Original scientific paper

Comparative Analysis of Efficiency of Automatic Heating Systems Developed with the Help of Artificial Intelligence and Human

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***Abstract* — The main goal of the study is to determine whether artificial intelligence can create mathematical and simulation models of the automatic room heating system, and therefore test the abilities of artificial intelligence in the field of engineering sciences. The scientific novelty of the article is the development of a simulation model of an automatic room heating system with relay temperature control using artificial intelligence. To fully and comprehensively disclose the purpose of the study, elementary physical laws are provided that describe the processes of heat transfer and thermal conductivity of the air in a confined space, such as Joule-Lenz's law or Ohm's law and describe the foundations of the theory of automatic control, and in particular the role of necessary links and negative feedback. Based on the operation of the built models, graphs of the resulting temperature are given, on the basis of which the operating time, the maximum achieved temperatures and the switching time of the heater are based.**

***Keywords* — automatic room heating system; artificial intelligence; energy efficiency; data analysis; modelling.**

I. Introduction

In recent years, artificial intelligence has begun to be actively used in many areas: programming, design, cinema, robotics and the gaming industry. Development to improve existing artificial intelligence and create a new one is still ongoing. Many experiments are being carried out - artificial intelligence is asked to analyze large amounts of data and predict trends based on them in areas such as medicine, physics, and ecology.

In order to test the capabilities of artificial intelligence, in the field of engineering sciences, this study will provide mathematical and imitation models of the automatic room heating system created by man and artificial intelligence and further analyzed.

Despite the fact that a number of studies have been carried out on the topic of development using artificial intelligence by scientists of various specialties, especially physicists, programmers and engineers, this problem is still not well understood. Of great interest today is artificial intelligence in the field of engineering sciences. For example, the NASA Curiosity robot, designed to study the composition of Martian soils and atmospheric components and thanks to the presence of artificial intelligence, Curiosity can not only study the terrain, but also remember safe paths, as well as lay new routes, taking into account previously acquired knowledge about the nature of the soil [1, 2, 3]. However, artificial intelligence cannot solve the problems of limited mobility due to limited power and energy, risks of equipment damage or blocking and the need for a long time to transfer data and commands due to the long distance between Mars and the Earth.

A team led by researchers at the McCormick School of Engineering at Northwestern University (USA) has developed the first artificial intelligence that is capable of designing robots from scratch. Sam Kriegman, assistant professor of computer science, mechanical engineering, chemical and biological engineering at the McCormick School of Engineering, states that in nine attempts it was possible to create a robot that is capable of passing half the length of its body in a second - about half the speed of the average human step. The entire design process - from a shapeless zero-motion unit to a full-fledged walking robot - took 26 seconds on a laptop. Kriegman noted that it used to take weeks of trial and error on a supercomputer to develop robots [4]. However, the creators do not focus on the significant disadvantage of the robot - it needs a cyclical airflow, thanks to which movement is carried out.

The use of artificial intelligence raises ethical, moral and philosophical questions due to the fact that using artificial intelligence the voices of the dead are recreated and songs with these voices are released. The world is already shrouded in traces of artificial intelligence, and even a person who has never used this technology has come across its creations in one way or another [5, 6]. Despite such widespread application, many people, especially in the engineering sciences, are skeptical about the accuracy and reliability of the data provided by artificial intelligence [7, 8, 9, 10].

The “Materials and methods” section presents the development of a mathematical model based on the laws of heat transfer, Joule-Lenz and Ohm. To obtain the transfer function of a multi-contour system, Mason's formula was used, which provides accurate and stable modeling of the system. Based on these calculations, a functional diagram was compiled, which served as the basis for creating a simulation model. This approach allows you to visualize the

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interaction of system components and assess their impact on the overall efficiency of thermal process management.

The "Results" section describes the results obtained during the creation and testing of the simulation model, including the initial data necessary to build the model. According to the mathematical model, a person creates an imitation model of the system. Then the AI reproduces its own simulation model, which allows you to explore the possibilities of computer-aided design of AI. A comparison is then made between the human-made model and the AI-designed model, allowing their effectiveness to be assessed.

The "Discussion" section describes a comprehensive analysis of the pros and cons of both human-designed and AI systems.

