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Investigation into the thermal protection of building enclosing structures in the case of emergency heat supply

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Abstract: In case of emergency situations in heat supply systems, the water temperature in the supply line of the system decreases. It is necessary to determine the allowable operational duration of the heating system in case there is an accident, taking into account heat accumulation in exterior building envelopes and the variable flow of water in the hot water supply system. Operational modes of the heat supply system during emergency heat release from the CHP are studied. Factors affecting the thermal regime of buildings with external fences of various levels of heat accumulation are considered. A method is developed for calculating the cooling rate of the inner surface of the outer fence and the temperature on this surface at a given time. Calculated dependences are obtained for determining the permissible operating time of the heat supply system with a limited heat supply.

Keywords: limited heat supply, heating, hot water supply system, heat accumulation

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Introduction

In the operation of large centralized heat supply systems, emergencies often occur at the heat source and within the heating networks. This requires the analysis of deviations and their influence on parameters in the heating network and consequently the heating that forms the room temperature regime, as well as studying the thermal protection of building structures (Rafalskaya, 2019a).

Issues related to the thermal stability of external structures during incidents in the heat supply system have been repeatedly raised in the following articles (Andrskevicius et al., 2000; Bhat et al., 2015; Keller et al., 1998; Rita et al., 2013), but in all studies, the heating system is considered separately from the hot water supply system; these studies mainly concern the complete shutdown of the heat supply system in the event of an accident. When operating the heating system with a limited supply provided by the network, there is significantly less heat available than that required to compensate for heat losses in the room. In this case, a question arises about the permissible operational duration of the heating system, both due to the use of heat from the hot water system when it is turned off, and when the heating and hot water systems work together. In (Samarin, 2007), a formula for determining the cooling time of building structures in an accident is proposed. However, this formula only takes into account the thermal stability of the main inner layer. In addition, it is necessary to control the temperature decrease on the inner surface of the structure due to the penetration of cold outdoor air, since the lower part of the walls is often frozen by air-permeable insulation at negative outdoor temperatures (Fasia et al., 2015; Jaraminieme et al., 2008; Perekhozhentsev, 2016; Urbikain et al., 2009). Therefore, this study is relevant as it is necessary to evaluate the thermal stability of external fences in these conditions.

1. Investigating the thermal protection of external walls in the case of emergency heat supply

In the case of an emergency related to heat supply, a centralized emergency limit on water temperature is applied, in Novosibirsk, for example, this is t_{p1}^{em} = 85°C. Consider the consequences of lowering the water temperature in the heat supply system during extreme weather conditions for Novosibirsk in the range of the calculated outdoor temperature and below.

Calculations were performed for several heat points in the city of Novosibirsk that serve residential buildings and have a different ratio ψ of the average load of hot water supply (DHW) and the maximum load of heating $\psi = Q_{hm}/Q_{omax}$. At each heat point, the heat exchangers of the hot water supply system were connected according to a two-stage scheme with a limit on the maximum consumption of network water. The calculation was performed according to the method described in detail in (Rafalskaya, 2019b). The results from calculating the operating modes of heat points depending on the current outdoor air temperature under conditions of maximum water consumption in the hot water supply system are shown in Figures 1 and 2 (Rafalskaya et al., 2017).

Figure 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. Figure 2 shows the relative flow rates: $\overline{G}_p$ – total in the heat network; $\overline{G}_{p1}^{hs.req}$ and $\overline{G}_{p1}^{hs.real}$ – required and valid in the heating system; $\overline{G}_{p2}^{\mathrm{II}}$ – in II stage of the hot water heat exchanger.

