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THE INFLUENCE OF RESOURCE RESTRICTIONS
ON DECISION MAKING BY A CONTROL SYSTEM
ON THE CHANGE OF STRUCTURE
OF A CONTROL OBJECT

Т.С. Добровольська. **Вплив ресурсних обмежень на прийняття рішення системою керування по зміну структури об'єкта керування.** Запропоновано підхід керування системою зі змінною структурою об'єкта. Об'єктом керування вибрано систему теплопостачання котеджу. В основу підходу покладено метод динамічного програмування. Удосконалений метод дозволяє підтримувати комфортну температуру повітря в приміщенні при обмеженні на паливно-електричні ресурси.

Ключові слова: динамічне програмування, змінна структура об'єкта, система теплопостачання, оптимальне керування.

Т.С. Добровольская. **Влияние ресурсных ограничений на принятие решения системой управления по изменению структуры объекта управления.** Предложен подход управления системой с переменной структурой объекта. Объектом управления выбрана система теплоснабжения коттеджа. В основу подхода положен метод динамического программирования. Усовершенствованный метод позволяет поддерживать комфортную температуру воздуха в помещении при ограничении топливно-электрических ресурсов.

Ключевые слова: динамическое программирование, переменная структура объекта, система теплоснабжения, оптимальное управление.

T.S. Dobrovolskaya. **The influence of resource restrictions on the control system's decision making as to the structural change of the control object.** An approach to the control of the system with a variable structure of the object is proposed. A heating system of a cottage has been chosen as a control object. The approach is based on the method of dynamic programming. The improved method allows the comfortable room air temperature to be maintained when fuel and electricity resources are limited.

Keywords: dynamic programming, variable structure of a (control) object, heating system, optimal control.

Creating a comfortable environment is an integral part of modern life. It helps to increase efficiency in manufacturing and complete rest at home. One of these conditions is heating a building in the cold season. A heating system has many uses, it can provide not only warmth but also hot tap water, heating greenhouses and heating the water in a swimming pool, etc.

In the article [1] there is a comparative analysis of the energy and environmental descriptions of six types of equipment for heating in the residential sector: a gas-fired condensing boiler, a wood pellet boiler, a micro-combined heat and power (MCHP), an air-to-water electric heat pump, an air-to-water gas absorption heat pump and an exhaust air-to-air electric heat pump. The MCHP and the absorption heat pump achieve the highest energy output, based on ideal sizing. The increase of size causes a considerable decrease in system efficiency. The air-to-water electric heat pump uses the most efficient technology; however, increasing the size influences the efficiency of the thermodynamic system. The wood pellet boiler is less efficient, but it has the lowest proportion of emissions into the environment.

Analyzing the dynamics of the prices of gas and electricity resources, the use of various types of energy equipment is economically feasible. In this regard, there is the task of rational use of equipment. The equipment can be operated either sequentially or simultaneously. It will be appreciated that the more units of equipment are available, the more possible solutions must be calculated. For exam-

ple, for two units of equipment we must calculate four possible solutions, for three — 8, for four - 16, etc. When the operator decides on a large number of possible solutions, the risk of making an irrational solution increases. Therefore it is necessary to automate the management system and process on/off equipment. It allows a reduction in the risk and the increase in labor productivity and quality of the product. The aim of this article is to develop a method for automating the process of finding a solution for the rational use of equipment and therefore the automation of control systems with a variable usage of energy, taking into account the available resources.

At first, we have to solve the task of choosing a method which calculates the optimal plan of switching equipment. The paper [2] presents a solution to the task of controlling a heating system by the method of linear programming. This method is universal for different tasks but for more than two units of equipment is rather laborious. In the work [3] is shown the solution to the task of finding the optimal way to restore network services using the method of Bellman's dynamic programming.

This method has been illustrated by the cottage heating system [4] to find the optimal plan of switching equipment. The thermal model of the object is described by expressions of the heat balance. The technical means of automation are two gas boilers and two heat pumps (HP) which have a mathematical model described in the paper [4].

