The use of solar energy in air temperature control systems in industrial premises

N A Tseligorov, A K Naser, A I Ozerskiy and E N Tseligorova
Don State Technical University, 1, pl. Gagarina, Rostov on Don, 344000, Russia
E-mail: nzelig@rambler.ru

Abstract. It has been proposed to use absorption chillers that use solar energy for food processing enterprises. The simulation of the system in the Matlab environment showed that it is necessary to install digital controllers in temperature control systems that ensure the maintenance of the specified accuracy.

1. Introduction
The food embargo introduced in 2014 reduced the import of many types of meat, fish and agricultural products into Russia. However, this prompted Russian producers to develop many sectors of food products. For meat products, in particular rabbit meat, the share of imports on the market decreased 6 times by 2020 [1]. To date, there are such large enterprises in Russia as Agroholding Semirechye (Tver Region), Lipetsk Rabbit, Russian Rabbit and others. Rabbit farming enterprises are also developing.

In 2018, the share of mushroom products accounted for about 50%, which were imported mainly from Belarus. In Russia, one of the largest mushroom producers is the My Leto company, which grows mushrooms in the Tula region. The production of champignons is also planned to be carried out by the retailer "Magnit" [2].

In recent years, the greenhouse market in Russia has been small and is distributed mainly between three associations: "Greenhouses of Russia", "South - Greenhouses of Russia" and "Union of Vegetable Producers". At the same time in the country the consumption of such vegetables as pepper, cucumber, tomatoes, eggplants is about 2.2-2.4 million tons per year, and the production of these vegetables is about 1.2-1.4 million tons [3]. The missing quantity has to be imported. Practice shows that greenhouse vegetable growing is shifting from the southern regions to such regions as Voronezh, Tambov, Lipetsk, Belgorod, and construction sites are chosen near gas pipelines, where there are free volumes of gas. The construction of greenhouses is planned in Michurinsk, Orel, Smolensk, Tver [3]. Also, greenhouses are planned to be located near nuclear power plants in the regions of such cities as Ivanovo, Udomlya, and Cherepovets, since cheap electricity and heat will reduce the cost of production. It should also be noted that flowers are also grown in greenhouses, which are a profitable export item for some countries.

Thus, the shift in the construction of greenhouses and farms for breeding rabbits and mushrooms to the central regions, where the average daily temperatures are sufficiently low, will affect the cost of production. One of the solutions is to use solar energy to maintain a given temperature in these rooms. The use of renewable energy sources is applied in devices [4-7] that operate on solar photovoltaic panels. The use of controllers with fuzzy logic to create a certain temperature regime is considered in
The study of robust systems that ensure the temperature conditions of the room are considered in works [11-13].

2. Materials and methods

An absorption chiller can be used in conjunction with a solar collector to maintain the desired room temperature. In [4-5], a solar photovoltaic panel was used to provide the entire installation with electricity. In this case, it is proposed to use a solar collector to heat water in the boiler of the chiller connected to the heating system. The advantage of such a system is:

- The availability of energy to maintain the temperature;
- Ease of use;
- Possibility of both heating and cooling the room;
- Environmental safety of the device, since water is used as a refrigerant in absorption refrigeration machines;
- The functional diagram of an absorption refrigeration unit can be as follows figure 1 [14].

![Figure 1. Functional diagram of an absorption refrigeration unit.](image1)

Solar collector design.

Solar collectors are of two types:

- Flat;
- Vacuum.

Solar collectors designed to heat the coolant (water) are usually represented by two designs - flat collectors and collectors with vacuum tubes [14].

Flat collectors.

A functional diagram of a flat collector is shown in figure 2.

![Figure 2. Functional diagram of a flat collector.](image2)
Structurally, a flat collector is a heat-insulated box, inside of which there is a copper pipe coil, through which the coolant circulates. The top of the box is covered with a sheet of glass to protect it from moisture and foreign objects.

A coolant circulates along the coil, which transfers the heat received from solar heating to the water in the ABHM generator.

The second type of solar collector is a vacuum collector.

Vacuum manifold.

