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Novel approach for heating/cooling systems for buildings based on photovoltaic-heat pump: concept and evaluation

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Abstract

The paper presents the complete results regarding the energy performance and reliability of a new heating/cooling system designed and developed around an economic and ecological concept: self-consume a maximum amount of energy produced by solar photovoltaic panels. To achieve this goal, a unique regulation system which takes advantage of each kW produced by the PV system was developed and implemented. This technology, compared to a conventional system, increases the performance coefficient for the HP, as well as for the overall installation. These improvements are justified by the accurate regulation of different components of the installation - power modulation of the HP and circulation pumps- and by use of photovoltaic panels allowing a reduction of the electrical energy consumed from the grid.
To quantify the contribution of the new system, the energy efficiency was established for the 2 cases: with and without solar PV panels. The results indicate that new system provides a significant gain in performance. This new technology, HP directly driven by PV, produces significant annual improvement compared with a conventional heating system, HP, of 22%.

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Keywords: heat pump; photovoltaic panel; storage; solar heating system; solar cooling system; artificial intelligence; regulation; energy production; solar energy; simulation; *economics*

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1. Introduction

Main actual challenges currently in the energy field are energy efficiency and energy dependence reduction to the grid. The current project uses a smart regulation to manage photovoltaic production, heat pump, storage management and thermal needs. This concept, based on the self-consumption, has been monitored on a pilot installation. Thanks to the monitored data, the energy efficiency of the pilot installation will be quantified and qualified.

Nomenclature

SC	Solar contribution	[%]
Q_h	Heat production by the heat pump (HP)	[J]
Q_{DHW}	Heat delivered to the domestic hot water (DHW) by the HP	[J]
Q_c	Cold source to the HP	[J]
$P_{el,HP}$	Electricity power consumed by the HP	[W]
$P_{el,PV}$	Electricity power provided by the photovoltaic panels	[W]
$P_{el,HPx}$	Electricity power consumed by the pumps of the heat pumps circuits	[W]
$P_{el,HS}$	Electricity power consumed by the pump of the geothermal heat poles	[W]
$P_{el,SH}$	Electricity power consumed by the pump of the heating system	[W]

2. Technological concept

Solarline was created on an economic and ecological concept: to self-consume a maximum of the energy produced by solar photovoltaic panels. It is a unique regulation system developed to achieve this goal. It allows to use every single kWh produced by the solar installation. Moreover, the system uses the storage capacity of water tanks to absorb the daily photovoltaic production variations. In water tanks, hot water can be stored as well as cold water for the cooling during summer. Another important point is the modulation of the heat pump power. The power is set to have the best performance and to consume the entire photovoltaic production.

2.1. Global technical installation concept

The technical system is composed of a heat pump, photovoltaic panels, a smart regulation and water tanks (Fig. 1). The heat pump is operated by the photovoltaic panels and the grid.

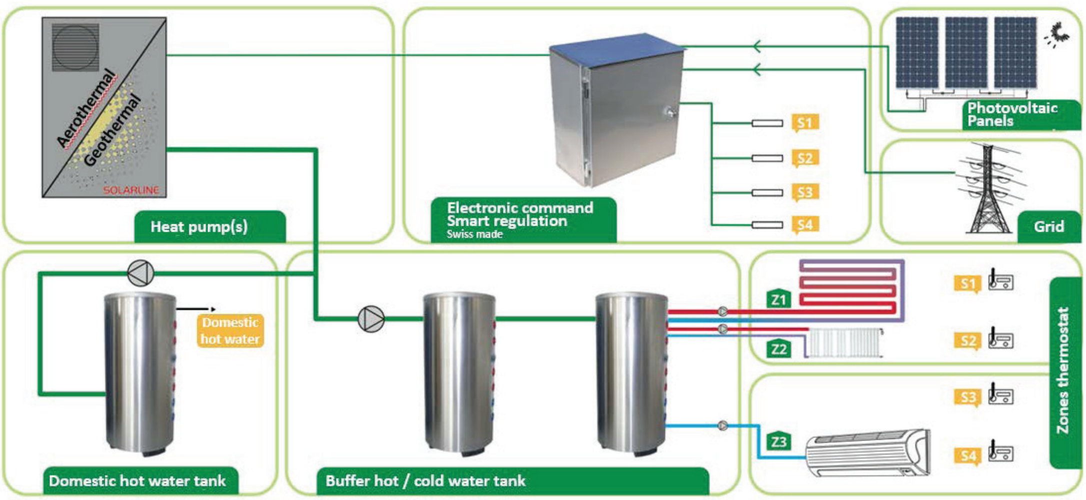

Fig. 1: Global technical system concept of Solarline

The entire electricity production of the photovoltaic panels is directly used by the heat pump. The exceeding energy produced is stored in the domestic hot water tank or the buffer tanks for heating. Therefore, the system needs a smart regulation performed by an electronic module connected to the inverter and to the temperature sensors of the building and the water tanks. All system components applied are field proven and available on the market.

2.2. Operating points

Depending on the solar irradiation and temperature conditions of the day, there are two operating conditions.

