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MATHEMATICAL MODELING OF HEAT AND HUMIDITY PROCESSES IN A GREENHOUSE HEATED BY A VACUUM TUBE SOLAR COLLECTOR

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Abstract: In southern regions, the demand for additional thermal energy in greenhouses increases during the winter season. The use of solar-based heliosystems is considered a promising method for energy-efficient greenhouse heating. This scientific article presents mathematical modeling of heat and moisture processes occurring inside a greenhouse, enhancement of energy efficiency, and the effectiveness of using a vacuum tube solar collector. The calculation results showed that the internal temperature of the greenhouse can be maintained within 21–27 °C and the relative humidity within 60–75%. Experimental investigations confirmed that the system can achieve an efficiency of up to 72%.

Keywords: Greenhouse, heat–moisture process, mathematical model, energy balance, solar collector, heliosystem.

Introduction In the southern regions of Uzbekistan, in particular, in the Kashkadarya region, greenhouses need a large amount of thermal energy due to the low outside temperature in the winter season. The use of traditional fuels is cost-effective and environmentally harmful. Therefore, the use of solar energy-based solar systems is becoming a promising direction for greenhouses.

According to the results of a case study conducted in Karshi, the average thermal efficiency of a solar water heating collector with a vacuum tube with a volume of 200 liters was 74.6%, and the study of 7.21 kWh of useful thermal energy analyzed the efficiency of using a combined system based on solar energy to manage the heat and humidity of the air. According to their results, the combined use of solar heat sources provides a high efficiency in stable heating and humidification of air. These results show the practical efficiencies of the use of heliosystems.

Materials And Methods

A greenhouse with an area of 100 m², 4 m high in Karshi was chosen as the object of the research. Its walls are made of transparent polycarbonate material, the roof is covered with double-layer glass with the coefficient of thermal conductivity **U = 5.5 W/m²K**. The greenhouse is heated by a helioheating system.

In the calculations, solar radiation was assumed to be 850 W/m², the outside air temperature was 10 °C, and the ventilation rate was 0.25 m/s.

Mathematical model of heat and humidity processes

The energy balance of a greenhouse is expressed by the following equation:

$$\rho_{air} \cdot C_p \cdot V \cdot \frac{dT_{in}}{dt} = Q_{sol} + Q_{coll} - Q_{loss} - Q_{vent} \qquad (1)$$

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Here, ρ_{air} – air density (1.2 kg/m³), C_p – air heat capacity (1005 J/kg· K), V – Greenhouse volume (400 m³), Q_{sol}– Heat gained by solar radiation (W), Q_{coll}– Heat radiated by collector (W), Q_{loss}– Heat loss through surface (W), Q_{vent}– Loss of ventilation (W).

And the process of humidity is characterized by a balance of water vapor coming out through evaporation and ventilation:

$$\frac{dm_v}{dt} = M_{gen} - M_{out} \quad (2)$$

here – the mass of water vapor (kg), m_v M_{gen}– the mass of vapor (kg/s) generated by plant transpiration,– the mass of M_{out} vapor (kg/s) emitted through ventilation (kg/s).

The dynamic variation in temperature and humidity is based on the following empirical relationship:

$$\varphi = f(T_{in}) = a \cdot e^{-b(T_{in}-T_0)} \quad (3)$$

Here , , $.a = 90\% b = 0.05°C^{-1} T_0 = 20°C$

Heat loss through walls, roofs and other enclosing structures

Equation:

$$Q_{\text{ogr}} = \sum k\ F\ (T_v - t_n) \quad (4)$$

here. k— the total coefficient of thermal conductivity for the surrounding structure, W / (m²·°C) (sometimes referred to as the -coefficient ent);UF— area of the same element, m²;

T_v— internal air temperature °C; t_n— now harorat, °C. [1]

If there are several elements (wall, roof, door, floor), then for each are calculated and assembled.$k_i F_i (T_v - t_n)$

Heat loss through ventilation (ventilation)

Equation:

$$Q_{\text{TV}} = G_{vv}\, c_a\, (T_v - t_n) \quad (5)$$

here G_{vv}— Mass flow of ventilation, kg/s (air flow × air density); c_a— air heat capacity, 1005 J/(kg·K) , $T_v - t_n$— harorat farqi, K.