II. Materials and Methods

This study is aimed at analyzing the data obtained as a result of the application of artificial intelligence methods in the context of the theory of automatic control, with an emphasis on optimizing the process of automatic heating of premises. The study aims to assess the effectiveness of the use of artificial intelligence to ensure a comfortable temperature regime in residential premises.

Research objectives:

1) Build a mathematical and simulation model of the automatic room heating system
2) Describe the model of the automatic room heating system developed by a person.
3) Consider the main components of the system and their functions.
4) Set a task for artificial intelligence to develop a model of the automatic room heating system
5) Describe the model of the automatic room heating system developed by artificial intelligence.
6) Analyze the effectiveness of using artificial intelligence to create an automatic room heating system.
7) Evaluate the advantages and disadvantages of using this model in comparison with a human-developed model.
8) Consider the prospects for the development of automatic heating systems created by artificial intelligence.

To create a simulation model of the automatic room heating system, you need to use physical laws that describe the processes that take place in the room during heating. First, we need to describe the law of heat transfer by convection. From the units of measurement of the thermal conductivity coefficient (W/°C) the formula for finding the thermal conductivity coefficient is obtained (1):

$$K = \frac{P_{пот}}{(T - T_c)} \tag{1}$$

where, $P_{пот}$ – the power of heat loss, which goes to heating street air, K – thermal conductivity coefficient in the indoor air, T – the desired indoor air temperature, T_c – the outdoor air temperature.

From here, the heat loss power formula is derived (2):

$$P_{пот} = K(T - T_c). \tag{2}$$

This law describes the dependence of the heat transfer rate on the difference in temperature and characteristics of the medium (for example, the heat transfer coefficient and surface area). The law of convection heat transfer allows you to take into account heat losses through convection and determine the efficiency of the heating system.

After that, the Joule-Lenz law is used (3) [11]:

$$Q = I^2 Rt \tag{3}$$

Since there is no current and resistance, the power formula is used (4):

$$P = U \cdot I \tag{4}$$

Where the Ohm's law stress is (5):

$$U = I \cdot R \tag{5}$$

Hence, the power formula is (6):

$$P = I^2 R \tag{6}$$

So, the Joule-Lenz law will look (7):

$$Q = Pt \tag{7}$$

But since time, power and time will change in this system, an integral is used to find the amount of heat (8):

$$Q = \int \Delta P(t)\, dt \tag{8}$$

where, Q – the amount of heat, ΔP – the difference between heater power and heat loss power, t – time.

This law allows you to describe the interaction of the heat loss of the room with heat sources and the heating system.

Subsequently, the heat quantity calculation formula for heating or cooling is used (9) [11]:

$$Q = \Delta \mathrm{T} \cdot m \cdot c \tag{9}$$

The formula allows you to calculate the amount of heat that will be transferred to air when its temperature changes.

After that, the formula of the difference between the heater power and the heat loss power is applied (10):

$$\Delta P = P - P_{пот} \tag{10}$$

where, P – heater power.

This formula allows you to calculate the difference between the power supplied to the system and the power lost during heat exchange.

The initial data allows you to find the mass of air that is necessary to find the amount of heat. To do this, the formula of the mass of air in the room is used (11) [12]:

$$m = v\rho \tag{11}$$

where, m – air mass, v – air volume in the room, ρ – air density.

The physical laws that are given above can be represented as links that are used in the theory of automatic control. Substituting these links in such an order that from the input signal - power the output value is obtained - the desired temperature, the transfer function is obtained.

The transfer function of the link $W(S)$ is the ratio of output and input values under zero initial conditions. The transfer function is one of the main tools in the theory of automatic control for the analysis and design of control systems and describes the relationship between the input and output signals of the system. The main goal of calculating the transfer function in the theory of automatic control is to analyze and optimize the dynamic properties of the control system. This allows you to assess how the system responds to changes in the input signal, predict behavior in various modes of operation, as well as determine its resistance and resistance to disturbances.

The calculation of the transfer function also allows the synthesis of control systems, the design of regulators that provide the required quality of control and the desired dynamic properties of the system.

In addition, the transfer function allows you to compare different control systems and choose the most efficient and stable solutions.