Structurally, the vacuum collector is implemented in the form of a frame, on which a platform with vacuum tubes is fixed, under which a reflector of solar radiation is located (figure 3). A heat exchange unit is installed in the upper part of the structure [14].

![Figure 3. Vacuum manifold design.](image)

All flasks of copper pipes coming out of the vacuum flasks are fixed in a heat exchange unit, in which a coolant circulates, which transfers the resulting heat to the chiller generator or to the boiler.

The choice of one or another type of solar collector is determined by financial capabilities, the geographical location of the building and the meteorological situation in the region.

Mathematical model of the studied system.

Currently, there are a large number of publications related to the mathematical modeling of temperature regimes in buildings that are residential, livestock and industrial premises. In works [11-12], mathematical models of temperature control systems inside a dwelling are considered. Insolation of buildings by solar irradiation is considered in [15-17].

The transfer function of the heated room in these publications is written in the following form.

\[
W(p) = \frac{K}{T_{PM}p + 1}
\]  

(1)

Where K is a function of the following thermo physical quantities:

- Thermal energy coming from the heater;
- Heat transfer coefficient of enclosing structures (walls);
- Areas of enclosing structures (walls);
- Temperatures of enclosing structures (walls);
- Room temperature.

In turn, the time constant of the heated room also depends on the following values:

- The mass of the room;
- Heat transfer coefficient of enclosing structures (walls);
- Areas of enclosing structures (walls);
- Specific heat capacity.
Analysis of the transfer function and the time constant of the heated room shows that the studied system contains the following uncertainties [11]:

- Exogenous (depends on the ambient temperature);
- Endogenous (depends on the supplied thermal energy and the mass of the heated room).

The task is to investigate the heating system as discrete, taking into account the influence of temperature and other uncertainties on robust stability. Simulate the heating system in the Matlab / Simulink software product.

Synthesis and study of a discrete model of the system.

In order to achieve the accuracy of the calculated parameters of the digital temperature controller, we will use the digital model of the object, having obtained it using the function c2d taking into account the zero-order extrapolator and the discreteness period $T = 1s$ [12]. After that, we will perform the synthesis of a digital PID controller using the pidtool program and the resulting digital model of the object. At the same time, as a preliminary criterion for achieving the robustness of the designed system, we use the maximum AFC of the closed loop of the system; the smaller it is, the greater the change in the parameters of the object can be allowed without loss of stability. The discrete transfer function of the controller obtained as a result of the synthesis has the form:

$$D(z) = \frac{9.650z^2 - 0.522z + 3.907}{1.667z^2 - 2.333z + 1}$$

(2)

The block diagram made for modeling in Matlab is shown in figure 4.

![Figure 4. Block diagram of a closed-loop temperature control system with a controller.](image)

The graph of the temperature variation of the heated room depending on the outdoor temperature $\epsilon_h = 0^\circ C$ is shown in figure 5.

![Figure 5. The graph of the temperature change of the heated room.](image)
3. Results
The simulation of the system under study shows that a digital system with a controller maintains the temperature regime of the room in accordance with the task. From the presented temperature change graph, it can be seen that the room temperature reaches the set level within an acceptable time.

4. Discussion
In connection with a decrease in imports of vegetable, meat, mushroom and other types of products, the leaders of large producers and farms have a desire to launch the construction of closed premises for growing such products. Moreover, there are tendencies towards a shift in the construction of closed premises to the more northern regions of the country. If there are sources of cheap heat and electricity in these territories and regions, then the cost of production will be low, otherwise the costs will be high. The paper proposes the use of renewable energy sources, in particular solar energy, to maintain the temperature of industrial premises in the required ranges. It is proposed to use an absorption chiller in conjunction with a solar collector as equipment to maintain the required temperature in closed rooms.

5. Conclusion
As a result of the study, it was found that the cost of a vacuum solar collector is much higher than a flat one, but the use of a vacuum solar collector makes it possible to obtain a higher temperature of the refrigerant, and, consequently, of the heated water in the boiler. The use of a discrete controller allows to provide the required accuracy of maintaining the temperature in a closed room in comparison with an analog controller. Moreover, there is a wide variety of discrete controllers on the market, both in terms of modifications and cost.

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