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The Heating System Capacity Calculation of the Cultivation Facilities

N Shiryaeva¹, O Mitroshina¹ and N Kharkova¹

¹Ural Federal University, 19 Mira Str., Ekaterinburg 620002, Russia

E-mail: n.p.shiriaeva@urfu.ru

Abstract. The article is devoted to the heating system capacity calculation of the cultivation facility, based on the conditions for ensuring the microclimate parameters regulated by the standards of technological design, depending on the external climatic conditions and the facility design parameters. One of the distinguishing features of the heating system capacity calculation of greenhouses is that the heat balance equation of the structure must be considered together with the equations of heat and mass transfer on the soil and covering constructions. The calculation is made for the greenhouse block № 3 in The Greenhouse Complex with a production area about 12 ha in the village of Sadovy, Ordzhonikidze District, Ekaterinburg. It takes into account convective and radiant heat exchange between the soil and the covering constructions, heat and mass exchange during evaporation and condensation and heat loss for heating infiltrating air.

Keywords. Cultivation Facility; Microclimate; Heat and Mass Transfer; Heating System Capacity.

1. Introduction

The plant's vital activity directly depends on the microclimate parameters. Therefore, it is necessary to maintain a certain level of air and soil temperature, as well as relative humidity in the cultivation facilities work zone.

It is analytically impractical to take into account just transmission heat loss in the heating systems design practice of the cultivation facilities, because the airspace, soil surface and covering constructions heat exchange must be considered.

The below calculation establishes an analytical relationship between the required parameters of the microclimate inside the greenhouse and the required heat flows for their provision.

The main feature of the cultivation facilities is their close connection with the external meteorological conditions, especially with the intensity of solar radiation. However, this calculation is made for the night period, as it is the most unfavorable in terms of heat loss, and, therefore, the load on the heating system is the peak.

2. Object of study

The greenhouse block № 3 in The Greenhouse Complex with a production area about 12 ha in the village of Sadovy, Ordzhonikidze District, Ekaterinburg, was chosen as the object of study. This facility is a block-type greenhouse, shown in Figure 1, and is a combination of several duo-pitch links



(sections) under one roof, where the walls between the links are replaced by supporting poles. Covering constructions are made of: walls - double glazing, slopes - single glazing.



Figure 1. The greenhouse block № 3 in The Greenhouse Complex with a production area about 12 ha in the village of Sadovy, Ordzhonikidze District, Ekaterinburg.

The following assumptions were made when drawing up the design scheme for the greenhouse block energy balance, shown in Figure 2:

- Construction night mode;
- Mass-exchanging processes take places only in the work zone;
- The screen (biomass) is not taken into account, due to the decline of radiant heat flow from the soil to the covering constructions;
- The heat and mass-exchanging processes conditions inside the building are stable.

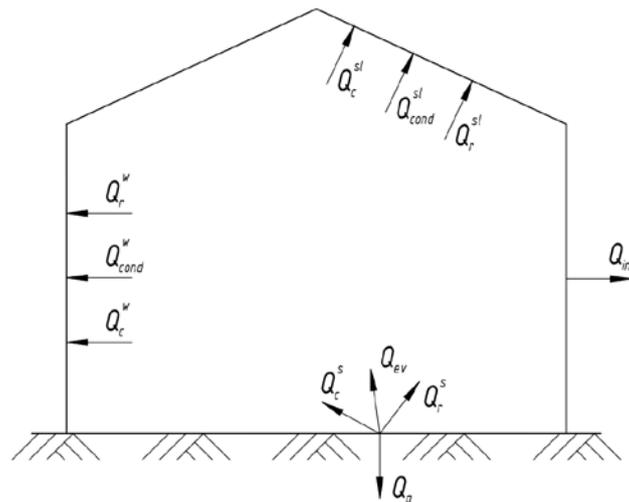


Figure 2. Heat flows scheme in the greenhouse for the night mode

The heat balance equation for the greenhouse airspace is:

$$Q_h = Q^s + Q^{con} + Q_{inf}, \quad (1)$$

where Q_h is the installed capacity of the greenhouse heating systems, W ; Q^s is the ground mass heat loss, W ; Q^{con} is the heat loss through the covering constructions, W ; Q_{inf} is heat loss by the infiltration, W .

