 https://doi.org/10.1051/e3sconf/202126304017

The influence of the climatic features of the construction area on the level of economical-efficient thermal protection of the office buildings

Anastasya Frolova*, and *Elena* Malyavina

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

Abstract. Now, the thermal protection of buildings is determined by the assessment of the heat consumption for heating and ventilation of buildings during the cold period, which should not exceed the energy consumption norms chosen by a volitional means. At the same time, the economic indicators of the operation of engineering systems serving the building are not taken into account, and energy costs for maintaining the thermal microclimate in the warm season are not considered. The economic assessment of the thermal protection of a building should take into account the year-round operating costs of maintaining a thermal microclimate in it and the capital costs of the systems themselves and their connection to power supply networks. These costs are in antiphase with the capital costs of building insulation, which increase with the strengthening of thermal protection. Since building insulation is a very expensive part of construction, it is important to determine its economically feasible level, taking into account the cost of all the listed costs in the conditions of the climate of the construction area and territorial economic indicators.

1 Introduction

The required level of thermal protection of various buildings affects the cost of their construction [1-3]. In addition, the energy consumption of the building for its heating and cooling depends on the level of thermal protection [4-8]. The capacity of engineering systems serving the building is also important [9-14]. All this makes construction an important factor in the country's economic development.

As a criterion for choosing an economically feasible level of thermal protection, a combination of the values of the specific thermal protection characteristics of the building and the aggregate [15, 16] discounted costs (TDC) for maintaining the specified temperature conditions in the building was previously proposed and justified.

* Corresponding author: FrolovaAA@mgsu.ru

2 Object of research

The problem was solved by calculation. To solve this problem, it is required to calculate the non-stationary thermal regime of each room.

Let us introduce the following assumptions into the description of the problem: the thermophysical characteristics of the materials of the layers in the problem under study do not depend on the moisture content and temperature of the material; heat transfer through the structure occurs due to thermal conductivity; the influence of the internal connections of fences, slopes of the window opening, joints, external corners, heat-conducting inclusions on the distortion of the temperature field of the fence is corrected by introducing equivalent thermal indicators, so that the temperature field of the structure can be considered one-dimensional; through the window, the heat transfer process, which is considered stationary due to the small thermal inertia of the window, occurs due to heat transfer, direct penetration of short-wave solar radiation through the translucent part of the window and infiltration through leaks in the windows; there is an ideal contact between the layers in each multilayer structure; the air temperature in the entire volume of the room at each moment of time is considered the same, as well as the temperature of each surface at each moment of time is described by one value.

In this study, rectangular buildings of various lengths are considered, but with the same building width, equal to 20.2 m in external measurements. The buildings have various lengths, ranging from 13.6 m to 115.6 m. Each building has windows only on the long sides of the building. The building options range from 1 to 40 floors. Windows are considered dense and infiltration is not included in these calculations. Calculations are carried out in two climatic regions of the Russian Federation: in Moscow and Astrakhan. The glazing percentage of the longitudinal walls is 55%. Some characteristics of the considered building options are presented in Table 1.

Table 1. Some characteristics of the considered building options

Building parameter	Building option					
	1	2	3	4	5	6
Length, m	13.6	20.4	61.2	88.4	115.6	115.6
Number of storeys	2	1	15	24	22	40
Building area, m^2	549	412	18 544	42 856	51 373	93 405
The area of external enclosing structures, m^2	802	729	10 760	22 116	25 638	44 705
Building volume, m^3	2 143	1 607	72 320	167 140	200 353	364 279

For rooms of the same size 6.8x10.1x3.9 (h) m, the thermal regimes and energy consumption for maintaining a given microclimate were calculated. There are four types of such premises in the building: ordinary of intermediate floors, ordinary of the top floor, corner on the intermediate floors, corner on the top floor.

The article deals with public buildings with a working day from 9 a.m. to 6 p.m., the specific heat input into the premises of which is selected at three levels: 0 W/m^2, 40 W/m^2 and 80 W/m^2. The ranges of heat input levels are selected on the basis of a full-scale experiment in an office building during the year [17]. During the day, the heat of solar radiation penetrating through the window was separately taken into account, and during working hours the internal heat inputs indicated above. When considering heat input from solar radiation, the coefficients of total solar energy transmission were taken into account with a two-chamber double-glazed unit 0.72, bindings 0.8 and sun protection devices at a level of 0.4.

