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GREENHOUSE ENERGY MANAGEMENT SIMULATION MODEL

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Abstract: *A simulation model for a gerbera crop greenhouse climate was developed. The equations were written for four parts of a greenhouse: outdoor air, indoor air, canopy surface and ground surface. The model parameters are the ambient air temperature, solar radiation values on the surface of normal solar radiation on the surface, the soil temperature inside the greenhouse and soil temperature. A computer program was written in EES language. Model outputs are the outside surface temperature greenhouses, indoor air temperature, surface temperature of the inner coating material and uncovered soil temperature and energy fluxes corresponding to modeled domains. Relative humidity of the inside air is calculated depending on the temperature and pressure using psyhrometric relations. Overall energy balances of the components of greenhouse are presented.*

Key words: *energy management, simulation model, greenhouse, thermal properties.*

1. Introduction

The present work a simulation mathematical model was developed based on the energy balance for greenhouse for gerbera crop. The model is consisting of a set of algebraic equations that describe a system with lumped parameters [2], [9]. The equations were written for components of the greenhouse respectively, outside surface coatings, indoor air, indoor surface of canopy and soil surface uncovered by crops.

The following assumptions have been considered for greenhouse plants model:

- the inside air is homogeneous at any time, so there the gradients of temperature or humidity in the air,
- condensation and evaporation on the greenhouse floor is negligible,
- indoor air is transparent to infrared wavelength radiation,
- each component temperature of the greenhouse: exterior roof, indoor air, indoor roof is the same throughout the greenhouse.

Overall energy balances of the components of greenhouse are presented.

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2. Energy Balance of the Cover of the Greenhouse

Energy balance of the cover roof of the greenhouse include solar radiation absorbed by the layer of coating, solar radiation reflected from crest culture of plants and soil uncovered plants that are absorbed by the coating, heat transfer by convection between the roof and the air outside the greenhouse, heat transfer by convection between the roof and indoor air exchange heat radiation from the roof and outdoor air, thermal radiation emitted by the inner surface of the coating material of the greenhouse thermal radiation emitted by the uncovered soil surface and absorbed by coating (Figure 1).

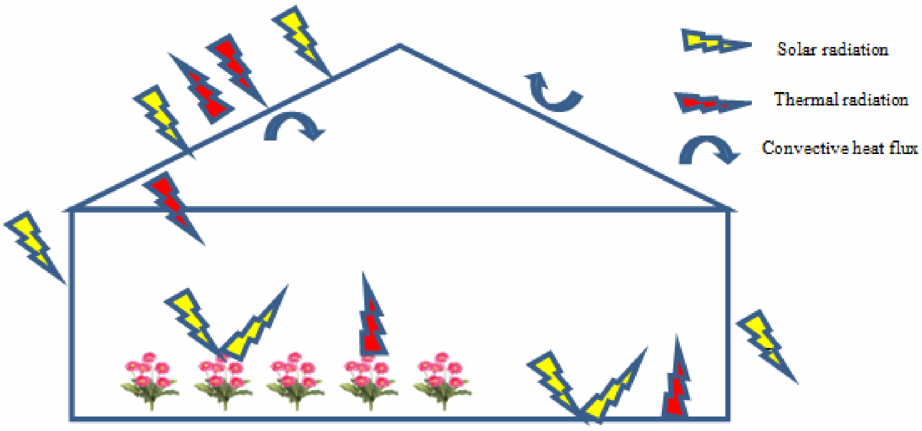

Fig. 1. *Energy balance of the greenhouse cover*

Overall energy balance of the cover surface of greenhouse is presented below:

$$\dot{Q}_1^{\text{cov}} - \dot{Q}_2^{\text{cov}} - \dot{Q}_3^{\text{cov}} + \dot{Q}_4^{\text{cov}} + \dot{Q}_5^{\text{cov}} + \dot{Q}_6^{\text{cov}} + \dot{Q}_7^{\text{cov}} - \dot{Q}_8^{\text{cov}} + \dot{Q}_9^{\text{cov}} - \dot{Q}_{10}^{\text{cov}} = 0 \quad (1)$$

where

$\dot{Q}_1^{\text{cov}} = I_g A_{ci} \alpha_c + I_g A_{cii} \alpha_c (1 + \tau_c)$ Solar radiation absorbed by the cover (1a)

