Analyzing the Efficiency of Introduction of the Intermittent Heating Mode

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Abstract. The efficiency of introduction of an optimal intermittent heating mode for a service center building in Chelyabinsk is estimated. The optimal intermittent heating mode ensures heat energy saving while maintaining the required microclimate parameters. The graphical dependencies of the amount of heat energy saving on the heat retention of the building and the outdoor air temperature are shown. The fundamental formulas which were the basis for calculating the periods of cooling, warming and expenditures of heat energy for the two heating modes are given. The literature on the issue is reviewed, the main points, advantages and disadvantages in the works of both Russian and foreign authors are revealed. The calculation was carried out in compliance with the modern state standards and regulatory documents. The capital costs of a system construction with an intermittent heating mode are determined.

1. Introduction

At present, it is impossible to imagine a new building, structure or system, which would not be at least partially oriented towards energy saving. Engineering systems in buildings under construction (heating, in particular) have a so-called “minimal set” of devices and measures for energy conservation:

- regulation of heat supply by facades;
- regulation of water temperature in the system of hot water supply;
- application of automatic and manual thermostatic control valves and heating appliances;
- installation of heat meters (as a measure for stimulating energy saving).

A constant rise in the cost of energy carriers, gradual revision of the state policy and the experience of other countries make Russians seriously think about the conservation of natural resources. Deterioration of heating networks, great heat loss during transportation and a rather low efficiency of most thermal power stations in Russia gradually decentralize the heat supply even more. Under the circumstances, it becomes possible to use such a means of saving thermal energy in public and industrial buildings as the intermittent heating mode (IHM). The IHM consists in maintaining the indoor air temperature at the required level during the use of buildings and reducing the indoor temperature, and accordingly the heating capacity of the heating system otherwise, i.e. at night, on weekends, etc. Moreover, [1] suggests designing such regulation of heat supply. The IHM is a measure that requires a minimum of capital investments in the form of equipment, but it allows saving...
6-9% of heat energy during a heating period. The main condition for its operation is the backup power of the heat source, which makes the application of such a system impossible when connected to a centralized energy source.

2. Analysis of the efficiency of introducing intermittent heating

The literature review fails to give a clear idea about the results of operation of such systems in various facilities. Analyzing the technical literature on intermittent heating [2-17], we have discovered a number of works on the experiments in selecting the most efficient heating appliance, testing mathematical and 3D models, and comparing the results of mathematical modeling with experimental ones. Most of the works contain complex calculation formulas and dependencies, which is often unattractive to the building owner or the project manager, who consider the intermittent heating mode as a means of saving heat energy.

A nonresidential service center building in Chelyabinsk was chosen as the subject of our research. For heating and hot water supply, a gas-fired hot-water boiler is used. The total heat loss is 64 kW. The main part of the premises has a general temperature regime $t_i = 18 \, ^\circ C$. Bimetallic radiators were selected as heating appliances, as they have low inertia and provide the maximum rate of interior warming, which is verified by experiments [5,17].

A workday at the facility under investigation lasts from 9-00 to 18-00, that is, the nonworking time is 15 hours. According to [1], in residential, public, administrative and industrial premises, the temperature of indoor air can be lowered, but it is necessary to provide the required temperature by the time when they are used. It must be ensured that the temperature of indoor air does not drop below the normalized value. According to [18], it is $t_{\text{min}} = 12^\circ C$.

The dependence of the amount of saved heat on the value which characterizes the thermal inertia of the building was analyzed. The time constant which characterizes the thermal inertia of the building was calculated according to the following formula [19]:

$$ T = \frac{c \cdot \rho \cdot F \cdot \delta}{2 q_0 V} \left( \frac{\delta}{R \lambda} + \frac{2}{R' \alpha_o} \right) = 39.3 \, h $$

where $c$ is the heat capacity of the exterior wall material; $\rho$ is the density of the exterior wall material; $F$ is the area of the building outer surface, $\delta, R$ are the thickness and the thermal resistance reduced to the thermal conductivity of the building exterior wall, respectively, $\lambda$ is the coefficient of thermal conductivity of the material, $\alpha_o$ is the coefficient of heat release for the outer surface of the building wall; $q_0$ is the specific thermal value of the building, $V$ is the building volume.

The wall construction consists of two layers; however, the time constant for the thermal insulation layer is insignificantly small. Hence, the time constant for the basic constructive layer, i.e. the brick one, was taken into the calculation.

Further, we determined the time intervals of cooling, $\tau_1$, and warming, $\tau_2$, of the building at different outdoor air temperatures, $t_o$.

