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Energy analysis of solar blind system concept using energy system modelling

Amir Vadiee [a,*], Mahmoud Yaghoubi [b], Viktoria Martin [c], Yousef Bazargan-Lari [d]

[a] School of Mechanical and Aerospace Engineering, Shiraz University of Technology, Shiraz, Iran
[b] School of Mechanical Engineering, Shiraz University, Shiraz, Iran
[c] Department of Energy, KTH, Stockholm, Sweden
[d] Department of Mechanical Engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran

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ABSTRACT

Energy conservation in the horticultural industry is one of the main challenging points regarding to the sustainable development. Commercial greenhouse is known as the most energy consuming and simultaneously the most effective cultivation method which promises 10 times more production yield than open field horticultural methods. Supplementary heating demand, electrical energy demand for artificial lighting system as well as active cooling systems are the main parameters which have to be reduced in order to have more energy efficient system. Usually, in the conventional greenhouse the solar radiation will blocked using a thermal screen to avoid the overheating problem and reduce the cooling demand. In this method, a large portion of solar irradiation will reflected and absorbed by curtain without any useful utilization. By introducing the solar blind system, the excess solar radiation will absorb and convert into useful thermal energy as well as electrical energy. As a matter of fact, the solar blind system consists of a series of thermal photovoltaic modules. The solar blind system will operate based on the defined set point temperature. By exceeding the greenhouse indoor temperature than set point temperature the solar blind thermal photovoltaic modules rotate over their axis to cover the greenhouse roof and block the solar radiation and it keeps blocking the solar irradiation until the indoor temperature drops below the set point. Therefore, the cooling demand will reduce considerably while the absorbed heat and electricity gain though the thermal photovoltaic cells can be utilized later to cover a part of the greenhouse thermal and electrical demand. The main aim of this paper is to assess the solar blind system performance for various set point temperatures. Therefore an energy model has to be developed and TRNSYS is used for this purpose. The results show that by considering 18 °C as the set point temperature, the highest thermal and electrical energy performance can be reached. The maximum thermal energy performance of the system is about 86% while the minimum that is corresponded to the highest set point temperature is 38%. By considering the solar blind system operated at 18 °C as the set point temperature, the cooling demand in the greenhouse can be almost covered totally, which is the main aim of this concept. However, the electrical demand is reduced almost by 73%. Additionally, by applying the solar blind system concept, the irradiation level inside the greenhouse kept in the optimal level that leads to more uniform cultivation during the whole year.

1. Introduction

Food supply security is one of the most global challenging issues in the recent decades (Ganguly and Ghosh, 2011). The ever increasing population growths and limited arable area cause to develop the cost and energy effective horticultural methods such as commercial greenhouses. Commercial greenhouse is a protected cultivation method that protects the crops against harsh climate fluctuations and other problems such as insects. The production yield in this method is almost 10 times higher comparing to the conventional open field cultivation method. However, energy demand in the commercial greenhouse is considerably larger than other cultivation methods (Vox, 2010).

The indoor temperature and humidity level needs to be kept in a specific range depending on cultivated crops. Therefore, based on the outdoor climate condition, supplementary heating or cooling

* Corresponding author at: Shiraz University of Technology, Modares blvd., Shiraz, Iran.

E-mail address: a.vadiee@sutech.ac.ir (A. Vadiee).

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Nomenclature

A	surface area (m^2)
Cp	specific heat in constant pressure ($J\ kg^{-1}\ K^{-1}$)
I	radiation energy (Wm^{-2})
L	heat of vaporization ($kJ\ kg^{-1}$)
Q	energy transfer in terms of heating of cooling (W)
R	resistance (sm^{-1})
S	absorbed solar radiation (Wm^{-2})
T	temperature (K)
U	conduction heat transfer coefficient ($Wm^{-2}\ K^{-1}$)
V	volume (m^3)
X	humidity ratio (kg (H_2O) kg^{-1} (dry air))
h	convection heat transfer coefficient ($Wm^{-2}\ K^{-1}$)
lf	mean leaf width (m)
m	mass (kg)

