

Feasibility study of the insulation of the enclosing walls of high-rise buildings

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Abstract. On the example of a typical residential multi-apartment building, a feasibility study was carried out on the choice of energy-saving measures for the thermal insulation of facades. The decision to increase the energy efficiency of the building was made on the basis of calculating the loss of thermal energy through the external walls. Based on the parameters of the heating period, capital costs for additional thermal insulation of facades and calculated values of operating costs for heating, the optimum thickness of the additional layer of insulation is determined, in which the payback period assumes a minimum value.

1 Introduction

Reduction of energy costs is the most prospective area of resource saving in design and operation of buildings. Previous technical solutions to decrease the construction cost led to increase in cost of electricity [1].

In recent years, energy saving has become essential for new buildings and houses built several decades ago, when the issue of heat consumption was not considered.

Nowadays the state program about repair of old buildings is being implemented. It is necessary that it correlates with the energy saving program [2, 4-7]. At the same time, the economic component of investment projects should not be ignored. Energy-saving measures should reduce the amount of consumed energy and ought to be recoupable.

2 Methods

2.1 Thermotechnical calculations of enclosing structures

Let's make the analysis of choice of energy-saving measures for insulation of facades. The building is 9-storey building located in Saint-Petersburg. The total area of external enclosing structures is equalled to 5963.1 sq.m. The climatic conditions for residential buildings are presented in table 1.

Table 1. Climatic conditions for residential buildings located in Saint-Petersburg [3].

No.	Indicator	Parameter label	Standard unit	Calculated value
1	Calculated indoor temperature	t_{int}	°C	20
2	Calculated outdoor temperature	t_{ext}	°C	-26
3	Duration of the heating period	Z_{ht}	days	220

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4	Heating season degree-day	D_d	$^{\circ}\text{C}\cdot\text{days}$	49
5	Average outdoor temperature during the heating period	t_{ht}	$^{\circ}\text{C}$	-1.8

The outer walls are multilayer and are made of concrete, brick, plaster and lime-sand mortar.

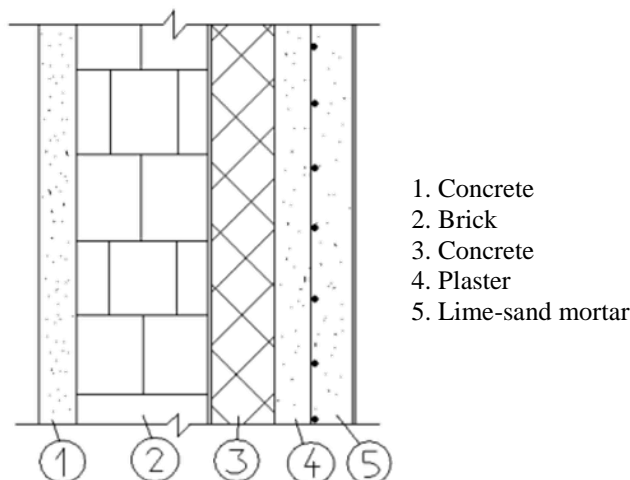


Figure 1. The structure of outer wall in residential apartment building

Thermotechnical characteristics of materials of outer wall are shown in table 2.

Table 2. Thermotechnical characteristics of materials of outer wall.

No.	Material	Thickness of layer (δ), m	Density (ρ), kg/m^3	Heat conductivity (λ), $\text{W}/(\text{m}\cdot^{\circ}\text{C})$
1	Concrete	0.02	2300	1.2
2	Brick	0.51	2100	0.72
3	Concrete	0.08	2300	1.2
4	Plaster	0.01	1800	0.93
5	Lime-sand mortar	0.01	1500	0.78

Thermal resistance of the wall (1):

$$R_0 = (R_{int} + R_{ext} + \sum R_i) = \frac{1}{23} + \frac{1}{8.7} + \left(\frac{0.02}{1.2} + \frac{0.51}{0.72} + \frac{0.08}{1.2} + \frac{0.01}{0.93} + \frac{0.01}{0.78} \right) = 0.97 \frac{\text{m}^2 \cdot ^{\circ}\text{C}}{\text{W}} \quad (1)$$

Thermotechnical calculation showed that thermal resistance of wall $R_0 = 0.97 \text{ m}^2 \cdot ^{\circ}\text{C}/\text{W}$ is lower than the required value $R_{req} = 3.08 \text{ m}^2 \cdot ^{\circ}\text{C}/\text{W}$.