$\dot{Q}_2^{\text{cov}} = h_{\text{cov}} A_c (T_c - T_{amb})$ Convective heat flow from cover to outside ambient air (1b)

$\dot{Q}_3^{\text{cov}} = \varepsilon_{sky} \sigma T_{sky}^4 A_c \alpha_{ct} - \varepsilon_c \sigma T_c^4 A_c$ Thermal radiation exchange between cover and sky (1c)

$\dot{Q}_4^{\text{cov}} = I_{gh} \tau_c A_{ca} \rho_{ca} \alpha_c$ Solar radiation reflected by canopy and absorbed by cover (1d)

$\dot{Q}_5^{\text{cov}} = I_{gh} \tau_c A_{sb} \rho_{sb} \alpha_c$ Solar radiation reflected by soil and absorbed by cover (1e)

$\dot{Q}_6^{\text{cov}} = \varepsilon_{ca} \sigma T_{ca}^4 A_{ca} \alpha_{ct}$ Thermal radiation emmited by canopy and absorbed by cover (1f)

$\dot{Q}_7^{\text{cov}} = \varepsilon_{soil} \sigma T_{soil}^4 A_{soil} \alpha_{ct}$ Thermal radiation emmited by soil and absorbed by cover (1g)

$\dot{Q}_8^{\text{cov}} = h_{cin} A_c (T_c - T_{air})$ Convective heat flow from cover to inside air (1h)

$\dot{Q}_9^{\text{cov}} = 0$ Latent heat due to condensation on inside of cover (assumed zero) (1i)

$\dot{Q}_{10}^{\text{cov}} = \varepsilon_c \sigma T_c^4 A_{ca} (1 - F_c)$ Thermal radiation emmited by inside cover (1j)

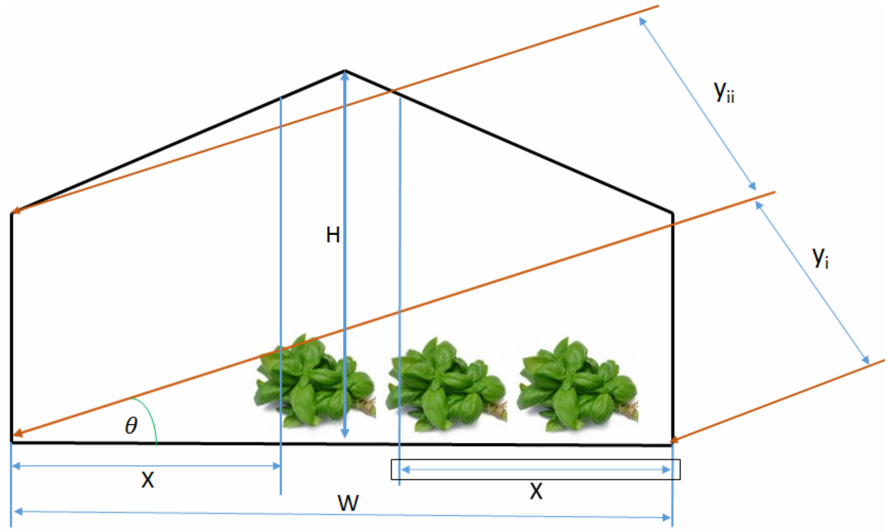

Fig. 2. *The projected areas*

The projected areas (Figure 2) to incident solar radiation are calculated with [2]:

$$A_{ci} = Y_i \cdot L, \quad A_{cii} = Y_{ii} \cdot L \tag{2}$$

where:

$$Y_i = W \cdot \sin\theta, \quad Y_{ii} = (H - X \cdot \tan\theta) \cdot \cos\theta \tag{3}$$

and A_{ci} is projected solar radiation incident area of cover through which solar radiations enter but not pass out, A_{cii} is projected solar radiation incident area through which solar radiations enter and pass out, *L*, *W*, *H* are the length, width and height of the greenhouse.

