Energy 35 (2010) 262–268

Contents lists available at ScienceDirect

Energy

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

Use of solar assisted geothermal heat pump and small wind turbine systems for heating agricultural and residential buildings

Onder Ozgener*

Solar Energy Institute, Ege University, 35100 Bornova, Izmir, Turkey

ARTICLE INFO

Article history:
Received 14 April 2009
Received in revised form
16 September 2009
Accepted 17 September 2009
Available online 12 October 2009

Keywords:
Geothermal energy
Geothermal heat pumps
Passive systems
Solar energy
Renewable energy
Wind energy

ABSTRACT

The main objective of the present study is twofold: (i) to analyze thermal loads of the geothermally and passively heated solar greenhouses; and (ii) to investigate wind energy utilization in greenhouse heating which is modeled as a hybrid solar assisted geothermal heat pump and a small wind turbine system which is separately installed in the Solar Energy Institute of Ege University, Izmir, Turkey. The study shows 3.13% of the total yearly electricity energy consumption of the modeled system (3568 kWh) or 12.53% of the total yearly electricity energy consumptions of secondary water pumping, brine pumping, and fan coil (892 kWh) can be met by using small wind turbine system (SWTS) theoretically. According to this result, modeled passive solar pre heating technique and combined with geothermal heat pump system (GHPS) and SWTS can be economically preferable to the conventional space heating/cooling systems used in agricultural and residential building heating applications if these buildings are installed in a region, which has a good wind resource.

1. Introduction

Key design features of high performance houses are investigated for improving energy efficiency in cold climates. Reference dwellings with typical constructions and system designs are compared with high performance houses using the best technology available [1].

Greenhouse heating applications have an important effect on yield, quality, and the cultivation time of products. Solar energy is an attractive substitute for conventional fuels for passive solar agricultural greenhouses and active heating of greenhouses. The solar greenhouse has been designed in order to reduce heat losses and increase useful solar gains on a daily and seasonal basis. Solar thermal energy can be stored as sensible heat, latent heat, heat of reaction, or a combination of these. In most storage systems, it is stored as sensible heat in materials such as water and rocks. In latent heat storage systems, the latent heat accompanying a phase change material is used for thermal energy storage. Most of the greenhouse heating demand can be supplied by latent heat storage systems [2,3]. Solar energy has been stored using the phase change materials such as parrafin with the latent heat technique in solar agricultural greenhouses. In addition to solar energy gain, greenhouses should be heated during nights and cold days. In order to establish optimum growth conditions in greenhouses, renewable energy sources should be utilized as much as possible [3].

Therefore, many passive heating and cooling renewable energy methods are developed by architects and engineers. Based on the studies of the energetic aspects of the residential and agricultural building heating systems which has appeared in the open literature (e.g., ref. [2–20]), we can classify them in three groups as follows: (i) solar thermal passive and active energy techniques; (ii) geothermal passive and active techniques – the concept of passive geothermal heating can be tracked back to 3000 B.C. when Iranian architects designed some buildings to be cooled by natural resources only [4,14]; and (iii) solar assisted geothermal heat pump technique which was used to analyze a solar greenhouse [5–8]. In addition, numerous studies have been undertaken from fundamental studies to energy and exergy analyses of geothermal and solar residential and agricultural building heating systems (e.g., refs. [9–31]).

In spite of difficulties primarily encountered in coupling wind energy with conventional space heating and cooling equipment, wind energy seems to be an exciting alternative [21]. In this paper an improved model for heating and electricity energy demand of agricultural and residential buildings is proposed by using wind energy. This new model is used to analyze two different interconnection schemes for the main users of the thermal energy: (i) to analyze energy gain rates of the geothermally and passively heated solar greenhouses; and (ii) to investigate wind energy utilization in

* Corresponding author. Tel.: +90 232 388 4000/1242; fax: +90 232 388 6027.
E-mail address: Onder.Ozgener@ege.edu.tr

0360-5442/$ – see front matter
doi:10.1016/j.energy.2009.09.018

a greenhouse heating with modeled hybrid solar assisted geothermal heat pump and small wind turbine systems, which are separately installed in the Solar Energy Institute of Ege University, Izmir, Turkey.

2. System description and modeling

The system theoretically designed is as shown in Fig. 1. Similar application of the system is available [21]. In this study, a 1.5 kW small wind turbine driving a geothermal heat pump (GHP), which is a hybrid system, to satisfy the thermal loads of a 12.54 m^2 solar greenhouse is assumed. This paper studies the heating system of a solar greenhouse which includes the following sub-systems – see Fig. 1: (a) GCC; ground coupling circuit (I–VIII); (b) RC; refrigerant (I–IV); (c) SCW; a secondary water and fan coil circuit (II, IX–XI); and (d) SWTS; a small wind turbine system (XII–XIII).

