

MODELLING THE WORK OF CLOSED SYSTEM OF HEATING AND VENTILATION OF GREENHOUSES

МОДЕЛЮВАННЯ РОБОТИ ЗАМКНУТОЇ СИСТЕМИ ОПАЛЕННЯ І ВЕНТИЛЯЦІЇ ТЕПЛИЦЬ

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ABSTRACT

A simulation mathematical model is proposed for the analysis of energy intensity of mushrooms production and greenhouse plants in the closed system of heating and ventilation of greenhouses of the type "plant greenhouse - mushroom greenhouse".

РЕЗЮМЕ

Запропоновано статична математична модель для аналізу енергоємності виробництва грибів і тепличних рослин в замкнутій системі опалення і вентиляції теплиць типу "рослинна теплиця - грибна теплиця".

INTRODUCTION

Vegetable production in the greenhouses is connected with significant energy expenses to heat the incoming air and necessity for its saturation with carbon dioxide for plant greenhouses and with oxygen for mushroom greenhouses, so reducing the energy intensity of production is especially important for greenhouses (Blasco X. et al, 2007; Kozhukhov V.A. et al, 2009; Golub G.A., 2010; Bakanova S.V., Haryna A.A., 2014; Demiyenko Y. et al., 2016).

This problem can be solved by using closed system of ventilation (The request №3-65929; Copyright certificate of USSR №950241; Girchenko M. et al, 2003), which uses the opposite principle of plants and mushrooms respiration (Grodzynsky D., 1982; Tkachenko V.A., Kondratiuk O.V., 2009).

In order to improve the energy efficiency in the greenhouses by using a closed system of ventilation, that allows the simultaneous growing of plants and mushrooms, we must organize the flow of air, saturated with carbon dioxide from the mushroom spawn in the plant greenhouse, and enriched with oxygen in the mushroom spawn. Substantiation of operating modes of such systems will provide their effective use in the production.

The nature and duration of transitional processes in the greenhouses at high production volumes require their modelling for the evaluation of the object in any area of the transitional process (Horobets V.H., Yatsenko O.V., 2014; Dudnyk A.O., 2014). This question is particularly relevant for closed systems of ventilation, because of their complexity.

Let us consider fig. 1 showing a closed heating and ventilation system as an object of mathematical modeling. Accepted limitation: the apparent stream of heat from the substrate is constant; evaporation from a wetted surface does not depend on temperature. Also adopted assumptions: CO₂ in the outside air and the air coming from the adjacent greenhouses during the ongoing transition process; the outside temperature during transients is constant; air density does not depend on the temperature and pressure inside the room; moving of the air in the room is not included. We distinguish two main components of the model - the heat balance and gas balance.

MATERIAL AND METHODS

Due to the fact that plant and mushroom greenhouses are connected by a common ventilation system, the heat balance of greenhouses will be in the form of the set of equations (1), kW.

$$\begin{cases} -Q_{O.H.1} - Q_{hv.1} + Q_{hl.1} - Q_{if.1} + Q_{fe.1} = 0 \\ -Q_{O.H.2} - Q_{hv.2} + Q_{hl.2} - Q_{if.2} + Q_{fe.2} = 0, \end{cases} \quad (1)$$

Where:

- $Q_{O.H.}$ is the general heat input to the room;
- Q_{hv} is the capacity of the heating and ventilation system;
- Q_{hl} is the capacity of heat losses;
- Q_{if} is the flow of heat from input air;
- Q_{fe} is the flow of heat from outlet air;
- 1 is the mushroom greenhouse; 2 is the plant greenhouse.

In the real conditions when growing the greenhouse crops, the air exchange in the room is actually different. It is also necessary to consider that in the air, during its circulation, contaminants accumulate in the closed system. Therefore, a mathematical model must take into account the air exchange with the external environment.

