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THE TEMPERATURE REGIME OF SOLAR GREENHOUSES, TAKING INTO ACCOUNT THE SEASONAL NON-STATIONARITY OF THERMAL PROCESSES PIERCED IN THEM

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Abstract:

Arthritis This article proposes calculation expressions for determining the timing of shelter, opening, as well as the duration of the periods of operation of greenhouses in autumn and spring, during which heating in film solar greenhouses of a semi-cylindrical shape, depending on the number of layers and orientation to the cardinal points of their translucent fences of greenhouses and can be carried out only at the expense of use of solar energy. This article propose calculated expressions to determine the timing of shelter, deployment, as well as the duration of the periods of operation of greenhouses in autumn and spring, during which heating in semi-cylindrical film solar greenhouses, depending on the number of layers and the orientation to the cardinal points of their translucent greenhouse enclosures, can be carried out only through the use of solar energy. A comparison of the air temperatures in the compared greenhouses also shows the obvious advantage of their latitudinal location compared to the meridional one. As can be seen from the comparison of the temperatures of the air environment, compared solar greenhouses, the advantage of a two-layer translucent fence compared to a single-layer fence, indisputable.

Keywords:

INTRODUCTION

Object of research: solar greenhouses with one - and two-layer film with solar radiation heat accumulators.

To increase the efficiency of using solar energy in greenhouses in the national economy, along with improving the optical and thermal properties of their translucent fences, it is necessary to strive to ensure the necessary temperature regime for normal development of crops grown in them at any changes in the main energy source - the energy of solar radiation and ambient temperature. In this regard, to increase the efficiency of using solar energy in the main greenhouses, taking into account the daily non-stationarity of the thermal processes pierced in them, one of the urgent tasks of the development of greenhouse vegetable growing and energy conservation in this area is represented. Unfortunately, the solutions to these problems have not been given due attention until recently. The solutions to these problems, unfortunately, have not received the attention they deserve until recently.

Let's consider some constructive solutions of solar greenhouses, as their thermal efficiency and basic qualities increase. The thermotechnical qualities of the enclosing elements of solar greenhouses are directly related to the climatic conditions of the area where they are built, in the work under consideration, the authors mainly limited themselves to the analysis of constructive solutions and created in the climatic conditions of the Central Asian republics. The methodology [1] is applicable for assessing the temperature regimes of solar greenhouses in a stationary mode and cannot be used for solving time-related issues. It should be noted that in a clear representation of the systems of equations describing the heat balance of cultivation structures, which were later used by various authors to determine certain parameters of the solar greenhouses developed by them [2-8].

From the above it is clear that the problems of studying the daily temperature regime of solar greenhouses, taking into account the non-stationarity of the solar radiation arrival, environmental temperature changes and thermal inertia of their massive, the influence of the vegetation cover inside solar greenhouses on the formation of their temperature regime, the process of natural accumulation of solar radiation energy in their soil [1-7] has not been studied enough.

Despite some shortcomings, scientific research performed by numerous [1-8] authors is a kind of step forward in the use of solar energy in greenhouses in order to develop existing methods of calculation and expand the scope of their practical application in the national economy.

METHODS AND MODELS

Research method: heat engineering calculation and experiment in natural conditions. The work performed in [9] makes it possible to determine the timing of switching on and off the traditional heating system in solar greenhouses, depending on the optical and thermotechnical qualities of their efficiency of using solar energy in greenhouses, as well as on the arrival of total solar radiation and ambient temperature. The research results obtained in [9] make it possible to determine the total thermal performance of solar greenhouses for the heating period, depending on the number of layers of translucent fencing used in them and their location on the cardinal points. The moments of the beginning and the end of the service life of translucent film fences in solar greenhouses can be determined from the condition [9]

$$t_a(z) \le t_{in}, \qquad (1)$$

that is, when the normalized average daily temperature of the air inside the greenhouses (t_{in}) is necessary for the normal development of plants, fully supported by the use of solar energy. In accordance with condition (1), replacing $t_a(z)$ in with t_{in}, we obtain

$$t_{in} - t_{a_0} = t_{a_1} \cos \omega z + t_{a_2} \sin \omega z, \qquad (2)$$

The moment of the beginning of the operation of a traditional heating system corresponds to the first (2), and the end - to the second root of equation (2)

$$z_{incl} = \frac{1}{\omega}\left[\pi - \arcsin\frac{t_{in} - t_{a0}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}} - \arcsin\frac{t_{a_1}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}}\right], \qquad (3)$$

$$z_{unp} = \frac{1}{\omega}\left[\pi - \arcsin\frac{t_{in} - t_{a0}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}} - \arcsin\frac{t_{a_1}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}}\right]. \qquad (4)$$

