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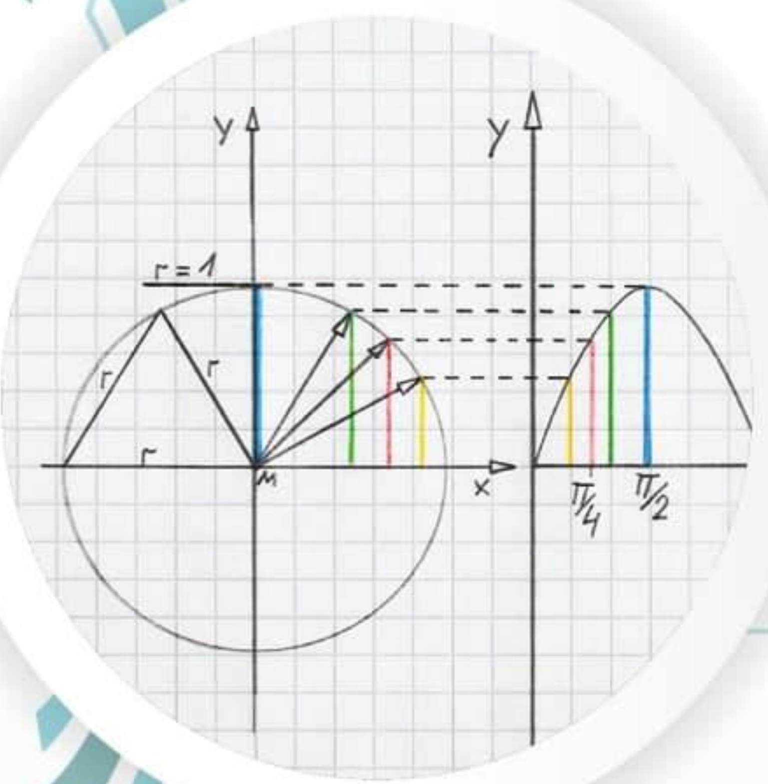

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Mathematical model of the internal temperature control system of the greenhouse

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Abstract. The article developed a mathematical model of an indoor and outdoor system of indoor air temperature control system MATLAB / Simulink package by balancing the heat load of the greenhouse with the utilization of the livestock building, solar energy and hot water from the biogas water boiler. On this basis, the daily and annual operating mode of the relay at a temperature of 18 ± 2 was developed.

Keywords: temperature adjustment, heat loss, heat transfer, heat energy, heat balance.

1. Introduction

On cold days of the year, it is important to create a temperate climate regime in greenhouses, a greenhouse wall (clear surface) that protects it from the cold external environment that surrounds it, and heating systems that provide comfortable greenhouse conditions. To ensure that the air temperature inside the greenhouse is at the required level, the recommended heating systems must emit a specified amount of heat. This will require the generation or transfer of the required heat. As a result, heating systems consist of three main components: a heat generator (heat generator), a device that transfers the generated heat from the source to the heated building (heat exchanger) and a heat exchanger (heating device).

In water heat supply systems, the quality of heat transfer is usually adjusted. It ends with a change in the temperature of the heat carrier according to the accepted temperature graph [1,2].

There are a number of steps to adjust the climatic conditions of heated greenhouses:

1) Installation of constant temperature adjustment device;

2) Installation of temperature adjustment device according to the schedule;

3) Installation of a device that simultaneously adjusts the greenhouse air through the graphic and adjustment device;

4) Divided control programs on the outside air temperature, on the schedule and the contours of the heating systems by installing temperature regulators.

The more temperature controls are installed, the more efficient the heat supply system will be. The inertia of the heating system is an important factor in energy saving.

In district heating, controlling the length of the heating network and the change in the size of the heat carrier throughout the system depending on climatic conditions over time is a long and complex process. This is much easier in autonomous heat supply systems. The heating system and its control automation detect outside air changes in a very short time. This, in turn, serves to save energy carriers.

