Applied Thermal Engineering 110 (2017) 253–264

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Performance study of an enhanced solar greenhouse combined with the phase change material using genetic algorithm optimization method

Behrooz M. Ziapour *, Amir Hashtroudi

Department of Mechanical Engineering, University of Mohaghegh Ardabili, Ardabil, Iran

HIGHLIGHTS

- An enhanced design of a solar greenhouse was simulated.
- Phase change material was used for saving the solar unnecessarily wavelengths thermal energy.
- Genetic algorithm optimization method was used for finding the design parameters of solar greenhouse.
- Simulation results showed the remarkable results in the energy budget and the economic factors.
- Results showed that there will be 62.4, 0.3, 11.4, 160.6, 27.7 and 17.6 $ saving in the cases a–f, respectively.

ARTICLE INFO

Article history:
Received 6 April 2016
Revised 10 July 2016
Accepted 24 August 2016
Available online 28 August 2016

Keywords:
Economic
Genetic algorithm
Greenhouse
Phase change material
Solar collector

ABSTRACT

There are several common shapes for solar greenhouses structure. In a special structure, the curved glass roof is equipped with a thin remarkable cover. In this case, the cover modifies the solar light spectrally and reflects the unnecessarily wavelengths on a tubular collector installed in the focal line of the curved roof, out of the greenhouse, for greenhouse multipurpose applications. In this work, the basic idea for mentioned above special greenhouse was enhanced. As a new study, the performance effects of the collectors numbers (here, 1, 2, and 3) used for roof of the one solar greenhouse system was investigated. Also, for better saving energy process, a specific amount of phase change material (PCM) was applied in the collector. A genetic algorithm method was used to optimize the collector pipe radius versus the volume of the PCM placed inside this pipe. Simulation results indicated that the use of this enhanced system solar greenhouse leads to the remarkable results in the energy budget and the economic factors.

1. Introduction

The Energy amount needed in agricultural processes is high. In an effective agricultural activity, energy uses must be in controlled and in the logical range. Indeed, in the world, food supplies are directly linked to the energy [1]. Already, developing in energy use in the agriculture is a response to population increasing, limited supply of useful lands and demand for better standards of living [2]. Comparison with the industrial structures, in the agricultural activities, calculating energy inputs is more difficult because of high number of parameters affects the production [3]. Apparently, the basic aim in every agricultural production is to increase products and decrease costs so the energy budget analyses are vital to improve production efficiency. Energy budget is defined as the numerical portion between input and output of a system in energy based terms [4]. Although, importance of enhancing the farmer's economic condition leads to investigate ways to increase production and reduce the costs detailed [5]. There are significant amount of papers about economic and energy analysis in the open – field agriculture [6–14].

Crop production in greenhouse is maybe the most expensive plant production and energy- consuming structure among the agricultural techniques so the energy budget is more important in the greenhouse production. For some examples about greenhouse economic investigations, in the study [15] the energy use patterns and cost of production in the greenhouse was compared with open-field grape production. Data used in that study was from an experiment at the Akdeniz university research field. Mohammadi et al. investigated the energy balance between the input and output energy per unit area for greenhouse cucumber production. Information was obtained from 43 cucumber production greenhouse in the Tehran province, Iran [16]. In 2011, Banaeian et al. analyzed Energy use efficiency in greenhouse strawberry production in Iran

* Corresponding author.
E-mail address: behrooz_m_ziapour@yahoo.com (B.M. Ziapour).

http://dx.doi.org/10.1016/j.applthermaleng.2016.08.153
1359-4311/

Nomenclature

ACO	ant colony optimization
$A_{in,pipe}$	surface area of collector dealt with proportional area of the reflector roof (m^2)
C_P	specific heat capacity (kJ/kg K)
DE	direct energy
DE	differential evolution
DEA	data envelopment analysis
E_{st}	monthly average daily stored energy in the collector (MJ)
GA	genetic algorithm
GHG	greenhouse gases
ha	hectare
h_L	latent heat (kJ/kg)
$\bar{H}$	monthly average daily radiation (MJ/m^2)
IDE	indirect energy
NIR	near infrared radiation
NRE	non-renewable energy
PCM	phase change material
PSO	Particle Swarm Optimization
r	collector pipe radius (m)
RE	renewable energy
$\bar{R}_b$	clear index
SA	Simulated Annealing
T	temperature (°C)
UV	ultra violet
V	volume (m^3)

