Introduction
The research group of the University of Perugia, Department of Industrial Engineering Department, has been actively working since many years on alternative refrigeration technologies, and in particular on absorption systems [1, 2]. During the last two years, the attention has been focused on the design, realization and analysis of a solar cooling plant with a commercial small size absorption machine, for the air conditioning of an office building. An experimental plant has been realized at the aim of verifying the performance of the machine with different external conditions, and validating the data sheet of the manufacturer. The solar cooling plant, its monitoring system and the first measurement campaign are described in the paper.

1 The plant
Figure 1 shows an overview of the plant layout, with some pictures of the main components, described as follows.

1.1 The absorption machine
The model chosen for this application is a Rotartica “045 Solar”, a single-stage absorption machine that uses Water-Lithium Bromide as working pair. Beyond the four main elements of common absorption groups (i.e. generator, evaporator, condenser, and absorber), the machine has the following peculiarity: the chamber that hosts the generator rotates with a speed of 550 rpm around an horizontal axis, to improve the heat transfer; the presence of the centrifugal force, in fact, allows a
reduction of the exchangers size, without affecting the efficiency.

The nominal chilling power is about 4.5 kW, with a thermal supply of 7.2 kW for a flow rate of 0.9 m³/h at 90°C. The chilled water is produced in nominal conditions at 12°C, but it can drop to a minimum value of 8°C. These working temperatures and the limited size permit to use the machine for air conditioning in the residential sector, therefore, many Italian companies seemed interested in evaluating its actual potentialities. The machine is equipped with an inner monitoring system to automatically control the flow rates of the external circuit and the feeding temperature; it begins the thermodynamic process only if such parameters are close to the nominal ones. An additional manual system has been installed to set and control all parameters.

Figure 1. Layout of the solar cooling plant.

1.2 The external circuit

The solar cooling plant is characterised by the three typical external circuits:

- hot circuit for the thermal feeding of machine;
• chilling circuit for the air conditioning of the office building;
• cooling circuit for heat extraction from the machine.

The proposed layout allows the setting of fluid flow rates in each external circuit and permits to control of the hot and cooling circuit inlet temperature.

1.3 The hot circuit
Two kinds of solar panels can feed the absorption chiller: solar vacuum tubes and flat plate collectors. In particular, the thermal energy for the machine is given by a primary circuit connected with 15 solar vacuum tube collectors (30 m²) or by another primary circuit linked to 15 solar flat plate collectors (30 m²).

Two heat exchangers divide the primary circuit by the secondary one; the latter links the heat exchangers to a single 2000 litres tank. Hence, a third circuit connects the reservoir to the machine; this layout was designed to link directly the machine to the heat exchanger, whenever is desired.

If the outlet temperature from the tank is higher than 60°C, the flow is directed to a second tank for domestic hot water storage. On the other hand, if the outlet temperature is lower than 60°C, the fluid is driven back to solar collectors. During the winter season, the 30 solar collectors are directly linked to the tank that supplies the hot water for the office building.

1.4 The cooling Circuit
The cooling circuit links the absorber and the condenser of the absorption machine to the cooling tower, a PMS 6/65 model of Mita, which has a nominal power of 65 kW, adapted to this application. The tower is placed on the roof of the building, to avoid problems of steam emission, noise and legionella.

1.5 Chilling Circuit
The chilling circuit connects the evaporator of the machine to two fan coils placed in two different offices. Each fan-coil (Riello) has a nominal power of 2,5 kW. It has to be underlined that the chilling circuit is directly linked to the (open) cooling circuit inside the machine. Therefore, when the chiller pump is stopped, the chilling circuit pipes are quickly emptied, hence, the designer has to take particular attention in placing the chiller pump at a higher quote than the absorption machine.
2 Measurement equipment and data acquisition

The equipment installed for measuring the plant parameters is made of:

- 3 transducers to measure flow rates of primary and secondary hot circuit, chilling and cooling circuit;
- 16 thermal resistances, model PT 100, to measure temperatures in different points of the external circuits, such as inlet and outlet temperature of the machine in the hot circuit, in the chilling circuit and in cooling circuit, inlet and outlet temperature of vacuum solar collectors and of flat plate solar collectors, inlet and outlet temperature of the tanks, inlet and outlet temperature of the cooling tower;
- pyranometer to measure the solar irradiation.

All parameters are acquired by a monitoring system (National Instruments) and elaborated by a Labview code; the operator can read each parameter in real time, evaluating the machine performance for different working conditions. Figure 2 shows the front panel of the acquisition systems.

3 First measurements

The first measurements were carried out at the beginning of July 2008, they were necessary to check the monitoring system and solve some hydraulic problems. It was
therefore possible to realize a complete campaign for first analyses of the plant performance.

In particular, these measurements highlight that if the cooling inlet temperature decreases under 25°C, the chiller cools water down to 7-8°C, but the COP becomes lower than 0.5. When the cooling inlet temperature is lower than 25°C, in fact, the generator is able to receive more heat than the nominal quantity, but only the nominal amount is used by the evaporator to produce the cooling power. The extra-heat is bypassed directly to the absorber (overflow effect). Therefore, the machine can work properly (COP 0.5 – 0.6) with a generator inlet temperature lower than the nominal one (90°C), if cooling inlet temperature is less then 30°C, whereas a cooling inlet temperature lower 25°C, with the same conditions, can decrease COP values under 0.5. In figure 3 an example of the main parameters acquisition during a typical sunny day is reported. It is evident that the vacuum tube collectors, guaranteeing a higher temperature level to the generator, assure a higher chilling power.

![Figure 3. Time variation of main parameters, feeding with vacuum and flat collectors.](image)

4 Conclusions
A solar cooling plant was realized to study a commercial small size single stage absorption refrigeration group; the plant fulfils the air conditioning requirements of two offices. After the plant installation, the measuring equipment and the acquisition system were set up and tested. A first measurement campaign was implemented to focus and analyse the plant behaviour with two kinds of solar collectors and for
different working conditions, with the aim of comparing acquired data with similar ones carried out in other countries [3, 4].

The first results confirm the machine nominal COP (between 0.55 and 0.65) at a thermal supply temperature of about 85°C and with an absorber inlet temperature between 25 and 30°C. Furthermore, it emerged a sensitive improvement of chilling power with vacuum collector, respect to flat solar panels; future measurements will define quantitatively the amount of this enhancement, at least at the latitude of central Italy.

**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
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<tbody>
<tr>
<td>COP</td>
<td>coefficient of performance</td>
<td>(-)</td>
</tr>
<tr>
<td>rps</td>
<td>revolutions per second</td>
<td>(s⁻¹)</td>
</tr>
<tr>
<td>Q</td>
<td>heat power</td>
<td>(kW)</td>
</tr>
<tr>
<td>T</td>
<td>temperature</td>
<td>(°C)</td>
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</table>

**Subscripts**

- c chilled
- e evaporator
- g generator
- in inlet
- out outlet
- t evaporative cooling tower

**References**


