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Using Life-Cycle Analysis to Assess Energy Savings Delivered by Building Insulation

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Abstract

The present paper contains calculations of energy savings delivered through the use of mineral wool insulation throughout the life cycle. The calculation of energy savings in the production of the insulation material is based on ISO 14025 Principles and Procedure of Environmental Labels and Declarations. The calculation of energy savings in the process of building operation is based on comparing the heat energy losses through the external walls of a model Moscow apartment building before and after façade insulation. The insulation material used is 100-mm ISOVER's staple glass wool with synthetic binding agents. The insulation system type is hinged ventilated facade. The calculations yield a decrease in heat leakage through II-18/12 buildings' external walls over heating period, achieved through façade insulation. Based on the calculated decrease in transmission loss, we were able to evaluate the energy savings potentially achieved over the life cycle of the insulation. The energy used to produce a unit of insulation material was compared to the amount of energy saved throughout the life cycle.

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Keywords: Energy efficiency, energy saving, efficiency indices, external enclosure structures, external envelopes, insulation coating, building energy saving, heat conductivity, investment, payback period, LCA, EPD, ISO 14025/

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1. Introduction

The majority of the residential buildings operated on the territory of the Russian Federation don't conform to the modern standard requirements of thermal insulation of external envelopes, which increased considerably since 2000, Construction Rules and Regulations II-3-79* were modified by Amendment No.3, and later replaced with Construction Rules and Regulations 23-02-2003. Essentially, this means that all buildings pre-dating 2000 don't meet the modern requirements to the level of thermal insulation, are obsolete and need reconstruction (heat insulation of facades and roof; replacement of external entrance doors and translucent external envelopes with more effective ones).

This paper provides a calculation of heat losses through external walls of the II-18/12A series residential buildings, before and after heat insulation of their facades by ISOVER. Is also provides an assessment of energy savings achieved through the use of a unit of insulation material throughout the lifecycle of the building, by comparing the amount of energy used for the production of the insulation material to the energy saved by its use throughout the building's lifecycle.

Many researchers have studied heat losses from reconstruction of buildings, and energy-saving measures [1-24].

2. Object of research

The calculation of the energy used to produce the mineral wool insulation in question was based on ISO 14025 and an Environmental Product Declaration developed in compliance with this standard. An environmental product declaration reports environmental data of products based on life cycle assessment. One of the quantitative indicators used in the paper is the energy consumption for the production and transportation of the material to the construction site.

The II-18/12 series panel residential building was chosen as the object of research. (This series was constructed in 1964-1969).

In Moscow, 12-storey panel buildings (1-section II-18-01/12 MIB and 2-section II-18-02/12 MIB) exist in almost all the areas developed in the 1960s and the early 1970s, namely: Beskudnikovo, Degunino, Koptevo, Khovrino, Zelenograd (districts 3, 4, 7, and 8), Northern Tushino, Shchukino, Knoroshevo-Mnevniki, Kuntsevo, Aminyevo, Solntsevo, Obruhevsky, Zuzino, Nagorny, Tsaritsino, Nagatino, Nizhegorodskaya st., Kapotnya, Tekstilshchiki, Kuzminki, Perovo, Izmailovo, Golyanovo, Bogorodskoye, Metrogorodok, Medvedkovo, Babushkin, etc. In the central part of Moscow II-18/12 series panel houses were built in the Basmanny District, Rogozhskaya Zastava, and Tishinka. Several buildings of this series also exist in a number of other central districts.

In the Moscow Region, II-18 12-storey panel houses are relatively rare (mostly concentrated in the town of Vidnoye). Outside the greater Moscow area, they were built in Tver and the Tver Region, the Vladimir Region, and in Tatarstan (Kazan and Naberezhniye Chelny).

These are pre-engineered panel houses, all of which were designed as towers, i.e. structures with a single entrance, and host efficiency-, one-bedroom- and two-bedroom- apartments.

