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Performance evaluation of a solar cooling plant applied for greenhouse thermal control

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Abstract

The greenhouses cultivation causes in summer season inner conditions characterized by high thermal levels such as to generate problems that can damage crops. Always more frequently for this reason it is common to provide greenhouse with air conditioning plants. In this work it will be presented an application of a solar cooling plant with absorption cooling machine for thermal control of a greenhouse and an advanced simulation model able to evaluate optimal plant configurations and controls. Solar cooling systems can be applied for greenhouse climate control in regions with high values of solar irradiation as alternative to traditional evaporative systems, allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.
The plant consists of a single effect LiBr-H2O absorption chiller fed by evacuated-tube solar collectors; the model was developed in Matlab-Simulink and is able to simulate dynamically, with time steps up to 15 minutes, the greenhouse cooling demand and the production of the solar field.
Present study proposes a plant configuration with a distribution system in which the cooling power is not provided for the entire volume of the greenhouse, but only for the air volume surrounding the crop with a considerable saving of reduction of energy demand and an extremely efficient use of solar energy. The simulation study is based on the experimental data collected at the experimental center of the University of Bari, Southern Italy.
The aim of the work is to demonstrate that solar cooling system could provide significant energy-saving opportunities for cooling greenhouses allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.

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1. Introduction

The paper describes the implementation of a dynamic simulation model of a solar cooling plant applied for a greenhouse. The plant modeled has the purpose of maximize the solar energy use in the summer season for air conditioning of the greenhouse exploiting the coincidence between the peak demand and the period of greatest availability of solar energy. Renewable energy is an important resource for the energy and environmental retrofitting of rural buildings because heating and cooling systems powered by fossil fuels have a strong influence on the cost and environmental sustainability of agricultural production, particularly for greenhouse cultivation. The model can be used as a tool to support the design and dimensioning of the plant, they can be simulated the different behaviors of the system when the operating or control settings change, to optimize the values of the set-point in order to develop best control strategies for maximum primary energy savings.

1.1. Description of greenhouse and solar cooling plant

The greenhouses have the aim to obtain a high efficiency of production and quality of the products to be cultivated also in the case in which the external climatic conditions are not favorable. To do this it is necessary that the microclimate that influence the development of the plant is suitable for the type of crop. The climate control regulates the concentration of carbon dioxide and oxygen, the temperature, humidity, brightness and a number of other factors that must be present in balanced quantities. Very important are temperature and humidity. The first acts on the vital functions of the plant and is generally critical above 70 ° C and below 0 ° C. Outside these limits cultures die or hibernate. The amount of water vapor in the air has effects in growth, transpiration, fertilization of the flowers and in the case of high values, in the development of diseases or in the induction of physiological stress. Conversely a low value of humidity increases the transpiration impeding photosynthesis. Some values of temperature and humidity for optimal type of culture are shown in table 1:

Table 1. Temperature and humidity for optimal type of culture

Cultivation	Optimum temperature range	Optimum humidity range
Lettuce	14°C-18°C	60-80%
Peas	16°C-20°C	65-75%
Beets	18°C-22°C	60-70%
Celery	18°C-25°C	65-80%
Beans	18°C-30°C	60-75%
Tomatoes and pepperoni	20°C-25°C	50-60%
Cucumbers	20°C-25°C	70-90%
Eggplant	22°C-27°C	50-60%
Watermelon	23°C-28°C	65-75%
Melon	25°C-30°C	60-70%
Zucchini	25°C-35°C	65-80%

In the Mediterranean region it's more difficult cooling the greenhouse in summer than heating in the winter while for other climates the opposite occurs, so you have to use different techniques to achieve each time the most appropriate internal microclimates. The solar radiation induces a very high overheating of indoor air, linked to the material of which the greenhouse is made of. Such thermal overload must be eliminated by ensuring that the external temperature is lowered to the optimal values. The following figure shows the trend of the temperature inside and outside the greenhouse during daylight hours.

