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MODEL OF THE HEAT BALANCE OF A SOLAR GREENHOUSE WITH A WATER HEAT ACCUMULATOR

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Annotation
The article proposes a mathematical model of soil-air, sheet-air and accumulator-air thermal processes in order to determine heat flows by creating heat balance equations for a solar greenhouse and a water heat accumulator installed in it.

Key words
solar greenhouse, dryer, heat accumulator, soil, convection, radiation, evaporation.

1. Introduction

Solar radiation passing through the transparent fence of the solar greenhouse is absorbed by plant leaves, the surface of the soil, the heat accumulator [1,2], and structural elements; by convection and radiation is transferred to the atmosphere through the fence in the form of heat losses. The sum of the amount of absorbed radiation constitutes the internal radiation regime and determines the heat balance in the solar greenhouse.

The heat balance is determined by the following system of equations:

$$Q_{tr} = Q_{hl}+Q_s+Q_p+Q_a ; \quad (1)$$

$$Q_{hl} = K_r(t_i-t_e) ; \quad (1a)$$

$$Q_s = a_{ss}(t_s-t_i) ; \quad (1b)$$

$$Q_p = a_{sp}(t_p-t_i); \quad (1c)$$

$$Q_a = a_{sa}(t_a-t_i); \quad (1d)$$

where, Q_{tr} - is the total solar radiation transmitted into the solar greenhouse, W/m²; Q_{hl}- total heat loss, W/m²; Q_s, Q_p, Q_a - heat from solar energy absorbed by soil, plant leaves, heat accumulator, W/m²; K_r-reduced heat transfer coefficient of solar greenhouse dryer, W/(m²*K); t_i, t_e- temperature of internal and external air, °C; t_s, t_p, t_a - temperature of the soil, plant leaves, heat accumulator, °C; a_{ss}, a_{sp}, a_{sa} - heat transfer coefficients on the surface of the soil, plant leaves, heat accumulator, W/(m²*K).

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2. Material and methods

When determining the amount of absorbed radiation, we make the following assumptions:

- the heat of solar radiation absorbed by the fencing design elements is not taken into account;

- scattered radiation is completely isotropic.

Absorbed solar energy is spent on evaporating moisture and heating the air (by convection and radiation), and is accumulated in the soil and heat accumulator (thermal conduction).

Solar radiation absorbed by the soil:

$$Q_s = Q_{tr}A_sF_s = (S_{tr}cosiK_s + D_{tr})A_sF_s \qquad (2)$$

plant leaves

$$Q_p = Q_{tr}A_pF_p = \left(S_{tr}cosiK_p + D_{tr}\right)A_pF_p \qquad (2a)$$

heat accumulator

$$Q_a = Q_{tr}A_aF_a = (S_{tr}cosiK_a + D_{tr})A_aF_a \qquad (2b)$$

A_s, A_p, A_a - absorption coefficients of solar radiation by soil, plant leaves, heat accumulator; F_s, F_p, F_a - a surface area of soil, plant leaves, accumulator, м²; Q_{tr}, S_{tr}, D_{tr} - total, direct and diffuse solar radiation transmitted into the greenhouse onto the surface perpendicular to the rays, W/m^2. i - angle of incidence of rays on the surface, degrees; K_s, K_p, K_a - irradiance coefficients of the soil surface, plant leaves, heat accumulator.

According to data [3-6] the soil surface, depending on humidity. 47...60% of incident radiation is absorbed. For the solar greenhouse condition, A_s=0.53 is assumed. Plant leaves absorb 60...75% of incident radiation [5-9]. For plants in protected soil, A_p=0.64 is accepted [5] Shading of the soil surface by the plant crown depends on the height of the sun. The leaf crown transmits 10% of direct solar radiation [3-6] and the irradiance coefficient varies in the range K_p=0.1...0.55.

