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INVESTIGATION OF THE DETERMINATION OF THE COST-OPTIMAL THICKNESS OF THE THERMAL INSULATION LAYER OF THE WALLS OF A MODERNIZED PUBLIC BUILDING

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Abstract. The aim of the work is to conduct an investigation of the determination of the cost-optimal thickness of the thermal insulation layer of the walls of a modernized public building. The tasks of the research are as follows: to create a research model by using a typical detail of a modernized Lithuanian public building; to perform calculations of the heat transfer coefficient of the walls of a public building; to determine the optimal thickness of the wall thermal insulation layer when using the energy of district heating networks; to analyze which energy efficiency class of a building and what thermal insulation thickness is rational for a modernized public building. Research methods: the analysis of technical and scientific literature, and empirical modeling. In this article, the author carried out a research on the typical wall detail of a public building, based on the principles of energy and economic efficiency. The empirical research has shown that the cost-optimal thermal insulation layer corresponds to an energy efficiency class ‘A+‘ building and the optimal insulation thickness is from 180 to 240 mm (EPS70N). Taking into account the Lithuanian construction technical regulation No. STR 2.01.02:2016, the energy efficiency classes ‘C‘ (120 mm) and ‘A++‘ (270 mm) are not the cost-optimal solutions.

Keywords: thermal insulation; walls; cost-optimal methodology; modernized public building.

INTRODUCTION

Significant energy savings may be achieved in the building sector when the optimal insulation thickness is designed for the buildings or the buildings are modernized effectively. In this field, buildings account for about 36% of CO_2 emissions and represent about 40% of energy consumption in the European Union (Cova et al., 2021). Therefore, this sector has a large potential for energy savings (Aviža et al., 2015).

The European Union is committed to developing a sustainable, competitive, secure and decarbonised energy system by 2050 (Dermentzis et al. 2021).

According to the requirements of the European directive 2010/31/EU, the European Union Member States will have to ensure that all new buildings will have to be nearly zero-energy buildings from 31 December 2020 (Pernetti et al., 2021). From 2050, the European Union Member States will have to ensure that the long-term renovation strategies will deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, according to the requirements of European directive 2018/844.

It has also been found that according to the requirements of European directive 2010/31/ES the cost-optimal framework methodology is based on the net present value (global costs) methodology (Fabbri et al. 2013).

Lithuania aims to improve the energy performance of buildings, as well. This requirement is enshrined in the Technical Building Regulation of the Republic of Lithuania ‘Design and Certification of Energy Performance of Buildings’ (STR 2.01.02:2016; Fig. 1).

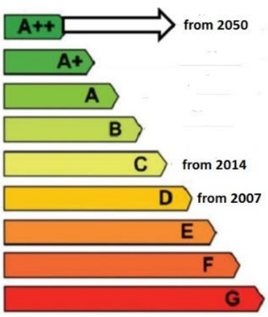

Figure 1. **Min. Requirements for Modernized Buildings (STR 2.01.02:2016)**

In order to achieve desired goals, i.e., to ensure a smooth transition from minimum energy performance requirements (efficiency class ‘C’) to the requirements for nearly zero-energy buildings

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(NZEB) of ‘A++’ class, it is important to assess an influence of cost-effectiveness on the final decision making.

In the scientific literature only new net-zero energy buildings (Chen She et al., 2021; Acar et al. 2021; Amani et al. 2020; Wu et al. 2021 and others) are analyzed. Therefore, there is a lack of information on the evaluation of cost-optimal solutions for modernized public buildings. This study will further investigate a typical wall unit of modernized public buildings, modifying only the insulation thicknesses. After performing the empirical analysis, the most effective and cost-optimal insulation thickness option of the wall will be identified.

The aim of this research is: to conduct an investigation of the determination of the cost-optimal thickness of the thermal insulation layer of the walls of a modernized public building.

The objectives of the research are as follows:

1. to create a research model by using a typical wall detail of a modernized Lithuanian public building;
2. to perform the calculations of the heat transfer coefficient of the walls of a public building and to determine the optimal thickness of the wall thermal insulation layer when using the energy of district heating networks;
3. to analyze which energy efficiency class of a building and what thermal insulation thickness is rational for modernized public building.

Research methods: the analysis of technical and scientific literature, and empirical modeling.

THE RESEARCH MODEL

A research model has been created for determining the optimal thickness of the wall thermal insulation layer for modernized public building (Fig. 2). The solutions of the designed model include the following:

1. For the purpose of calculations, the typical detail of the wall of a Lithuanian public building was selected (Table 1).

