Safety of engineering systems of buildings with limited heat supply

Tatyana Rafalskaya
Novosibirsk State University of Architecture and Civil Engineering (Sibstrin), Leningradskaya, 113, Novosibirsk, 630008, Russia

E-mail: rafalskaya.ta@yandex.ru

Abstract. In case of emergencies in large heat supply systems, the water temperature in the supply line of the heat supply system is reduced. It is necessary to determine the acceptable duration of the heat supply system during an emergency, taking into account the thermal accumulation of the external fencing and variable water consumption in the hot water supply system. A study was made of the operating modes of the heat supply system in conditions of emergency heat supply from the CHP. The factors affecting the thermal regime of buildings with external fences of various constructions with limited heat supply are considered. A method has been developed for calculating the cooling rate of the inner surface of the outer fence and the temperature on this surface at a given point in time. Calculated dependencies are obtained to determine the acceptable duration of the heat supply system with limited heat supply. Application of the developed methodology can increase energy efficiency and contribute to the energy saving of buildings in the event of emergencies in the heat supply network.

1. Introduction

During the operation of large district heat supply systems, emergencies at the heat source and the heat supply network often occur, which necessitates analyzing the influence of deviations of the parameters in the heat supply network on the heating, which forms the temperature regime of the premises, and exploring the possibilities of thermal protection of building constructions [1].

The issues of heat resistance of outdoor constructions for various emergencies of the heat supply system were repeatedly raised in articles [2-6], however, in all studies, the heating system is considered separately from the hot water supply system, mainly these studies concern of the complete shutdown of the heat supply system in an accident. When the heat supply system operates in conditions of limited heat supply, the amount of heat supplied by the heat supply network to the heating system is significantly lower than that required to compensate for the heat losses of the premises. In this case, the question arises of the permissible duration of the heating system work, both due to the use of heat of the hot water supply system when it is turned off, and when the heating and hot water supply systems work together. In [7], a formula was proposed for determining the cooling time of building structures in an accident. However, in this formula only the heat resistance of the main inner layer is taken into account. In addition, it is necessary to control the decrease in temperature on the inner surface of the structure due to the infiltration of cold outside air, since often the freezing of the lower part of the walls with breathable heaters at negative outside temperatures [8-
Therefore, it is necessary to assess the heat storage capacity of the outer fences in these conditions, which makes the study relevant.

2. The study of thermal protection of external fencing during emergency heat supply

In the emergency operation of heat supply, an emergency graph of centralized regulation is applied, with the upper cutoff of water temperatures, for Novosibirsk, for example, \( t_{pt1} = 85^\circ C \). Consider the consequences of lowering the water temperature in the heat supply system under extreme weather conditions for Novosibirsk in the range of the calculated outdoor temperature \( t_{ext,o} \) and below it.

The calculations were carried out for several heating points in the city of Novosibirsk serving residential buildings and having different ratios \( \psi \) average load on hot water supply and maximum load on heating \( \psi = Q_{hm} / Q_{omax} \). At each heating point, the heat exchangers of the hot water supply system are connected in a two-stage scheme with the limitation of the maximum flow rate of network water for entering the heating point. The calculation was carried out according to the method described in detail in [12]. The results of calculating the operating modes of heating points depending on the current outdoor temperature \( t_{ext} \) under conditions of maximum water consumption in the hot water supply system are presented in Fig. 1, 2 [13].

![Figure 1](image1.png)  
**Figure 1.** Network water temperatures during an emergency heat supply graph from the CHP; 1 – \( \psi \)=0.5; 2 – \( \psi \)=0.63; 3 – \( \psi \)=0.79.

![Figure 2](image2.png)  
**Figure 2.** Relative flow rates of network water in heating points  
1 – \( \psi \)=0.5; 2 – \( \psi \)=0.63; 3 – \( \psi \)=0.79.

In fig. 1 shows water temperature: \( t_{p1}, t_{p2} \) – in the supply and return lines of the heat supply network; \( t_{p1}^{hs}, t_{p2}^{hs} \) – in the supply and return lines of the heating system. In fig. 2 shows the relative flow rates: \( \overline{G_p} \) – total in the heat network; \( \overline{G_{p1}}^{hs\text{req}} \) и \( \overline{G_{p1}}^{hs\text{valid}} \) – required and valid in the heating system; \( \overline{G_{p2}}^H \) – on II stage of the hot water heat exchanger.