Some of the one-bedrooms in II-18/12 houses have communicating rooms, while others have separate room design.

According to the design, these building represent 12-storey single-entrance panel houses with a utility level (Fig. 1). It is equipped with two passenger elevators with a loading capacity of 400 kg. The ceiling height in the habitable areas is 2.5 m. The external walls are made of large-format 400-mm claydit panels.

During Luzhkov's term as the mayor of Moscow II-18-01/12 MIB and II-18-02/12 MIB buildings were considered for the second phase of demolition plan (2014–2025), but currently they are on the list of buildings scheduled for the first phase of capital repair (rehabilitation).

Fig. 1. II-18/12 series buildings

This series' model floor plan is shown in Figure 2.
Living area: 3,640.8 m2, room area: 2,317.2 m2.
External wall area (excl. windows): 3,006 m2.

Fig. 2. Model floor plan of II-18/12 series residential buildings

3. Study objective

This paper aims to demonstrate the net life-cycle energy savings delivered by the insulation product used for the reconstruction of residential buildings.

The authors calculated the heat loss through external walls of II-18/12A residential houses before and after façade insulation with an ISOVER synthetic-binder staple glass wool product manufactured by Saint-Gobain Construction Products Rus LLC. Assuming that the external wall insulation material is ISOVER VentFacade Mono (100 mm), let us consider the façade insulation impact on the heat loss for this type of building.

4. "Initial data for calculation

Thermal characteristics of external walls before heat insulation of facades

During the construction of II-18/12 series the external envelopes design standard was II-A.7-62. According to the requirements, the heat transfer resistance of external walls must be no less than R_0^{req}, determined by the following formula:

$$R_0^{req} = \frac{(t_{\text{int}} - t_{ext}) \cdot n \cdot b}{\alpha_{\text{int}} \cdot \Delta t_{ext}} \tag{1}$$

where

t_{int} is the temperature of internal air (equal to 18ºC according to SNIP - Russian Building Code).

t_{ext} is the temperature of external air (equal to -26ºC under Construction Rules and Regulations II-A.6-62 for massive external envelopes);

n is the ratio depending on the position of the external envelope in relation to external air; for external walls assumed equal to 1;

b is the thermal insulation performance coefficient equal to 1. for walls without insulation;

α_{int} is the heat absorption coefficient, assumed equal to 7.5 W/(m·ºC) for external walls of residential buildings; and

Δt_{ext} is the normalized difference between the temperature of internal air and the temperature of an internal surface of the envelope, for external walls of residential buildings assumed equal to 6ºC.

Proceeding from the presented data, we will calculate the required resistance to heat transfer of the external walls for buildings constructed in the 1960s with the following formula:

$$R_0^{req(initial)} = \frac{(t_{\text{int}} - t_{ext}) \cdot n \cdot b}{\alpha_{\text{int}} \cdot \Delta t_{ext}} = \frac{(18-(-26)) \cdot 1 \cdot 1}{7.5} = 0.98 \ (\frac{m^2 \cdot {}^0C}{W}) \tag{1}$$

The calculated value will be used as the reference value $R_0^{initial}$, indicating the resistance to heat transfer of the II-18/12-series buildings' external walls.

To describe the thermal characteristics of external walls after facade renovation, we will assume the double-skin facade as our design solution for heat insulation of external walls of the existing II-18/12 series buildings. The thermal characteristics of the insulator are presented in Table 1.

