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Energy efficiency and ecological quality of buildings by process control of heat supply systems

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Abstract. The article presents special characteristics of mathematical modeling of the process control a resource efficient heat supply system of industrial buildings and facilities, where constant temperature maintenance is especially critical for the process. A functional diagram of the operation of the continuous heat supply process is provided. The dependence of temperature at the point of heat-transfer fluid mixing on environmental is analyzed and control system operation algorithm is proposed.

1 Introduction

Today the subject of energy efficiency has a great importance worldwide. Russian state program "Energy conservation and energy efficiency improvement for the period up to 2020" shows, that even government has its interest in high quality energy system. Moreover, the Paris Agreement has entered into force giving a boost to the transition towards a clean, smart, and secure energy infrastructure. In this context the issue of the enhancing the quality of the heat flow distribution in heat supply systems becomes significant as well. Improvement of heat flow control is an important problem of energy conservation to be considered in terms of impact on the environment.

2 Scope of the work

The heat balance in heating system pipelines was examined in the scientific works [1-4]. The formula (1) presents it for steel pipes:

$$t_A = t_\kappa \left(1 - e^{-\frac{\tau-\tau_3}{T}}\right) + t_1 e^{-\frac{\tau-\tau_3}{T}} \tag{1}$$

Where t_1, t_A, t_κ – are the temperatures: of the heat-transfer fluid of the delivery pipeline, at point A, and air in the heated space respectively ^oC; τ – the time, s; τ_3, T – are the complete lag time in the transient process and the constant of heat load correspondingly, R, s.

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The dependence is provided on Fig.1

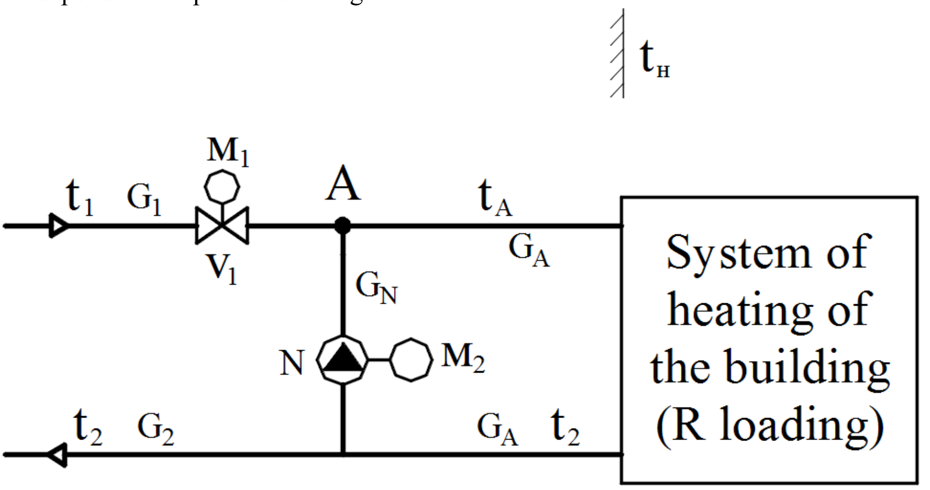

Fig. 1. Diagram of the dependent connection of a heating system with water mixing.

Expression (2) from (1) implies that:

$$t_к = \frac{t_A + t_1 e^{-\frac{\tau-\tau_3}{T}}}{1 - e^{-\frac{\tau-\tau_3}{T}}} \quad (2)$$

3 Methodology and discussion

The expression does not include the value of external air temperature impact $t_н$. This parameter is included in (2) to study the heat balance in such a scope. The correlation of $t_н, t_A, t_к$ is provided below (3):

$$t_k = \frac{t_A + \bar{k} \cdot t_н}{\bar{k} + 1} \quad (3)$$

Where $\bar{k}$ - is the dimensionless constant which includes heating system pipelines structure determined according to the equation (4):

$$\bar{k} = \frac{k_2 F}{k_1 \pi d_2 \ell} \quad (4)$$

and (5):

$$k_1 = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{mp}}{\lambda_{mp}} + \frac{1}{\alpha_2}}, \quad (5)$$

Where $\frac{1}{\alpha_1}, \frac{1}{\alpha_2}$ – are the heat resistances of heat interchange between the warm water in the pipeline and inner surface of the pipe wall and between the outer surface of the pipe wall and the air in the heated space W/(m^2 °C); $\frac{\delta_{mp}}{\lambda_{mp}}$ − is the heat resistance of the pipe wall, W/(m^2 °C); d_2, ℓ − are the outer diameter of the pipe and the length of the pipeline in the heating system, m.

$$k_2 = \frac{1}{\frac{1}{\alpha_3} + \frac{\delta_{cm}}{\lambda_{cm}} + \frac{1}{\alpha_4}}, \tag{6}$$

