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ENSURING THE PARAMETERS OF MICROCLIMATE OF HOTHOUSES DURING A WARM SEASON

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ABSTRACT

On the basis of justification of the heat and mass transfer processes inside the hothouses during a warm season authors developed methods and means that control dynamics of temperature and humidity parameters and air conditions with the help of complex systems of removal of overheat in hothouses during the all year round and diurnal operations at minimum power inputs.

Keywords: processes of the air parameters changes, systems of water aerosol cooling, stepwise removal of overheat.

1. INTRODUCTION

Under the climatic conditions of sharply continental climate in most regions of Russia growing vegetables in cold season is only in winter hothouses. Exploitation of winter hothouses in warm season is difficult due to overheating of the air inside of them because of the increased intensity of solar radiation. Crop losses in this period can reach 50 - 80 %, and sometimes there is a destruction of plants [1].

2. METHODS

The authors have developed complex system of removal of overheat in hothouses in the warm season. Given technique includes the use for the longest period of natural (passive) systems providing microclimate parameters (transoms, technological openings, aeration shaft) and for short-term inclusion of active systems, their key elements are the systems of water aerosol cooling (SWAC). While the process of system of water aerosol cooling, the water is spraying in the whole hothouse through the nozzles, and during the adiabatic evaporation water lowers the temperature of the internal air [2-4].

3. RESULTS AND DISCUSSIONS

We studied six typical modes of complex system of heat removal to ensure acceptable temperature parameters of air in hothouses: mode I - organized natural ventilation; mode II - co-operation of systems of organized natural ventilation and active aeration; mode III - co-operation of the mechanical ventilation and natural ventilation; mode IV - co-operation of the SWAC and natural ventilation; mode V - co-operation of the SWAC, natural ventilation and active aeration; mode VI - co-operation of the SWAC, natural ventilation and mechanical ventilation.

Dynamics of changes of air temperature in unventilated hothouse with plants in warm season, while openings and transoms are closed, is shown on the *i–d*-diagram of humid air (Figure-1).

In early morning hours the air temperature in the hothouse with plants in the phase of cultivated biomass t^m_{int} is close to or slightly higher than the outside air temperature t^m_{ext} (point H^m), relative air humidity $\varphi^m_{int} \to 100$ % (point B^m). We can observe condensate on the inner surface of translucent enclosures of hothouses. In this period of the day the temperature t^m_{int} can be below, equal to or higher than the design temperature, shown in figure 1 by the hatched area (1) with temperature gradient Δt_{calc}.

The point B^d with the parameters t^d_{int}, φ^d_{int}, moisture content d^d_{int}, g / kg of dry air, enthalpy of i^d_{int}, kJ / kg, shows the air condition in the hothouse during daylight hours in the absence of ventilation (area 3). The air temperature t^d_{int} is increased by solar radiation and significantly exceeds the allowable values. Such temperature conditions in hothouses arise in the climate conditions of central part of Russia, starting from mid-April.

In the first approximation we consider that the parameters of internal air (point *B*) are on the line B^m – B^d, that is the geometric position of the points of air state in unventilated hothouses [5-7].

The first stage of reducing the air temperature is natural ventilation of hothouse by opening transoms (mode *I*). Further lowering of air temperature in the hothouse is achieved by opening of technological openings and exhaust aeration shafts (mode *II*). Then additionally the exhaust fan is turned on (if any), located in the exhaust aeration shaft (mode *III*). During the light period of the day the position of point *B* on the line $B^m - B^d$ depends on the ventilation rate *n*, h^{-1}, the ability of biomass to self-regulate the temperature around the plant. Ventilation rate changes from n = 5 ... 10 h^{-1} under the natural air-change to n = 25...30 h^{-1} under the mechanical ventilation [1]. Therefore, the location of the point *B* (on the *i-d*-diagram

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of the moist air) will strive along the line $B^m - B^d$ to the point B^m in ratio of 1: (*n* – 1).