Table 1. Thermal characteristics of VentFacade Mono

Characteristic	Value
Heat conductivity, W / (m·K), λ10, max	0.034
Heat conductivity, W / (m·K), λ25, max	0.036
Heat conductivity, W / (m·K), λD, max	0.038
Heat conductivity, W / (m·K), λM, max	0.040

The thickness of the thermal insulation layer (δ_{ins}) is taken at 100 mm. Considering additional heat insulation of facades, external walls' resistance to heat transfer will be:

$$R_0^{new} = R_0^{initial} + \frac{\delta_{ins}}{\lambda_{ins}} = 0.98 + \frac{0.1}{0.040} = 3.48\ (\frac{m^2 \cdot {}^0C}{W}) \quad (2)$$

Where R_0^{inital} is the initial resistance of external walls to heat transfer in existing II-18/12 residential buildings before renovation, m2·ºC/W;

δ_{ins} is the thermal insulation layer thickness; for the purpose of our calculation taken at 100 mm;

λ_{ins} is the heat conductivity of a thermal insulation layer for conditions of "M"; it is taken at 0.040 W/(m·ºC) according to the data of Table 1.

These calculations don't account for the influence of the heat transfer resistance of the external surface of a wall, because it's negligible compared to the thermal resistance of a layer of the insulating material.

The thermal uniformity coefficient, r_{fas}, for the considered hinged ventilated facade system was taken at 0.68., which gives us an adjusted external walls' resistance to heat transfer after insulation:

$$R_{fas}^{new} = R_o^{new} \cdot r_{fas} = 3.48 \cdot 0.68 = 2.37\ (\frac{m^2 \cdot {}^0C}{W}) \quad (3)$$

5. Calculation methodology

To calculate heat loss through the external envelopes of buildings it is convenient to use the reciprocal of resistance to heat transfer, which in international standards is called the U-value (coefficient of heat transfer of the external envelopes of buildings). The formula for its calculation is:

$$U = {}^1\!/_{R_0} \quad (4)$$

For example, the resistance to heat transfer of 1.0 m2·ºC/W corresponds to the heat transfer coefficient

$$U = {}^1\!/_{R_0} = {}^1\!/_{1.0} = 1.0\ ({}^W\!/_{m^2 \cdot {}^0C})$$

This coefficient shows what amount of heat (W) passes through 1 sq. m of external wall if the difference of internal and external temperatures at the two sides of the external envelope equals 1 ºC. It means that for 1 sq. m of external wall with a 1 ºC difference of internal and external temperatures at the two sides of the external envelope the thermal stream density is 1 W, while with a temperature density it will be 20 W, etc. To calculate the quantity of thermal energy (kW·w) passing through 1 sq.m of external wall, this value (U) must be multiplied by the number of hours in a heating period and an average temperature difference for the heating period. These data for each climatic area are defined in Construction Rules and Regulations 23-01. These data for Moscow are presented in Table 2. The above considerations can be expressed by the following formula [9]:

$$Q_{kW\cdot w} = \frac{U \cdot (t_{\text{int}} - t_{av}) \cdot z_{heat} \cdot 24}{1000} \tag{5}$$

where

t_{int} is the temperature of internal air, in accordance with GOST 30494 taken at 20 ºC;

t_{av} is the heating period-average temperature of external air; under Construction Rules and Regulations 23-01 for Moscow taken at -3.1 ºC (see also Table 2);

z_{heat} is the number of days of the heating period, for residential buildings in Moscow taken at 214 days (Table 2);

24 is the number of hours in a day;

1,000 is the coefficient used to adjust thermal stream density from Watts to kWatts.

Table 2. Climatic conditions for residential buildings in Moscow used in calculations.

Indicator	Designation of parameter	Unit	Expected value
Heating period-average temperature of external air	t_{av}	°C	- 3.1
Heating period duration	z_{heat}	days/year	214
Heating season degree-days	HSDD	°C·days/year	4943
Expected temperature of internal air	t_{int}	°C	20

Thus, using formula (5) we can calculate average loss of thermal energy through 1 sq.m for the heating period, expressed in kW·h. The same value can be expressed in gigacalories (Gcal) if we divide (5) by 1,163, since 1 Gkal=1,162.(7) kW·h. Since the cost of thermal energy for consumers (heat tariff) is expressed in rub/Gkal, thermal energy calculations were performed in the same units. l. Then formula (5) can be written down as:

$$Q_{\text{Gcal}} = \frac{U \cdot (t_{\text{int}} - t_{av}) \cdot z_{heat} \cdot 24}{1000 \cdot 1163} \tag{6}$$

We use the same designations as in formula (5), and 1,163 is the coefficient used to translate kW·h to Gcal.

