Impoving the energy efficiency by coupling of a heat pump and hybrid PV-T panels

The concern about climate change has lead European Union and national governments to take some measures (EPBD Directive, RES Directive…) in order to reduce the impact the building sector has on the global contribution of greenhouse gas emissions.

As a consequence of such regulations, maximum values of primary energy use (kWhPE/m²) are then allowed when a new building is being constructed or largely renovated and a minimum share of RES should be used.

ERIC AUZENET
CIAT Research & Innovation Centre, Ftance,
e.auzenet@ciat.fr

ALAIN GUIAVARCH
Hachem Ben Nejma Centre for Energy and Processes, MINES ParisTech

ISMAEL LOKHAT
CYTHELIA,
France

FABRICE CLAUDON
CEA INES,
France

Architects and building engineers have to find solutions to build efficient buildings. As an example, for the French case (Réglementation Thermique RT2012), a value of 50 kWhPE/m²/year (for heating, cooling, DHW, lighting and auxiliaries) is the average target for every new building as from 1st January 2013. A minimum of 5 kWhPE/m²/year of RES has also to be considered for individual residential buildings.

Future versions of these regulations will be even stricter and the fact that buildings will have to become energy providers (net or positive energy buildings) probably by 2020 is already in discussion.

Heat pumps and PV panels are two types of equipment that may represent interesting solutions for building designers. Although today they are very often installed with no interaction between the two, the objective of the project described herewith was to take advantage of each piece of equipment in order to obtain an efficient coupled system and meet the regulation requirements, thus providing a technical answer for future buildings.

Principle Objectives and Description

As described in numerous studies, a photovoltaic collector produces electricity but also thermal energy which can be recovered by air or water to heat the building. This solar component is generally described and modelled as a combination of a photovoltaic collector and an air solar collector, leading to what is commonly called a hybrid photovoltaic-thermal (PV-T) collector. It is also well known that the efficiency of a PV panel decreases with its operating temperature as well as its lifetime. As a consequence, some benefits may be obtained when the PV panel is cooled down.

The coefficient of performance of a heat pump depends strongly on the temperatures of the source and of the sink. This is particularly true for air-source heat pumps. It is possible to significantly improve the seasonal Coefficient of Performance (COP) of an air source heat pump by coupling its external unit with pre-heated air-sources integrated into or near the building.

A system has been designed and installed on a demostration builiding.

Demonstration Building Description

The developed prototype has been installed in a new building, "La Petite Maison Z.E.N (PMZ)", which is a Zero Energy Net building of 116 m², hosting offices and located in the Montagnole village, near the city of Chambéry, in the French Alps.

Figure 1. Case building : La Petite Maison Z.E.N.

It was designed to have a yearly overall consumption lower than 50 kWh/m², for all uses. To reach such levels of performance, both the building design and the equipment have to be very efficient.

Not complex architecturally speaking, the building is compact. On the north face, the window area is fitted with triple glazing. For the South and East faces, with larger window areas, passive solar gains are favoured with double glazing windows.

To reduce solar gains in summer, an architectural mask in the south facade has been created by the eaves.

The building structure is made from a wood frame of 145 mm. It is insulated with 140 mm of wood wool between the frame, plus 60 mm of fiber wood in the exterior in order to prevent hermal bridges.

To limit the ventilation losses, a mechanical ventilation system with a 90% heat recovery efficiency exchanger has been installed.

Fan coil units equipped with fans driven by EC motors are used as low inertia emitters for heating and cooling.

System Description

Photovoltaic Collector

The south-oriented roof (70 m²) is fully covered with photovoltaic modules divided into 2 parts:

- 7.2 kWp of thin film CIGS modules on the roof itself.
- 1 kWp of see-through micromorph modules integrated in the roof of the patio (10 m²).

Thanks to the air flow, the module temperature should rarely be higher than 60°C.

