Chillventa CONGRESS 2022
Heat Pumping Technologies
Use of R744 in a solar assisted heat pump for residential heating applications

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Solar Assisted Heat Pump with integrated PV-T evaporators

- Development of a dual source heat pump that can use two heat sources alternatively: Air and Solar energy
- Study a solar hybrid (PV-T) collector that is able to convert solar radiation into electrical power and to operate as an evaporator for the refrigerant loop

Main novelties of this work

- Use of R744 (CO₂) as refrigerant
- Photovoltaic-thermal (PV-T) collector working as the evaporator
- Evaporator in dry expansion in PV-T collector
- Evaporator in flooded configuration in natural or forced circulation mode in PV-T collector
HEAT PUMP PROTOTYPE

- Maximum thermal capacity 5kW
- The heat pump can work with a finned coil evaporator or with three PV-T evaporators

The heat pump is installed at the Solar Energy Conversion Laboratory of the Department of Industrial Engineering (Padova, Italy)

Manufactured by ENEX S.r.l.
Main heat pump components

- Compressor: Inverter-driven rotary compressor (COMP)
- Gas cooler: brazed plate heat exchanger (GC)
- Internal heat exchanger: brazed plate heat exchanger (INT)
- Throttling device (HPV)
- Low pressure liquid receiver (REC)
## PV-T Module and Sensors Installed

### Photovoltaic Module

<table>
<thead>
<tr>
<th>Photovoltaic module</th>
<th>Sheet-and-tube heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of modules</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>1650 x 992 mm</td>
</tr>
<tr>
<td><strong>Tilt angle</strong></td>
<td>45°</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Multicrystalline silicon</td>
</tr>
<tr>
<td><strong>Connection</strong></td>
<td>Series</td>
</tr>
<tr>
<td><strong>Number of cells</strong></td>
<td>60</td>
</tr>
<tr>
<td><strong>Peak Power</strong></td>
<td>270 W</td>
</tr>
</tbody>
</table>

### Sensors

- Refrigerant and water temperatures
- Refrigerant pressure along the circuit
- Coriolis flow meter on the water loop
- Solar irradiance
- Wind velocity
- Power consumptions and power generated by the PV cells
**Evaporator**

**SOLAR:**
- 3 PV-T collectors
  - Dry expansion
  - Flooded
  - Natural circulation
  - Forced circulation

**AIR:**
- Finned coil
  - Dry expansion

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**Diagram Notes:**
- Two evaporators in parallel
  - Air source (FAN)
  - Solar source (PV-T)
After the HPV, the refrigerant is directly sent to the PV-T through a distributor.

With a high number of collectors, a possible maldistribution of the two-phase mixture can be present.
After the throttling device, the CO2 is sent to the low-pressure receiver (REC)

- The receiver feeds the collectors with liquid refrigerant extracted from the bottom
- **Natural circulation**, the flow is driven by the hydrostatic pressure applied by the liquid column
The thermodynamic vapour quality at the outlet of the evaporator

- The evaporation pressure changes with the external ambient temperature or with the solar radiation
- The temperature of the refrigerant along the piping of the collectors is constant, allowing an efficient cooling of the PV modules
- The superheating at the compressor inlet is ensured by the internal heat exchanger
Compressor speed: 50% of the rate speed
Heating capacity $\approx 1.8 - 2.1$ kW
High pressure: 80 bar
Water temperature Gas-cooler: 30-35°C
Solar Irradiance $\approx 850$ W/m²

\[
\text{COP} = \frac{q_{\text{GC}}}{P_{\text{comp}} + P_{\text{aux}}}
\]

Increase of the photovoltaic power production when cooling is active +10.5%
Experimental Results – Compressor Speed 75%

Compressor speed: 75% of the rate speed
Heating capacity ≈ 2.5 – 3.5 kW
High pressure: 80 bar
Water temperature Gas-cooler: 30-35°C
Solar Irradiance ≈ 750-800 W/m²
After the throttling device, the CO2 is sent to the low-pressure receiver (REC)

- The receiver feeds the collectors with liquid refrigerant extracted from the bottom
- **Forced circulation**, the flow is assured by a magnetic driven gear pump equipped with an inverter
EXPERIMENTAL RESULTS — FLOODED MODE

Compressor speed: 75% of the rate speed
Heating capacity ≈ 2.5 – 3.1 kW
High pressure: 80 bar
Water temperature Gas-cooler: 30–35°C
Solar Irradiance ≈ 925 W/m²
Air temperature: 12 °C

\[
\text{COP} = \frac{q_{GC}}{P_{\text{comp}} + P_{\text{aux}}} 
\]

Temperature along the PV-T serpentine

**Temperature**

- **TC - Forced**
- **TC - Natural**
- **T evap. - Forced**
- **T evap. - Natural**

**COP**

- **NATURAL**
- **FORCED**
A model of the heat pump has been realized in Matlab
- Steady state conditions
- Dynamic conditions

**Input**
- Ambient conditions
- Operative conditions

**Physical model**
- Receiver
- Gas cooler
- PV-T evaporator
- Finned coil evaporator

**Output**
- Evaporation temperature
- Energy fluxes and COP
Creation of iso-COP maps in dry expansion mode

**Control strategy**

**Design purposes**

**Compressor input: 50%**

**Collectors area: 3.6 m²**

**Solar irradiance: 700 W m⁻²**

**Air temp.: 5°C**
A solar assisted heat pump prototype for water heating has been studied

- R744 is the working refrigerant
- It operates with two different evaporators: finned coil or PV-T collectors
- The evaporation mode can be dry expansion or flooded (in natural or in forced circulation)

The experimental tests showed that:

- In dry expansion mode, the heat pump is able to self-regulate the evaporation pressure in order to guarantee saturated vapour conditions at the outlet of the evaporator
- At low compressor speed, the use of the PV-T collectors can increase the COP compared to the air source
- At high compressor speed, when the PV-T collectors work in flooded mode - natural circulation, superheated vapor at the PV-T outlet can be present and this reduces the COP of the heat pump
- Forced circulation using a pump is a solution to solve the problem of superheating

A steady state and a dynamic numerical model of the heat pump have been realized to predict the performance in different operative conditions
This work has been realized with the support of CSEA (Cassa per i servizi energetici e ambientali) through the project CCSEB_00075 - SOLAIR-HP.
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