Due to identified discrepancy, it is necessary to insulate outer walls of construction object. Minimal value of allowable thermal resistance of the thermal insulation material:

$$R_{ins}^{req} = R_{req} - (R_{int} + R_{ext} + \sum R_i) = 3.08 - 0.97 = 2.11 \frac{\text{m}^2 \cdot ^{\circ}\text{C}}{\text{W}} \quad (2)$$

Nowadays there are many options for insulation. We will determine the required thickness of wall with ISOVER Warm walls insulation to provide the required thermal resistance of wall:

$$\delta_{ins}^{req} = \lambda_{ins} * R_{ins}^{req} = 0.036 * 2.11 = 76 \text{ mm} \quad (3)$$

Insulation ISOVER Warm walls is available in the form of plates with a thickness of 50 and 100 mm. Let's consider that the thickness of the insulation will be equal to 100 mm:

$$R_0^{ins} = (R_{int} + R_{ext} + \sum R_i) = \frac{1}{23} + \frac{1}{8.7} + \left(\frac{0.02}{1.2} + \frac{0.51}{0.72} + \frac{0.08}{1.2} + \frac{0.01}{0.93} + \frac{0.01}{0.78} \right) + \frac{0.1}{0.036} \quad (4)$$

$$= 3.75 \frac{m^2 * ^\circ C}{W}$$

According to the result, $R_0 = 3.75 \text{ m}^2 * ^\circ C / W > R_{req0} = 3.08 \text{ m}^2 * ^\circ C / W$, the thickness of insulation is chosen right. The same calculations for other well-known insulations are given in table 3.

Table 3. Technical assessment of insulation [8-13].

Insulation	Heat conductivity (λ_{ins}), $\frac{W}{m^2 * ^\circ C}$	Required thickness of insulation (δ_{ins}^{req}) [†] , m	Cost of 1 sq.m. insulation (C_{ins}), RUB	Thermal resistance of insulated wall (R_0^{ins}), $\frac{m^2 * ^\circ C}{W}$
ISOVER Warm walls	0.036	0.076 (0.1)	141	3.75
ISOVER Warm house	0.038	0.080 (0.1)	135	3.60
PAROC Extra Smart	0.036	0.076 (0.1)	222	3.75
ROCKWOOL Rockfacade	0.037	0.078 (0.1)	590	3.67
URSA Terra	0.036	0.076 (0.1)	127	3.75
KNAUF Therm Wall PRO	0.042	0.089 (0.1)	274	3.35
KNAUF Therm Facade PRO	0.038	0.080 (0.1)	370	3.60

Insulation URSA Terra as the most low-cost insulation material which provides the biggest value of thermal resistance is chosen for insulation of facades (table 3).

3 Results and Discussion

3.1 Return on investment in insulation of facades

The equation (5) is used to calculate the discounted payback period of investments aimed at additional insulation of facades [14].

$$T_D = \frac{\ln \left(1 + \frac{\Delta K}{\Delta E} * \frac{r - i}{1 + i} \right)}{\ln \left(\frac{1 + r}{1 + i} \right)} \quad (5)$$

where T_D – discounted payback period of investments in years;

[†] The required thickness of insulation is written in brackets.

ΔK – the difference between the capital costs for the construction of insulated and basic variants of the exterior walls (facades) of the building, RUB;

ΔE – the difference between the loss of thermal energy through the outer walling before and after insulation, RUB;

r – average increase of electricity pricing in %;

i - discount rate in %.

