Energy-saving solutions in the construction and housing and utilities sectors of Russia

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Abstract. As an object of research, the direction of optimizing energy saving and increasing energy efficiency of multi-layer enclosing structures (in particular, external walls) of buildings (with insulation and ventilated facades) was adopted. The high relevance of the research is related to the achievement of rational use (to an optimal level) of material and energy resources (with the correct choice of properties and location of the insulation in the wall). The accepted research method is based on the application of thermal engineering calculation of the external fence and its temperature field, other elements of the building heating system with the establishment of dependencies between the values and comparing them with the standard performance indicators (using the Mathcad program). Specific results of the study include determining the temperature distribution in the thickness of the 5-layer outer wall with fixing the plane with zero temperature of the material, which shows the place of possible freezing in the structure.

1. Introduction

1.1. Object of research.
The object of the research is the direction related to ensuring and optimizing energy saving and improving the energy efficiency of buildings and structures by using multi-layer enclosing structures (in particular, external walls) with effective thermal insulation materials (in the form of insulation) and ventilated facades (with air gaps in the form of interlayers).

1.2. Relevance of the research.
The problems of energy efficiency and energy saving in Russia (including in the construction and utility sectors) are of high relevance, since they are related to the rational use (to an optimal level) of material and energy resources in all areas of the economy (production, household, social, and scientific and technical).
1.3. Review of information in literature sources.
Information can be related to the solution of the task, the normative documents [1-6] contain requirements for providing the necessary microclimate in the premises of residential and public buildings; for designing microclimate conditioning systems in buildings; for outdoor air parameters; for indicators and methods of calculating thermal protection in buildings.

[7-16] reflects the issues of calculation, modeling, and design of thermal insulation structures as part of external fences of buildings; selection of effective materials.

According to [13], the calculated actual heat transfer resistances of the outer wall for two insulation options have the following values: for the first (expanded polystyrene-0.15 (m); brickwork - 0.5 (m)) – \( R_{OF} = 3.315 \) ((m²·°C)/W); for the second (foam-0.1 (m); brickwork-0.5 (m)) - \( R_{OF} = 3.273 \) ((m²·°C)/W), which are more than the required heat transfer resistance according to sanitary standards \( R_{OF} = 3.087 \) ((m²·°C)/W).

The performed verification of the calculation results based on the data [13] led to different values of the reduced heat transfer resistances, respectively, to a different temperature distribution in the wall thickness and to incorrect recommendations for their design schemes.

In [8] it is proposed to evaluate the durability (service life) of external walls (with thermal insulation material as insulation inside) not by aging them from mechanical load, but by the criterion of loss of heat-protective qualities of the wall.

The results of calculation of the external wall structure (and analysis of influencing factors on its heat-protective qualities) given in [8,13] are used as initial data for evaluating the heat-protective properties of external walls made of various structural and heat-insulating layers (by type of materials).

In publications [17-21], new thermal insulation materials (cellular concrete, composite types, etc.) are considered, whose improved heat-conducting properties ensure their use for energy-efficient buildings, and in [22] the role of energy-active construction for energy conservation is noted.

[23-26] presents the results of research on the properties of thermal insulation materials based on household and agricultural waste, which provides savings of natural raw materials.

[27-31] shows the influence of heat power engineering, including construction, on environmental ecology.

1.4. The purpose of the research:
The purpose of the study is to substantiate the need to apply energy-saving solutions and measures in the design, construction and operation of buildings; in particular, to improve the thermal insulation properties of multilayer enclosing structures in the construction and operation of buildings.

1.5. Objectives of the study:
1. Assessment of the reliability of information provided in publications when using them as input data for further development of scientific research (in terms of the prospects of the topic).
2. Determining the nature of the temperature distribution in the thickness of the building structure, depending on the value of the reduced resistance to heat transfer, the parameters of external and internal air.
3. Assessment of factors that affect the deterioration of thermal properties of insulation (as part of the structure of the outer wall) and the cost of heating the building.
4. Obtaining a type of regression relationship between the heat load on heating and the heat transfer resistance of the fence.