The problem of modeling heat transfer processes in different environments has been studied [3-8], the purpose of which is to focus on the process of heat exchange inside the heated object, that is, to develop a mathematical model of adjusting the internal temperature of the greenhouse. One of the sources of renewable energy in Uzbekistan is favorable climatic conditions for the use of solar energy. In the following years, various projects on the basis of solar energy have been created in our country and their availability is being improved. One of the main elements of solar devices is the heat accumulator in it.

2. Method and materials.

Parameters given for modeling Determining heat loss from a heated building. Dimensions of the heated greenhouse: 30x6x3m. The external construction of the greenhouse consists of a two-layer film, so that the north side is bordered by the wall of the livestock building, we cannot ignore the heat loss from this part. For the sake of simplification, we will only consider basic heat losses. The heat lost to the external wall environment at night or in the absence of solar radiation can be recorded as follows [9,10]:

$$Q_{ex.w.} = k_{ex.w.} F_{g.h.} K_{set} (t_{g.h.} - t_{ext}) K_{\inf} \quad (1)$$

here $k_{ex.w.}$ - is the heat transfer coefficient of the greenhouse external wall, for a two-layer polyethylene film $k_{ex.w.} = 5{,}8W/(m^2 \cdot {}^0C)$; $F_{g.h.}$ - working area of the greenhouse, m^2; K_{set} - is the set coefficient, which is estimated by the ratio of the total external wall of the greenhouse to the working area; $t_{g.h.}, t_{ext}$ - greenhouse and external ambient temperature of the greenhouse, respectively ${}^0C$; $K_{\inf}$ - infiltration coefficient.

During the colder times of the year (mainly winter) when the outside air temperature is lower than the inside temperature of the greenhouse, the heat flow in the outer wall of the greenhouse is directed outwards along the wall. If it is required to keep the temperature inside the greenhouse in a large or small continuous state, it is necessary to constantly compensate for the amount of heat lost for heating. The internal temperature of the greenhouse should be 18^{0}C. Modeling is performed using the program MatLab [11,12].

Calculation of heating equipment. The greenhouse is built next to the livestock building and the north side of the greenhouse is bordered by the wall of the livestock building. The fans in the wall between the livestock and greenhouse complex are designed to circulate the air of the heated livestock building to the greenhouse due to the free heat released from the livestock. Based on this, the system of heat supply to the greenhouse on sunless days and at night will consist of two components:

1) through the hot air flow due to the utilization of air in the livestock building;

2) The hot water obtained by burning the biogas obtained from the processing of animal waste in a bioreactor in a water heating boiler through a heat exchanger located inside the greenhouse.

We know that the temperature inside the bioreactor should not exceed 55^{0}C when obtaining biogas by thermophilic method. The hot water from the water heating boiler exits the heat exchanger inside the greenhouse through the heat exchanger inside the bioreactor and the temperature at which the water returns to the boiler is required to be not less than 55^{0}C. In this case, the temperature of the hot water at the outlet of the water heater should be 65-70^{0}C.

The heat supplied to the greenhouse by the hot air flow due to the air utilization of the livestock building can be expressed as follows [13]:

$$Q_{ven.} = L\rho_{air}c_{air}(t_{liv.} - t_{g.h.}) \tag{2}$$

where L - volumetric consumption of air exchange between the livestock building and the greenhouse, m^3/s; $\rho_{air} = 1{,}293\, kg/m^3$ - air density; $c_{air} = 1005\, J/(kg \cdot {}^0C)$ - specific heat capacity of air; $t_{liv.}$ - air temperature in the livestock building, ${}^0C$.

Heat transfer from the heat exchanger located inside the greenhouse to the hot water obtained by burning biogas from the processing of livestock waste in a bioreactor in a water heating boiler Q determined from the following expression [14]:

$$Q_{heat} = G_w c_w (t_w - t_w') \tag{3}$$

here G_w - mass consumption of heat carrier, kg/s; c_w - specific heat capacity of the heat carrier, $J/(kg \cdot {}^0C)$; t_w, t_w' - the temperatures at the input and output of the heat carrier to the greenhouse heating system, respectively ${}^0C$.

