Pulse control of temperature mode of buildings with elevator system connection heating

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Abstract. The problem of energy saving when heating buildings is considered. The problem of weather regulation of heating systems with an elevator connection has been solved, including during the "cut-off" of the temperature regime. An algorithm for impulse control and the composition of automation systems for its implementation have been developed. The duty cycle of the control pulses is determined by the results of measuring either the temperature of the heating system and its flow rate, or the temperature of the coolant at the inlet of the heating system and its flow rate in it. The repetition period of control pulses is selected based on the required quality of regulation in the steady state. This takes into account both the heat-shielding properties of the heated buildings and the characteristics of their heating systems. A qualitative analysis of the dependences of the duty cycle and the repetition period of control pulses on influencing factors has been carried out. At the same time, the approach to solving the problem used in the work, in contrast to the previously used, is more "transparent" and simpler.

1. Introduction

In the Russian Federation, more than one third of all extractive fuel is spent for heat supply of buildings, and the main costs are heating costs. Therefore, there is a task of developing modern approaches to the rational usage of energy resources spent on heating. Ways of the solution of this problem are following: design-and-engineering methods; an adjustment and operation of mounted and operating systems of heating, and the operation can be as manual, and with automatic equipment.

Possibilities of design-and-engineering methods are rather limited, for example, if we consider thermal behavior of buildings it is difficult to take into account such factors as solar radiation; thermal emissions from the equipment and people; excess power of heating system at the temperature of external air. Also, there is a problem when considering fluctuations of temperature of external air, speed and the direction of wind and other indignations from the external environment; randomness of an operating mode of ventilation systems, etc. However, we can do it by means of automatic equipment.

There is an expectation to reduce the energy consumption almost twice due to an increase in requirements to heat-shielding properties of buildings. However, it led to the saving only at a rate of
1/3 from the expected size, and 2/3 it is still lost through the windows because of the over-heating. It is an operation problem. There are no systems of automation or they are not adjusted properly.

Heat-shielding properties of modern buildings have considerably grown, satisfactory temperature conditions can be supported even without heating devices by means of that energy which arrives through a stack. Therefore, in inter-season there is great over-heating, especially when the one-pipe system of heating is used. At the same time, the technical means offered for realization of heating systems and ventilation, and automation systems for them are rather perfect. All problems are in the technologies of heating and ventilation, in control algorithms of these systems, in the adjustment of these systems.

Thus, one of the main ways of the solution of the energy saving problem is automation of heating systems. That is why the development of the questions, which are directly connected, with automation of heating systems and their improvement is one of the most urgent problems of the present. Many works are devoted to the solution of this problem and quite interesting and important results are received.

In this paper, the problem of management of heat supply of buildings with the elevator scheme of accession to thermal networks is considered. It is well-known [1], elevator nodes still have wide circulation in systems of heating and will be applied for a long time, despite a tendency of transition to independent schemes of accession of heating systems.

Usually for elevator systems, two-position regulators are used, operating on the air temperature in the control rooms of the building. This is due, in particular, to the fact that the proportional control of the heat carrier flow is unacceptable due to the hydraulic misalignment of the heating installations. At the same time, due to the large inertia of the feedback loop, the quality of control is not high. In addition, it is rather difficult to select control rooms and place temperature sensors in them. As a result, in some cases, the temperature of returning water is used as the feedback signal, which, in general, is not a sufficiently reasoned solution. In this paper, we propose a pulse control system that is realized within the framework of the old normal technical structure of the weather regulator, which is a noticeable advantage. The necessary algorithmic support is developed for this.

2. Formulation of a management problem

We offer applying the non-continuous heating that realized by means of the mode of pulse management of heating system instead of the on-off regulator and the weather schedule or feedback on temperature of the internal air $t_\text{e}$. 