As calculations showed, the smaller \( \psi \), the higher the outside temperature, the heating system begins to receive the required amount of heat. So, in emergency mode, the amount of water (and heat) from the heating system is less than the required amount, starting from \( t_{ext} = -16^\circ C \) and lower at \( \psi = 0.5 \); starting from \( t_{ext} = -18^\circ C \) and lower at \( \psi = 0.63 \); starting from \( t_{ext} = -20^\circ C \) and lower at \( \psi = 0.79 \) [13]. This is due to the fact that the reserve of thermal power of hot water supply, which can be directed to the heating system, is low at low ratios \( \psi \).
The relative decrease in heat consumption for the heating system $\bar{Q}_{em} = \bar{Q}_{o} / \bar{Q}_{o}^{req}$ in comparison with the required flow rate at the current outdoor temperature, which arises as a result of a reduced heat supply from the supply line of the heat supply network to the heating system, is shown in Fig. 3.

As can be seen from fig. 3, the lower $t_{ext}$ and less $\psi$, the greater the decrease in thermal power of the heating system.

The decrease in thermal power of the heating system during the emergency period can be partially compensated by the heat resistance of the outer fences of buildings. The question of the rate of cooling of the building in emergency mode is important, because, firstly, the comfort of being in the premises depends on it, and, secondly, the time available to the repair services affects the need to drain expensive water from the local heating system.

Figure 3. The relative heat consumption for the heating system for various $t_{ext}$ and $\psi$.

To verify the fulfillment of this condition, two types of building structures with different thermal accumulations, shown in Fig. 4 and 5 [14].

Figure 4. Wall construction with $\beta = 97$ h and characteristics:
1. 4 – cement-sand mortar ($\rho = 1800$ kg/m$^3$);
2 – silicate brickwork ($\rho = 1800$ kg/m$^3$);
3 – rigid mineral wool boards ($\rho = 200$ kg/m$^3$).

Figure 5. Wall construction with $\beta = 33$ h and characteristics:
1 – cement-sand mortar ($\rho = 1800$ kg/m$^3$);
2 – foam concrete ($\rho = 400$ kg/m$^3$);
3 – shell rock ($\rho = 1400$ kg/m$^3$).
The coefficients of thermal accumulation, \( h \), for these structures were determined by the formula [15]

\[
\beta = \frac{k_i \sum \delta_i c_i \rho_i F_i / 2}{\sum k_i F_j + L(c_p)_{inf}},
\]

(1)

where \( k_i \) – dimensionless coefficient, taken by [15], for corner living quarters with radiator and convecter heating systems \( k_i = 0.92 \); \( \delta_i \) – thickness of the \( i \)-th layer of material, m; \( \rho_i \) – density of the \( i \)-th layer of material, kg/m\(^3\); \( c_i \) – heat capacity of the \( i \)-th layer of material, J/(kg\( \cdot \)K); \( F_i \) – area of the \( i \)-th layer of material, m\(^2\); \( L \) – infiltration air flow, m\(^3\)/h; \( \rho_{inf} \) – density of infiltrating air, kg/m\(^3\); \( c_{inf} \) – heat capacity of infiltrated air, J/(kg\( \cdot \)K); \( k_j \), \( F_j \) – heat transfer coefficient, W/(m\(^2\)\( \cdot \)K) and construction area, m\(^2\).

To estimate the cooling time of premises with structures with different heat accumulation at limited heat supply and the need to turn off the second stage of hot water supply heat exchanger, the operation modes of the central heating points were calculated at different outdoor temperatures, Fig. 6. The calculation results are shown in Fig. 7-9.

