Evaluation of heat losses of the solar greenhouse during the heating season

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Abstract. The article presents the results of calculation of heat losses in greenhouses with different coatings, taking into account thermal-physical properties of coatings. In addition, based on the results of changes in external air temperature and solar radiation over time, numerical calculations were made on the heat load of a greenhouse with a useful area of 108 m^2 and the thermal power provided by solar energy.

1 Introduction

Today, in order to meet the needs of the world's population, it is one of the urgent issues to create new, fast-growing, resistant varieties of plant products, fruits and vegetables, suitable for various vegetative cultivation requirements. As a result of scientific research in the field of ensuring the continuity of the production of fruits and vegetables and agricultural products, special attention is being paid to the development of greenhouses in countries engaged in agrarian policy [1].

Greenhouses are the main production facilities that supply the consumer market with local fresh vegetables throughout the year. Research shows that such production is expensive and requires large amounts of energy. One of the most important requirements in such cases is to minimize energy consumption. In order to reduce energy consumption, it is necessary to choose the optimal design in terms of heat losses in greenhouses and use effective heat insulating materials based on heat engineering calculations. One of the necessary elements of thermal engineering calculation is the modeling of temperature distribution in the greenhouse and the soil around it, which allows to calculate the heat loss through the side walls, roof and soil [1-5].

In the design of greenhouses, the following options were considered based on the type of coating and constructions [2]:

- Types of greenhouses according to the type of covering materials: polyethylene film, glass, polycarbonate, double-glazed, double-glazed polycarbonate.
- Types of greenhouses according to their construction: straight-sloped, arched and semi-cylindrical.
- Types of greenhouses according to the type of foundation: ground, buried (or the lower part of the walls is insulated).

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We conduct numerical calculations on heat losses through the walls, roof and foundation of the greenhouse based on the calculation scheme in Figure 1. The greenhouse is 18 meters long, 6 meters wide and 3.8 meters high. The height of the wall (area 4) is 0.7 meters and the buried foundation (area 3) is 0.3 meters.

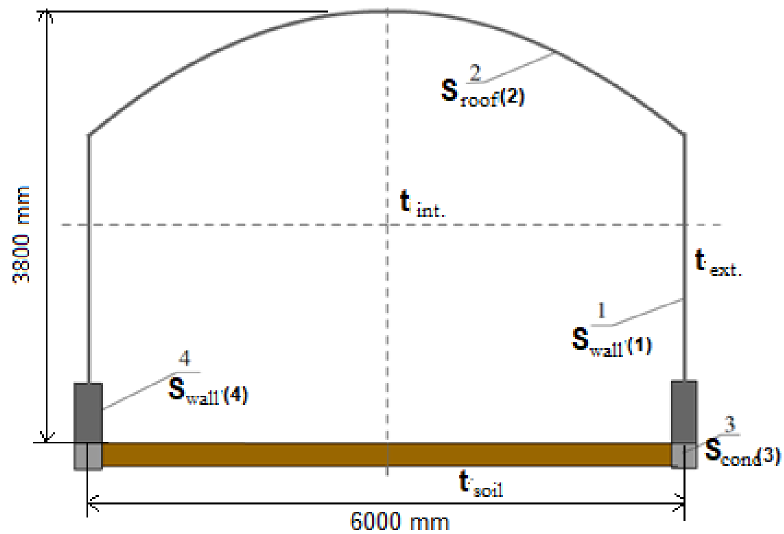

Fig. 1. Calculation scheme for determining heat loss in a greenhouse.

The calculation was made for a greenhouse with different coating materials: polyethylene film, glazed, polycarbonate, double-glazed, double-polycarbonate.

2 Materials and methods

The following formula was used to calculate heat losses [3-4]:

$$Q_{yo'q.} = (k_{wall(1)}S_{wall(1)} + k_{wall(4)}S_{wall(4)} + k_{roof(2)}S_{roof(2)}) \times (t_{\text{int.}} - t_{ext.}) + k_{conc(3)}S_{conc(3)}(t_{\text{int.}} - t_{soil}) \quad (1)$$

Here is a giant; roof; page; indices of walls (areas 1 and 4), roof (area 2) and foundation (area 3); k - heat transfer coefficient, $W/(m^2 \cdot {}^0C)$; S - surface area, m^2; $t_{ext.}, t_{soil}, t_{\text{int.}}$ - external air, soil and greenhouse internal temperatures, °C; Calculations for heat loss are calculated by the days of the heating period.

