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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 m^2 of heated area during a heating season in Russia is 2.9-4.3 times higher that 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_{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 $_{tw}$– corresponds to calculation taking into account wind and thermal pressure.

The amount of heat consumed for infiltration air, taking into account wind pressure $Q_{i\ tw}$, is established with account of consumed heated air G_h which equals the total amount of infiltrating air coming through external enclosure leaks ΣG_{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 Δp, 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]:

$$\Sigma G_{ee} = 0.216\sum A_1 \Delta p^{0.67} / R_n + \sum A_2 G_{ee} (\Delta p / \Delta p_1)^{0.67} + \\ + 3456\sum A_3 \Delta p_1^{0.5} + 0.5\sum l \cdot \Delta p / \Delta p_1 \tag{1}$$

where Δp_1, Δp_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_1, 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

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

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
γ_{out}, γ_{in} = specific gravity, at outdoor t_{out} and indoor t_{in} air temperature, H/m^3, respectively, defined as

$$\gamma = \frac{3463}{273 + t} \tag{3}$$

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_n = -0.6.

IOP Conf. Series: Materials Science and Engineering **791** (2020) 012007 doi:10.1088/1757-899X/791/1/012007

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 ΣG_{ee} and $Q_{i\ tb}$ in order to establish calculated heat loss in a premise Q_{calc} for each of the rooms from the 14th to the 1st storey at t_{out}= -23; -20; -10; -5; and 0 °C. Results are presented as a diagram (Figure 1).

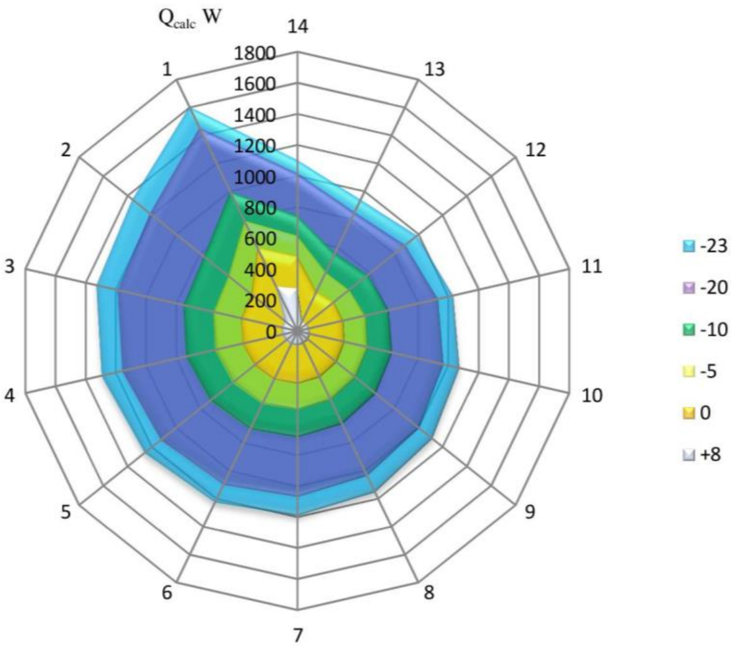

Figure 1. Calculated heat loss in a premise Q_{calc} for each of the rooms from the 14th to the 1st storey at t_{out}= -23; -20; -10; -5; and 0°C, provided that Q_i=$Q_{i\ tw}$.

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

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

$$ {}^f t_{in} = \frac{n_{\sec} f_{\sec} t_{pr} K_{ac} + t_{in}(F_{wa}K_{wa} + F_{wall}K_{wall} + 0.28 \cdot G_{\inf} \cdot \rho_{in} \cdot c_{in})}{n_{\sec} f_{\sec} K_{ac} + (F_{wa}K_{wa} + F_{wall}K_{wall} + 0,28 \cdot G_{\inf} \cdot \rho_{in} \cdot c_{in})} \quad (4) $$

P_{in}, c_{in} – density, kg/m^3, and heating capacity, kJ/kg·°C, of indoor air, respectively.