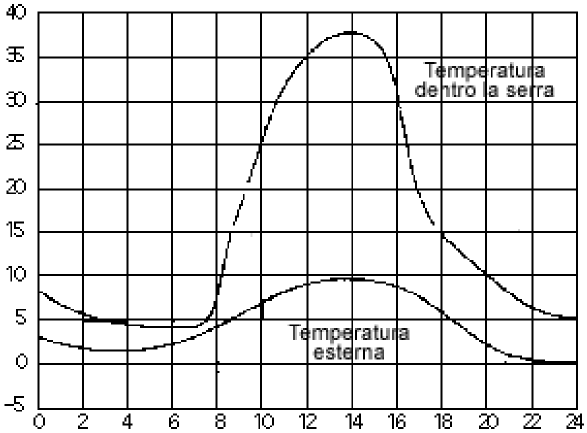

Fig. 1. Greenhouse inside and outside temperature

The experimental greenhouse is located in Valenzano (Bari, Italy) and is made of tubular galvanized steel, an arched roof type covered with plastic film, south-north oriented, having a covered area of 300 m^2 (30 m in length, 10 m in width), 4.45 m high along the ridge and 2.45 m along the gutters (Fig. 2). The greenhouse covering film is an ethylene-vinyl acetate copolymer film (EVA), with a thickness of 200 μm, characterised by a solar total transmissivity coefficient of about 85-90% in the wavelength range 300–3,000 nm.

The cultivation of the plants takes place in plastic pots (1.00 m x 0.40 m x 0.40 m) with a growing substrate made of a mixture of soil and peat.

The main component of the solar cooling plant are:

- A solar field, placed on the ground and made of 18 evacuated tube collectors, (with a tilt angle of 30°) for a total area of 68 m^2;
- a hot tank with a global capacity of 1000 liters;
- a single effect LiBr-H_2O absorption chiller fed only by evacuated-tube solar collectors having a cooling capacity of 18 kW with a heat input of 25.1 kW, an electrical consumption of 1.45 kW, a $COP_{thermal}$ of 0.70;
- a cooling tower with a heat rejection of 43 kW;
- a cold tank with a global capacity of 500 liters;
- dry cooler to dissipate the to dissipate the excess power produced by the solar field.

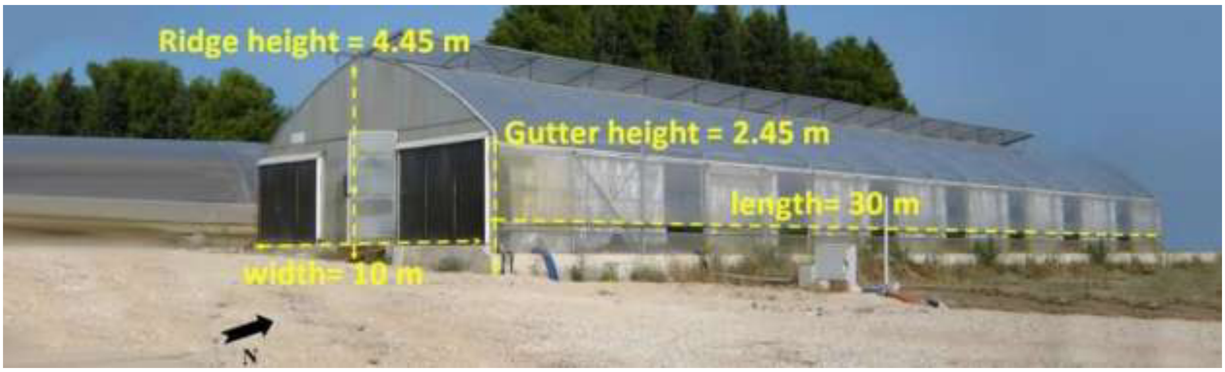

Fig. 2. Experimental greenhouse

2. The model

The simulation model was developed in Matlab Simulink. This allows the use of various types of elements (blocks) in order to create models for simulating a dynamic system; that is, a system that can be represented by a model of differential equations or difference whose independent variable is time. Simulink interface allows to place the blocks, specify the setting parameters and interconnect multiple blocks to build models of systems more and more complex. The model processes the variables according to the sequential modular approach so that the output data of a component are used as input to the next component. To start the simulation, the user must specify a time step, a start time, a final time and an integration method. Signal values are updated during the simulation at each time step between the initial and the final step. The solar cooling model built was developed by connecting the various components (solar collectors, accumulation, absorption chiller, etc.) which in turn were created on the basis of physical equations related to their operation (Puglisi et al., 2014).

Below the description of the models developed.

2.1. Solar collectors

The development of the model of the solar field started with the model configuration for the individual collector, based on the Bliss equation which expresses the efficiency of the collector as the ratio of the energy absorbed by the heat transfer fluid and the potentially exploitable from the sun; the equation was adapted to the characteristic of our plant by inserting some corrective correlations to consider: the different flow rates than those of tests defined by the relevant regulations, the number of collectors connected in series and the direction of the solar radiation not perpendicular to the surface of the solar radiation absorber (Duffie &Beckman., 2006).

