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Dynamic modeling of the environment in a naturally ventilated, fog-cooled greenhouse

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Abstract

A dynamic simulation model for heat and water vapor transfer in a naturally ventilated, fog-cooled greenhouse was developed to predict the temperatures of air, plant, cover and floor surface and the relative humidity in the greenhouse. Transpiration and evaporation were also predicted. An experiment was conducted on a hot summer day (Aug. 9, 2004) in the Tokyo area to measure the environments inside and outside a glass-covered greenhouse with a floor area of 26 m^2. The greenhouse was cooled intermittently by spraying water fog at a constant rate of 0.01 $kg\,s^{-1}$ for different fogging and interval times (0.5 min on followed by 1.5 min off; 1 min on–3 min off and 1.5 min on–4.5 min off). The system of equations of the model was solved numerically by using the predictor–corrector technique for the differential equations and the iteration procedure for the algebraic equation. The input parameters to the model were the meteorological conditions and the thermo-physical properties of the greenhouse cover, plant, air and soil. The predicted results using the present model were compared with the measured values and showed a good agreement at different fogging and interval times.

Keywords: Dynamic; Modeling; Natural ventilation; Fogging; Cooling; Greenhouse

1. Introduction

The need for greenhouse cooling is an essential requirement during the hot summer in many areas of the world. Increased interest of this requirement has been stimulated by the

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Nomenclature

Alphabetic symbols

A_c	surface area of the greenhouse cover (m^2)
A_f	surface area of the floor (m^2)
A_p	surface area of the plant leaves (m^2)
C_p	specific heat ($J\,kg\,C^{-1}$)
D	soil heat flux ($W\,m^{-2}$)
F_{1-2}	shape factor between two surfaces 1 and 2 (dimensionless)
Gr	Grashof number (—)
G_s	solar radiation flux ($W\,m^{-2}$)
G_{sky}	sky thermal radiation flux ($W\,m^{-2}$)
h_{1-2}	convective heat transfer coefficient between surface 1 and 2 ($W\,m^{-2}\,°C^{-1}$)
I	enthalpy of moist air ($J\,kg^{-1}$)
K_m	diffusion coefficient of soil surface to water vapor transfer ($kg\,m^{-2}\,s^{-1}$)
K_s	thermal conductivity of greenhouse soil ($W\,m^{-1}\,°C^{-1}$)
L	characteristic length (m)
LAI	leaf-area index (A_p/A_f)
$\dot{M}_p$	transpiration rate ($kg\,s^{-1}$)
$\dot{M}_{pot}$	pot soil surface evaporation rate ($kg\,s^{-1}$)
$\dot{m}_w$	fogging rate ($kg\,s^{-1}$)
$\dot{m}_v$	rate of water vapor associated with ventilation ($kg\,s^{-1}$)
$\dot{m}_a$	ventilation rate of dry air ($kg\,s^{-1}$)
$\dot{m}_{ven}$	ventilation rate of moist air ($kg\,s^{-1}$)
m_g	mass of the greenhouse air (kg)
Q	convective or sensible heat flux ($W\,m^{-2}$)
QE	emissive power (W)
RC	thermal radiation absorbed by the cover ($W\,m^{-2}$)
RF	thermal radiation absorbed by the soil surface ($W\,m^{-2}$)
RP	thermal radiation absorbed by the plant layer ($W\,m^{-2}$)
Re	Reynolds number (dimensionless)
SC	solar radiation absorbed by the cover ($W\,m^{-2}$)
SP	solar radiation absorbed by plant layer ($W\,m^{-2}$)
SF	solar radiation absorbed by the soil surface ($W\,m^{-2}$)
SL	solar radiation loss to outside the greenhouse ($W\,m^{-2}$)
T	temperature (K or °C)
V_w	wind speed ($m\,s^{-1}$)
z	soil depth (m)

Greek symbols

α_{lc}	absorbtance of cover to thermal radiation (dimensionless)
α_{sc}	absorbtance of cover to solar radiation (dimensionless)
β	fraction of the evaporated fog (dimensionless)
ε	surface emittance (dimensionless)