Number of heating unit sections is taken in compliance with conditions of the1-st thermal design using the formula:

$$n = \frac{Q_{calc}^{st}}{a_{\sec} \cdot q_{ac}} \cdot \frac{\beta_4}{\beta_3} \tag{5}$$

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;
β_4– correction factor, taking into account method of radiator installation [13], assumed β_4=1 [7, page 47];
β_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=$Q_{i\ r}$ is different from those in calculation with Q_i=$Q_{i\ tw}$. So, it should be noted that maximum value of $^f t_{in}$=38.9°C is observed in the 14th storey at t_{out}= -23°C, and minimum value $^f t_{in}$=15.9°C corresponds to t_{in} = +8°C in a room at the 12th storey. Overestimation of $^f t_{in}$ against recommended range of indoor air values $^f t_{in}$ = +18…20 °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 $Q_{i\ tw}$, not to the largest of $Q_{i\ r}$ and $Q_{i\ tw}$, W (in our case, $Q_{i\ r}$ >$Q_{i\ tw}$, W) values.

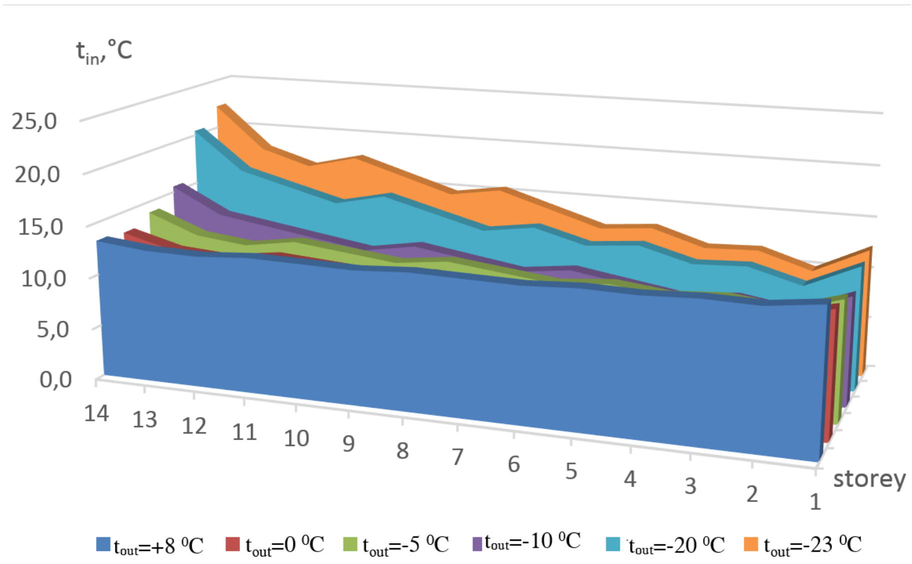

Figure 2. Diagram of expected indoor temperature $^f t_{in}$, °C design data in premises from the 1st to the 14th storey inclusive.

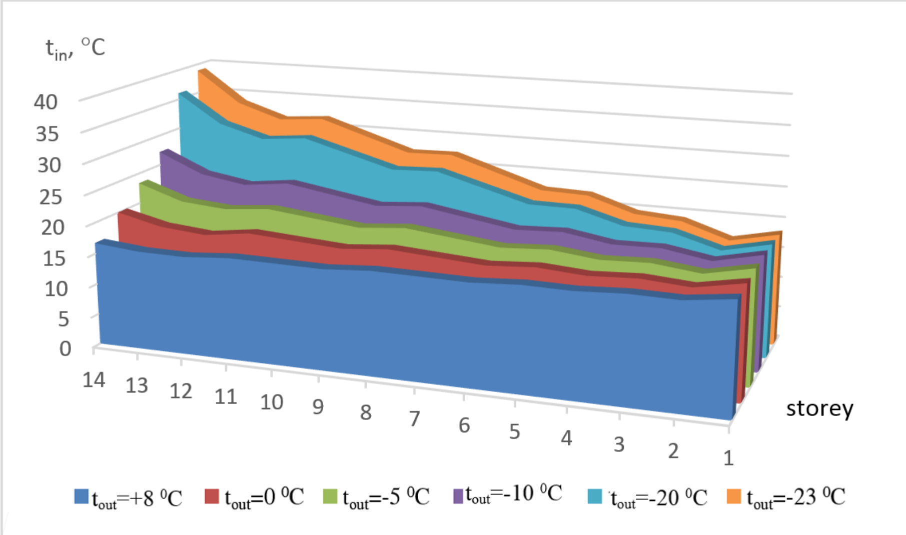

Figure 3. Diagram of expected air temperature value at ${}^{f}t_{in}$, 0 °C when Q_i=$Q_{i\ tw}$, W and t_{out}= -23; -20; -10; -5; and 0 ^{0}C.

Let us calculate the resultant value of expected indoor air temperature ${}^{f}t_{in,}$°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 $Q_{i\ \mathrm{tw}}$, 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.

