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Experimental Study of a Novel Integrated System for Air Conditioning and Domestic Hot Water Production

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The integration between heat pumps and renewable energy sources is a recognized strategy to be pursued to reduce primary energy consumption in new or energetically retrained residential buildings. This paper presents the experimental research of a novel integrated system for air conditioning developed by RSE and built in the Terni laboratory at the Business Innovation Centre Umbria. The system named SINCLER (Sistema Integrato di Climatizzazione Efficiente e Rinnovabile) has been designed to meet the needs of air conditioning and domestic hot water for civil buildings using a reversible air heat pump assisted by hybrid solar panels. The thermal energy produced by the hybrid panels is used to produce hot water, while the electrical energy to power the heat pump and the various electrical equipment. The system also relies on two different storage tanks, one inside the heat pump and the other directly connected to the solar circuit, allowing a better temperatures management of the hybrid panels which effectively improved their efficiencies. The performance of the system has been evaluated in operation from June to December 2016, registering a seasonal EER (from June to September) equal to 2.9 and a seasonal COP (from October to December) equal to 3.2.

1. Introduction

In recent years, the world has been facing the growing problem of climate changes and of the depletion of traditional energy resources. The concentration of carbon dioxide has increased by more than 30% in the atmosphere since the industrial revolution (Rashidi et al., 2013). The greenhouse gas emissions have increased in parallel with global economic well-being, and several studies have investigated possible correlations between economic growth and global pollution, as discussed by Nan and Xu (2018). To face this problem, as suggested by the analysis of Nordin and Kun (2018), countries must improve the technology's efficiency and the use of renewable energy. In this respect, Europe has fixed the target of reducing by 20 % of the primary energy consumption by 2020. To achieve this goal, several technological strategies can be mentioned, both in the industrial sector and the residential sector. The smart utilization of heat pumps can be an exciting solution. They can be exploited for "total heat recovery", as reported by Liew and Walmsley (2016). Regarding this aspect, Wang et al. (2018) proposed a criterion for the selection of the heat pump in industrial processes. Another exciting solution is the coupling between them and the renewable energies, represented by the Solar Assisted Heat Pumps (SAHP), as reported in the early study of Sporn and Ambrose (1955). Since then, this topic has been widely studied. Dikici and Akbulut (2008) made a performance analysis on a SAHP for domestic space heating, finding a seasonal COP of 3.08; Yang et al. (2011) found an average COP of the system around 2.97-4.16. Besides, Scarpa et al. (2015) reported that with the proper condition, a COP equal to 6 can be reached. Considering the experimental activity of Kuang and Wuang (2006), a solar-assisted heat pump for climatization and hot water production has been tested: the implemented technology was able to provide a system COP for space heating in the range of 2.1-2.7 and to supply 200 liters of 50 °C domestic hot water each day. This coupling has also been investigated in the recent study of Besagni et al. (2018), in which a multifunctional SAHP for heating/cooling applications and domestic hot water (DHW) production has been discussed, finding an averaged energy performance approximately equal to 3. To this end, the present study investigates a novel integrated system for air conditioning and domestic hot water production experimentally. The system is called SINCLER (*Sistema Integrato di Climatizzazione Efficiente e Rinnovabile*), and it is an

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efficient integrated technology which can fulfil the climatization and domestic hot water requirements of civil buildings, exploiting a reversible air/water heat pump, with internal water storage, hybrid solar panels, a valid system of distribution and a domestic wastewater heat recovery. The concept of the SINCLER system has been tested in the experimental plant at the Terni laboratory at the Business Innovation Centre Umbria. In addition to the SINCLER system, the plant, considering his demonstrative nature, has been realized with different types of hybrid solar panels and with traditional photovoltaic panels, to make a comparison. The monitoring of the system has been conducted in the period between June and December of 2015 and then of 2016. The experimental set up has given the possibility of evaluating the SINCLER feasibility and the possibility of comparing the performances of different types of solar panels. This paper aims to describe into the detail the features of the SINCLER system, to present the experimental plant adopted for testing the technology and to report the most important results of the monitoring, including the SINCLER performances and the comparison between solar panels.