Adjust the air temperature in the greenhouse. The analysis of the temperature adjustment of the heated greenhouse can be expressed in the form of a differential equation. In order to simplify the process of greenhouse air temperature analysis, we consider the interior of the greenhouse as a homogeneous body and the temperature at all its points is the same.

Heat energy transferred to the greenhouse Q, to heat the greenhouse air Q_{air} and to cover the heat energy lost through the outer wall $Q_{ex.w.}$ is spent

$$Q = Q_{air} + Q_{ex.w.} \tag{4}$$

The amount of heat introduced into the greenhouse over a short period of time $Qd\tau$, greenhouse temperature $dt_{g.h.}$ to heat $\rho_{air}V_{air}c_{air}dt_{g.h.}$ and to cover heat losses through the external wall $k_{ex.w.}F_{g.h.}K_{set}(t_{g.h.} - t_{ext})K_{\inf}d\tau$ we have a differential equation equal to:

$$Qd\tau = \rho_{air}V_{air}c_{air}dt_{g.h.} + k_{ex.w.}F_{g.h.}K_{set}(t_{g.h.} - t_{ext})K_{\inf}d\tau \qquad (5)$$

Bunda τ - time, s; V_{air} - the size of the greenhouse, m^3 .

The left and right sides of the last equation $k_{ex.w.}F_{g.h.}K_{set}K_{\inf}d\tau$ we write as follows:

$$\frac{Q}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}} = \frac{\rho_{air}V_{air}c_{air}}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}}\frac{dt_{g.h.}}{d\tau} + t_{g.h.} - t_{ext}$$

$$\frac{Q}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}} + t_{ext} = T_{g.h.}\frac{dt_{g.h.}}{d\tau} + t_{g.h.} \qquad (6)$$

where Q - heat energy transferred to the greenhouse, W; $T_{g.h.} = \frac{\rho_{air}V_{air}c_{air}}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}}$ - the time constant of the heated greenhouse, s.

From the existing equation we have the transfer function of the heated greenhouse

$$W(p)_{g.h.} = \frac{\frac{Q}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}} + t_{ext}}{T_{g.h.}p + 1} \qquad (7)$$

From the above it can be concluded that:

1) Heating or cooling the greenhouse does not depend on the amount of heat supplied. This process also depends on the mass of greenhouse air. The greater the mass and heat capacity of the greenhouse air and the smaller the thermal conductivity of the barriers and others, the greater the time constant $T_{g.h.}$ for the greenhouse.

2) After the heating system is turned off (on sunny days), the drop in greenhouse air temperature slows down when the outside air temperature is high [14,15].

3. Results and Discussions

Schematic diagram of air temperature adjustment in an open system. An outdoor temperature $t_{ext} = -6^0C$. The temperature of the heat carrier at the entrance and exit to the greenhouse is taken from the experimental results, $t_w = 69{,}8^0C$, $t_w' = 64{,}7^0C$. The temperature of the livestock building $t_{liv.} = 26{,}8^0C$. The size of the greenhouse: $V_{air} = 30\cdot 6\cdot 3 = 540\ m^3$.

Time constant of the heated greenhouse:

$$T_{g.h.} = \frac{\rho_{air}V_{air}c_{air}}{k_{ex.w.}F_{g.h.}K_{set}K_{\inf}} = \frac{1{,}293\cdot 540\cdot 1005}{5{,}8\cdot 180\cdot 1{,}25\cdot 1{,}11} = 484{,}4\ sek. \qquad (8)$$

Now we determine the heat energy supplied to the room from the heating device.

Mass consumption of heat carrier $G_w = 1kg/s$; Specific heat capacity $c_w = 4190\,J/(kg\cdot^0 C)$ [16,17,18].