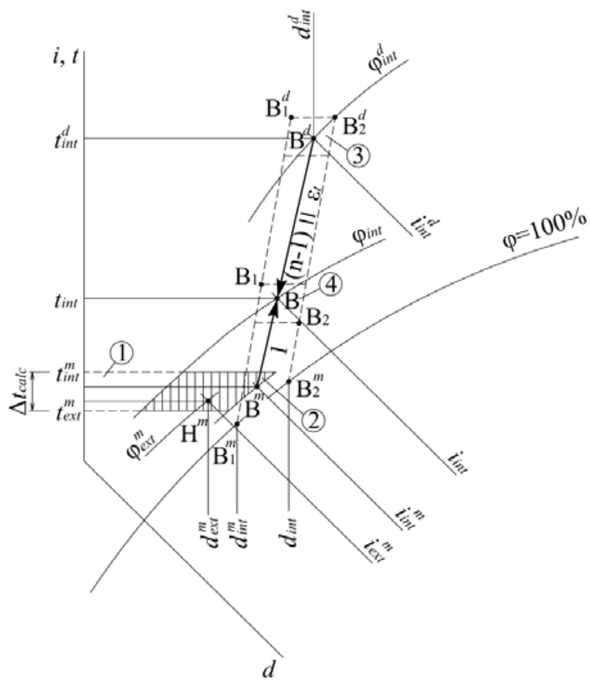

Figure-1. The area of self-regulation of the temperature in the hothouse in the process of untreated air supply: *1* – the area of technological temperatures in the hothouse; *2* – the area of the temperatures during the morning hours; *3* – the area of maximum temperatures in the absence of ventilation; *4* –the area of possible temperatures in the process of outdoor air ventilation.

So the area, bounded by the points B_1^m –B_1– B_1^d – B_2^d –B_2– B_2^m, characterizes the borders of temperature and humidity condition of the air in the daytime hours in the hothouse during the warm period of the year at the expense of natural and mechanical ventilation by the untreated atmospheric air and self-regulation of plants [8-9].

After exhaustion of the cooling effect of outdoor air to maintain technological parameters of microclimate, need for artificial cooling of the air in hothouses arises. Such a period of time usually occurs during the daylight hours, when the total solar radiation reaches 450 W/m^2 or more (from May till October).

Figure-2 shows the processes of changing the air state in the hothouse with the biomass during the operation of system of water aerosol cooling. After switching SWAC there is adiabatic cooling of air in hothouse according to i_{int} = const to φ = 97…98 % (process is schematically shown to φ = 100 % on the Figure-2) from the temperature t_{int} to the temperature of the wet thermometer $t_{w.t}^{int}$, which corresponds to the parameters of the point *B*. Concurrently moisture content in the hothouse increases from d_B to d_A according to the relative humidity in the point *A* (97 – 98 %). If the amount of the heat of solar radiation in the hothouse exceeds the amount of heat absorbed during evaporation of water aerosol droplets, the process of air cooling is terminated at the point *C* during the temperature t_C, the relative humidity φ_C and the moisture content of air d_C.

The air temperature after its processing by SWAC to point *A* or to point *C* (Figure-2) may be reduced to a range of technologically necessary temperatures in the hothouse (beam *B-A*) or be above them (beam *B–C*). Specific parameters of the air in the hothouse with volume V_h, m^3, during the ventilation rate *n*, h^{-1}, are determined by increment of its water content Δ*d*, which depends on the flow rate of sprayed water $G_{s.w}$, kg/h, and air density ρ_{int}, kg/m^3:

$$\Delta d = d_C(d_A) - d_B = \frac{1000 \cdot G_{s.w}}{V_h \cdot n \cdot \rho_{int}}. \quad (1)$$