The evaluation of the effectiveness of the control system is considered by discrete function $J(x, t)$ whose arguments are time from regulation and the plan for switching the equipment. This function takes into account the cost of expenses $S(x, t)$ for gas and electricity resources, as well as the efficiency $E(x, t)$ and probability $R(x, t)$ of failure of the operating equipment while maintaining the highest possible quality $Q(x, t)$ of the transition process. All of these components of the function are normalized and are supplemented by weighted coefficients w_r, w_q, w_e, w_s, equal to 0,25. Discrete function is presented below:

$$J(x,t) = \sqrt{(w_r R_{\text{н}}(x,t))^2 + (w_q Q_{\text{н}}(x,t))^2 + (w_e E_{\text{н}}(x,t))^2 + (w_s S_{\text{н}}(x,t))^2} . \tag{1}$$

The task of finding an optimal plan for the switching of equipment must satisfy the condition $J(x,t) \to \min\limits_{x \in X, t \in T}$.

The probability of failure-free operation of the whole system and quality components of the assigned temperature in the room has been changed.

$$R_{\text{н}}(x,t) = \sqrt{\sum \alpha_i^2(x,t)} , \tag{2}$$

where

$$\alpha_i = \frac{t_i + N_{sw} R_{sw}}{(R_{sw} + \Delta t) \cdot t / \Delta t};$$

t_i — work time of ith unit of equipment in the limit of modeling $[t_0, t]$, sec;
N_{sw} — the total number of switching of the i-th equipment;
R_{sw} — work time for one switching of the equipment;
Δt — time step, sec.

$$Q_{\text{н}}(x,t) = \frac{\left| T_{assigned} - T_{room} \right|}{\Delta T} , \tag{3}$$

where

T_{room}, $T_{assigned}$ — the current and assigned air temperature in the room, ºC;
ΔT — value by which the normalized temperature(0,5 ºC).

The equipment operates in the nominal mode. The assigned temperature is equal to 23 °C.

The object modeling results with unlimited gas and electricity resources are shown (Fig. 1): the graphic of the current room temperature, the graphics of switching of the energy equipment, the graph of the target function. The total modeling time is eight hours. The graph of the target function is shown in the stabilized portion of the system. The air temperature in the room varies within certain limits.