System and Water Loop Description

Ambient air is pumped and circulates under the PV panels thanks to the fans incorporated into the air handling unit. Before being rejected outside the building, it crosses the coil where heat is extracted and directed to the evaporator of the water to water heat pump through the brine circuit (**Figure 2**).

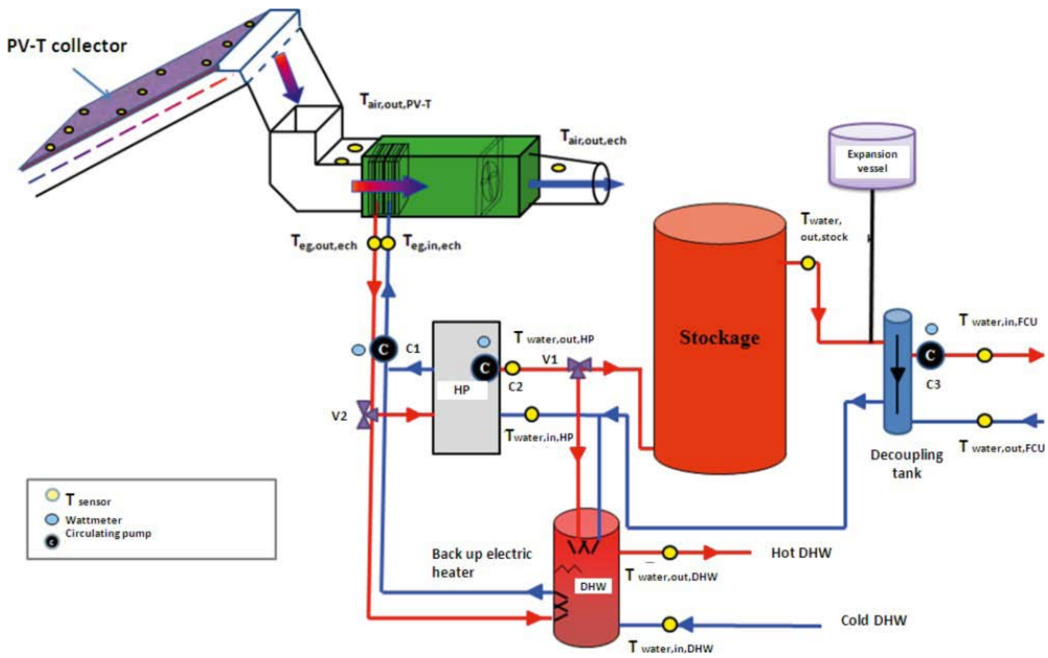

Figure 2. Detailed diagram of the air and hydraulic circuit.

On the secondary side of the heat pump, thanks to a motorized three way valve, heat can either be dispatched on the main loop composed of a large storage tank connected to the decoupling tank that feeds the fan coil units or on the DHW tank.

If the temperature of the extracted air is high enough, the heated brine can be sent directly to the serpentine of the DHW tank by bypassing the heat pump with a motorized three way valve. The system is reversible and can produce cold water in summertime.

Modelling of the system

The models of the different components of the system are coupled and integrated into a building simulation tool.

PV-T collector

The production of electricity by photovoltaic modules is calculated with the 1-diode model, assuming the collector is grid-connected.

In the case of a ventilated air gap, a model has been developed to calculate the thermal efficiency of the PV-T collector. This model assumes steady-state conditions and a one-dimensional conduction heat transfer perpendicular to the collector surface.

Heat pump

The heat pump model is based on a steady-state empirical model and considers full load and part load conditions.

In order to validate and define more accurately some parameters of the heat pump model, some steady state tests have been performed on a semi-virtual test bench.

Domestic Hot Water Tank

The model is derived from type 340 from the TRNSYS library. In this model, it is assumed that the stratified hot water tank is divided into horizontal, thermally uniform water layers.