Fig. 1 illustrates a schematic of the modeled system combined with GHPS and SWTS, while Fig. 2 shows various views of three main components of the theoretically studied system, namely a GHPS, a SWTS, and solar greenhouse. Furthermore, Fig. 1 shows a schematic diagram of the system designed and investigated, which is an air/refrigerant vapor compression solar assisted heat pump composed mainly of a rated power of electric motor driving 1.4 kW compressor, 6.66 kW condenser, 8.2 kW evaporator, expansion device equipped with a series of capillary tubes 1.5 m long with an inside diameter of 1.5 mm, and 1.5 kW small wind turbine. The main characteristics of the elements of the designed and investigated system are given in Table 1. All the corresponding experimental instruments used in the studies were described clearly, e.g., the type, the model, the precision, etc., in author's companion papers Table 2 [3–8,22,23,32]:

- Measurement of outdoor and greenhouse air temperatures and humidities by using Oregon Scientific multi channel 433 MHz cable free thermo-hygrometer, ±%1.5.
- Measurement of surface temperatures of greenhouse surfaces by non-contact infrared thermometer, ±%1.5.
- Measurement of voltage, current, power by power anlyzer ±%1.
- Measurement of solar flux inside and outside greenhouse by an Eppley black and white pyranometer and measured data by State Meteorological Station installed in Bornova [24].

Previous studies [3,5–8] show that energy consumption for heating greenhouses depends on seasons and daily changing climatic conditions. In addition to solar energy gain, greenhouses should be heated during nights and cold days. The utilization of the modeled system is as follows: the greenhouse will be conditioned during the summer and winter seasons according to the type of the agricultural products to be raised in it. Solar energy utilizes drying process in summer seasons. The process operates under an isobaric condition with simultaneous heat and mass transfer between gas (air) and solid. Selected product contains 30–32% water. Generally, drying process (pre-drying and final drying) takes between 5 and 18 h and dry product will have 13% relative humidity (water content/moisture). Drying experiments were carried out at 40, 45 and 49 °C drying air temperatures, 0.1 and 0.3 m/s drying air velocity and between 0 and 700 W/m^2 solar incident radiations [32].

Thermodynamic analysis of SWTS and GHP are not described in this paper and more detail can be found in a series of papers [3,5–8,22,23]. However, models for all sub-systems are presented. The sub-systems (SWTS, greenhouse, and GHP) of the studied model were implemented at Ege University Solar Energy Institute (Izmir, Turkey). The active GHP heating system provides a larger amount of heat than the heat provided by the passive solar heating system. Almost all the solar energy collected is not used for space heating but to heat brine in the ground heat exchanger. Almost all space heating thermal load was covered by using the classical air heater (fan coil) that operated mainly during the cold days from the 20th of January till 31st of March 2004. [3].

3. Results and discussion

The study reveals that on a yearly basis it is more advantageous to use improved passive heating techniques and SWTS drives GHP for residential and agricultural buildings. In the present study, the results obtained from GHP and SWTS performance experiments over the heating periods of 16 December 2003–31 March 2004 [3,5], September–August 2003, and 30 October–5 November 2003 [22] are evaluated for comparison purposes to determine the performance characteristics of the developed and investigated system.

3.1. Individual performances of main components

3.1.1. Solar passive pre heating performance

Evaluation of the passive heating system was done according to experimental and theoretical study in 2005/2006 heating season, and meteorological data such as the variation of monthly average values of ambient temperatures, relative humidity were obtained for the outside greenhouse [24], whereas greenhouse air temperatures and humidities were measured by means of multi channel cable free thermo-hygrometer. The measurement of the surface temperatures of glass reinforced plastics (GRPs) greenhouse was performed with infrared thermometer. The tests were conducted on the passive heated greenhouse under steady state conditions in the 2005/2006 heating season. Daily average values of nine measurements from 8.30 am to 4.30 pm with an interval of 60 min are given in Figs. 3–5. Daily minimum and maximum temperatures and humidities were measured by means of multi channel cable free thermo-hygrometer. As expected, energy consumption rates were found minimum during the night. The maximum uncertainties associated with greenhouse air temperatures and thermal load were ±5.03 and ±6.42%, respectively.

A heat loss calculation is the first step in determining heating system capacity before selecting the system and its various components. The heating system should be properly sized to meet the needs of the greenhouse under extreme weather conditions. The rate of heat loss from the greenhouse is calculated by the following equation [25],

$$\dot{Q}_{\mathrm{GRP}} = \left[\frac{A_1}{R_1} + \frac{A_2}{R_2} + \cdots\right] T_{\mathrm{i}} - T_o f_W f_c f_s \quad (1)$$

Using Eq. (1) and assuming that the construction type factor (f_c), the system factor (f_s), and the wind factor (f_w) are 1.08, 1.00, and 1.13, respectively, the average heating load of the prototype solar greenhouse considered is obtained to be 7.4 kW at design conditions. In this calculation, GRP surface area of greenhouses is 48.512 m^2, the thermal resistance of GRP is 0.16 m^2K/W and the temperature difference between greenhouse inside and outdoor temperatures (T_i–T_o) is 20° [3]. To give perspective for these computed thermal load values in Fig. 3, we also show measurement data during the 2005/2006 heating season from a passive greenhouse located in Izmir, Turkey. From mid March to mid November, there is no demand for greenhouse heating, which is in good agreement with the prediction of our model. Results reported in Fig. 3 show that during the heating season the computed values generally underestimate the real thermal load.