For the duration of the heating season in solar greenhouses from (3) and (4) we have

$$\Delta z = z_{unp} - z_{incl} = \frac{1}{\omega}\left[\pi + 2\arcsin\frac{t_{in} - t_{a0}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}}\right], \qquad (5)$$

The calculation results for determining z_{unp}, z_{incl} and Δz for solar greenhouses with one- and two-layer with translucent fences, located in the latitudinal and meridional directions along the cardinal points, at t_{in}=18,7^{0}C are given in Table 1.

Table 1.

Quantity, Unit of measurement	Number of layers of translucent film fencing			
	1		2	
	Location on the cardinal points			
	Latitudinal	Meridional	Latitudinal	Meridional
Z_{incl}, number	28.10/29.10	28.10 /29.10	11.11/13.11	08.11/11.11
Z_{unp}, number	05.04/05.04	01.04/01.04	20.03/20.03	16.03/17.03
Δz, day	159/158	155/154	129/127	128/126

* In the numerators and denominators, respectively, in the presence and absence of vegetation in solar greenhouses.

The moment of the beginning and end of the service life of translucent film fences in solar greenhouses can be determined from the condition

$$t_{in} \le t_e(z), \qquad (6)$$

that is, when the normalized average daily temperature of the air environment inside the greenhouses (t_{in}), required for the normal development of plants, will not be lower than the average daily ambient temperature.

Similarly, to (1), we repeat the procedure and have the equations

$$t_{in} - t_{e_0} = t_{e_1} \cos \omega z + t_{e_2} \sin \omega z, \qquad (7)$$

The search for the roots of equation (7), the first of which corresponds to the start moment, and the second to the end of the operation of translucent film fencing in solar greenhouses, is carried out in a similar way,

$$z_{shel} = \frac{1}{\omega}\left[\pi - \arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}} - \arcsin\frac{t_{e_1}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}}\right], \quad (8)$$

$$z_{discl} = \frac{1}{\omega}\left[2\pi + \arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}} - \arcsin\frac{t_{a_1}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}}\right]. \quad (9)$$

Using solutions (3), (4) and (8), (9), we can set the duration of the periods of operation of greenhouses in autumn Δz_1 and spring Δz_2, during which heating of greenhouses can be carried out only through the use of solar energy

$$\Delta z_1 = z_{incl} - z_{shel} = \frac{1}{\omega}\left[\arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}} + \arcsin\frac{t_{e_1}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}} - \arcsin\frac{t_{in} - t_{a_0}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}} - \arcsin\frac{t_{a_1}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}}\right], \quad (10)$$

$$\Delta z_2 = z_{discl} - z_{unp} = \frac{1}{\omega}\left[\arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}} + \arcsin\frac{t_{a_{11}}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}} - \arcsin\frac{t_{in} - t_{a_0}}{\sqrt{t_{a_1}^2 + t_{a_2}^2}} - \arcsin\frac{t_{a_1}}{\sqrt{t_{e_1}^2 + t_{e_2}^2}}\right] \quad (11)$$

The results of calculations to determine the timing of shelter (z_{shel}), opening (z_{discl}), as well as the duration of the periods of operation of greenhouses in autumn Δz_1 and spring Δz_2, during which heating of greenhouses can be carried out only through the use of solar energy, are given in Table 2.

Table 2.

Quantity, unit of measurement	Number of layers of translucent film fencing			
	1		2	
	Location on the cardinal points			
	Latitudinal	Meridional	Latitudinal	Meridional
Z_{shel}, number	25.09	25.09	25.09	25.09
Z_{discl}, number	11.05	11.05	11.05	11.05
Z_{discl}-Z_{shel}, day	228	228	228	228
Δz_1, day	33	33	47	49
Δz_2, day	36	40	52	54
$\Delta z_1 + \Delta z_2$, day	69	73	99	103

The main thermotechnical indicators of solar greenhouses, directly affecting their economic performance, are: the amount of total solar radiation passed through the translucent fence and absorbed by plant leaves during the heating season ($Q_{abs_p}^{\Delta z}$),the average value of the air temperature inside the greenhouses during the heating period (with the formation of only by the use of solar energy) ($\bar{t}_a^{\Delta z}$),the coefficient of fuel replacement by the solar (insolation) heating system ($\bar{k}_{sub}^{\Delta z}$) and average for the heating period value of the coefficient of penetration of solar radiation through the translucent fence ($\bar{k}_{os}^{\Delta z}$).

