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Calculation of heat loss for choosing a heating system in the chamber

A M Denmukhammadiev[1*], A I Pardaev[1], M X Abdullayev[2] and B Urinov[2]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, 39, Kori Niyazov st., Tashkent, 100000, Uzbekistan
[2]Urgench state university, 14, Kh. Alimdjan str, Urgench city, 220100, Uzbekistan

*E-mail: aquvvat@mail.ru

Abstract. The work studied the features of the chamber (linear dimensions, wall materials, etc.). It was revealed that the smaller the temperature difference between the environment and the air temperature inside the chamber, the lower the percentage of losses in the chamber. It has been established that due to the convective action, the hot air in the chamber predominantly rises upward. In this case, the heating elements were connected in series with each other. Power was supplied from a 220 V network through power lines. We have developed a system for monitoring the temperature inside the chamber and lamp operation in the Automation Studio 5.2 program. This system allows one to regulate the air temperature inside the chamber. Calculations were also carried out to identify the effect of temperature differences on heat loss in the chamber device. Experiments and engineering calculations have shown that in a small chamber the temperature required for seed germination cannot be achieved immediately. In the two - position closed chamber load plot, the energy consumption area is 9.4% larger than the energy consumption areas of the subsequent periodic energy consumption areas. It can be seen that heating the chamber itself requires additional electricity.

1. Introduction

This article has developed a technique based on the balance of flows entering and exiting the oven, considering different cooking modes, for example, steam mode. The researchers also recommended creating an energy - efficient project using the developed methodology and identifying possible technical solutions to achieve the implementation of efficient energy use [1]. Some types are equipped with temperature control devices and sensors to automatically shut off in case of overheating. Heating elements for heating can be selected depending on the optimal power for a particular situation (see figure 1). The following designations are shown in this picture: 1 – ceramic insulator; 2 – fastening device; 3 – electrical contact rod; 4 – heating coil; 5 – periclase (special crystalline filler); 6 – tubular shell; 7 – sealant (seal). In this article, we were able to heat the air inside a chamber of a given size using a heating element. Some researchers have also studied the periodic rotation of a building in a horizontal plane in accordance with the movement of the Sun in order to maintain the internal temperature of a building of a fixed size [2].

Considering that σ - the relative electrical conductivity of fruits and vegetables depends directly on the initial temperature (T). Therefore, it is believed that the temperature of fruits and vegetables has a great influence on electrical conductivity [3]. This is a graph of the dependence (see figure 2) of the relative electrical conductivity (S) of fruits and vegetables on temperature (T) and shows curves for 1 – apricots, 2 – plums, 4 – apples (fruits) and 3 – carrots (vegetables).

According to the authors, analysis of a priori data shows [4] that as a result of various electrophysical and magnetic influences on onion seeds, positive changes are observed. Researchers have recommended a new electrotechnological method that involves treating soaked onion seeds with electric current. As a result of studies carried out with onion seeds in preliminary experiments with an electric heater, the thermal power on the surface of soaked onion seeds 5 mm thick was 12.08 W.

L – length of the heating element along the tubular shell (cm). L_k – length of the of the electrical contact rod (cm). L_a – active length (cm). L_h – installation length (mm).

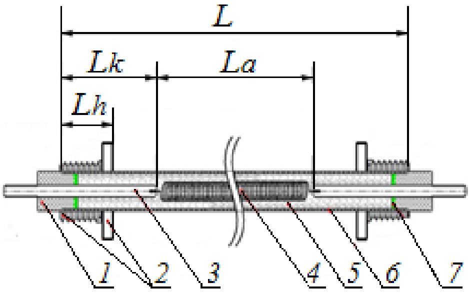

Figure 1. Tubular electric heater.

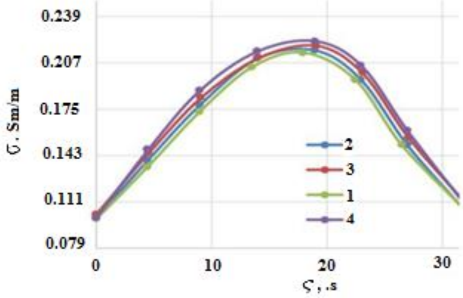

Figure 2. Graph of dependence of relative electrical conductivity (σ) of fruits and vegetables on temperature (T).

