Contribution of heat loss by infiltration to energy saving and microclimate in multi-family residential buildings

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Abstract. The problem of energy performance takes a leading position in world politics today. In the territory of RF a number of regulatory documents have been developed and put in force in construction industry, regulating the activity of design and construction organizations in the field of energy performance, including energy loss issues. The article analyses current methodology of calculating infiltration heat loss in a multi-storey residential building with account of the number of storeys. Calculation results in graphic form have been shown for the determination of infiltration heat loss for a 14-storey typical residential building, and imperfection of the methodology has been shown on the basis of these results. A conclusion has been drawn that infiltration loss calculation using current methodology gives overestimated values leading to unreasonable excess consumption of heat energy, and consequently, to economic losses. The article will be useful for engineers of designers of heating systems, employees of management companies.

Keywords: infiltration, heat loss, energy saving in heating, resource-saving, thermal resource saving, economy heating mode, control of building heating parameters, optimization of building heating parameters.

1. Introduction

Energy saving is one of top priority tasks of national energy politics in Russia today [1]. It is explained by inefficient use of energy and fuel resources and by their ever growing cost. For instance, relative consumption of heat energy for house heat supply systems (heating, ventilation, air conditioning, hot water supply) per 1 m² of heated area during a heating season in Russia is 2.9-4.3 times higher than that in countries with similar climatic conditions, e.g., in Sweden and Finland. Obviously, efficiency of energy resources used for house climatisation needs is low, and energy saving is needed. Solution of this problem is possible through development and implementation of energy saving measures, technologies and calculation methods [2, 3].

Residential houses’ heating represent the most important sector of power consumption [4, 5]. To determine the required calorific power of the heating system, heat loss of each of the house premises is determined, including heat loss due to outer (infiltrating) air heating [6-8]. This heat loss may reach up to 60% and more of the total heat loss of the house, depending on initial conditions. Current methodology concerning calculation of the amount of heat required for infiltrating air heating do not consider a number of factors, resulting eventually in overheated air in premises, excessive thermal energy consumption, and insufficient thermal acceptability.
We believe that emphasis in achieving energy saving in heat supply of multi-storey buildings should be made on the methodology of calculating the amount of heat required for infiltration air heating, which has determined timeliness of this study.

2. Materials and Methods
For convenience, first let introduce some notations:
- \( Q_{\text{calc}} \) - calculated heat loss, W;
- \( Q_i \) - calculated heat loss by infiltration, W;
- index \( r \) - corresponds to calculation as per regulatory requirements;
- index \( v \) - corresponds to natural exhaust ventilation performance records;
- index \( \text{tw} \) - corresponds to calculation taking into account wind and thermal pressure.

The amount of heat consumed for infiltration air, taking into account wind pressure \( Q_{i\text{tw}} \), is established with account of consumed heated air \( G_h \) which equals the total amount of infiltrating air coming through external enclosure leaks \( \Sigma G_{ee} \) [9-11]. Let us note that \( \Sigma G_{ee} \) depends on the type and character of external enclosure leaks and is determined for each storey and premise separately [8, 12]. Besides, the value of differential air pressure \( \Delta p \), Pa at outer and inner enclosure surfaces corresponding to a particular premise [8, 12] is taken into account.

Based on the formula for the calculation of infiltrating air consumption [8, 12]:

\[
\Sigma G_{ee} = 0.216 \sum A_i \Delta p_1^{0.67} / R_n + \sum A_2 G_{ee} (\Delta p / \Delta p_1)^{0.67} + 3456 \sum A_3 \Delta p_1^{0.5} + 0.5 \sum l \cdot \Delta p / \Delta p_1
\]  

(1)

where \( \Delta p_1 \), \( \Delta p_2 \), respectively, is the difference in air pressure at inner and outer surface of windows, balcony doors and outer doors in a standard storey and at the first storey level, Pa;
\( l \) - length, m, of wall panel joints;
\( A_i, A_2 \) - area of windows, balcony doors and other enclosures, m\(^2\);
\( A_3 \) - area of crackage, leaks through window apertures, outer doors, m\(^2\);
\( R_n \) - resistance of windows, balcony doors to air infiltration, (m\(^2\)h Pa)/kg;
and the formula for the calculation of difference in air pressure at inner and outer enclosure surfaces

\[
\Delta p = (H - h)(\gamma_{\text{out}} - \gamma_{\text{in}}) + 0.5 \cdot V^2 \rho_d (c_d - c_u) k_v - p_{\text{int}}
\]  

(2)

\( H \) - height of the building, from ground level to cornice, centre of skylight exhaust openings or ventilation shaft, m
\( h \) - design height, from ground level to top of the windows, balcony doors or to the axis of wall panel joints, m
\( \gamma_{\text{out}}, \gamma_{\text{in}} \) = specific gravity, at outdoor \( t_{\text{out}} \) and indoor \( t_{\text{in}} \) air temperature, H/m\(^3\), respectively, defined as

\[
\gamma = \frac{3463}{273 + t}
\]  

(3)

