Influence of the heat accumulator's storing capacity to increase the efficiency of helogreenhouses

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Abstract: The theoretical study carried out shows that the main geometric and energy characteristics of solar greenhouses are the coefficients of enclosure and heat accumulation. The influx of solar radiation depends little on the angle of incidence of the rays on transparent surfaces, and mainly depends on the surface area of the transparent fence. The amount of heat accumulated in a heat accumulator is determined by its heat-storing efficiency: material, ability to absorb solar radiation, volume, location. With sufficient mass values of the heat-storing elements, all or almost all of the solar energy captured by the heat-storing elements is usefully used, overheating in the greenhouse is eliminated, and daily fluctuations in air temperature in the greenhouse are smoothed out.

1 Introduction

The energy needs of the world's countries are increasing every year. The development of energy supply and meeting the needs for fuel and energy resources is currently achieved mainly through coal, oil, gas and nuclear energy. In recent years, research has been conducted all over the world aimed at finding and involving new energy sources in the fuel and energy balance. Particular interest is shown in renewable energy sources, such as solar energy, wind energy, hydropower of small rivers, tidal energy, etc. Solar energy is one of the fast-growing branches of science, engineering and technology. The basis of this development is the creation and improvement of highly efficient power plants for converting solar energy into thermal and electrical energy [1-5].

Currently, energy saving and rational use of energy resources in the agro-industrial complex is an urgent problem for many enterprises in the industry. The high energy intensity of agricultural products, limited energy resources and the high cost of energy today are the main energy indicators of agricultural production [6-19]. Energy and resource saving are one of the ways to reduce the cost of manufactured products. The current level of development

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of the agricultural industry and the state of its raw material base require a fundamentally new approach to solving the problem of its energy supply, including through the use of traditional and renewable energy sources. The main contribution to increasing the energy efficiency of the agricultural sector can be made by measures to introduce renewable energy sources in the agricultural sector.

The use of energy from renewable energy sources will save traditional scarce energy resources and improve the environment of production. In agriculture, a significant share of the cost of fuel and energy resources falls on maintaining optimal microclimate parameters in agricultural buildings and structures, which helps to increase productivity. That is why power plants with renewable energy sources are recommended, in which savings in fuel and energy resources can be up to 60–70% or more [5,6].

2 Materials and methods

Greenhouses are the most energy-intensive structures. With the increase in prices for hydrocarbon energy resources, the relevance of increasing their thermal and technological indicators increases. The efficiency of a solar greenhouse design is determined by its ability to accumulate heat from solar radiation.

The defining energy characteristics of solar greenhouses are the following:

1) maximum solar radiation entering the greenhouse,

2) minimal heat losses,

3) maximum accumulation of heat and energy from solar radiation transmitted into the greenhouse.

The most important geometric and energy characteristics of solar greenhouses are the enclosure coefficients K_o and accumulation of K_a:

$$K_o = F_o / F_s;\ K_a = \Sigma Q_{ac} / \Sigma Q_{en} \tag{1}$$

where F_o – surface area of the solar greenhouse enclosure; F_s – greenhouse soil surface area; ΣQ_{ac} – the amount of solar radiation energy accumulated in the greenhouse; ΣQ_{en} - the amount of solar radiation energy entering the solar greenhouse.

The task of thermal and geometric optimization of a solar greenhouse is the most effective combination of the parameters of the enclosure coefficients K_o and accumulation K_s.

Traditionally, solar greenhouses are located along the length in the latitudinal direction [3-5,7-8]. The surfaces that receive solar radiation are directed to the south, the northern walls and slopes are thermally insulated.

The height of the greenhouse from the ground surface to the bottom of the greenhouse structures must be at least h = 2.2 m, span width should not exceed b = 9 m [6-8]. The angle of inclination of the southern transparent slopes determines the amount of solar radiation entering the greenhouse.

Total solar radiation entering the greenhouse during the insolation period:

$$\Sigma Qen = \Sigma Sen + \Sigma Den \tag{2}$$

Where ΣS_{en}, ΣD_{en} – the sum of direct and diffuse solar radiation transmitted into the greenhouse :

$$\Sigma S_{en} = \Sigma S_{\perp} B_s \cos i;\ \ \Sigma D_{en} = \Sigma D B_d \tag{3}$$

$S_{\perp}$, D – direct and diffuse radiation incident on the transparent surface of the greenhouse; B_s, B_d – light transmittance coefficients of direct and diffuse radiation.

