EXPERIMENTAL EVALUATION OF THE PERFORMANCE OF A PROTO-TYPE HYBRID SOLAR PHOTOVOLTAIC-THERMAL (PV/T) AIR COLLECTOR FOR THE INTEGRATION IN SLOPED ROOF

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ABSTRACT

Detailed simulation studies on the design and development of PV/T systems are being carried out at the Politecnico di Milano, for their possible integration with a sloped roof. Subsequently, a proto-type PV/T air heating collector has designed, manufactured and tested at the experimental site Parco Lambro in Milan in collaboration with a private industry. Thermal and electric efficiencies have been assessed during several days of experimentation. The present paper shows the results of such tests and focus on the relationships among collector performances and design (integrated with building and HVAC systems) conditions.

INTRODUCTION

Solar energy provides an inexhaustible source of energy and therefore, is a feasible alternative at the time when fuel cost is rising and energy shortage is predicted. Further the environmentally compatible nature of solar energy makes it more attractive. Presently, wide-ranging research and development programmes in developed as well as in developing countries are oriented towards the effective utilization of solar energy technologies. Moreover, current interest and activities in photovoltaic systems for various applications are also expending rapidly. A considerable amount of experimental and theoretical works has been carried out in the literature on the utilization of solar energy for various applications. Presently solar energy systems can be divided broadly in to two categories: Thermal and Photovoltaic. A third kind of system that combines both photovoltaic and thermal (PV/T) or hybrid system has been also proposed and studied by various authors. PV/T are expected to play a significant role in the future built environment. The potential for integrating PV in the built environment is large in terms of available area on roofs of houses and buildings and on facades. The long-term goal is to realize PV/T systems that produce electrical as well as thermal energy at sufficiently low cost. This means that investment costs has to be lowered as much as possible. This can only be achieved by careful design, proper realization, optimisation, standardization and mass production. In addition to this, PV/T building elements should also be designed in such a way that they meet architectural requirements and technical standards and look attractive to consumers as well.

DETAILS ON PV/T TECHNOLOGY

Hybrid photovoltaic-thermal (PV/T) systems convert solar radiation into thermal and electrical energy simultaneously. These kind of systems have the characteristics of both the solar thermal as well as the photovoltaic modules. The basic structure of a hybrid PV/T system consists of a flat plate collector equipped with a PV laminate. The solar radiations are absorbed by solar cells and the thermal energy also transferred to a fluid (air or liquid) flowing through the collector. This hot fluid is used for low or intermediate thermal applications e.g. space heating, domestic hot water, drying etc.

The performance of a PV/T system directly depends on the plant configuration (type of fluid used, plant dimension, PV technology), operating parameters (flow rate), type of application and of course climatic parameters. For the air-based PV/T technology which is mostly diffused in the present market, the overall system efficiencies (thermal + PV) varies from 20 to 40% and sometimes more. The PV efficiency for the case of crystalline silicon cells has been seen as 10-12 % and rest contributes to thermal efficiency.

In a PV/T system, the heat drawn by the fluid also help to reduce the temperature of the solar cells increasing their efficiency. It has been observed [Vandaele, et al, 1998] that for large size PV/T air-based plants, the flowing air reduces the cell temperature up to 10 °C from the maximum achievable. It allows an increase of about the 5% of the PV efficiency.

The integration of a PV/T system into a building is a very attractive application as the PV/T collectors can be used as a part of the building envelope (roof or facade) and, at the same time, the energy produced by the system is used for the building consumption demand.

DESIGN OF THE PV/T COLLECTOR

The research work on the development of a PV/T air heating system is being carried out at the Politecnico di Milano. In this respect, a collaborative project between industry Secco Sistemi (Preganziol, Treviso, Italy), Dept. BEST and Dept. Energetica of the Politecnico di Milano has been conceptualised. The research project is based on the design and development of a PV/T component for building integration.

The conceptual design of this component is a flat plate solar air collector in which the glass-cover is replaced by a PV laminate. In practice, the design of the component is complex and innovative in respect of the use of materials and geometry. The component is seen as a modular unit which can substitute partially or completely the weatherproof layer (including thermal insulation) of a sloped roof in a building.

The PV/T system consists of following three components:

- photovoltaic sandwich;
- air-flow channel;
- insulation box.

The collector frame for support is made of aluminium mullions which are fixed on roof slab with the help of chemical expansion plug which can be used effectively for all kind of support e.g. concrete, wood etc. The insulation of the collector is realized by putting polymer insulation inside a metal box which is fixed at the back of the collector. The polymer insulation can resist to the highest stagnation temperatures reached by the system. The air duct between the PV sandwich and insulation box is realized to flow the air either in natural or forced (using fan) ventilation mode. The photovoltaic laminate is inserted into a supplementary frame for making the system more resistant to the static and wind loads.