The component of quality $Q(x, t)$ is equal to 0,0071, the value of the objective function $J(x, t)$ — 0,051. The equivalent value of resources is used of 12,24 UAH.
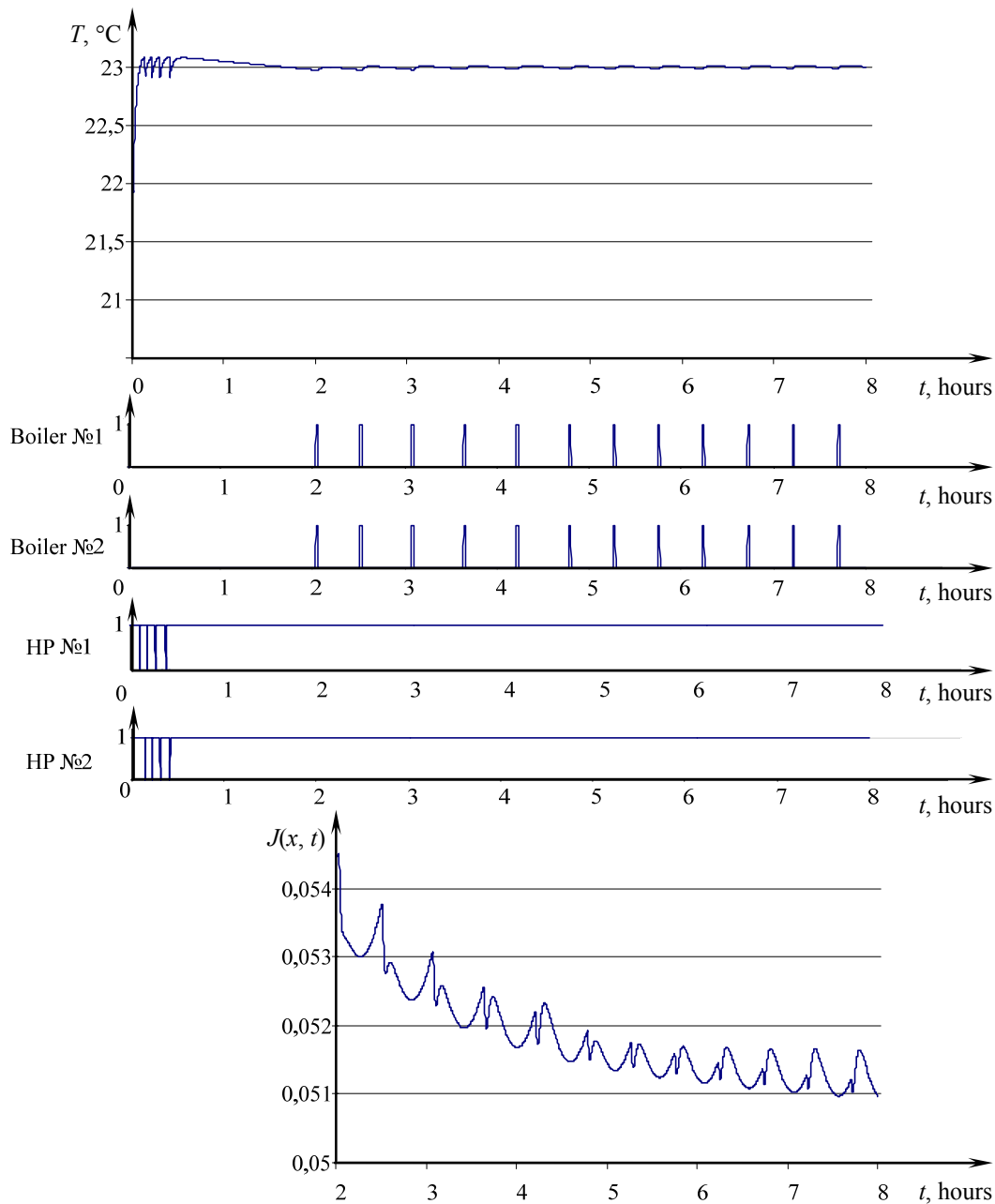

