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Solar heating by radiant floor: Experimental results and emission reduction obtained with a micro photovoltaic–heat pump system

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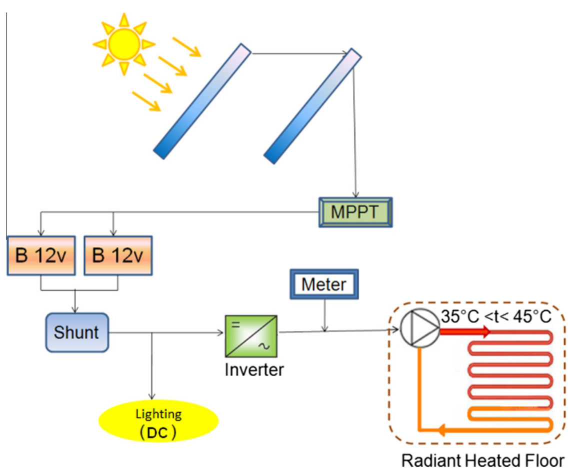
HIGHLIGHTS

- This work presents a PVT multicrystalline solar heating system for buildings.
- The PV DC electricity generated was converted to AC to drive an air–water heat pump.
- Experimental results obtained from December 1, 2012 to April 30, 2013 are detailed.
- An environmental study is also presented.

GRAPHICAL ABSTRACT



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ABSTRACT

An experimental research with a solar photovoltaic thermal (PVT) micro grid feeding a reversible air–water, 6 kW heating capacity heat pump, has been carried out from December 2012 to April 2013. Its purpose is to heat a laboratory that is used as a house prototype for the study of heating/cooling systems. It was built in accordance with the 2013 Spanish CTE, and has an area of 35 m^2 divided into two internal rooms: one of them housing the storage system, the solar controller, the inverter and the control system; the other one is occupied by three people. Its main thermal characteristics are: UA = 125 W/°C and a maximum thermal load about 6.0 kW at the initial time. The PVT field consists of 12 modules, with a total area of 15.7 m^2 and useful area of 14 m^2. Each module is composed of 48 polycrystalline silicon cells of 243.4 cm^2, which with a nominal efficiency 14% can generate a power of 180 W, being the total nominal power installed 2.16 kW. The PV system stores electricity in 250 Ah batteries from where is converted from DC to AC through a 3.0 kW inverter that feeds the heat pump. This works supplying 840 l/h of hot water at 35–45 °C to the radiant floor. The data storing system is recording variables such as solar radiation; temperatures; input power to batteries; heat produced; heat transferred by the radiant floor; heat pump's COP; isolated ratio; and solar fraction. The objective of this work is to present and discuss the experimental results and the emission reduction of CO_2 obtained during the period from 01/12/2012 to 30/04/2013, including the detailed results of two representative days of Madrid's climate: 28/12/2012 using only PV electricity and 21/01/2013 mixing PV and conventional electricity. The heat pump worked

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Nomenclature

A	area (m^2); amperes
AC	alternating current
B	battery
COP	coefficient of performance
D	thermal demand
DC	direct current
d	days
E	calorific energy (kW h)
GWP	global warming potential
h	hours
ISE	intercepted solar energy (kW h)
ITH	interval time horizon
P	electric power (kW)
PV	photovoltaic
Q	thermal power (W)
R	refrigerant
Rad	solar radiation (W/m^2)
T	temperature (°C)
TH	thermal load (kW)
U	global heat transfer coefficient (W/m^2°C)
V	voltage difference (V)
W	electrical energy (kWh)

Greek

η	efficiency (%)
RF	radiant floor
S	surface

Subscripts

B	batteries
C	condenser
E	evaporator
D	demand
EG	electrical grid
F	floor
IN	indoor
HP	heat pump
MF	module field
PV	photovoltaic
OUT	outdoor

with a maximum COP about 6 when the difference of temperatures T_C–T_F was maximum, being the seasonal COP about 3.2. The period efficiency to DC electricity generation of the PV field was 9.2% and the efficiency to conversion to AC electricity to drive the heat pump was 5.7%. The global efficiency of solar conversion into heat was 18.2%, the isolation ratio was 69.3%, and the solar fraction about 65.3%. The saving emissions were 836 kgCO_2/period in the case of a Gasoil boiler substitution and 574 kgCO_2/period in the case of a Natural Gas boiler substitution. The heat pump contains 1.7 kg of refrigerant R410A with a GWP of 3400 kg equivalent CO_2 to IHT of 20 years. The emission of R410A to atmosphere was 0.031 kg in 13 months, being the equivalent mass of CO_2 about 106 kg. The thermal component of the modules field has not been used.

1. Introduction

It's well-known the interest that solar energy photovoltaic conversion has generated since the decade of 1970. As a consequence of scientific activity this technology has experienced a remarkable development which can be seen in the increasing number of this type of installations all over the world. The acceptance of photovoltaic systems has spread due to its easy installation, to being a producer of a clean way of energy like electricity and the institutional support, which results in an economic support.

Unfortunately, as a consequence of the economic crisis that EU is suffering, this support is being questioned in some countries, like Spain [1], where subventions have been recently reduced.

Legal system is also changing and specifically in Spain the concept of 'net balance' will be implemented trying to boost the 'self-consumption' [2] which improves the consumption of photovoltaic electricity in buildings and houses. This tries to avoid as much as possible the use of the electrical supply for the exportation by small consumers.

Consequences of this change in legislation are already palpable even before its publication. First of these consequences is the fact that solar systems of lower power are demanded, which implies that the economic investment will also be lower. This fact is having a positive influence because the number of installations is increasing. This increase in the demand has also to do with the competitiveness in the industry that produces the main component: the photovoltaic unit. In accordance with the information supplied by the European Photovoltaic Industry Association (EPIA) the cost of the photovoltaic watt has experienced a remarkable descent, reducing up to 25% between 2000 and 2011, as Fig. 1 shows, according to [3].

The second of these consequences, which will probably be shown in the future, but which is already being noticeable, is that the development of small power systems is related to the use of electricity for the consumption of lighting and small electrical appliances. However, the use of photovoltaic energy for some other uses like space heating and cooling in houses and buildings may suffer a recession because they use systems that require bigger areas. Precisely this inconvenience may act as an incentive to increase the efforts in finding ways to use photovoltaic electricity for heating and cooling [4].

This interest is shown in the investigations that have been recently, among others, published; for example studies in different climate [5,6], development of large scale systems [7], simulation of facilities for small offices under different environmental conditions [8,9], further of other applications [10,11]. Hartmann [8] has developed a theoretical model that studies the air-conditioning of two small offices in two different buildings: one in Freiburg and another one in Madrid. In his work he compares the profitability of using thermal and photovoltaic conversion for heating and cooling. He concludes that the photovoltaic system is the most