2. The SINCLER technology and the experimental plant

2.1 The SINCLER system

The SINCLER system has been ideated and developed by RSE, to satisfy, in an efficient way, the heating, the cooling and the domestic hot water requirements of buildings. It has a suitable size to meet the needs of a single-family house of small size; however, its structure can also be extended to larger facilities. In Figure 1 it is schematically represented. The hybrid solar panels convert solar energy into electrical and thermal energy, which is transmitted by glycolate water to the storage tank. The mains water is sent to this tank, and it is heated up by the thermal fluid coming from the solar panels. The reversible air/water heat pump operates for cooling/heating the building and contributes to the production of domestic hot water, when the solar radiation is not sufficient, using an internal water tank, different from the panel storage. The distribution system is made by fan-coils or radiant floor, and there is a heat exchanger for the recovery of the heat from the domestic wasted water, heating the mains water. The electricity produced is sent to the grid to compensate the electrical energy needed for the system operations or for other utilization (appliances, lighting…) or it is sold to the grid when it is in excess. Hybrid solar panels are connected to a tank where thermal energy is accumulated, which is used to produce ACS. Hot water from this tank is mixed with other water produced by the heat pump in its internal tank, to meet the demands of ACS also when solar radiation is not enough. This choice was made, instead of using a single tank, to obtain better performance of the solar panels, as it avoids maintaining the stored water temperature higher than that resulting from the solar radiation when the heat pump operates to produce ACS. In this way, the efficiency of the panels is improved.

2.2 The monitored experimental plant

The experimental plant was installed at the RSE laboratory in Terni, a closed area of 140 m^2, made by a lobby, an office, a comprehensive and high local and a shed designed to install solar panels. In the construction of the demonstration plant, greater emphasis has been placed on the use of the most widespread or promising types of hybrid solar panels to be able to compare their performance, even compared to the more traditional solar panels photovoltaic or thermal systems. In the plant, due to its experimental and demonstrative aim, three types of hybrid solar panels, three types of photovoltaic solar panels and a type of thermal panel have been installed. In the construction of the plant, precautions have also been included to replace any components ensuring other comparative analysis efficiently. Figure 2 shows the plant of Terni laboratory. On the shed, there are different types of hybrid solar panels, monitored in comparison with the equivalent photovoltaic panel (with the same number of cells), and there is a type of thermal panel. Every kind of hybrid solar panels is connected to a storage tank. To replicate the real groundwater temperature, a water-cooling system has been installed which cools down the inlet water heated by the exposed pipes. The air conditioning system is made by a reversible air/water heat pump, with a water tank of 186 liters. Fan coils and radiant floor characterize the distribution system. During summer, the internal setpoint temperature has been fixed at 24 °C, the supply temperature at 8.5 °C, without a climatic curve. During winter, the inner setpoint temperature has been selected at 20 °C; the supply temperature has been regulated with the climatic curve: 40 °C with external air at 2 °C and 30 °C with external air at 15 °C. Finally, we have an air renewal system with active thermodynamic recovery and a heat recover from the waste domestic hot water. An automized system simulates the hot water withdrawals with the following logic: the exit of the hot water only from the boiler if the tank temperature is higher than 40 °C; integration with the hot water produced by the heat pump if the panel tank temperature is between 30 °C and 40 °C; utilization of the hot water produced by the Heat Pump if the temperature of the panel tank is lower than 30 °C. In particular, the production of domestic hot water has been set to meet the needs of a standard family of three persons (150 l/d through three withdrawals 50 litres, executed at 8.30 am, 1.30 pm and 7.30 pm respectively).