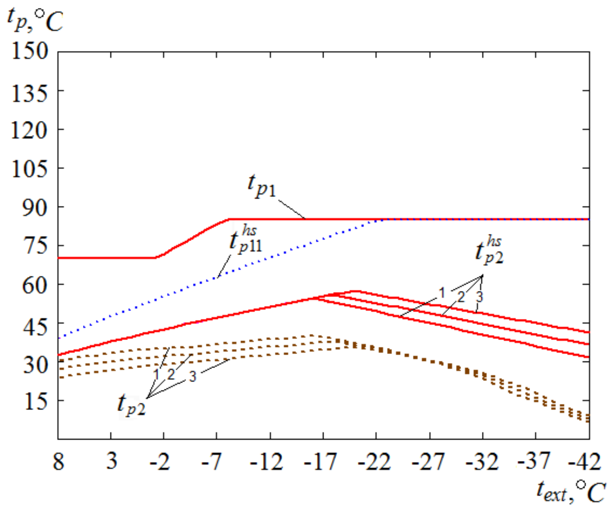

Fig. 1. Water temperature in the heat supply system during emergency operation of the CHP; 1 – ψ = 0.5; 2 – ψ = 0.63; 3 – ψ = 0.79 (Rafalskaya et al., 2017)

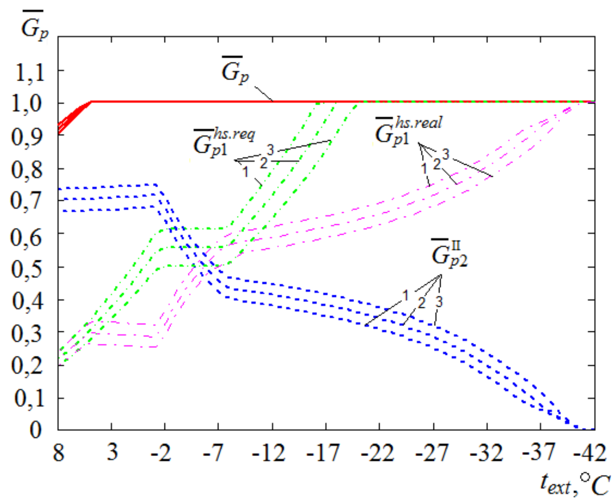

Fig. 2. Relative flow rates of network water in heat points; 1 – ψ = 0.5; 2 – ψ = 0.63; 3 – ψ = 0.79 (Rafalskaya et al., 2017)

As calculations show, the smaller the value of ψ, the higher the outside temperature at which 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°C and lower at ψ = 0.5; starting from t_{ext} = –18°C and lower at ψ = 0.63; starting from t_{ext} = –20°C and lower at ψ = 0.79 (Rafalskaya et al., 2017). This is due to the fact that the reserve of thermal power of the hot water supply, which can be directed to the heating system, is low at low ratios ψ.

The relative decrease in heat consumption for the heating system $\bar{Q}_o^{em} = Q_o / Q_o^{req}$ 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 Figure 3 (Rafalskaya et al., 2017).

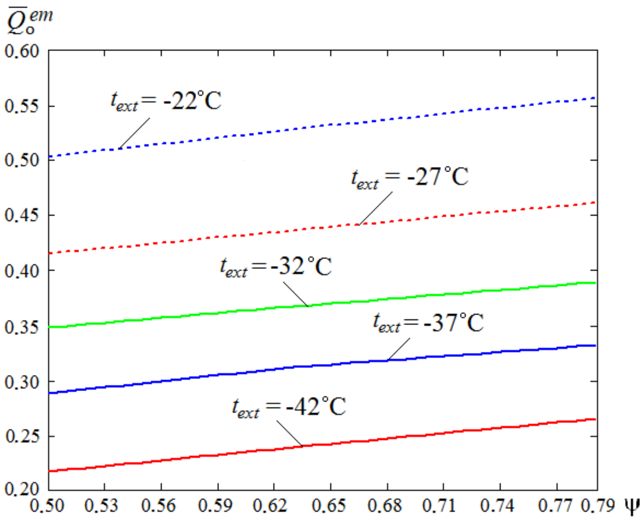

Fig. 3. The relative heat consumption for the heating system for various t_{ext} and ψ (Rafalskaya et al., 2017)

