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Thermal balance of greenhouse complexes of the V generation in the summer period

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Abstract. When growing various crops in greenhouses an important condition for obtaining high yields is compliance with the required parameters of the temperature regime of the air environment. The air conditioning systems currently used in greenhouses of the V generation "Ultra Clima" are equipped with adiabatic panels that cool the air entering the room by evaporation of moisture from their surface. However, in some cases, such systems are not able to support the required values. This is due to the large heat flows entering the greenhouse in the summer. The paper analyzes the temperature balance of the air environment of greenhouses of the V generation, evaluates the main heat flows, determines the operating modes of cooling systems that guarantee sufficient cooling capacity to achieve the required temperatures in the room.

1 Introduction

Modern semi-closed greenhouses of the V generation, equipped with microclimate adjustment systems, provide ample opportunities for their use in a number of regions of our country. The heating, cooling and humidification systems used in them, as well as CO_2 enrichment, are largely able to neutralize the negative impact of the environment. This becomes especially relevant in the development of such a direction as the biologization of agriculture. The relatively high isolation of the air environment of modern greenhouses, the increased pressure created in them, favorable air, solar and temperature-humidity regimes contribute to a significant reduction in the pesticide load when growing various crops.

At the same time, in some cases, during the hot season, the cooling systems that greenhouses are equipped with do not allow the indoor air to cool sufficiently, and therefore, its values may slightly exceed the temperatures set by the regulations, the values of which for some crops are shown in Table 1.

Table 1. Recommended air temperatures in greenhouses.

Culture	Air temperature before fruiting, ºC	Air temperature during the fruiting period, ºC
Cucumber	25 - 26	21 - 23
Tomato	24 - 26	20 - 22
The head lettuce	20 - 23	18 - 20
Radish	20 - 22	18
Peking cabbage	20	20
Dill, spinach	17 - 18	18 - 22

2 Materials and Methods

In order to determine the required cooling capacity of the air conditioning system, we will calculate the thermal balance of the greenhouse for the summer period. We will consider the most critical period of daylight in terms of the number of external heat accesses - from about 12 to 15 hours. The volume of air supplied to the greenhouse is limited by two factors: the air velocity in the plant placement area, which should be within 0.25 - 0.50 m/s and in rare cases may increase for a short time, but not more than 1m /s, as well as the level of CO_2 concentration, which with a large volume will tend to the street value of 440 ppm, whereas higher values are required for full photosynthesis.

Heating of the air environment inside the greenhouse is due to the receipt of energy from solar radiation, as well as from the lighting system. Cooling is carried out by a ventilation (air conditioning) system and heat transfer through the walls as long as the air temperature in the greenhouse is above street temperature. However, with a decrease in temperature inside the greenhouse below the outdoor heat flow unfolds and becomes positive - heats the greenhouse. Let's consider them in detail.

The value of heat gain with solar radiation can be determined by the formula:

$$Q_{pr} = K_{pr} Q_{sr} S_t \tag{1}$$

where Q_{pr} is the penetrating solar radiation, J; K_{pr} is the permeability coefficient of solar radiation. Its value depends on the time of year, geographical location, design features, surface cleanliness and is given in Table 2 for a two-layer glass clean surface; Q_{sr} - solar radiation on a horizontal surface, MJ/m2. Depends on the time of year and latitude. The values, in accordance with SN and R 23-01-99, are given in Table 2. S_t – greenhouse area, m2.

Table 2. Solar radiation per horizontal surface per month. The permeability coefficient of solar radiation.

Month	K_{pr}	Geographic latitude, degrees north latitude							
		Q_{sr}, MJ/м2							
		40°	44°	48°	52°	56°	60°	64°	68°
May	0,8	893	872	862	850	840	825	824	809
June	0,8	897	889	881	880	873	877	864	865
July	0,8	891	886	877	882	875	856	855	889
August	0,75	803	768	736	719	695	660	641	639

The thermal load from the lighting system is defined as:

$$Q_{osv} = q_{osv} S_t \tag{2}$$

where Q_{osv} is the thermal load from the lighting system, J; q_{osv} is the value of specific heat flows per 1m^2 of the calculated room, W/m^2. In the case of incandescent lamps, its value is assumed to be 25 W/m^2, for fluorescent lamps – 10 W/m^2.

Negative constant (independent of temperature differences and other factors) heat flows include the heat flow supplied to the greenhouse room by the ventilation system - Q_{vent}. According to its energy component, it is really negative, because in the hot season it enters the greenhouse with a lower temperature, cooling it. We can find its value by the formula:

$$Q_{vent} = C\rho G_{vh} t_n \tag{3}$$

where C is the heat capacity of the air, J/kg· ºC ; ρ is the air density, kg/m^3; G_{vh} is the air flow rate, m^3/s; t_n is the temperature of the outdoor (street) air, ºC.

Part of the heat is removed from the room together with the air removed from it. Its quantity can be estimated by the formula:

$$Q_{out} = C\rho G_{out} t_v \tag{4}$$

G_{out} - the flow rate of air removed from the greenhouse through the ventilation roof vents, m^3/s; t_v - the temperature of the air removed from the greenhouse, ºC.

Depending on the temperature difference inside the greenhouse and outside, there is an alternating heat flow that enters or exits the room due to heat transfer through the walls enclosing the greenhouse. In a stationary thermal regime , its value is determined by the formula:

$$Q_{ogr} = k_{ogr} F_{ogr} \left(t_n - t_v\right) \tag{5}$$

k_{ogr} is the heat transmission coefficient, W/(m2· ºC). For double glazing, it is equal to 0.46 W/(m2· ºC), and for triple glazing - 0.57 W/(m2· ºC); F_{ogr} is the area of the fence, m^2.

