Energy-saving parameters of greenhouses for small businesses

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Abstrat. Approximately 95% of the total heat losses of a greenhouse for year-round use are losses through translucent enclosing structures. Therefore, to reduce energy costs, the area of the enclosing structures of the cultivation structure should be minimal. The purpose of the study included the derivation of formulas to substantiate the energy-saving space-planning parameters of greenhouses offered by the market for farms, and a comparative assessment of various types of structures. Formulas were obtained for determining the minimum fencing factor for greenhouses of various shapes, on the basis of which they were compared in terms of heat losses and material consumption for enclosing structures.

1. Introduction

The cultivation of agricultural products in cultivation facilities is one of the types of farming activities. For year-round use by factories - manufacturers offer various types of farm greenhouses, the main of which are shown in figure 1 [1-5]. Translucent enclosing structures of greenhouses have low thermal resistance and in the cold season, heat losses through them are very significant [6-10]. The choice of a rational form and size of the cultivation facility allows to reduce heat losses and increase the profitability of production.

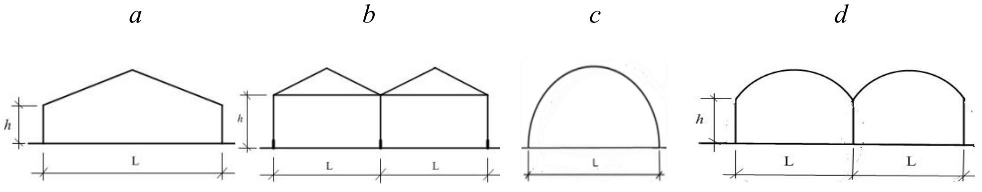

Fig. 1. The main types of farm greenhouses: a - hangar with rectilinear slopes; b - block (multi-span) with rectilinear slopes; c - arched with a circular outline of the coating; d - multi-span with the outline of the slopes around the circumference.

The purpose of the study is to establish dependencies for determining the size of greenhouses that minimize heat losses through enclosing structures, and to compare various types of farm greenhouses in terms of specific heat losses and specific consumption of materials for enclosing structures.

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2 Materials and methods

To achieve the intended goal, an analytical method was used using the provisions of mathematical analysis. Comparison of specific heat losses and specific consumption of materials when evaluating greenhouses of various shapes can be performed based on the analysis of the fencing coefficient, which shows the ratio of the area of translucent enclosing structures to the greenhouse building area. A structure with a lower fencing coefficient corresponds to a lower value of heat losses and the area of the enclosing structures. The relationship between specific heat losses and the barrier factor is shown by the following formula

$$q = mK_{ОГР}, \tag{1}$$

where q – specific heat losses, $W / m2$; m – thermal characteristic equal to the product of the heat transfer coefficient by the temperature difference, $W / m2$; KOGR – fencing factor.

3 Results and discussion

The mathematical expression for the fencing factor of the hangar greenhouse (Fig. 1, a),

$$K_{ОГР} = \frac{2h}{L} + \frac{1}{\cos\alpha} + \frac{2h}{A} + \frac{L}{2A} tg\alpha \ , \tag{2}$$

where h is the height of the longitudinal vertical fence, not less than 1.5 m; L and A are the width and length of the greenhouse, respectively; α is the angle of inclination of the roof slopes, usually equal to 30°.

The minimum value of the fencing factor can be set by substituting the value of the greenhouse length A = F / L (F is the required area of the greenhouse) into formula (2), differentiating the expression by L and solving the resulting equations for the width of the greenhouse. So, for a greenhouse with an area of 500 m^2 we get

$$L^3 tg\alpha + 2hL^2 - 1000\,h = 0\,. \tag{3}$$

Whence the optimal value of the greenhouse span $L_{опт}$ = 12 m, and the corresponding minimum fencing coefficient $K_{огр}$ = 1,56.

In single-span greenhouses with the same areas and slopes of flat slopes, a change in the fencing coefficient occurs due to a change in the areas of the side and end walls, the roof area remains constant when the planning dimensions of the structure change.

A block greenhouse (Fig. 1, b) can be considered as consisting of n gable greenhouses. Consequently, the greenhouse fencing factor will depend only on the change in the area of the end and longitudinal walls. End and longitudinal wall areas

$$F_T = 2n(Lh + \frac{L^2 tg\alpha}{4})\,; \tag{4}$$

$$F_{ПР.СТ} = 2hb = 2h\frac{F_П}{Ln}\,, \tag{5}$$

where n is the number of spans in the greenhouse; L – span, m; h – the height of the longitudinal glass walls, not less than 2.1 m; α is the angle of inclination of the roof slopes in degrees; b is the length of the greenhouse, m; $F_П$ – greenhouse floor area, m.