The sunlight vertical angle (θ) East-West varies with time. It depends on the latitude (*l*) of the place of greenhouse, the elevation angle (β), azimuth angle (γ), declination angle (δ) and hour angle (*h*). To calculate the East-West vertical angle is used the following equation:

$$\theta = \arctan\left(-\frac{ctg(90-\beta)}{\cos\gamma}\right). \tag{4}$$

$$\beta = \arcsin(\cos l \cos h \cos\delta + \sin l \sin\delta) \tag{5}$$

$$\gamma = \arccos\left(\frac{\cos l \sin\delta + \sin l \cos h \cos\delta}{\cos\beta}\right) \tag{6}$$

$$\delta = \arcsin\left(\sin 23.45 \cdot \sin\left(\frac{360}{365}(day - 81)\right)\right) \tag{7}$$

where *day* is the day of the year beginning from January 1st.

The heat transfer convective coefficients are calculated as follows [3]:

Between cover and outside air

$$h_{\text{cov}} = 0.95 + 6.76 \cdot V^{0.49}. \tag{8}$$

Between cover and inside air

$$h_{cin} = 1.95 \cdot (T_{\text{cov}} - T_{air})^{0.3}. \tag{9}$$

Between soil and inside air

$$h_{cin} = 1.52 \cdot (T_{soil} - T_{air})^{0.33} + 5.2 \cdot \left(\frac{V_{in}}{L}\right)^{0.5}. \tag{10}$$

Between plant leaf and inside air

$$Nu = 0.37 \cdot (Gr - 6.92\,\text{Re}^2)^{0.25}. \tag{11}$$

Between inside walls and air

$$h = 2.8 + 3.0 \cdot V. \quad (12)$$

The sky temperature is calculated with the relation:

$$T_{sky} = T_{amb} - 6. \quad (13)$$

3. Energy Balance of the inside Air

The overall energy balance of inside air of the greenhouse is considered only the convective heat transfer. It is assumed that solar radiation is absorbed by the air. Heat transfer convection inside greenhouse is given by convection heat transfer from plants and air heat transfer at the surface of the canopy to indoor air by convection of the air inside plus to uncoated surface of the soil.

Heat losses due to ventilation or air infiltration exchanges are assumed zero for this model. This may be considered valid if it involves stopping the fans. The heat absorbed by the water spray is also assumed to be zero at this stage.

Overall energy balance of the inside air is:

$$-\dot{Q}_1^{Air} + \dot{Q}_2 - \dot{Q}_3 - \dot{Q}_4 - \dot{Q}_5 + \dot{Q}_6 = 0 \quad (14)$$

where

$\dot{Q}_1^{Air} = h_{in-ca} A_{ca} (T_{air} - T_{canopy})$ Convective heat flow from inside air to canopy (14a)

$\dot{Q}_2^{Air} = 0$ Heat flow input into greenhouse (heating) (14b)

$\dot{Q}_3^{Air} = h_{in-soil} A_{soil} (T_{air} - T_{soil})$ Convective heat flow from inside air to uncovered soil (14c)

$\dot{Q}_4^{Air} = 0$ Heat loss due to ventilation and infiltration (14d)

$\dot{Q}_5^{Air} = h_{in-\text{cov}} A_c (T_{air} - T_{\text{cov}er})$ Convective heat flow from inside air to cover (14e)

$\dot{Q}_6^{Air} = 0$ Heat flow absorbed by water spraying (14f)

4. Energy Balance of the Canopy Surface

The heat exchange between cover and air is occurring with convective heat transfer, radiation heat exchange heat with the ground surface between the canopy and the soil surface under the canopy. The canopy absorbs heat and emit thermal radiation emitted the greenhouse covering material. Solar radiation is also absorbed by the canopy.