To obtain the transfer function of a multi-loop system, the Mason formula is used (12):

$$W_{xg} = \frac{X(S)}{Y(S)} = \sum_{i=1}^{m} \frac{W_i \Delta_i}{\Delta} \quad (12)$$

where, $X(S)$ and $Y(S)$ – the input and output variables of the system, W_i – the transfer function of the i-th simple path from vertex x to vertex y (from input to output) equal to the product of the transfer functions of the arcs included in this path, m – the total number of such paths, Δ – the determinant of the system (13).

$$\Delta = 1 - \sum W_{0j} + \sum_{j,k} W_{0j} W_{0k} - \sum_{j,k,l} W_{0j} W_{0k} W_{0l} \quad (13)$$

where, in the first sum W_{0j} – the transfer function of the j-th simple contour equal to the product of the transfer functions of the arcs included in this contour, and summation is carried out over all simple contours; in the second sum $W_{0j}W_{0k}$ – the product of the transfer functions of the j-th and k-th loops and summation is carried out over all non-touching pairs of loops; in the third sum $W_{0j}W_{0k}W_{0l}$ – the product of the transfer functions of the j-th, k-th, l-th loops and summation is carried out over all non-touching triples of loops, etc. Δ_i – the determinant function for that part of the block diagram that does not contact the i -and straight circuit from the input to the output [13].

The transfer function can also be depicted as a structural diagram (Fig. 1).

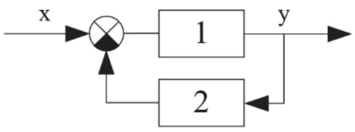


Fig. 1. Block diagram. *Source: Compiled by the authors.* where, x – input impact, 1 and 2 – links that form a contour, y – output value.

The path in this diagram includes only link 1. At that time, link 2 is included in negative feedback, as the effect of the system output on the input is called, which reduces the effect of the input signal on the system.

By Mason's formula the transfer function of the automatic heating system, modeled by man (14 – 16) is:

$$W_1(S) = \frac{1}{S} \cdot P \cdot \frac{1}{\rho v c} + \text{To} = \frac{P + \text{To} \cdot S \cdot \rho v c}{S \cdot \rho v c} \quad (14)$$

$$W_2(S) = (K - \text{Tc}) \quad (15)$$

$$W_{o6}(S) = \frac{P + \text{To} \cdot S \cdot \rho v c}{S \cdot \rho v c (1 + (K - \text{Tc}) \cdot (\frac{P + \text{To} \cdot S \cdot \rho v c}{S \cdot \rho v c})} \quad (16)$$

where, $W_1(S)$ – the path transfer function, $W_2(S)$ – the negative feedback transfer function that corresponds to the heat loss law, $W_{o6}(S)$ – the transfer function of the entire circuit, P – the input signal equal in number to the power value, $\frac{1}{S}$ – the integrating link that converts power into the amount of heat, $\frac{1}{\rho v c}$ – the link that corresponds to the formula for finding the temperature change, To – the signal equal to the value of the initial temperature in the room.

The branch, which goes from the output signal to the first adder, corresponds to negative feedback; it includes the K – coefficient of thermal conductivity and Tc – temperature of street air.

The transfer function of the automatic heating system modeled by artificial intelligence (17):

$$W(S) = \frac{1}{S} \cdot P \cdot \frac{1}{K \cdot A} + \text{To} = \frac{P + \text{To} \cdot S \cdot A}{S \cdot A} \quad (17)$$

where, A – the area of the room, P – an input signal equal in number to the power value, $\frac{1}{S}$ – an integrating link that converts power into the amount of heat, $\frac{1}{K \cdot A}$ – a link that corresponds to the formula for finding the temperature change, To – a signal equal to the value of the initial temperature in the room.

The difference between transfer functions will affect both the general view of the circuit and the operation of the model, since unaccounted heat loss can affect the output temperature and stability of the entire system.

Using the derived transfer function formulas of the two systems, you can construct structural diagrams of models of automatic room heating systems. Both schemas will consist of two paths and one path.

Original human-modeled structural diagram in which negative feedback simulates heat loss (Fig. 2).