2. Methods
The accepted method of research of thermal efficiency of an external fence and in General of a building includes its thermal engineering calculation (on elements-specifically in relation to an external wall). When calculating, determine (using known methods using the Mathcad program) the reduced or total resistance to heat transfer of the wall; the temperature distribution (temperature field)
in the thickness of the fence (for example, an external wall); the location of the plane (zone) of condensation of water vapor in the wall. According to the obtained values find the transmission heat loss (including infiltration and incremental losses or without them) and power systems (with a choice of heating equipment); establish the variation of the capacity of the heating system by reducing the resistance to heat transfer; perform a comparison of the calculated values characterizing the thermal regime of the building elements, with target and actual indicators of its design and operation; evaluate the thermal efficiency of the thermal insulation structure of the fence and the amount of energy saving of the building (in comparison with design, operational and information data).

3. Results and Discussion

To justify the optimal (or close to it) ratio between the heat transfer resistance of thermal insulation and the entire structure of the fence by comparing the levels of thermal protection of external fences of buildings, two building structures are considered below (with the specified and calculated thermal properties of materials):

1. Single-layer concrete slab (no insulation) thickness $\delta_1=0.3$ (m) and density $\rho_1=2300$ (kg/m$^3$) (when the coefficient of thermal conductivity $\lambda_1=1.51$ (W/(m·°C)), the coefficient of heat absorption $s_1=17$ (W/(m$^2$·°C)), thermal resistance $R_1=\delta_1/\lambda_1=0.3mm/1.51=0.1987$ ((m$^2$·°C)/W) and the coefficient of thermal inertia (massiveness) $D_1=R_1S_1=0.1987\cdot17=3.38$).

2. A double wall of reinforced concrete slabs (with options "first option") and a layer of insulation type "Izopoli" printed on the inner surface of the outer wall (after assembling the frame) with a thickness $\delta_2=0.04$ m, density $\rho_2=40$ (kg/m$^3$) (at $\lambda_2=0.0197$ (W/(m·°C)), $s_2=0.581$ (W/(m$^2$·K)), $R_2=0.04/0.0197=2.03$ ((m$^2$·K)/W), $D_2=2.03\cdot0.581=1.18$).

Obtained the following values of transmission heat losses in steady state due to heat transfer from inside air to the outside (excluding the extension and infiltration heat losses):

1) $Q_1=F\cdot(t-t)/R_o1 = 4180 \cdot (20+26)/0.3565 = 539.4$ (kW).

2) $Q_T2= 4180\cdot(20+26)/2,3865 = 80.6$ (kW).

According to calculations and experience of construction of buildings (in particular, administrative buildings) with thermal insulation (applied by spraying on the outer surfaces of the fence), a reduction in transmission heat losses was achieved by 1.85 times.

Regulatory information [4] the value of the coefficient characterizing the ratio of the thermal resistance of the multilayer insulation (homogeneous) walling to the total resistance to heat transfer is $put=0.85$; wherein said coefficient is the optimal thermal efficiency of the structure.

Fig.1 shows the design of a five-layer external wall (with an external ventilated facade), which is used for performing heat engineering calculations.

![Figure 1. The structure of the outer wall (in Russian)](image-url)
The thickness of the outer wall layers (from the outer surface to the inner) is (see Figure 1):

- \( \delta_i \): facing tiles – 5; aluminum substructure (not included in the calculation); air layer – 60; PENOLEX facade 35 (kg/m\(^3\)) – 60; masonry of ceramic bricks on a cement-sand solution – 510; cement-sand screed – 20 (mm).

The correct design of the thermal insulation system of the exterior wall and the heating system of the building (with a power reserve) ensures the saving (economy) of heat and energy resources, as well as financial resources for heating the building. If the heating reserve is insufficient (or exhausted), which is determined by a number of influencing factors, including the required heat transfer of heating devices \( Q_{PR} \) (W), the cost of supplying heat resources increases. This follows from results in [8] graphic dependence between the increase in required heat radiators \( \Delta Q_{PR} \) directly proportional to the increase in the cost of heating, and decrease the heat resistance of the wall \( \Delta R_o \) %.

For convenience, the estimated operating state of the exterior walls and heating system on the totality of design points [8], we have obtained analytical expression in the form of the exponent. Graphical (by calculation points) and analytical (by regression expression) dependencies are shown in Figure 2.

