Justification of the estimated difference in the potential of the water autonomous heating system

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Abstract. This paper provides a method for justifying the cost-effective ratio of heat supply and the surface of the heat output of heating system appliances. The results of a comparative assessment of changes in operating costs from the parameters of the heating system are presented.

1. Introduction

The cost of the heating system and the cost of its operation are determined by the main characteristics of the system - estimated power, the surface of heat recovery of heating devices, hydraulic resistance of the system [1,2]. The latter two characteristics initially depend on the temperature difference taken during the design of the system between the hot and the cooled heat carrier \( \Delta t_{co} = t_x - t_o \). In systems connected to a centralized heating supply, this difference is determined by regulatory values. But in independent heating facilities, the parameters of the heating system can be assigned from the conditions of optimal operating costs and individual elements or equipment (heating appliances, circulating pumps).

2. Materials and methods

This paper considers a possible way to justify the estimated temperature differences of the coolant in the autonomous heating system (if you have
your own heat generator) from the condition of minimizing the cost of heating devices, circulating pumps and energy to carry out the circulation of the coolant. In the autonomous heating system of a given thermal power, the change in the estimated temperature difference of the coolant is accompanied by effects affecting one-time and operating costs: -change in the heat transfer ratio of heating appliances and, as a result, to change the required surface of heat, and hence The cost of these items The need to provide an estimated consumption of the coolant, which entails the use of different characteristics of circulating pumps, with the corresponding cost of circulation. At the same time, the consequences of changing the parameters of the coolant have a different direction - if the reduction of the estimated temperature difference increases the heat output ratio of heating devices, the estimated consumption increases.

It is therefore useful to study this issue in terms of minimizing the cost of these components of the heating system. The method of selecting the optimal estimated temperature differences of the heat carrier of the heating system is based on the use of analytical expressions and statistical models of the characteristics of the selected elements, determining the cumulative effect of the optimization.

3. Results
Effect of changes in estimated temperature difference $\Delta t_{co}$ we will evaluate by the size of the unit relative costs $C_{np}$:

$$C_{np} = \frac{C_t}{C_o},$$

where $C_t$ and $C_o$ - specific costs for performance-changing elements and system operation, respectively, at the current $\Delta t_{co}$ and basic $\Delta t_{co,0}$ temperature differences, ruble/year.

Expression for unit costs, with high-quality regulation of heat consumption, we will present in the following form [3]:

$$C = K_t * c_A * A_{Heating} + c_e * N_{Heating} * t_{co},$$

where is $K_t$ - ratio of the estimated period of self-sufficiency of capital investments in the heating system, year$^{-1}$; $c_A$ - the specific cost of the heating system elements, which is given to the unit of the surface of the heating devices of the system, rub./m$^2$; $A_{Heating}$ – the calculated surface of the heating system heating devices, m$^2$; $c_e$ - the cost of electricity rubles/
(W*h); $N_{u,n}$ - the power of the circulation pump, W; $\tau_{co}$ - duration of the heating period, h.

One-time costs $C_A$ we will divide the heating system into two components: - the cost of the circulation pump, - $C_{u,n}$; - cost of heating appliances - $C_{H.A}$.

Then the specific cost of the heating system will be expressed by the equation:

$$C_A = \frac{C_{u,n} + C_{H.A}}{A_{HII}} = \frac{C_{u,n}}{A_{HII}} + \frac{C_{H.A}}{A_{HII}} = \frac{C_{u,n} + C_{H.A} \cdot A_{HII}}{A_{HII}} = \frac{C_{u,n}}{A_{HII}} + C_{H.II},$$

where is $C_{H.II}$ - the cost of a unit of the heating device area, rub./m².