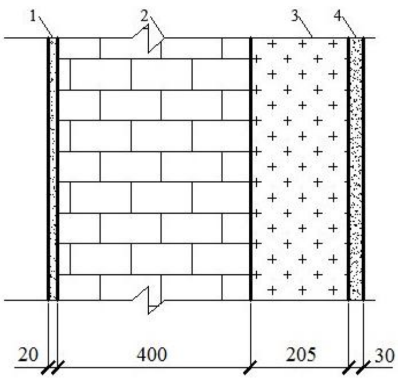

Fig. 4. Wall construction with β = 97 h and characteristics:
1, 4 – cement-sand mortar (ρ = 1800 kg/m^3);
2 – silicate brickwork (ρ = 1800 kg/m^3);
3 – rigid mineral wool boards (ρ = 200 kg/m^3)
(Mansurov et al., 2019)

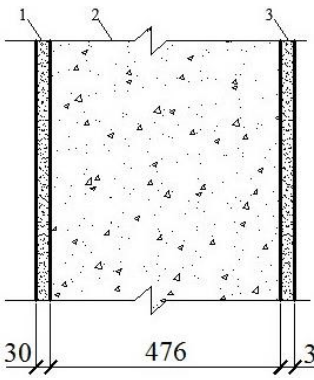

Fig. 5. Wall construction with β = 33 h and characteristics:
1 – cement-sand mortar (ρ = 1800 kg/m^3);
2 – foam concrete (ρ = 400 kg/m^3);
3 – shell rock (ρ = 1400 kg/m^3)
(Mansurov et al., 2019)

The coefficients of thermal accumulation (β) in h, for these structures were determined by the formula (Kononovich, 1986).

$$\beta = \frac{k_t \sum \delta_i c_i \rho_i F_i / 2}{\sum k_j F_j + L(c\rho)_{inf}}, \tag{1}$$

where: k_t – dimensionless coefficient, taken by (Kononovich, 1986), for corner living quarters with radiator and convector heating systems k_i = 0.92; δ_i – thickness of the *i*-th layer of material, m; ρ_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·K); F_i – area of the *i*-th layer of material, m^2; L – infiltration air flow, m^3/h; ρ_{inf} – density of infiltrating air, kg/m^3; c_{inf} – heat capacity of infiltrated air, J/(kg·K); k_j, F_j – heat transfer coefficient, W/(m^2·K), and construction area, m^2.

To estimate the cooling time of premises with structures with different heat accumulation with 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 Figures 7-9.

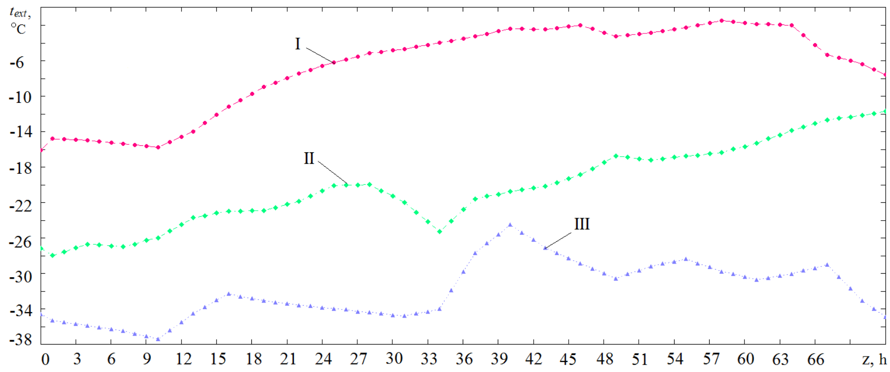

Fig. 6. Outdoor temperature (*own research*): I – January 9-12, 2018; II – January 14-17, 2018; III – January 21-24, 2018

