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USE OF LOW-ENTHALPY GEOTHERMAL RESOURCES FOR GREENHOUSE HEATING: AN EXPERIMENTAL STUDY

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Abstract. The energy and economic performance analysis of integrated photovoltaic and geothermal systems, for greenhouse heating, was investigated in a experimental study developed at the University of Bari, Southern Italy. A 7.2 kW geothermal heat pump combined with a 120 m vertical double U-bend ground heat exchanger was installed in order to supply the thermal energy demand of 48 m^2 single plastic skin greenhouse. Heat extraction energy from the soil, air temperature above the heated cultivated surface, growing media temperature, water temperature inside the heating system were measured and recorded continuously by a system composed of sensors and data logger. Results of the experiment showed that the use of geothermal sources integrated with photovoltaic panels can supply of totally heat energy demand of greenhouse with zero air emission and economy saving of 40% compared to the traditional heating systems.

Key words: greenhouse heating, renewable energy sources, heat pump, geothermal energy

INTRODUCTION

Greenhouse crops are one of the most innovatory examples of modern agriculture and it is envisageable for them to expand more and more in future, especially in the areas with unfavourable climatic conditions. In the European Countries there are present 111,500 ha of greenhouses and large tunnels for vegetables and flowers production [Scarascia Mugnozza et al. 2011b]. They are one of the highest man-made forms of agricultural activity, because of the intense technological and bio-agronomic inputs in confined portions of the agricultural environment [Scarascia Mugnozza 1995]. The use of large quantities of pesticides, fertilizers and plastic films for greenhouse cultivation

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and the use of fossil fuel for greenhouse heating have a major impact on the cost and environmental sustainability of vegetable production [Scarascia Mugnozza 1992, 1997].

The conventional greenhouse heating systems supplied from fossil fuel have a strong negative impact on agro-ecosystems [Scarascia Mugnozza 1992] and in Italy there are the cause of 1.300.000 tCO_2/year air emission [Campiotti et al. 2010]. Energy consumption is also one of the main cost factor in commercial greenhouses since high amount of energy is used for greenhouse climate control in order to obtain bigger yields and high quality [Korner et al. 2004]. Energy necessary to heat 1 m^2 of greenhouse area ranges from 500 to 2700 MJ m^{-2} yr^{-1}, depending on the site, the cultivated plants, the greenhouse covering and the level of climate control. Therfore the use of fossil fuel for greenhouse heating have a major impact on the cost and environmental sustainability of vegetable production [Scarascia Mugnozza et al. 2011a].

Many researches have been made to reduce greenhouse energy consumption for greenhouse climate control, while interest has recently been aroused in alternative energy sources, which include renewable energy sources [Vox et al. 2006]. Renewable energy sources are particularly appropriate to ensure optimal microclimatic conditions for the growth of greenhouse crops and provide a major impetus to the ecological conversion of greenhouse heating systems [Ozgener and Hepbasli 2005; Scarascia Mugnozza and Anifantis 2009]. In this context, the greenhouse heating with geothermal heat pump result to be very convenient in terms of environmental and economic [Ozgener 2010; Adaro et al. 1999].

Heat pumps are the most widespread technology for the use of low enthalpy geothermal resources [Lund et al. 2005] and are considered a renewable source of energy by the European Directive 2009/28/EC. In Europe, in 2008, were surveyed 782,461 heat pumps with a total installed thermal power of 8920 MW [ENEA 2010]. In Italy, in 2008, it is estimated a total of 7,500 geothermal heat pumps installed for a thermal power of 150 MW [EurObserv 2009]. In Italy there are present 25,000 ha of greenhouses [Scarascia Mugnozza et al. 2011b] but only 46 ha located in Tuscany, Veneto and Lazio are heated with geothermal energy [ENEA 2009].

Aim of the research was to assess the potential of the photovoltaic and geothermal heat pump integration system for greenhouse heating in terms of energy production, efficiency and economy.

MATERIAL AND METHODS

The performance analysis of integrated photovoltaic and geothermal systems for greenhouse heating was investigated in an experimental study carried out at the Aldo Moro University of Bari, Southern Italy. Two experimental greenhouses with the same geometric and constructive characteristics (Fig. 1), have been realized, one of them heated and the other one unheated for comparison. The greenhouses have an extension of 48 m^2 in plan, a height of 3.5 m and are covered with EVA (Ethylene Vinyl Acetate) plastic films.