Using known ratios between the heat consumption of the system and the parameters of the coolant [2] let's say the equation (3) through the basic characteristics of the heating system:

$$A_{HII} = \frac{Q_o}{\Delta_t m \cdot K_{HII}}; \quad N_{u,n} = \Delta P_{co} \cdot G_{co} \cdot \rho_{w}^{-1} \cdot \eta^{-1}; \quad \Delta P_{co} = S_{co} \cdot G_{co}^2;$$

$$\Delta t_m = \tilde{t}_{HII} - t_{o}; \quad G_{co} = \frac{Q_o}{\Delta t_{co} \cdot c_{w}}; \quad \Delta t_{co} = t_{z} - t_{o};,$$

where is $Q_o$ - estimated thermal power of the heating system, W; $\Delta P_{co}$ - hydraulic resistance of the heating system, Pa; $\eta$ - efficiency pump; $\Delta t_m$ - The temperature pressure of the system's heating devices, °C; $\Delta t_{co}$ - average temperature difference of the coolant in the heating system, °C; $t_{HII}$ - average surface heating temperature, °C; $t_{z}$, $t_{o}$ and $t_{a}$ - estimated temperatures, respectively, direct and return heat and internal air, °C; $G_{co}$ - heat consumption in the heating system, kg/sec; $\rho_{w}$ - heat density, kg/m³;

$S_{co}$ - hydraulic characteristic of the heating system, (Pa*sek²)/kg²; $c_{w}$ - heat capacity of water, J/ (kg*°K); $K_{HII}$ - heat transfer ratio of heating surface, W/ (m² °K).

Hydraulic characteristics of the heating system $S_{co}$ can be determined from the estimated resistance values $\Delta P_{co,o}$ and expense $G_{co,o}$, determined by the estimated varying level $\Delta t_{co,o}$.
\[ S_{co} = \frac{\Delta P_{co,o} \cdot c_w^2 \cdot \Delta T_{co,o}^2}{Q_{co}} = S_{co,\tau} = \frac{\Delta P_{co,\tau} \cdot c_w^2 \cdot \Delta T_{co,\tau}^2}{Q_{co}}. \] (4)

And accordingly hydraulic resistance of the system at the current temperature differences \( \Delta t_{co,\tau} \):

\[ \Delta P_{co,\tau} = S_{co,o} \cdot c_w^2 \cdot \Delta T_{co,\tau}^2 = \Delta P_{co,\tau} \cdot \frac{\Delta t_{co,\tau}}{Q_{co}}. \] (5)

Then, accordingly, the expression (1) will take the form of:

\[
\bar{C}_{co} = [K_r \cdot (\frac{c_{u,o,t}}{Q_o} * \frac{c_{H.H.}}{c_{\text{in}}}) + \frac{1}{K_{H.H.} \cdot (t_c - 0.5 \cdot \Delta t_{co,o} - t_o)} + (c_w \cdot \Delta P_{co,o} \cdot \Delta T_{co,o}^2 \cdot \rho_w^{-1} \cdot \Delta t_{co,o} \cdot \eta_{t_c})] \cdot (t_c - 0.5 \cdot \Delta t_{co,o} - t_o) + (c_w \cdot \Delta P_{co,o} \cdot \Delta T_{co,o}^2 \cdot \rho_w^{-1} \cdot \eta_{t_c}) \cdot \tau_{co}].
\] (6)

where \( t \) and \( o \) - indices corresponding to the values of the parameters at the current \( \Delta t_{co,o} \) and base \( \Delta t_{co,o} \) temperature differences.

For water heating systems, the heat transfer factor \( K_{H.H.} \) the surface of the heat output depends on the type of heating appliances and temperature pressure \( \Delta t_m \).

For aluminium radiators, two-tube systems and \( \Delta t_m \geq 5^\circ \text{C} \) this dependency can be expressed by the following ratio:

\[ K_{H.H.} = 8.39 + 0.052 \cdot (t_c - 0.5 \cdot \Delta t_{co,o} - t_o). \] (7)

In (7) the temperature pressure of the heater and the temperature of the cooled water is presented through the desired temperature difference \( \Delta t_{co} \):

\[ \Delta t_m = (t_c - 0.5 \cdot \Delta t_{co,o} - t_o); \quad t_o = t_c - \Delta t_{co,o}. \]

From the analysis of the existing prices for aluminum radiators of the most well-known suppliers, the cost of a unit of the heating device area (at the beginning of 2020), you can take an equal to 1640 rubles/m² [4].

And accordingly hydraulic resistance of the system at the current temperature differences \( \Delta t_{co,\tau} \):

\[ \Delta P_{co,\tau} = \frac{S_{co,o} \cdot c_w^2 \cdot \Delta T_{co,\tau}^2}{Q_{co}}. \] (8)

The cost of circulating pumps \( c_{u,n} \) depends on the prices of the manufacturers and the speculative component of the sellers and can therefore be considered as a statistical value. Taking into account that the systems currently use pumps of well-known brands (Grundfos, Wilo) the average cost of this equipment will be presented in conditional units (i.e.) [5]:

\[ c_{u,n} = 69.4 \cdot \exp[0.167 \cdot (H_N - 2)]. \] (9)
where is $H_N$ - nominal (passport) pump pressure, m of water. Art.