In Moscow, the heating period on average lasts 205 days, that is, most of the year, in Astrakhan - 169 days [18], that is, slightly less than half a year. During the heating period, at an outside air temperature of +8 °C and below, the round-the-clock operation of the heating system was taken into account, maintaining the internal temperature at 20 °C. It was believed that the room cooling system worked only during working hours, maintaining 22 °C in the room. In this work, there is no cooling of the internal air during non-working hours.

When calculating the annual electricity consumption of a building, only the building's need for heat and cold is taken into account to maintain a given thermal regime. All additional heat losses due to the inefficiency of engineering systems were not taken into account. In this study, natural cooling is used at outdoor temperatures below +5 °C. The economic assessment takes into account the costs of thermal energy for heating and electricity for the operation of a vapor compression refrigeration machine Electricity consumption for cooling was determined by recalculation from the required cold consumption. At the same time, for free cooling, the average coefficient EER=6.95 was taken, for machine cooling - the average coefficient EER=3.31. The power plant efficiency was taken to be 0.3.

In this work, the economic assessment is carried out with three options for the thermal protection of the building. The heat transfer resistance data are set and differ only for external walls and building coatings. In option 1, the resistance to heat transfer is calculated from the sanitary and hygienic conditions according to the formula (5.4) SP 50.13330.2012 "Thermal protection of buildings". In option 2, heat transfer resistances were determined from the energy saving condition according to the formula (5.1) SP 50.13330.2012 using regional decreasing coefficients equal to 0.63 for external walls and 0.8 for coatings. In option 3, the resistances to heat transfer are calculated using the formula (5.1) SP 50.13330.2012 without the use of decreasing coefficients. The values of resistance to heat transfer, $m^2 \cdot °C/W$, for external enclosing structures corresponding to options 1, 2 and 3 are given in Table 2.

It is clear that with an increase in thermal protection (from option 1 to option 3), the heating load decreases. Previously, we found out [19] that the need for free and machine cold grows from option 1 to option 3 of insulation of enclosing structures because structures with high resistance to heat transfer more actively prevent heat outflow from the room. The need for free cooling in both cities with increased thermal protection increases due to the fact that during the period of the year when the outside temperature is below +5 ° C, the higher the level of thermal protection, the worse the outflow of heat into the external environment through the enclosing structure. The need for machine cold is formed during periods when the outside air temperature is above +5 ° C. During this second period, with an increase in thermal protection, the load on the machine cold falls. In Astrakhan, the period with high outdoor temperatures is long. Despite this, the influence of the period with a lower outside temperature on the formation of the load on the machine cooling prevails, therefore the total annual load on the machine cooling increases with the increase in thermal protection.

Table 2. Characteristics of fences in options for thermal protection of a building in Moscow and Astrakhan

Outdoor name building envelope	Heat transfer resistance (required/reduced), $m^2 \cdot °C/W$		
	Option 1	Option 2	Option 3
Moscow			
Outer wall	1.226/1.2236	1.619/1.621	2.57/2.576
Coating	1.379/1.371	2.74/2.7475	3.42/3.4226
Window	0.66	0.66	0.66
Astrakhan			
Outer wall	1.05/1.0567	1.40/1.4004	2.22/2.224
Coating	1.18/1.18	2.37/2.3709	2.96/2.967
Window	0.59	0.59	0.59

3 Calculation results

As we have already said, it is obvious that the heat input into the premises from internal sources and solar radiation increases the load on the air conditioning system during the warm and transitional periods of the year. And in the cold season, on the contrary, in some cases it reduces the load on the heating system.

In an economic assessment of the level of thermal protection of a building, it turned out to be productive to compare the total discounted costs (TDC) for a cut of 25 years. It is important to take into account all the factors affecting the formation of the TDC of the considered option of thermal protection [16, 21]. The option of thermal protection of a building, leading to the lowest value of TDC at equal costs of building insulation, heat and cold during the year for heating and cooling, systems for maintaining a given microclimate in the premises of the building, connecting them to power supply networks, was considered appropriate. Earlier it was shown that the generalization of various geometric characteristics of a building is convenient and legitimate to perform with the help of its specific heat-shielding characteristics, calculated in accordance with [22].

Since the specific heat-shielding characteristic k_{shsc} also depends on the resistance to heat transfer, which are different in Moscow and Astrakhan, then the values of k_{shsc} of buildings of the same geometry in different cities are different. The correspondence of the values of the specific heat-shielding characteristic k about buildings of different geometry and thermal protection is shown in Figures 1 and 2.