Intake of scattered radiation *D* practically little depends on the angle of incidence of rays on transparent surfaces, mainly depends on the surface area of the transparent fence. Therefore, the amount of transmitted radiation is a function of direct radiation S_{en}, falling on the surface of a transparent fence, and the angle of their incidence *i*:

$$\Sigma Q_{en} = f(S_{\perp}, i) \tag{4}$$

The angle of inclination of the lower transparent slope is taken within the range ρ = 45° ... 60° [2-8].

3 Results and discussions

As calculations show, at angles of inclination up to ρ = 60°, the influx of solar radiation during the heating season increases, and at angles above ρ = 65° it decreases (Fig. 1).

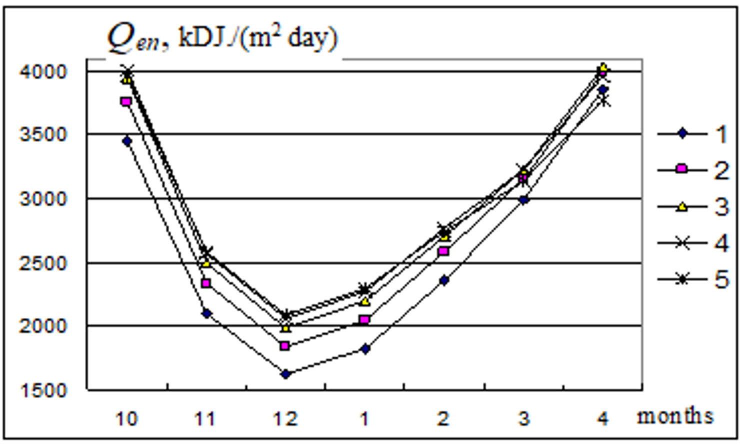

Fig. 1. Average monthly total solar radiation entering the greenhouse at Q_{en} perpendicular to the rays depending on the angle of inclination of the southern slope ρ: 1 – ρ= 30°; 2 - ρ= 40°; 3 - ρ= 50°; 4 - ρ= 60°; 5 - ρ= 70°

For the conditions of the Kashkadarya region, the most optimal is ρ = 60° . The angle of inclination of the upper southern slope is taken within the limits ρ_1 = 25° ... 50° [5-10].

Let us determine the change in the barrier coefficient K_o depending on the geometric parameters of the greenhouses . We accept constant values h = 2.2 m; ρ= 60°, ρ_1 =30° . Variables : span width b = 3...7 m, greenhouse length l = 10...30 m .

The fencing coefficient will be determined by the formula:

$$K_o = \frac{(h+b/\cos\rho_1+h/\sin\rho)\cdot l+2hb+b^2/(2ctg\rho_1)+h^2 ctg\rho}{(b+h\cdot ctg\rho)\cdot l} \text{x}; \tag{5}$$

where h , b , l – height , span width and length of the greenhouse; ρ, ρ_1 – angles of inclination of the lower and upper southern transparent slopes.

As can be seen from Fig. 2, with an increase in the span width of the greenhouse within b = 5...6 m, the fencing coefficient K_o drops sharply. Increasing the length of the greenhouse more than l = 26...28 m changes the K_o values little.

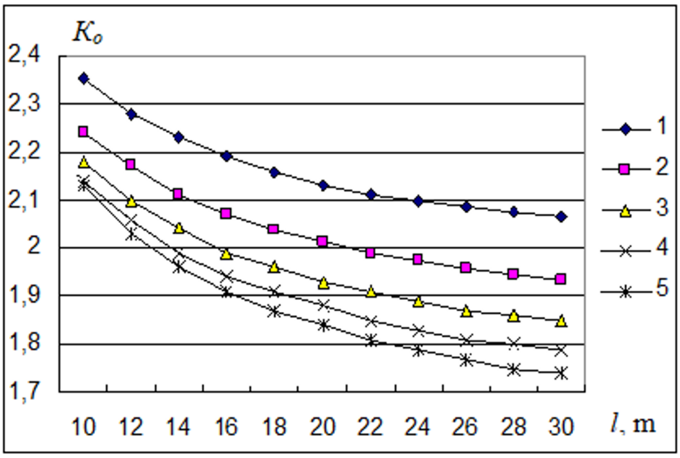

Fig.2. Change in the fencing coefficient K_o depending from span width b and greenhouse length l :1- b = 3 m; 2 - b = 4 m; 3- b = 5 m; 4- b = 6 m; 5 - b = 7 m.