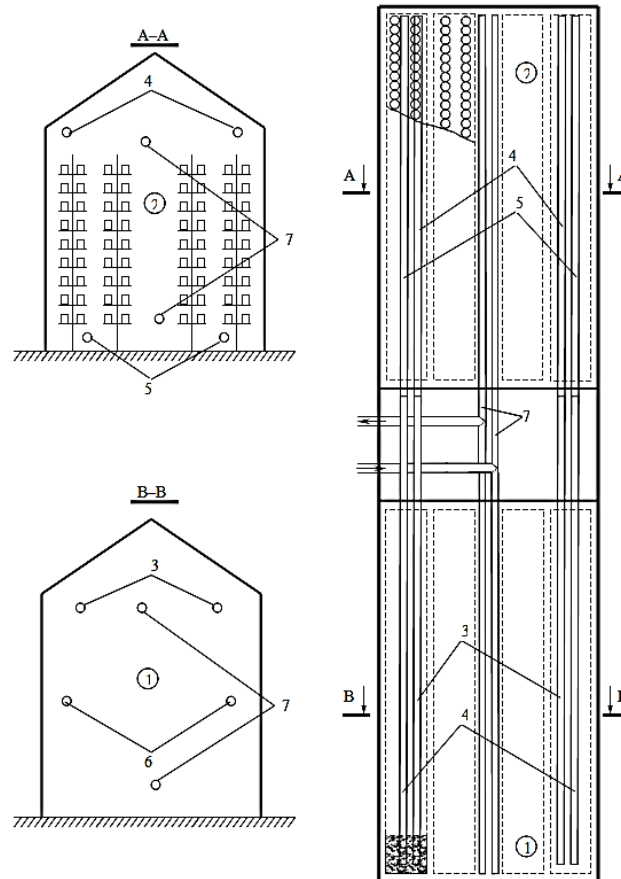


Fig. 1 - The layout of closed system of ventilation

- 1 - plant greenhouse; 2 - mushroom greenhouse; 3 - air ducts of intake air enriched with O_2 ; 4 - air ducts of input air enriched with O_2 ; 5 - air ducts of intake air enriched with CO_2 ; 6 - air ducts of input air enriched with CO_2 ;
- 7 - air ducts of air exchange with the external environment

Let us suppose that due to the technological requirements the air exchange in the rooms $G_{M.1}$ and $G_{M.2}$ is different - in the mushroom room, it is higher, but in the plant room, it is lower. Then, there is an excess of G_M in the first room, on the basis of which it is necessary to organize the air exchange with the external environment. In this case, after mathematical transformations we get the set of equations:

$$\begin{cases} -Q_{O.H.1} - Q_{hv.1} + Q_{hl.1} - c_p \cdot [G_{M.1.1}(t_{ai.2} - t_{e.1}) + G_{M.1.2}(t_{ae} - t_{ai.1})] = 0 \\ -Q_{O.H.2} - Q_{hv.2} + Q_{hl.2} - c_p \cdot G_{M.1.1} \cdot (t_{ai.1} - t_{ai.2}) = 0 \end{cases} \quad (2)$$

where:

- $G_{M.1.1}$ is the air exchange between the greenhouses (kg/s);
- $G_{M.1.2}$ is the air exchange with the external environment (kg/s);
- t_{ai} is the air temperature in the greenhouse ($^{\circ}C$);
- t_{ae} is the outdoor air temperature ($^{\circ}C$).

RESULTS

This is an example of using the simulation model (2) to determine the air exchange in the experimental greenhouse, where oyster mushroom was grown in the mushroom greenhouse and the leek in the plant

greenhouse. The calculation was made for the winter period ($t_{ae} = -15\text{ }^{\circ}\text{C}$, $t_{ai1} = 16\text{ }^{\circ}\text{C}$, $t_{ai2} = 14\text{ }^{\circ}\text{C}$).

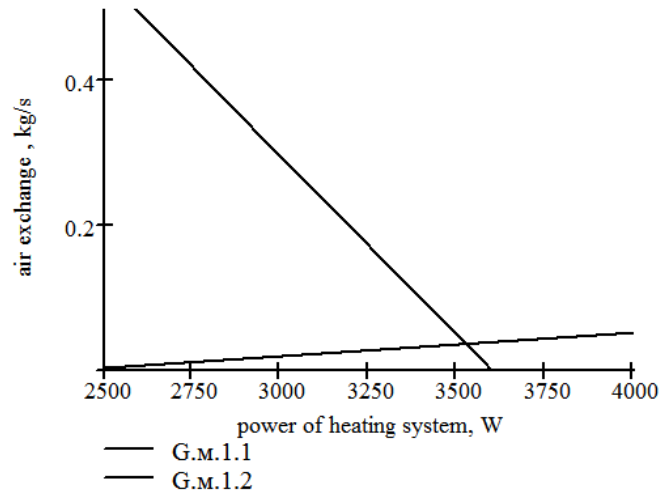


Fig. 2 - The dependence of the air exchanges on the capacity of the heating system

The example of the use of simulation model for determining the temperature is shown in Figure 3, ($t_{ae} = -15\text{ }^{\circ}\text{C}$, $G_{M.1.1} = 0.0346\text{ kg/s}$, $G_{M.1.2} = 0.0194\text{ kg/s}$).