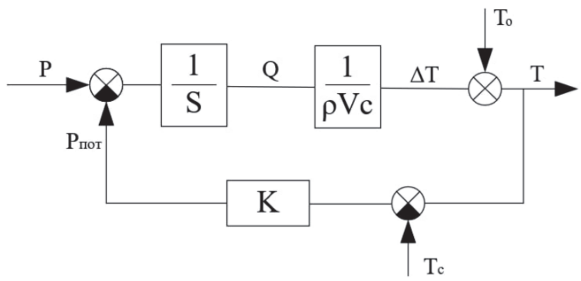


Fig. 2. Original functional diagram, where, P – input signal equal in number to the power value, $\frac{1}{S}$ – integrating link, which converts power into the amount of heat, $\frac{1}{\rho v c}$ – link, which corresponds to the formula for finding temperature change, To – signal equal to the value of the initial temperature in the room. *Source: Compiled by the authors.*

The branch, which goes from the output signal to the first adder, corresponds to negative feedback, it includes K – coefficient of thermal conductivity and Tc – temperature of street air.

The last two links responsible for taking into account the loss of heat on the heating of street air are absent in the structural diagram modeled by artificial intelligence (Fig. 3).

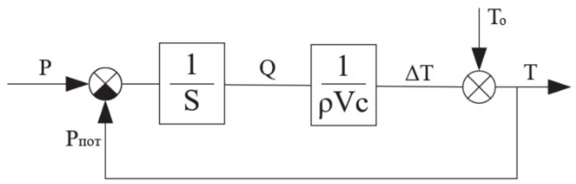


Fig. 3. Functional circuit modeled by artificial intelligence. *Source: Compiled by the authors*.

In both circuits, the input signal is the power value of the heater, which, due to the links included in the circuit, is converted into a signal numerically equal to the temperature output by the heating system. This signal is returned to the input using a negative link, which in automatic control theory is used to stabilize and correct the operation of the system. In an automatic room heating system, negative feedback reduces the difference between the desired and actual output temperature, responds to changes in the system and maintains the specified operating parameters, making the system more stable, accurate and reliable.

Using structural diagrams as a basis, simulated models of the automatic room heating system in the SimInTech program were built. In order to keep the desired temperature constant, a relay temperature control method was used, which is based on the use of a relay - an electromechanical device operating on the principle of opening and closing an electrical contact when a certain threshold value is reached.

III. RESULTS

To create a model of the automatic heating system, initial data were entered and a mathematical model was built, the same data was provided to artificial intelligence (Table 1).

TABLE 1: SOURCE DATA.

Characteristics	***Values***
Room volume V, m^3	110
Heater power P, W	32000
Thermal conductivity coefficient in the indoor air K, W/°C	426
Initial air temperature in the room T_o, °C	-15
Outdoor air temperature T_c, °C	-25
Desired indoor air temperature T, °C	30±4
Air density ρ, kg/m^3	1,225
Specific air heat capacity c, kJ/kg·°C	1,03

Source: Compiled by the authors.

Applying the physical laws described above, a mathematical model of the automatic room heating system was compiled (18):

$$\begin{cases} Q = \int \Delta P(t)\,dt \\ P_{пот} = K(T - T_c) \\ \Delta T = Q\frac{1}{\rho vc} \end{cases} \quad (18)$$

Thanks to the mathematical model, source data and source structure diagram, a simulation model was created in the SimInTech program. In order to keep the desired temperature constant, a relay element was connected to the simulation model, which turns on the heater when the temperature drops below the desired limit and turns off if it rises to the upper limit.

Another branch is also added, to which the relay element is connected and which is responsible for constant control of the output temperature, passing the resulting value to the key. The input power passes through the adder, and then the link in which it is integrated by formula (8) and converted into a signal equal to the amount of heat. Subsequently, the signal enters the link, where it is transformed according to (9) and becomes equal to the temperature change. Passing through the adder, where the initial temperature value is subtracted from the signal value, an output signal equal to the output temperature value in the room is obtained. The same signal is sent to the relay, which decides whether to turn off the heater or not. The output value also goes to the integrating link, thereby creating a simulation of heat loss (Fig. 4).