Thus, as a first approximation, we can recommend a span width $b \geq 6$ m, greenhouse length $l \geq 25$ m.

Let us determine the change in the fencing coefficient K_o depending on the angle ρ_1 within the range $\rho_1 = 25^o ... 50^o$. We accept the hundredth of slopes h_1 constant (not depending on the angle ρ_1) at $\rho_1 = 30^o$, which is determined by the formula:

$$h_1 = \frac{b}{2} \cdot tg\rho_1 = \frac{b}{2} \cdot tg30^o = \frac{b}{2} \cdot 0{,}577 \quad (6)$$

In this case, the fencing coefficient is:

$$K_o = \frac{\left(h + \sqrt{h_1^2 + (b - h_1/tg\rho_1)^2} + h/\cos\rho_1 + h/\cos\rho\right) \cdot l + 2hb + h_1 b + h^2 ctg\rho}{(b + h \cdot ctg\rho) \cdot l} x \quad (7)$$

As can be seen from table. 1, with a change in angle ρ_1, the fencing coefficient K_o changes slightly. The smallest value of K_o is at ρ_1 =30°, the largest is at ρ_1 =50 °.

Table 1. Change in the fencing coefficient K_o depending on the angle of inclination ρ_1 at b = 6 m, l = 25 m.

P_1, deg	25	30	35	40	45	50
K_o	1.827	1.822	1.825	1.831	1.84	1.85

For the complete geometric and thermal characteristics of the solar greenhouse, let us consider the influence of the angle of inclination ρ_1 of the upper southern slope on the ratio of the sum of transmitted solar radiation ΣQ_{en} and heat losses ΣQ_{hl} in the greenhouse.

With an increase in the angle of inclination ρ_1 *of* the southern slope 1, the input from the average monthly total solar radiation Q_{en} decreases in proportion to the increase in the angle of inclination ρ_1 (Fig. 3).

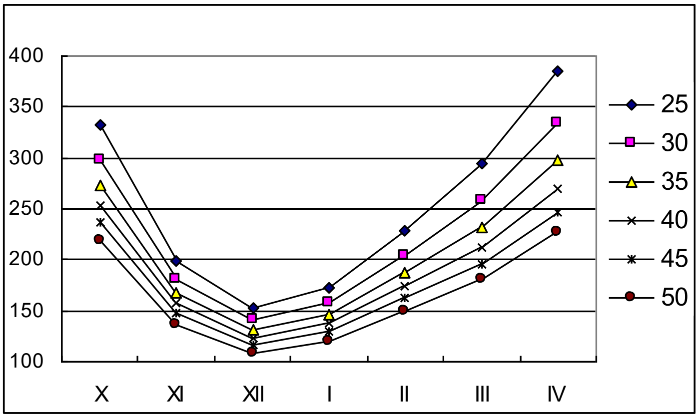

Fig 3. Average monthly total solar radiation Q_{en}, incoming through the southern slope 1 at ρ_1 = 25…50°.

The total heat loss through the upper slopes is determined by the sum of heat losses through slopes 1 and 3:

$$\Sigma Q_{hl} = \Sigma Q_{m1} + \Sigma Q_{m3} \tag{8}$$

Heat loss through slopes 1 and 3 is determined by the formula:

$$\Sigma Q_{mi} = K_i\,(t_{in} - t_{ex})\,F_i\,\tau \tag{9}$$

where *K is* the heat transfer coefficient; *F is* the surface area of the slope; t_{in}, t_{ex} – temperature of internal and external air; τ – time; i = 1 and 3 slopes.