The heat amount for heating soil is:

$$Q^s = Q_g + Q_c^s + Q_r^s + Q_{ev}, \quad (2)$$

where Q_g is the heat loss through the soil massif, W ; Q_c^s and Q_r^s are respectively, convective and radiant heat flows from the soil to the air in the work zone, W ; Q_{ev} is heat flow characterizing the heat expenditure for moisture evaporation from the soil, W .

The heat amount for heating covering constructions is:

$$Q^{con} = Q_c^{con} + Q_r^{con} - Q_{cond}^{con} = Q_c^{sl} + Q_r^{sl} - Q_{cond}^{sl} + Q_c^w + Q_r^w - Q_{cond}^w, \quad (3)$$

where Q_c^{sl} and Q_r^{sl} are heat flow as a result of heat exchange by convection of the inner surface, respectively, of slopes and walls with air in the work zone, W ; Q_r^{sl} and Q_r^w are radiant heat flow from the inner surface, respectively, of the slopes and walls, W ; Q_{cond}^{sl} and Q_{cond}^w are heat flow characterizing the heat released during the condensation of steam on the inner surface, respectively, of the slopes and walls, W .

The equation of the heating system capacity calculating of the greenhouse with regarding formulas (2) and (3) is:

$$Q_h = Q_g + Q_c^s + Q_{ev} + Q_c^{sl} + Q_r^{sl} - Q_{cond}^{sl} + Q_c^w + Q_r^w - Q_{cond}^w + Q_{inf}, \quad (4)$$

2.1. Convective heat exchange

The heat amount received (given away) by covering constructions and soil by convection is determined as:

$$Q_c = \alpha_c \cdot F \cdot \Delta t, \quad (5)$$

where α_c is convective heat transfer coefficient, $W/(m^2 \cdot ^\circ C)$; F is the heat exchange surface area, m^2 ; Δt is the difference between the work zone and the heat exchange surface air temperatures, $^\circ C$.

According to [2], turbulent air movement is observed in greenhouses near all surfaces because of their surfaces large sizes of the soil, walls, slopes, and significant temperature differences between covering constructions and air temperature, therefore, the convective heat transfer coefficient does not depend on the size and looks like:

$$\alpha_c = A \cdot m \cdot \sqrt[3]{\Delta t}, \quad (6)$$

where A is the coefficient for the convective heat transfer calculation (is a function of the heat exchange surface temperature and the ambient air, taken from the data given in [4]; m is the coefficient for the convective heat transfer calculation taken according to [4] for vertical surfaces $m = 1$, for vertical surfaces facing the heated side up $m = 1.3$, for slopes it is determined by the formula:

$$m = \frac{F_w + 0.7F_{sl}}{F_w + F_{sl}} \quad (7)$$

2.2. Radiant heat exchange

Heat transfer by the radiation of the soil surface to the covering constructions is determined using the Stefan-Boltzmann law with the replacement of the fourth-degree difference by the value difference in the first degree [3]:

$$Q_r = C_r \left[\left(\frac{\tau_0 + 273}{100} \right)^4 - \left(\frac{\tau_{con} + 273}{100} \right)^4 \right] F_0 \approx 0,814 C_r F_0 (\tau_0 - \tau_{con}), \quad (8)$$

where C_r is reduced emissivity; τ_0 is the soil temperature, °C; τ_{con} is the temperature of the greenhouse covering constructions, °C.

$$C_r = \frac{5,67}{\frac{1}{\varepsilon_0} + \frac{F_0}{F_{con}} \left(\frac{1}{\varepsilon_{con}} - 1 \right)}, \quad (9)$$

where ε_0 and ε_{con} are the emissivity factor, respectively, of the soil and covering constructions; F_0 and F_{con} are the surface area, respectively, of the soil and covering constructions, m^2 .