Coupling and implementation into a dynamic thermal simulation tool

The demonstration building has been modelled and simulated thanks to a thermal simulation tool of multi-zone buildings named COMFIE: it allows heating and cooling loads, as well as temperature profiles in different zones, to be evaluated.

The hourly outputs of the resulting simulation tool are for instance the absorbed energy and the COP of the heat pump. These results, once integrated over one year, will give the efficiency of the whole system. Other variables (hourly mean temperatures or electricity produced by the PV-T collector for instance) can also help to assess its performance.

Monitoring system

The monitoring system aims at comparing the numerical model with real measurements as well as highlighting the performance of the demonstrator.

Data is logged every minute by the monitoring system. Meteorological data recorded on site are the ambient temperature and the relative humidity. Each component of the system is monitored.

Comparison between modelling results and in situ test results

Figure 3 gives the comparison between the model and the monitoring results in terms of the outlet air temperature of the PV-T collector, for 3 days of the first week of November 2011.

The figure shows a good concordance between the tuned model and the experiment. Nevertheless, we can note some discrepancy during the night, because the radiation heat exchange between the PV collector and the sky is not accurately taken into account in clear sky conditions.

Figure 4 gives the comparison between the model and the experiment for the coefficient of performance of the heat pump for one day in February 2012 (more precisely from 12 pm to 4 pm). The figure shows a good concordance between the model and the experiment.

Modelling of Annual Performances

It was shown that the modelling of the system is very close to the monitoring results measured in real operating conditions. It thus enables us to validate the complete model and to perform an all year round simulation of the complete installation, including the calculation of the building needs. The demonstration system has been simulated as well as a reference system composed of an on/off air-to-water heat pump and of an unventilated PV roof having the same size as the one installed on the demonstration building. No coupling exists between the air/water heat pump and the PV roof and there is no water storage, as in the reference case. The heating system as well as the building are identical for both cases of simulation. The coupling improves the PV production by around 10% and decreases the heat pump electricity consumption by around 20%. The net benefit is of around +10% for the coupled case (see **Figure 5**).

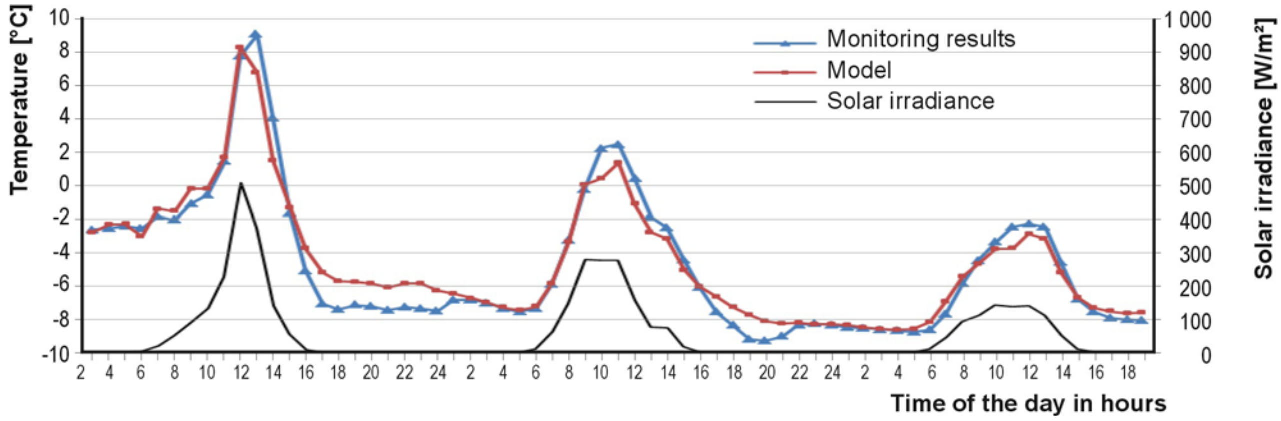

Figure 3. Outlet air temperature of the PV-T collector.