Heat transfer coefficient *K* through fences [10-15], internal *and* external temperatures t_{ex} air do not depend on the angle of inclination ρ_1 of slope 1. Glass slopes 1 have a significantly higher heat transfer coefficient than opaque slopes 3. Therefore, with increasing width b_1 for slope 1 total heat loss ΣQ_{hl} increases with increasing width b_3 for slope 3 – fall. The ratio of heat loss through slopes can be presented in the following form [16]:

$$B_1 = \frac{K_1 \cdot b_1}{K_1 \cdot b_1 + K_3 \cdot b_3};\quad B_3 = \frac{K_3 \cdot b_3}{K_1 \cdot b_1 + K_3 \cdot b_3} \tag{10}$$

In Fig. Figure 4 shows graphs of changes in the share of heat loss B_1 and B_3 through the upper slopes, depending on the angle of inclination of the southern slope ρ_1 with average heat transfer coefficients K_1 = 6.4 W/(m ^{2}K) and K_3 = 3...4 W/(m ^{2}K).

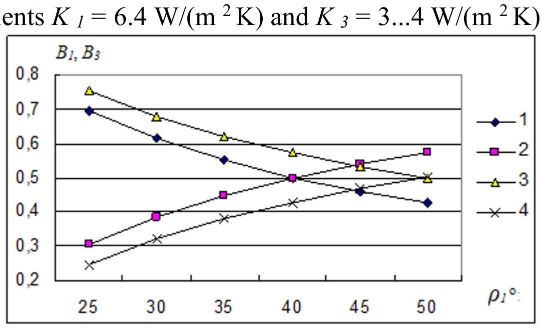

Fig.4. Change in the share of heat loss B_1 and B_3 through the upper slopes depending on the angle of inclination of the southern slope ρ_1.

1-southern slope 1 and 2-northern slope 3 at K_3 = 4 W/(m^2 K); 3-southern slope 1 and 4-northern slope 3 at K_3 = 3 W/(m^2 K).

Heat loss fractions B_1 and B_3 change in proportion to the increase in the angle of inclination ρ_1 (B_1 – falls; B_3 – increases). With an increase in the heat transfer coefficient K_3, the share of heat losses B_3 *decreases*. Functions *in* $_1$ (B_3) = $f(\rho_1)$ do not have extrema points.

Conclusions. Thus, analysis of the results obtained allows us to draw the following conclusions. As an optimal option for the geometry of a solar greenhouse, we can recommend the following parameters (Fig. 1): span width $b \geq 6$ m; greenhouse length $l \geq 25$ m; height of supporting structures h = 2.2 m; the angle of inclination of the lower southern slope $\rho = 60^o$; the angle of inclination of the upper southern slope $\rho_1 = 30^o$.

The amount of heat accumulated in the greenhouse structure:

$$\Sigma Q_{ac} = \Sigma Q_{en} - \Sigma Q_{hl}; \tag{11}$$

where ΣQ_{hl} – heat loss in the greenhouse.

The heat accumulated in the greenhouse is expressed by the following amount

$$\Sigma Q_{ac} = \Sigma_{sa} + \Sigma Q_{ha} \tag{12}$$

where ΣQ_{sa}, ΣQ_{ha} – heat accumulated in the greenhouse structure and heat accumulator.

The heat accumulated during the period of insolation in the greenhouse structure ΣQ_{sa} is determined by the surface area of the soil and the presence of large masses in the greenhouse enclosure.

The amount of heat accumulated in a heat accumulator is determined by its heat-storing efficiency: material, ability to absorb solar radiation, volume, location.

To a first approximation, the required total volume of heat storage elements can be determined from the relation [9]:

$$V_a = C_{ua} F_p / C_r \tag{13}$$

where is C_{ua} – specific heat capacity of the heat accumulator, related to 1 м^2 the area of the transparent fence, J/(m^2 K).

4 Conclusions

For heat storage elements V_a from containers with water at the specific heat capacity of water C_p = 4186 kJ/(m^3 K) and C_{ya} =620 kJ/(m^2 K) [9], with area and surface of the transparent fence F_p =150 m^2, volume of heat-storing elements is V_a =22,2 m^3.

With sufficient mass values of the heat-storing elements, all or almost all of the solar energy captured by the heat-storing elements is usefully used, overheating in the greenhouse is eliminated, and daily fluctuations in air temperature in the greenhouse are smoothed out.

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