In that case, when the actual power of heating system $W_{co}$ at these values of parameters of the heat carrier and temperature of external air is superfluous, in the building some temperature $t_\text{e}^{\text{MAX}}$ that will exceed considerably the present value $t_\text{e}$ is established. This situation is not only during “cut” of the temperature schedule of regulation, but also during any other period as “… creation of the schedule is focused on the depersonalized building … at a settlement temperature of internal air 18 °C” [2, p. 458].

In that case, for the purpose of economy of warmth consumption for heating and for providing the acceptable internal climatic conditions, the pulse mode of heating of buildings at which during some period $T$ the heating system works at full capacity $W_{co}$ for a time $\gamma \cdot T$ can be applied, then it is completely disconnected until the end of the period. So, there is a question: in what way can a duration of the period $T$ and the pulse ratio $\gamma$ be chosen, considering that temperature in the building is maintained in the set limits?

3. The solution of the management problem

The pulse ratio $\gamma$ can be defined by the following reasons. At the stationary mode, the power of the heating system $W_{co}$ has to equal to heat losses of the building at that temperature, which was established in it, and at that temperature which is outside. If heat losses are estimated using N.S.
Yermolaev’s formula, then for a case when the heating system at the power $W_{CO}$ works at the mode of constant switch the following ratio has to be carried out:

$$W_{CO} = q_v \times (t_u^{MAX} - t_H) \times V,$$  \hspace{1cm} (1)

where $q_v$ – the specific thermal characteristic of the building, $V$ – its volume, $t_H$ – temperature of the external air. When a pulse ratio is chosen in a right way, we receive that

$$\gamma \times W_{CO} = q_v \times (t_e' - t_H) \times V.$$  \hspace{1cm} (2)

where $\gamma \times W_{CO}$ – the average power of the heating system for the period at the pulse mode. If the equation (2) is divided by the equation (1), we will receive that the pulse ratio should be defined as:

$$\gamma = \frac{(t_e' - t_H)}{(t_u^{MAX} - t_H)}.$$  \hspace{1cm} (3)

The temperature $t_u^{MAX}$ can be calculated using a mathematical model of the thermal behavior of the building that has to be adjusted according to a real process. In particular, it can be done by the equation (1) which represents mathematical model of the stationary mode. It is necessary to take into consideration that the power of the heating system can be calculated on the following formula:

$$W_{CO} = \frac{(kF)_{CO} \times (t_{CO} - t_H)}{1 + \frac{(kF)_{CO}}{(q_v \times V) + \frac{(kF)_{CO}}{(2cG_{CO})}}},$$  \hspace{1cm} (4)

where $t_{CO}$ – the water temperature at the input of the heating system (after elevators), $c$ – the specific heat storage capacity of the heat carrier, $G_{CO}$ – a mass consumption of the heat carrier through the heating system, $(kF)_{CO}$ – multiplying the coefficient of a heat transfer by a value of the heat exchange surface area for all heating system, it is that parameter which should be defined at the model identification of the heating system.

Substituting this expression in the equation (1), we will find from it a formula for the calculation $t_u^{MAX}$:

$$t_u^{MAX} = \frac{t_H + (kF)_{CO} \times (t_{CO} - t_H)}{(q_v \times V) + (kF)_{CO} + \frac{(kF)_{CO}}{(2cG_{CO})}},$$  \hspace{1cm} (5)

and then the required pulse ratio $\gamma$:

$$\gamma = \frac{(t_e' - t_H)}{(t_{CO} - t_H)} \times \left[1 + \frac{(q_v \times V)}{(kF)_{CO} + \frac{(q_v \times V)}{(2cG_{CO})}} \right].$$  \hspace{1cm} (6)

