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APPLICATION OF HYBRID PHOTOVOLTAIC/THERMAL SOLAR SYSTEMS TO BUILDINGS

Jasna Radulovic[1)]
Milorad Bojic[1)]
Milan Despotovic[1)]
Danijela Nikolic[1)]
Jasmina Skerlic[1)]

1) Faculty of Engineering, University at Kragujevac, Serbiajasna@kg.ac.rs,milorad.bojic@gmail.com,mdespotovic@kg.ac.rsdanijelan@kg.ac.rsjskerlic@gmail.com

Abstract: *Photovoltaic/thermal (PV/T) hybrid technology has been intensively developed over the last few decades. Nowadays, this technology is very popular in terms of harvesting solar energy. Hybrid photovoltaic/thermal (PV/T) solar systems convert solar energy into electricity and heat with a single device which is a good advancement for future energy demands. This report presents the review of applications of photovoltaic thermal (PV/T) solar systems as building integrated photovoltaic/thermal (BIPV/T) systems. This report also covers research works on future development of a PV/T collector as a building integrated photovoltaic/thermal (BIPVT) system.*
Keywords:*Hybrid solar systemsBuilding,Building integrated photovoltaic/thermal systems*

1. INTRODUCTION

Hybrid photovoltaic/thermal (PV/T) solar systems consist of PV modules coupled into water or air heat extraction devices, which convert the absorbed solar radiation into electricity and heat [1]. During the last 30 years different types of solar thermal collectors and new materials for PV cells have been developed for efficient solar energy utilization, [2]. A number of theoretical and experimental studies referred to hybrid PV/T systems with air and/or water heat extraction from PV modules, and some of the works that follow the first period of PV/T system development are [3,4,5].

A thermal system and an electrical system combined and integrated into buildings are known as building integrated photovoltaic–thermal system (BIPV/T). PV/T solar collector can be installed on the roof as a roofing material and to wall as a wall material, [6]. Therefore, the cost of the building construction, and also the payback period of the building can be reduced.

The first studies regarding building integrated PV/T systems included considerations and practical results of these systems, [7,8]. Further, the monitoring results from a BIPV PV/T system that operates during winter for space heating and during summer, [1], for active cooling are given in [9].

A dynamic thermal model for a building integrated photovoltaic–thermal system, the Mataro Library building, near Barcelona, had been developed in [10]. Some interesting modeling results on air cooled PV modules, for applying BIPV/T concept in Southern China are given in [11]. A thermal system combined with photovoltaic cells and integrated into building is considered in [12]. Results showed that the concept of BIPV/T is capable of achieving energy payback periods between 4 and 16.5 years. A novel

BIPV/T solar collector is designed and its performances were tested in [13]. The design system was unique because it had been integrated into the building as a part of the building, [6]. The performance of a combination of BIPV/T and unglazed transparent collector (UTC) in building facades are studied in [14]. The concept was applied to a full scale office building in Montreal, Canada. The usage of semi-transparent photovoltaic–thermal system, which had been becoming very popular, is examined in [15]. An analytical expression of building integrated semi-transparent photovoltaic–thermal system for roof and façade was evaluated in [16].

In a number of studies performance analysis and life cycle costs were evaluated for the BIPVT systems with different PV technology in comparison with the similar BIPVT system, [17]. In one of them, [18], the results show that the use of BIPV/T systems has always been more advantageous both from the efficiency and the economic point of view than similar BIPVT systems. The mono-crystalline silicon BIPV/T systems have higher energy and exergy efficiencies so they were suitable where energy and exergy demands were higher and where the space for mounting such systems was limited, like multi-storey buildings, [18].

Design and performance improvements of hybrid PV/T systems with water or air as heat removal fluids have been carried out recently, [19,20,1]. At the University of Patras, an extended research on PV/T systems has been performed aiming at the study of several modifications for system performance improvement [1].

PV/T collectors are very promising devices, but despite this fact, commercial application of these collectors is still marginal. Future work should be focused on improvement the efficiency of PV/Tcollectors and cost reduction, whichwillmake them more competitive in the present market. Also, wider applications of hybrid collectors are expected in the future, when many building facades and inclined roofs will be covered with PV/T collectors [1].

2. PV/T SYSTEMS

The PV modules that are combined with thermal units, where circulating air or water of lower temperature than that of PV module is heated, constitute the hybrid photovoltaic/thermal systems and provide electrical and thermal energy, increasing therefore the total energy output from PV modules [1].

2.1 General aspects

The PV/T solar systems can be effectively used in the domestic and in the industrial sector, mainly for preheating water or air. The water-cooled PV modules (PV/T water systems) consist of a water heat exchanger in thermal contact with the PV rear side and are suitable for water heating, space heating and other applications (Figure 1a). Air-cooled PV modules (PV/T air systems) can be integrated on building roofs and facades and apart of the electrical load they can cover building heating and air ventilation needs (Figure 1b). PV/T solar collectors integrated on building roofs and facades can replace separate installation of thermal collectors and photovoltaics, resulting to cost effective and aesthetic application of solar energy systems. An additional glazing for thermal loss reduction (Figure 2a,Figure 2b, increases thermal output but decreases the electricity production due to the additional optical losses, [1].

