UDC 62-97

MODELING THE SPATIAL DISTRIBUTION OF TEMPERATURE ZONES IN THE GREENHOUSE

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The features of the division of space in the greenhouse temperature zones are shown. There is created a mathematical model and on its basis simulation model of spatially distributed temperature parameters of greenhouse atmosphere. In this case the identification of such parameters for each zone of greenhouse section is made by taking into account the external perturbation. The comparison of the calculated and experimental temperature meanings are done.

Actuality. Biologists proved that one of the main technological parameters for the greenhouse plants in greenhouse structures is the temperature, which is provided by microclimate system [1]. The maintaining of a given temperature in industrial greenhouse is a difficult task because the most areas are large and that promotes heat losses, uneven transfer of heat from the heating system, the influence of external disturbances. [1, 2]. The above mentioned leads to uneven temperature distribution.

The purpose of the study. The development of spatially distributed mathematical model of temperature in the greenhouse for its use in automatic control systems of uniform temperature distribution in greenhouse area.

Materials and methods of research. The conducted analysis of literature [3, 4] gives the reason to believe that the greenhouse is seen as an object with lumped parameters. At the same time the measuring parameters of the greenhouse atmosphere showed uneven distribution of temperature and formation of temperature zones that affect the efficiency of crop and peculiar only for objects with distributed parameters (Fig. 1).

There is developed a mathematical model for temperature determination in the greenhouse based on the results of various disturbances, that takes into account the spatial coordinate by the section width and can be used by the intellectual system for appropriate control algorithm implementation.

Essence of the method is in creation and research of mathematical model with spatially

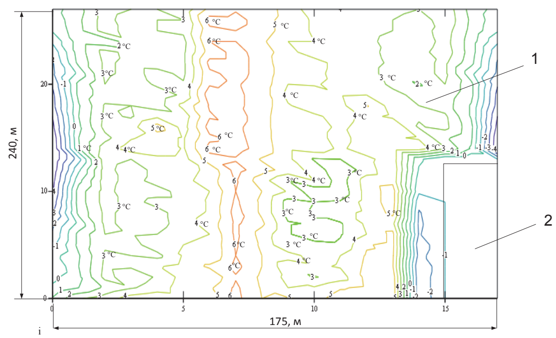

Fig. 1. Measurement results in the greenhouse difference the between actual and technologically desired values of temperatures: 1 – area for growing tomatoes; 2 – area for main and auxiliary control systems in growing plants

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distributed parameters, which developed on the basis of balance equations. Hereat was used Simulink MATLAB software, that allowed to research temperature distribution in the entire area of the greenhouse.

Results. In the production of vegetable products block houses were used. The space of one greenhouse section is conventionally divided into 8 temperature zones across the width of the greenhouse with regard to structural section features (Fig. 2). Apparently, zoning is carried out by vertical "sections".

It should be noted that the set temperature zones create sections, which in its turn compose the greenhouse block and at that the lateral zones 1, 8 are in contact with side surfaces (e) of sections zones or the outside air.

Parametric scheme model of greenhouse microclimate is shown in Fig. 3.

In the model development are made the following assumptions:

- for each zone, the option is considered homogeneous environment throughout of its area;
- the heat exchange with greenhouse soil will not consider due to the nature of the thermal protection of soil from the environment effects;
- the concentration of carbon dioxide is the same for all sections;

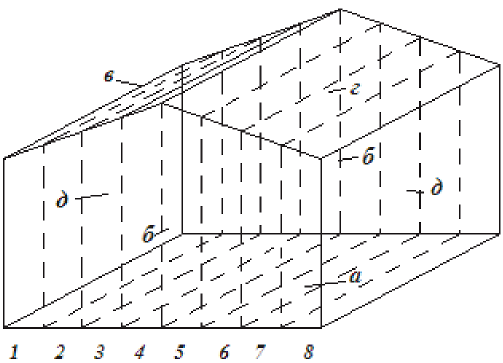

Fig. 2. Greenhouse volume separation into zones a – ground surface of greenhouse; b – face surfaces; c, d – the roof of greenhouse

