Investigation of the influence of heat protection characteristics of protecting designs on residential buildings heat storage capacity

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Abstract. The article presents the methodology of determining the heat storage factor of residential buildings heated by the central heating system. This calculation method is considered on the example of one-room corner apartment on the ground floor of an apartment building. The results of heat accumulation factor calculation are presented and the parameter changes depending on the value of normative multiplicity of air exchange and external air temperature are shown. The calculation of indoor air temperature after switching off the heating system was performed. The results presented in the article allow to draw a conclusion about the significant impact of natural ventilation during an accident on the heat network. The increase in air exchange in this case reduces the internal air temperature significantly. The obtained results should be used when choosing measures to ensure energy security of buildings and structures.

1. Introduction
According to the technical regulations “safety of buildings and structures”, the parameters of the microclimate of premises should be harmful to human health.

During the operation of residential buildings that are heated from centralized heat supply systems accidents occur periodically. They are associated with the pipeline wear and tear and resulting poor coolant circulation. Therefore, the designed buildings are subject to regulatory requirements for the heat storage capacity of residential premises. Before emergency situations are eliminated, there is a significant decrease in the temperature of the internal air in buildings and the heat carrier in heating and hot water systems. The process of premises cooling occurs in conditions of non-stationary heat transfer between internal and external air, which complicates the method of solving the problem under consideration significantly. In works [1-10] the results of thermal engineering calculation of enclosing structures operated under conditions of changing internal air temperature are presented. In [2, 6] the results of the study of the influence of the non-stationary thermal regime of enclosing structures on the heating system of buildings are presented. Works [1, 3-10] are devoted to solving the conjugate problem of heat exchange in the process of premises heating and cooling.

2. Methodology for calculating room storage capacity
The heat storage capacity of buildings according to [4] is characterized by the heat storage coefficient $\beta$, measured in hours. To determine it, there are experimental and computational methods described in detail in [1, 4].
The indoor air temperature in living quarters $t_{in}$ when the heating system is turned off is determined according to [4] by the formula

$$t_{in} = t_{out} + \left(t_{in_0} - t_{out}\right)e^{-\frac{\tau}{\beta}}$$

(1)

where $t_{out}$ - outdoor temperature, ($^\circ$C); $t_{in_0}$ - internal air temperature before the heating system is turned off, ($^\circ$C); $\tau$ - room cooling time, (h).

The value of the heat storage coefficient is significantly influenced by the heat-protective characteristics of enclosing structures, their heat capacity, as well as the multiplicity of air exchange.

An approximate analytical method for determining the above coefficient was proposed by Yu. V. Kononovich in [7].

According to [7], the value of the coefficient $\beta$ is calculated using the formula

$$\beta = \frac{C_{\text{protecting design}}}{3.6Q_{sp}}$$

(2)

where $C_{\text{protecting design}}$ - heat capacity of the building protecting design, (kJ/$^\circ$C); $Q_{sp}$ - specific heat loss of the room, (W/$^\circ$C).

Value $C_{\text{protecting design}}$ external protecting design and internal partitions is calculated by the formula

$$C_{\text{protecting design}} = K_i \sum_{i=1}^{n} \delta_i c_i \rho_i \frac{F_i}{2}$$

(3)

where $\delta_i$, $c_i$, $\rho_i$ - thickness, specific heat and density of the layer material of protecting design; $F_i$ - protecting design square, (m$^2$); $K_i = \frac{t_{R} - t_{out}}{t_{in_0} - t_{out}}$ - dimensionless coefficient; $t_{R}$ - radiation temperature of the protecting design, ($^\circ$C).

The radiation temperature of the building protecting design to [7] is determined by the formula

$$\tau_i = t_{in_0} - \frac{t_{out}}{R_{pr}^i \alpha_{in}}$$

(4)

where $R_{pr}^i$ - resistance to heat transfer of the protecting design, determined according to SP 50.13330.2012 “Thermal protection of buildings”, (m$^2$$\cdot$$^\circ$C)/W; $\alpha_{in}$ - heat transfer coefficient from the side of the inner surface of the protecting design, W/(m$^2$$\cdot$$^\circ$C).

The value of specific heat loss according to [7] is calculated by the formula

$$Q_{sp} = \sum_{i=1}^{n} k_i F_i + Lc_{in} \rho_{in}$$

(5)

where $k_i$ - coefficient of heat transfer of the external protecting design W/(m$^2$$\cdot$$^\circ$C); $L$ - the flow of infiltrating outdoor air through the enclosing structures, the standard value of which for residential buildings is 3 m$^3$/h per 1 m$^2$ of residential premises of the apartment.

3. Results of calculating the heat storage capacity of the room

As an example, we considered the determination of the heat storage capacity of a residential apartment located on the first floor of an apartment building.

Figure 1 shows the plan of the corner room in the apartment under consideration. Thermal engineering indicators of the apartment's enclosing structures are shown in table 1.
Figure 1. Plan of the corner living room.