Thus, in the general case, we obtain the equation of the energy balance in the greenhouse in the form:

$$Q_{pr} + Q_{osv} + Q_{vent} + Q_{out} + Q_{ogr} = 0 \tag{6}$$

3 Results and Discussion

Solving the last equation with respect to t_v, it is possible to determine the dependence of the required amount of G_{vh} air entering the room on its temperature. The calculation results are shown in Fig. 1.

It is known that adiabatic panels, which are equipped with cooling systems of modern Generation greenhouses, are able to cool the air entering the room by no more than 8-10 ºC. As a result of calculations, it was found that with such a cooling depth, in order to achieve regulated temperatures in the greenhouse, in some cases it is necessary to provide an increased supply of cooled air in a volume of more than 250 thousand m^3/hour. In turn, this can lead to air velocity values in the plant growth zone above the maximum permissible.

Figure 2 shows the characteristics of a plate water vapor cooler in the form of a phase plane, which illustrates the nature of the dependence of air flow on temperature.

Each point of the phase plane carries information about the characteristics of the cooler. If the point lies on the graph of the function, then the temperature in the cooled object will be maintained at the specified level. If the point lies above the curve, then a lower temperature will be maintained in the room, which can be found from the balance equation.

In addition, air consumption is limited by several factors. Firstly, the minimum value of the air flow G_{min} is due to the minimum air exchange (this is the mass amount of air supplied to the room per unit of time to ensure the regulatory level of pollution of its air environment). Secondly, the maximum value of the G_{max} air flow is due to the maximum permissible air velocity in the plant placement area and the CO_2 concentration.

In the case of using a direct water vapor cooler, the temperature at the outlet of the cooler cannot be lower than the temperature of the wet t_{mt} thermometer.

Thus, the characteristics of the air conditioner at a given indoor temperature tv and a given outdoor temperature tn must satisfy the coordinates of the points located within the curved trapezoid ABCD

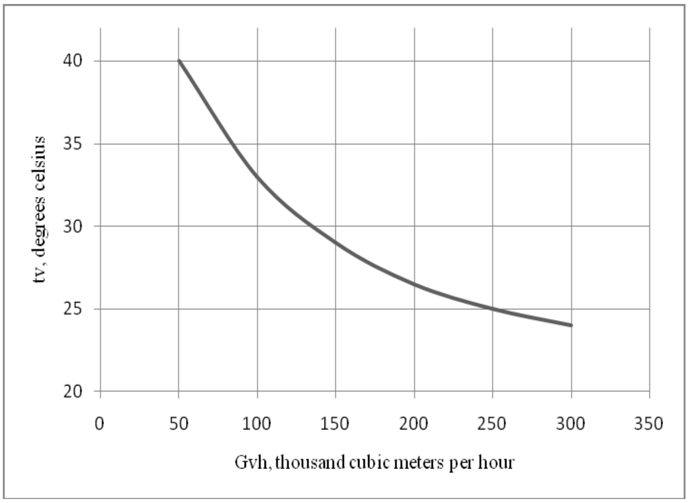

Fig. 1. The temperature regime of the greenhouse.

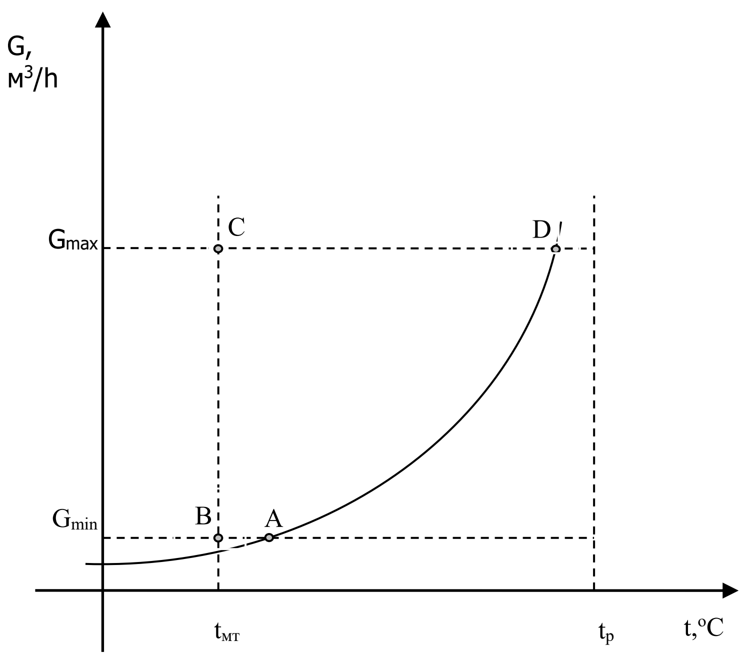

Fig. 2. The temperature regime of the greenhouse.

4 Conclusion

Thus, we come to the conclusion that in order to achieve regulated temperature values in the greenhouse in the hot season, it is necessary to use more efficient plate water-evaporating air coolers. Their use will allow to increase the depth of cooling of the supplied air flow, and therefore, it will be possible to reduce the volume of its supply, which will allow to withstand the regulated values of air velocity in the area of plant placement its CO_2 values.

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