The heat given off by heating the greenhouse can be calculated by taking into account the expressions (2) and (3) as follows:

$$\begin{gathered} Q = Q_{ven.} + Q_{heat} = L\rho_{air}c_{air}(t_{liv.} - t_{g.h.}) + G_w c_w(t_w - t_w') = \\ 1{,}18\cdot 1{,}293\cdot 1005\cdot(26{,}8 - 18) + 1\cdot 4190\cdot(69{,}8 - 64{,}7) = 34862{,}5\ W \end{gathered}; \qquad (9)$$

This thermal working area completely covers the heat load of a 180 m^2 greenhouse. But on sunny days, the above calculations will also need to take into account solar radiation. As a result, the temperature inside the greenhouse rises and the greenhouse air temperature needs to be adjusted. The average daily amount of solar radiation $q_{rad} = 150W/m^2$ assuming the above heat load is as follows:

$$\begin{gathered} Q = Q_{ven.} + Q_{heat} + Q_{rad} = L\rho_{air}c_{air}(t_{liv.} - t_{g.h.}) + G_w c_w(t_w - t_w') + \alpha_{trans}k_{trans}F_{g.h.}q_{rad} = \\ 1{,}18\cdot 1{,}293\cdot 1005\cdot(26{,}8 - 18) + 1\cdot 4190\cdot(69{,}8 - 64{,}7) + 0{,}8\cdot 0{,}8\cdot 180\cdot 150 = 52142{,}6\ W \end{gathered}; \qquad (10)$$

Considering expression (10), we construct a block diagram of the transfer function in expression (7) in the MatLab / simulink package (Figure 1). Greenhouse temperature the modeling results are shown in Figure 2.

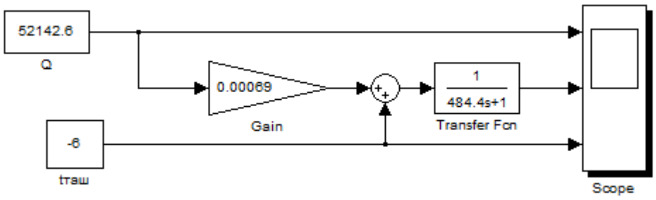

Figure 1. Block diagram of the MatLab / simulink package for temperature adjustment in an open system.

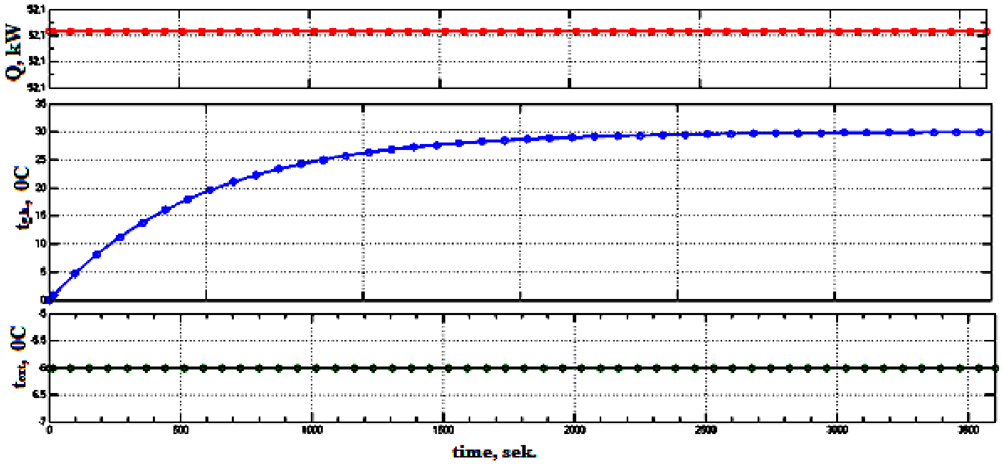

Figure 2. Modeling results for greenhouse greenhouse temperature.

As can be seen from Figure 2, the amount of air temperature set in the greenhouse is 30^{0}C, which is much higher than the required 18^{0}C temperature. It turns out that it is necessary to adjust the air temperature in the greenhouse.