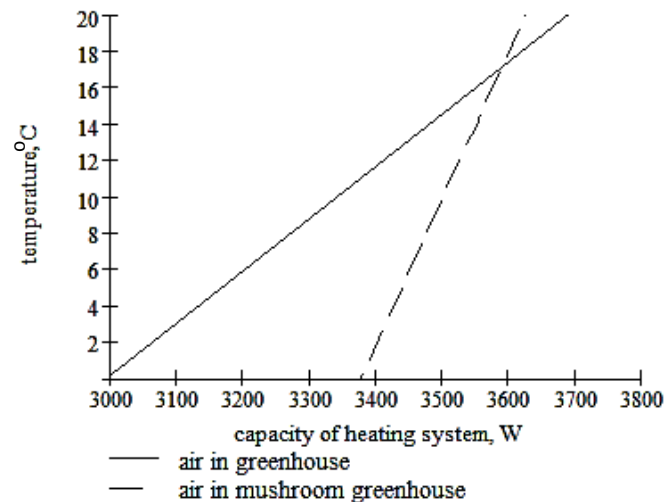


Fig. 3 - The dependence of the air temperature in the plant and mushroom greenhouses depending on the capacity of heating system

In fig.1 and fig.2 we can see that while reducing the capacity Q_{hv2} , the air exchange between the rooms $G_{M.1.1}$ increases and the exchange with the external environment $G_{M.1.2}$ is reduced, but the temperature in the plant and mushroom greenhouses goes down. Thus, the amount of air exchange and the room temperature can be controlled by changing the capacity of the heating system of the mushroom spawn.

Figure 4 shows the comparative dependence of total capacity of the open-loop and closed-loop system from the temperature of external environment, according to given example. For example, the heating capacity of closed system reduces to 1160 W (13%) at the outdoor temperature $-15\text{ }^{\circ}\text{C}$, by comparison with the open-loop system.

The heating capacity of closed heating and ventilation system of greenhouses reduces to 12.7–20.5% in the range of external temperature from $-20\text{ }^{\circ}\text{C}$ to $+14\text{ }^{\circ}\text{C}$.

The air-exchange with CO_2 in closed heating and ventilation systems in greenhouses is of great interest (Pukhalskaia N.V., 2000; Bohdanov K.B., Uskov E.Y., 2005).

For example, let us consider a system of “vegetable greenhouse-mushroom greenhouse” facilities, making assumption that the density of the air outside and inside is the same and does not change over time. In this case, the system takes the form of the following equations:

$$\begin{cases} L_c^1 + L_{z_v}^1 C_{z_v} = L_v^1 C_v^1 \\ -L_c^2 + L_{z_v}^2 C_{z_v} = L_v^2 C_v^2 \end{cases} \quad (3)$$

Where:

- L_c - consumption of CO₂, which is produced in the premises as a result of the process, ltr/sec;
- L_{z_v}, L_v - volumetric stream rate, respectively, outside and inside air, m³/sec;
- C_{z_v}, C_v - respectively, concentration of CO₂ in the outside and inside air, ltr/m³.

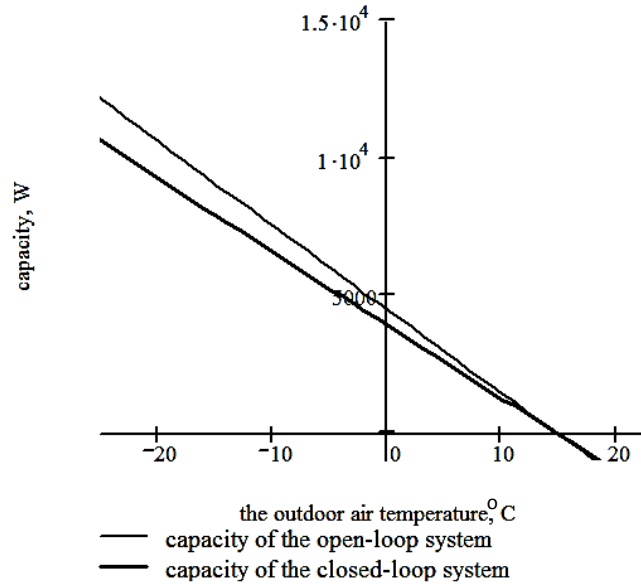


Fig. 4 - The dependence of heating system capacity on the outdoor air temperature