Table 1. Thermal characteristics of structures and materials used in the calculation.

| Protecting design type | Area of the fence | Thickness | Coefficient of thermal conductivity | Specific heat capacity | Density | Heat transfer resistance of the protection |
|------------------------|-------------------|-----------|-------------------------------------|------------------------|---------|------------------------------------------|
|                        | $F_i$ m²          | $\delta_i$ m | $\lambda_i$ W/(m·°C) | $c_i$ kJ/kg °C | $\rho_i$ kg/m³ | $R_{0i}$ (m²·°C)/W |
| **External protecting design** |                   |           |                                      |                        |         |                                         |
| External walls:         | 20.94             | -         | -                                   | -                      | 3.24    | -                                        |
| - expanded clay concrete panels | -         | 0.350     | 0.330                               | 0.84                   | 1000    | -                                        |
| - basalt mineral wool   | -                 | 0.100     | 0.042                               | 0.84                   | 120     | -                                        |
| - textured layer of the facade system | -        | 0.0035    | 0.700                               | 0.84                   | 1600    | -                                        |
| Window blocks with double-glazed Windows in bindings | 4.5       | -         | -                                   | -                      | 0.55    | -                                        |
| The ceiling above the unheated basement: | 21.6       | -         | -                                   | -                      | 1.75    | -                                        |
| - the linoleum on mastic | -                 | 0.0015    | 0.29                                | 1.47                   | 1600    | -                                        |
| - cement-sand solution  | -                 | 0.03      | 0.76                                | 0.84                   | 1800    | -                                        |
| - PENOPLEX              | -                 | 0.04      | 0.031                               | 1.34                   | 35      | -                                        |
| - cement-sand solution  | -                 | 0.02      | 0.76                                | 0.84                   | 1800    | -                                        |
| - reinforced concrete hollow floor slab | -          | 0.22      | 1.74                                | 0.84                   | 2500    | -                                        |
| **Internal protecting design** |                   |           |                                      |                        |         |                                         |
| Interroom partition:    | 13.9              | -         | -                                   | -                      | -       | -                                        |
| - laying of ceramic bricks on a cement-sand solution | -                 | 0.12      | 0.70                                | 0.88                   | 1800    | -                                        |
| - lime-sand plaster     | -                 | 0.04      | 0.70                                | 0.84                   | 1700    | -                                        |
| Interroom partition:    | 9.54              | -         | -                                   | -                      | -       | -                                        |
| - laying of ceramic bricks on a cement-sand solution | -                 | 0.25      | 0.7                                  | 0.88                   | 1800    | -                                        |
| - lime-sand plaster     | -                 | 0.04      | 0.7                                  | 0.84                   | 1700    | -                                        |
| Floor:                 | 21.6              | -         | -                                   | -                      | -       | -                                        |
| - heat and sound insulation linoleum | -                 | 0.0035    | 0.04                                | 1.47                   | 1000    | -                                        |
| - cement-sand solution  | -                 | 0.03      | 0.76                                | 0.84                   | 1800    | -                                        |
| - PENOPLEX              | -                 | 0.03      | 0.031                               | 1.34                   | 35      | -                                        |
| - reinforced concrete floor slab | -          | 0.22      | 1.74                                | 0.84                   | 2500    | -                                        |
The value of the specific heat loss of a living room was determined by the formula (6), the heat capacity of protecting design by the formula (3). The results of calculating the coefficient of heat storage at different outdoor temperatures are shown in table 2.

**Table 2.** Results of calculating the accumulating capacity of a residential apartment.

| Outdoor temperature $t_{\text{out}}$ °C | Outdoor air density $p_{\text{out}}$ kg/m$^3$ | Mass flow rate of infiltrating air $G_{\text{in}}$ kg/h | Specific heat loss $Q_{\text{sp}}$ W/°С | Radiant temperature $t_{\text{out}}$ °C | Heat capacity $C_{\text{protecting design}}$ kJ/°С | $\beta$ h |
|-----------------------------------|-----------------------------------|-----------------------------------|-----------------|-----------------|-----------------------------------|---|
| 0                                 | 1.29                              | 83.6                             | 50.17           | 19.4            | 0.97                              | 7955.3 | 44.05 |
| -10                               | 1.34                              | 86.8                             | 51.07           | 19.21           | 0.974                            | 7988.2 | 43.45 |
| -20                               | 1.39                              | 90.1                             | 52.0            | 19.01           | 0.975                            | 7996.3 | 42.72 |
| -30                               | 1.45                              | 93.98                            | 53.07           | 18.8            | 0.976                            | 8004.5 | 41.9  |

From the data presented in table 2, it follows that the coefficient of heat storage decreases slightly when the outdoor temperature decreases. The average value of the coefficient $\beta$ was 43 hours.