The sum of end and longitudinal walls.

$$F_T + F_{ПР.СТ} = 2Lnh + \frac{L^2 tg\alpha n}{2} + 2h\frac{F_П}{Ln}. \quad (6)$$

Considering L as a known value (technologically specified), we set n corresponding to the minimum of the sum of the wall areas. To determine the extreme values of function (6), we take the first derivative with respect to n

$$\frac{d(F_T + F_{ПР.СТ})}{dn} = 2Lh - \frac{2hF_П}{Ln^2} + \frac{L^2 tg\alpha}{2}. \quad (7)$$

Equating the derivative to zero, we determine n corresponding to the minimum of the sum of the wall areas $\sum(F_T + F_{ПР.СТ})$

$$2Lh - \frac{2hF_П}{Ln^2} + \frac{L^2 tg\alpha}{2} = 0. \quad (8)$$

Then

$$n = \frac{2}{L}\sqrt{\frac{hF_П}{4h + Ltg\alpha}}. \quad (9)$$

Substituting into (9) the value of the technologically required span L, it is possible to determine the number of spans n, and then the width of the block greenhouse corresponding to the minimum value of the fencing coefficient.

From the mathematical expression of the fencing coefficient of an arched single-span greenhouse with a circular outline of the coating (Fig. 1, c)

$$K_{ОГР} = \frac{\pi}{2}\left(\frac{L^2}{2F_П} + 1\right), \quad (10)$$

it follows that with a constant greenhouse area $F_П$ with an increase in the span L (diameter of the circle), the value of the $K_{ОГР}$ increases. The smallest fencing factor will correspond to the minimum allowable span according to the technological requirements.

The fencing factor of a multi-span arched greenhouse with a circular outline of the covering (Fig. 1, d)

$$K_{ОГР} = \frac{\pi}{2b} + \frac{2h}{Ln} + \frac{n(2Lh + \pi L^2)}{F_П}. \quad (11)$$

The obtained formulas of the minimum fencing coefficient for the accepted values of the span and area of the greenhouse for the most typical types of farm greenhouses are summarized in Table 1. The formulas make it possible to determine the energy-saving volumetric-planning parameters of cultivation facilities.

Table 1. Formulas for the minimum fencing factor of a greenhouse.

Coating	Minimum fencing factor $K_{ОГР}^{\min}$	The optimal number of spans n with an appropriate $K_{ОГР}^{\min}$
Gable with an angle of inclination of the slopes 30°	$K_{ОГР}^{\min} = \frac{1}{\cos 30^o} + \frac{2h}{Ln} + \frac{2h}{b} + \frac{Ltg30^0}{2h}$	$n = \frac{2}{L}\sqrt{\frac{hF_П}{4h + 0{,}577L}}$
Circled	$K_{ОГР}^{\min} = \frac{\pi}{2b} + \frac{2h}{Ln} + \frac{n(2Lh + \pi L^2)}{F_П}$	$n = \frac{2}{L}\sqrt{\frac{2hF_П}{8h + \pi L}}$
Elliptical outline	$K_{ОГР}^{\min} = 1{,}075 + \frac{2h}{Ln} + \frac{2Lnh + \frac{\pi L^2 n}{4}}{F_П}$	$n = \frac{4}{L}\sqrt{\frac{hF_П}{16h + \pi L}}$
Unequal with slope angles of 30° and 60°	$K_{ОГР}^{\min} = \frac{1}{\cos 30^o} + \frac{1}{\cos 60^o} + \frac{2h}{Ln} + \frac{(Lh + 0{,}216L^2)2n}{F_П}$	$n = \frac{1}{L}\sqrt{\frac{hF_П}{h + 0{,}216L}}$

The area of a farm greenhouse for year-round use is recommended to be taken equal to 300 m^2 by the norms of technological design of greenhouses NTP 10-95. For this area, the minimum fencing factors for the main types of farm greenhouses are calculated (Table 2)

Table 2. Minimum fencing factors for greenhouses with an area of 300 m^2.

Hangar with rectilinear slopes (Fig. 1, a)	Block (multi-span) with rectilinear slopes (Fig. 1, b)	Arched with a circular outline of the coating (Fig. 1, c)	Multi-span with the outline of the slopes around the circumference (Fig. 1, d)
1,56 (117%)	1,74 (130%)	2,63 (197%)	1,34 (100%)

Note. The coefficients $K_{ОГР}^{\min}$ are determined for the following values of the quantities: h =2,1m; α =30° ; L = 6 m for arched and multi-span greenhouses.

From the data in Table 2, it follows that with the accepted values of the greenhouse area FП and the span of block greenhouses L, the smaller value of the fencing coefficient corresponds to a multi-span greenhouse with the outline of the slopes around the circumference. Consequently, the consumption of materials for the enclosing structures and heat losses will be lower in relation to other types of greenhouses considered.

4 Conclusion

Dependences have been derived for determining the rational size of the main types of farm greenhouses, which make it possible to reduce energy costs for heating and the consumption of materials for enclosing structures.

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