**Figure 6.** Outdoor temperature:

I – January 9-12, 2018; II – January 14-17, 2018; III – January 21-24, 2018

**Figure 7.** Indoor air temperature, January 9-12, 2018
At relatively high outdoor temperatures (I range of outdoor temperatures in Fig. 6), the decrease in internal temperature is determined mainly by the ratio of heat fluxes $\psi$ and to a lesser extent depends on the coefficient of thermal accumulation $\beta$. So, in Fig. 7, with $\psi = 0.8$ decline of internal temperature $t_{\text{int}}$ approximately the same as at $\beta = 97 \, \text{h}$, so at $\beta = 33 \, \text{h}$, although at $\beta = 33 \, \text{h}$ large fluctuations in the temperature of the internal air are observed. However, the smaller $\psi$, the greater the role the coefficient of thermal accumulation $\beta$ begins to play. For instance, at $\psi = 0.5$ the decrease $t_{\text{int}}$ occurs faster at $\beta=33 \, \text{h}$, than at $\beta = 97 \, \text{h}$. Nevertheless, even in this case, a decrease in $t_{\text{int}}$ to $16^{\circ} \, \text{C}$ will occur in about $57 \, \text{h}$. In other cases, the duration of reaching the standard time will be much longer and the system can provide heating of hot water to the standard temperature.

At average winter outside temperatures (II range of outdoor temperatures in Fig. 6), a decrease in the internal temperature will strongly depend on both the ratio of heat fluxes $\psi$, and the coefficient of thermal accumulation $\beta$, Fig. 8. At high thermal accumulation $\beta = 97 \, \text{h}$ and different $\psi$ the temperature of the internal air will reach $16^{\circ} \, \text{C}$ in $21-33 \, \text{h}$, but the temperature of the inner surface of the walls will not reach the dew point $t_{\text{w}}$ within three days. In structures with low thermal accumulation $\beta = 33 \, \text{h}$ the temperature of the internal air drops to $16^{\circ} \, \text{C}$ in $7-9 \, \text{h}$, and the temperature of the internal surface of the structure reaches the dew point in $16-20 \, \text{h}$. Turning off the second stage of the hot water heater in this range of outdoor temperatures will be effective for buildings with high thermal accumulation of external walls at any ratio $\psi$. So, at $\psi = 0.8$ and $\psi = 0.65$ the temperature of the internal air in this case will not drop below $16^{\circ} \, \text{C}$, Fig. 8. For buildings with low values of $\beta = 33 \, \text{h}$ disconnection the second stage of the hot water heater will be effective at large ratios $\psi$. So, at $\psi = 0.8$ this measure will significantly increase the temperature of the indoor air, which can even become higher than the temperature of the indoor air in buildings with $\beta = 97 \, \text{h}$, although large temperature fluctuations will be observed. At the ratio $\psi = 0.65$ the temperature of the internal air can also be significantly increased. At the same time, turning off second stage of the hot water heater at $\psi = 0.5$ and $\beta = 33 \, \text{h}$ does not make sense, since it will not have a noticeable effect on the temperature of the internal air, Fig. 8.

**Figure 8.** Indoor air temperature, January 14-17, 2018:
1 – at the working second stage of the hot water heater;
2 – at turning off second stage of the hot water heater
At low and extremely low outdoor temperatures (III range of outdoor temperatures in Fig. 6) the decrease in the temperature of the internal air will be determined mainly only by the coefficient of thermal accumulation \( \beta \) and will depend little on the ratio of heat fluxes \( \varphi \), Fig. 9. Therefore, in this range of outdoor temperatures, turning off the second stage of the hot water heater will only worsen the quality of hot water and will not increase the allowable time for repair work.

![Image](image.png)

**Figure 9.** Indoor air temperature, January 14-17, 2018

1 – at the working second stage of the hot water heater;

2 – at turning off second stage of the hot water heater

3. Calculated dependencies for determining the permissible duration of the heat supply system with limited heat supply

It is possible to obtain analytical dependencies for calculating the allowable duration of the heat supply system in emergency situations, taking into account the coefficient of heat accumulation and the ratio of heat fluxes, from the formula E. Ya. Sokolov [16] or a similar formula proposed by A. A. Ionin [17] in his theory of limited heat supply. Then the real temperature of the indoor air, which will be established in the room in time \( z \):

\[
t_{\text{int}}^\text{real}(z) = t_{\text{ext}} + \left[ \frac{Q_o}{Q_o^{eq}} + \left( t_{\text{int}}^\text{cur} - t_{\text{ext}} - \frac{Q_o^{eq}}{Q_o} \right) e^{-\beta z} \right] (t_{\text{req}} - t_{\text{ext}}),
\]

where \( t_{\text{int}}^\text{cur} \) – current indoor air temperature over a period of time over time \( z, h \).