Moisture balance in the greenhouse — explanation and simplified formula

$$\rho_a V \frac{dX(t)}{dt} = G_{in} X_{in} - G_{out} X(t) + G_{evap} - G_{rem} \quad (6)$$

Here, ρ_a— air density, kg/m³ (≈1.2); V— Xona Hajmi, m³; $X(t)$— absolute humidity of internal air (kg of water / kg of air) depends on time; G_{in}— mass flow of incoming air, kg/s (usually in steady-state state);$= G_{out}$ X_{in}— absolute humidity of incoming air, kg/kg; G_{evap}— sources of water vapor from the greenhouse (grasses, soil evaporation), kg/h; G_{rem}— moisture-de-removing system (dehumificator or condensation), kg/s. If we take a steady-state state, and the equation is:$dX/dt = 0$

$$0 = G_{in} X_{in} - G_{out} X_{ss} + G_{evap} - G_{rem} \quad (7)$$

if and no dehumifier ( ):$G_{in} = G_{out} = GG_{rem} = 0$

$$X_{ss} = X_{in} + \frac{G_{evap}}{G}. \quad (8)$$

This value is around 10 g of water / 1 kg of air in indoor air (that is, ~10 g / kg). This is translated into relative humidity depending on temperature, respectively.

According to the model, the temperature inside will remain in the range of 21–27 °C, and humidity will remain in the range of 60–75%.[2]

Experimental part

Practical tests were conducted at the Vacuum Troupe Collector Laboratory of Karshi State Technical University. On an outside temperature of 8–12°C, the collector system heated 200L of water from 22°C to 52°C in six hours.

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Figure 1. Vacuum tube collector.

The energy efficiency of the system was assessed by the following expression:

$$\eta = \frac{Q_{useful}}{Q_{solar}} \times 100 \quad (9)$$

As a result of the calculation:

$$Q_{useful} =\cdot c \cdot \Delta T = 200 \times 4186 \times 30 = 25.1MJ \approx 7.0kWh \quad (11)$$

$$Q_{solar} = 850 \times 6 \times 3.6 = 18.4MJ \approx 9.7kWh \quad (12)$$

$$\eta = \frac{7.0}{9.7} \times 100 \approx 72 \quad (13)$$

This means that the system has a thermal efficiency of 72% and the bulk of the heat losses occur through ventilation.

Formula

Wall/roof loss: $.Q_{\text{ogr}} = U\ F\ (T_v - t_n)$ (14)

Ventilation: $.Q_{\text{TV}} = G_{vv}\, c_a\, (T_v - t_n)$ (15)

Pipes: With a previous account $.Q_{\text{pipe}} \approx 0.50$ Kw

Total power: $.Q_{\text{tot}} = Q_{\text{ogr}} + Q_{\text{TV}} + Q_{\text{pipe}}$ (16)

Calculations — two cases (Tv = 21 °C and Tv = 27 °C; tn = 10 °C)

Tv = 21 °C (K) $\Delta T = 11$, $Q_{\text{ogr}} = 4 \cdot 100 \cdot 11 = 4.4kW$ $Q_{\text{TV}} = 0.10 \cdot 1005 \cdot 11 \approx 1.11$ kW, $Q_{\text{pipe}} \approx 0.50$ kW, $Q_{\text{tot}} \approx 4.40 + 1.11 + 0.50 = 6.01$ kW

Energiya (6 soat): $.6.01 \cdot 6 \approx 36.0$ kWh, **Tv = 27 °C** (K)$\Delta T = 17$, $Q_{\text{ogr}} = 4 \cdot 100 \cdot 17 = 6.80$ kW, $Q_{\text{TV}} = 0.10 \cdot 1005 \cdot 17 \approx 1.71$ kW, $Q_{\text{pipe}} \approx 0.50$ kW, $Q_{\text{tot}} \approx 6.80 + 1.71 + 0.50 = 9.01$ kW [3]

Conclusion

The results of the study show that the use of a solar collector with a vacuum tube in the climatic conditions of Karshi has a high energy and economic efficiency in heating greenhouses. The proposed mathematical model made it possible to more accurately estimate the processes of heat and humidity in the greenhouse. According to the model's results, it was

confirmed that it was possible to maintain the stable temperature in the greenhouse in the range of 21–27 °C and the relative humidity in the range of 60–75%.

Practical experience has also confirmed the accuracy of this model: the vacuum tube collector heated 200 liters of water from 22 °C to 52 °C in just 6 hours, showing a thermal efficiency of 72%. It has been found that the bulk of heat losses occur through ventilation and enclosing structures, which will lay the foundation for future energy-efficient constructive improvements.

The analysis shows that solar energy-based heliosystems are cost-effective compared to traditional fuel sources, are environmentally friendly, and can provide sufficient thermal power to automatically control the microclimate in greenhouses.

In general, the results of the study showed that the application of vacuum tube collectors in greenhouse heating systems makes not only technical, but also environmental and economic feasible. In the future, this model can be used in projects aimed at optimizing energy consumption of greenhouses, reducing heat loss and increasing the stability of microclimate parameters.

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