In the calculations, the costs of individual components that were in force in 2019 were taken:

- connection to power grids from 550 to 100 000 rubles/kW;
- connection to heating networks from 550 to 50,000 rubles/kW;
- the cost of the heating system is from 17 250 to 115 000 rubles/kW;
- the cost of heat energy in Moscow is from 2.2 to 4.5 rubles/kWh, in Astrakhan from 1.6 to 4.5 rubles/kWh;
- the cost of electricity in Moscow is from 4.0 to 6.5 rubles/kWh, in Astrakhan from 3.53 to 5.85 rubles/kWh;
- the cost of refrigeration equipment for artificial cooling from 46 000 to 92 000 rubles/kW;
- the cost of refrigeration equipment for free cooling from 1 725 to 8 050 rubles/kW;
- the cost of insulation is from 9 000 to 22 000 rubles/m^3.

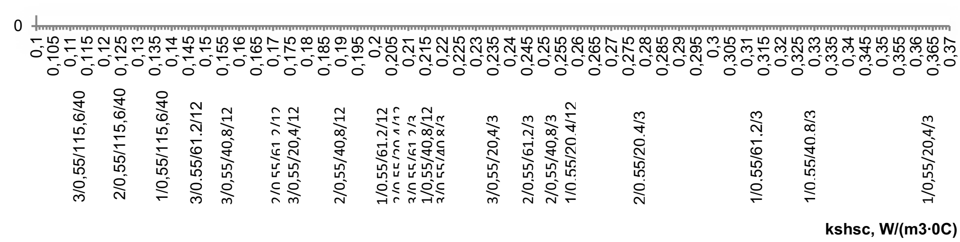

Fig. 1. Correspondence of the values of the total heat transfer coefficient in Moscow, k_{shsc}, W/(m^{3}·°C), to the variants of the buildings under consideration. Consistently specified: option of the building thermal protection, the portion of the façade glazing, the length of the building, m, the number of floors

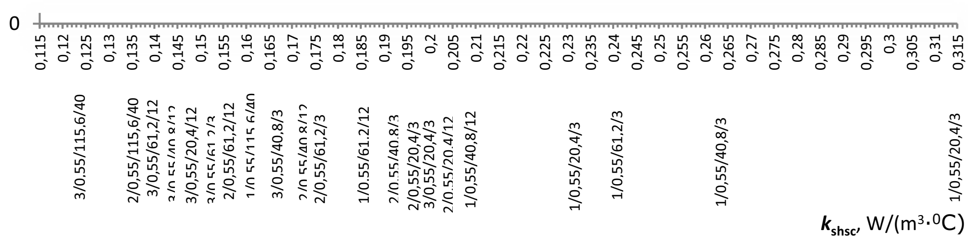

Fig. 2. Correspondence of the values of the total heat transfer coefficient in Astrakhan, k_{shsc}, W/(m^{3}·°C), to the variants of the buildings under consideration. Consistently specified: option of the building thermal protection, the portion of the façade glazing, the length of the building, m, the number of floors

At least 50% of the TDC value for Moscow and 70% for Astrakhan depends on the cost of machine and free cooling systems, as well as the connection to the power grid. Up to 20% of the TDC value for Moscow and 10% for Astrakhan depends on the cost of the heating system and connection to the heating network. Up to 30% of the SDZ value depends on depreciation charges. If we consider the option of the maximum cost of insulation (22,000 rubles/m^{3}) and the minimum cost for everything else, then the weakest thermal protection is beneficial. With a change in the cost of heating system equipment for 1 kW of power, option 2 becomes an advantageous option for thermal protection, calculated with reduced coefficients from the option for energy saving. A local increase in all other components does not lead to another variant of the profitability of thermal protection (that is, variant 1 remains profitable in terms of sanitary and hygienic requirements).

Based on the results of calculating the specific (per 1 m^{2} of floor space) total discounted costs, the zones of their combinations with the values of the specific heat-shielding characteristics of buildings for various levels of economically feasible insulation in the climatic conditions of Moscow and Astrakhan were determined. Some results of these calculations are shown in Figures 3 and 4.