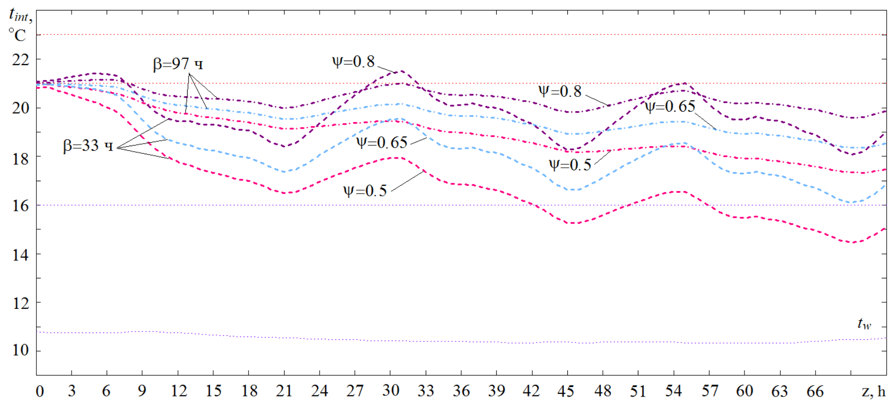

Fig. 7. Indoor air temperature, January 9-12, 2018 (*own research*)

At relatively high outdoor temperatures (I range of outdoor temperatures in Figure 6), the decrease in internal temperature is mainly determined by the ratio of heat fluxes ψ and to a lesser extent depends on the coefficient of heat accumulation β. So, in Figure 7, at ψ = 0.8, the decrease in tint is approximately the same as at β = 97 h and at β = 33 h, although at β = 33 h, large fluctuations in the internal air temperature are observed. However, the smaller ψ, the more importance the coefficient of heat accumulation β begins to play. For example, at ψ = 0.5, the tint decreases faster at β = 33 h than at β = 97 h. However, even in this case, the reduction of the internal temperature of tint to 16°C will occur in approximately 57 hours. In other cases, the duration of reaching the standard time will be much longer and the system can provide heating of water for hot water supply to the standard temperature.

At average winter outdoor temperatures (II range of outdoor temperatures in Fig. 6), the decrease in internal temperature will strongly depend on both the ratio of heat fluxes ψ and the coefficient of heat accumulation β (Fig. 8).

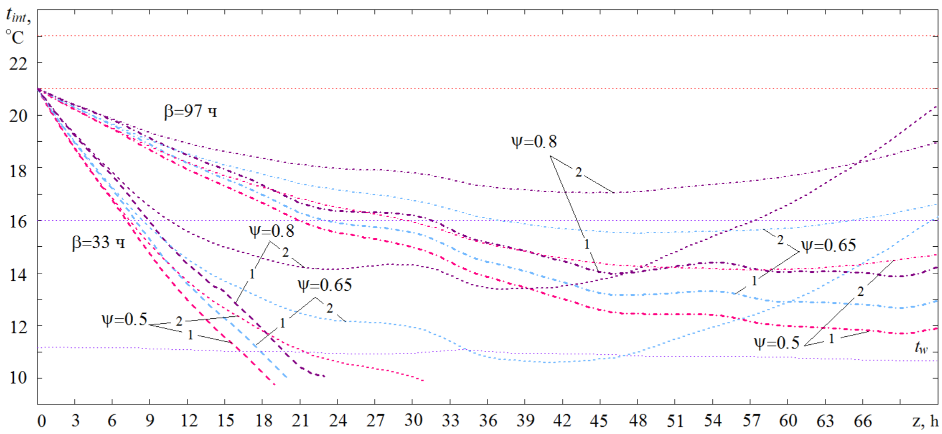

Fig. 8. Indoor air temperature, January 14-17, 2018; 1 – at the working second stage of the hot water heater; 2 – at turning off second stage of the hot water heater (*own research*)

At high β = 97 h and different ψ, the internal air temperature will reach 16°C 21-33 h, but the temperature of the inner surface of the walls will not reach the dew point t_w for three days. In structures with low thermal accumulation β = 33 h, the internal air temperature will drop to 16°C in 7-9 h, and the internal surface temperature of the structure will reach the dew point in 16-20 h. Switching 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 ψ. So, at ψ = 0.8 and ψ = 0.65, the internal air temperature in this case will not fall below 16°C (Fig. 8). For buildings with low values β = 33 h, switching off the second stage of the hot water heater will be effective at high ratios ψ. So, at ψ = 0.8, this measure will significantly raise the internal air temperature, which may even at some points in time become higher than the internal air temperature in buildings with β = 97 h, although there will be large temperature fluctuations. With the ratio ψ = 0.65, the internal air temperature can also be significantly increased. At the same time, switching off the second stage of the hot water heater at ψ = 0.5 and β = 33 h does not make sense, since it will not have a noticeable effect on the internal air temperature (Fig. 8).

