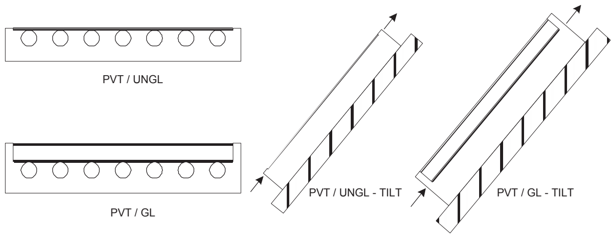

Fig. 1. Cross section of the studied PV/T models (left) – tilted roof installation (right)

PV/T solar energy systems without additional glazing (PVT/UNGL) provide satisfactory electrical output (depending on the operating conditions), but the thermal efficiency is reduced for higher operating temperatures due to the increased thermal losses from the PV module front surface. The addition of glazing (PVT/GL) increases the thermal efficiency for a wider range of operating temperatures, but the additional optical losses reduce the electrical output of the PV modules. As indicated before, hybrid PV/T systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation. We tested outdoors PV/T prototypes consisted of pc-Si PV modules and heat exchanger of copper sheet with copper pipes, for two system types (PVT/UNGL and PVT/GL). Commercial PV modules were used, which give about 8%-15% efficiency, depending on the operating temperature and the use or not of additional glazing. During the experiments the generated electricity was transmitted to a load, thus simulating a real system operation. The steady state tests were performed outdoors and the results for the collector thermal efficiency obtained are shown in Fig.2. As can be seen, the glazed PV/T collector presents a remarkably higher thermal output than the unglazed PV/T collector, but its electrical output is reduced due to additional optical losses.

