Renewable Energy 96 (2016) 509–519

Contents lists available at ScienceDirect

Renewable Energy

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

Solar energy conservation in greenhouse: Thermal analysis and experimental validation

Hassan Ghasemi Mobtaker [a, *], Yahya Ajabshirchi [a], Seyed Faramarz Ranjbar [b], Mansour Matloobi [c]

[a] Department of Biosystems Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran
[b] Department of Mechanical Engineering, Mechanical Engineering Faculty, University of Tabriz, Tabriz, Iran
[c] Department of Horticultural Science, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form
15 April 2016
Accepted 27 April 2016

Keywords:
Greenhouse
Solar energy
Energy consumption
Steady state analysis
North wall

ABSTRACT

The present study investigated six most commonly used shapes of greenhouses including: even span, uneven span, vinery, single span, arch and quonset type from energy consumption point of view under the climatic condition of Tabriz, Iran. The greenhouses were studied for both east–west and north–south orientation and the length width and height of them were kept same. The steady state analysis was used to calculate total additional energy (except solar radiation) required to maintain desirable temperature of plant. The effects of north brick wall on the energy consumption of greenhouses were studied and considered in model. Experimental validation of model was carried out in a single span, east-west orientated greenhouse for a typical day in winter. The results showed that the additional energy requirement to maintain the temperature desirable for the plants' growth was lowest in an east-west oriented single span greenhouse with north brick wall. It was concluded that north wall insulation can reduce heating demand of the greenhouse by as much as 31.7%. There was a fair agreement between experimental and theoretical results. The correlation coefficient and mean percentage error of developed model were calculated as 0.79 and −2.34%, respectively.

1. Introduction

The attempt to reduce environmental impacts of the fossil fuels and increasing energy demand of the world had motivated considerable research attention in an application of renewable energy [1]. Considering the geographical location of Iran, solar energy occupies one of the most important positions among the available alternative energy sources with multiple applications in different fields. One of the important applications of solar energy in new technologies is its use in greenhouses. In greenhouse cultivation, solar energy not only drives the photosynthesis process in plants but also it allows the plants to get warm during the cold months by means of greenhouse effect. In cold climates such as Tabriz, fossil fuel consumption for greenhouse heating accounts for more than 50% of total yearly energy used in greenhouses. It was determined that the rate of thermal energy required by a greenhouse depends on the solar radiation which received inside the greenhouse [2].

Considerable studies have been conducted on different methods of greenhouse heating [3–10]. These studies attempted to reduce energy consumption in greenhouse by one or combinations of these methods: increasing solar radiation availability inside the greenhouse, decreasing energy loss to ambient environment and increasing storage capacity of greenhouse component. Berroug et al. [11] studied thermal performance of a north wall made with phase change material (PCM) as a storage medium in east–west oriented greenhouse. They developed a model by energy balance equations for different components of a greenhouse in order to study the impact of the PCM on greenhouse temperature and humidity. The results indicated that application of PMC in greenhouse wall can increase temperature of plants and air inside. Esen and Yuksel [12] evaluated greenhouse heating using various renewable energy sources in Turkey. For this purpose, biogas, solar energy and a ground source heat pump greenhouse heating system with horizontal slinky ground heat exchanger was designed and set up. The experimental results indicated that the designed system can be

* Corresponding author.
E-mail addresses: mr.mobtaker@yahoo.com, mobtaker@ut.ac.ir (H. Ghasemi Mobtaker).