In this model [5], it will be possible to conduct high-speed experiments throughout the year with high accuracy. This method [6] involves heating air in a limited area by solar radiation, which creates a temperature difference and causes air movement. In these studies, work was carried out to study the heat flow and temperature changes in composite plates and cylinders [7]. Researchers in their work [8] emphasize the positive effect of coating onion seeds with amino acids on germination and pigment formation.

It is known [9] that onion seeds have a limited shelf life compared to seeds of other vegetable crops. According to the researchers, it is important to identify the mechanisms that cause tolerance to storage conditions and reduce seed spoilage. To achieve this goal, the authors assessed changes in germination, biochemical, physiological and molecular characteristics of several varieties of onion seeds); experiments were carried out at different stages of growth (development) (control, three-day and six-day accelerated).

2. Materials and methods

Theoretical calculations for the stationary method of thermal measurements are described in detail in [10]. In particular, the process of thermal conductivity of a multilayer wall was studied in detail. We wrote equations for three- and four-layer wall models based on the above methods. In this case, the heated and cooled air space near the wall air space was taken as a layer.

Let us consider the similarities and differences of these processes using the examples of a four-layer (figure 3, a) and a flat wall (three-layer wall), washed by flows on both sides (figure 3, (b)). For each layer (figure 3, (a)), the temperature difference can be calculated using the formula below:

$$\mathrm{q} = \frac{\mathrm{Q}}{\mathrm{F}\cdot\tau} = \frac{\lambda}{l}(t_1 - t_2) \tag{1}$$

The above formula is called the specific heat flow formula.

As a result, we have:

$$t_1 - t_5 = \left(\frac{l_1}{\lambda_1 \mathrm{F}} + \frac{l_2}{\lambda_2 \mathrm{F}} + \frac{l_3}{\lambda_3 \mathrm{F}} + \frac{l_4}{\lambda_4 \mathrm{F}}\right)\frac{\mathrm{Q}}{\tau} \tag{2}$$

The sum of the thermal resistances of the existing layers is given in brackets.

It is known that during convective exchange, a wall separates two environments A and B (figure 3(b)). In this case, only the temperatures of the air volume on both sides of the wall (t_1 and t_5) are known. There are two boundary layers: 1-aerodynamic and 2-thermal. The aerodynamic layer is the distance from the wall at which the speed differs from the speed of the undisturbed flow from the cross section by a certain amount. A thermal boundary layer is a layer of liquid or gas (air) near a wall, inside which the temperature varies from a value equal to the temperature of the wall to equal to the temperature of the gas (air) far from the body.

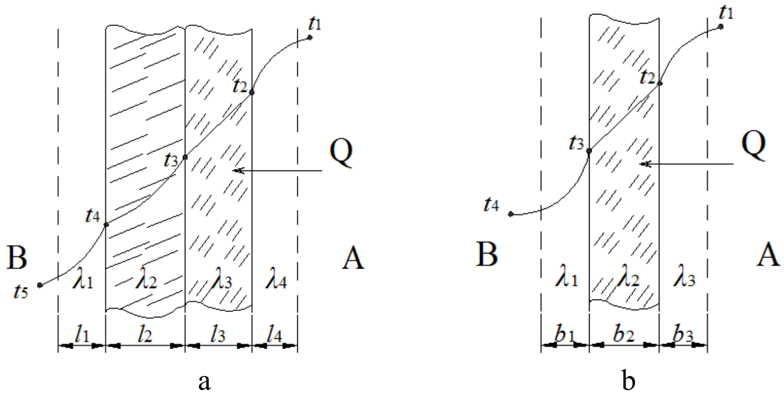

Figure 3. Heat transfer schemes: a - through a multi-layer flat wall; b - a flat wall washed by streams on both sides.

That is, the entire change in gas (air) temperature (figure 3, (b)) is concentrated in a relatively thin layer. The depth of the boundary layer depends on many factors.