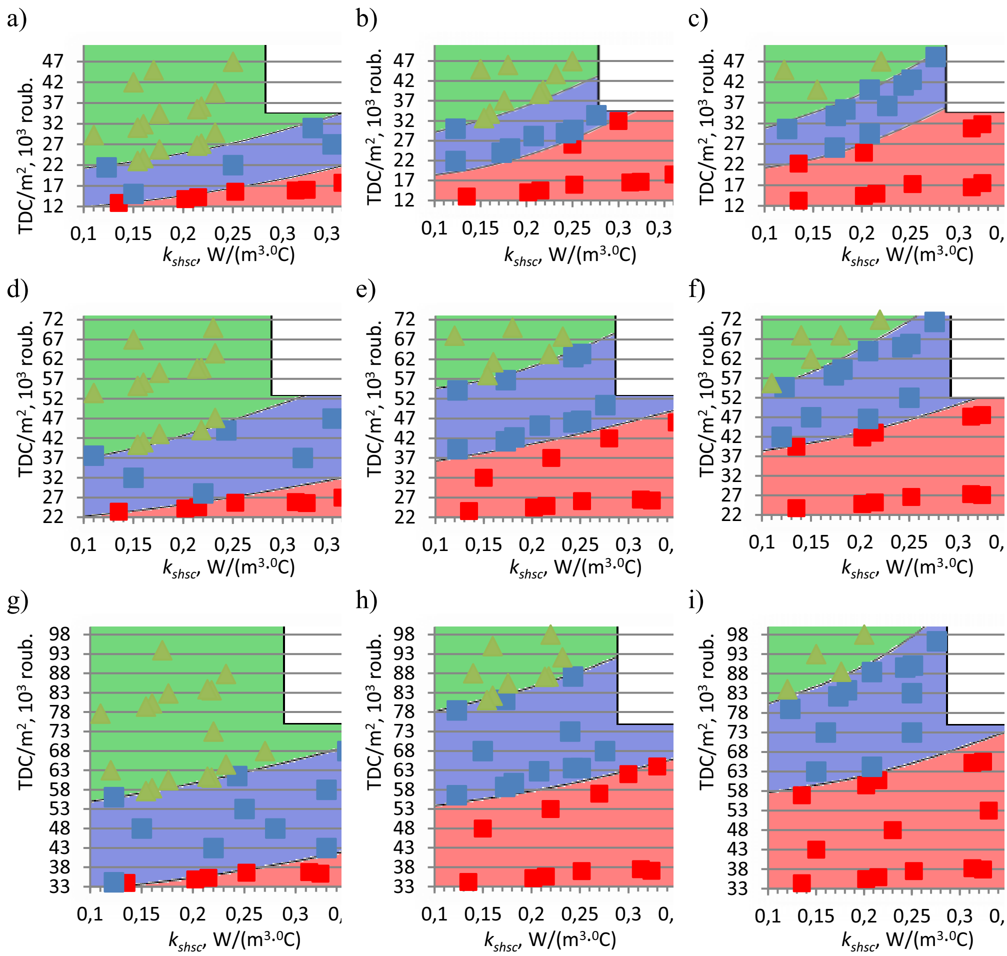

Fig. 3. Zones of economically viable options for thermal protection of buildings in Moscow (red zone - option 1, blue zone - option 2, green zone - option 3) when changing the specific thermal characteristics of the buildings k_{shsc}, W/(m³·°C), with the cost of insulation 9 000 rubles/m³ (a, d, g), with the cost of insulation 15 000 rubles/m³ (b, e, h), with the cost of insulation 22 000 rubles/m³ (c, f, i). With the internal heat inflows a, b, c – 0 W/m², d, e, f – 40 W/m², g, h, i – 80 W/m². At a discount rate of 10%.

It can be seen from the above figures that with the minimum cost of all components, the option with the least requirements for thermal protection is beneficial. With an increase in the cost of the components of the total discounted costs, reinforced insulation is less profitable. Moreover, in Astrakhan, the option of insulation according to the norms of table 3 SP 50.13330.2012 (option 3) is not advisable with the most expensive insulation in the absence of internal heat release, and with significant specific internal heat release of 80 W/m², such insulation is beneficial only with expensive energy resources and engineering systems and cheap insulation. In Moscow, the same trend can be traced, but since the main share of the year a cheaper heating system compared to the air conditioning system operates, consuming heat that is cheaper than electricity, the increased insulation of the building is advisable with expensive energy sources, and the zones of expedient combinations of k_{shsc} and TDC decreases with an increase in specific internal heat inputs and an increase in the cost of insulation. This fact can be easily explained by the fact that the lower the heat transfer resistance of the enclosing structure, the more excess heat outflow from the room to the outside, provided that the outside air temperature is lower than the indoor air temperature.