http://dx.doi.org/10.1016/j.renene.2016.04.079
0960-1481/

Nomenclature

A	area (m^2)
A_i	area of walls and roofs (m^2)
C	specific heat (J kg^{-1} K^{-1})
E_v	heat transfer through ventilation (W)
F_n	ratio of solar fraction falling on the north wall over the total incoming radiation at the same time (−)
F_{pr}	shape factor between plant and greenhouse room (−)
F_t	ratio of the transmitted solar radiation falling on walls/roof inside the greenhouse to the total transmitted solar radiations inside the greenhouse at the same time (−)
h_a	convective heat transfer coefficient between the greenhouse floor and inside air (Wm^{-2} K^{-1})
h_b	bottom heat transfer coefficient between the greenhouse floor and the ground beneath (Wm^{-2} K^{-1})
h_d	heat transfer coefficient from the greenhouse door to the ambient air (Wm^{-2} K^{-1})
h_p	convective heat transfer coefficient between plant and inside air (Wm^{-2} K^{-1})
h_{pr}	convective and evaporative heat transfer coefficient from the plant to the inside air (Wm^{-2} K^{-1})
h_r	radiation heat transfer coefficient between plant and inside air (Wm^{-2} K^{-1})
I_b	beam radiation (Wm^{-2})
I_d	diffuse radiation (Wm^{-2})
M	total mass (kg)
P	partial vapor pressure at saturation (pa)
Q_p	rate of additional energy (W)
R_b	the ratio of beam radiation on the tilted surface to that on a horizontal surface (−)
R_d	view factor of tilted surface to the sky (−)
R_r	view factor of tilted surface to the ground (−)
$S_i(t)$	total solar radiation on various walls and roofs (Wm^{-2})
S_t	total solar radiation falling on the greenhouse cover (W)
T	temperature (°C)
$e_{c,ave}$	average calculated values of additional energy (MJ)
$e_{i,c}$	*i*th calculated values of additional energy (MJ)
$e_{i,m}$	*i*th measured values of additional energy (MJ)
$e_{m,ave}$	average measured values of additional energy (MJ)
t	time (s)
U_{tc}	overall heat transfer coefficient of the greenhouse cover (Wm^{-2} K^{-1})
U_{tw}	overall heat transfer coefficient of the north wall (Wm^{-2} K^{-1})
v	wind velocity (ms^{-1})

Greek letters

α_g	ground absorptivity of solar radiation (−)
α_p	plant absorptivity of solar radiation (−)
β	slope of the surface with horizontal (°)
γ	surface azimuth angle (°)
γ_r	relative humidity (−)
δ	declination angle of the sun (°)
ε	emissivity (−)
θ_i	angle of incidence (°)
θ_z	zenith angle (°)
ρ	reflectivity of the ground (-)
ρ_c	reflectivity of the north wall (−)
ρ_w	reflectivity of the greenhouse cover (−)
σ	Stefan–Boltzmann constant (Wm^{-2} K^{-4})
τ	transmissivity of the greenhouse cover (−)
ω	hour angle (°)
Φ	latitude angle of a place (°)

Subscripts

a	ambient
c	greenhouse cover
d	greenhouse door
g	greenhouse ground
p	plant
r	room air
w	north wall
0	underground

used for greenhouse heating in the east and southeast regions of Turkey. In a study conducted in Tunisia, the potential use of a solar water system for greenhouse heating during the coldest period of the year was investigated. The heating system was composed of: a flat plate collector, storage tank and circulation pumps. The results showed that this system could not fulfill the heating needs of a big greenhouse, but can be satisfying for small greenhouse [13].

The total solar radiation received by a greenhouse depends on its shape and orientation. In some studies the structural analysis were conducted to select optimum design and orientation of the greenhouses for maximum capture of solar energy. Pieters and Deltour [14] investigated the constructional factors which influence the solar energy received by greenhouses under Western European conditions. They reported that solar energy collecting efficiency of greenhouses depended mainly on their position and geometry and on average greenhouse catch about 70% of the available solar radiation. In a study which was carried out in Turkey, the structural and functional characteristics of the some greenhouses were determined. The results of this study indicated that constructing greenhouses in east–west (E-W) direction increases the solar energy efficiency [15]. Sethi [16] studied five most commonly used greenhouses from total transmitted solar radiation point of view and developed models for the solar radiation availability and internal air temperature. The results showed that uneven-span shape greenhouse receives the highest and quonset shape receives the least solar radiation. In another study Cakır and Sahin [17] compared five common greenhouse types with regard to total solar radiation availability. They reported that the elliptic type was the optimum type in the studied region and shape and type of the roof were main effective parameters on solar energy gaining rates of greenhouses. El-Maghlany et al. [18] devoted a model to calculate the amount of solar energy that can be captured by the greenhouse surface. The investigation was done for different elliptic curved surface aspect ratios to reach the optimum design of the greenhouses. The results showed that at aspect ratio equals 4, solar energy received per square meter of the greenhouse land area was the highest.

Energy demand estimating is able to improve the energy efficiency and energy savings of the agricultural greenhouses. It is necessary to enhance energy management and energy savings of the greenhouses [19]. Several models have been developed to predict the energy requirement of greenhouse. Gupta and Chandra [20] used mathematical model to study the effect of greenhouse design parameters on greenhouse energy conservation in northern