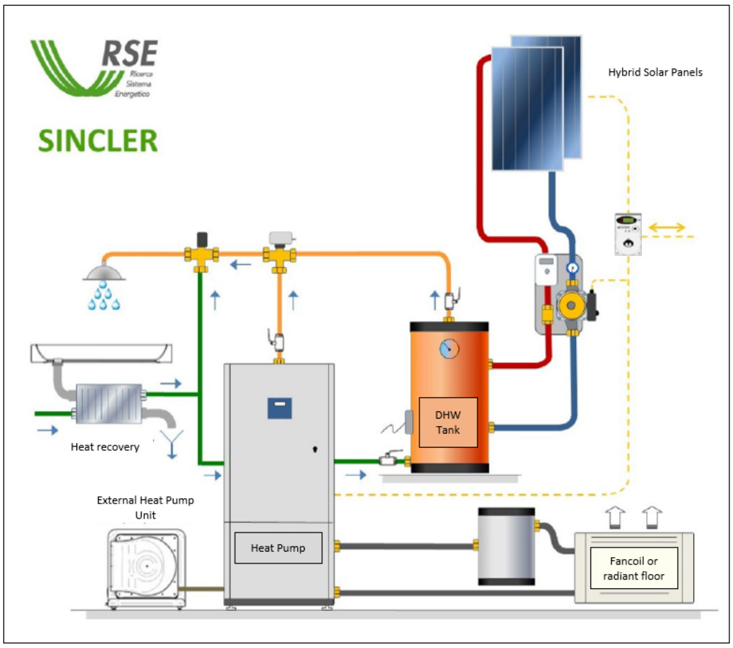

Figure 1: Layout of the SINCLER system

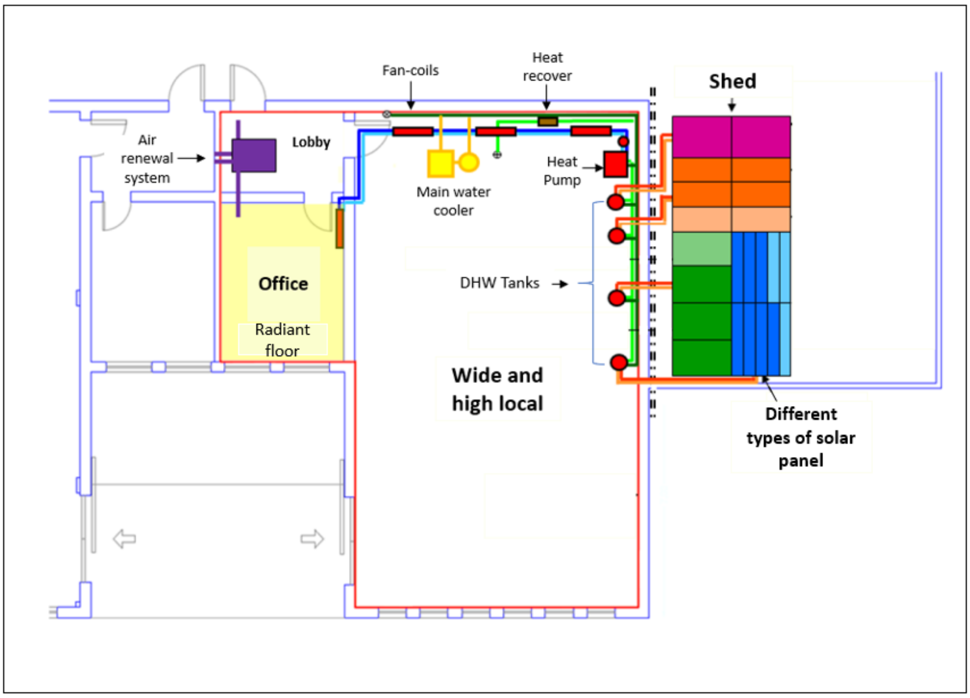

Figure 2: Installation at the RSE laboratory in Terni

3. Results of the monitoring

3.1 SINCLER system performances

As described in detail in Chapter 2, the SINCLER system is an efficient integrated technology, which couples the operation of a reversible heat pump with the thermal and electrical production of the hybrid solar panels, adopting some innovative features, as the domestic wastewater heat recovery, a separated water tank inside the heat pump and an efficient system of distribution. The experimental campaign shows that the hybrid solar panels have been able to ensure a degree of domestic hot water coverage of 95-100 % during the summer months. During winter, this ability weakens, but the heat pump can integrate the domestic hot water production, exploiting the thermal energy of the air. Further details about the performances of the hybrid panels can be found in section 3.2. The performances of the wastewater heat recovery have been determined experimentally by measuring the temperatures of the fluid at the inlet and the outlet of the heat exchanger, considering the relative mass flow rate. This heat exchanger demonstrates to be able to reduce the energy required to produce domestic hot water by a factor of 1/3. Considering the radiant floor, it permits to fix a climate curve with the temperature of supply water lower than the one in the case of fan coils as distribution systems. These aspects positively affect the performances in terms of COP. All these aspects contribute to improving the efficiency and the sustainability of the system. In table 3, the heat pump monthly performances are reported, related to the monitoring campaign of 2016. The table shows the thermal energy produced by the heat pump, the electrical energy required, the Coefficient of Performance and the Energy Efficiency Ratio. The seasonal EER (June to September) was 2.7, considering the circulation pump, with average temperature and humidity of the external air of 24.8 °C and of 60.8 % respectively. The seasonal COP (October to December) was 2.9, considering the circulation pump, with average temperature and humidity of the external air 11.8 °C and 82.2 % respectively. If the circulation pump energy consumption is not considered, the seasonal value of the COP and the EER are equal to 3.2 and 2.9, respectively. From Table 1, it can be noticed that the winter performances are higher than the summer ones. This is another important aspect due to the utilization of the radiant floor distribution system, which allows containing the temperature of the supply water during winter, while in summer the supply temperature is set at 8.5 °C.