Overall energy balance for canopy surface of greenhouse is given below:

$$\dot{Q}_1^{Can} + \dot{Q}_2^{Can} - \dot{Q}_3^{Can} - \dot{Q}_4^{Can} - \dot{Q}_5^{Can} + \dot{Q}_6^{Can} = 0 \quad (15)$$

where

$\dot{Q}_1^{Can} = I_{gh} \tau_c S_{sh} A_{ca} \alpha_{ca}$ Short wave radiation absorbed by the canopy (15a)

$\dot{Q}_2^{Can} = \varepsilon_c \sigma T_c^4 \alpha_{cat} (A_r S_{fr} + A_{s1} S_{f1} + A_{s2} S_{f2})$ Thermal radiation emmited by cover and absorbed by canopy (15b)

$$\dot{Q}_3^{Can} = \varepsilon_{ca}\sigma T_{ca}^4 A_{ca}$$ Thermal radiation emmited by canopy (15c)

$$\dot{Q}_4^{Can} = h_{can}A_{ca}\left(T_{can} - T_{air}\right)$$ Convective heat flux from canopy to inside air (15d)

$$\dot{Q}_5^{Can} = h_{ea}A_{ca}\left(T_{can} - T_{air}\right)$$ Latent heat flux due to transpiration (15e)

$$\dot{Q}_6^{Can} = \varepsilon_s\sigma T_{sc}^4 A_{sc}\alpha_{cat} - \varepsilon_{ca}\sigma T_{ca}^4 A_{ca}$$ Thermal radiation exchange between canopy and soil (15f)

5. Energy Balance of the Soil

For the soil component the heat flows at the soil surface due to thermal radiation emitted by the greenhouse roof and which are absorbed by the soil uncovered surface, plus the direct solar radiation absorbed by the soil surface. The soil heat is transferred by radiation emitted from the uncovered soil surface, by the conduction heat transfer in the soil and by the convective heat transfer between the soil surface and the air in the greenhouse.

Energy balance of the soil surface of greenhouse is presented below:

$$\dot{Q}_1^{soil} - \dot{Q}_2^{soil} - \dot{Q}_3^{soil} - \dot{Q}_4^{soil} + \dot{Q}_5^{soil} = 0 \quad (16)$$

where

$$\dot{Q}_1^{soil} = I_{gh}\tau_c A_{soil}\alpha_{bs}$$ Solar radiation absorbed by soil (16a)

$$\dot{Q}_2^{soil} = h_{si}A_{soil}\left(T_{soil} - T_{air}\right)$$ Convective heat flux from soil to first soil layer (16b)

$$\dot{Q}_3^{soil} = \frac{k}{z_1}A_{soil}\left(T_{soil} - T_{ground}\right)$$ Conductive heat flux in soil to z_1 layer (16c)

$$\dot{Q}_4^{soil} = \varepsilon_{bs}\sigma T_{soil}^4 A_{soil}$$ Thermal radiation emmited by soil (16d)

$$\dot{Q}_5^{soil} = \varepsilon_c\sigma T_c^4\alpha_{cat}\left(A_r S_{frs} + A_{sw}S_{fsws}\right)$$ Thermal radiation emmited by cover and absorbed by soil (16e)

6. Results

The material properties used in the simulation model, such as absorptivity, reflectivity, emissivity, conductivity, etc. are selected from the literature for the materials used in this greenhouse. Some properties are determined by heat transfer relations, i.e. wall shape factors. The values of material properties used in the model are shown in Table 1 and the values of wind speed and the shape factor are given in Table 2.

The equations were solved using EES software [10] to determine the cover temperature (T_{cover}), the indoor air temperature (T_{air}), the surface temperature of the canopy (T_{Can}) and the temperature of the soil surface (T_{sb}) during a summer day from sunshine to dawn of 1st July from Braşov city, Romania.

Also, the heat flow by convection, thermal radiation and solar radiation is calculated for each greenhouse component.

The temperature evolution is presented in Figure 1.