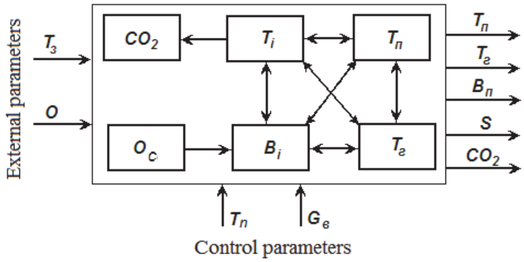

Fig. 3. Parametric scheme of climate model used in greenhouse section with account of external parameters and control parameters: TP – average air temperature, Tg – soil temperature, CO2 – carbon dioxide content in the section, S – intensity of solar radiation in the section; Tn – hot water temperature; Gv –hot water consumption; Oh – the intensity of solar radiation; Ts – ambient temperature

- heat transmitted from the Sun depends on the day period and the angle of incidence to the roof of the greenhouse (in zones 1-4, 5-8 this angle is different because of the characteristics of greenhouse roof slope).

The temperature and humidity in the area – Ti and Bi is considered on the basis of 8 interacting zones.

The arrows in the Figure of parametric diagrams indicate the relationship between the internal variables used.

According to the parametric scheme equation of thermal balance for each zone can be written as:

$$Q_i = Q_n + Q_к + Q_m + Q_в + Q_z + Q_c \quad (1)$$

where Qi – warmth in the i-th zone, J; Qp – the warmth from the heating system, J; Qk – warmth transferred through the roof and side walls, J; Qt – warmth transmitted through the side walls, J; Qv – warmth for ventilation air heating, J; Qz – warmth by heat transfer from neighboring areas, J; Qs – warmth from the solar radiation, J.

Each section affects the greenhouse temperature balance. In addition the amount of warmth for i-zone Qi will depend on the amount of warmth given or received from neighboring areas (i + 1, i-1) Qi + 1 and Qi-1. Thus:

$$\frac{dQ_i}{d\tau} = Q_{t,i} + Q_{s,i} - Q_{sr,i} - Q_{v,i} + Q_{i+1}, \quad (2)$$

where i = 1..8, Qt – the amount of warmth received from the heating system; Qs – the amount of warmth received from the Sun, J; Qv – warmth losses through the greenhouse roof and side walls, J; Qi + 1, Qi-1 – the amount of warmth received from the adjacent temperature zones, J; Qsr, and – the amount of warmth absorbed by plants and i-zone, J.

Quantity of warmth in the greenhouse depends on:

$$Q_i = C_p V_p \rho_p t_i, \quad , \quad (3)$$

where CP – warmth capacity of air, J/kg • ° C; ρr – air density, kg/m3; tp – temperature, • °C; Vp – greenhouse volume, m3:

Warmth quantity that is given in a greenhouse by the heating system is determined by:

$$Q_{t,i} = k_{tp} S_t (t_{w,i} - t_i), \quad , \quad (4)$$

where ktp – coefficient of heat transfer through the wall of the pipe heating W / m • °C, St – heating tube surface area, m2; tw, and – the water temperature in the pipes and i-zone, • ° C; Ti – the air temperature in the i-zone and, °C.

The model also takes into account the effect of solar energy, which is equal to:

$$Q_{s,i} = k_s S_{k,i} O_{cv}, \quad , \quad (5)$$

where ks – coefficient of heat transfer through the glass surface of the greenhouse, W / m • ° C; Sk – the glazed surface of the greenhouse roof, m2; Osv – solar radiation intensity, W/m2.

Heat transfer coefficient is calculated as [2]:

$$k_{tp} = \frac{1}{\frac{1}{\alpha_{vt}} + \frac{\delta_t}{\lambda_t} + \frac{1}{\alpha_{tp}}}, \quad ,(6)$$

$$k_s = \frac{1}{\frac{1}{\alpha_{pc}} + \frac{\delta_c}{\lambda_c} + \frac{1}{\alpha_{cz}}},$$

where αvt, αtp, αpc, αcz – heat transfer coefficient from water to the pipe wall, from the pipe wall to the greenhouse air, from greenhouse air to glass wall of a greenhouse, from the glass to the external air, respectively, W / m2 • ° C ; λt, λc – coefficient of tubes thermal conductivity and walls glass respectively, W / m2 • ° C; δt, δc – pipe wall and glass thickness, mm.