3. Results and discussion

Using known methods (table values), we calculate the heat loss of the chamber over the same area.

Let's calculate the heat balance in a chamber surrounded on all sides by room temperature (the linear dimensions of the chamber are shown in figure 4 below).

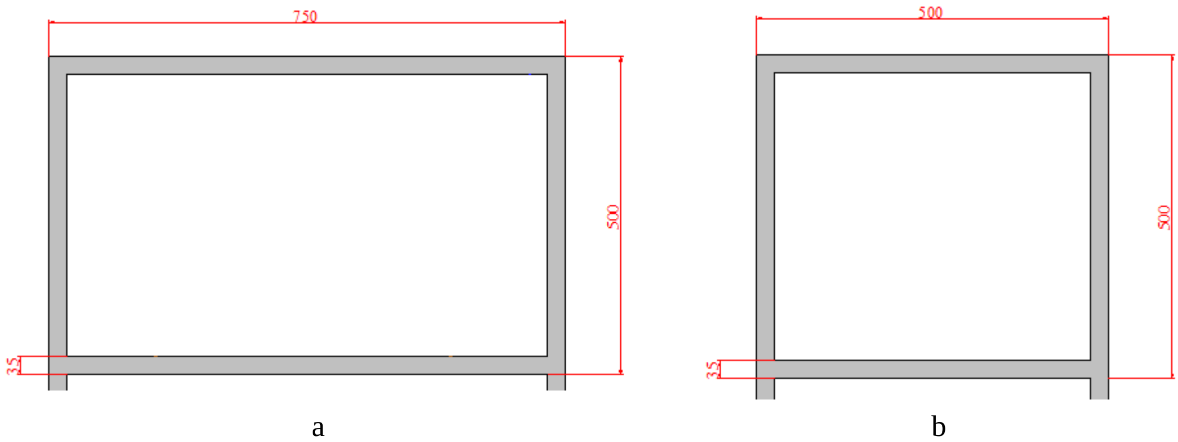

Figure 4. Camera layout (diagram): a - front view and b - side view.

Camera Features: dimensions and area – 0.5 m x 0.75 m (0.375 m²); ceiling height compared to a steel floor – 0.5 m; number of external walls – 4; material and thickness of the outer walls - organic transparent glass 0.5 cm thick; number of windows – 4, two with glass (height – 0.43 m, width – 0.43

m); the floor is made of a metal sheet 0.2 cm thick; at the bottom of the floor, above and on the outer surfaces of the windows there is a lower chamber - it is surrounded by room air, the room temperature is on average 18.5 °C. We carry out engineering calculations based on this temperature indicator.

The temperature required for seed germination inside the chamber is 22 °C. First, let's calculate the areas of heat transfer surfaces.

Window area F_1 (glass surfaces) (Swindow):

$$F_1 = 2 \cdot [43 \cdot 43 \cdot 10^{-4}] + 2 \cdot [68 \cdot 43 \cdot 10^{-4}] = 0.9546\, m^2.$$

The area of the external walls of the two-layer part of the chamber, excluding windows, is equal to F_2 (Swalls):

$$F_2 = 0.0651 + 0.0826 = 0.1477\, m^2.$$

Floor surface of chamber F_3 (floor):

$$F_3 = 75 \cdot 50 \cdot 10^{-4} = 0.375\, m^2.$$

Ceiling area F_4 (Sceiling):

$$F_4 = 75 \cdot 50 \cdot 10^{-4} = 0.375\, m^2.$$

The area of the internal parts and shelves is not taken into account, since they have the same temperature on both sides and heat does not escape through them. Based on the results obtained above, we calculate the heat loss Q of each surface:

Thermal conductivity (λ) for walls made of carbon steel (2 and 4 mm): $\lambda_1 = 45\ \frac{\mathrm{W}}{\mathrm{m \cdot K}}$, for plexiglass:

$$\lambda_2 = 0{,}19\, \frac{\mathrm{W}}{\mathrm{m \cdot K}}.$$

Heat loss from glass surfaces

$$Q_{windows} = \tau \cdot \Delta t \cdot \frac{\lambda_2 \cdot F_1}{l_2} = 120\ s \cdot 3.5\ K \cdot \frac{0.19 \dfrac{W}{m \cdot K} \cdot 0.9546\, m^2}{0.5 \cdot 10^{-2} m} = 15235.4\, Joul$$