In electric-heated buildings it is more convenient to use formula (5); for buildings centrally serviced by a combined heat and power plant it is expedient to use formula (6).

Note that $(t_{int} - t_{av})\cdot z_{heat}$ in formulas (5) and (6) of Construction Rules and Regulations 23-02 designates a heating season degree-day (HSDD). For the residential buildings in Moscow HSDD is equal to 4,943°C·days/year (Table 2). Thus, formulas (5) and (6) can be brought to a following form

$$Q_{kW\cdot w} = \frac{U \cdot HSDD \cdot 24}{1000} = 0.024 \cdot U \cdot HSDD \tag{7}$$

$$Q_{\text{Gcal}} = \frac{U \cdot HSDD \cdot 24}{1000 \cdot 1163} = \frac{0.024 \cdot U \cdot HSDD}{1163} \tag{8}$$

If we know the area of the external envelopes, for example external walls, the total heat losses through it for a heating period can be calculated in the following manner:

$$Q_{kW\cdot w} == 0.024 \cdot U \cdot HSDD \cdot A_{ee} \tag{9}$$

$$Q_{\text{Gcal}} = \frac{0.024 \cdot U \cdot HSDD \cdot A_{ee}}{1163} \tag{10}$$

where A_{ee} is the area of external envelope, sq.m.

6. Example of calculation

We will consider the model of panel buildings of the II-18/12 series built in Moscow in the 1960s (see Figure 1).

According to the input data, the expected value of resistance to heat transfer for external walls ($R_0^{initial}$) conforms to the standard requirements that existed during construction and is 0.98 m2·ºC/W. The coefficient of heat transfer of external walls is $U_{fas}^{initial}$ =1.02 W/(m2·ºC).

After the renovation of facades with heat insulation using double skin facades R_{fas}^{new} = 2.37 m2·ºC/W. The coefficient of heat transfer of external walls after renovation will be: U_{fas}^{new} =0,42 W/(m2·ºC).

For the residential buildings in Moscow HSDD is equal to 4,943 (Table 2).

Formula (9) allows to calculate losses of thermal energy (kW·h) through any type of an external envelope. Then heat losses through external walls before renovation will be:

$$Q_{initial} = 0.024 \cdot U_{fas}^{initial} \cdot HSDD \cdot A_{fas} = 0.024 \cdot 1.02 \cdot 4{,}943 \cdot 3606 = 436{,}343 \; (\frac{\text{kW·h}}{\text{year}}) \qquad (11)$$

and after renovation (fig. 3):

$$Q_{new} = 0.024 \cdot U_{fas}^{new} \cdot HSDD \cdot A_{fas} = 0.024 \cdot 0.42 \cdot 4{,}943 \cdot 3{,}606 = 436{,}343 \; (\frac{\text{kW} \cdot \text{h}}{\text{year}}) \qquad (12)$$

The difference of heat use before and after the renovation of facades can be calculated using the following formula:

$$\Delta Q = Q_{new} - Q_{initial} = 0.024 \cdot (U_{fas}^{initial} - U_{fas}^{new}) \cdot HSDD \cdot A_{fas} \qquad (13)$$

Since we have all the necessary data, we can put them in formula (13) and get:

$$\Delta Q = Q_{new} - Q_{initial} = 0.024 \cdot (U_{fas}^{initial} - U_{fas}^{new}) \cdot HSDD \cdot A_{fas} =$$

$$0.024 \cdot (1.02 - 0.42) \cdot 4{,}943 \cdot 3{,}606 = 256{,}672 \; (\frac{\text{kW} \cdot \text{h}}{\text{year}})$$