\( G_e \) - density of external air, kg/m\(^3\);
\( V \) - wind velocity, m/s;
\( c_d, c_u \) - aerodynamic factors for downwind and upwind enclosure surfaces, respectively, \( c_d = 0.8 \), \( c_u = -0.6 \).
3. Results

As thermal design of heating system calorific power is made for the lowest temperatures of outdoor air, a possibility to control thermal conditions inside the premises must be provided; on that basis, several possible variants will be analyzed:

1-st design: thermal design taking into account regulated heat flow for the riser passing through the living rooms of single-type flats in a 14-storey residential building with the upper heating agent supply as per current regulatory documents;

2-nd design: thermal design where heating radiator length must cover 50-70% of window aperture length;

3-rd design: we shall calculate expected air temperature taking into account increased consumption of heating agent, without increasing heating unit surface area;

4-th design means increasing both heating unit surface area and heating agent consumption;

5-th design assumes taking into account the impact of the number of radiator sections on temperature head in heat loss calculation.

Let us calculate total consumption of infiltration air $\Sigma G_{ee}$ and $Q_{itb}$ in order to establish calculated heat loss in a premise $Q_{\text{calc}}$ for each of the rooms from the 14th to the 1st storey at $t_{out} = -23; -20; -10; -5; \text{and } 0 ^\circ C$. Results are presented as a diagram (Figure 1).

![Figure 1. Calculated heat loss in a premise $Q_{\text{calc}}$ for each of the rooms from the 14th to the 1st storey at $t_{out} = -23; -20; -10; -5; \text{and } 0 ^\circ C$, provided that $Q_{r}=Q_{t, tw}$.](image)

Comparing obtained values, note that heat loss design indices for premises, assuming that $Q_{r}=Q_{t, w}$ and $Q_{r}=Q_{t, tw}$, have different values in conformity with the temperature of outdoor air, namely, $Q_{\text{calc}}$ at $Q_{r}=Q_{t, tw}$ is less than $Q_{\text{calc}}$ at $Q_{r}=Q_{t, w}$.

Let us recalculate expected air temperature $t_{in}$ taking into account heat consumed for infiltration air $Q_{t, tw}$, depending on pressure difference at the two sides of the airtight element of the building at standard storeys using formula:

$$
\frac{f_{t_{in}}}{m_{sec}} = \frac{n_{sec} \cdot f_{sec} \cdot K_{sec} \cdot m_{sec}}{n_{sec} \cdot f_{sec} \cdot K_{sec} \cdot m_{sec} + (F_{sec, K_{sec} \cdot m_{sec}})} + t_{m_{sec}} (F_{sec, K_{sec} \cdot m_{sec}} + F_{wall, K_{wall} \cdot m_{sec}} + 0.28 \cdot G_{\text{inf}} \cdot \rho_{m_{sec}} \cdot c_{m_{sec}})
$$

$$
\frac{f_{t_{in}}}{m_{sec}} = \frac{n_{sec} \cdot f_{sec} \cdot K_{sec} \cdot m_{sec}}{n_{sec} \cdot f_{sec} \cdot K_{sec} \cdot m_{sec} + (F_{sec, K_{sec} \cdot m_{sec}} + F_{wall, K_{wall} \cdot m_{sec}} + 0.28 \cdot G_{\text{inf}} \cdot \rho_{m_{sec}} \cdot c_{m_{sec}})}
$$
\( P_{in}, c_{in} \) – density, kg/m\(^3\), and heating capacity, kJ/kg\(^\circ\)C, of indoor air, respectively.

Number of heating unit sections is taken in compliance with conditions of the 1-st thermal design using the formula:

\[
n = \frac{Q_{calc}^{st}}{a_{sec} \cdot q_{ac} \cdot \beta_4} \cdot \beta_3
\]

where \( Q_{calc}^{st} \) – calculated heat loss of the storey under consideration, which equals to required radiator heat transfer, W;

\( a_{sec} \) – heating surface area of one section, for MS-140 radiators, \( a_{sec} = 0.244 \) m\(^2\);

\( \beta_4 \) – correction factor, taking into account method of radiator installation [13], assumed \( \beta_4 = 1 \) [7, page 47];

\( \beta_3 \) – factor depending on the number of sections in the radiator, as per recommendations [14];

\( q_{ac} \) – actual density of heating unit heat flux for conditions differing from standard ones [10], W/m\(^2\).

Comparing the data under condition of the 1-st design (Figure 2) and condition of 2-nd design (Figure 3), we may make a conclusion that expected air temperature value in corresponding rooms in view of radiator thermal designs at \( Q_i = Q_{ir} \) is different from those in calculation with \( Q_i = Q_{itw} \). So, it should be noted that maximum value of \( t_{in} = 38.9 \)\(^\circ\)C is observed in the 14-th storey at \( t_{out} = -23 \)\(^\circ\)C, and minimum value \( t_{in} = 15.9 \)\(^\circ\)C corresponds to \( t_{in} = +8 \)\(^\circ\)C in a room at the 12-th storey. Overestimation of \( t_{in} \) against recommended range of indoor air values \( t_{in} = +18 \ldots 20 \)\(^\circ\)C is the evidence of excessive heat demand to cover heat loss in the case when real heat loss by infiltration \( Q_i \), W equals to the heat loss with the account of wind pressure impact \( Q_{itw} \), not to the largest of \( Q_{ir} \) and \( Q_{itw} \), W (in our case, \( Q_{ir} > Q_{itw} \), W) values.