It is well-known that fungi respiration rate is higher, therefore there is an excess of CO₂ in the first room; in this case, air-exchange system should be based on mushroom greenhouse. After mathematical transformations, we form the following system:

$$\begin{cases} L_N^1 + L_{PP3}^1 - L_{VP3}^1 + L_{PP.1.1}^1 - L_{VP.1.1}^1 + L_{PP.1.2}^1 - L_{VP.1.2}^1 = 0 \\ -L_N^2 + L_{VP3}^2 - L_{VP3}^2 + L_{PP.1.1}^2 - L_{VP.1.1}^2 = 0 \end{cases} \quad (4)$$

Where:

- $L_c = L_{CO_2 gr} \cdot m_c$ - CO₂ stream from substrate, m³CO₂/h.;
- $L_{PP 1.2} = C_{air} \cdot L_{M.1.2} \cdot m_c$ - carbon dioxide stream with tidal ventilation air, m³ CO₂/h.;
- $L_{VP1.2} = C_{gr} \cdot L_{M.1.2} \cdot m_c$ - carbon dioxide stream with blown off ventilation air m³ CO₂/h.;
- $L_{PPi} = C_{air} \cdot L_{infiltr} \cdot m_c$ - carbon dioxide stream with tides of infiltrated air, m³ CO₂/h.;
- $L_{pp 1.1} = C_m \cdot L_{m1.1} \cdot m_c$ - carbon dioxide tidal stream from a greenhouse, m³ CO₂/h.;
- $L_{vp 1.1} = C_{gr} \cdot L_{M.1.1} \cdot m_c$ - carbon dioxide stream with incoming fresh air into a greenhouse, m³ CO₂/h.;
- $L_{M1.1}$ - air-exchange between rooms, m³/h · kg;
- $L_{M1.2}$ - air-exchange with outside surroundings, m³/h · kg;
- $L_{CO_2 gr}$ - carbon dioxide evaporation per 1 kg of substrate mass, m³ CO₂/h · kg;
- C_m - carbon dioxide concentration in tidal air, m³ CO₂/m³;
- C_{gr} - carbon dioxide concentration in a mushroom greenhouse, m³ CO₂/m³;
- m_c - substrate mass in kilograms.

Such a model helps determine the value of air between rooms and different environment, different values at different CO₂ concentration in a greenhouse or concentrations of carbon dioxide in areas with known values of air-exchange. If relevant changes and amendments are made, other parameters of the system can be determined.

The simulation model of the system (4) is used to determine the air-exchange when an experimental oyster mushroom is grown in an experimental room, and a hastening crop in a vegetable greenhouse - scallion, shown in Fig. 5, where the curve $L_{M.1.1}$ is the air-exchange between rooms and $L_{M.1.2}$ —the air exchange with the environment. Calculations are made for winter period when the outdoor temperature $t_{outdr} = -15\text{ }^{\circ}\text{C}$ and indoor air temperatures in a mushroom greenhouse $t_{indr}=16\text{ }^{\circ}\text{C}$ and the greenhouse $t_{indr2} = 14\text{ }^{\circ}\text{C}$. By setting different values of CO_2 concentration in the greenhouse at a constant value of mushroom greenhouse concentration, the value of air exchange can be defined $L_{M.1.1}$ and $L_{M.1.2}$.

Fig. 5 clearly shows that by increasing concentration of CO_2 in the greenhouse, the air-exchange between rooms increases, while the air-exchange between mushroom greenhouse and outside environment decreases. In case we change the concentration of CO_2 in the mushroom greenhouse and its constant value in the greenhouse, we have the curves shown in Fig. 6.