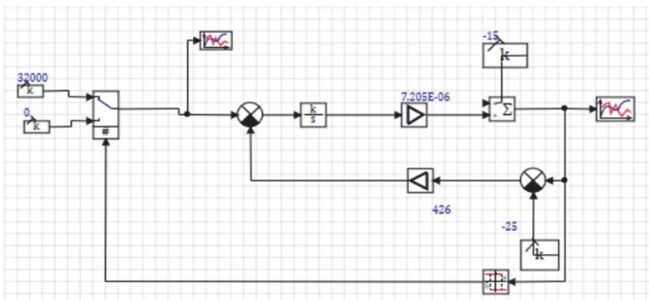


Fig. 4. The model is an automatic room heating system compiled by a person. *Source: Compiled by the authors.*

The popular ChartGPT was used as artificial intelligence, which also created a mathematical model of the automatic heating system, taking into account the initial data. Based on these initial data, artificial intelligence step by step explained the creation of a simulation model with a relay method of temperature control in the SimInTech program (Fig. 5).

Artificial intelligence also described the mathematical model in more detail, adding formula (8) and describing the way to find the area (19 – 20):

$$A = 6 \cdot h^2 \quad (19)$$

$$h = \sqrt[3]{V} \quad (20)$$

where, h – room height, A – room area, V – volume.

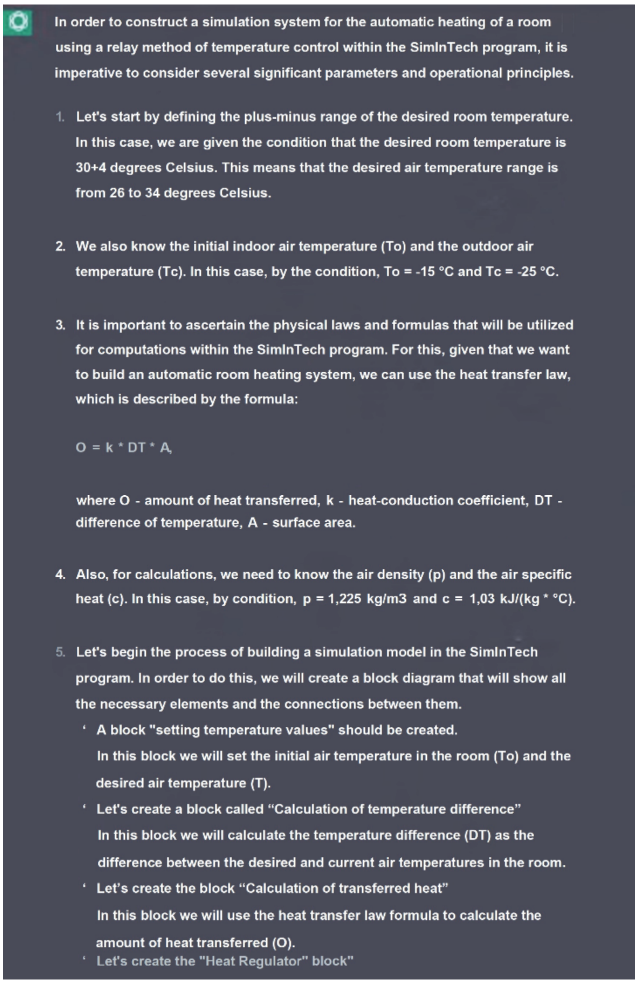
Artificial intelligence, derived such a formula assuming that the room has a cube shape, but artificial intelligence did not take into account the loss of heat and ambient air parameters in its system.

Grouping the resulting description of the mathematical model, a system of equations was compiled (21):

$$\begin{cases} Q = \int \Delta P(t)\,dt \\ \Delta T = Q\frac{1}{K \cdot A} \end{cases} \quad (21)$$

According to the explanation and with the help of the provided mathematical model, the second model of the automatic heating system in the SimInTech program was built (Fig. 6).

As the "Set Temperatures" unit, the Rele16 unit acts, which sets the upper and lower limits of the desired values, receives the test temperature at the input, compares it with the required range and gives a command to the key that turns on and off the heater. The Temperature Difference Calculation unit converts the signal output from the inverting link, making it numerically equal to the actual temperature difference. “Heat transfer calculation” is an inverting link that converts the heater's power signal into the amount of heat. The system consists of the Rele16 unit and the key is the “Heat Regulator”.