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 by the coefficient of thermal accumulation β and will depend little on the ratio of heat fluxes ψ (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.

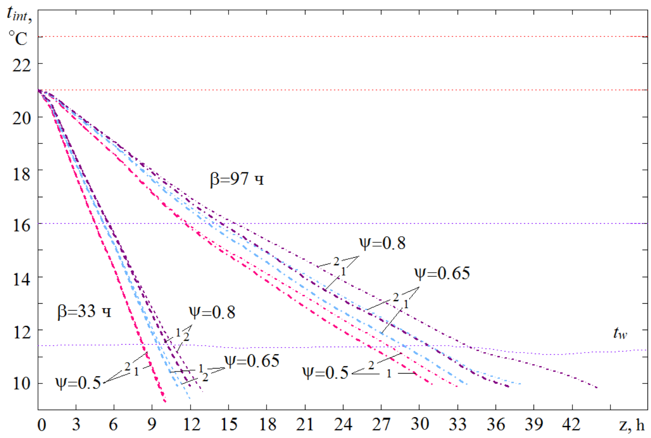

Fig. 9. Indoor air temperature, January 14-17, 2018; 1 – at the working second stage of the hot water heater; 2 – at turning off second stage of the hot water heater (*own research*)

2. 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 (Sokolov, 2001) or a similar formula proposed by (Ionin, 1989) in theory of limited heat supply. Therefore, the real temperature of the indoor air, which will be established in the room in time *z* is shown as:

$$t_{\text{int}}^{real}(z) = t_{ext} + \left[\frac{Q_o}{Q_o^{req}} + \left(\frac{t_{\text{int}}^{cur} - t_{ext}}{t_{\text{int}}^{req} - t_{ext}} - \frac{Q_o}{Q_o^{req}} \right) e^{\frac{-z}{\beta}} \right] \left(t_{\text{int}}^{req} - t_{ext} \right), \qquad (2)$$

where t_{int}^{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):

$$z = -\beta \ln\left[1 - \frac{t_{\text{int}}^{req} - t_{\text{int}}^{ass}}{t_{\text{int}}^{req} - t_{ext}} \cdot \frac{1}{1 - \bar{Q}_o^{em}}\right], \tag{3}$$

where t_{int}^{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 $\bar{Q}_o^{em}$ of the heating system with limited heat supply for various ψ can be determined from Figure 3.

We can assume that the dependence of the heating system heat capacity in emergency mode on ψ 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 $t_{ext.o}$ and ψ = 0.5 (for the city of Novosibirsk $t_{ext.o}$ = –37°C), $\bar{Q}_o^{em} = 0.29$. The magnitude of the change of $\bar{Q}_o^{em}$ by one degree of the outside temperature according to Figure 3, corresponds to 0.014. For any outside temperature t_{ext}, at ψ = 0.5, $\bar{Q}_o^{em}$ can be defined as

$$\bar{Q}_o^{em}\Big|_{\psi=0.5} = 0.29 - 0.14\left(t_{ext.o} - t_{ext}\right).$$

Then the dependence $\bar{Q}_o^{em}$ on ψ at any external temperature t_{ext} can be described by the formula

$$\bar{Q}_o^{em} = 0.16\left(\psi - 0.5\right) + 0.29 - 0.14\left(t_{ext.o} - t_{ext}\right). \tag{4}$$

Substituting (4) in (3), we obtain

$$z = -\beta \ln\left\{1 - \frac{t_{\text{int}}^{req} - t_{\text{int}}^{ass}}{t_{\text{int}}^{req} - t_{ext}} \cdot \frac{1}{1 - \left[0.16\psi + 0.21 - 0.14\left(t_{ext.o} - t_{ext}\right)\right]}\right\}. \tag{5}$$

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.

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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