The values of ($Q_{abs_p}^{\Delta z}$), ($\bar{t}_a^{\Delta z}$), ($\bar{k}_{sub}^{\Delta z}$) and ($\bar{k}_{os}^{\Delta z}$),, in turn, are determined from the formulas

$$Q_{abs_p}^{\Delta z} = \int_{z_{incl}}^{z_{unp}} q_{abs_p}(z)dz, \quad (12)$$

$$\bar{t}_a^{\Delta z} = \frac{1}{\Delta z}\int_{z_{incl}}^{z_{unp}} t_a(z)dz, \quad (13)$$

$$k_{sub}^{\Delta z} = \frac{Q_{hl}^{s}}{Q_{hl}}, \quad (14)$$

$$\bar{k}_{os}^{\Delta z} = \frac{Q_{abs_p}^{\Delta z}}{Q_{ser}^{\Delta z}\alpha_s}, \qquad (15)$$

where Q_{hl}^{s} – for solar energy in the total heat balance of solar greenhouses for the heating period; Q_{hl} – total calculated heat loss of solar greenhouses for the heating period; $Q_{ser}^{\Delta z}$ – the amount of total solar radiation supplied during the heating period to the horizontal (open) surface; α_s - the absorption coefficient of plant leaves inside greenhouses. The values of Q_{hl}^{s}, Q_{hl} and $Q_{ser}^{\Delta z}$ can be determined from

$$Q_{hl}^{s} = k_{giv}(\bar{t}_a^{\Delta z} - \bar{t}_e^{\Delta z})\Delta z, \qquad (16)$$

$$Q_{hl} = k_{giv}(t_a - \bar{t}_e^{\Delta z})\Delta z, \qquad (17)$$

$$Q_{ser}^{\Delta z} = \int_{z_{incl}}^{z_{unp}} q_{ser}(z)dz, \qquad (18)$$

where

$$\bar{t}_e^{\Delta z} = \frac{1}{\Delta z}\int_{z_{incl}}^{z_{unp}} t_0(z)dz. \qquad (19)$$

Substituting (16) and (17) into (14), we have

$$k_{sub}^{\Delta z} = \frac{\bar{t}_a^{\Delta z} - \overline{t_e^{\Delta z}}}{t_{in} - \bar{t}_e^{\Delta z}}. \qquad (20)$$

Taking into account the natural periodic regime of external conditions, the expressions for the temperatures of the surface of the leaves and the air environment inside the solar greenhouse can be written in the form

$$t_{sur}(z) = t_{sur_0} + t_{sur_1}\cos\omega z + t_{sur_2}\sin\omega z, \qquad (21)$$

and

$$t_a(z) = t_{a_0} + t_{a_1}\cos\omega z + t_{a_2}\sin\omega z. \qquad (22)$$

Substituting (21) into (12) and integrating the latter, we have

$$Q_{abs_3} = Q_{abs_0}\Delta z + \frac{1}{\omega}[Q_{abs_1}(\sin\omega z_{unp} - \sin\omega z_{incl}) - Q_{abs_2}(\cos\omega z_{unp} - \cos\omega z_{incl}). \qquad (23)$$

Based on the method of harmonic analysis of the annual variation of the absorbed surface of the leaves of plants, the total solar radiation and the ambient temperature can be represented as

$$Q_{abs_p}(z) = Q_{abs_{p0}} + Q_{abs_{p1}}\cos\omega z + Q_{abs_{p2}}\sin\omega z, \qquad (24)$$

and

$$t_e(z) = t_{e_0} + t_{e_1}\cos\omega z + t_{e_2}\sin\omega z. \qquad (25)$$

For the soil surface has the form

$$t_s(x=0,z) = t_{s_0} + t_{s_1}\cos\omega z + t_{s_2}\sin\omega z. \qquad (26)$$