Greek symbols

β	the slope (°)
ρ_g	ground reflectance
ρ	density (kg/m^3)

Subscripts

T	tilted surface
d	diffuse radiation
w	water
melt	melting point
i	initial
pa	paraffin wax

and reached economical results in those cases. Their primary data was obtained from 25 strawberry greenhouse farmers using face to face method. Their work revealed that 78% of the energy consumption was generated by diesel fuel, 10% from chemical fertilizers, and 4.5% from electricity. Energy ratio, Specific energy and net energy of greenhouse strawberry production were 0.15, 12.55 MJ/kg and −683488.37 MJ/ha, respectively [2]. In the other work, Heidari et al. investigated cucumber greenhouses in Yazd province, Iran. Using data envelopment analysis (DEA) method, they indicated efficient greenhouses in order to energy use. According to the information, the Energy productivity was 0.14 MJ/kg, and net energy value was estimated to be −1043360 MJ/ha [17]. In 2013, Pishgar-komleh et al. added greenhouse gas (GHG) emissions studies to the energy use analyzes in the same province in Iran. In their study, the total energy input was calculated 1284 GJ/ha where the output energy was 125 GJ/ha. Energy use efficiency and productivity were 0.10 and 0.12 kg/MJ, respectively. Diesel fuel and electricity were the biggest factors in the total energy input [18]. Bolandnazar et al. performed the similar method with [17] to analyze cucumber greenhouse production in Jiroft, Iran. They used data gathered from 60 local cucumber greenhouses. The results revealed that greenhouse cucumber production consumed a total energy of 306,117.57 MJ/ha which 58.5% of total was supplied by diesel fuel. Energy use efficiency, Energy productivity and net energy were found to be 0.51, 0.64 kg/MJ and −149317.57 MJ/ha, respectively [19]. Khoshnevisan et al. studied energy consumption and GHG emission in strawberry greenhouses and compared with the open field strawberry production in Gilan province, Iran. They performed a face to face questionnaire to gather data from 70 open fields and 33 greenhouses. The total average of energy input and output was estimated at 1356932.8 MJ/ha and 137772.4 MJ/ha, respectively for greenhouse strawberry production [20]. In mentioned works, numerical analysis on the greenhouses carried out using diverse statistical methods and results were reported as the economic parameters.

In the other hand, there are several common shapes for greenhouses structure. Many of them are studied numerically and experimentally. Some of the shape models are even- span, uneven span, vinery, arc, quonset and lean - to greenhouses [21–24]. Energy consumption in these types is investigated and results are in touch in the literature [21,25]. In a different work, Sonneveld et al. has been presented a new shape with a specific curved roof. In this special model, the curved glass roof is equipped with a thin remarkable cover. The cover modifies the solar light spectrally and reflects some wavelengths that can be turn to the heat. Using a collector in the focal line of curved roof leads to save the magnificent amount of energy to use for multipurpose applications in the greenhouse [26].

In this work, the basic idea for the Sonneveld et al. study [26] was enhanced. Number of collectors and the used area was investigated. For better saving energy process, a specific amount of phase change material (PCM) was applied in the collector. A genetic algorithm method was used to optimize the collector pipe radius versus the volume of the PCM placed in the pipe. Collected energy in this new system was calculated and the novel greenhouse system was applied to the [2,15,16,18–20] works. Using this system and substitution saved heat with the diesel fuel and natural gas energy led to remarkable results in the energy budget and economic factors.

2. Geometry and optimization

In the cold weather belongs to northern countries, to supply better growing conditions, greenhouses heating is so necessary and providing energy is counted important. In the opposite side and in the southern countries, cooling is very vital issue due to high outdoor temperatures and high global radiation during summer [27]. For providing energy in winter and cooling in summer in a single system, applying seasonal storage of excess solar energy and exploiting saved energy for heating in winter seems to be useful [28]. Saving in cooling and heating costs is an apparent advantage of this kind of systems.

2.1. Geometry developing process

In the Sonneveld et al. work [26] entrance solar radiation is analyzed in its role for crop production and in the greenhouse warming. It is a familiar fact that photosynthetic active radiation (PAR) with wavelengths between 400 and 750 nm is the basic factor in crop production [28]. As shown in Fig. 1. [29], the energy portion of the PAR is about half of the solar radiation total energy content,