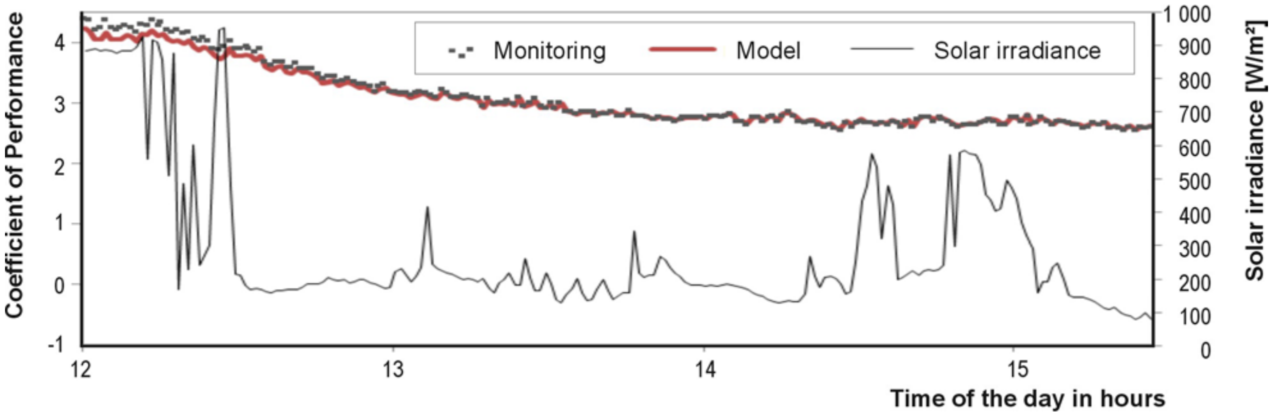

Figure 4. COP of the heat pump.

Conclusions and Perspectives

A system coupling a PV-T roof to a heat pump has been designed and installed in a demonstration building. It has been operating since the autumn of 2011, as has its controlling system. It is able to heat, cool and produce DHW (either with the heat pump or by direct solar heating).

Its modelling has been performed, showing that such coupling benefits the efficiency of the heat pump as well as the PV panels electricity production, as was expected at beginning of the project. The results of the experiments show that some improvements may be made on the system (Air Handling Unit coil design, control of the system…).

Some studies and experiments on larger building are planned to be done. ■

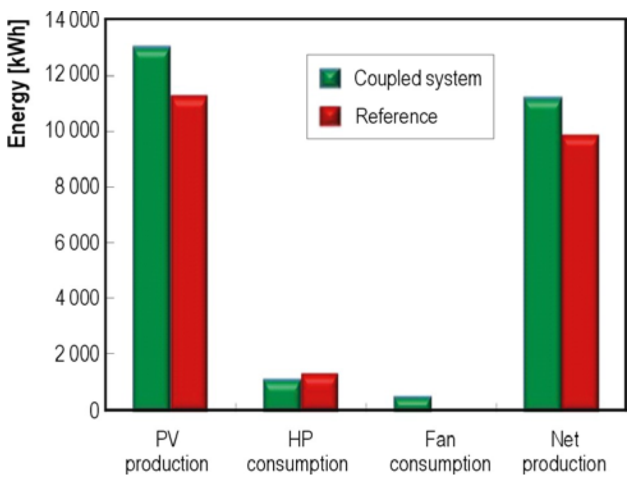

Figure 5. COP of the heat pump.

Acknowledgements: This work, carried out between January 2009 and December 2012, was backed by the French Research National Agency (ANR).

This article is based on the paper published in the proceedings of the Clima 2013 Conference:

Karel Kabele, Miroslav Urban, Karel Suchý, Miloš Lain (Eds.) CLIMA 2013 - 11th REHVA World Congress and the 8th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings, 16.-19.6. 2013 Prague Congress Centre, 5. května 65, 140 21 Praha 4, Czech Republic, Pages: 6882, ISBN 978-80-260-4001-9