3. Results

Solar radiation absorbed by the soil is determined based on the heat balance at the soil-air interface

$$Q_s = Q_{sc}+Q_{sr} + Q_{stc}+Q_{se} \qquad (3)$$

where, Q_{sc}, Q_{stc}, Q_{se} - is heat transferred by convection and radiation by thermal conductivity and evaporation of moisture, W;

Heat flow by convection and radiation from the soil surface [3-9]

$$Q_{sc} = (a_{sc} + a_{sr})(t_s - t_i)F_s \qquad (4)$$

Heat transferred by conduction to the soil layer

$$Q_{sr} = \lambda \frac{\partial t_s}{\partial y}\Big|_{y=0} F_s \qquad (5)$$

Heat of evaporation of moisture from the soil surface

$$Q_{se} = r_s G_s F_s \qquad (6)$$

where, α_{sc}, α_{sr} are the coefficients of heat transfer by convection and radiation from the soil surface, W/(m^2*K); λ - soil thermal conductivity coefficient, W/(m*K); r_s - specific heat of vaporization, J/kg; G_s - rate of moisture evaporation from the soil surface, kg/(m^2*s).

The evaporation of moisture G_s from the soil surface is associated with convective heat transfer Q_{sc} determined by the Bowen relation [3,7,10]

$$Bo_s = \frac{Q_{sc}}{Q_{se}} = \frac{a_{sc}(t_s - t_i)}{r_s G_s} \qquad (7)$$

The Bowen ratio for the soil surface is determined by the Penman method [10]

$$Bo_s = \gamma \frac{t_s - t_i}{\mathrm{P}_s(t_s) - \mathrm{P}_s(t_i)}; \quad \gamma = \frac{C_p P_i}{0{,}662 r_s} \qquad (8)$$

After transformations from equations (7) and (8) we obtain

$$G_s = \frac{a_{sc}(t_s - t_i)}{r_s Bo_s} = \frac{a_{sc} 0{,}662[\mathrm{P}_s(t_s) - \mathrm{P}_s(t_i)]}{C_p P_i} \qquad (9)$$

Solar radiation absorbed by plant leaves is determined based on the heat balance at the leaf-air interface

$$Q_r = Q_{rc} + Q_{rr} + Q_{re} \qquad (10)$$

where, Q_{rc}, Q_{re} - is the heat transferred by convection and radiation and evaporation of moisture from the surface of the leaves, W;

Heat flow by convection and radiation from the surface of leaves [3,5]

$$Q_{rc} = (a_{rc} + a_{rr})(t_{\mathrm{p}} - t_i) F_p \qquad (11)$$

where, α_{rc}, α_{rr} – heat transfer coefficients by convection and radiation of the leaf surface, W/(m^2 K).

Heat of moisture evaporation from the leaf surface

$$Q_{re} = r_s G_p F_p \qquad (12)$$

where, G_p is the rate of moisture evaporation from the leaf surface, kg/(m^2s).

The evaporation of moisture from the leaf surface G_p is similar to (7), (8) and (9) and is determined through the Bowen relation by the Penman method [10]

$$G_p = \frac{a_{pc}(t_p - t_i)}{r_s Bo_p} = \frac{a_{pc} 0{,}662[\mathrm{P}_p(t_p) - \mathrm{P}_p(t_i)]}{C_p P_i} \qquad (13)$$

4. Discussion

Solar radiation absorbed by the heat accumulator is determined based on the thermal balance at the accumulator-air interface

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$Q_a = Q_{ac} + Q_{ar} + Q_{aa}$ (14)

where, Q_{ac}, Q_{aa} - heat transferred to the air by convection and radiation, accumulated in a heat accumulator, W;

Heat flow by convection and radiation from the surface of the battery

$Q_{ac} = (a_{ac} + a_{ar})(t_a - t_i)F_a$ (15)

where, a_{ac}, a_{ar} - heat transfer coefficients by convection and radiation of the battery surface, W/(m^2*K); t_a - is the surface temperature of the heat accumulator, °C.