Warmth expenditures are determined by the taking into account all side surfaces of greenhouse, which borders the appropriate temperature zone:

$$Q_v = k_{pz} (S_{b,i} - S_{k,i})(t_i - t_z), \quad (7)$$

where kpz – coefficient of warmth transfer through the side surfaces of the greenhouse to environment W / m2 • ° C; Sb,i – the surface area of the i-zone, m2; ti, tz – the air temperature in the i-zone and the outdoor temperature respectively, °C.

To assess the impact of plants on the temperature conditions in the cross-section of the greenhouse, the heat value that falls in the greenhouse i-zone, and will be calculated by the formula:

$$Q_{sr,i} = \mu_i \cdot Q_s \quad ,(8)$$

where μi – a coefficient which takes into account the selection of light by plants to photosynthesis in i-zone, W / m2.

This ratio will depend on the plant size and the area of its leaves. It is obtained from the experimental data.

Warmth quantity that is transferred between greenhouse zones is defined as:

$$Q_{i-1} = \lambda_p S_{i-1,i} (t_{i-1} - t_i) \quad , (9)$$

where λr – thermal conductivity of i-zone air J / m • ° C; Si-1,i – the surface area between adjacent temperature zones, m2; ti-1 – the temperature in the adjacent zone, ° C.

In the same sequence the amount of heat is calculated that is transferred into another adjacent temperature zone:

$$Q_{i+1} = \lambda_p S_{i+1,i} (t_{i+1} - t_i) \quad . (10)$$

A mathematical model is developed for the greenhouse of 4.2 hectares area: the length of the block – L2 = 50 m, the width of section – 16 m, the slope of the roof is 30 °. Because of the width between rows one zone

Table. The geometrical dimensions of temperature zones

№	Height of zone, m	Area of Lateral surface, m^2	Volume of zone, m^3
1	5,155	9,155	457,735
2	6,309	11,464	573,205
3	7,464	13,774	688,675
4	8,619	16,083	804,145
5	8,619	16,083	804,145
6	7,464	13,774	688,675
7	6,309	11,464	573,205
8	5,155	9,155	457,735

is set equal to L1 = 2 m, the height of extreme bearing wall H1 = 4 m. During the calculations was taken into account that the surface areas of land between the center of the greenhouse will be increased by the height increasing of each zone (case-angle roof) (Fig. 4)

The roof area is the same in each zone – Sk = 86 m2.

Knowing the geometric dimensions of the greenhouse and found warmth transfer coefficients, we can write the final warmth balance equation for the i-zone explicitly:

$$64434{,}168\cdot t\frac{dQ_i}{d\tau}=1657{,}92\cdot(t_{w,i}-t_i)+3\cdot S_{k,i}+4\cdot(S_{b,i}-S_{k,i})(t_i-20)+ \\ +0{,}026\cdot S_{i-1,i}(t_{i-1}-t_i)+0{,}026\cdot S_{i+1,i}(t_{i+1}-t_i)-3{,}3\cdot S_{k,i}. \qquad (11)$$

The mathematical model of warmth balance (11) is implemented in Simulink MATLAB mathematical package by the simulation model (Fig. 5)

Each zone model is connected parametric with the adjacent temperature zones. In extreme zones of the first and eighth, moreover a heat exchange originates with the environment. The heat exchange happens with the environment also gets through section end surfaces. Solar energy is transmitted through the roofs of each zone based on roof slope.

As already noted the greenhouse section consists of 8 temperature zones, and its heat balance equation is shown by the equation set that can be implemented in the mathematical package Simulink MATLAB:

$$\begin{cases} 644341{,}68t\dfrac{dQ_1}{d\tau}=11\cdot S_t(t_{w,1}-t_1)+1180{,}52\cdot(t_1-20)+ \\ +8{,}19\cdot(t_2-t_1)-25{,}8; \\ 644341{,}68t\dfrac{dQ_i}{d\tau}=11\cdot S_t(t_{w,i}-t_i)+3\cdot S_{k,i}+4\cdot S_{b,i}+S_{k,i})(t_i-t_z)+ \\ +0{,}026\cdot S_{i-1,i}(t_{i-1}-t_i)+0{,}026\cdot S_{i+1,i}(t_{i+1}-t_i)-3{,}3\cdot S_{k,i}, \quad i=2...7; \\ 644341{,}68t\dfrac{dQ_8}{d\tau}=11\cdot S_t(t_{w,8}-t_8)+258+1180{,}52\cdot(t_8-t_{i+1})+ \\ +8{,}19\cdot(t_7-t_8)-25{,}8. \end{cases} \qquad (12)$$

The model which is represented by system (12), studied at ambient temperature of 20 °C and with the intensity of solar energy at 300 W/m2.