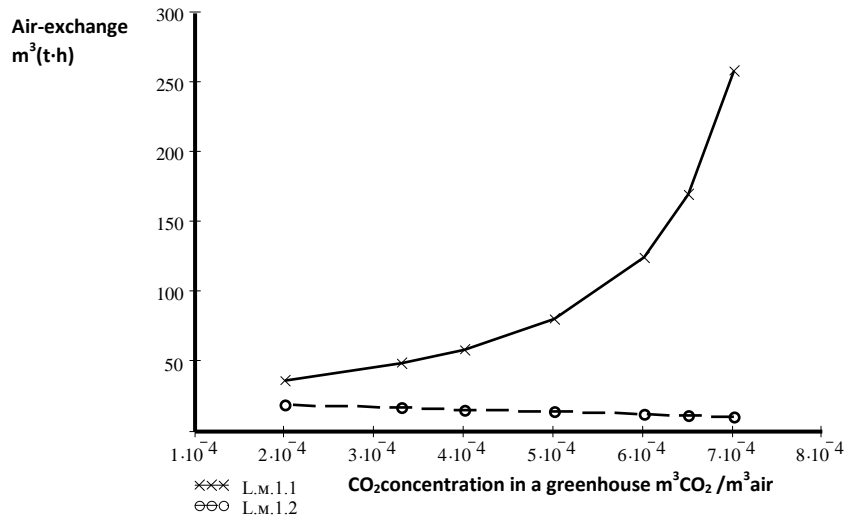


Fig. 5 - The relevance of air-exchange to CO_2 concentration in a greenhouse at $C_{msh} = 0.0008\text{ m}^3\text{CO}_2 / \text{m}^3\text{air}$

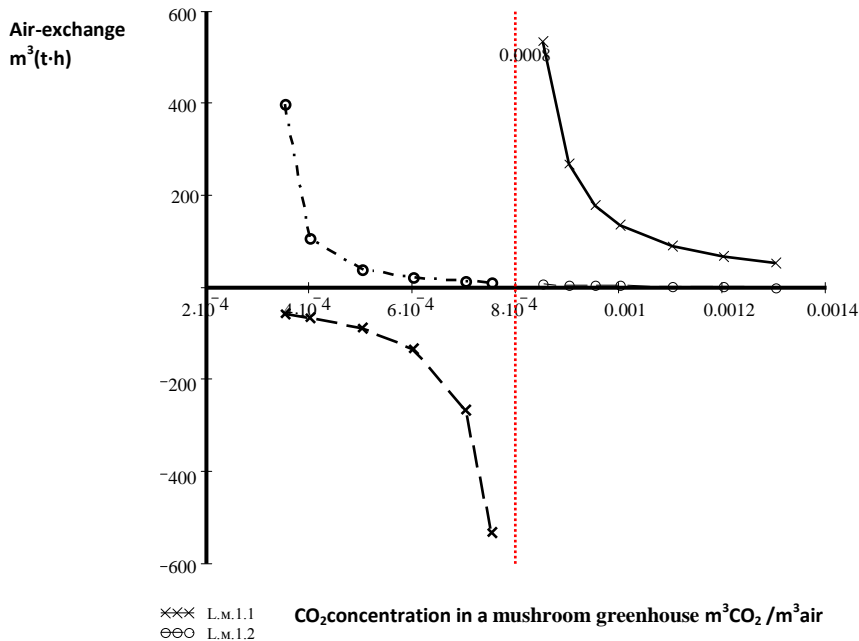


Fig. 6 - The relevance of air-exchange and concentration of CO_2 in the mushroom greenhouse at $C_{wrth} = 0.0008\text{ m}^3\text{CO}_2 / \text{m}^3\text{air}$

As shown in the graph (Fig. 6) the air exchange with the environment is reduced because of increasing the concentration of carbon dioxide in the mushroom greenhouse. At the same time, when the

concentration is $\text{CO}_2 = 0.0008 \text{ m}^3\text{CO}_2/\text{m}^3\text{air}$, the direction of air movement between rooms is changed and when the concentration is bigger than $0.0008 \text{ m}^3\text{CO}_2/\text{m}^3\text{air}$, it takes the direction from the mushroom greenhouse to the greenhouse.

It quite clear, that the left part of the chart is irrelevant, due to the stated concentration of CO_2 (in our case: $0.0008\text{m}^3\text{CO}_2/\text{m}^3\text{air}$) as there is no need to direct the stream of CO_2 from the greenhouse to the mushroom greenhouse (in which carbon dioxide is consumed).

CONCLUSIONS

The research conducted by using simulation mathematical model of air exchange system shows that the highest efficiency of system work is at low temperature of outdoor air and at extremely large temperature difference in the greenhouses.

In terms of observing gas balance of a closed system, it must be included into the work to achieve accepted concentration value in one of the rooms. This condition can fail if the system is working and / or on thermal balance.

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