To calculate the heat transfer coefficient, the following formula is used for a multi-layer wall [5-7]:

$$k_{wall-roof} = \frac{1}{\frac{1}{\alpha_{\text{int}}} + \sum_i \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{ext.}}}, \quad k_{conc.} = \frac{1}{R_c + \sum_i \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{\text{int.}}}} \quad (2)$$

Here δ_i, λ_i - i-layer thickness and thermal conductivity, $\alpha_{ext.}$, $\alpha_{\text{int.}}$ - coefficient of heat transfer through external and internal walls, $W/(m^2 \cdot {}^0C)$.

The calculation results were based on the following initial data [8-11]: $t_{int.} = 18^o C, t_{soil} = 7^o C,\ \alpha_{ext.} = 23 W/(m^2 \cdot^0 C),\ \alpha_{int.} = 8,7 W/(m^2 \cdot^0 C),\ R_c = 2,1 (m^2 \cdot^0 C)/W \cdot$

For wall and roof part [5]:

- Polyethylene film: $k = 6,3\ W/(m^2 \cdot^0 C),\ \lambda = 0,36\ W/(m \cdot^0 C),\ \delta = 0,0001\ m;$
- Glazed: $k = 6,19\ W/(m^2 \cdot^0 C),\ \lambda = 1\ W/(m \cdot^0 C),\ \delta = 0,003\ m;$
- With polycarbonate: $k = 5\ W/(m^2 \cdot^0 C),\ \lambda = 0,2\ W/(m \cdot^0 C),\ \delta = 0,008\ m;$
- Double layer glazed: $k = 0,48\ W/(m^2 \cdot^0 C),\ \lambda = 1\ W/(m \cdot^0 C),\ \delta = 0,003\ m;$ for the air layer: $\lambda = 0,026\ W/(m \cdot^0 C),\ \delta = 0,05\ m;$
- Double layer polycarbonate: $k = 0,46 W/(m^2 \cdot^0 C),\ \lambda = 0,2\ W/(m \cdot^0 C),\ \delta = 0,003\ m;$ for the air layer: $\lambda = 0,026\ W/(m \cdot^0 C),\ \delta = 0,05\ m;$

For foundation buried in the ground (concrete). $k = 0,42\ W/(m^2 \cdot^0 C)$: $\lambda = 1,69\ W/(m \cdot^0 C), \delta = 0,3\ m$;

For a three-layer wall on the top of the foundation $k = 0,4\ W/(m^2 \cdot^0 C)$: cinder block $\lambda = 0,65\ W/(m \cdot^0 C),\ \delta = 0,16\ m;$ internal and external cement-sand putty $\lambda = 0,93\ W/(m \cdot^0 C),\ \delta = 0,02\ m.$

Putting the values of the above expression (2) and the results of the geometric calculation on the surface into the expression (1), we find the value of the heat lost in the greenhouse. From the site power.larc.nasa.gov [6] Based on the change of the hourly value of the outdoor air temperature (for the city of Karshi) in January 2021, we represent the monthly change of heat loss in Figure 2. Calculation of heat losses was carried out with different greenhouse coating (transparent surface).

The external coating of the greenhouse with a useful area of 108 m^2, built at the "Alternative Energy Sources" heliopolygon of the Karshi Engineering Economics Institute, is made of polyethylene film, and the heat load is covered by solar energy and a low-potential source. We determine the heat load brought by solar energy using the following expression [11-13].

$$Q_{rad} = (\alpha\tau) S q_{rad} \tag{1}$$

Here: $\alpha\tau$ - light absorption and reflection coefficients of a clear surface; S-useful area of the greenhouse, m^2; q_{rad} - total solar radiation falling on a surface unit, W/m^2.

3 Results and Discussion

Considering the infiltration coefficient in the expression that calculates heat losses, it represents the heat load of the greenhouse. Based on the expressions (1)–(3), the heat load of the single-layer film-covered greenhouse and the heat load from solar radiation were calculated, and the calculation results are shown in Figure 3.

It can be seen from Figure 2 that heat losses depend on the type of greenhouse coating materials and the number of layers, and heat losses are minimal in a two-layer polycarbonate coating.