Structure diagram of temperature regulation in a closed system. Adjustment is done using a thermostat. Deviation from the required temperature $\pm 2^0 C$ if high, then the signal at the thermostat output is equal to one, otherwise - to zero. In the diagram in Figure 1, to perform this adjustment method, the air temperature in the greenhouse must be performed inversely related.

Suppose the outside air temperature for 132 days-10^{0}C and +8^{0}C assuming that the minimum value in the range is -10^{0}C. ga teng. For example, outside air temperature on November 1st +8^{0}C, On December 31, it was -10^{0}C, and since March 2, the outside air temperature has reached +8^{0}C. It can be concluded that the outside air temperature is a periodic function, the period of its change and its maximum and minimum values are known to us.

We construct a block diagram using the MatLab / simulink package (Figure 3). Greenhouse air temperature $t_{g.h.}$ outdoor air temperature t_{ext} We represent the modeling result in Figure 4.

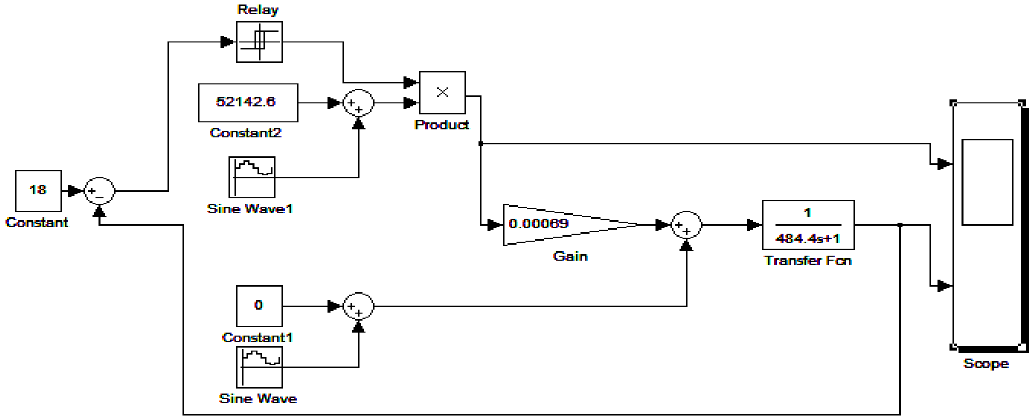

Figure 3. Block diagram of the MatLab / simulink package for temperature adjustment in a closed system.

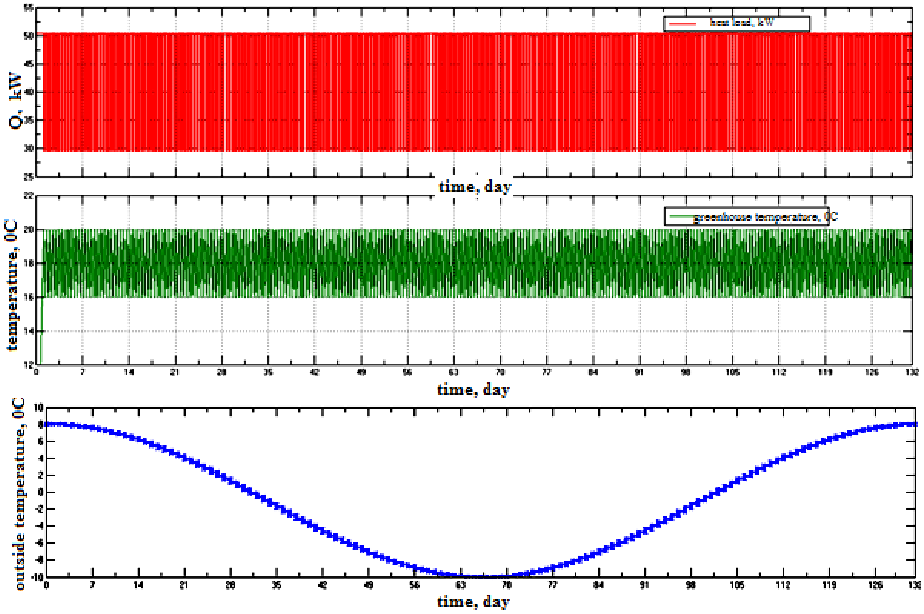

Figure 4. The process of transition of air temperature in the greenhouse.