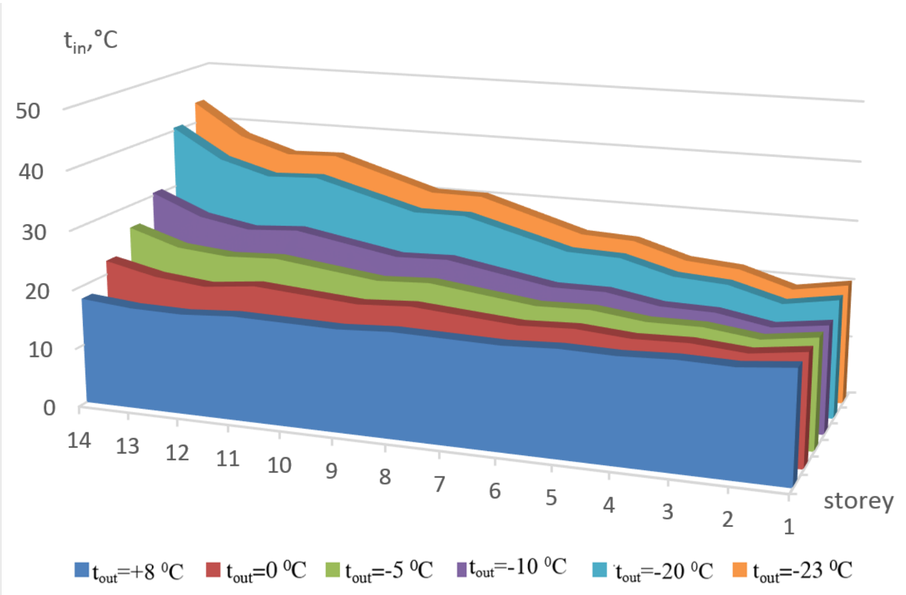

Figure 4. Diagram of expected indoor temperature ${}^{f}t_{in}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account changed number of radiator sections under condition of the 2nd *design* and assuming that Q_i=$Q_{i\ tw}$, W

Relying on obtained values ${}^{f}t_{in}$ (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 ${}^{f}t_{in}$=17 °C, while maximum indoor temperature ${}^{f}t_{in}$ is 44 °C.

IOP Conf. Series: Materials Science and Engineering **791** (2020) 012007 doi:10.1088/1757-899X/791/1/012007

According to the diagram of ${}^{f}t_{in}$, °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…-23 °C, in some rooms, excessive indoor temperature ${}^{f}t_{in}$ as compared with the comfort range is observed [15, 16].

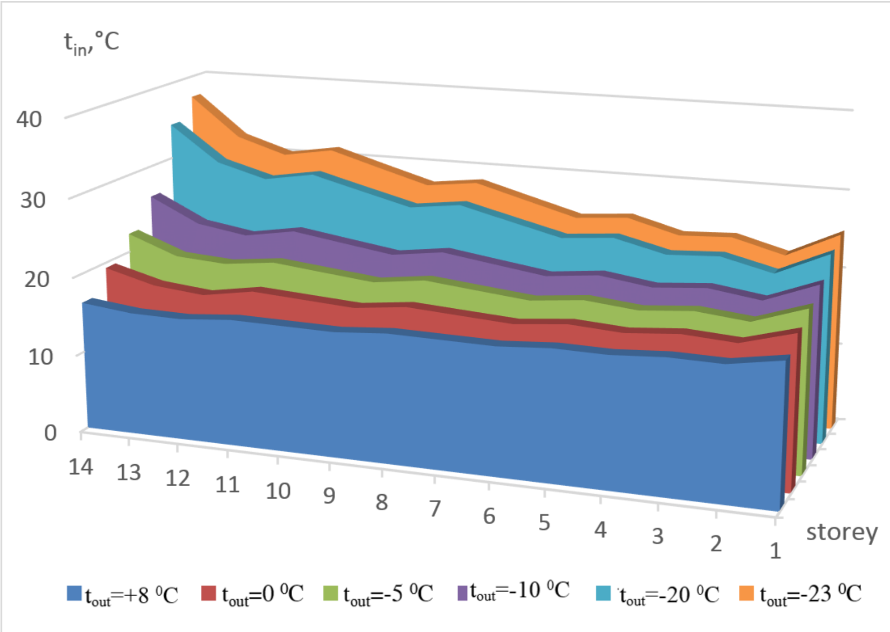

Figure 5. Diagram of expected indoor temperature ${}^{f}t_{in}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account increased heating agent consumption as per the 3rd design, and assuming Q_i=$Q_{i\ tw}$.

