Analysis of economic efficiency of the internal air temperature control

Sergey Kuzmin¹, Tatyana Vasilevskaja¹

¹ Angarsk State Technical University, 665835, Angarsk, Russia

Abstract. In this paper, analysis of economic efficiency of energy-saving activities of the internal air temperature regulation during the daily period by means of individual regulators.

1 Introduction

The relevance of the issue of energy savings called for reasonable predictions from those used for these purposes, activities and technical resources [1-6]. One way to reduce the annual heat consumption heating systems in buildings is to reduce the internal air temperature relative to the calculated value in certain hours of the day: night and nonworking time [7,8]. However, the implementation of this decision raises the need to install additional regulatory systems that increases capital costs on heating system [9]. On this basis, subject to prior justification efficiency from sales of energy saving in this way.

2 Materials and methods

In the present work proposes an analysis of the effectiveness of periodic lowering the temperature of internal air and use for this purpose, the individual means of regulating heat transfer appliances. The analysis is based on the use of analytical expressions and mathematical models of system
parameters of heating, outdoor and indoor climate-related elements that define a comprehensive evaluation of the effectiveness of the method.

3 Results

Economic efficiency of periodic internal air temperature reduction compared with the normative values express via the relation obtained savings from reducing heat consumption for heating buildings ∆C and the additional technical means, to ensure the heat consumption mode:

$$\bar{C}_t = \frac{\Delta C}{c_G} = \frac{\sum_{i=1}^{T} \Delta W_{P,i} c_{W,i}}{c_G},$$

(1)

where is- ∆W - thermal energy savings from the reduction of indoor air temperature during heating period will be equal, Gcal/year;

T - the period of operation of the regulatory system, year;

i - year of operation, the internal air temperature control mode;

$c_{W,i}$ - the cost of thermal power in the i-th year of operation, rubles/Gcal.

Given the number of unhealthy days [10] (which can decrease indoor air temperature) of the year in the expression for the expected savings of heat takes the form:

$$\Delta W_p = 24Vq_0\Delta t_B [0,68 \left(\overline{Z_B} - 1\right) + 1],$$

(2)

where is $V$ – heated volume of the building (m$^3$);

$q_0$ – specific heat characteristics of building, Gcal/°C (m)$^3$;

$P$ – the duration of the heating period, days;

$\Delta t_B$ – the internal air temperature reduction, °C

$\overline{Z_B}$ - о relative length of the internal air temperature during the day.

Reducing the heat consumption of heating system concerning the calculation $W_p$ (without temperature control):

$$\Delta W_p = \frac{\Delta W_{P}}{w_p} = \frac{\Delta t_B \left[0,68 \left(Z_B - 1\right) + 1\right]}{(t_\gamma - t_{\mu p})},$$

(3)

where is $t_{\mu p}$ – design temperature of outside air during the heating season, °C.

Consider the impact of outdoor climate and reduction in the size of the throttling settings heat consumption. The average temperature in heating period in large parts of the country ranges from -10 to +5 °C, and at specified temperature of internal air in +20 °C, allowed reducing the temperature will not exceed15°C[11]. Dynamics for these conditions
influence depth and duration used for reducing the internal temperature of the reduction of heat consumption is shown in Fig. 1.

As can be seen from the calculation of the thermal energy savings can reach considerable size (up to 30%) even when the temperature only in the nonworking days. If this same technique extended to non-working period working days, then the total reduction of energy consumption for heating buildings is approaching 70%. It is noteworthy that under identical periods and terms the internal air temperature decrease the magnitude of the relative energy savings more than warmer regions to colder.

If the internal air temperature control is the most accessible means-radiator regulators [12], with the location of their heaters and heating systems, taking into account the increasing tariff on thermal energy in time cost of management tools $C_{PT}$ put as follows:

$$\Delta W_p C_W (1 + \Delta C_{PT})^{(Z_{\text{ok}}-1)} Z_{\text{ok}} = C_{PT},$$

where is $C_W$ – the cost of thermal power, Gcal/h;

$\Delta C_{PT}$ - the annual increase in the rate of thermal energy as compared to the previous year;

$Z_{\text{ok}}$- the payback period of the one-time non-recurrent costs, year.

The total cost of the "radiator" regulators of temperature in hot-water heating system will depend on the number of $N_{PT}$ and the difference in price $\Delta C_{PT}$ temperature regulator and conventional shut-off tap to be installed before the heater. Since the accession of heating appliances to eyeliner is via the stopcocks, installation costs, you can ignore the regulators because they are commensurate with the cost of installation of the shut-off valves. Then the expression (8) can be represented as follows:

$$24Vq_{p}P\Delta t_{B} [0,68 (Z_{\text{ft}}- 1) + 1]C_W (1 + \Delta C_{PT})^{(Z_{\text{ok}}-1)} Z_{\text{ok}} = N_{PT}\Delta C_{PT}.$$
Figure 1. Change the relative value of reducing heat consumption.
а) \( t_{HP} = 5^\circ C \); б) \( t_{HP} = 0^\circ C \); в) \( t_{HP} = -5^\circ C \);