When applying perturbation steps (ambient temperature varies from 0 to 20 °C and the temperature of the hot water heating system from 0 to 60 °C), the temperature in

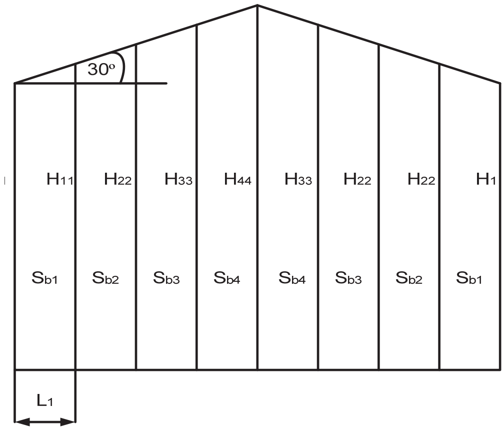

Fig. 4. the greenhouse zone sections with its cross–section: Hi – altitude areas; Sbi – the area of the lateral surface area; 1..8 – zones

different zones at the end of the transition process is stabilized on the level from 23.5 to 26 ° C and the time acceleration in this case is from 2000 to 6000 seconds (Fig. 6). This is explained by the different zone volume and by the different operation of various external disturbance on extreme and inner zones, which leads to uneven greenhouse atmosphere heat exchange with heating pipes.

Herein compared the results of the calculation according to model and the experimental measurements of temperatures in cross-section (temperature relief) of greenhouse section from 1 to 8 zones (Fig. 7).