Fig. 1. The object modeling results with unlimited gas and electric resources

The object modeling results with limited electric resources are shown (Fig. 2). The limitation on the electric resources is of 28000000 kW/hour. The graph of the target function shows the output from the stabilized portion of the system. The graph shows when the electricity resource is depleted, the heat pumps (HP) switch off and the air temperature begins to decrease. Then the gas boilers are switched. The boilers operate as long as the temperature does not stabilize at the assigned temperature. The component of quality of $Q(x, t)$ is equal to 0,1510, the value of the objective function $J(x ,t)$ — 0,0618. The equivalent value of resources is used of 29,96 UAH.
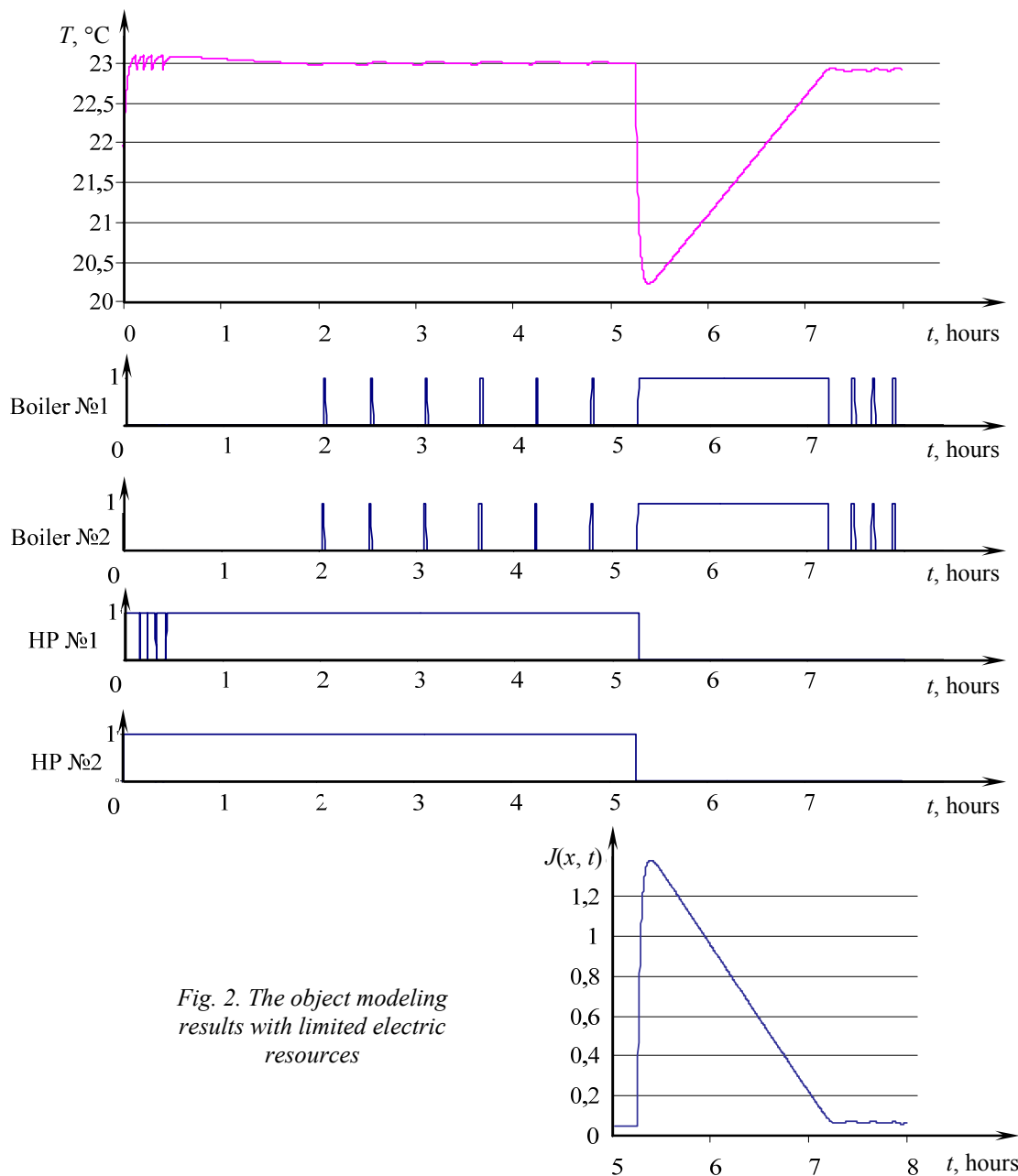
Fig. 2. The object modeling results with limited electric resources

The object modeling results with limited gas resources are shown (Fig. 3). The limitation on the gas resources is 1 m³. When the gas resource is depleted gas boilers turn off but the heat pumps operate and with minimal change in the air temperature is shown in the graphs.