The number of regulators will correspond to the number of heating equipment in the building. Accordingly, the number of devices (and regulators) will be equal to:

\[
N_{PT} = N_{HP} = \frac{Q_0}{Q_{HH}} = \frac{V_q (c_b - t_{HB})}{Q_{HH}}.
\]

(6)

An expression to determine the marginal cost of heat consumption of building management will look:

\[
\Delta C_{PT} = \frac{24V_q (c_b - t_{HB}) [0.68 (Z_{AT} - 1) + 1]C_W (1 + \Delta C_W) (Z_{aw} - 1) Z_{aw} Q_{HH}}{24P \Delta t_b [0.68 (Z_{AT} - 1) + 1]C_W (1 + \Delta C_W) (Z_{aw} - 1) Z_{aw} Q_{HH}}
\]

(7)

where \( t_{HB} \) - design temperature of external air for heating system.

The duration of the heating period and estimated temperature of external air for heating are normative characteristics of the location object. Heat transfer device \( Q_{HH} \) usually is 2000W (1720 Kcal/h). The cost of heat energy though depends on the object to the air conditioning, but even within the energy system may apply different rates to different customers. So the cost of automation of the heating system to include the cost of heat energy in the initial year of operation:

\[
\Delta C_{PT} = \frac{24V_q (c_b - t_{HB}) [0.68 (Z_{AT} - 1) + 1]C_W (1 + \Delta C_W) (Z_{aw} - 1) Z_{aw} Q_{HH}}{24P \Delta t_b [0.68 (Z_{AT} - 1) + 1]C_W (1 + \Delta C_W) (Z_{aw} - 1) Z_{aw} Q_{HH}}
\]

(8)

Thus, the expression obtained completely determines the ratio between costs and possible savings obtained from the internal air temperature regulation and accordingly could be the basis for the analysis of the conditions of the use of profitability This method of energy saving.

4 Discussion

Changing the relative cost of individual cost-efficient temperature regulator on the term sustainability at various initial conditions is shown in Fig. 2-4. Trend of profitable cost temperature controller does not depend on the object location area (see fig. 2)-with increasing time of recovery of outlay profitable are becoming increasingly expensive machinery and equipment. But it’s interesting that, other things being equal, more profitable is to regulate the internal air temperature for areas with more mild climate and long heating period. So for the harsh conditions of Yakutsk with the design temperature \( t_{HB} = -54^\circ C \) and duration of heating period commensurate with the Irkutsk (269 days 258 days, respectively) after the first year of operation becomes profitable appliance cost about 48% of the cost of a unit of heat.
energy, and for Irkutsk \( t_{H_{B}} = -33^\circ C \) this rate will be 65%. Even more important (over 85%) conform to the relatively mild climate of Murmansk \( t_{H_{B}} = -27^\circ C \), but with prolonged heating period (302 days). At the same time, in spite of different temperature and time indicators of Irkutsk and Moscow \( t_{H_{B}} = -28^\circ C; P = 231 \) days) the value of the profitability of the regulator are almost identical.

The most significant impact on the profitability of possible regulatory system have a period and the value of the internal air temperature reduction (see Figure 3.4). Reduction of 5\(^\circ\)C during the period of less than a day provides the maximum permissible value of 62\% level regulator from \( C_{W} \) in the first year of operation and, consequently, this figure increases to 450\% at designated payback in 5 years. If a valid period \( T_{A} \) the building can make 3:00 pm per day, respectively, have 83\% and 610\%.

![Figure 2. Changing the relative value of individual cost effective regulator of the payback period when automation systems \( Z_{B} = 0.4 \) and \( \Delta t_{B} = 5^\circ C \).](image)

![Figure 3. Changing the relative value of individual cost effective regulator of payback period automation systems for terms and conditions of Irkutsk when \( \Delta t_{B} = 5^\circ C \).](image)
Figure 4. Changing the relative value of individual cost effective regulator of the payback period of the automation system for conditions of Irkutsk when $Z_{At} = 0.4$.

Lowering the air temperature at 15 °C during 10:00 during business day increases the marginal cost of 185% for Governor $Z_{ow} = 1$ year up to 1360% for the five-year payback period.

5 Conclusion

Bearing in mind that the difference in the cost of shut-off tap and radiator temperature regulator on average does not exceed $10 and heat rate currently stands at about 1000 rub./(Gcal/h), it could be argued that the device system individual heating and cooling units can be recouped after only one year of operation, even if the moderate temperature control of internal air. Thus it can be concluded that the regulation of parameters of the heating system in the operation of individual devices is a cost-effective way of reducing heat consumption of buildings. Of course if the attendants or "users" of the system enough patience every day responsibly regulate each heater during heating season. Otherwise, you must apply for these purposes, local, and therefore significantly more expensive automation system that naturally affect the final Effect.

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