2.2. Hot and cold tanks

The model was built on the hypothesis of perfect mixing with the uniform temperature in the whole tank . This temperature is variable as a function of time due to energy supplied or extracted during loading and unloading processes and to the interactions with the environment. The behavior of the tank is then described by an equation of energy balance in differential form. The control system is inserted in the model via an S-function in which the temperature of the tank, compared with that of reference and with that output temperatures of the solar circuit, is used to controls the activation of the circulation pump of the solar circuit.

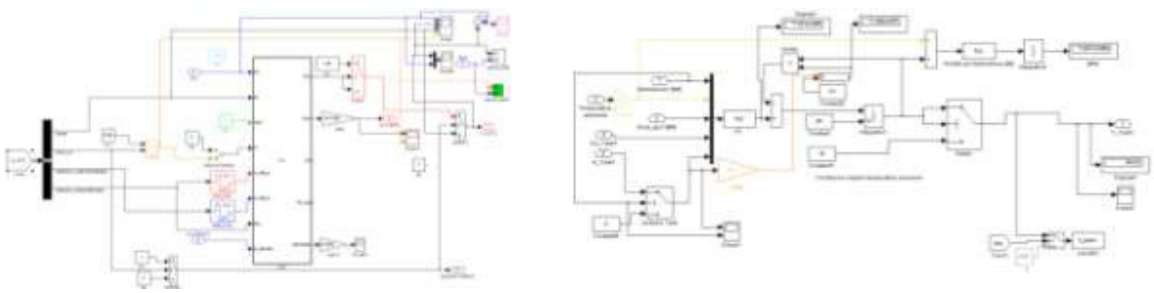

Fig. 3. Simulink model of solar collector (left) and tank (right)

2.3. Absorption chiller

The model is able to predict the cooling power delivered by the machine having as input the temperature of the inlet water to the absorber and the environmental conditions (temperature, humidity). The performance are obtained using the specifications provided by the manufacturer. Via a pair of lookup table have been implemented curves, parameterized for different water temperatures of exit from the cooling tower, these allow to obtain the thermal power input and the cooling produced, as a function of the hot water temperature supplied (Granryd et al, 2011).

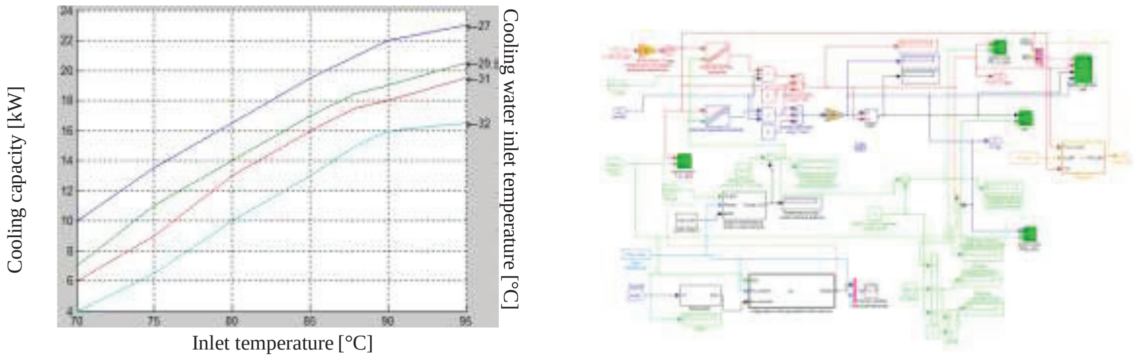

Fig. 4. Absorption chiller model performance (left) and Simulink model (right)

3. Simulation results

Analysing the characteristics of the greenhouse, described above (Campiotti et al., 2014)the cooling power needed is about 110 kW and in the hypothesis of supplying this load with a solar cooling system, the solar collector surface required is about 350 m^2.

The present study proposes a plant configuration with a distribution system in which the cooling power is not provided for the entire volume of the greenhouse, but only for the air volume surrounding the crop.

The cooling distributing system consists of various lines of pipes, positioned at the crop level, along the longest side of plastic pots, through which the cooled water circulates lowering the plant temperature. The resulted surface which must be cooled was estimated in 40 m^2, with a maximum power of 18 kW.

This evaluation led to determine the cooling load of the greenhouse from the data collected at the experimental centre of the University of Bari, which represent the cooling demand that the solar cooling model must supply.