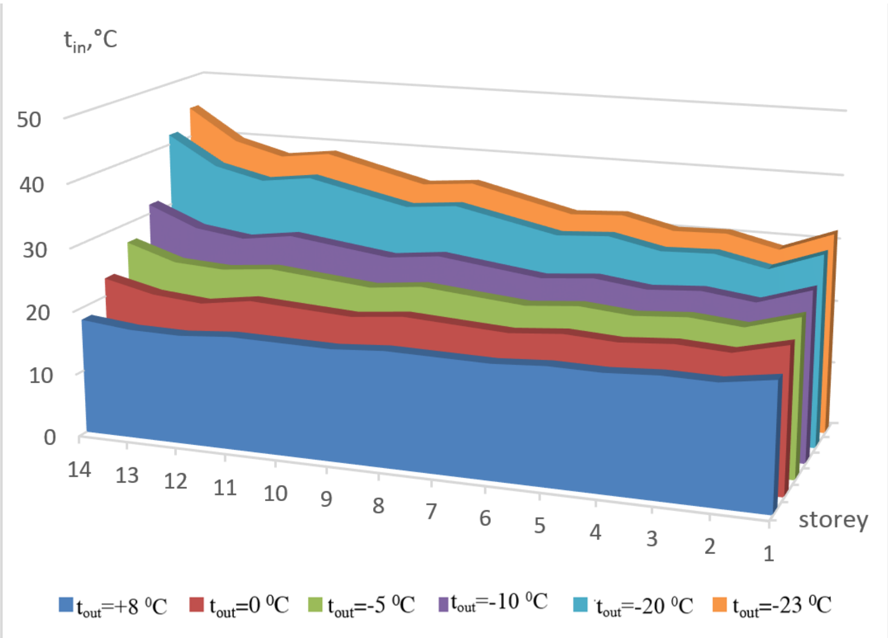

Figure 6. Diagram of expected indoor temperature ${}^{f}t_{in}$, °C design data in premises from the 1st to the 14th storey inclusive, taking into account increased heating agent consumption but without heating unit surface area increase, and assuming Q_i=$Q_{i\ tv}$.

IOP Conf. Series: Materials Science and Engineering **791** (2020) 012007 doi:10.1088/1757-899X/791/1/012007

Analyzing the diagram with obtained data of ${}^{f}t_{in}$ changes in rooms at t_{out} = -23; -20; -10; -5; 0; and +8 °C (Figure 6), let us put emphasis on too high value of ${}^{f}t_{in}$ when the value range of t_{out}= -10…-23 °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…-20 °C is reached. For this purpose we decrease the number of sections n_{sec} until the requirement of ${}^{f}t_{in}$=+18…-20°C is met; it is assumed that Q_i=$Q_{i\ tw}$.

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

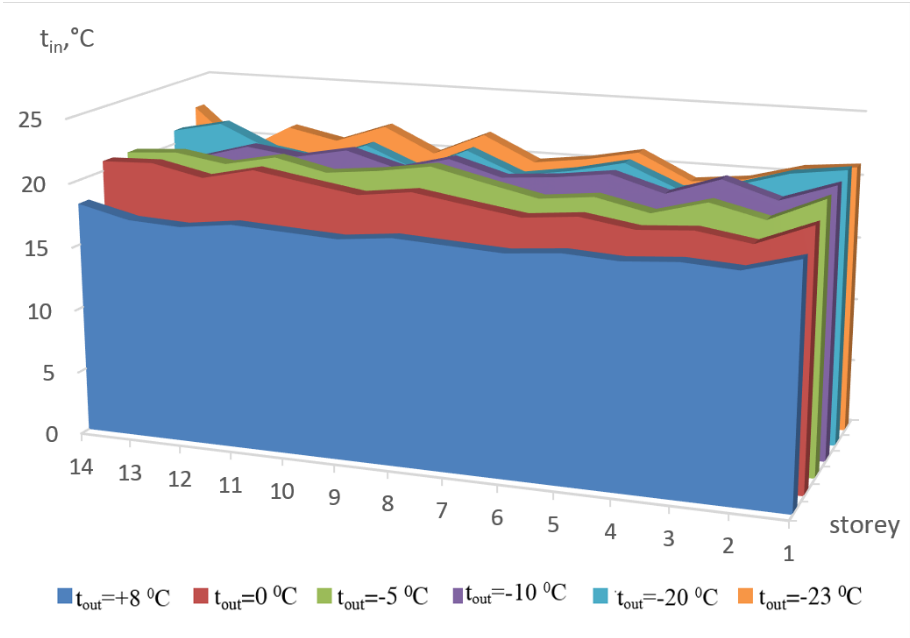

Figure 7. Diagram of actual air temperature values ${}^{f}t_{in}$ when radiator sections are shut off and Q_i=$Q_{i\ tw}$.

