STUDY OF THE PERFORMANCE OF GREENHOUSE WITH SHORT TERM HEAT STORAGE AND NIGHT INSULATION

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1. Introduction

The optimal air temperature inside the greenhouse is 18-25°C. The main surface of the greenhouse bulk is light translucent enclosures, which have low thermal resistance, so for obtaining desired temperature in the greenhouse required more heat, than other types of buildings. Location of Uzbekistan is convenient to use solar energy to provide the required level of temperature in the greenhouse.

The air temperature inside the greenhouse depends on many factors, such as ambient temperature, intensity of the incident solar radiation, greenhouse orientation, angles of slopes, materials of enclosures and etc. Fluctuation of air temperature inside the greenhouse with large amplitudes is negative influence for plant growth. One of solutions of the problem is accumulation of heat (thermal energy) during the day and using it at night. In this case it is required to determine and optimize the location and quantity of heat storage.

In this work presented some results of investigations of thermal properties of greenhouse with short-term heat storage, which placed in front of the object with night insulation covering. Developed mathematical model of dynamic thermal mode of the system and corresponding experiments in Bukhara Province, Uzbekistan (39.1 ^{o} latitude).

2. Greenhouse

Principal scheme of experimental greenhouse is presented in Fig.1. The inclination to horizon of lower (short) southern light transparent slope with length 1.7*m* is 54°, upper ones with length 4.5*m* is 30°, and northern thermal insulation slope with length 1.8 *m* is 45°. The width and length of the greenhouse are respectively 7*m* and 8*m*.

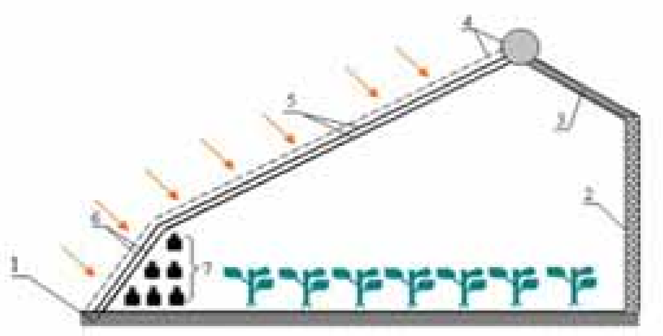

Fig.1. Principal Scheme of greenhouse:
1-ground; 2-northern wall; 3-thermal insulation slope; 4-thermal insulation cover; 5 and 6-upper and lower slopes; 7-short term heat storage (polyester tanks).

Placing of heat storages on front parts of greenhouse enables to accumulate of surplus heat and using of thermal insulation cover at night prevents sharply falling of the air temperature inside of greenhouse. The general volume of short-term heat storage is 0.4 m^3 which consists from 400 polyester tanks (the volume of each is 1*l*). As a light transparent enclosure of greenhouse used double-layer polyethylene films with air layer (thickness 5*sm*) between of them, and as a thermal insulation cover material used a tarpaulin at night time and cloudy days.

3. Mathematical Description

For the determination of rational volumetric-planning and constructive decisions of small scale greenhouses and for the developing of the real temperature mode of their internal air under different changes of parameters of surrounding ambiences offered mathematical model of dynamic thermal mode of greenhouse proposed type.

In developing of the proposed mathematical model of the greenhouse accepted following assumptions:
- the thermal inertia of the transparent enclosure is neglected;

- heat flows through the enclosures are one-dimensional;
- air temperature at any given time is the same throughout the volume of the greenhouse;
- thermal properties of materials layer enclosures are not dependent on temperature;
- the temperature of 1*m* soil depth (T_{gr}) is equal to the average soil temperature at a depth of 1*m*.