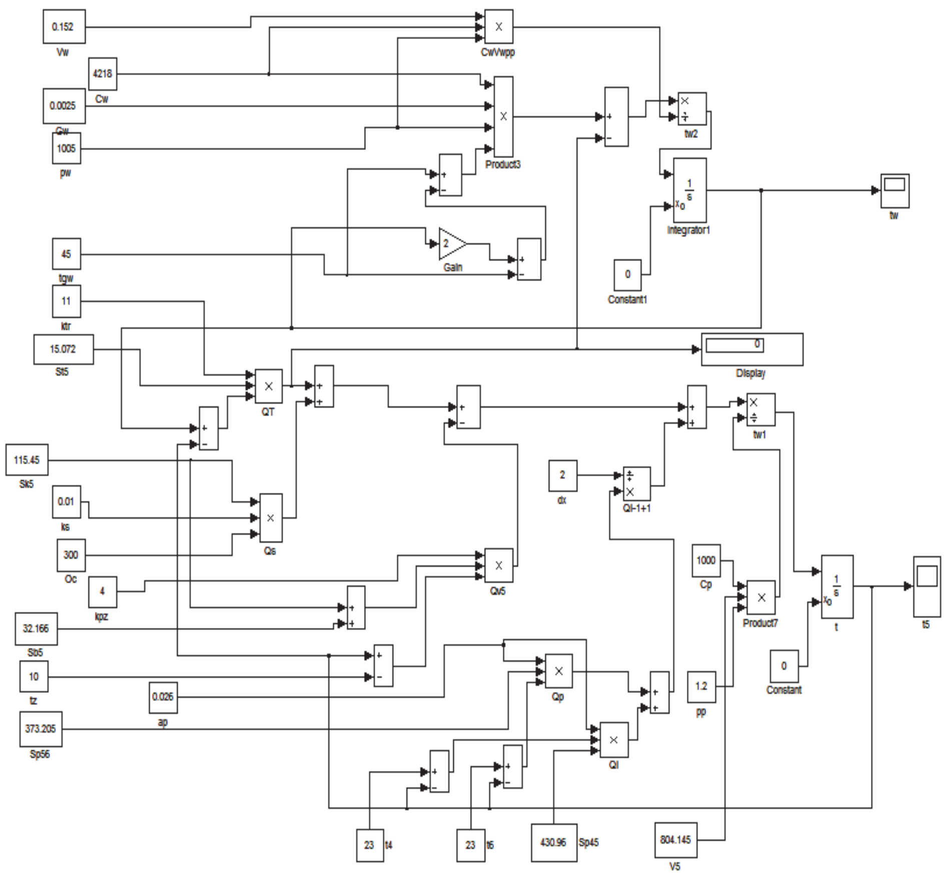

Fig. 5. Simulation model of temperature zones in the greenhouse section of the Simulink MATLAB package

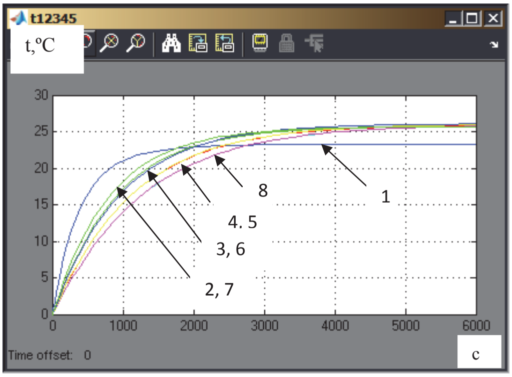

Fig. 6. Temperature change in the greenhouse section: 1..8 – air temperatures in their respective areas under the section according to Fig.

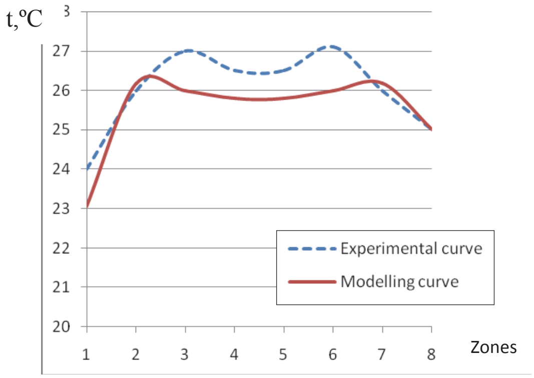

Fig. 7. Comparison of temperature calculations results by the model and its experimental measurements used for greenhouses (static mode)

To assess the adequacy of the developed mathematical model is usied mean-square deviation calculated by the known algorithm:

$$\delta = \sqrt{\frac{\sum_{i=1}^{n}(t_i - t_{pi})^2}{n-1}}, \qquad (13)$$

where δ – calculating standard deviation of measurements; ti – the result of the calculation of the model that investigated; tri – parameter value based on the results of experimental measurements; n – sample size.

The calculated standard deviation equal to 1,05 ° C, confirming the model adequacy.

Conclusions

Proposed the mathematical model of the greenhouse as an object with distributed parameters. The results of simulation modeling confirmed the use of this model in controlling systems of electrotechnical complexes. Herein mean-square deviation of calculated from experimental measurements of temperature did not exceed 1.05 °C.

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АНОТАЦІЯ

Лисенко В.П., Мірошник В.О., Лендел Т.І. *Моделювання просторового розподілу температурних зон у теплиці// Біоресурси і природокористування. – 2015. – 7, № 1–2. – С. 159–164.*

Показано особливості поділу простору в теплиці на температурні зони. Розроблено математичну і на її основі імітаційну модель просторово розподілених температурних параметрів атмосфери теплиці. При цьому визначення параметрів для кожної зони секції теплиці здійснюється з урахуванням дії зовнішнього збурення. Проведено порівняння розрахованих значень температури з експериментальними.

АННОТАЦИЯ

Лысенко В.П., Мирошник В.А., Лендел Т.И. *Моделирование пространственного распределения температурных зон в теплице // Биоресурсы и природопользование. – 2015. – 7, № 1–2. – С. 159–164.*

Показаны особенности разделения пространства теплицы на температурные зоны. Разработана математическая и на ее основе имитационная модель пространственно распределенных температурных параметров атмосферы теплицы. При этом определение таких параметров для каждой зоны секции теплицы осуществляется с учетом действия внешнего возмущения. Проведено сравнение рассчитанных значений температуры с экспериментальными.