Water-cooled PV/T systems are practical systems for water heating in domestic buildings but their application is limited up to now. Air-cooled PV/T systems have already been applied in buildings, integrated usually on their inclined roofs or facades. These systems keep the electrical output at a sufficient level, covering building space heating needs during winter and ventilation needs during summer, also avoiding building overheating [1].

a)

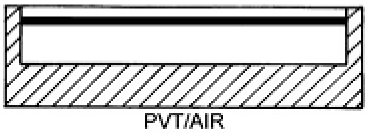

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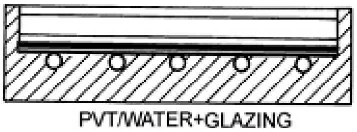
Figure 1 – Cross section of the main PV/T geometries a) PVT/water (unglazed) b) PVT/air (unglazed), [1]



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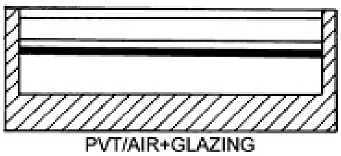

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Figure 2 – Cross section of the main PV/T geometries with glazing a) PVT/water with glazing b) PVT/air with glazing

The PVT/water collectors have more limitations in system design and operation than the PVT/air collectors. This is due to the necessary heat exchanger element, which should have good thermal contact with PV rear surface, while in PVT/air systems the air is heated directly from the front or/and the back surface of PV modules. But on the other hand the air heat extraction is less efficient than the water one, due to the low density of air and improvements are necessary to make PVT/air system efficient and attractive for real applications, [1].

2.2 PV/T application to buildings

In BIPV/T systems solar collector can be installed on the roof as a roofing material and to walls as a wall material. Therefore the cost of building construction can be reduced as well as the building payback period [6]. In [21] it is concluded that a mono-crystalline silicon BIPV/T system was the most suitable choice for high demand energy efficiency but limited mounting space, like in multi-story buildings. But, from an economic point of view, amorphous silicon BIPV/T system was the best choice, suitable for urban and remote places [21].

The facade and tilted roof integrated PV/T systems are more effectively insulated on their rear surface, compared to the ones installed on horizontal roof, as they are attached on the facade wall or the tilted roof. The additional thermal protection increases the thermal efficiency of the system, but the lower thermal losses keep PV temperature at a higher level, therefore they are operating with reduced electrical efficiency [1].

Smaller size PV and PV/T systems, using aperture surface area of about 3–5 m^2 and water storage tank of 150–200 l, can be installed on one-family houses, but larger size systems of about30–50 m^2 and 1500–2000 l water storage are more suitable for multi-flat residential buildings, hotels, hospitals, industries, etc. An interesting building application of solar energy systems is to use linear Fresnel lenses as transparent material of atria, sunspaces, etc, to control lighting and temperature of these spaces, providing also electricity and heat and cover building energy needs, [1].

Further work on improving efficiency,

cost reduction and building integrated application of PV/T technology seem to be very important in order to obtain optimal performance of the collector.

3. SOME NOVEL APPLICATIONS OF BIPV/TSYSTEMS

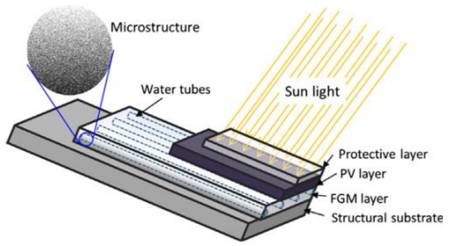
Two interesting applications of photovoltaic thermal (PV/T) solar systems as building integrated photovoltaic/thermal (BIPV/T) systems are illustrated in this chapter.

3.1Hybrid solar system integrated on roof

The proposed energy system in [22] seamlessly integrates novel hybrid solar panels into the building structure as a building integrated photovoltaic/thermal system (BIPV/T), and adaptively uses several operating modes to optimize panel and system performance as the environmental conditions vary seasonally and daily. The system is also designed to be customized to different climates and building configurations. Using a highly efficient panel design and optimized operating modes, excellent panel and system-wide energy and cost efficiencies can be achieved.

The overall approach towards designing and manufacturing a multifunctional high-performance roof for sustainable buildings has to start with the recognition and specification of the various performance parameters, such as architectural requirements, esthetic appearance, mechanical strength and durability, thermal efficiency, material compatibility, moisture migration, and material sustainability.

In Figure 3a, a novel hybrid solar roofing panel is proposed to perform the multiple functions of both a roof structural component and an energy harvesting device. The cross section of the residential system with the integrated hybrid solar panel is presented at Fig. 3b. The innovations illustrated above create the following synergistic benefits of energy generation andsavings: increased PVefficiency, free heating supply, reduced cooling demand, efficient in all climates, snow and ice removal.