Table 1: Heat pump performances (year: 2016)

Heading1	Th. Energy [kWh]	Elt. Energy [kWh]	COP [-]	EER [-]
June	242.2	87.1	-	2.8
July	412.6	166.7	-	2.5
August	431.0	169.4	-	2.5
September	416.6	130.7	-	3.2
October	48.2	13.6	3.5	-
November	180.6	52.2	3.5	-
December	598.5	215.5	2.8	-

3.2 Comparison between hybrid panels and photovoltaics

In addition to the evaluation of the SINCLER components performances, the demonstrative experimental plant at the Terni laboratory gives the possibility to evaluate the performances of hybrid solar panels, compared to the performances of traditional photovoltaic ones. In particular, the comparison is made considering photovoltaic panels with the same number of cells of the hybrid type. The panels, operating under the same climate conditions, are compared in terms of electrical energy produced and in terms of primary energy saving. The results of the panels monitoring of the year 2015 are reported in Table 1 and in Table 2. These tables show the thermal and electrical energy produced and the primary energy saved by the two types of panels coupled with the heat pump, as happens in the SINCLER system. As Table 1 shows, the thermal energy produced by the hybrid solar panels has the highest values in June, July and August, then it progressively decreases for the following months. The electricity produced by the hybrid panels or by the photovoltaic ones has the same behavior as before, but with smoother variations from the warm months to the cold months. An essential result of this monitoring is that the electrical energy produced by the hybrid panels is always higher than the electrical energy of the photovoltaic panels and this difference is higher during warm months. To explain this topic, Figure 3 compares the electrical production of a photovoltaic panel and a hybrid panel on a summer day at the beginning of June. It can be noticed that at the activation of the solar circulation pump at 9 am, the electrical power curve produced by the hybrid panel remains higher than the electrical power curve of the photovoltaic panel until 3.30 pm. As a result, the hybrid panel has more energy than the corresponding photovoltaic one, because of the water circulation, which keeps it colder. The heat removal is also visible from the comparison between the temperature of the water coming out of the hybrid panel and the temperature measured at the back cell of the photovoltaic panel. It can also be observed that, at the withdrawal of domestic hot water from the storage tank (1.15 pm), the temperature of the solar water decreases, increasing electricity production.