The component of quality of $Q(x, t)$ is equal to 0,1095, the value of the objective function $J(x, t)$ — 0,0577. The equivalent value of resources is used of 11,88 UAH.
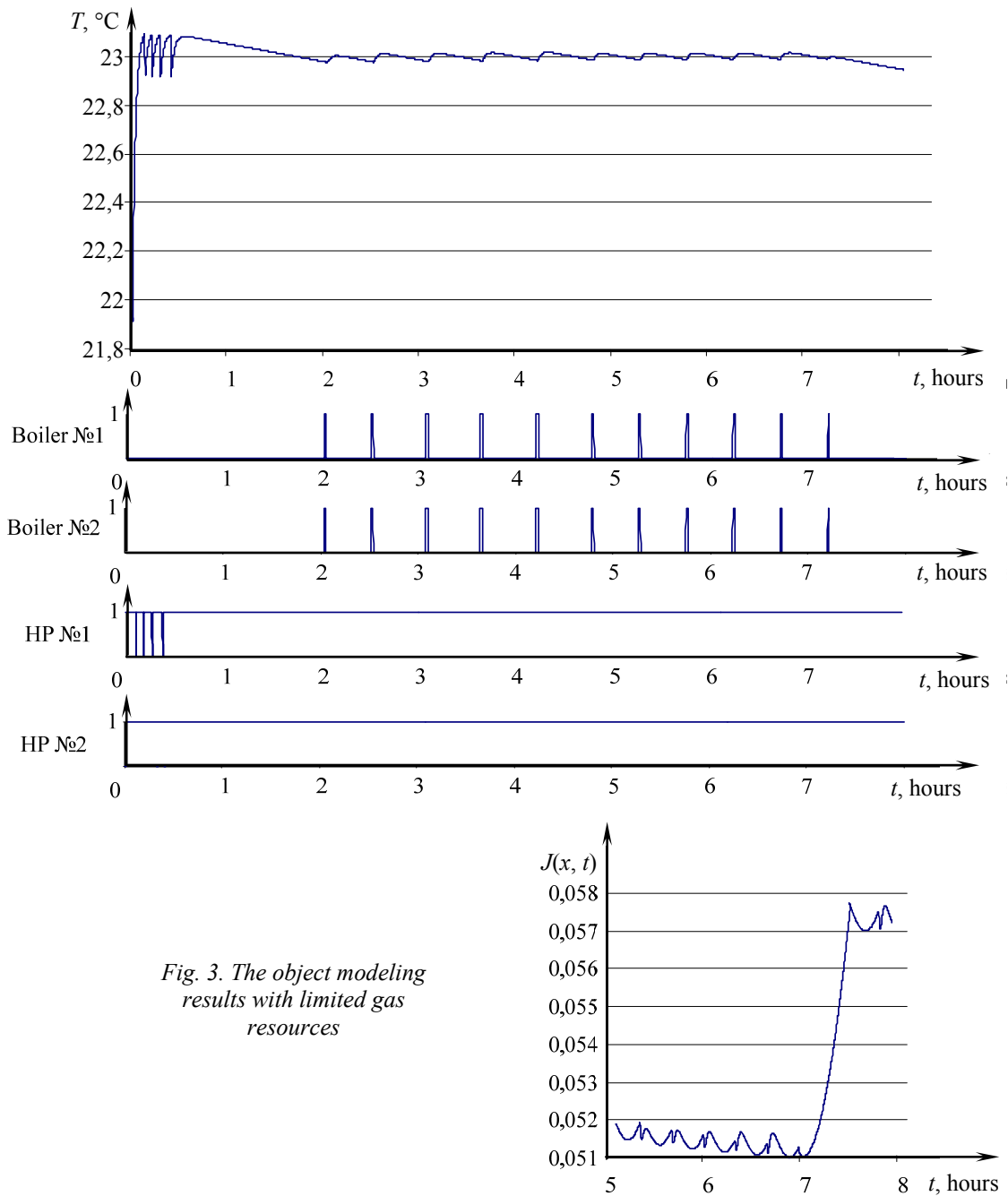
*Fig. 3. The object modeling
results with limited gas
resources*