Substituting (22) into (13) and integrating the latter, taking into account (25), we obtain

$$\bar{t}_e^{\Delta z} = t_{a_0} - \frac{\sqrt{t_{a_1}^2 + t_{a_2}^2 - (t_{in} - t_{e_0})^2}}{\frac{\pi}{2} + \arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{in_1}^2 - t_{a_2}^2}}}, \qquad (27)$$

$$\bar{t}_e^{\Delta z} = t_{e_0} - \frac{\sqrt{t_{a_1}^2 + t_{a_2}^2 - (t_{in} - t_{e_0})^2}}{\frac{\pi}{2} + \arcsin\frac{t_{in} - t_{e_0}}{\sqrt{t_{a_1}^2 - t_{a_2}^2}}} \cdot \frac{t_{e_1}t_{a_1} + t_{e_2}t_{a_2}}{t_{a_1}^2 + t_{a_2}^2}. \qquad (28)$$

$$Q_{abs}^{\Delta z} = Q_{abs_0}\Delta z + \frac{1}{\omega}[Q_{abs_1}(\sin\omega z_{unp} - \sin\omega z_{incl}) - Q_{abs_2}(\cos\omega z_{unp} - \cos\omega z_{incl})]. \qquad (29)$$

Using (29) and (24), we can obtain expressions for determining the average values for the heating period Q_{abs}, Q_{ser} i.e.

$$Q_{abs}^{\Delta z} = Q_{abs_0} + \frac{1}{\omega \Delta z}[Q_{abs_1}(\sin \omega z_{unp} - \sin \omega z_{incl}) - Q_{abs_2}(\cos \omega z_{unp} - \cos \omega z_{incl})] \quad (30)$$

$$Q_{ser_p}^{\Delta z} = Q_{ser_0} + \frac{1}{\omega \Delta z}[Q_{ser_{p_1}}(\sin \omega z_{unp} - \sin \omega z_{incl}) - Q_{ser_{p2}}(\cos \omega z_{unp} - \cos \omega z_{incl})]. \quad (31)$$

The values of $Q_{ser_{p0}}, Q_{ser_{p1}}, Q_{ser_{p2}}, t_{a_0}, t_{a_1}, t_{a_2}, z_{incl}, z_{unp}, \Delta z$, depending on the number of layers of the used translucent fence in solar greenhouses and the location of the latter relative to the cardinal points, can be borrowed from Table 3.1.

Table 3.1

Quantity, unit of measurement	Number of layers of translucent film fencing			
	1		2	
	Location on the cardinal points			
	Latitudinal	Meridional	Latitudinal	Meridional
$Q_{ser_{p0}}$, W/m^2	91.0	101.9	81.7	89.5
$Q_{ser_{p1}}$, W/m^2	56.3	76.7	52.1	68.6
$Q_{ser_{p2}}$, W/m^2	21.9	24.1	19.5	20.6
t_{sur_0}, ^{0}C	31.7	33.9	37.0	39.3
t_{sur_1}, ^{0}C	21.8	25.8	24.8	29.5
t_{sur_2}, ^{0}C	11.0	11.3	11.4	11.5
t_{a_0}, ^{0}C	22.6	23.7	28.9	30.3
t_{a_1}, ^{0}C	16.4	18.4	19.7	22.7
t_{a_2}, ^{0}C	9.9	10.2	11.7	11.7
t_{s_0}, ^{0}C	22,6	23,7	28,9	30,3
t_{s_1}, ^{0}C	15,4	17,3	18,3	21,1
t_{s_2}, ^{0}C	10,0	10,3	11,7	12,2

The value of the normalized average daily air temperature in solar greenhouses t_{a_n} in accordance with [10] can be taken as 18.7^{0}C, in accordance with 0.8.

RESULTS AND DISCUSSION

As follows from the data in Table 2, the period of operation of a translucent film fence in solar greenhouses does not depend on their location on the cardinal points and the number of layers of the fence and is 228 days. This period begins on September 25 and ends on May 11. During the specified period, the duration of the independent operation of the solar heating system is: for greenhouses with a single-layer translucent fence, having a latitudinal and meridional location, respectively 69 days and 73 days, for greenhouses with a two-layer translucent fence, having a latitudinal and meridian location, respectively, 99 days and 103 days.

The duration of the heating season in solar greenhouses with two-layer translucent film fences is shorter than in single-layer ones: by 30 days in the latitudinal and 27 in the meridionals located solar greenhouses.