Heat accumulated in a thermal accumulator

$Q_{aa} = mC_w(t_{a1} - t_{a0})$ (16)

where, m - is the mass of the heat accumulator, kg; C_w - specific heat capacity of water, J/(kg K); t_{a0}, t_{a1} – mass average initial and final temperature of the heat accumulator, °C.

Equations (1)-(16) constitute a mathematical model of the thermal balance of a solar greenhouse. The values of $K_r, a_{sc}, a_{sr}, a_{pc}, a_{pr}, a_{ac}, a_{ar}, P_s(t_s)$ are determined according to the method given in [2,5,7,8,11,12,13,14,15].

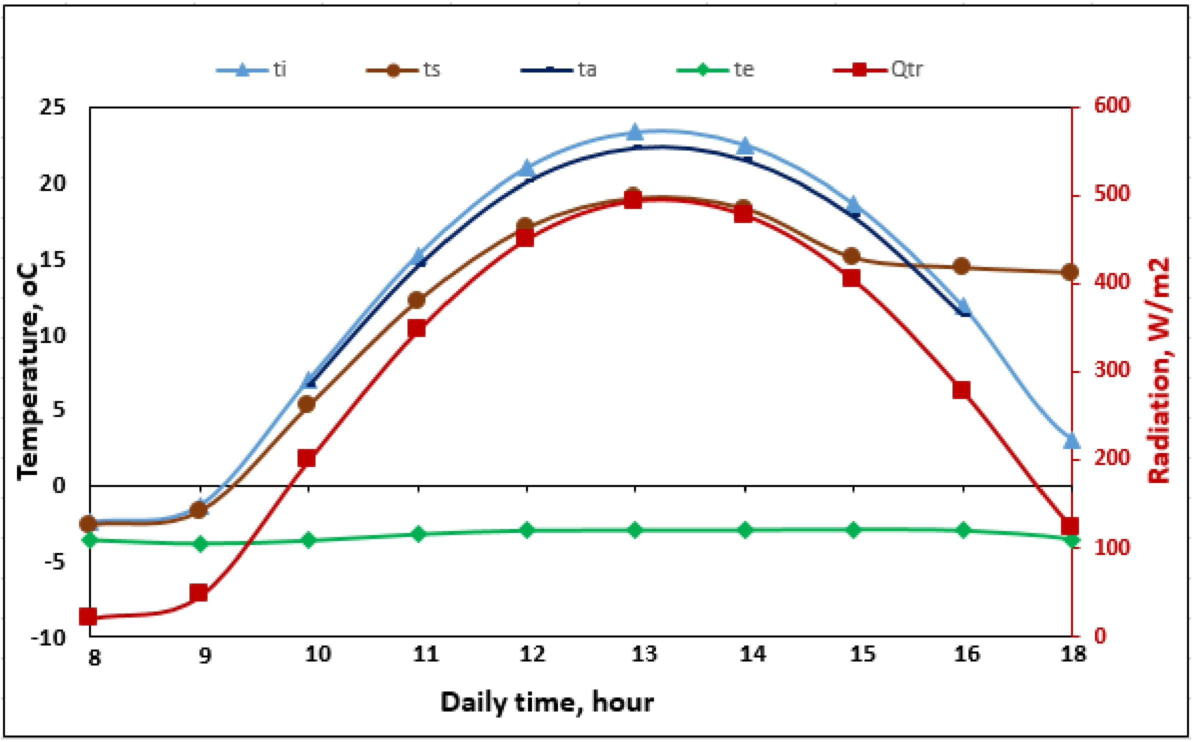

Fig.1. Graphic changes in temperature and solar radiation during the day

5. Conclusion

The given model, under known radiation-climatic conditions, makes it possible to predict the temperature regime in a solar greenhouse during periods of deficiency and excess of solar radiation energy, the power of additional heating, and the efficiency of the heat accumulator.

Analysis of the results obtained shows, depending on the shape and type of fencing, radiation and climatic conditions, the energy supply of solar greenhouses with solar radiation ranges from 24...43% (in January) to 79...101% (in April).

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