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The effect of nocturnal shutter on insulated greenhouse using a solar air heater with latent storage energy

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Abstract

In order to reduce the energy consumption in agricultural greenhouses at night, two similar greenhouses with a nocturnal shutter are constructed and installed in the CRTEn (Research and Technologies Centre of Energy) in Tunisia. The first is equipped with a heating system. The solar heating system is a solar air heater collector with latent heat storage. At daytime, thermal solar energy is stored, however, at night it can be restored. Moreover, the shutter is used only at night. The analysis of the thermal energy is used to examine the repartition of the absorbed, the useful, the stored and the losses of energy in the greenhouse; with or without nocturnal shutter. The balances of the various components of the greenhouse are used to study the portions of the energy recovered, absorbed, stored and lost.

The experimentally obtained results show that: the nocturnal variations of temperature inside the two greenhouses exceed 2 °C between the first (with shutter) and the second one (without). Also, the nocturnal temperature inside the greenhouse equipped with solar heating system was maintained to 15 °C while the outside temperature decreases to 8 °C.

Keywords: Latent heat storage; Greenhouse climate control; Packed bed solar air heater

1. Introduction

From 2005 to 2008, the greenhouse areas of Tunisia increased from 4600 ha to 8683 ha (APIA). One of the greatest problems encountered in greenhouses is the control of the internal climate. The lack of heating has unfavorable effects on the precocity of production. The basic strategy of greenhouse passive heating system is to reduce the heat losses and at the same time to transfer excess heat from inside the greenhouse during the day to heat storage.

The use of thermal screens to reduce the heat losses in the greenhouse are cited in literature. Bailey (1981) verified that the use of the thermal screens are commonly drawn over the crop at sunset and removed at sunrise; can reduce the overnight heat loss by 35–60%. Thermal radiation can become the dominant mechanism of night-time heat loss from a greenhouse, particularly when there is a clear sky (Silva and Rosa, 1987). In addition to reducing thermal radiation, screens that are impermeable to air decrease the volume of the greenhouse air that needs to be heated and form an extra air gap between the crop and the greenhouse roof (Öztürk and Basçetinçelik, 1997), thereby reducing the heat transfer to the surroundings.

The use of energy-saving screens allows for an increase in night temperatures but when they are fixed screens they decrease radiation so their use is of no interest (López et al., 2003). However, some growers do use them, in order

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Nomenclature

A	surface area (m^2)
C	thermal capacity
C_p	specific heat of air at constant pressure (J/kg K)
d_a	density of air (kg/m^3)
F	view factor
h	heat transfer coefficient (W/m^2 K)
I_{dir}	diffuse solar radiation (W/m^2)
I_{dif}	direct solar radiation (W/m^2)
I_T	total solar radiation (W/m^2)
k_v	canopy attenuation coefficient
LAI	leaf area index
l	characteristic length of the leaf canopy (m)
$P(T)$	saturated water vapor pressure at temperature T (kPa)
p_v	fraction of area
Q	heat rate (W)
RE	rate of air infiltration (m^3/s)
r_a	aerodynamic resistance (s/m)
r_s	stomatal resistance (s/m)
T	temperature (K)
$\overline{T}$	average temperature (K)
t	time (s)
U	loss coefficient (W/m^2 K)
V_o	wind speed (m/s)
y	psychometric constant (0.0667 kPa/K)
z	depth of soil (m)

Greek symbols

α	absorptivity for solar radiations
α_t	absorptivity for thermal radiations
ε	emissivity
γ	fraction of the solar radiation
λ	thermal conductivity (W/m K)
θ	incident angle
ρ	reflectivity
σ	Stefan–Boltzmann constant ($5.670 \cdot 10^{-8}$ W/m^2 K^4)
τ	transmissivity

Subscripts

c	cover of greenhouse
col	collected
g	greenhouse
i	inside greenhouse
inf	infiltration
los	loss
net	net
o	outsider greenhouse
s	soil
sto	stored
sky	sky
sun	sun
v	canopy

Exposants

C	convective heat
Cd	conductive heat
inf	infiltration
L	latent heat
R	radiation heat
S	solar radiations

to limit the fall of water droplets (from condensed water vapor or from the rain in artisan low-cost greenhouses) over the crop. Furthermore, because screens reduce thermal radiation, heat loss by radiation from the crop is reduced and crop temperature is expected to be raised. Kittas et al. (2003) considered the influence of an aluminized thermal screen on greenhouse microclimate and canopy energy balance, and reported that with a thermal screen the microclimate at crop level was more homogeneous and the average air and canopy temperatures were higher than without a screen. However, the energy saving with a 65% aluminized thermal screen in their experiments was only about 15%. Mobile thermal screens improve the yield and adapt well to multi-tunnel greenhouses, being of more interest in heated greenhouses than in unheated ones (Meca et al., 2003). Thus, they keep the internal air temperature higher than it would be without a screen (Montero et al., 2005). Baille et al. (2006) analyzed the night energy balance of an air-heated greenhouse in mild-winter climatic conditions. They enhanced that the energy efficiency would be: to improve the air tightness of the greenhouse, to reduce radiative losses by means of thermal screens, and to increase the soil efficiency in storing solar energy and releasing it during the night. Teitel et al. (2009) reported that the thermal screen did not reduce the heat loss from the greenhouse because it was relatively small in area and only 20% of its area was covered by reflective aluminized material.

The solar energy is an attractive substitute for conventional fuels for passive and active heating applications. However, the intermittent characteristic of the solar radiations has led to the improvement of suitable collection and storage technologies.

In a greenhouse, the use of solar thermal energy covers one part of the crop heating demand needed during the day; its handling during nighttime requires an efficient storage system, so that the excess of heat is stored for later use during the night.

The use of PCMs (Phase Change Materials) is one of the most efficient ways of storing thermal energy for heating and cooling applications (Jurinak and Adbel-Khalik, 1978; Morrison and Abdel-khalil, 1978; Ghoneim and