Energy Conversion and Management 79 (2014) 543–553

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

# Experimental study of an air conditioning system to control a greenhouse microclimate

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ARTICLE INFO

*Article history:*
Received 5 September 2013
Accepted 9 December 2013
Available online 25 January 2014

*Keywords:*
Solar energy
Chapel greenhouse
Energy storage
Capillary heat exchanger
Vacuum solar collector
Heating cooling/storing

ABSTRACT

In this papper, a thermal model is developed to investigate the possibility to use the ground thermal energy for the greenhouse heating or cooling. A control system of the ground heat storing is integrated in a chapel greenhouse located in the premises of the Technology and Research Energy Center, Tunis, Tunisia. Polypropylene capillary heat exchangers, suspended in the air and buried into the ground of the greenhouse, are used to store or destore solar energy excess. During the day, the air-suspended exchangers recuperate the solar energy in excess. This recuperated energy is then stored into the ground through the buried exchangers. At night the stored thermal energy is brought back by the suspended exchangers to heat the greenhouse air. The purpose of this study is to contribute in the greenhouse microclimate control. In order to maintain the greenhouse air temperature at 20 °C, suitable for a defined agriculture, the solar energy and the cold water are respectively used for heating and cooling the greenhouse inside air. The design and construction of a chapel greenhouse equipped with the control system is carried out. The studied system is used, at the same time for; heating, cooling the greenhouse air and storing the solar energy in excess.

Experiments were conducted during the years 2012–2013, to evaluate the effectiveness of the control system achieved. The measured values of the greenhouse air temperatures with and without the control system are discussed.



## 1. Introduction

The continuous increase in the level of greenhouse gas emissions and the rise in fuel prices are the main driving forces behind the efforts for more effectively use of various renewable energy sources. In many parts of the world and specifically in Tunisia, the direct solar radiation is considered to be one of the most promising sources of energy. Annual sunshine can reach 3288 kw h/m$^2$/year (9 kw h/m$^2$/day). A greenhouse using active conventional heating consumes 1 litter of fuel/m$^2$/year. Tunisian greenhouses cover about 1000 ha which corresponds to 10,000 L of fuel/year [1]. In order to reduce the cost of greenhouses control climate in Tunisian, solar heating systems are used.

In the Mediterranean regions, most greenhouses are equipped with a ventilation system and are not heated. Insufficient ventilation in the summer and no heating during the winter causes extreme temperatures inappropriate for the plant. With too low temperatures during winter nights and too high temperatures during summer days, large diurnal amplitude of air and soil temperatures are frequent. These problems affect the product quality and the production. In order to reduce the cost of agricultural greenhouse heating, we use the vacuum solar collectors. Their efficiency depends at the same time upon the ambient climatic conditions and the collector's thermal performances [2]. Capillary polypropylene exchangers are used to attenuate the differences between the diurnal and nocturnal air temperatures under the greenhouses. The water circulates in the heat exchangers according to the closed hydraulic circuit and three operating modes are used; heating, cooling and storing.

A greenhouse heating system is used to increase the stored thermal energy inside the greenhouse during the day or to transfer excess heat from the greenhouse to the heat storage area; the ground or the water storage tank. This heat is recovered at night to satisfy the heating needs of the greenhouse. During the coldest months in Mediterranean areas, the greenhouses face overheating problems during the day and excessive cold at night. Greenhouse heating is one of the most important and essential requirements for better growth during coldest period and especially during cold nights. However, in a composite climate where greenhouse heating is required in winter nights and cooling is required in summer days, a single system cannot meet the requirements of such a climate type. Hence the idea of the conception and implementation of an air conditioning system for the direct control of the climate

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http://dx.doi.org/10.1016/j.enconman.2013.12.023

**Nomenclature**

| | |
|---|---|
| $A$ | collector area ($m^2$) |
| $a_0$ | intercept (maximum) of the collector efficiency (kJ/h $m^2$ K) |
| $a_1$ | negative of the first-order coefficient in collector efficiency equation (kJ/h $m^2$ K) |
| $a_2$ | negative of the second-order coefficient in collector efficiency equation (kJ/h $m^2$ $K^2$) |
| $C_{pf}$ | specific heat of the tank fluid (kJ/kg K) |
| $C_p$ | specific heat of collector fluid (kJ/kg K) |
| $G$ | global radiation incident on the solar collector (kJ/h $m^2$) |
| $e$ | polycarbonate cover thickness (m) |
| $K_e$ | convective coefficient (W $m^{-2}$ °$C^{-1}$) |
| $Q_{pc}$ | polycarbonate covers loss of energy (W) |
| Qgr | ground loss of energy (W) |
| $Q_{\text{inf}}$ | infiltration loss of energy (W) |
| $Q_{cb}$ | support loss of energy (W) |
| $Q_c$ | heat collected by solar collector (kJ) |
| $Q_n$ | restored noctural heat (kJ) |
| $Q_p$ | recovered diurnal heat (kJ) |
| $Q_{\text{load}}$ | greenhouse heating load (kJ) |
| $R$ | thermal conductivity ($m^2$ K $W^{-1}$) |
| $T_o$ | outlet temperature of fluid from collector (°C) |
| $T_j$ | daily (air) temperature (°C) |
| $T_a$ | ambient (air) temperature (°C) |
| $T_{\text{amb}}$ | ambient air temperature during the test (°C) |
| $T_m$ | average storage temperature (°C) |
| $t$ | time (h) |
| $U_b$ | the loss coefficient of the tank (W/$m^2$ °C) |
| $U$ | overall heat transfer coefficient (W $m^{-2}$ $K^{-1}$) |
| $V$ | tank volume ($m^3$) |