The object modeling results with both limited resources are shown (Fig. 4). The limitation on the power resource is of 28000000 kW/hour and the limitation on the gas resource is 1 m³. When both resources are depleted, the heat pumps and gas boilers are switched off and the temperature begins to decrease. This is shown in the graphs for switching of the energy equipment and the air temperature. The system operates inefficiently as shown in the graph of the target function. The component of quality of $Q(x, t)$ is equal to 7,0316, the value of the objective function $J(x, t)$ — 1,7582. The equivalent value of resources used is 8,68 UAH.
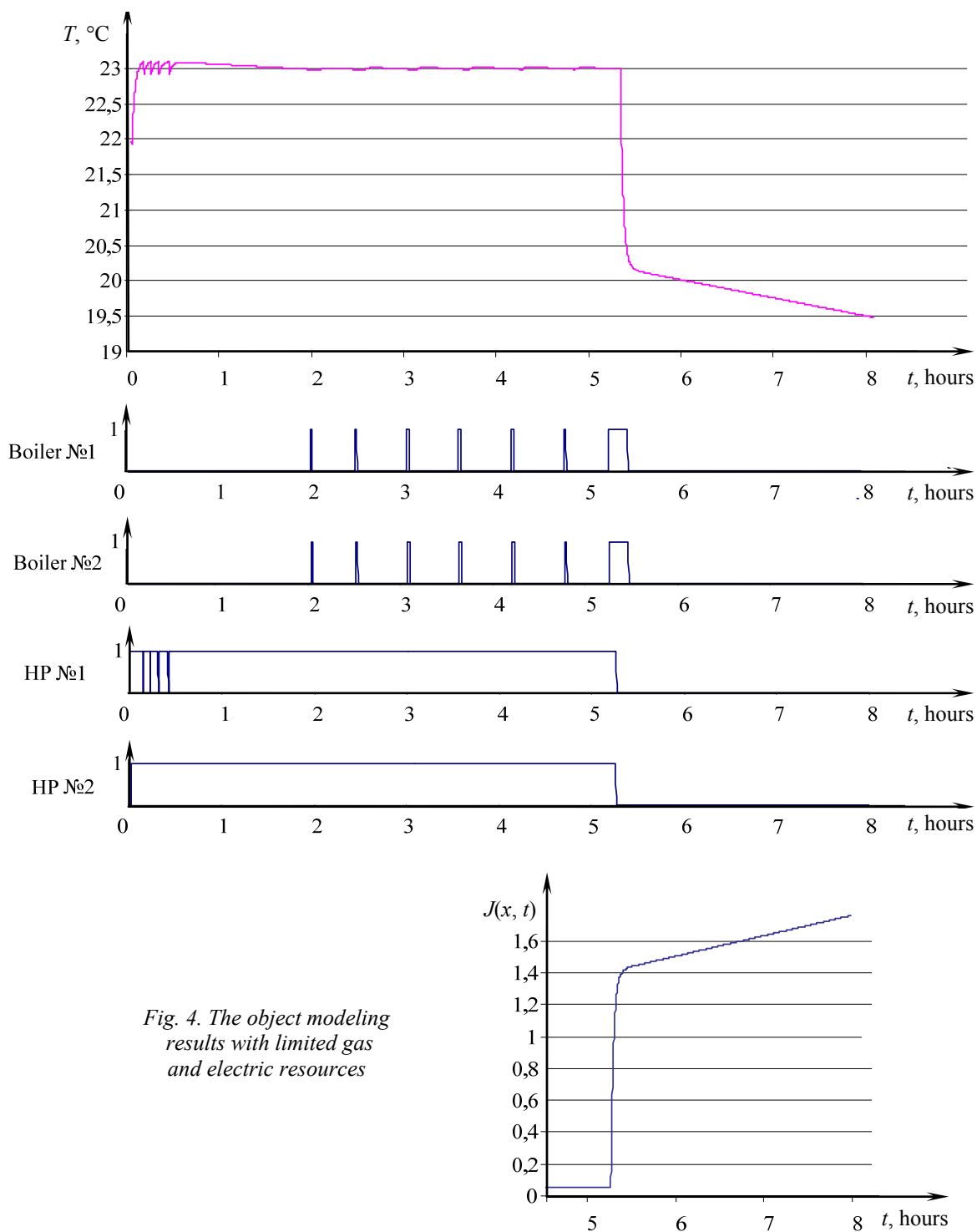
*Fig. 4. The object modeling
results with limited gas
and electric resources*