Moreover, heat energy expenditures in the IHM and in the standard heating mode were calculated. Thus, the amount of heat expended by the heating system was estimated with the following dependences [19]:

- heat consumption for the heating system which implements the intermittent heating mode, $W_h$,

$$ I_{\text{in}} = W_1 \tau_1 + W_2 \tau_2 $$

- heat consumption for the standard heating system, $W_h$,

$$ I = W_0 \tau $$
where $W_1$ is the capacity of the heating system in the building cooling mode, according to [19], it equals 0 W; $W_2$ is the capacity of the heating system in the building warming mode – the maximum possible (nameplate), $W$; $\tau_1$, $\tau_2$ are the cooling time and the warming time of the building when implementing the intermittent heating mode, $h$, respectively; $\tau$ is the nonworking time, $h$ (in this case it is 15 h). The calculation data are given in Table 1.

| $t_0$, $^\circ$C | $\tau_1$, h | $\tau_2$, h | I, W·h | $\tau_1$·W·h | Heat saving, % | Heat saving, % | $t_i$, actual |
|------------------|-------------|-------------|--------|--------------|----------------|---------------|---------------|
| 8                | 12.53       | 2.47        | 184615 | 158248       | 26367          | 14.3          | 15.27         |
| -3               | 9.6         | 5.39        | 387692 | 344654       | 43038          | 11.1          | 13.44         |
| -9               | 7.9         | 7.07        | 498462 | 452471       | 45991          | 9.2           | 13.07         |
| -14              | 6.5         | 8.53        | 590769 | 545989       | 44780          | 7.6           | 13.14         |
| -20              | 4.6         | 10.36       | 701538 | 663003       | 38536          | 5.5           | 13.77         |
| -25              | 3.0         | 11.95       | 793846 | 764853       | 28993          | 3.7           | 14.79         |
| -30              | 1.4         | 13.61       | 886154 | 871002       | 15152          | 1.7           | 16.33         |
| -34              | 0.0         | 14.99       | 960000 | 959269       | 730            | 0.0761        | 17.98         |

When studying buildings with higher thermal inertia, we found that the efficiency of the IHM decreases with the time constant increasing. This is shown in Figure 1.

![Figure 1. Dependence of the heat energy saving on the time constant $T$ which characterizes the thermal inertia of the building.](image)

We determined the financial savings which result from the implementation of the intermittent heating mode as compared with the standard (traditional) heating mode taking into account the monthly demand for heat energy of the building at real (actual) outdoor air temperatures. The monthly demand for heat of the facility, Gcal (gigacalories), is calculated by the formulas:

- in intermittent heating mode

$$I_{in}^{new} = W_2 \tau_2 n$$  \hspace{1cm} (1)

where $n$ is the number of days in a billing month.
in standard heating mode

\[ I_{\text{mon}} = W_{\text{mon}} \tau \ n \]  

(2)

where \( W_{\text{design}} \) is the design capacity of the heating system, \( t_i \) is the indoor air temperature, \( t_{i,av} \) is the actual monthly average outdoor air temperature, \( t_{\text{design}} \) is the design temperature of outdoor air, and \( \theta \) is the difference between the indoor temperature and the actual monthly average outdoor air temperature.

Other months of the heating season are calculated similarly. The calculation data are given in Table 2.

The cost of 1 Gcal of heat energy in Chelyabinsk in 2015-2016 heating season was 1937.4 rubles. Thus, the money expenditures for the standard heating mode during the entire heating season will be 147682.3 rubles. When the IHM is implemented, they will make 133219.9 rubles. Total savings for the heating season will make 14462 rubles.

The implementation of the intermittent heating mode at the facility requires:
- the sensor of indoor air temperature ESM-10 Danfoss (3057 rubles per item);
- the sensor of outdoor air temperature ESMT Danfoss (3575 rubles per item);
- the controller of heating modes and heating substation Danfoss ECL Comfort 310 - controller 087H3040 (32790.56 rubles);
the two-way control valve for Danfoss VB2 heating system with electric drive AME 13 (68322 rubles)
However, both the controller and the control valve in modern heating systems are installed in the standard heating systems, therefore allocating them as capital costs for the IHM implementation is illogical.

Totally:
- 120490 rubles – when reconstructing a completely non-automated heating unit.
- 6632 rubles – when upgrading a modern automated heating unit.

In the first case, the payback will be:

\[
\text{Payback time} = \frac{120490}{14462} \approx 8.33 \text{ heating seasons} (\text{years})
\]

In the second case:

\[
\text{Payback time} = \frac{6632}{14462} \approx 0.45 \text{ heating seasons} (\text{years})
\]

Table 2. Comparison of the standard heating mode and the intermittent heating mode.

| Month     | Average temperature, °C | Heat expenditures for the IHM, MW (Gcal) | Heat expenditures for the standard mode, MW (Gcal) | Financial savings, rubles. |
|-----------|--------------------------|------------------------------------------|--------------------------------------------------|----------------------------|
| April     | 7.4                      | 5.057(4.35)                              | 5.889(5.065)                                      | 1384.30                    |
| March     | -4.0                     | 11.219(9.648)                            | 12.577(10.817)                                   | 2263.89                    |
| February  | -6.5                     | 11.401(9.805)                            | 12.670(10.896)                                   | 2114.65                    |
| January   | -17.2                    | 18.840(16.202)                           | 20.146(17.325)                                   | 2175.91                    |
| December  | -7.2                     | 13.030(11.206)                           | 14.444(12.422)                                   | 2355.58                    |
| November  | -6.8                     | 12.398(10.662)                           | 13.762(11.835)                                   | 2272.58                    |
| October   | 1.5                      | 8.010(6.889)                             | 9.148(7.867)                                     | 1895.34                    |

3. Conclusion
Basing on the results obtained, we can conclude that the intermittent heating mode is a low-cost, easily implemented and efficient energy-saving measure. It is noteworthy that an independent heat source is required for its implementation. In addition, we proved the diseconomy of the current heating mode, when a building is connected to the central heating networks.

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