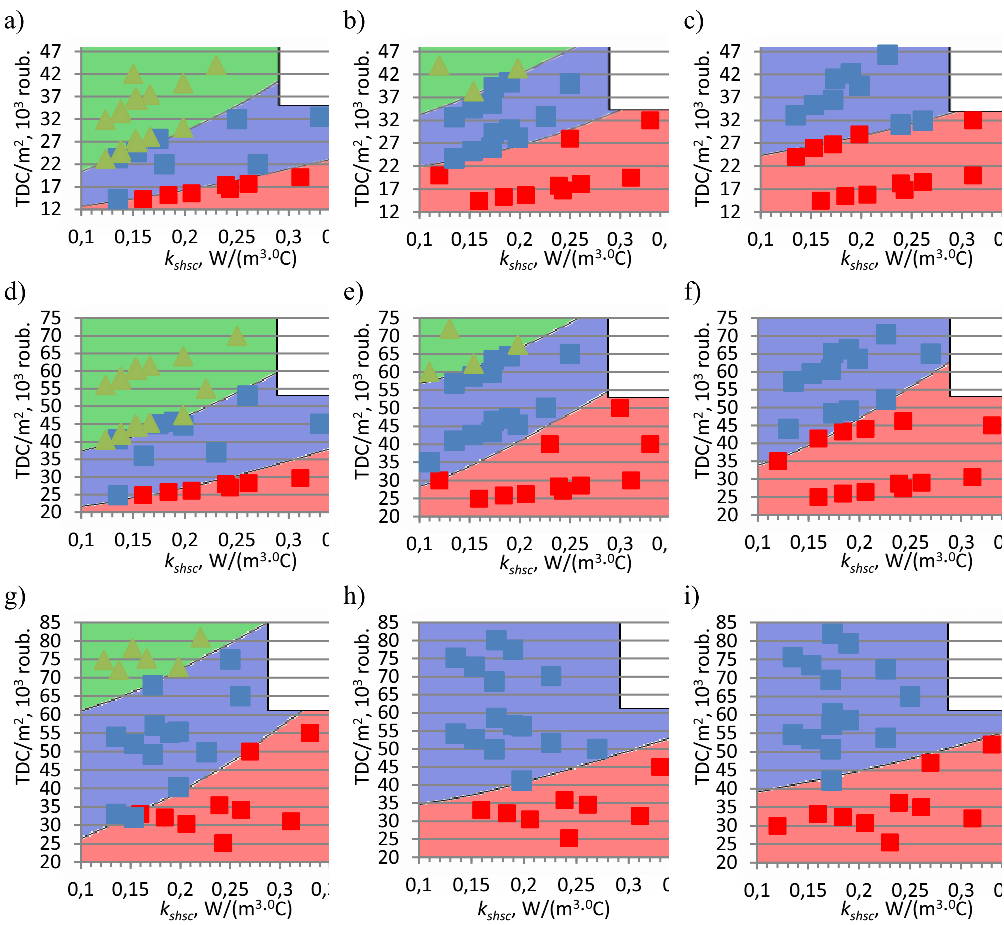

Fig. 4. Zones of economically viable options for thermal protection of buildings in Moscow (red zone - option 1, blue zone - option 2, green zone - option 3) when changing the specific thermal characteristics of the buildings k_{shsc}, W/(m^3·°C), with the cost of insulation 9 000 rubles/m^3 (a, d, g), with the cost of insulation 15 000 rubles/m^3 (b, e, h), with the cost of insulation 22 000 rubles/m^3 (c, f, i). With the internal heat inflows a, b, c – 0 W/m^2, d, e, f – 40 W/m^2, g, h, i – 80 W/m^2. At a discount rate of 10%.

Interestingly, with a decrease in the cost of insulation in both cities, the zone of appropriate insulation according to sanitary and hygienic standards decreases (option 1). In Moscow, this tendency manifests itself more clearly, since the strengthening of thermal protection here leads mainly to a reduction in the cost of cheaper heat for heating, and in Astrakhan, more expensive electricity for cooling. It is also interesting that in buildings of a small volume with high values of k_{shsc}, heat protection in terms of sanitary and hygienic conditions is advantageous with higher TDC/m^2 than in buildings of larger volume.

