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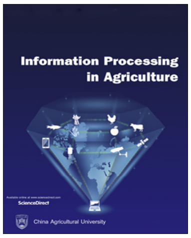

Application of dynamic model to predict some inside environment variables in a semi-solar greenhouse

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ABSTRACT

Greenhouses are one of the most effective cultivation methods with a yield per cultivated area up to 10 times more than free land cultivation but the use of fossil fuels in this production field is very high. The greenhouse environment is an uncertain nonlinear system which classical modeling methods have some problems to solve it. There are many control methods, such as adaptive, feedback and intelligent control and they require a precise model. Therefore, many modeling methods have been proposed for this purpose; including physical, transfer function and black-box modeling. The objective of this paper is to modeling and experimental validation of some inside environment variables in an innovative greenhouse structure (semi-solar greenhouse). For this propose, a semi-solar greenhouse was designed and constructed at the North-West of Iran in Azerbaijan Province (38°10′N and 46°18′E with elevation of 1364 m above the sea level). The main inside environment factors include inside air temperature (T_a) and inside soil temperature (T_s) were collected as the experimental data samples. The dynamic heat transfer model used to estimate the temperature in two different points of semi-solar greenhouse with initial values. The results showed that dynamic model can predict the inside temperatures in two different points (T_a and T_s) with RMSE, MAPE and EF about 5.3 °C, 10.2% and 0.78% and 3.45 °C, 7.7% and 0.86%, respectively.

1. Introduction

One of the challenging subjects for global ambitions because of the sustainability, is the sustainable agriculture [1]. Three important aspects are at the center of attention including: energy utilization, environmental impact and cost-efficiency. Growth in population needs higher production yield. The higher production demand leads to increase in energy consumption and final cost [2]. Although energy using in agricultural industry is small as compared to the total energy demand in many countries, it is fairly considerable in some countries like Netherlands where it represents 8.1% of total energy use [3]. For increasing in yield and controlled growth in all climates, greenhouses are used. In the horticultural industry, the greenhouse is one of the most profitable sectors since it has a very high output which is 10–20 times

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Nomenclature

Q	heat transfer (W)	λ_{nw}	north wall thermal conductivity (W/m K)
α	heat transfer coefficient (W/m^2 K)	$a-o$	inside air to outside
v	outdoor wind speed (m/s)	$rd-s$	radiation absorption by soil
I	solar radiation (W/m^2)	a	inside air
T	temperature (K)	$s-ss$	upper to lower soil
F	view factor (–)	V	volume (m^3)
E	emission coefficient (–)	η_{ri-Is}	absorption coefficient shortwave radiation by roof (–)
c_p	specific heat capacity (J/kg K)	nwi	inside north wall
f	infiltration facto (–)	$a-s$	inside air to soil
σ	Stefan-Boltzmann constant (W/m^2 K^4)	ri	inside roof
ρ	density (kg/m^3)	d	thickness (m)
$a-ri$	inside air to roof	s	inside soil
λ_s	soil thermal conductivity (W/m K)		

higher than the outdoor farming. However, the high cultivation output requires a considerable capital investment cost, labor, fertilizers and energy input, primarily for heating and lighting. When considering the continuing increase in cost of energy, especially for fossil fuels, the external energy demand must be reduced to cut down the total annual operating cost. So, a good understanding of the energy utilization in the commercial greenhouse sector is essential [4,5].

A greenhouse is a structure which is covered by a transparent device such as glass in order to use solar energy while controlling the temperature, humidity and other parameters according to the requirements for cultivation or protection of the particular plants. The commercial greenhouses are used to grow plants in order to reach better quality and protect them against natural environmental effects such as wind or rain [2]. Another benefit of using a greenhouse is giving the ability for out of season growing. The operation of greenhouses makes use of the greenhouse effect. Then, the short wavelengths of solar irradiation, the visible light, can pass through a transparent medium and is absorbed by the objects on the other side. The heated objects will re-radiate longer wavelengths, infrared radiation, that cannot pass through the transparent medium. The temperature will increase because of the accumulation of heat in this process [6].

The management of the greenhouse environment is mainly depending on the temperature manipulation. Temperature manipulation is critical for influencing plant growth, quality and morphology and also is a major strategy in environmental modification of crops. The greenhouse environment is a very complex dynamic system covered with thin and transparent materials. Many modeling methods have been applied to control the environment of greenhouse; such as mechanism, transfer function and black-box modeling. The mechanism model provides a clear physical explanation of the greenhouse environment, such as the early static and dynamic model presented by Bot [7] or improved models presented by Van Henten [8] and De Zwart [9] Static and dynamic models are used for this purpose as a function of the metrological conditions and the parameters of the greenhouse components [10,11]. The static models are based on the static energy balance of the greenhouse components; i.e. cover, inside air, plant, and soil under steady state conditions. The heat storage capacities of these components are neglected in the static models [12–16]. Joudi and Farhan [17], presented a dynamic model to predict the inside air and soil temperature in an innovative greenhouse in Iraq. The input parameters of this model collected from measured meteorological conditions and the thermo-physical properties of the greenhouse components which include the cover, inside air, and soil. Comparisons between the predicted and measured results showed a good agreement. The absolute error in this dynamic model was lower that 10% for inside air and soil temperature. Du et al. [18], applied the simulation way to predict the inside air and soil in a greenhouse with heat pipe system. The model validated with experimental data and found to be in close agreement. The absolute error between predicted and desired data was about ±20%. Çakır and Şahin [19], developed a mathematical model to select the optimum type of greenhouse according to sizing, position and location. The results showed that greenhouses were usable and suitable for using in cold climate regions to increase the productivity. In addition, the elliptic type was the optimum one in all analyzed types of greenhouses for Bayburt conditions (Turkey) for all floor areas. It was followed by uneven-span, even-span, semi-circular and vinery type of greenhouses respectively. Tong et al. [20], studied the boundary conditions were based on hourly measured data for the solar insolation and the sky, soil (1 m below the soil surface) and outside air temperatures, plus other parameters describing the external convection and radiation in a greenhouse. Results showed that the simulated air and soil temperatures had the same profile as the measured temperatures with the average temperature differences between the simulated and measured air temperatures during the nighttime less than 1 °C on the clear days and no more than 1.5 °C during the entire cloudy day. Taki et al. [21], compared some mathematical models (include dynamic and Multiple Linear Regression (MLR)) with innovative method (Artificial Neural Network) and selected the best one to predict inside air and roof (T_a and T_{ri}) temperature and energy transfer in a semi-solar greenhouse in Iran. Comparing MLP and dynamic

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