EXPERIMENTAL SET-UP

On the basis of the design concept, a proto-type PV/T air heating system has been fabricated and installed at the experimental site Parco Lambro of Politecnico di Milano (Figure 1). A series of experiments are being carried out on proto-type and a computer based real time monitoring system has been installed to measure the thermal and electrical performance of the system.

Figure 1: Test proto-type installation

The proto-type PV sub-system consists of 2 BP SX 60 photovoltaic module (manufactured by BP Solarex) of 60 W_p connected in series to an inverter and one BP SX 120 photovoltaic module of 120 W_p connected to another inverter. This scheme allows for evaluating the performance of two different kind of modules separately. The two inverters, 120 W each, are by Mastervolt.
The photovoltaic module BP SX 60 contains 36 polycrystalline cells of 114 x 114 mm size and has a length of 1065 mm and width of 495 mm.
The photovoltaic module BP SX 120 contains 72 polycrystalline cells of 114 x 114 mm size and has a length of 1065 mm and width of 980 mm.
The air duct between the PV sandwich and insulation box is of 75 mm in width and 1065 mm in length. The upper side of the insulation box is painted black to make it secondary absorber.
The support in which the photovoltaic/thermal collector is fixed, allows to change the tilt of the collector.
In the proto-type, the external air enters into the collector through a grid at the lower side. The air flow can be varied and controlled by means of an exhaust fan along with a regulator, connected to the upper side of collector by a flexible duct. Table 1 shows three possible configuration of the air-side sub-system.

Velocity	**Position of Regulator**	**Mass Flow Rate**
0,5 m/s	2	0,035 m^3/s
1 m/s	3	0,07 m^3/s
2 m/s	9	0,138 m^3/s

Table 1: Velocity and mass flow rate of air at different regulator position

The experimental programme will be conducted with the aim of evaluate the system performance where the following parameters are changed:

- air flow
- collector's tilt
- air-gap thikness

The data monitoring system consists of the following equipment:

-1 solar radiation probe installed at the tilt and orientation of collector for measuring the solar radiation over the modules
-1 manual hot-wire anemometer to measure the air mass flow rate
-6 surface probe of type PT-100 installed at different position to measure the temperature of PV laminate and secondary absorber.
-4 probe of type PT-100 to measure the temperature of the air at inlet, inside and outlet of the collector.
-1 meteorological station installed near the system to measure climatic parameters.
A Hewlett Packard data acquisition system (HP VEE) supported by an HP Personal computer is used for monitoring programming and storage of data. Data are acquired every 10 minutes.

RESULTS AND DISCUSSION

A first set of data is today available. It is referred to the start-up period of the programme, once the data monitoring system has been tested and some minor arrangements have been made to the set-up. Figure 2 shows, for a typical sunny day, the time series of the monitored parameters.