The time allowed for the duration of the heat supply system in emergency situations, taking into account the coefficient of thermal accumulation and the ratio of heat fluxes, can be found from formula (2):

\[
z = -\beta \ln \left[ 1 - \frac{t_{\text{int}}^\text{ass} - t_{\text{int}}^\text{ass}}{t_{\text{int}}^\text{cur} - t_{\text{ext}}} \cdot \frac{1}{\frac{Q_o^{eq}}{Q_o}} \right],
\]

where \( t_{\text{int}}^\text{ass} \) – preset value for lowering the temperature of the internal air, which can be taken equal to 16°C or the temperature corresponding to the dew point of the inner surface of the fencing or any other temperature.
The relative decrease in the thermal power $\bar{Q}_{o,\text{em}}$ of the heating system with limited heat supply for various $\psi$ can be determined from Fig. 3.

We can assume that the dependence of the heating system heat capacity in emergency mode on $\psi$ and the outside temperature is described by parallel linear dependences, the angular coefficient (slope) of which can be taken to be 0.16.

At the calculated outside temperature for the design of heating $t_{\text{ext,o}}$ and $\psi = 0.5$ (for the city of Novosibirsk $t_{\text{ext,o}} = -37^\circ\text{C}$), $\bar{Q}_{o,\text{em}} = 0.29$. The magnitude of the change of $\bar{Q}_{o,\text{em}}$ by one degree of the outside temperature according to Fig. 3, corresponds to 0.014. For any outside temperature $t_{\text{ext}}$ at $\psi=0.5$, $\bar{Q}_{o,\text{em}}$ can be defined as

$$
\bar{Q}_{o,\text{em}} \Big|_{\psi=0.5} = 0.29 - 0.14(t_{\text{ext,o}} - t_{\text{ext}}).
$$

Then the dependence $\bar{Q}_{o,\text{em}}$ on $\psi$ at any external temperature $t_{\text{ext}}$ can be described by the formula

$$
\bar{Q}_{o,\text{em}} = 0.16(\psi - 0.5) + 0.29 - 0.14(t_{\text{ext,o}} - t_{\text{ext}})
$$

(4)

Substituting (4) in (3), we obtain

$$
z = -\beta \ln \left\{ 1 - \frac{t_{\text{int}}^{\text{req}} - t_{\text{int}}^{\text{ass}}}{t_{\text{int}}^{\text{ass}} - t_{\text{int}}} \frac{1}{1 - 0.16\psi + 0.21 - 0.14(t_{\text{ext,o}} - t_{\text{ext}})} \right\}.
$$

(5)

Formula (5) can be used to calculate the cooling time of premises to a predetermined temperature during emergency heat supply. A feature of the obtained formula is the ability to take into account the ratio of heat flows to hot water supply and heating, i.e. parts of the reserve of thermal power, which can be sent to the heating system. In addition, the thermal accumulation coefficient is included in formula (5), which makes it possible to take into account not only the internal thermal stability of the fences, but also the thermal characteristics of the entire enclosing structure and the air exchange in the premise.

4. Conclusions
1. A study was made of the operating modes of the heat supply system in conditions of emergency heat supply from the CHP. The factors affecting the thermal regime of buildings with external fences of various designs are considered.
2. The heat resistance indices were determined for two structures of the outer fences of buildings with different thermal accumulations. For various ranges of outdoor temperatures, a change in the temperature of the indoor air of the premises was determined with the associated supply of heat to the heating and hot water supply systems. Unfavorable modes of joint operation of heating systems and hot water supply were determined; designs that did not ensure the maintenance of comfortable conditions in the room were identified.
3. The calculated dependencies are obtained to determine the permissible duration of the heat supply system with limited heat supply.
4. According to the proposed method, it is possible to determine the temperature of the internal air at which condensation occurs on the inner surface of the fences. Application of the developed methodology can increase energy efficiency and contribute to the energy saving of buildings in the event of accidents in the heating network.

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