The optimal option for additional insulation of facades will be considered the one for which the payback period will be minimal, i.e. the condition [15, 17-19]:

$$T = f(\delta_{ins}) \rightarrow \min \quad (6)$$

Capital costs for additional insulation of the outer wall is equaled to 1 637 RUB / sq.m.:

127 RUB / sq.m. - cost of insulation URSA Terra 100 mm [16],

110 RUB / sq.m. – cost of fasteners;

280 RUB / sq.m.- cost of dry building mixtures;

1120 RUB / sq.m. – cost of full cycle of construction works.

We will accept that building company took out a loan for 13.7% for 3 years ($m = 36$) for additional insulation. In this case, the annuity coefficient will be 0.034:

$$A = \frac{p_{loan} * (1 + p_{loan})^m}{(1 + p_{loan})^m - 1} = \frac{0.011 * (1 + 0.011)^{36}}{(1 + 0.011)^{36} - 1} = 0.034 \quad (7)$$

where m – duration of credit payment in months;

p_{loan} – monthly discount rate.

$$p_{loan} = \frac{0.137}{12} = 0.011 \quad (8)$$

Thus summed investments will be equaled to 2 003.70 RUB per sq.m.:

$$\Delta K = 36 * 0.034 * 1637 = 2003.70 \text{ RUB/sq. m.} \quad (9)$$

The annual saving, which is achieved because of works on renovation of facades of the existing building, is defined by the formula:

$$\Delta E = (V_1 - V_2) * \frac{0.024 * D_d}{1163} * c_T \quad (10)$$

Heat conductivity of outer walls without additional insulation:

$$V_1 = \frac{1}{R_0^1} = \frac{1}{0.97} = 1.03 \frac{W}{m^2 * ^\circ C} \quad (11)$$

The required thermal resistance for the exterior walls of residential buildings due to the climatic conditions of Saint-Petersburg is equal to $R_{req} = 3.08 \text{ m}^2 * ^\circ C / W$, which corresponds to the heat conductivity V_2 :

$$V_2 = \frac{1}{R_0^{req}} = \frac{1}{3.08} = 0.325 \frac{W}{m^2 * ^\circ C} \quad (12)$$

Considering the fact, that electricity cost c_T is equaled to 1 678.72 RUB/Gcal, the value of decrease of operation costs for the first heating period including results of energy-saving measures is 117.13 RUB / m².

$$\Delta E = (V_1 - V_2) * \frac{0.024 * D_d}{1163} * c_T = (1.03 - 0.325) * \frac{0.024 * 4796}{1163} * 1678.72 = 117.13 \text{ RUB/sq. m.} \quad (13)$$

Electricity pricing has been increasing at 11.3 % per year for last 10 years (table 4). Thus, the average annual growth of pricing is equaled to 0.113 [20, 21].

Table 4. Dynamics of growth of electricity pricing in Saint-Petersburg for last 10 years.

Year	Electricity pricing, RUB / Gcal	Difference between electricity pricing in last and actual years
2008	650.00	-
2009	795.73	+22.4%
2010	931.00	+17.0%
2011	1 050.00	+12.8%
2013	1 175.00	+11.9%
2014	1 351.25	+15.0%
2015	1 408.01	+4.2%
2016	1 541.78	+9.5%
2017	1 621.95	+5.2%
2018	1 678.72	+3.5%

Discount rate of future cash flows is equaled to 7.5% [22].

Thus, the payback period of investment in the insulation of facades of the existing building will be equaled to 13.6 years:

$$T_D = \frac{\ln\left(1 + \frac{\Delta K}{\Delta E} * \frac{r - i}{1 + i}\right)}{\ln\left(\frac{1 + r}{1 + i}\right)} = \frac{\ln\left(1 + \frac{2003.7}{117.13} * \frac{0.113 - 0.075}{1 + 0.075}\right)}{\ln\left(\frac{1 + 0.113}{1 + 0.075}\right)} = 13.6 \text{ years} \quad (14)$$

4 Conclusion

Energy-saving measures should be recoupable. Unfortunately, the problem of optimization of long-term investments in energy-saving measures in the construction and operation of buildings is rarely considered, especially using parametric models.

In this article, the decision to improve the energy efficiency of residential building was made based on the calculation of heat losses through the outer walls. The optimal insulation thickness is determined due to the parameters of the heating period, capital costs for additional insulation and calculated operating costs and allowed to minimize the payback period.

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