Consequently, the chosen method allows a solution to the task with a restriction to only one re-source, but cannot cope with the task by limiting both types of resources. The method needs to be im-proved. One option is to reduce the temperature value which will reduce the loss into the environment.
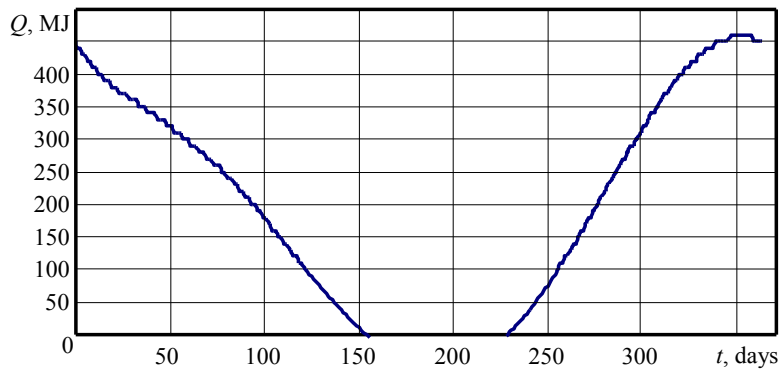
Fig. 5. The graph of the curve losses to the environment

The curve on the graph is losses to the environment (the room temperature is equal to 23 °C) is shown (Fig. 5). The environment temperature is described by polynomials[4].

Based on this curve, the total loss per year can be calculated. This allows a calculation of the necessary amount of resources to compensate for these losses. If the required quantity exceeds the available quantity of resources, air temperature $T*$ decreases in increments of 0,5 °C and the construction of a new loss curve for the temperature $T*$. Based on this data, the total losses per the year can be calculated, enabling the necessary amount of resources to be found. Calculation continues until the available resources are insufficient to compensate for losses into the environment. When enough resources are available, a calculated plan for switching equipment for the new value assigned temperature is equal to T^*.

The object modeling results improved method with both limited resources is shown (Fig. 6). The limitation on the electricity resource is of 28000000 kW/hour and the limitation on the gas resource is 1 m^3. The new value of the assigned temperature is equal to 21 °C. The air temperature in the room varies within certain limits. The component of quality $Q(x, t)$ is equal to 0,1527, the value of the objective function $J(x, t)$ — 0,0906. The equivalent value of resources used is 7,49 UAH. The system operates efficiently as shown in the graph of the target function.

Based on this experience, we can say that the selected units of equipment cancel each other out. With a shortage of resources for one of the pieces of equipment included, the other piece of equipment compensates for the absence (Fig. 2, 3).

Data from all five experience results are tabulated in the order that they appear in the article.

Total results of the experiences

№ expirience	S(x, t)	Q(x, t)	R(x, t)	E(x, t)	J(x, t)	Cash costs, UAH
1	0,0581	0,0071	0,1953	0,0000002	0,051	12,24
2	0,1421	0,1510	0,1346	0,00000072	0,0618	29,96
3	0,0564	0,1095	0,1951	2.00E-07	0,0577	11,88
4	0,0412	7,0316	0,1307	0	1,7582	8,68
5	0,0355	0,1527	0,3266	0,0000002	0,0906	7,49

