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# Energetic and financial evaluation of solar assisted heat pump space heating systems

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ABSTRACT

Using solar energy for space heating purposes consists an alternative way for substituting fossil fuel and grid electricity consumption. In this study, four solar assisted heat pump heating systems are designed, simulated and evaluated energetically and financially in order to determine the most attractive solution. The use of PV collectors with air source heat pump is compared to the use of FPC, PVT and FPC with PV coupled with a water source heat pump. A sensitivity analysis for the electricity cost is conducted because of the great variety of this parameter over the last years. The final results proved that for electricity cost up to 0.23 €/kW h the use of PV coupled with an air source heat pump is the most sustainable solution financially, while for higher electricity prices the coupling of PVT with an water source heat pump is the best choice. For the present electricity price of 0.2 €/kW h, 20 $m^2$ of PV is able to drive the air source heat pump with a yearly solar coverage of 67% leading to the most sustainable solution. Taking into account energetic aspects, the use of PVT leads to extremely low grid electricity consumption, fact that makes this technology the most environmental friendly.

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## 1. Introduction

The role of energy becomes increasingly important to fulfil the needs of modern societies and to follow the fast economic and industrial growth worldwide. Growing global concern regarding climate change motivates the governments to create specific legislation about energy policy. For European Union members, the greenhouse gasses emissions and energy consumption should have been reduced by 20% up to 2020 in order to meet the Directive 2009/28/EC [1,2]. Energy consumption in Building sector is about the 1/3 of the worldwide energy consumption, fact that proves the high importance of reducing the energy consumption in buildings [3,4].

The use of renewable energy sources in buildings is a promising way for diminishing the fossil fuel and the electricity consumption as a result to mitigate the environmental problems [5,6]. Solar energy utilization for covering building energy needs becomes more and more an attractive idea because it has high availability and it is able to be captured with simple and low cost devices. Flat plat collectors (FPC) and Photovoltaic (PV) modules are the most established solar energy conversion devices for producing useful heat and electricity respectively. The conjugation of these technologies is able to cover all the energy needs of each building.

Especially for countries with adequate solar energy potential, as Mediterranean countries, solar energy utilization is a determining factor to reach the energy goals that were set by EU. Greece with a yearly solar potential of about 1600 kW h/$m^2$ [7] is among the top 10 countries in solar energy utilization in building sector, mainly for domestic hot water production (DHW) [8]. The next step for enforcing the solar energy exploitation is to apply the solar energy systems for other proposes as space heating and cooling in order to minimize the grid electricity and the fossil fuel consumption. By using different solar collectors, the solar energy is able to be transformed to different kinds of energy. An innovative collector known as PVT (Photovoltaic thermal collector) produces electricity and useful heat simultaneously and it is a promising technology for the building sector.

Heat pump is a technology that gains more and more attention over the last years because of its low electricity consumption. Especially in Greece, the substitution of conventional boiler heating systems with heat pumps is usual because of the high fossil fuel cost. The next step is to combine solar energy utilization with heat pump creating environmentally and financially sustainable systems. The idea of using the solar energy to drive a heat pump is similar to the ground source heat pumps. The difference in the solar assisted systems is the lower initial cost [9] and for this reason in the areas with high solar energy potential, solar systems are preferred.

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**Nomenclature**

| | |
|---|---|
| $A$ | area ($m^2$) |
| $b$ | temperature coefficient of cell ($K^{-1}$) |
| $C$ | cost (€) |
| $c_p$ | specific heat capacity (J/kg K) |
| $E$ | energy (kW h) |
| $f$ | electrical solar coverage |
| $F'$ | collector fin efficiency |
| $G_T$ | solar irradiation on titled surface ($W/m^2$) |
| $H$ | daily solar energy (kW h/$m^2$) |
| $I$ | current (A) |
| $k$ | thermal conductivity (W/m K) |
| $K_{el}$ | specific electricity cost (€/kW h) |
| $m$ | mass flow rate (kg/s) |
| $M$ | water mass (kg) |
| $N$ | project life (years) |
| $P$ | power (kW) |
| $Q$ | heat (kW) |
| $r$ | discount factor |
| $T$ | temperature (°C) |
| $U$ | heat loss coefficient ($W/m^2$ K) |
| $V$ | voltage (V) |
| $V_T$ | storage tank volume ($m^3$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | plate absorbance |
| $\beta$ | collector slope (°) |
| $\varepsilon_p$ | plate emittance |
| $\eta$ | efficiency |
| $\rho$ | density ($kg/m^3$) |
| $\tau$ | cover transmittance |