Heat loss of two - layer external walls

$$t_1 - t_3 = \left(\frac{l_1}{\lambda_1 \cdot F} + \frac{l_2}{\lambda_2 \cdot F}\right) \cdot \frac{Q}{\tau}$$

$$Q_{wall} = \tau \cdot \Delta t \cdot \frac{1}{\left(\dfrac{l_1}{\lambda_1 \cdot F_2} + \dfrac{l_2}{\lambda_2 \cdot F_2}\right)}$$

$$= 120\ s \cdot 3.5\ K \cdot \frac{1}{\left(\dfrac{0.4 \cdot 10^{-2} m}{45\ \dfrac{W}{m \cdot K} \cdot 0.1477\, m^2} + \dfrac{0.5 \cdot 10^{-2} m}{0.19 \dfrac{W}{m \cdot K} \cdot 0.1477\, m^2}\right)} = 23.57\, Joul$$

We assume that heat loss on the floor surface of the chamber is zero:

$$Q_{floor} = 0$$

Due to convective action, the hot air in the chamber predominantly rises upward. Therefore, we do not take into account heat loss from the floor.

Heat loss in the ceiling area

$$Q_{ceiling} = \tau \cdot \Delta t \cdot \frac{\lambda_2 \cdot F_4}{l_2} = 120\ s \cdot 3.5\ K \cdot \frac{0.19 \frac{W}{m \cdot K} \cdot 0.375\, m^2}{0.5 \cdot 10^{-2} m} = 5985\, Joul$$

In total, the total heat loss of the chamber is:

$$Q_{total} = Q_{windows} + Q_{wall} + Q_{floor} + Q_{ceiling} = 15235.4 + 23.57 + 0 + 5985 = 21243.93\,Joul$$

Symmetrically to the center line of the chamber floor, two electric heating elements with a power of $500\ W$ each are placed on special metal supports. Heating elements connected in series with each other are connected to a $220\ V$ network through power lines (figure 5). Let us calculate the total thermal energy released from these heating elements.

$$U = U_1 + U_2$$

$$I = \frac{P}{U_1} = \frac{500\ W}{110\ V} = 4.55\ A$$

$$R = \frac{P}{I^2} = \frac{500\ W}{20.6\ A^2} = 24.2\ Om$$

$$R_{com} = R + R = 48.4\ Om$$

$$Q = I^2 \cdot R_{com} \cdot t = 20.6\ A^2 \cdot 48.4\ Om \cdot 120\ s = 119644.8\,Joul$$

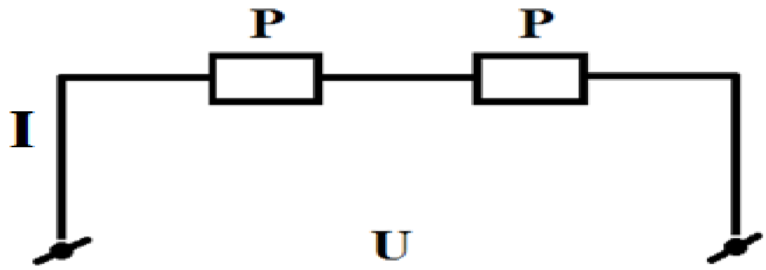

Figure 5. Connection diagram for heating elements.

The total thermal energy released from the heating elements in 2 minutes is $Q = 119644.8$ Joules.

Calculations of the influence of temperature differences on heat loss in the chamber device are given in table 1.

Table 1. Calculations of the influence of temperature differences on heat loss in a chamber device.

No	Δt ,(K)	Q_{total}, (Joul)	ΔQ, (Joul)	Losses, (%)
1	3.5	21243.93	98400.87	17.75
2	8.5	51592.4	68052.4	43.12
3	13.5	81940.9	37703.9	68.49

As can be seen from the table above, the temperature change in the second column is taken with a difference of 5 degrees, and the corresponding percentages in the fifth column do not differ by the same amount. It is clearly seen that the smaller the temperature difference, the lower the percentage of losses in the chamber.