When operating residential buildings, the multiplicity of air exchange varies from 0.25 to 1.0. The minimum value corresponds to the duty mode of the ventilation system in the absence of people.

Table 3 shows the results of calculating the heat storage coefficient for different values of air exchange multiplicity.

**Table 3.** Heat storage capacity of a residential apartment at different values of the multiplicity of air exchange.

| Outdoor temperature $t_{\text{out}}$ °C | Ventilation rate $n$ h$^{-1}$ | Specific heat loss $Q_{\text{sp}}$ W/°С | Heat capacity $C_{\text{protecting design}}$ kJ/°С | $\beta$ h |
|-----------------------------------|-----------------|-----------------|-----------------------------------|---|
| 0                                 | 0.25            | 32.78           | 7955.3                            | 67.41 |
|                                  | 0.50            | 36.58           | 7988.2                            | 60.41 |
|                                  | 0.75            | 44.39           | 7996.3                            | 49.78 |
|                                  | 1.00            | 50.17           | 8004.5                            | 44.05 |
| -10                               | 0.25            | 33.00           | 7988.2                            | 67.24 |
|                                  | 0.50            | 39.03           | 7996.3                            | 56.85 |
|                                  | 0.75            | 45.05           | 8004.5                            | 49.26 |
|                                  | 1.00            | 51.07           | 8004.5                            | 43.45 |
| -20                               | 0.25            | 33.23           | 7996.3                            | 66.84 |
|                                  | 0.50            | 39.48           | 8004.5                            | 56.26 |
|                                  | 0.75            | 45.74           | 8004.5                            | 48.56 |
|                                  | 1.00            | 52.00           | 8004.5                            | 42.72 |
| -30                               | 0.25            | 33.50           | 8004.5                            | 66.37 |
|                                  | 0.50            | 40.02           | 8004.5                            | 55.56 |
|                                  | 0.75            | 46.55           | 8004.5                            | 47.77 |
|                                  | 1.00            | 53.07           | 8004.5                            | 41.90 |

From the data presented in table 3, it follows that the coefficient of heat accumulation decreases with an increase in the multiplicity of air exchange.

The term from formula (1) will be denoted as the dimensionless temperature of the internal air

$$\theta_{in} = \frac{t_{\text{in}} - t_{\text{out}}}{t_{\text{in}} - t_{\text{out}}}$$ (6)

The temperature of the internal air during the cooling of the living room was determined by the formula (6)
To calculate the dimensionless temperature $\Theta$, it is proposed to use table 4, which shows the results of calculating $\Theta$ for different values of the heat storage coefficient.

$$\Theta = e^{-\frac{v}{\beta}}$$

Table 4. Results of calculating the process of cooling residential premises.

| Cooling time $\tau$, h | Dimensionless internal air temperature at values $\beta$, h |
|------------------------|----------------------------------------------------------|
|                        | 40            | 50            | 60            | 70            |
| 0                      | 1.000         | 1.000         | 1.000         | 1.000         |
| 5                      | 0.880         | 0.904         | 0.920         | 0.931         |
| 10                     | 0.778         | 0.818         | 0.845         | 0.866         |
| 15                     | 0.686         | 0.740         | 0.778         | 0.806         |
| 20                     | 0.605         | 0.669         | 0.716         | 0.750         |
| 25                     | 0.533         | 0.605         | 0.658         | 0.699         |
| 30                     | 0.471         | 0.547         | 0.605         | 0.650         |

Using table 4, it is possible to determine the value of the dimensionless temperature of indoor air in residential premises in emergency situations.

4. Discussion

The results of calculation of accumulation capacity of the considered room show, that the heat storage factor changes insignificantly relative to its average value. The data presented in table 2 were obtained with a standard air exchange equal to one rate.

Further investigation of room storage capacity at air exchange multiplicity from 0.25 to 1, has shown changes in average value of heat accumulation factor from 67 to 43 hours. It is obvious that in order to increase room storage capacity during emergencies on heat networks it is necessary to reduce specific heat losses during this period of time. According to the data presented in table 3, it is necessary to reduce air exchange in the given room by closing vents, transoms, window vestibules or breathing valves.

Thus, the air exchange rate is of great importance for the room storage capacity. It should be noted that these studies were conducted for a residential building with a natural ventilation system. However, not only the air exchange but also the heat protection characteristics of the protecting designs should be taken into account when switching off the heating system.

5. Conclusions

The results of calculation of heat accumulation factor of an apartment building showed that the work of natural ventilation system has a significant influence on the degree of heat accumulation in a room at violation of circulation of the coolant in the heating system. Normative air exchange decrease allows maintaining the maximum allowed temperature of internal air at switching-off of heating system. To increase the cooling time of the room, it is necessary to reduce air exchange to 0.25 times at the time of stopping heat supply, however, when restoring heat supply, it is recommended to increase air exchange to standard values. The results obtained should be taken into account when developing energy saving measures and measures to ensure buildings energy security.

References

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