A 7.2 kW low enthalpy heat pump (Fig. 2) combined with a 120 m vertical double U-bend ground heat exchanger was installed in order to satisfy the thermal energy demand of 48 m^2 single plastic skin greenhouse.

The ground heat exchanger was sized using the values of power extraction from the ground available in the literature [Tinti 2008]. This value is 42 $W \cdot m^{-1}$ in the area where the plant has been installed. The correct sizing of ground heat exchanger is necessary to achieve the thermodynamic equilibrium of the soil, the sustainability and reliability of energy production in the long-term [Rybach and Eugster 2010].

Fig. 1. Experimental greenhouse
Rys. 1. Szklarnia eksperymentalna

The heat pump was sized using the following equation for the calculation of greenhouse energy requirements:

$$Q_{Heating} = Q_c + Q_v + Q_i \text{ [W]} \quad (1)$$

where:
- Q_c – transmission of energy by conduction and convection through the greenhouse cover system [W];
- Q_v – transmission of energy for ventilation [W];
- Q_i – transmission of energy by irradiation [W].

The electrical energy for heat pump operation is provided by an array of 9 photovoltaic panels (12 m^2) in monocrystalline silicon with a pick power of 1620 W.

The heat pump is connected through a submerged coil with a heat storage (1000 l of capacity) where case the heat exchange with the water used for greenhouse heating. The heating circuit inside the greenhouse is composed of a grid of 12 rows of low-density polyethylene pipes (Fig. 3).

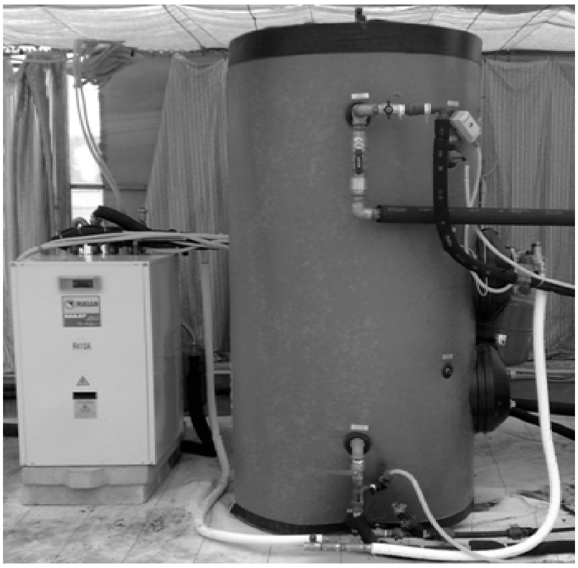

Fig. 2. Heat pump and heat storage
Rys. 2. Pompa ciepła z magazynowaniem energii

Fig. 3. Heating system inside the greenhouse
Rys. 3. System grzewczy wewnątrz szklarni

The main physical and environmental parameters were measured over the winter period in order to analyze the energetic performance of the afore mentioned integrated system for greenhouse heating. Particularly the thermal energy extracted from the soil, the electrical energy adsorbed by the heat pump, the internal and external greenhouse air temperatures, the plant working fluid temperatures were measured and recorded continuously by suitable sensors connected to a data logger.

RESULTS AND DISCUSSION

The heat pump turned 1620 kWh of electric energy in 6480 kWh of thermal energy during the three winter months of working (from December 2010 to February 2011). In the same period the photovoltaic panels produced 2226 kWh of electrical energy. Then the electric energy required for heat pump operation was supplied entirely by photovoltaic panels. The obtained results showed that the use of geothermal sources integrated with photovoltaic panels can supply the total heating energy demand of a greenhouse. The 75% of the thermal energy (4860 kWh) was provided from the soil with an economy saving of 40% compared to the traditional heating systems.