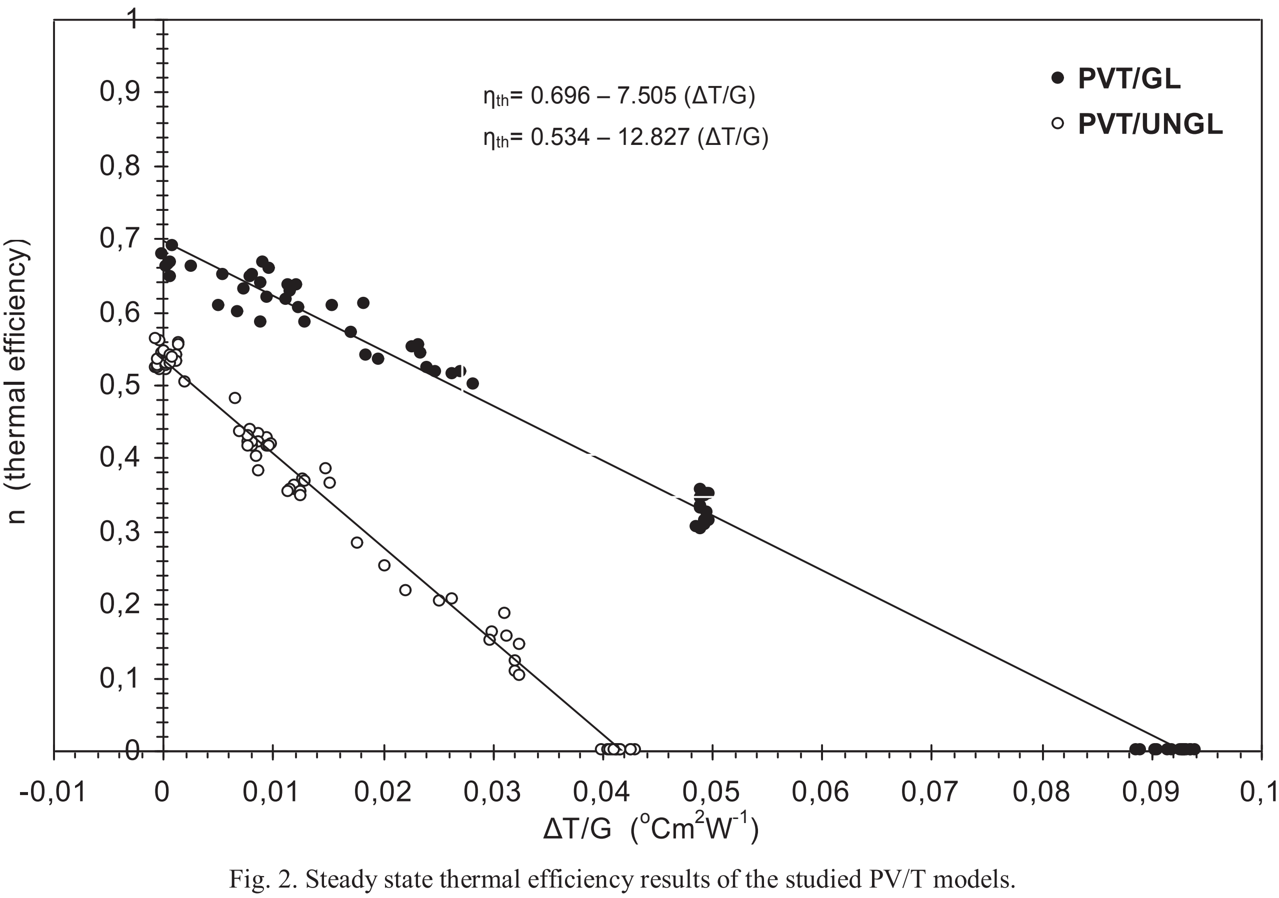

Fig. 2. Steady state thermal efficiency results of the studied PV/T models.

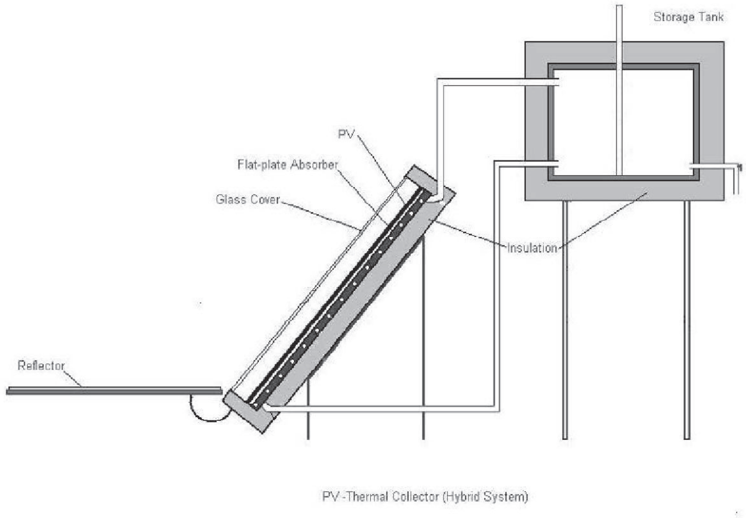

Fig. 3. Thermosiphonic type of PV/T system

Apart of the steady state operation, both PVT/WATER collectors were connected with a water storage tank for a normal complete system operation with forced (pumped) or natural (thermosiphonic) water flow. In Fig. 3 the cross section of the thermosiphonic type of the PV/T system is presented. In Fig. 4 the daily profile for the natural water flow is presented, showing the variation of the mean temperature of PV module (T_{PV}), circulating water (T_m), water in the storage tank (T_{ST}) and ambient temperature (T_a), including also the incoming solar radiation (G) and the wind speed (V_W). The systems were also tested with booster diffuse reflectors, which are fixed for the case of the horizontal building roof system installation [1, 2], but they can be adjusted (see Fig. 3) in the case of small size units. The contribution of the reflectors is estimated positive in all cases, considering the increase in output energy and their low additional initial cost.

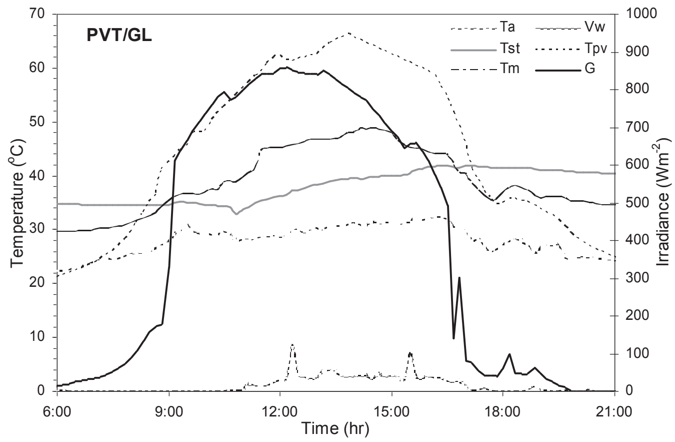

Fig. 4. Daily profile of temperatures, solar radiation and wind speed for the PVT/GL system with natural water flow operation