According to the table, we draw the conclusion that the proposed method of dynamic programming has the smallest and the best value of the target function $J(x, t)$ equal to 0,051 for an unlimited number of resources. When restricted to the gas or electric resources, the target function is slightly changed 0,0618 and 0,0704, which had little effect on the quality of the system, although the monetary cost almost doubled (12, 24 to 29,96 UAH) in comparison to the continuous operation of gas boilers (Fig. 2). If possible, pre-calculate the necessary amount of resources that allows you to maintain a comfortable temperature in the room, although lower than the initial value (Fig. 6). Value of quality $Q(x, t)$ and the target function $J(x, t)$ constitute 0,1527 and 0,906, respectively. This is significantly better than exhausting all resources and lowering the temperature to 19,5 °C. Values of the quality $Q(x, t)$ and the target function $J(x, t)$ which equal to 7,0316 and 1,7582, respectively, also reduce cash costs from 8,68 to 7,49 UAH. The modified method allows us to maintain a comfortable indoor temperature that promotes proper rest at home and good human productivity at work.
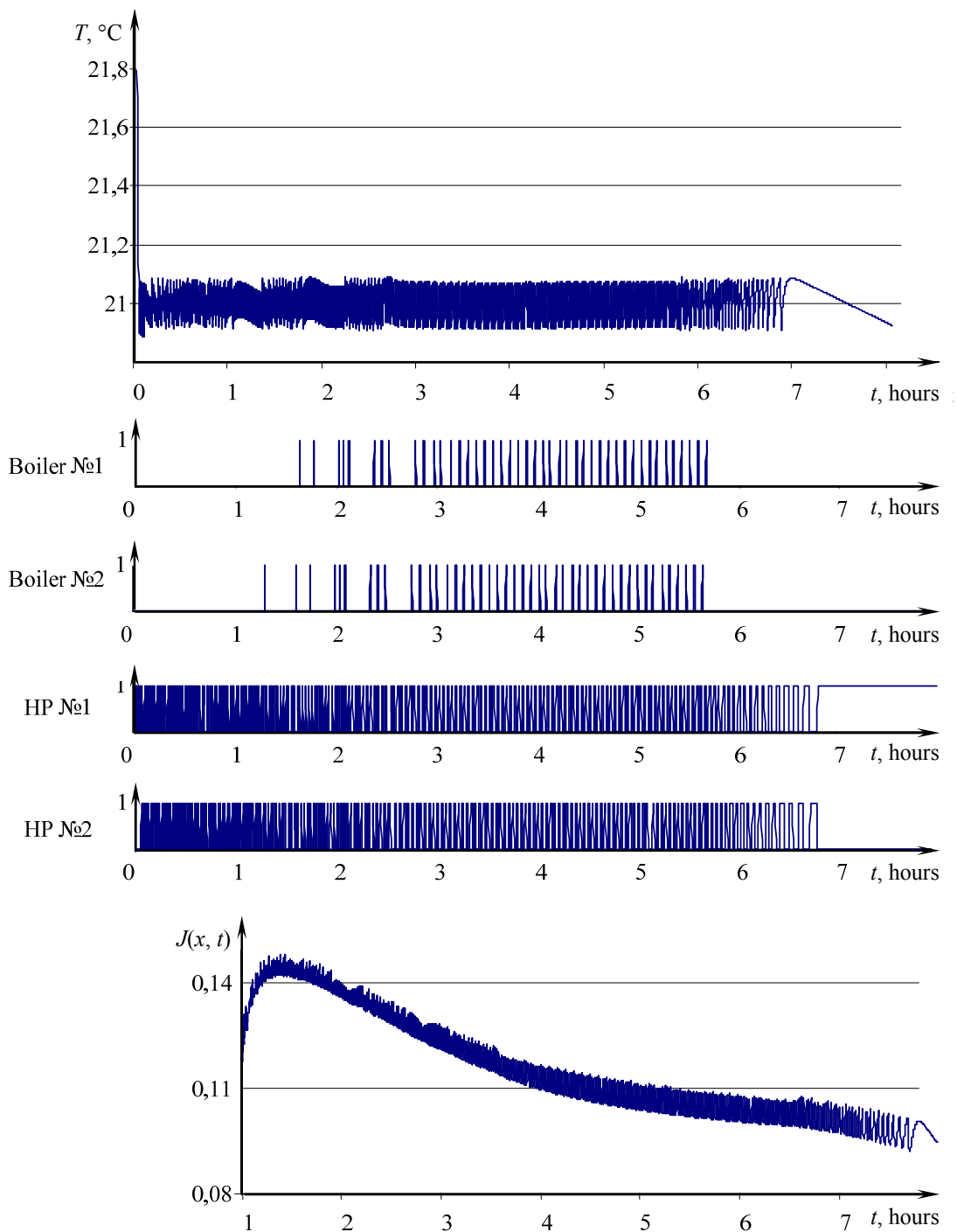
Fig. 6. The object modeling results improved method with both limited resources

Consequently, the modified method allows efficient use of disposable fuel and power resources. This allows you to maintain a comfortable indoor environment.

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