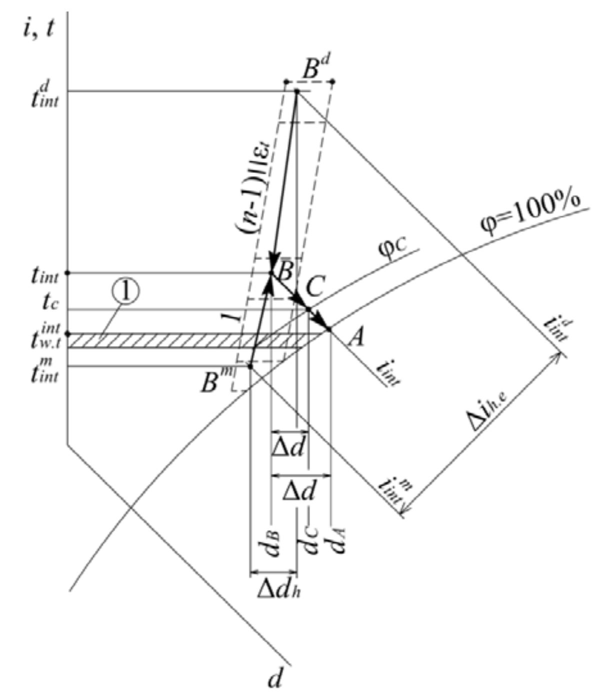

Figure-2. The processes of changing the air state in the hothouse with the biomass: *1* – the area of technological temperatures in the hothouse.

The reducing of intensity of solar radiation in the afternoon is accompanied by the decrease of internal air temperature. SWAC is switched off, but the exhaust fan, built inside the shaft, continues to operate; transoms and technological openings are opened. The parameters of internal air are transformed into the state of point *B*,

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corresponding to the parameters before the activation of adiabatic cooling system. The relative humidity and moisture content of the air decrease, but the temperature increases. This thermodynamic process is inevitable, because the heat capacity of the equipment in hothouses is negligible and plants can self-regulate the air parameters around themselves in the process of adaptive reactions during transpiration of moisture [10].

The process of removing the intensity of solar radiation in the day period after switching off SWAC and further regulation of the air parameters in the hothouses within a standardized technological values will be carried out by changing the position of point *B* on the line $B^m - B^d$.

These processes are possible when changing ventilation rate *n* by switching - off the exhaust fan, opening - closing the technological openings and transoms. In the evening when the internal air temperature in hothouse decreases to the design temperature and below, all the technological openings and transoms are closed.

The direction of the beam of the process is on *i*–*d*-diagram $\varepsilon_t = \Delta i_{h.e} / \Delta G_{m.r}$. The total heat emissions in the hothouse $i_{h.e}$ are determined according to the intensity of insulation heat gains. Moisture release in hothouse $\Delta G_{m.r} = \Delta d_h V_h \rho_{int}$ is composed of secretions of plants and evaporation from soil surface. After analyzed literature data and our field studies we recommend to take ε_t = 3700…4800 kJ/kg for central part of Russia during the peak of heat.

A coefficient of probability of operation of cooling systems K_{pr}^d was adopted as an indicator of the efficiency of removal of overheat for a day (*N* = 24 h) during the period of the field studies. Its value shows the share of total number of hours for a day, which does not allow to exceed the internal air temperature in a hothouse relative to the design temperature:

$$K_{pr}^d = (N - m)/N, \quad (2)$$

where *m* – the number of hours of temperature rises for a day.

Figures 3 and 4 show generalized experimentally obtained temperatures in the hottest period of sunny day. The shaded part indicates the area of optimal temperatures of internal air for growing crops. Operation Mode IV of complex system of overheat removal is not typical in practical terms and, therefore, has not been studied.