Keep in mind that pump selection is made according to the performance of pumps (pressure $H_p$ and performance $Q_p$) at maximum efficiency. And as a rule, the ratio between $H_p$ and $H_N$ leaves 0.75. Then the expression (8) can be converted:

$$c_{u,n} = 69.4 \exp\left[0.222 \times (H_p - 1.5)\right].$$

(10)

Performance $H_p$ usually corresponds to the hydraulic resistance of the heating system $\Delta P_{\text{co}}$. Figure 1 shows graphs of changes in the specific given costs of the building's water heating system at different characteristics at a basic estimated temperature difference $\Delta t_{\text{co},0} = 40^\circ C$ and (i.e.=62 rub.).

A common trend for any initial level of heating system parameters is the greater impact of estimated cost on more powerful systems. Maximum reduction $\bar{C}_c$ is almost 20% in systems with an estimated thermal capacity of 20 kW, against 15% in systems with a capacity of 10 kW.
**Figure 1.** Changing the specific costs from the estimated temperature difference of the heating system for \( K_x = 0.1 \) year\(^{-1}\):

\[ c_{\text{u,}K} = 2 \text{ rub./kW} \cdot \text{h} \]

a) \( \Delta P_{\text{co},o} = 10 \text{ kPa} \);  
b) \( \Delta P_{\text{co},o} = 5 \text{ kPa} \)

The second common factor is the significantly superior impact of the cost of the circulation pump over the cost of moving the coolant and the change in the total cost of heating devices. With the constant hydraulic performance of the system \( S_{\text{co}} \) correspond to their temperature changes depending on the parameters of the system.

Reducing the estimated temperature differences below 15 degrees Celsius leads to a sharp increase in the resistance of the system and, accordingly, an increase in the cost of the pump, which is practically not compensated by the reduction in the required area of heat return of the devices, even when the relatively long lifespans of systems. Nevertheless, under the conditions discussed, there are quite pronounced minimums of unit costs. The magnitude and conditions of the minimum \( C_{\text{co}} \) correspond to their temperature changes depending on the parameters of the system.
**Figure 2.** Changing the specific costs from the estimated temperature difference of the heating system for \( K_r = 0.2 \) year\(^{-1} \); \( c_{\eta, n} = 2 \) rub./kW*h

- a) \( \Delta P_{co,o} = 10 \) kPa; b) \( \Delta P_{co,o} = 5 \) kPa

So with relatively cheap electricity (2 rub./kW*h) the minimum cost comes at a time when \( \Delta t_{co,o} = 15^\circ C \) and \( \Delta t_{co,o} = 20^\circ C \) for systems with high initial hydraulic resistance and a capacity of 20 kW and 10 kW respectively (see Figure 1 a). But with less, this minimum is the same for systems with different power (see Figure 1 b). And this trend is manifested regardless of the life of self-sufficiency of the systems (see Figure 2). In addition, under these conditions, the values of the lows \( \bar{C}_{co} \) almost do not depend on the length of the heating period.

**Figure 3.** Changing the specific costs from the estimated temperature difference of the heating system for \( K_r = 0.1 \) year\(^{-1} \); 

\( c_{\eta, n} = 10 \) rub./kW*h

- a) \( \Delta P_{co,o} = 10 \) kPa; b) \( \Delta P_{co,o} = 5 \) kPa

As the cost of electricity increases, the minimum cost shifts towards an increase in the estimated temperature differences, but the impact of this parameter on improving the efficiency of the system becomes less (Figure 3).

4. Conclusion
Analysis of the results obtained from the proposed target function model (2-9) shows the presence of a certain optimal value of the estimated difference in the potential of the coolant. The spread of the economic indicator of the heating system reaches more than 35%, which confirms the conclusion that it is necessary to make a reasonable choice of estimated temperature difference for the design of heating. Of course, individual indicators in the model can be specified based on the existing policy of equipment prices, but this can be taken into account by the introduction of adjustment ratios or the introduction of the current cost of elements of the system.

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