*Subscripts and superscripts*

| | |
|---|---|
| *am* | ambient |
| *b* | back part of the collector |
| *c* | collector |
| *cell* | PV cell |
| *e* | edge |
| *el* | electrical |
| *grid* | grid electricity |
| *h* | hot |
| *heat* | heating |
| *hot, in* | inlet hot |
| *hot, out* | outlet hot |
| *in* | inlet |
| *l* | load |
| *load, in* | inlet load |
| *load, out* | outlet load |
| *loss* | thermal loss |
| max | maximum |
| *mp* | maximum power |
| *out* | outlet |
| *r* | reference |
| *s* | solar |
| *source* | heat source |
| *st* | storage tank |
| *T* | tank |
| *th* | thermal |
| *tot* | total |
| *u* | useful |

*Abbreviations*

| | |
|---|---|
| COP | coefficient of performance |
| FPC | flat plate collector |
| HP | heat pump |
| NOCT | nominal operating cell temperature |
| PV | photovoltaic collector |
| PVT | thermo-photovoltaic collector |
| TMY | typical meteorological year |

In the literature there are numerous studies related to solar energy and heat pump coupling. Air source heat pump, ground source heat pumps, solar assisted heat pumps and dual source heat pumps have been compared and tested for various climates. First of all, it essential to state that the water source heat pumps (solar and ground) performs better than air source heat pumps. More specifically, the coefficient of performance (COP) in water source heat pumps is about 4–5 [10], while for air source heat pumps is approximately 3 [11]. Moreover, Sun et al. [12], compared a solar assisted heat pump heating system with an air source heat pump and concluded that the first performs better in all weather conditions.

Many studies have focused on the combination of solar energy with ground source heat pump in order to achieve a high COP the days with high solar irradiation. Mehrpooya et al. [13] and Zhu et al. [14] studied this system with FPC and both concluded to a yearly COP of about 4.2. Dual source heat pumps which use hot water and ambient air energy have been also studied from many researchers. Chargui and Sammouda [15] used TRNSYS to simulate a residential house coupled with a dual source heat pump and concluded that a higher temperature of hot water improves the performance of the system and can give COP values greater than 6. Wang et al. [16] studied a novel solar PVT air dual-heat-source composite heat pump hot water system. In this system, ambient air and hot water are the heat sources for the heat pump which finally proved to have a satisfying efficiency. The COP was calculated to be ranged from 3 to 4, performing better than usual air source heat pumps.

The use of PVT with heat pumps is not usual in literature; however some interesting studies have been conducted. Tsai [17] studied an innovative PVT heat pump system for hot water production. The collector is the evaporator of the system and the condenser is located inside the hot water storage tank. The final results proved very good operation of this system with the electricity output from PVT to be adequate for the compressor needs. Good et al. [18] examined various solar collector systems in order to achieve zero energy consumption for a single family building in Norway. The studied systems were a combination of solar thermal and PV, a combination of covered PVT and PV, and a system with only PV. The final results proved that the system with only PV is the one that gets closest to reaching net zero energy balance. Calise et al. [19] studied with TRNSYS a polygeneration system using PVT coupled with heat pump and adsorption chiller for producing heating, cooling, domestic hot water and electricity. The optimum collecting area was proved to be about 25 $m^2$ and this system can be financially feasible when the initial cost will be reduced about 50%. Moreover, the use of PVT with water source heat pumps has been referred as a promising technology from other researchers [20,21].

In other studies, solar assisted heat pump systems with FPC have been analyzed successfully. Kuang et al. [22] investigated the thermal performance of a solar assisted heat pump system with FPC and water storage tank during the winter in north China. Svard et al. [23] described a new design procedure for solar assisted heat pump systems for space heating purposes. They sta-

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