It is interesting to note that the area of the lowest level of thermal protection (option 1) for heat gains of 0 W/m^2 slightly differs in the value of TDC/m^2 for the two cities.

Since internal heat dissipation reduces the load on cheaper heating and increases the load on more expensive cooling in Astrakhan, the tendency with an increase in heat input to a decrease in thermal protection is more pronounced.

If only the cost of insulation and heat is taken into account in the total discounted costs, then the picture of economically feasible zones of resistance to heat transfer of the building will be completely different. Some results of such a calculation are shown in the work of the authors [16]. These results confirm that in order to correctly assess the feasibility of a certain level of thermal protection, it is necessary to take into account all the components of the costs of maintaining the microclimate in the premises of an office building year-round.

4 Conclusions

1. For the economic justification of the level of thermal protection of buildings in which the parameters of the internal environment are maintained year-round, it is necessary to consider energy consumption throughout the year. The level of thermal protection of a building affects the following economic costs: as capital costs - the cost of insulating a building, heating and cooling equipment, connecting systems to power supply networks, as operating costs - the cost of heat, electricity and depreciation.
2. The more expensive the heat protection, the higher the price of the components of the TDC/m^2, the option of heat protection for sanitary and hygienic conditions remains profitable. In both cities, the cheaper the building is insulated, the more profitable is the option of reinforced insulation. In buildings of a small volume, heat protection in terms of sanitary and hygienic conditions is advantageous with higher TDC/m^2 than in buildings of a larger volume.
3. In Moscow, for the main part of the year, cheaper heating is required, and in Astrakhan, more expensive cooling of the building. Therefore, in Moscow, at high values of TDC/m^2, insulation according to the basic version is beneficial at any cost of insulation. In Astrakhan, with high values of TDC/m^2, basic insulation is beneficial only with cheap insulation.

References

1. Tolstova U 2017 *J. Conference Paper: Energy saving and energy efficiency in industrial enterprises and in housing and communal services* 188–194
2. Hong T, Le Yang, Hill D and et al. 2014 *J. Applied Energy* **126** 90–106
3. António M. Raimundo, Nuno B. Saraiva and A. Virgílio M. Oliveira 2020 *J. Building and Environment* **182** 107107
4. Skorik T, Glazunova E and Bezugliy A 2017 *J. Conference Paper: Transport* 163–167
5. Orr H, Wang J, Fetsch D and Dumont R 2013 *J. Journal of Building Physics* 294-307
6. Wenjie Gang, Shengwei Wang, Kui Shan and Diance Gao 2015 *J. Energy and Buildings* **94** 1–9
7. Salameh T, Assad M E H, Tawalbeh M and et al. 2020 *J. Solar Energy* **199** 617–629
8. Niemann P, Schmitz G 2020 *J. Building and Environment* **182** 107027
9. Rezanov E, Petrov P *J. Conference Paper: Topical energy issues* 18–21
10. D'Orazio M, Perna C. Di, Giuseppe E. Di. and Morodo M 2013 *J. Journal of Building Physics* **36** 229-246
11. Vasilev G 2011 *J. Energy saving* **6** 14–23
12. Makarova O and Krasilnekova G 2016 *J. Conference Paper: Modern problems and prospects of socio-economic development of enterprises, industries, regions* 37–41
13. Usikov S 2018 *J. International Journal of Civil Engineering and Technology* **9(2)** 755–764
14. Klein K, Herkel S, Henning H-M and Felsmann C 2017 *J. Applied Energy* **203** 917–937

15. Malyavina E and Frolova A 2019 *J. E3S Web of Conferences* **97** 03022
16. Malyavina E and Frolova A 2018 *J. MATEC Web of Conferences* **196** 04078
17. Frolova A 2021 *J. IOP Conf. Ser.: Mater. Sci. Eng.* **1030** 012061
18. SP 131.13330.2012 Building climatology Sc. and research institute of the construction physics of RAASN, Moscow, 2018
19. Malyavina E and Frolova A 2017 *J. Ventilation, Heating, Air Conditioning, Heat Supply and Building Thermal Physics* **1** 18–23
20. Malyavina E and Frolova A 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1015** 012044
21. Lapteva S and Poliakova M 2017 *J. Economy and entrepreneurship* **10–1 (876–1)** 724–727
22. SP 50.13330.2012 Thermal protection of buildings Sc. and research institute of the construction physics of RAASN, Moscow, 2018