In order to construct a simulation system for the automatic heating of a room using a relay method of temperature control within the SimInTech program, it is imperative to consider several significant parameters and operational principles.

1. Let's start by defining the plus-minus range of the desired room temperature. In this case, we are given the condition that the desired room temperature is 30+4 degrees Celsius. This means that the desired air temperature range is from 26 to 34 degrees Celsius.

2. We also know the initial indoor air temperature (To) and the outdoor air temperature (Tc). In this case, by the condition, To = -15 °C and Tc = -25 °C.

3. It is important to ascertain the physical laws and formulas that will be utilized for computations within the SimInTech program. For this, given that we want to build an automatic room heating system, we can use the heat transfer law, which is described by the formula:

   O = k * DT * A,

   where O - amount of heat transferred, k - heat-conduction coefficient, DT - difference of temperature, A - surface area.

4. Also, for calculations, we need to know the air density (p) and the air specific heat (c). In this case, by condition, p = 1,225 kg/m3 and c = 1,03 kJ/(kg * °C).

5. Let's begin the process of building a simulation model in the SimInTech program. In order to do this, we will create a block diagram that will show all the necessary elements and the connections between them.
   - A block "setting temperature values" should be created. In this block we will set the initial air temperature in the room (To) and the desired air temperature (T).
   - Let's create a block called “Calculation of temperature difference” In this block we will calculate the temperature difference (DT) as the difference between the desired and current air temperatures in the room.
   - Let's create the block “Calculation of transferred heat” In this block we will use the heat transfer law formula to calculate the amount of heat transferred (O).
   - Let's create the "Heat Regulator" block

Fig. 5. Mathematical and simulation model described by artificial intelligence. *Source: Compiled by the authors.*

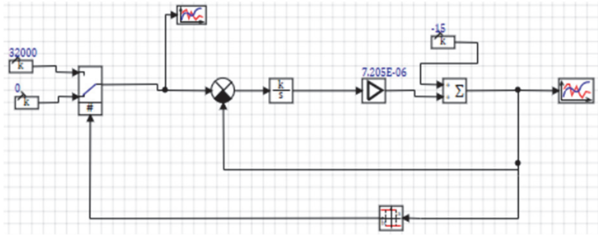


Fig. 6. Model automatic room heating system, compiled by artificial intelligence. *Source: Compiled by the authors.*

Based on the obtained systems, temperature versus time graphs were generated. Human-modeled system reaches approximate desired temperature in 378 seconds (Fig. 7).

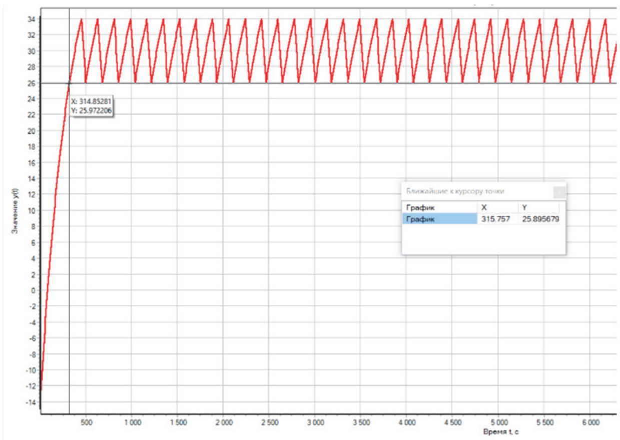


Fig. 7. Plot of the resulting temperature. *Source: Compiled by the authors.*

In this case, it can be seen that the heater, reaching a threshold value of 26ºC in 316 seconds, continues to heat up to 34ºC. The heater turns off when it reaches this value and is off until the temperature drops to 26ºC, continuing the cycle.

AI-modeled system hits the lower bound in 174 seconds (Fig. 8).