![Figure 2. Diagram of expected indoor temperature \( t_{in} \), \(^\circ\)C design data in premises from the 1-th to the 14-th storey inclusive.](image-url)
Figure 3. Diagram of expected air temperature value at $t_{in}$, 0 °C when $Q_i = Q_{tw}$, W and $t_{out}$ = -23; -20; -10; -5; and 0 °C.

Let us calculate the resultant value of expected indoor air temperature $t_{in}$, °C for premises in storeys 1-14 at $t_{out}$ = -23; -20; -10; -5; 0 and +8 °C, similar to conditions of 2nd and 5th designs but taking into account that infiltration loss $Q_i$ equals to heat consumption for infiltrating air heating $Q_{tw}$, where the amount of heated air $G_h$ is considered equivalent to the amount of infiltrating air penetrating through the leaks of external enclosure. Final calculation values are shown in the form of diagrams.

Figure 4. Diagram of expected indoor temperature $t_{in}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account changed number of radiator sections under condition of the 2nd design and assuming that $Q_i = Q_{tw}$, W

Relying on obtained values $t_{in}$ (Figure 4), it must be emphasized that condition of increasing heating unit surface area at 50-70% of window aperture has resulted in reaching minimum value of $t_{in}$=17 °C, while maximum indoor temperature $t_{in}$ is 44 °C.
According to the diagram of $t_{inr}$ °C values (Figure 5), with the increase of heating agent flow, indoor temperature in rooms of storeys 2nd to 14th at $t_{out} = +8$ °C does not meet the minimum recommended value of $t_{in} = +18$ °C, while at $t_{out} = -20 \ldots -23$ °C, in some rooms, excessive indoor temperature $t_{in}$ as compared with the comfort range is observed [15, 16].

Figure 5. Diagram of expected indoor temperature $t_{inr}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account increased heating agent consumption as per the 3rd design, and assuming $Q_i = Q_{irv}$.

Figure 6. Diagram of expected indoor temperature $t_{inr}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account increased heating agent consumption but without heating unit surface area increase, and assuming $Q_i = Q_{irv}$. 
Analyzing the diagram with obtained data of $t_{in}$ changes in rooms at $t_{out} = -23; -20; -10; -5; 0$; and $+8 \, ^\circ C$ (Figure 6), let us put emphasis on too high value of $t_{in}$ when the value range of $t_{out} = -10 \ldots -23 \, ^\circ C$, which shows the need to apply individual regulation, that is, to shut down a required number of sections $n_{sec}$ until recommended condition of $t_{in} = +18 \ldots -20 \, ^\circ C$ is reached. For this purpose we decrease the number of sections $n_{sec}$ until the requirement of $t_{in} = +18 \ldots -20 \, ^\circ C$ is met; it is assumed that $Q_i = Q_{i,tw}$.

As in the 5th design, let us recalculate $t_{in}$ and $Q_{ac}$ due to dependence of average temperature head of the unit $\Delta t_{av}$ on the number of unit sections, proceeding from the relevant formulae and assuming that $Q_i = Q_{t,w}$. Calculation results are shown in the diagram (Figure 7).

![Diagram of actual air temperature values $t_{in}$ when radiator sections are shut off and $Q_i = Q_{t,w}$](image)

Figure 7. Diagram of actual air temperature values $t_{in}$ when radiator sections are shut off and $Q_i = Q_{t,w}$.

Shutting down individual sections facilitates reaching comfort values of $t_{in}$ [16] in residential rooms of all storeys at various values within outdoor air $t_{out}$ temperature range [17].

4. Conclusions
Taking into account calculated data of actual indoor temperature $t_{in}$ under various conditions of design variants 1 and 2, we may observe dependence of this parameter not only on $t_{out}$, but on conditions and accuracy of heating units’ thermal design. So, a change in $t_{in}$ is directly determined by the amount of heat required for infiltration air heating $Q_i$, which highlights the need of taking into account the real value of $Q_i$ in the process of heating system design in order to determine a required number of radiator sections.

Thermophysical properties of the heating agent and heating units also determine the indicator of the heating surface area; for this reason, their deviation from nominal coefficients used in standard thermal design of heating systems leads to incorrect decision when determining required radiator surface area, which may explain the source of actual indoor temperature non-conformity with accepted standards.

Individual regulation of units heat transfer by means of mechanical shutdown of unit sections allows reaching comfort values of $t_{in}$ in various outdoor air temperatures with minimum impact on average radiator temperature head $\Delta t_{av}$, which does not cause significant changes in thermophysical properties of the heating agent and the heating unit itself.
Thus, imperfection of current methodology of calculating infiltration heat loss has been analyzed in operation, using a typical residential building as an example. As this methodology is the basis for regulatory documents, this fact should be taken in consideration first and foremost when designing energy efficient facilities.

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