The calculation results for the determination of $Q_{abs}^{\Delta z}, Q_{ser_p}^{\Delta z}, Q_{abs}^{\Delta z}, Q_{ser_p}^{\Delta z}, \bar{t}_e^{\Delta z}, \bar{t}_a^{\Delta z}, \bar{k}_{os}^{\Delta z}, k_{sub}^{\Delta z}$ in solar greenhouses, depending on the number of layers of the film translucent fence and the location of the latter on the cardinal points are given in table. 4.

Table 4.

Quantity, unit of measurement	Number of layers of translucent film fencing			
	1		2	
	Location on the cardinal points			
	Latitudinal	Meridional	Latitudinal	Meridional
$Q_{abs}^{\Delta z}$, W/m²	90.97	88.63	79.10	77.63
$Q_{ser_p}^{\Delta z}$, W/m²	48.34	44.40	37.51	32.44
$Q_{abs}^{\Delta z}$, 10^3J/m²	1248.1	1184.6	881.6	857.2
$Q_{ser_P}^{\Delta z}$, 10^3J/m²	663.2	593.5	418.1	358.1
$\bar{k}_{os}^{\Delta z}$	0.664	0.626	0.593	0.522
$k_{sub}^{\Delta z}$	0.342	0.314	0.487	0.433
$\bar{t}_e^{\Delta z}$, ^{0}C	3.76	3.60	2.54	2.50
$\bar{t}_a^{\Delta z}$, ^{0}C	8.87	8.34	10.41	9.52

Analysis and comparison of the thermal performance indicators of solar greenhouses, given in Table 4, allows you to choose not only the most advantageous location on the cardinal points, but also the number of layers of translucent fencing of solar greenhouses. So, for example, replacing a single-layer translucent film fence with a two-layer one makes it possible to increase the replacement coefficient of the solar heating system by 42.4% at latitudinal and by 37.9% at meridional locations of solar greenhouses to the cardinal points.

A simple measurement of the location of greenhouses from meridional to latitudinal makes it possible to increase the values of 8.9% in a single-layer and 12.5% in a two-layer film translucent fences.

With the latitudinal location of solar greenhouses, the amount of solar energy converted into low potential heat during the heating period is 11.7% higher in greenhouses with single-layer and by 16.8% with double-layer fences compared to the meridional location.

From the data in Table 4, it also follows that with a latitudinal location of greenhouses, the coefficient of solar radiation entering through a translucent fence during the heating period is 6.1% more in a single-layer and 13.6% in two-layer film fences compared to a meridional location.

Based on the analysis of the results of the seasonal thermal performance of greenhouses, it can be summarized that a two-layer translucent film fence with a latitudinal location of greenhouses to the cardinal points is the most effective solution to improve the technical and economic performance of solar greenhouses.

CONCLUSION

Developing methods of thermomechanical calculation of solar greenhouses taking into account the seasonal non-stationarity of thermal processes pierced in them, the corresponding calculated expressions for the annual course of values of temperatures of air environment, plant leaf surfaces and soil depending on the number of layers and location along the sides of the transparent film fences, presence or absence of vegetation cover inside the solar greenhouses are established.

1. The dates of the beginning and the end of the use of the traditional heating system in solar-fuel greenhouses, the terms of sheltering and opening of the film translucent fences, depending on the number of layers and the location of the latter on the cardinal points, have been established.

2. The optical and thermal technical indicators of solar greenhouses are established depending on the number of layers and the location on the cardinal points of the film translucent fencing used in them:

a) with a latitudinal arrangement of solar greenhouses, the amount of solar energy converted into low potential heat during the heating season is 11.7% higher in greenhouses with single-layer and 16.8% with double-layer fences compared to the meridional arrangement;

b) with the latitudinal distribution of radiation through their translucent fence during the heating period compared to 6.1% in single-layer and 13.6% in double-layer fences.

3. Based on the analysis of the results of seasonal heat engineering indicators of solar greenhouses, the indisputable advantage of using a two-layer film translucent fence (instead of a single-layer one) and the location of the latter in the latitudinal direction along the cardinal points has been revealed:

a) replacing a single-layer film translucent fence with a two-layer one allows increasing the replacement coefficient of the solar heating system by 42.4% at latitudinal and by 37.9% at meridional locations of solar greenhouses to the cardinal points;

b) changing the location of greenhouses from meridional to latitudinal makes it possible to increase the replacement coefficient of the solar heating system by 8.9% in a single-layer and 12.5% in a two-layer film translucent fences.

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