Where $\frac{1}{\alpha_3}, \frac{1}{\alpha_4}$ − are the heat resistances of heat interchange between the warm air in the heated space and the inner surface of the building walls and roof, and between the outer surface of building walls and roof and the external air surrounding the building W/(m^2 °C); F − is the total area of the walls and roof, m^2.
Comparing (2) and (3) we obtain the following expression:

$$t_A = \frac{(\bar{k}+1)e^{-\frac{\tau-\tau_3}{T}} t_1 + (e^{-\frac{\tau-\tau_3}{T}} - 1)\bar{k} \cdot t_н}{\bar{k} + e^{-\frac{\tau-\tau_3}{T}}} \tag{7}$$

Let us put the expression (7) in the following form:

$$t_A = \frac{(\bar{k}+1)e^{-\frac{\tau-\tau_3}{T}}}{\bar{k} + e^{-\frac{\tau-\tau_3}{T}}} \cdot t_1 - \frac{(1 - e^{-\frac{\tau-\tau_3}{T}})\bar{k} \cdot}{\bar{k} + e^{-\frac{\tau-\tau_3}{T}}} t_н \tag{8}$$

Let us obtain the dependence between the flow rates G_1 and G_N of the delivery pipeline and the mixing pump correspondingly, using equation (8) and system (9):

$$\begin{cases} G_A = G_1 + G_N \\ G_A(t_A - t_2) = G_1(t_1 - t_2) \end{cases} \tag{9}$$

Having plugged (8) into (9) we obtain:

$$G_1 = \frac{G_N}{\left(\frac{(t_1 - t_2)\left(\bar{k}e^{-\frac{\tau-\tau_3}{T}} + 1\right)}{(\bar{k}+1)t_1 + \bar{k}t_н\left(e^{-\frac{\tau-\tau_3}{T}} - 1\right) - t_2\left(\bar{k}e^{-\frac{\tau-\tau_3}{T}} + 1\right)} - 1 \right)} \tag{10}$$

Expression (10) allows us to select some external air temperature $t_н$ as a control variable, and fluid flow rate G_1 in the delivery pipeline of the heating system as a controlled variable.

Using expressions (7) and (10) the control of the process of building heating in case of dependent connection to heat supply systems can be represented as a block diagram (Fig.2).

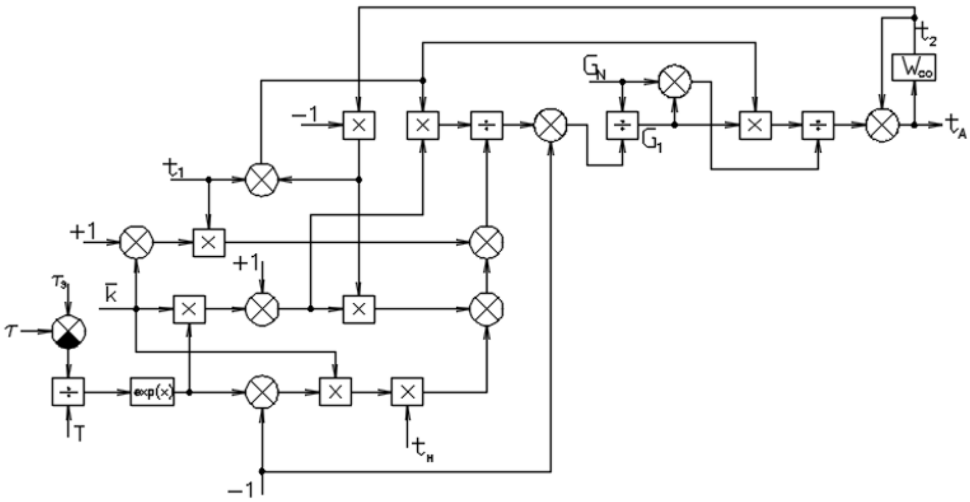

Fig. 2. Block diagram of continuous process control of building heat supply.

Based on the experimental information transient characteristics have the form of smooth curves [5]; the structure of the object of control in channel t_A can be represented as a serious connection of a pure lag element and a first-order lag block, which is theoretically substantiated in (11):

$$W_{co} = \frac{k}{TS+1} \cdot e^{-S\tau_3} \tag{11}$$

Where τ_3, T – are the pure lag time and the constant of a heating system, s; k – is the gain ratio; S – is the parametric variable.

However, regarding modern approach to the constriction and technology within the buildings with ecological aspects [6-8] even in that efficiency process control of heat supply systems above should be consider ecological quality of living environmental [9-10]. Therefore energy efficiency and ecological quality of buildings must also consider economics model and risk management [11-13]. For example, energy consumption data can help consumers change their behaviour and become more energy efficient. It is also useful for policy-makers to effectively target, monitor and evaluate their measures and actions.

4 Conclusions

1. The article presented developed mathematical model of heating systems control for dependent connection of the heat load to heating networks.

2. Fig.2 demonstrates the heating process control block diagram for independent connection to heating networks in transient mode.

3. Analyzing the obtained mathematical model basic control variable $t_н$ and basic controlled variable t_A were found.

4. Increasing of the energy performance of buildings can have a positive impact, not only in economic terms, but also regarding public health and safety with indoor climate improving.

5. There is a need to improve the technical skill of the workers, dealing with energy systems equipment. The trainings are to provide the staff with the knowledge of the modern hardware and software and the key aspects of ecological issues of engineering systems of the buildings.

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