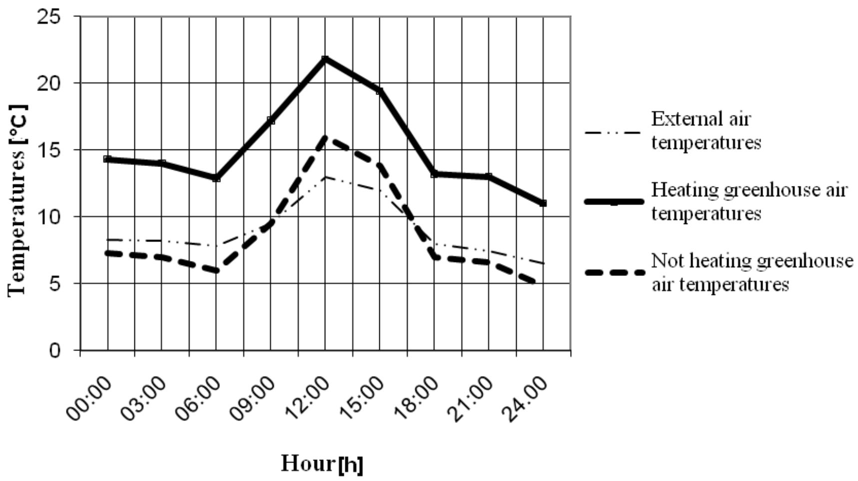

Fig. 4. External and internal greenhouse air temperatures on January 1, 2011
Rys. 4. Temperatury powietrza na zewnątrz i wewnątrz szklarni 1 stycznia 2011 r.

a) b)

Fig. 5. a) iceberg lettuce in heated greenhouse b) iceberg lettuce in unheated greenhouse
Rys. 5. a) sałata lodowa w ogrzewanej szklarni b) sałata lodowa w nieogrzewanej szklarni

The difference between the heating greenhouse and the external air temperatures was 6°C; moreover the difference between the heating and not heating greenhouse air temperatures was 8°C (Fig. 4).

As well know, due to the phenomenon of nocturnal thermal inversion the air temperature inside the not heated greenhouse was less than the external one, then the use of the heat pump has been useful both to avoid the nocturnal thermal inversion and to increase the air temperature inside the greenhouse.

During the experimental study in the greenhouse "iceberg lettuce" was grown with a biological minimum temperature of 6°C, optimal daytime temperature of 16–20°C and optimal nightime temperature of 10 and 12°C. In the heated greenhouse has obtained a mean weight gain of iceberg lettuce" produced by about 30% compared to the unheated greenhouse and an advance on the production of 12 days (Fig. 5).

CONCLUSIONS

The obtained results clearly show that the greenhouse energy demand can be effectively, efficiently and ecologically satisfied by the realized experimental system. During the experimental test the geothermal heat pump has saved about 75% of the energy for greenhouse heating than a conventional.

The coupling of geothermal heat pump with photovoltaic panels allowed to decrease the CO_2 emissions and to save primary energy of fossil fuels.

The environmental benefits of the realized system will be evaluated by life cycle assessment in the next step of the research.

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WYKORZYSTANIE ZASOBÓW GEOTERMALNYCH O NISKIEJ ENTALPII DO OGRZEWANIA SZKLARNI: BADANIA EKSPERYMENTALNE

Streszczenie. W Uniwersytecie w Bari (południowe Włochy) przeprowadzono eksperymentalne badania oraz analizy energetycznej i ekonomicznej wydajności zintegrowanych fotowoltaicznych systemów geotermalnych stosowanych w ogrzewaniu szklarni. Zainstalowano geotermalną pompę ciepła o mocy 7,2 kW wraz z podwójnym gruntowym, pionowym wymiennikiem w celu dostarczenia energii cieplnej do szklarni o powierzchni 48 m^2 pokrytej pojedynczą warstwą tworzywa sztucznego. Energia cieplna z gleby, temperatura powyżej uprawianej powierzchni, temperatura medium, temperatura wody wewnątrz systemu ogrzewania były mierzone i rejestrowane w sposób ciągły przez układ składający się z czujnika i rejestratora danych. Wyniki eksperymentu wykazały, że przy wykorzystaniu źródeł geotermalnych zintegrowanych z panelami fotowoltaicznymi można całkowicie pokryć zapotrzebowanie w energię cieplną w szklarni uzyskując przy tym 40% oszczędność w porównaniu z tradycyjnymi systemami grzewczymi.

Słowa kluczowe: ogrzewanie szklarni, odnawialne źródła energii, pompa ciepła, energia geotermalna

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