The heat load of the greenhouse changes depending on the outside air temperature. According to the calculation results in Figure 3, the low outdoor temperature and solar radiation at the beginning of January leads to a decrease in the share of solar energy in the heat load of the greenhouse.

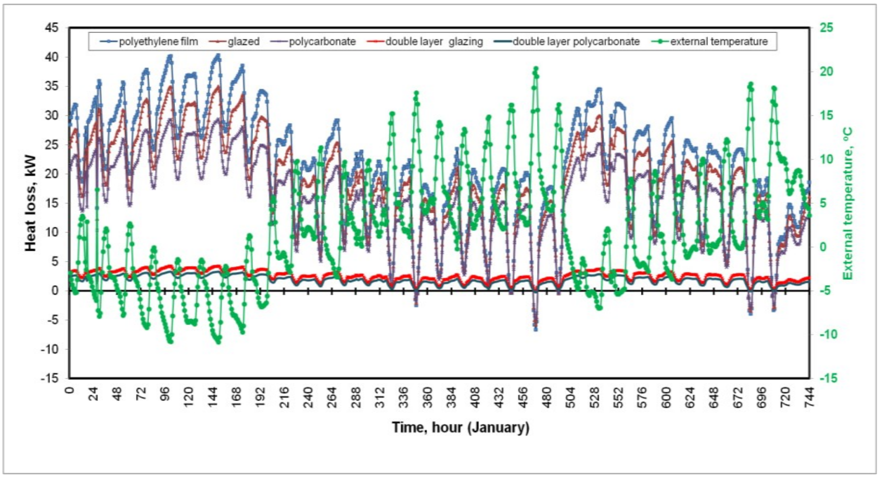

Fig. 2. Variation of heat loss (on the left ordinate axis) and external temperature (on the right ordinate axis) over time in a greenhouse with different coatings (January 2021).

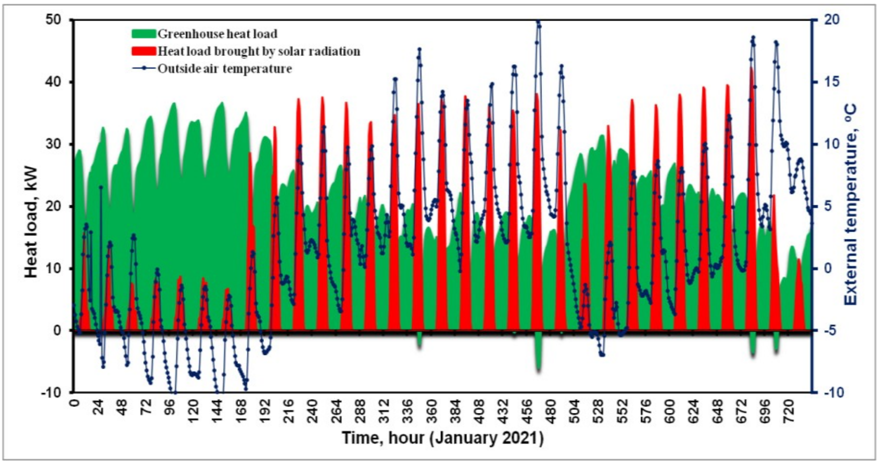

Fig. 3. Variation of heat load, solar heat, and outside air temperature of a film-covered greenhouse (January 2021).

4 Conclusion

Heat-technical parameters of four areas (transparent wall, solid wall, roof and foundation) were taken into account when calculating heat losses in the greenhouse.

Thermal technical calculations were made for a greenhouse with different coating materials, i.e. polyethylene film, glass, polycarbonate, double glass, double polycarbonate.

According to the calculation results based on the weather data of January 2021 (Figure 2), the average heat loss in a greenhouse with a polyethylene film coating and a working area of 108 m^2 is 21.4 kW, in a glass coating it is 18, 6 kW, 15.6 kW in polycarbonate coating, 2.6 kW in double-glazed coating and 1.9 kW in double-layer polycarbonate coating. These heat losses represent the heat load of the greenhouse, taking into account the infiltration coefficient.

The average monthly heat load of a greenhouse with a film-covered area of 108 m^2 is 21.4 kW and 31.3% (6.7 kW) of this heat load can be covered by solar energy.

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