Table 2: Hybrid panels performances (year: 2015)

Heading1	Th. Energy [kWh/m^2]	Elt. Energy [kWh/m^2]	Pr. En. Saved [kWh/m^2]
June	33.1	25.8	89.3
July	36.3	25.8	92.4
August	30.1	23.3	80.7
September	22.9	18.5	63.0
October	10.8	11.2	72.9
November	8.1	10.6	52.4
December	2.5	9.1	40.1

Table 3: Photovoltaic panels performances (year: 2015)

Heading1	Elt. Energy [kWh/m^2]	Pr. En. Saved [kWh/m^2]
June	24.8	53.9
July	24.7	53.8
August	21.9	47.7
September	17.7	38.5
October	10.9	60.1
November	10.4	43.6
December	8.9	37.3

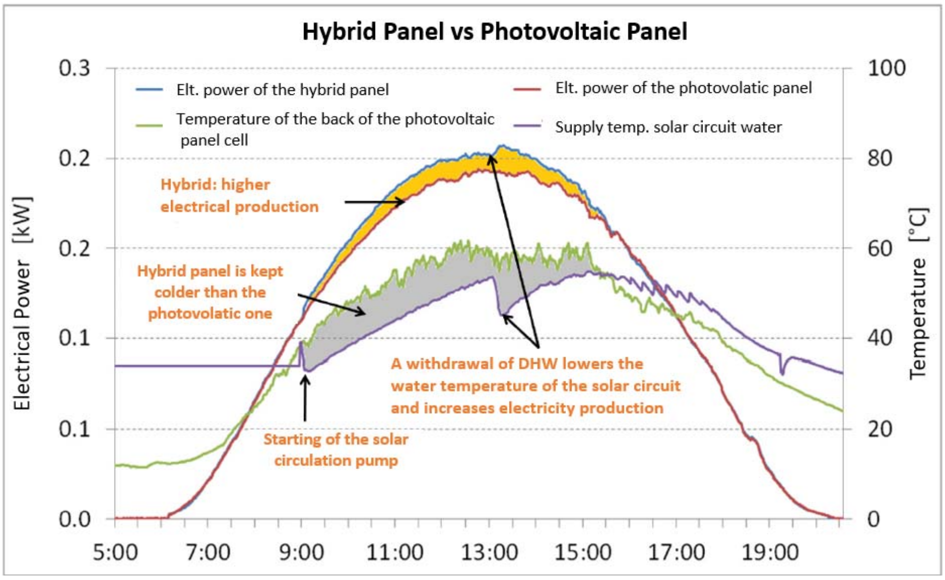

Figure 3: Comparison of the performances of a hybrid panel and a photovoltaic panel with the same cells

4. Conclusions

This paper experimentally investigates, an integrated system for air conditioning and domestic hot water production, considering a monitoring campaign from June to December of 2015 and 2016, detected in an experimental laboratory, located at Terni. During this experimental investigation, the main features of the SINCLER system have been monitored and comprehensive comparison between hybrid and photovoltaic panels has been made, to understand the efficiency of the two types of panels in these operating conditions. The monitoring showed that the incident solar radiation is exploited efficiently by the hybrid solar panels, which transform it into electrical and thermal energy: electricity can be used to power the heat pump and the thermal energy to produce domestic hot water (DHW). During periods with weak solar radiation, the heat pump can integrate the production of domestic hot water, using the water stored in its separate tank. The performances of the system are promising; the monitoring reports a seasonal EER (Jun-Sep) equal to 2.9 and a seasonal COP (Oct-Dec) equal to 3.2. The hybrid panels have had a higher electrical production concerning the photovoltaic ones with the same cells. This aspect is clearly due to their cooling by the glycolate water, which flows within them. Besides, they have an appreciable thermal efficiency. An essential contribution to this result is due to the choice of using two different tanks for the storage, instead of one, to avoid maintaining the temperature of the only tank higher than the resulting one from solar radiation, when the heat pump is required to integrate the domestic hot water production. The hybrid solar panels allow having a great primary energy saving, which can also be achieved in winter months, when the thermal energy of the air can be exploited by the heat pump, using the electricity produced by the panels. In conclusion, this work points out the reliability and the efficiency of an integrated system, which can satisfy the conditioning and hot water requirements of a civil building, operating sustainably, decreasing the primary energy consumption significantly, and giving us a perspective on how to achieve the European and global goals for facing climate change and primary sources depletion.

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