Shutting down individual sections facilitates reaching comfort values of ${}^{f}t_{in}$ [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 ${}^{f}t_{in}$ 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 ${}^{f}t_{in}$ 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 ${}^{f}t_{in}$ in various outdoor air temperatures with minimum impact on average radiator temperature head Δt_{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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References

[1] Zadvinskaya T O and Gorshkov A S 2014 Metodika povy`sheniya e`nergoe`ffektivnosti tipovogo mnogokvartirnogo doma putem vnedreniya sistem ucheta, avtomatizacii i regulirovaniya teplovoj e`nergii [Method of energy efficiency of residential house by implementing of automatic controlled heat metering system] *Stroitel`stvo unikal`ny`x zdanij i sooruzhenij* [*Construction of Unique Buildings and Structures*] **8(23)** 79-92 [In Russian]
[2] Ghiaus C 2013 Causality issue in the heat balance method for calculating the design heating and cooling load *Energy* **50** 292-301
[3] Sasin V I 2002 K voprosu o snizhenii raschetny`x parametrov teplonositelya v sistemax otopleniya [On the problem of reducing the design parameters of the coolant in heating systems] *Akvaterm* **1** 24-6 [In Russian]
[4] Vasilyeva E 2017 Formation of Conceptual Provisions for the Development of the Energy Efficient Housing Construction in Russia *IOP Conf. Ser.: Earth Environ. Sci* **90(1)** 012216
[5] Lauenburg P and Wollerstrand J 2014 Adaptive control of radiator systems for a lowest possible district heating return temperature *Energy and Buildings* **72** 132-40
[6] Lobayev B.N 1996 *Raschet sistem otopleniya* [Calculation of heating systems] (Kiev: Budivel'nik) [In Russian]
[7] Shchekin R V, Berezovskiy V A and Potapov V A *Raschet sistem tsentral'nogo otopleniya* [Calculation of central heating systems] (Kiev: Vishcha shkola) [In Russian]
[8] Yeremkin A I 2008 *Teplovoy rezhim zdaniy* [The thermal regime of buildings] (Rostov on Don: Feniks) [In Russian]
[9] Kubenin A S 2015 Metodika opredeleniya maksimal'nykh raskhodov teploty na nagrev infil'truyushchegosya vozdukha cherez okna zdaniya za ves' otopitel'nyy period [Methods determination of the maximum heat consumption for heating infiltrating air through the windows of the building full heating season] *Naukovedenie* **5(5)** [In Russian]
[10] Bogoslovskiy V N 1991 *Otopleniye* [Heating] (Moscow: Stroyizdat) [In Russian]
[11] Ahn B-C and Song J-Y 2010 Control characteristics and heating performance analysis of automatic thermostatic valves for radiant slab heating system in residential apartments *Energy* **35** 1615-24
[12] Seminenko A S and Elistratova Y V 2017 Analysis of thermal design of heating units with meteorological climate peculiarities *IOP Conf. Ser.: Mater. Sci. Eng.* **327** 042097
[13] Staroverov I G 1990 *Vnutrenniye sanitarno-tekhnicheskiye ustroystva v 3 ch. CH. I. Otopleniye* [Internal sanitary facilities at 3 p.m. I. Heating] ed I G Staroverova and Yu I Shillera (Moscow: Stroyizdat) [In Russian]
[14] Široký J, Oldewurtel F, Cigler J and Privara S 2011 Experimental analysis of model predictive control for an energy efficient building heating system *Applied Energy* **88** 3079-87
[15] Pérez-Lombard I, Ortiz J and J.F. and Coronel J F 2011 A review of HVAC systems requirements in building energy regulations *Energy Build*. **43(2–3)** 255-68
[16] Chutia D, Bhattacharyya D K and Sarma 2017 An effective ensemble classification framework using random forests and a correlation based feature selection technique *Trans. GIS* **21(6)** 1165-78
[17] Bychikhin S A, Svirin M V and Trubaev P A 2019 Evaluation of energy-saving effect during the installing process of automated heating stations in educational institutions *IOP Conf. Ser.: Mater. Sci. Eng.* **552** 012019