2.3. Heat and mass exchange during evaporation and condensation

According to [2], 90% of the water used for irrigation evaporates from the soil. In this case, assuming the evaporation uniformity, the heat amount spent on the evaporation processes from the soil is calculated by the formula:

$$Q_{ev} = 0.25 \cdot G_{w.c.} \cdot r_l, \quad (10)$$

where $G_{w.c.}$ is the irrigation water rate, l/h; r_l is the specific latent heat of evaporation, respectively, taken at the temperature of the soil.

According to [3], the amount of moisture obtained by condensation of water vapor is:

$$Q_{cond} = 0.278 \cdot G_{cond} \cdot r_l, \quad (11)$$

where G_{cond} is the amount of moisture condensed on the covering construction surface; l/h.

$$G_{cond} = 2.2 \cdot 10^{-6} \cdot (t_d + 273)^{0,42} \cdot \left(\frac{t_{wz} - \tau_{con}}{\nu^2} \right)^{0,33} \cdot \Delta\varepsilon \cdot F_{con}, \quad (12)$$

where t_{wz} is the temperature in the greenhouse working zone, °C; t_d is the determining temperature, °C, equal to $\frac{t_{wz} + \tau_{con}}{2}$; $\Delta\varepsilon$ is the difference in volumetric vapor content in air, %; ν is the coefficient of kinematic viscosity of air, m^2/s , accepted at t_d .

$$\Delta\varepsilon = 100 \cdot \left(\frac{\varphi_{wz} \cdot e_{t_{wz}}^s - e_{\tau_{con}}^s}{P_n} \right), \quad (13)$$

where φ_{wz} is relative air humidity in the work zone, %; $e_{t_{wz}}^s$ and $e_{\tau_{con}}^s$ are the elasticity of saturated water vapor at t_{wz} and τ_{con} , kPa; P_n is the atmospheric pressure under normal conditions, kPa.

2.4. Heat loss through the soil massif

Heat loss through the soil massif is determined by the formula:

$$Q_g = \frac{t_g - t_{ext}}{R_0^{av}} F_0, \quad (14)$$

where t_g and t_{ext} are, respectively, generalized and external air temperature, °C; R_0^{av} is area-weighted average resistance to the soil heat transfer, $(m^2 \cdot °C)/W$.

$$t_g = \frac{133.9 - C_r \left| 55 - \left(\frac{\tau_{con} + 273}{100} \right)^4 \right|}{C_r + 8.6} \approx \frac{133.9 - C_r |55 - (0.814\tau_{con} + 55.55)|}{C_r + 8.6}, \quad (15)$$

$$R_0^{av} = \frac{2F_{1,0}2.11 + 2F_{2,0}4.3 + 2F_{3,0}8.6 + F_{4,0}14.2}{F_0}, \quad (16)$$

where $F_{1,0}$, $F_{2,0}$, $F_{3,0}$, $F_{4,0}$ are the greenhouse soil surface, adjacent to the covering constructions and with a width of 2 m or 2, 4 and 6 meters over, respectively, m^2 .

2.5. Heat loss for heating infiltrating air

In cultivation facilities, infiltrating air flows mainly through the rabbet ledge of the windows and bay windows and depends on their length and width, wind speed and the difference between the densities of external and internal air [5]. The heat amount required to heat the infiltrating air is determined by the formula:

$$Q_{inf} = \frac{m_{inf} \cdot c \cdot (t_{wz} - t_{ext})}{3600}, \quad (17)$$

where m_{inf} is the air mass entering through the rabbet ledges, kg/h ; c is air specific heat, $J/(kg \cdot ^\circ C)$.

$$m_{inf} = \sum (m'la), \quad (18)$$

where m' is the mass of air entering through the 1 m rabbet ledge depending on the design wind speed, $kg/(m \cdot h)$ [5]; l is the length of the rabbet ledge, m ; a is correction coefficient taken 0.5 for windows and bay windows [5].