The thermal balance equations for each volumes and elements of greenhouse are as following:
-for an air inside of greenhouse

$$m_a c_a \frac{dT_a}{d\tau} = \sum_{i=1}^{n} (h_c A_s)_i \left[(T_s)_i - T_a \right] + \sum_{j=1}^{m} (h_c A_w)_j \left[(T_w)_j - T_a \right] + h_c A_{gr} \left(T_{gr} - T_a \right) + h_c A_{st} \left(T_{st} - T_a \right) + (\tau\alpha)_a \sum_{i=1}^{n} (A_s q_\perp)_i \quad (1)$$

- for inner layer of double-layer light transparent enclosure

$$m_p c_p \frac{dT_{p1}}{d\tau} = h_c A_{p1} \left(T_a - T_{p1} \right) + h_r A_{p1} \left(T_{p2} - T_{p1} \right) + h_c A_{p1} \left(T_{p2} - T_{p1} \right) + (\tau\alpha)_{p1} A_{p1} q_\perp \quad (2)$$

- for outer layer of double-layer light transparent enclosure

$$m_p c_p \frac{dT_{p2}}{d\tau} = h_c A_{p2} \left(T_o - T_{p2} \right) + h_r A_{p2} \left(T_{p1} - T_{p2} \right) + h_c A_{p2} \left(T_{p1} - T_{p2} \right) + (\tau\alpha)_{p2} A_{p2} q_\perp \quad (3)$$

- for short-term water heat storage

$$m_{st} c_{st} \frac{dT_{st}}{d\tau} = h_c A_{st} \left(T_a - T_{st} \right) + (\tau\alpha)_{st} A_{st} q_\perp \quad (4)$$

-for northern wall

$$C_1 \rho_1 x_1 \frac{dT_w}{d\tau} = h_c \left(T_a - T_w \right) + R_{in} \left(T_{av} - T_w \right) + (\tau\alpha)_w q_\perp \quad (5)$$

$$C_2 \rho_2 \left(x_2 - x_1 \right) \frac{dT_{av}}{d\tau} = R_{in} \left(T_w - T_{av} \right) + R_{out} \left(T_{out} - T_{av} \right) \quad (6)$$

$$C_3 \rho_3 \left(x_3 - x_2 \right) \frac{dT_{out}}{d\tau} = h_c \left(T_o - T_{out} \right) + h_r \left(T_{sky} - T_{out} \right) + R_{out} \left(T_{av} - T_{out} \right) + \alpha_w q_\perp \quad (7)$$

where,

$$R_{in} = \left(\frac{x_1}{k_1} + \frac{x_2 - x_1}{2 \cdot k_2} \right)^{-1}, \; R_{out} = \left(\frac{x_3 - x_2}{k_1} + \frac{x_2 - x_1}{2 \cdot k_2} \right)^{-1} \quad (8)$$

Thermal-physical properties of multilayer wall could be determined as following:

$$C(x), \rho(x), k(x) = \begin{cases} C_1, \rho_1, k_1 & when \quad 0 \le x \le x_1 \\ C_2, \rho_2, k_2 & when \quad x_1 < x \le x_2 \\ C_3, \rho_3, k_3 & when \quad x_2 < x \le x_3 \end{cases} \quad (9)$$

For the rest elements of system (southern, eastern and western walls, ground-soil) thermal balance equations would be similar to (5)-(9).

Daily change of total solar radiation incident on the surface of the translucent enclosure and the outer part of the enclosures (walls) of greenhouse are determined by the method, which described in [1]. The effective coefficients of reflection, absorption and transmission translucent enclosure defined in accordance with the method, which described in [2]. Heat transfer coefficients at the soil surface, light transparent enclosures and walls are defined in accordance with the expressions given in [1].

For determination of balance equations for each elements of greenhouse used method of control volumes with using of Gauss-Zeidell iteration method, since coefficients of heat transfer on the surfaces of floor, light transparent enclosure and walls depends on their temperature. The calculations have been done by using of MathCAD-2001 Pro. Maximum allowed inaccuracy in all calculations is 10^{-4}, and the step on time $\Delta t = 2min$. For determination of the dependencies of thermal-physical characteristics of an air and water on temperature method of interpolation is used.

4. Results

Fig.3 shows the daily changes of surface flux densities of the total incident solar radiation on the surface of down (1) upper (2), insulated (3) slopes, Northern (4), Western (5) and Eastern (6) walls of greenhouse under clear weather.