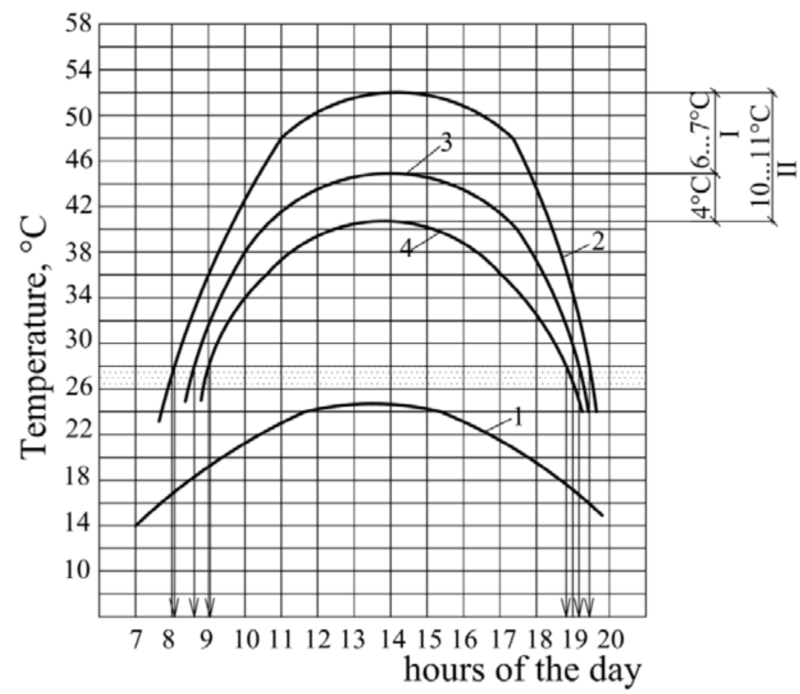

Figure-3. Changing of air temperature in a hothouse during the period of fruiting in daylight hours: *1* – outdoor air; *2* – internal air without operation of systems of removal of overheat; *3* – operation of the systems of organized ventilation (mode *I*); *4* – co-operation of the systems of organized ventilation and active aeration (mode *II*).

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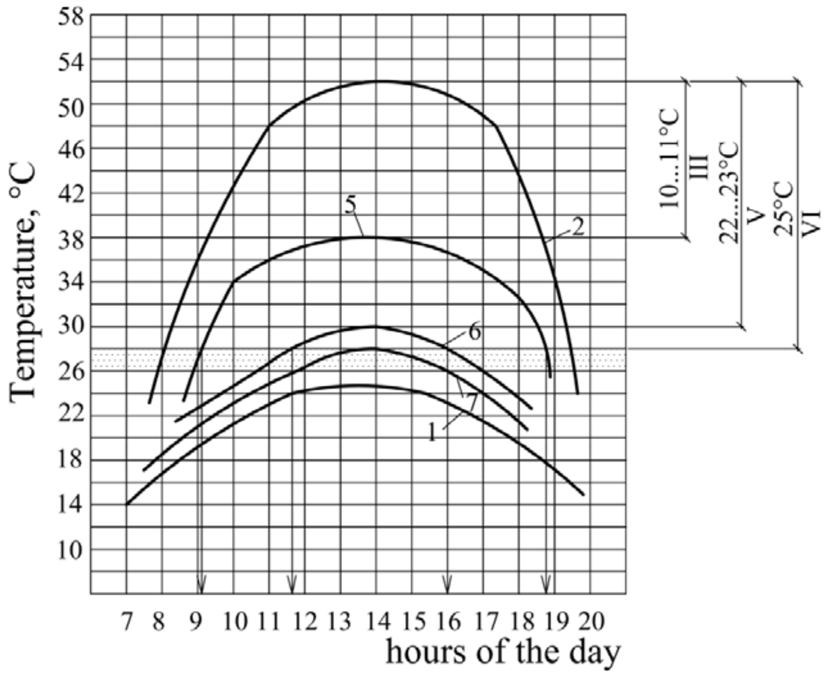

Figure-4. Changing of air temperature in a hothouse during the period of fruiting in daylight hours: *1* - outdoor air; *2* - internal air without operation of systems of removal of overheat; *5* - co-operation of the systems of organized ventilation and mechanical ventilation (mode *III*); *6* – co-operation of the systems of organized ventilation and SWAC (mode *V*); *7* - co-operation of the systems of organized ventilation, active shaft or mechanical ventilation and SWAC (mode *VI*).

The results of determining the values of a coefficient of probability of cooling systems operation during the day K_{pr}^{d} and quantitative indicators of reducing temperature in each of the operating modes of the complex system of removal of overheat Δt_{int} are shown in Table-1.

Table-1. Values K_{pr}^{d} and Δt_{int}.