Greenhouse properties values used Table 1

Component	Property	Symbol	Value
Sky	Emissivity	ε_{sky}	0.90
Polyethylene cover	Transmissivity	τ_c	0.65
	Absorbtivity for solar radiation	α_c	0.20
	Reflectivity for solar radiation	ρ_c	0.15
	Emissivity	ε_c	0.90
	Absorbtivity for thermal radiation	α_{ct}	0.90
Gerbera canopy	Transmissivity	τ_{ca}	0.0
	Absorbtivity for solar radiation	α_{ca}	0.77
	Reflectivity for solar radiation	ρ_{ca}	0.23
	Emissivity	ε_{ca}	0.98
	Absorbtivity for thermal radiation	α_{cat}	0.98
Soil	Transmissivity	τ_{soil}	0.0
	Absorbtivity for solar radiation	α_{soil}	0.80
	Reflectivity for solar radiation	ρ_{soil}	0.20
	Emissivity	ε_{soil}	0.90
	Thermal conductivity	k_{soil}	0.70

Variable values used in Greenhouse model Table 2

Variable name	Symbol	Value
Area of the canopy inside the greenhouse [m^2]	A_{ca}	72
Area of the uncovered soil inside the greenhouse [m^2]	A_{soil}	120
Area of the greenhouse cover [m^2]	A_c	370
Area of the roof of the greenhouse [m^2]	A_r	192
Area of the side wall above the canopy [m^2]	A_{s1}	24
Area of the side walls [m^2]	A_{sw}	48
Wind velocity inside the greenhouse [m/s]	V_{in}	0.2
Wind velocity outside the greenhouse [m/s]	V	2.85
Canopy coverage area factor	S_{hf}	0.75
Shape factor roof to canopy	S_{fr}	0.229
Shape factor first side wall to canopy	S_{f1}	0.529
Shape factor second side wall to canopy	S_{f2}	0.210
Shape factor roof to uncovered soil	S_{frs}	0.471
Shape factor side wall to uncovered soil	S_{fsws}	0.40

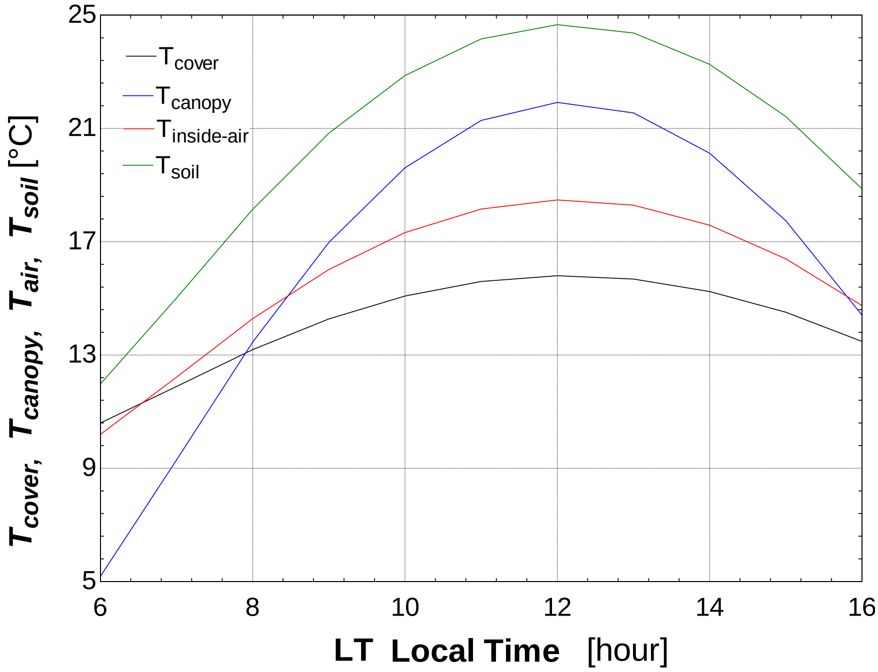

Fig. 3. *Temperature evolution for greenhouse during a summer day*

7. Conclusion

A simulation model was made based on the energy balance for gerbera crop greenhouse. The equations were written for components of the greenhouse respectively, outside surface coatings, indoor air, indoor surface of canopy and soil surface uncovered by crops.

Overall energy balances and temperature evolution during a summer day for each component of the greenhouse are presented.

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