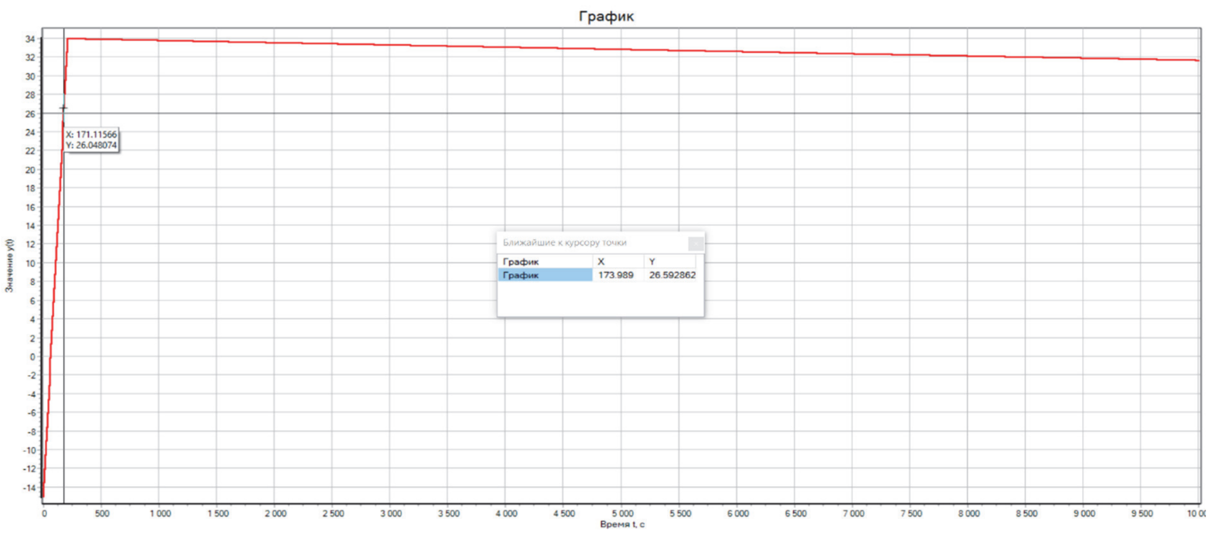


Fig. 8. Plot of the resulting temperature. *Source: Compiled by the authors.*

After reaching the lower limit, the temperature continues to rise to the value of 34ºC, then the heater turns off, since it reaches the upper limit and drops to 26ºC. However, the drop in the output temperature is much slower than in a human-made system.

IV. Discussion

This study shows that artificial intelligence was able to simulate an automatic room heating system, although not ideal. Similar results were obtained from scientists from NASA who created the Curiosity rover, which, thanks to the presence of artificial intelligence, can study the terrain, remember safe paths, and lay new routes [1, 14, 15, 16]. However, artificial intelligence has failed to address the challenges of limited mobility, the potential risk of damaging or blocking equipment, and the long duration of data and command transfers.

A group of researchers from the United States, who asked artificial intelligence to create a walking robot, also achieved some success. This robot was filled with air, it expanded, and then narrowed, due to this the robot moved. This result is unusual for a person, but working. In addition, the robot does not contain electronics, which means that artificial intelligence has created a simplified version of the required result [2, 17, 18].

Also in this study, artificial intelligence modeled only the necessary functions of the automatic heating system, without taking into account the loss of heat [19, 20, 21].

Further analysis on the topic of research on data provided by artificial intelligence and existing sources showed that, given the growing need for artificial intelligence in various fields, it is not able to fully take into account all the factors for self-creation of any product.

V. Conclusion

As a result of the study, the goal was fully achieved. Mathematical and simulation models of the automatic room heating system created by man and artificial intelligence in the SimInTech program were built and analyzed.

Artificial intelligence was able to cope with the task, describe the need for each link in the scheme, and consistently explain the receipt of a mathematical model. However, the system simulated by artificial intelligence does not consider the loss of heat, as a result of heat exchange between the walls of the room and the street temperature, the turn on and off of the heater is slow, because of which the constant desired temperature cannot be maintained in the room, the mathematical model contains an error in the law of the amount of heat.

Despite the diverse applications of artificial intelligence in the modern world, the application of this development in engineering sciences, in particular in the theory of automatic control, is not yet possible.

The results of this work can contribute to the development of research in the field of the use of artificial intelligence in the theory of automatic control. This can be achieved by using artificial intelligence, specially trained to solve the problems of the theory of automatic control and modernization of mathematical and imitation models.

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