Using the Automation Studio 5.2 program, a model was developed to control the temperature inside the chamber and the operation of the lamp. The model of the developed circuit was analyzed, and in this article, adding additional elements to the model makes it easier to control the necessary parameters.

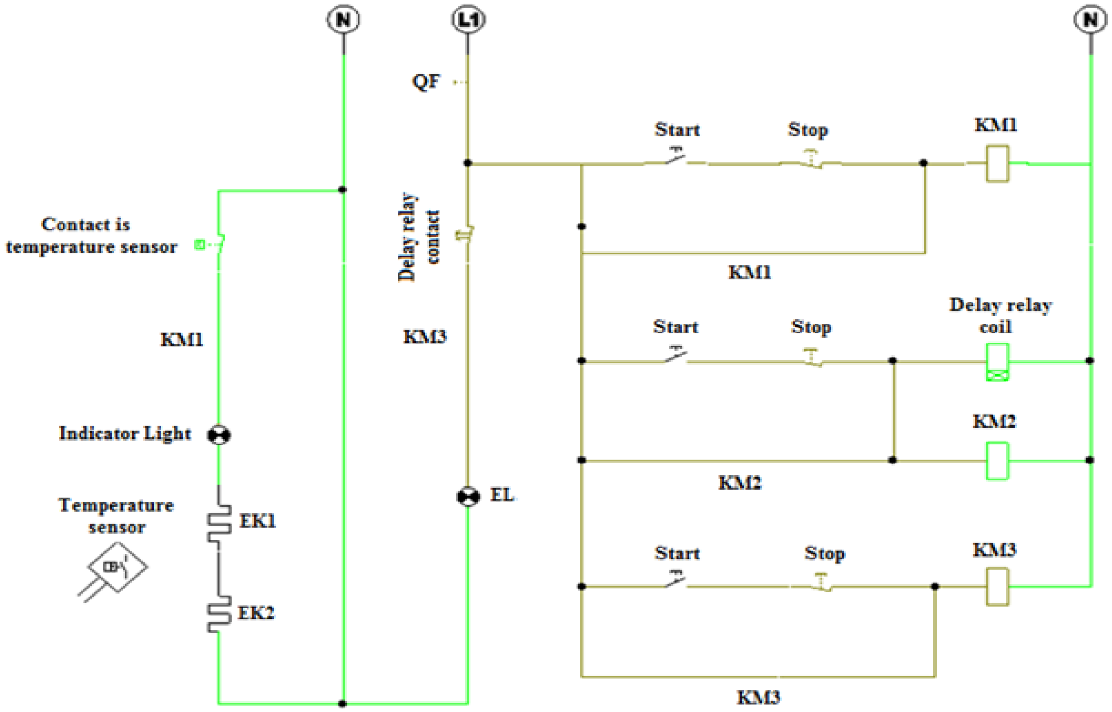

Figure 6. System for monitoring the temperature inside the chamber and lamp operation in the Automation Studio 5.2 program.

All elements (figure 6) necessary for the electrical circuit of the module are selected from the IEC basic library of electrical engineering. AC 220 V L1 (Power Supply L), Neutral, Pushbutton Normally Open, Examine if Closed, Indicator Light, Heating Element, Magnetic Coil, Contact Normally Open, Coil with On Delay, Contact with On Delay Normally Clos, Thermal Switch, Temperature Switch Closed (Thermal Switch Normally Close). Based on the above components, an additional module for monitoring the temperature inside the chamber and lamp operation was developed.

To maintain the temperature inside the chamber at a given value, within 20…22 °C, a pair of electric heaters (EK1, EK2) are installed along the chamber to heat the temperature inside the chamber by connecting to the network. To control the temperature at a given value, a temperature sensor is placed inside the chamber between the heating elements. The required temperature for laboratory research is set in the thermostat adjustment window. When the temperature reaches the required value, after the temperature sensor (Thermal Switch) gives a signal, the closed switch (Thermal Switch Normally Close) opens, and with the help of the open contact KM1 (Contact Normally Open) of the magnetic starter, the heating elements (EK1, EK2) are turned off from the network, the temperature is below the set value; when it decreases, the temperature sensor gives a signal and the heating elements are turned on again, thus the temperature in the chamber is maintained within the specified range of values.