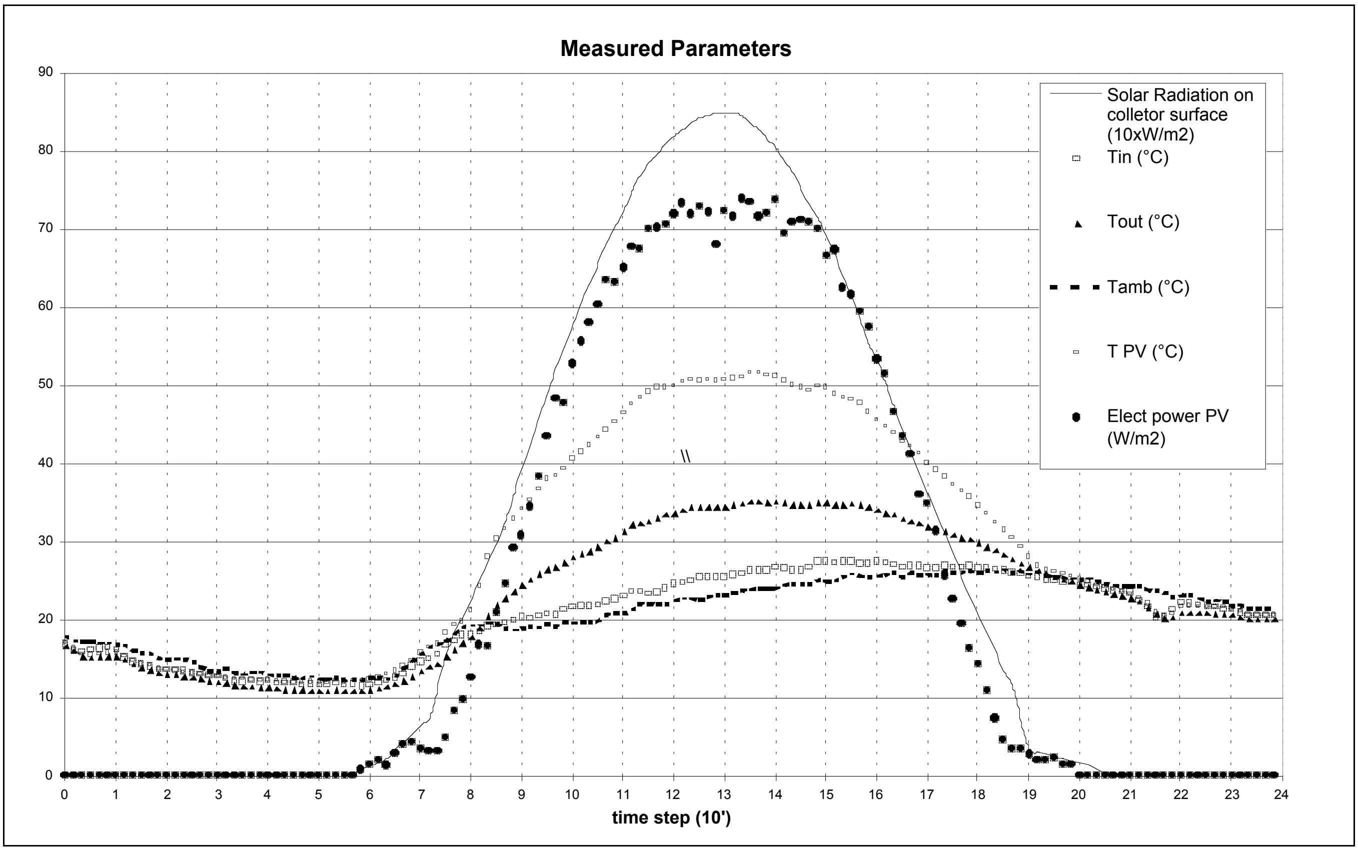

Figure 2 : Example of time series resulting from monitoring

The following figures shows the measured values of PV and thermal efficiencies (fig.3), the electricity and the thermal energy yield in some days compared with the available solar energy (fig. 4).