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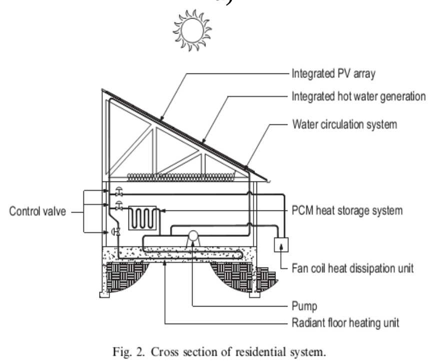

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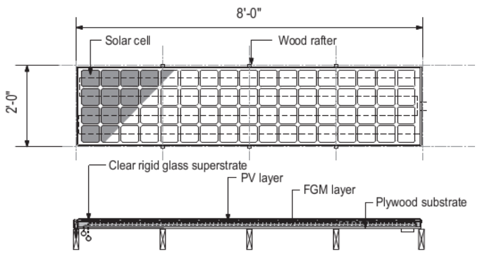


c)

Figure 3 – Hybrid solar system integrated on roof, a) Novel hybrid solar roofing panel,b) Cross section of the residential system with the integrated hybrid solar panel, c) Design of the proposed BIPVT panel: top view (upper) and section view (lower) [22]

The substrate of the panel is designed

to be integrated into the building skin, allowing the panel to serve as both structural sheathing and waterproofing. This eliminates the material redundancies of current industry standard designs and the embodied carbon associated with those materials. The integration of the panel into the building skin also eliminates the waterproofing concerns associated with the roof penetrations required to mount conventional panels on a sloped surface, [22].

Figure 3c shows the design of the proposed BIPV/T panel.

Based on the design philosophy, the benefits of this novel building integrated roofing system are: high efficiency conversion of solar energy reduces or eliminates the need for conventional grid power and the need for heat in winter, a holistically designed building envelope and the removal of heat from the roof will drastically reduce energy use by minimizing the need for cooling in summer and the total amount of materials needed to construct the combined roof and alternative energy system is reduced as redundant functions are eliminated[22].

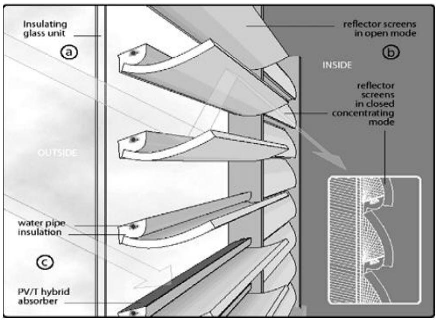
The cost and performance analysis indicates that the proposed hybrid solar panel exhibits great potential for significant system energy benefits with a small additional.

3.2 Building-integrated multifunctional PV/T solar window

The solar window is a PV/T hybrid collector with tiltable insulated reflectors integrated into a window. It simultaneously replaces thermal collectors, PV-modules and sunshade, [23].

In [23,24] building-integrated multifunctional PV/T solar window, which is constructed of PV cells laminated on solar absorbers placed in a window behind the glazing, is developed and evaluated, Figure 4a [2].

To reduce the cost of the solar electricity, tiltable reflectors were introduced in the construction to focus radiation onto the solar cells. The reflectors render the possibility of controlling the amount of radiation transmitted into the building. The insulated reflectors also reduce the thermal losses through the window.



a)

b)

Figure 4 – Building-integrated multifunctional PV/T solar window,a) Solar window at Lund in the south of Sweden, b) The solar window in Solgarden, Sweden with closed reflectors

A model for simulation of the electric and hot water production was developed and it was able to perform the yearly energy simulations for different features, such as the shading of the cells and/or effects of the glazing can be included or excluded. The simulation can be run with the reflectors in active, passive, up right and horizontal positions. The simulation program has been calibrated against the measurements on a prototype solar window placed in Lund, Southern Sweden and against a solar window built into a single family house at Solgarden, Central Sweden, Figure 4b, [2].

The results obtained from the simulation showed that the solar window annually produces about 35% more electric energy per unit cell area as compared to a vertical flat PV module [2, 23].

The building integration lowers the total price of the construction since the collector utilizes the frame and the glazing in the window. When it is placed in the window a complex interaction takes place. On the positive side is the reduction of the thermal losses due to the insulated reflectors. On the negative side is the blocking of solar radiation that would otherwise heat the building passively. This limits the performance of the solar window since a photon can only be used once. To investigate the sum of such complex interaction a system analysis has to be performed, [24].

4. CONCLUSION

Further work on improving efficiency, cost reduction and building integrated application of PV/T technology seem to be very important in order to obtain optimal performance of the collector. One of the most attractive applications of PV/T air or water based collectors are building integrated photovoltaic thermal (BIPV/T) systems which have undergone rapid developments in recent years. BIPV/T system is a promising system to generate both energies due to its higher reliability system with lower environment impact. In the future, the PV/T technology will become the most promising one for building integration, which will increase commercialization of BIPV/T.

By proper architectural design and configuration, electrical and thermal efficiencies can be further improved in future. It is expected that over the next few years, there will be a rapid growth in BIPV/T publications and products.

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