When the time interval entered in the “with a certain time delay” field reaches the specified value, the signal is transmitted to the time relay coil (Coil with On Delay), then the open time relay contact (Contact with On Delay Normally Close) is opened using the KM3 magnetic starter contact (Contact Normally Open), the EL lamp is disconnected from the network.

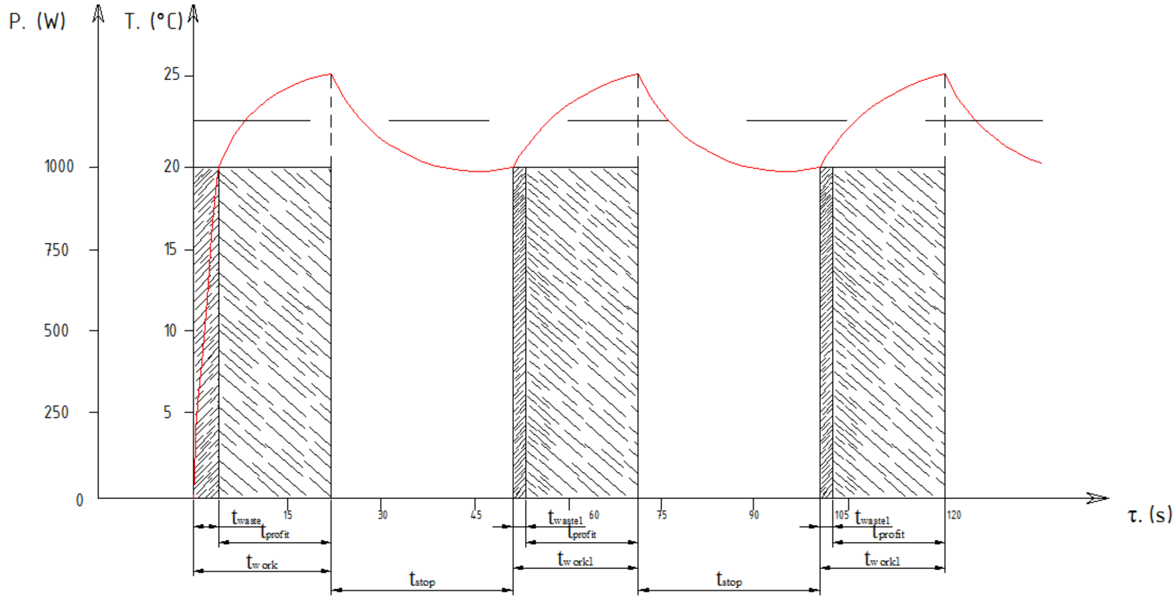

Figure 7. Two-position loading graph of closed chamber.

$$\Delta W_{com} = \Delta W_{profit} + \Delta W_{a\,waste}$$

$$\Delta W_{average} = 20 \div 22\ ℃$$

$$t_{work} = t_{a\,waste} + t_{profit}$$

In a small chamber, the temperature required for seed germination cannot be achieved immediately. In the two-position closed chamber load plot shown above, the energy consumption area on the left is slightly (9.4%) larger than the energy consumption areas in the middle and on the right (figure 7). Because the chamber itself requires additional electricity to heat up. In the results section of the article, specific engineering calculations related to this process are performed.

4. Conclusion

Research on calculating the thermal conductivity of walls in enclosed spaces is analyzed. In particular, the work presents engineering calculations on the heat losses of a small-volume chamber to quickly determine the germination capacity and energy of the germination of vegetable seeds in the initial plant vegetation. In a small chamber, the temperature required for seed germination cannot be achieved immediately. Specific engineering calculations have shown that in two-position load control of a closed chamber, in the initial region of energy consumption, there are losses within 9.4%. Because heating the chamber itself requires additional electrical energy.

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