As reflected the formula (6), the pulse ratio $\gamma$ is a function of the temperature of the external air $t_H$, the set value of the temperature of the internal air $t_e'$, a water temperature at the input of the heating system $t_{CO}$ and a consumption of water through the heating system of the building $G_{CO}$. Besides, the pulse ratio $\gamma$ depends on the characteristic of the heating system (it is a parameter $(kF)_{CO}$), and heat-shielding properties and the sizes of the building (it is a parameter $(q_v \times V)$).
The figure 1 presents the dependence of pulse ratio $\gamma$ from the temperature of the external air $t_H$ for three values of temperature at the input of the heating system $t_{CO}$: the first curve $t_{CO} = 70^\circ C$, the second curve $t_{CO} = 50^\circ C$, and the third curve $t_{CO} = 30^\circ C$. The calculations were made by the formula (6) at the following values: $q = 0.168 W \times (m^3 \times ^\circ C)^{-1}$, $(kF)_{CO} = 1680 W \times (^\circ C)^{-1}$, $t'_c = 18^\circ C$, $V = 1700 m^3$, $G_{CO} = 1.57 kg \times s^{-1}$.

From the figure 1, we can see that with the increase in temperature of the external air $t_H$ the pulse ratio $\gamma$ decreases, that was expected. The analysis of the formula (6) including direct calculations, have shown that pulse ratio $t_H$ grows in the following cases:

1. with the increase of a parameter $(q \times V)$, i.e. with the deterioration in heat-shielding properties of the building;
2. with the decrease of a parameter $(kF)_{CO}$, i.e. with deterioration the characteristics of heating system and its power with other things being equal;
3. with the decrease of a water consumption $G_{CO}$ through the heating system.

According to the formula (6) for calculating $\gamma$ it is required to measure the temperature of the external air $t_H$, temperature $t_{CO}$ and a water consumption $G_{CO}$ at the input of the heating system (after elevators or any other unregulated nodes of mixture). The scheme of such control system is on figure 2.

![Figure 1. The dependence of pulse ratio from the temperature of the external air $t_H$.

![Figure 2. The diagram of the 1-st option of impulse management system.]
where 1 – the controller, 2 – the double-thread valve with the electric drive, 3 – the temperature sensor of the outside air, 4 – the temperature sensor of the direct water, 5 – an elevator, 6 – the differential pressure regulator, 7 – a flow meter.

It is possible that the measurement of the temperature $t_c$ and a water consumption $G_c$ in the flow pipe will be more preferable; in this case, the power of the heating system $W_{CO}$ should be expressed through temperature $t_c$ as it is made in [3].

This formula will be the following:

$$W_{CO} = c \times G_c \frac{(t_c - t_H)}{1 + \chi + \frac{0.5}{1 + c \times G_c}} + \frac{c \times G_c}{kF_{CO} + \frac{c \times G_c}{q_f \times V}}, \quad (7)$$

where $\chi$ – a mixing coefficient. The diagram of management system for this case is provided on fig. 3.

![Diagram of management system](image)

**Figure 3.** The diagram of the 2nd option of a pulse control system.

At the realization of the offered way it is necessary to take into account that its efficiency depends on the accuracy of the model reflecting the influence of insurge on the output size of an management object i.e. on characteristics of the channel “a temperature of the external air – adjustable temperature”.

It is well known, these characteristics considerably change, for example, because of aging of the building and its heating system, at accumulation of moisture in the protecting designs, etc. Thus, it is clear that for creating a high-quality control system it is necessary to monitor changes of these characteristics, i.e. to solve an identification problem of a model of the channel. There are detailed ways of the solution of this problem in the source [4].

The duration of the period $T$, allowing to reach the set quality of the management process should be determined on the mode of work [5].

According to the paper [6], a warmth saving from usage of high-quality systems of automation depends on the over-heating at initial control mode, from standard temperature of the internal air and on the temperature of the external air and amounts to 15…20%.

In addition, as is known [7-11], fluctuations in air temperature near its optimal value with amplitude in residential and public buildings have a beneficial effect on people's well-being, which also indicates the expediency of the proposed solution.

4. Conclusions

The solution of the problem of energy saving when heating buildings is considered. The way of pulse management of temperature condition of buildings with elevator accession of the heating systems is
developed. Two options of structure of a control system and the procedure of a calculation of pulse ratio according to the measurement or the temperature of water and its consumption, or the heat carrier at input of the heating system and its consumption are given.

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