Operating modes	I	II	III	V	VI
Δt_{int}, ºC	6…7	10…11	14…15	22…23	up 28
K_{pr}^{d}	0,567	0,60	0,63	0,833	1,0

It is necessary to determine coefficient of probability of temperature conditions in hothouse during the warm period in the annual cycle K_{pr}^{an} , for the period of fruiting of tomatoes and cucumbers, which lasts from April 1st to August 1st. The values of the coefficient are calculated by the formula:

$$K_{pr}^{an} = 1 - \left(N^{an} - m^{an}\right) / N^{an} . \qquad (3)$$

The number of days of fruiting for the central part of Russia is K_{pr}^{an} ≈ 120 days. The duration of the period of maintenance of maximum permissible internal air temperature ($t_{int} \leq 28$ ºC) m^{an}, days, in the hothouses from April to July, depending on operation modes of systems of maintenance of parameters of technological microclimate calculated by figure 5 that are obtained as a result of field studies. Changing the temperature t_{int} in the hothouse under the co-operation of SWAC with active shaft aeration and mechanical ventilation (mode *VI*) can be traced by the curve *6*. The maximum reducing temperature in hothouse during operation of complex system is 23 - 25 ºC. It almost always provides the necessary temperature regime for all the phenological phases of vegetables, including the fruiting stage (April - July) [11].

Therefore, the value K_{pr}^{an} ≈ 1 - (120 - 120)/120 ≈ 1, 0.

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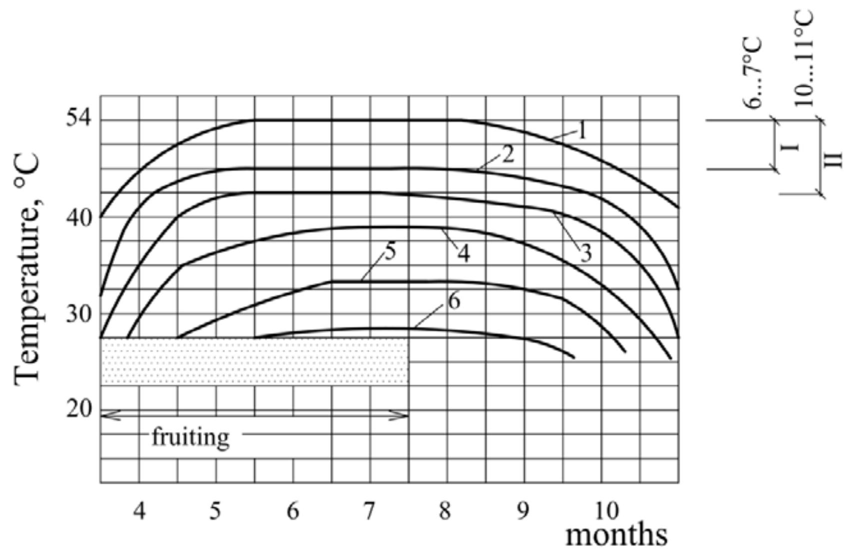

Figure-5. Changing of air temperature in a hothouse during the period of fruiting: *1* - without operation of systems of removal of overheat; *2* - operation of systems of organized ventilation (mode *I*); *3* - co-operation of the systems of organized ventilation and active aeration (mode *II*); *4* – co-operation of the systems of organized ventilation and mechanical ventilation (mode *III*); *5* – co-operation of the systems of organized ventilation, active aeration and SWAC (mode *V*); *6* – co-operation of the systems of organized ventilation, active shaft or mechanical ventilation and SWAC (mode *VI*).

The results of determining a coefficient of probability of the operating mode for the annual cycle of fruiting period are summarized in Table-2.

Table-2. The values of K_{pr}^{an} for the period of fruiting.

Operating modes of the complex system	I	II	III	V	VI
N^{an}, day	120	120	120	120	120
m^{an}, day	0	0	6	3,0	120
K_{pr}^{an}	0	0	0,05	0,25	1,0

4. CONCLUSIONS

Graphic-analytical and field studies of the thermodynamic processes in the hothouses showed that the internal air temperature during the period of maximum heat gain of solar radiation can be reduced by 23 – 25 ºC. The authors obtained quantitative values of coefficients of air temperature parameters in the hothouses during warm period of the year for the climate of central part of Russia in daily and annual cycles of operation of hothouses.

5. ACKNOWLEDGEMENTS

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