As can be seen from Figure 4, the thermostat connection rate increases as the outside air temperature decreases.

Figure 5 shows the results of the system for adjusting the temperature of the greenhouse without disconnecting from the hot water supply, placing the results in the block diagram in Figure 3, measuring the hourly variation of outside air temperature and solar radiation on 11.01.2021.

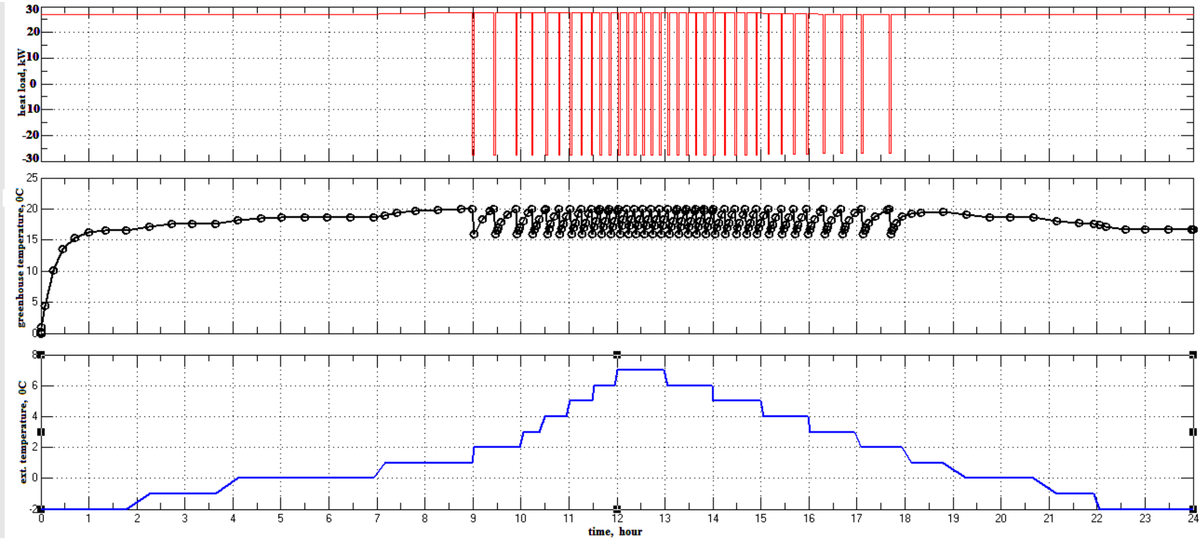

Figure 5. The process of daily transition of air temperature in the greenhouse (11.01.2021).

As can be seen from Figure 5, the livestock building is required to adjust the internal temperature of the greenhouse during the day, ie from 9:00 to 18:00, when there is a constant exchange of air through the greenhouse. In the meantime, the thermostat connection rate is increasing. During the day, when the outside air temperature is 7^0C and the amount of solar radiation is 388 W/m^2, there is a need to accumulate excess heat in the greenhouse.

4. Conclusions

A block diagram has been developed to maintain the air temperature $18 \pm 2\ {}^0C$ in the greenhouse.

The advantages of the obtained structural scheme are:

1) Simplicity;

2) Taking into account the heat lost in the greenhouse;

3) The ability to clearly demonstrate the dynamic changes in external conditions (temperature);

Disadvantages of the scheme:

1) Consideration of one type of heat exchange in the considered structure;

2) Additional heat losses to be taken into account: the location of the boundary structure depending on the light drop; heat loss through the soil; the effect of wind on boundary structures; that the cooling of the greenhouse from the opening of the doors was not taken into account. Heat exchange through plants in the greenhouse is not taken into account.

The results of modeling in the MatLab program confirm the performance of the block diagram and its applicability in practice. The shortcomings mentioned above can be remedied by modernizing the scheme in accordance with the given conditions.

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