*Greek letters*

| | |
|---|---|
| $\rho_f$ | fluid density (–) |
| $\eta$ | collector thermal efficiency for entire array (–) |
| $\Gamma$ | coefficient of absorption of the greenhouse (–) |
| $\Phi_p$ | heat flux (W) |
| $\Delta TLM$ | mean logarithmic difference temperature (°C) |

*Subscripts*

| | |
|---|---|
| $f$ | final (–) |
| $i$ | initial (–) |
| L.E.P.T | Laboratory of Energetic and the Thermal Processes (–) |

meteorological circumstances we face. Greenhouse heating can be carried out either by passive or an active method [3]. The greenhouse heating study by the passive method has been studied by many researchers [4–6]. The passive heating may be realized through water storage, rock bed storage, north wall, mulching, phase changing material, movable insulation and thermal curtain. Among passive heating modes, the thermal curtain is considered the most practical and appropriate means for reducing the energy consumption in the greenhouse [7–9]. For the active heating methods, we can cite the ground collectors, the geothermal, an earth-air heat exchanger and phase change storing material. The greenhouse heating using the active method has been investigated by many researchers namely Lazaar et al. [10], Santamouris et al. [11], Jain and Tiwari [12] and Kurklu [13]. A proper understanding of the greenhouse thermal behavior can lead to the good choice of the cooling system which will give satisfactory performances in the most extreme conditions. Natural ventilation can be used in many cases, sometimes in combination with an exhaust fan (forced ventilation) or a partially reflective screen (shading), to prevent the entry of solar radiation that is superfluous to the plant's requirements. In those areas of the world where summers are not severe and the maximum ambient temperature remains less than 33 °C, ventilation and shading techniques can work well. In the extreme environmental locations, where ambient temperatures in summer generally exceed 40 °C, evaporative cooling is the most efficient mean of greenhouse cooling. Evaporative cooling using fan-pad and fog/mist inside a greenhouse and roof cooling systems can be used. The composite system is used for both; heating the greenhouse in winter and cooling it in summer. Currently, earth-air heating exchanger system (EAHES) is the most successfully utilized composite system for agricultural greenhouses. EAHES use the underground constant temperature of earth mass to transfer/dissipate heat to/from the greenhouse. In addition to EAHES, aquifer coupled cavity flow heating exchanger system (ACCFHES) has also been developed. It utilizes the constant temperature of deep aquifer water at the ground surface through an irrigation tube for heating as well as cooling the greenhouse [14]. Photovoltaic panels are integrated with the greenhouse to generate the required electrical power. This system shows an energy efficiency level of approximately 4% [15].

In this work, we present the experimental results concerning the greenhouse climatic parameters. We consider a chapel greenhouse with a control system which is simultaneously a heating system using solar energy, a storage system using the ground and cooling system using the ground and the cold water. Each mode of the control system is used when it is needed.

## 2. Theoretical study

In order to find the best spacing between the buried exchangers, one theoretical study was conducted. The greenhouse diurnal balance is written in the following form:

$$\Phi p = \gamma R_G - K(T_j - T_o) - C\left(\frac{dT_m}{dt}\right) \tag{1}$$

When the term $\Phi p$ is positive, it represents the potentially recoverable diurnal energy, and when it is negative, it represents the nocturnal heating contribution that should be provided to maintain the greenhouse climate on the required temperature level.

At day, the storage term $(\frac{dT_m}{dt})$ can be linearized. It is proportional to the air temperature difference between the day and the night, $(T_j - T_o)$ [16].

Eq. (1) becomes:

$$\Phi p = \gamma\, R_G - K(T_j - T_0) - C'(T_j - T_0) \tag{2}$$

At night, the solar contribution $R_G$ is null. The balance energy is written:

$$\Phi n = K(T_n - T_o) - C\left(\frac{dT_m}{dt}\right) \tag{3}$$

Then the necessary heating to maintain the require temperature according to the needs of the chosen cultivation is:

$$\Phi total = \Phi n + \Phi p \tag{4}$$