2.6. Calculation procedure

Initial data: $t_{ext} = -32^\circ C$; $t_{wz} = 15^\circ C$; $\tau_0 = 20^\circ C$; $\varphi_{wz} = 60\%$; $\varepsilon_0 = 0.96$; $\varepsilon_{con} = 0.92$; $F_0 = 40785 m^2$; $F_w = 4289 m^2$; $F_{sl} = 45518 m^2$, the temperature on the walls and slopes surfaces, respectively, $\tau_w = -2,5^\circ C$ and $\tau_{sl} = -18^\circ C$.

The calculation process is shown in Table 1:

Table 1. Heating system capacity calculation of the cultivation facility.

Formula number	Symbol	The calculation result	Dimension	Notes
6	α_c^s	3.69	$W/(m^2 \cdot ^\circ C)$	$A = 1.66$ by $t_d = 17.5^\circ C$, $m = 1.3$; $\Delta t = 5^\circ C$
5	Q_c^s	752510	W	$\Delta t = 5^\circ C$
6	α_c^w	4.36	$W/(m^2 \cdot ^\circ C)$	$A = 1.68$ by $t_d = 6.3^\circ C$, $m = 1$; $\Delta t = 17.5^\circ C$
5	Q_c^w	327250	W	$\Delta t = 17.5^\circ C$
7	m	0.73		
6	α_c^{sl}	3.98	$W/(m^2 \cdot ^\circ C)$	$A = 1.7$ by $t_d = -1.5^\circ C$, $m = 0.73$; $\Delta t = 33^\circ C$
5	Q_c^{sl}	5978335	W	$\Delta t = 33^\circ C$
9	C_r^w	3.03		$\varepsilon_0 = 0.96$; $\varepsilon_{con} = 0.92$
8	Q_r^w	2266650	W	
9	C_r^{sl}	5.06		$\varepsilon_0 = 0.96$; $\varepsilon_{con} = 0,92$
8	Q_r^{sl}	6389045	W	
10	Q_{ev}	1264840	W	$G_{w.c.} = 2040 l/h$
13	$\Delta \varepsilon^w$	0.52	%	$e_{t_{wz}}^s = 1.71 kPa$; $e_{\tau_{con}}^s = 0.50 kPa$
12	G_{cond}^w	216/5	l/h	$v = 13.83 \cdot 10^{-6}$ by $t_d = 6.3^\circ C$
11	Q_{cond}^w	148420	W	
13	$\Delta \varepsilon^{sl}$	0.89	%	$e_{t_{wz}}^s = 1.71 kPa$; $e_{\tau_{con}}^s = 0.12 kPa$
12	G_{cond}^{sl}	4975/0	l/h	$v = 13.15 \cdot 10^{-6}$ by $t_d = -1.5^\circ C$
11	Q_{cond}^{sl}	3410639	W	
15	t_g^w	11.1	$^\circ C$	$C_r^w = 3.03$
16	R_0^{av}	13.67	$(m^2 \cdot ^\circ C)/W$	$F_{1,0} = 1704 m^2$, $F_{2,0} = 1672 m^2$,

Formula number	Symbol	The calculation result	Dimension	Notes
				$F_{3,0} = 1640 \text{ m}^2, F_{4,0} = 35770 \text{ m}^2$
14	Q_g^w	128615	W	
15	t_g^{sl}	4.6	$^{\circ}\text{C}$	$C_r^{sl} = 5.06$
14	Q_g^{sl}	109080	W	
18	m_{inf}	123354	kg/h	$m' = 4.95 \text{ kg}/(\text{m} \cdot \text{h}); l = 49840 \text{ m}$ $a = 0.5$
17	Q_{inf}	1610455	W	$c = 1000 \text{ J}/(\text{kg} \cdot ^{\circ}\text{C})$
4	Q_h	15267721	W	

3. Conclusion

Thus, the heating system capacity of the greenhouse block № 3 in The Greenhouse Complex with a production area about 12 ha in the village of Sadovy, Ordzhonikidze District, Ekaterinburg, is 15.3 MW, while the transmission heat loss is 13.9 MW. Therefore, the difference between the capacities is 10%. It shows this calculation allows us to more accurately determine the heating system capacity of the cultivation facility.

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