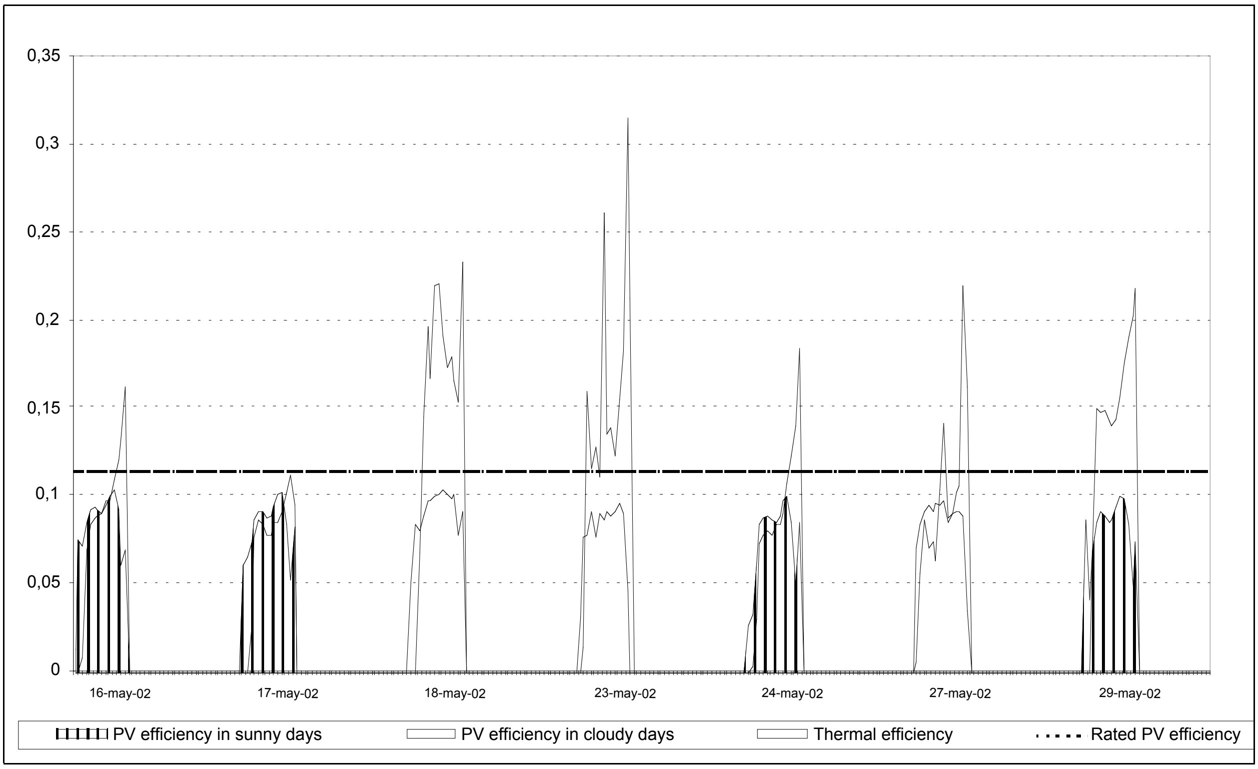

Figure 3 : Measured values of PV and thermal efficiencies of the collector

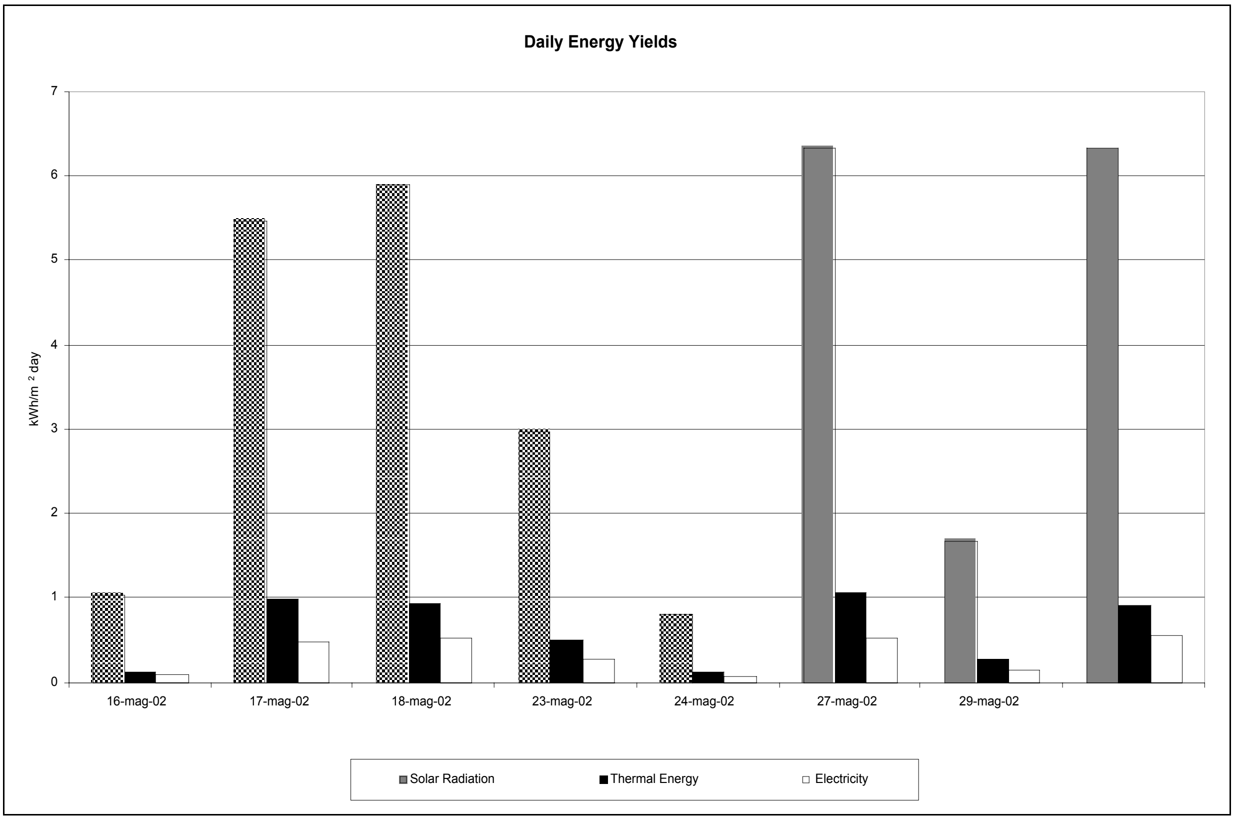

Figure 4 : Measured energy yields of the collector

It is clear that the here shown results are partial, and represents only a first essay of what the monitoring campaign will provide after a longer period of tests.

The aim of the working group is to define the performances of the collector in terms of electric and thermal efficiencies under several working conditions.

This results will be achieved together with the validation of a dynamic numerical model that has been developed by the authors for the calculation system performance on a hourly time base [Aste, Beccali, Solaini, 1999]. Future works will focus on this aspect.

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