The reduced resistance to heat transfer of the estimated external wall, the design scheme of which is shown in figure 1 (according to our calculation) is:

\[ R_{opr} = 3.197 (m^2\cdot°C)/W \] (as opposed to [8], where \( R_{opr} = 3.2375 ((m^2\cdot°C)/W) \), which are greater than the standard (required) value (according to [1]):

\[ R_{o\,norm} = 3.067 ((m\cdot°C)/W) \) (for the conditions of Tambov).

![Figure 2](image)

**Figure 2.** The dependence of increasing heat transfer of heating devices in the building heating system on reducing the resistance to heat transfer of the wall structure: a – by calculation points; b – by exponential regression

In this case, the coefficient of insulation of external walls \( p_w = R_{opr}/R_{opr}=1.935/3.197=0.605 \), which is less than the recommended value of 0.85, that is, it is not optimal.

For the \( R_{OP} \) option = 3.197 (m\(^2\cdot°C)). The following temperature distribution was obtained in the wall layers (Fig. 3, a): \( t = 20; \) TVP = 18.27; TC = 17.88; TC = 6.94; \( t_a = -22.12; \) TNP = -27.36; \( t_c = -28 \) °C, which differ from the results in [8].

Figure 3 (a, b) shows a separate representation of dependencies and figure 3 (C) shows a joint representation on the coordinate plane. The horizontal line shows the temperature value of 0°C and divides the wall into two parts (with or without freezing).

To ensure the maintenance of the required comfort in the room, it is necessary to increase the heat load and power in the heating system (and its heating devices), some reserve of which can be laid in the power reserve when designing the heating system (10-15%). In addition, the use of accumulating properties of external walls is implemented.

When the heat transfer resistance of the outer wall is reduced by 50 %, for example, to the value of \( R_o=3.197/(1-0.5)=1.599 ((m^2\cdot°C)/W) \) you will need to increase the heat transfer of the heating system (its heating devices) by
\[ \Delta Q_{PR} = 2.64 \times 10^{-3} \times (\exp(0.13 \cdot 50) + 23.687) = 25.4\%, \] this will not only lead to a violation (deterioration) of the heat and humidity condition of the wall, but also to the misalignment of the heating system.

**Figure 3.** The temperature distribution over the material layers (after them) along the thickness of the outer walls from its inner surface to the outer at two values of the reduced heat transfer resistances \( a \)-3.19; 6-1.599 ((m\(^2\) · °C)/W)

To assess the degraded condition of the insulation is considered the temperature distribution in NS with reduced 2 times the value of heat transfer resistance \( R_o = 1.599 ((m^2 \cdot °C)/W) \), the results of which are shown in figure 3,b in comparison with the temperature distribution at the \( R_{o,PR} = 3.197 ((m^2 \cdot °C)/W) \) (Fig.3.a).

Given the temperature distribution in the thickness of the walls indicates the possibility of the destruction: a – in the 1st with a layer of insulation (less dangerous); b – in the 2nd embodiment, the layer of masonry (which is dangerous for the strength of the wall and deterioration of the microclimate in the premises).

Therefore, a decrease in the reduced resistance to heat transfer of the wall (due to aging or incorrect design and operational decisions in the choice of wall construction and insulation) can lead to an increase in the cost of heating (heating system) and deterioration of living conditions in apartments.

### 4. Conclusion

According to the results of scientific research, the following conclusions are made (based on the analysis of the studied publications and the performance of verification thermal engineering calculation of the 5-layer external wall structure):

1. A significant effect of reducing the resistance to heat transfer on the deterioration of the nature of the temperature distribution in the wall thickness (with the displacement of the water vapor condensation zone towards the inner surface of the wall) and on increasing the load on the heating system and, accordingly, on the deterioration of the microclimate of the room.
2. When the resistance to heat transfer decreases (for example, by 2 times), the vapor condensation zone (at zero temperature in the material layer) shifts to the side to the inner surface of the wall, exposing the brickwork to destruction.
3. Fitted nonlinear regression dependence (the exponent) increase the thermal load on the heating from reducing the thermal resistance of the fence (in connection with the deterioration of insulation); and in the range of the increments of thermal resistance 0-60 %, this dependence has a linear character.
4. The scientific and technical information provided in publications is sometimes contradictory, not justified, which makes it necessary to check them.
5. When choosing design and operational solutions in construction and housing and communal services for thermal insulation and heating systems, it is necessary to check their technical
characteristics with appropriate calculations using computer software (for example, the Mathcad program).

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