Greek Symbols

α	radiation absorption coefficient (–)
ε	radiation emissivity coefficient (–)
η	efficiency factor (–)
θ	slope of solar collector surface
ρ	density ($kg\ m^{-3}$)
σ	Stefan-Boltzmann constant ($Wm^{-2}\ K^{-4}$)
τ	radiation transmission coefficient (–)
ϑ	wind speed (ms^{-1})

Subscripts

a	ambient
b	beam
c	crop
$comb$	combined
$cond$	conduction heat transfer
$conv$	convection heat transfer
d	diffusion
dew	dew point
gc	convective gain
gh	greenhouse
i	inside
inf	infiltration
n	net, normal
o	outside
s	stomatal
sw	shortwave radiation
tot	total
$vent$	ventilation terms

Abbreviations

ACH	air change ratio
PAR	photosynthesis active radiation
VP(D)(S)	vapor pressure (deficit)(saturation)
RH	relative humidity
ET	evapotranspiration rate
IAM	incident angle modifier

system will be used in order to keep the indoor climate condition in the desirable level. As a rule of thumb, the indoor temperature in the commercial greenhouse shouldn't be less than 16 °C and shouldn't exceed 30 °C while the usual range of humidity level (relative humidity) is about 60–85% (Jahns, 2011). The indoor temperature in the commercial greenhouse in the sunny warm days will easily exceed 30 °C without considering the cooling methods due to the greenhouse effect. Therefore, in all commercial greenhouses, there is some excess heat which is considered as cooling demand. The cooling demand in the conventional greenhouse is usually covered by passive cooling method (i.e. free cooling method using open ventilation windows). Simultaneously, a thermal screen is usually utilized in order to block the solar irradiation (Sanford, 2011). In the first cooling method, passive ventilation system, the excess latent and sensible heat will be lost through opening ventilation windows. In the second method, thermal screen, a reflective shading system will block the solar radiation and reflect it to the atmosphere to avoid the overheating issue in the greenhouse (Vadiee, 2011). Therefore, by applying the conventional passive cooling methods, a considerable amount of energy will be lost through the environment without any useful utilization. This, certainly, causes extra energy and production costs correspondingly (Amir Vadiee, 2014).

Beside the cooling demand, a supplementary heating system is also required in all commercial greenhouses in order to keep the greenhouse indoor climate within a desirable level. However, the cooling system and heating system may operate at the same times in order to control the humidity and temperature. For example, during the overcast days, the ventilation windows are usually open to reduce the humidity level while the heating systems are operating at the same time to keep the indoor temperature in a desirable range, which is causes an extra energy cost (Eugene and Scales, 2003).

In the recent decade, by increasing the energy cost, energy conservation is one of the key points in any sustainable development strategies. Solar blind system concept is a sustainable and innovative solution to maximize solar energy utilization in the commercial greenhouse and reduce the total energy demand.

Solar blind system concept consists of thermal photovoltaic solar cells which acts as thermal screen in order to avoid the overheating issue in the commercial greenhouse while it covers a portion of electricity and heating demand of the commercial greenhouse. The solar blind system will operate once the indoor greenhouse temperature is reached to the set point (which should be less than maximum allowable indoor temperature 30 °C) and then it converts solar energy to electricity and heat instead of blocking and reflecting that was occurred in the conventional thermal screen. The generated electricity can be utilized in the artificial lighting system or in the active cooling system while the heat gain through the solar blind system can be stored in a thermal energy storage system and cover a part of greenhouse heating demand later.

Then, TRNSYS (Klein, 2010), as a dynamic energy system modeling tool, is used in this study in order to assess the greenhouse energy performance with and without considering the solar blind system. A commercial greenhouse is chosen in Shiraz, Iran as the case study in order to verify the proposed greenhouse energy model.

2. System modeling description and governign equations

A greenhouse energy model is proposed based on a commercial greenhouse located in Shiraz, Iran as the reference model. The case studied greenhouse is an even span 5000 m^2 greenhouse located near Shiraz in Iran. This greenhouse has a pipe framed structure