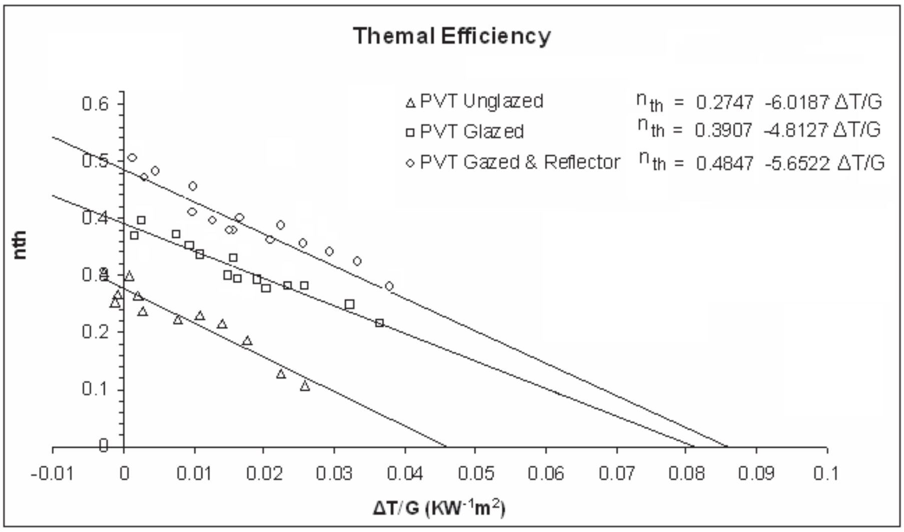

Fig. 5. Thermal efficiency results of the studied PV/T models

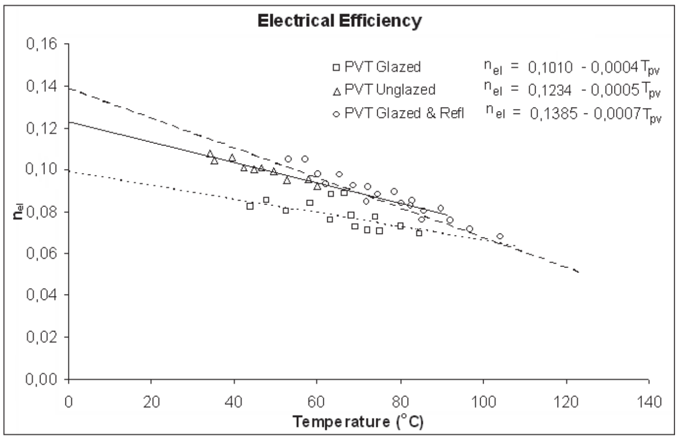

Fig. 6. Electrical efficiency results of the studied PV/T models

A considerable improvement is obtained both for the provided electricity and hot water produced by the use of the booster diffuse reflector in front of the PVT panel (as it is indicated in Fig. 3). The results from the use of this reflector are interesting and prove that it increases satisfactorily the electrical and thermal output as shown in Figs 5 and 6. Regarding the normal type unit, system performance is usually lower than that of the conventional flat plate thermosiphonic solar water heaters because they are of higher performance due to better thermal protection and better absorber coatings employed on the collector surface. On the other hand, looking forward to a wider application of PV modules, their combination with thermal collectors in the same unit can solve the problem of available space limitations and lower the amounts of materials required. In countries where water heating is successfully applied for many years like Greece, Cyprus and other Mediterranean countries, the application of PV/T collectors could possibly be the next step for favourable investments in Renewable Energy.

CONCLUSIONS

Hybrid PV/T solar water heaters have been studied experimentally at Physics Department at the University of Patras and numerically by the Department of Mechanical Engineering of the Cyprus University of Technology. These systems can be applied in houses and other type of buildings for the production of both electricity and hot water and are mainly suitable for applications under high values of solar radiation and ambient temperatures. The experimental results of the outdoors tests showed that thermosiphonic type of PV/T systems can provide both hot water and electricity for domestic applications with a satisfactory efficiency.

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