2.2.1. Nominal condition

The daily solar supply covers all the needs: heating, cooling and domestic hot water. The exceeding energy produced by the photovoltaic panels is converted by the heat pump into hot or cold water and stored into the water tanks. This energy has been stored during the day and can be used during the night. To store energy in water tanks is more economic and less polluting than the storage in batteries.

2.2.2. High needs conditions

If the daily solar supply doesn't cover all the needs, the system takes the electricity from the grid to keep the building at the setpoint temperature. Moreover, if the electricity price is advantageous during the night, the system uses this energy to heat up the water in the buffer tank to fulfill the heat needs of the next day.

3. Pilot facility

The pilot site, see Fig. 2, is a 4 floors building in Switzerland. The building RUIDA contains offices and one flat for a total of 2'154 m^2. The technical system is composed of 4.8 kWp of photovoltaic panels, a 500 l DHW tank, three 500 l buffer tanks and three 17 kW heat pumps coupled with 1'000 m geothermal heat poles.

Fig. 2. Pilot site - RUIDA building in Switzerland

3.1. Monitoring

This entire heating system is monitored during one year, in 2012. The instantaneous data are available online[2]. The monitoring includes the measures of the heating, cooling and DHW needs as well as the electricity consumption

[2] http://www.cosseco.ch/performance-pompe-a-chaleur-solarline/

from the grid and the energy production from the photovoltaic panels (Table 1). The data are used to achieve the energy efficiency of the system. The solar contribution, the ratio between the photovoltaic contribution and the total electricity consumption, is evaluated and represents 22% (Equ. 1).

$$SC = \frac{\int P_{el,PV} dt}{\int (P_{el,HP} + \sum_{i}^{3} P_{el,HPi} + P_{el,HS} + P_{el,SH}) dt} \quad (1)$$

Table 1. Energy consumption and production of the heating system for year 2012

Heat			Electricity consumption			
Heat [kWh]	DHW [kWh]	Cooling [kWh]	Photovoltaic electricity [kWh]	Grid [kWh]	Total [kWh]	Photovoltaic part [%]
Q_h	Q_{DHW}	Q_c	$E_{el,SC}$	E_{grid}	E_{tot}	
101'049	17'342	15'211	5'632	19'430	25'062	22%

The self-consumption has reached the maximum of 100%. The Fig. 3 compares total electricity consumption, electricity consumption form the grid and PV production for each month. As PV production is completely self-consumed, PV panels are sized so that the PV production never exceeds electricity consumption.

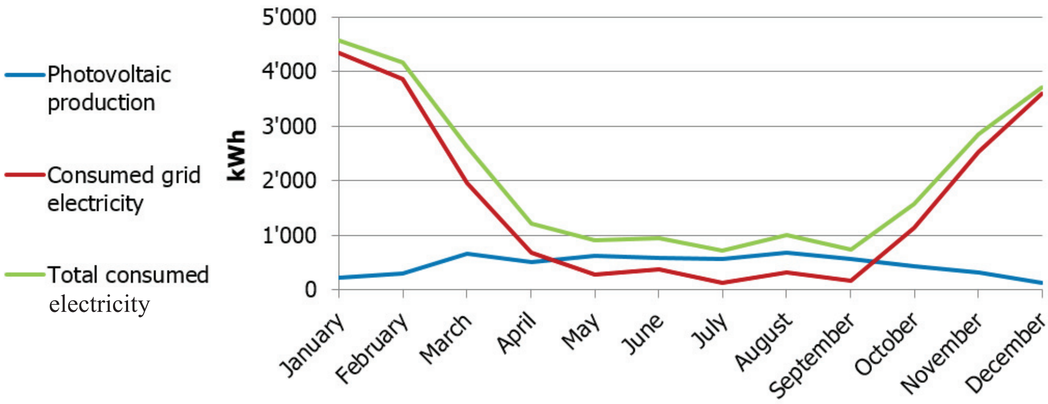

Fig. 3. Comparison of the monthly consumptions and PV production

3.2. Energy efficiency

The energy efficiency is quantified through the seasonal performance factor (SPF). It corresponds to the average of the coefficient of performance (COP). This is the ratio between the heat production and the electricity consumption within the defined system boundary. The factor is calculated three times depending on the system boundaries illustrated in the Fig. 4 and are compared with the performance of the heat pump according to the manufacturer.