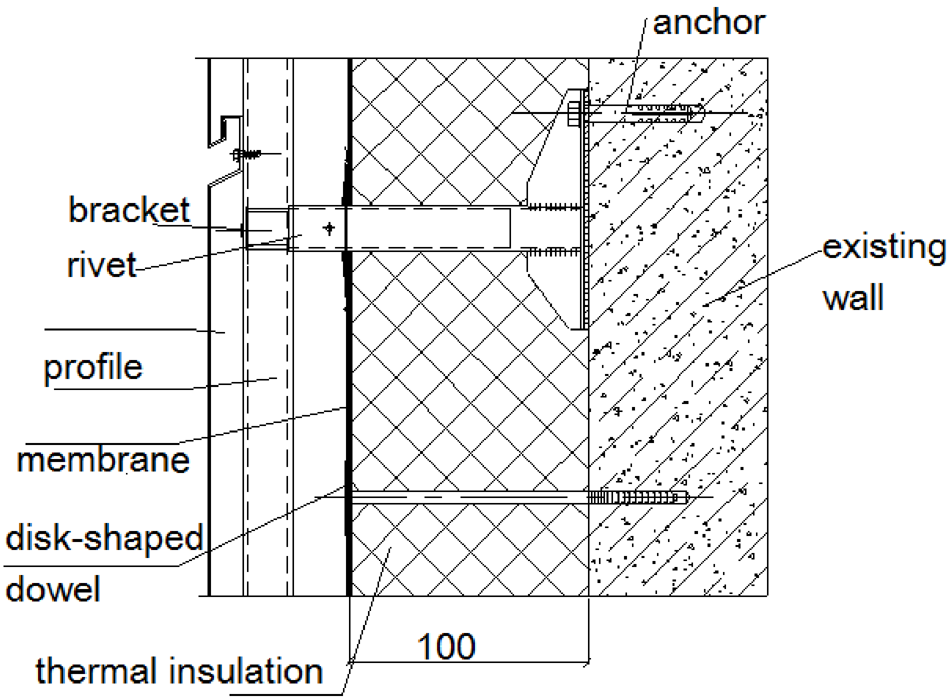

Fig. 3. Design of an External Wall of a II-18/12 Residential Building after Façade Renovation.

The calculations above only apply if a residential building has an automated thermal point with automated temperature control.

Fig. 4. II-18/12 Series Building after Facade Insulation

7. Energy Savings Throughout Life Cycle

The method of insulation described above allows cutting net energy consumption by 221,097 kWh per year. The primary energy coefficient for central heating in Moscow is 1.1. Therefore, net primary energy consumption is decreased by 243,207 kWh per year.

During the assumed 50-year life cycle of the building after rehabilitation, the net primary energy savings would equal 243,207 kWh/year*50 years*3.6 = 43,777,206 MJ.

To calculate net life-cycle energy savings in this paper, the authors used Environmental Product Declarations published by ISOVER in Russia (link: isover.ru web site, Section: EPD http://www.isover.ru/index.php?pid=126)

According to ISOVER's EPDs, 1 sq. m. of 100-mm VentFacade Mono is requires 214.59 MJ of energy. The area of a building's insulated surface is 3,006 sq. m., which means net energy savings per 1 sq. m. is:

First- 43,777,206 / 3,006 .= 14563 (MJ / sq. m). The savings during life-cycle per 1 sq/meter of insulation material. so you kow your energy savings per 1 sq.m.

14563 / 214.59 = 67.87

Therefore, throughout its life cycle a unit of mineral wool insulation saves 67.87 times more energy than the amount used for its manufacturing.

8. Summary

Throughout the life cycle, one unit of 100 mm ISOVER VentFacade Mono mineral wool insulation saves 67.87 times more energy than the energy spent in the production, transportation and installation of the unit.

The calculation of annual heat loss reduction for external walls of existing buildings through facade insulation (Figure 4) were made fort he Moscow (Russia) climate and II-18/12-series houses.

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