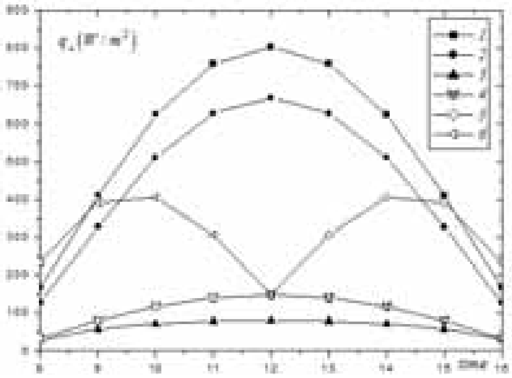

Fig.3. Daily changes of surface flux densities of the total solar radiation: *the incident on the surface of the lower (1) upper (2), insulated (3) slopes, Northern (4), Western (5) and Eastern (6) walls of greenhouse under clear weather.*

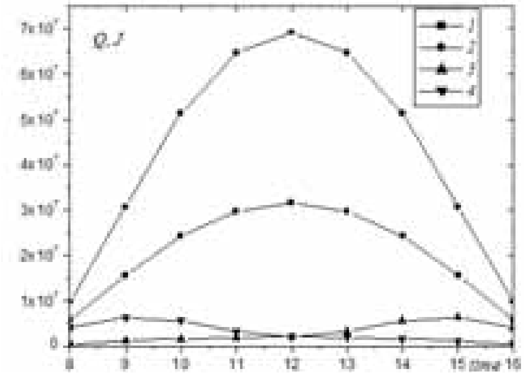

Fig.4. Daily changes of entering flux of the total solar radiation: *1,2 – respectively, through lower and upper light transparent slopes; 3,4 – respectively, through light transparent part of Western and Eastern walls.*

In Fig.5 and Fig.6 presented the comparison of calculated and experimental values of daily changes of air temperature in greenhouse and short-term water heat storage, depending on the type of weather.

As can be seen from the graphs in Fig.5, in clear weather for three consecutive days when the maximum value of the total flux of solar radiation to horizontal surface $(q_{\perp})$ 425 *W/m*^{2} and ambient temperature ranges from 0 to 20 °*C*, maximum temperature of water in the elements of a short-term heat storage (T_{st}) reaches up to 65-70 °*C*, an air temperature (T_a) inside of greenhouse ranges from 15 to 34 °*C*. Fig.5 also shows that the experimental data agree well with the numerical results.

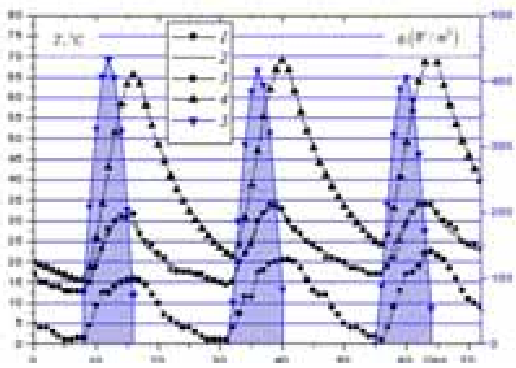

Fig.5. Daily changes of temperatures: *the environment (1), air inside of greenhouse (2), water in the heat storage (3)* **and surface flux density of the incident total solar radiation to horizontal surface** *(4) in clear weather*

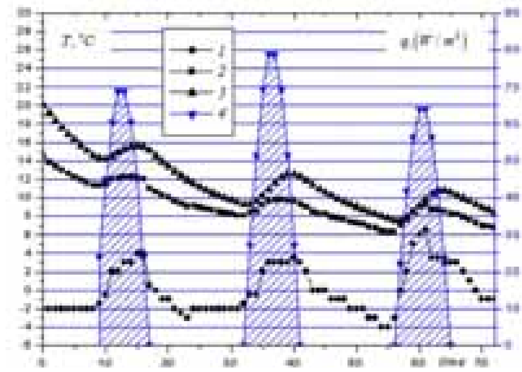

Fig.6. Daily changes of temperatures: *the environment (1), air inside of greenhouse (2), water in the heat storage (3)* **and surface flux density of the incident total solar radiation to horizontal surface** *(4) in cloudy weather*

5. Conclusion

As can be seen from the results above, developed mathematical model agreed well with experimental data. Placing heat storages in front of a greenhouse allows accumulating more heat. Night-time use of thermal protection prevents sharp drop in air temperature inside the greenhouse.

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