Figures 5 and 6 show hourly trend of the cooling demand of the greenhouse and of the cooling power produced by the absorption chiller, given by Simulink simulation, for the period 1st April – 30th September.

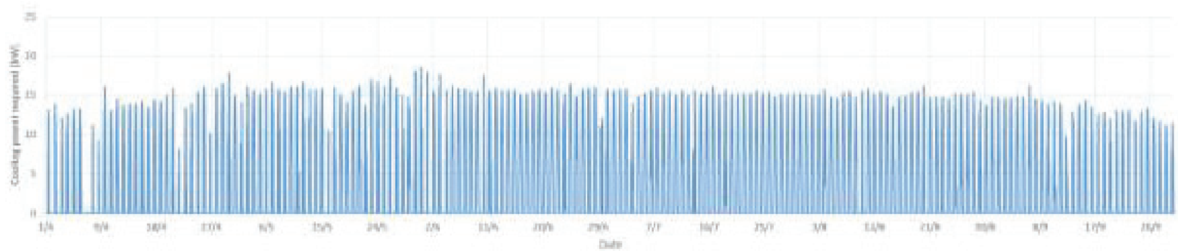

Fig. 5. Cooling power required [kW]

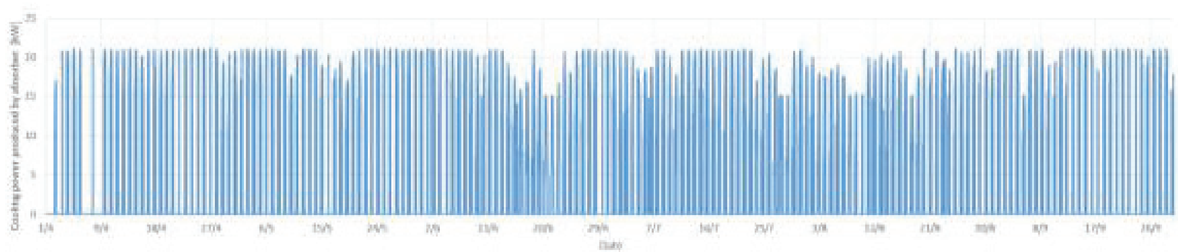

Fig. 6. Cooling power produced by absorber chiller [kW

The figure 7 report the trend of the cold tank temperature for the period 1st April – 30th September.

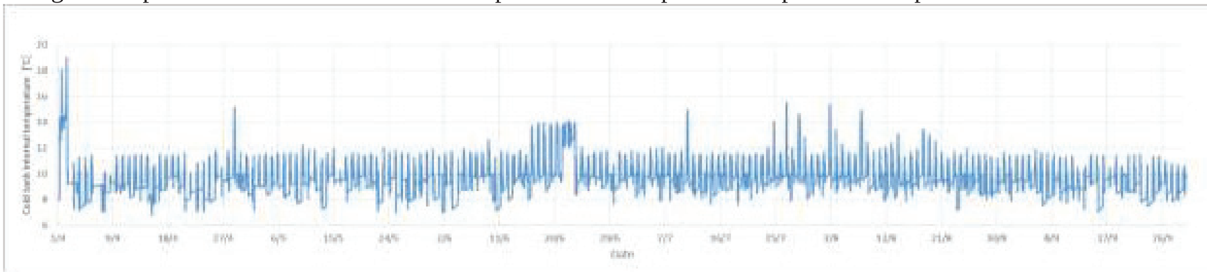

Fig. 7. Cold tank temperature trend
[°C]

The three figures demonstrate that the model is able to supply the cooling demand every time step: the power generated is always higher then that demanded; furthermore the cold tank has a temperature included in a range [7-12 °C] which guarantee that the system is well balanced from an energetic point of view because this range correspond to the work conditions of outlet water produced by absorption chiller.

4. Conclusions

The simulations performed confirm the correct design of the system and the choice of the size of the components. The model allowed to evaluate if the system was able to provide the cooling power needed, due to the delay between the onset of solar radiation and the cooling demand of the greenhouse. The dynamic model developed was therefore used as a tools for verification and confirmation of correct design and can be used as a platform to test new control and management strategies in order to minimize the consumption of primary energy.

In order to reduce primary energy consumption for cooling demand in greenhouse, a solution with a localised cooling system was analysed. The real efficiency of this method will be demonstrated experimentally in the plant described in the paper.

The solution proposed provide, as the simulation demonstrates, that solar cooling systems could provide significant energy-saving opportunities for cooling greenhouses allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.

Acknowledgements

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