- SPF+: includes all the pumps, the energy production heat pump, the PV production and the electricity from the grid

$$SPF_{SHP+} = \frac{\int (\dot{Q}_h + \dot{Q}_{DHW} + \dot{Q}_c)dt}{\int (P_{el,tot} - P_{el,PV})dt} \tag{2}$$

- SPF: same boundaries as SPF+ without taking account the PV production (just all the pumps, heat pump, grid):

$$SPF_{SHP} = \frac{\int (\dot{Q}_h + \dot{Q}_{DHW} + \dot{Q}_c)dt}{\int (P_{el,HP} + \sum_{i}^{3} P_{el,HPi} + P_{el,HS} + P_{el,SH})dt} \tag{3}$$

- SPF HP: considers only the heat pump. It includes the heat pump energy production and its consumption

$$SPF_{HP} = \frac{\int (\dot{Q}_h + \dot{Q}_{DHW} + \dot{Q}_c)dt}{\int P_{el,HP}dt} \tag{4}$$

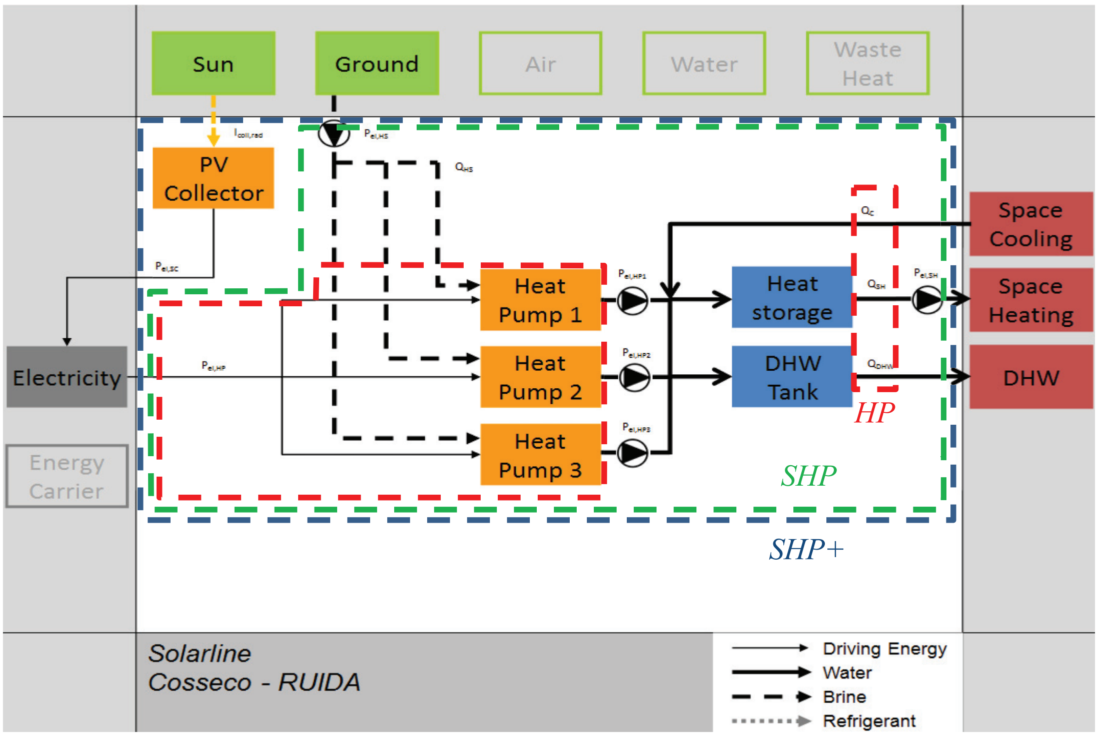

Fig. 4. Scheme illustrating the system boundaries used to estimate the energy efficiency: SHP+, SPF and SP HP [1].

Table 2. SPF of the heating system compared with the heat pump COP according to the manufacturer

SPF_{SHP} (Equ. 2)	SPF_{SHP+} (Equ. 3)	SPF_{HP} (Equ. 4)	Heat pump COP
Taking into account: pumps, DHW, heating and cooling	**Taking into account:** PV, pumps, DHW, heating and cooling	**Taking into account:** DHW, heating and cooling	**HP COP** (value from EN 14511) – **B10W35** [2]
5.3	6.9	6.2	5.4

If the system boundary takes into account the photovoltaic production as a free source of electricity (SHP+), the entire system has a high SPF: for 1 kWh of the grid, the system produce 6.9 kWh of thermal energy. Without the photovoltaic production, energy efficiency of the system drops to 5.3. Thus, using photovoltaic panels rises the SPF by 1.6, representing almost 23% increase.

The heat pump COP given the manufacturer is compared to the SPF_{HP}. It is much lower, around 13%. Thus, this pilot installation is performant and the regulation allows maximizing the heat production. The results indicate that the new system provides a significant gain in performance. The reasons of the high efficiency are the storage management and also the power modulation of the heat pumps. By this way, the heat pump runs at the optimized power.

4. Conclusions

Solarline is an innovative technology based on the regulation of a hybrid system, heat pump and photovoltaic panels. The objective is to maximize the self-consumption from the photovoltaics panels to cover the building's heating needs while reducing the electricity consumption from the grid. The energy balance of the innovative installation comprising intelligent regulation for the heat pump – solar photovoltaic system applied to a building heating system was establish.

This technology, compared to a standard stand-alone heat pump installation, allows to rise the SPF of the heat pump and of the global system by 23%. These increases of performance are justified by the heat pump power modulation and the electricity reduction from the grid due to the self-consumption.

References

[1] Norme EIA SHC, Task 44, 2012
[2] Norme EN14511, 2011