Table 1

The layers of the external wall

No.	Wall layer	Thickness, mm
1-2	Old Wall Structure (U=1,48 W/(m^2·K))	-
3	Expanded polystyrene (EPS70N) foam, λ_D= 0,032 W/(m·K)	0-1000
4	Anchor with plastic nail	-
5	Adhesive mortar coated with masonry sealer	5
6	Reinforcing mesh	
7	Decorative coat	

2. The thermal resistance of the external surface of the wall is R_{se} = 0.04 m^2×K/W and the thermal resistance of the internal surface is R_{si} = 0.13 m^2×K/W.
3. The expanded polystyrene (EPS70N) foam was used as insulation, in accordance with the requirements specified in the document No. ST 2124555837.01:2021 – Insulation of buildings with EPS (Fig. 2). The declared value of the heat conductivity coefficient is λ_D = 0.032 W/(m·K). The design value of the accepted heat conductivity coefficient is 0.034 W/(m·K) (according to the document No. STR2.01.02:2016).

Figure 2. **External Wall – (for the layers see Table 1) – Test Layer No. 3; Source: ST 2124555837.01:2021**

4. The following economic indicators were adopted in this study (Table 2).

Table 2

Primary data - Economic indicators

No.	Parameter	Value
1	Expanded polystyrene (EPS70N) foam price (01-10-2021), €/m³ Source: *www.kainos.lt*	75,87
2	Energy price (01-10-2021) for district heating, €/kWh Source: National energy regulatory council; *www.regula.lt*	5,62
3	Yearly energy price increase rate, % Source: *EU Reference Scenario 2016*	3,00
4	Nominal Discount rate, % Source: *EU energy outlook to 2050*	4,00
5	Calculation period, year Source: *EU Regulation Nr. 244/2012*	30,00

The research calculations were performed using the same wall model as well as the solutions for the design of the buildings. The thickness of the wall thermal insulation layer was changed only.

THE RESEARCH METHODOLOGY

As for this study, general data and formulas for the calculations of the external wall partitions were taken from the document 'Design and Certification of Energy Performance of Buildings' (2016) No. STR2.01.02:2016.

The total heat transfer coefficient U (W/(m^2×K)) of the external wall can be calculated as follows:

$$R_t = R_{si} + R_{s1} + R_{se}; \quad (1)$$

$$U = \frac{1}{R_t} = \frac{1}{R_{si} + R_{s1} + R_{se}}, \quad (2)$$

where: R_{si} – the thermal resistance of the internal surface of the wall (m^2·K/W); R_{se} – the thermal resistance of the external surface of the wall (m^2·K/W); R_{s1} – the sum of the thermal resistance of wall layers (m^2·K/W); R_t – the total thermal resistance of external wall construction (m^2·K/W).

The thermal resistance of the thermal insulation layers of the wall are calculated as follows:

$$R = \frac{d}{\lambda_{ds}}, \quad (3)$$

where: d – the thickness of the layer (m); λ_{ds} – the design value of the thermal conductivity coefficient of expanded polystyrene (W/(m·K)).

The main verification condition is the heat transfer coefficient of the external wall partition that must satisfy normative requirements:

$$U_w \leq U_{N.w}, \quad (3)$$

where: U_w – the design value of the heat transfer coefficient of the wall partition W/(m^2·K) that directly depends on the investigated object, i.e. thermo-insulation (EPS70N) thickness (see Fig. 2); $U_{N.w}$ – the normative heat transfer coefficient of the wall W/(m^2·K) depending on energy efficiency class (see Table 3).

According to the Regulations (Commission Delegated Regulation document (EU) No 244/2012), the global cost (in 30 years period) must be calculated according to EN15459 as:

$$C_g(\tau) = C_I + \sum_J \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \cdot R_d(i)) - V_{f,\tau}(j) \right], \quad (4)$$

where: τ - means the calculation period; $C_g(\tau)$ - global costs referring to the starting year $\tau 0$; C_I - initial investment costs; $C_{a,i}(j)$ - annual costs year i for energy-related component j (energy costs, operational costs, periodic or replacement costs, maintenance costs); $R_d(i)$ - discount rate for year i (depending on interest rate); $V_{f,\tau}(j)$ - final value of component j at the end of the calculation period (referred to the starting year $\tau 0$).

The cost-optimum calculations are based on a net present value calculation. Cost optimal range: ± 15 % (Fig. 3).

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Table 3

Normative value of the thermal transmittance coefficient of walls in public buildings $U_{N.w}$, W/(m²·K), STR 2.01.02:2016

No.	Energy performance class	$U_{N.w}$, W/(m²·K)
1	D	0,31
2	C	0,25
3	B	0,22
4	A	0,18
5	A+	0,15
6	A++	0,12

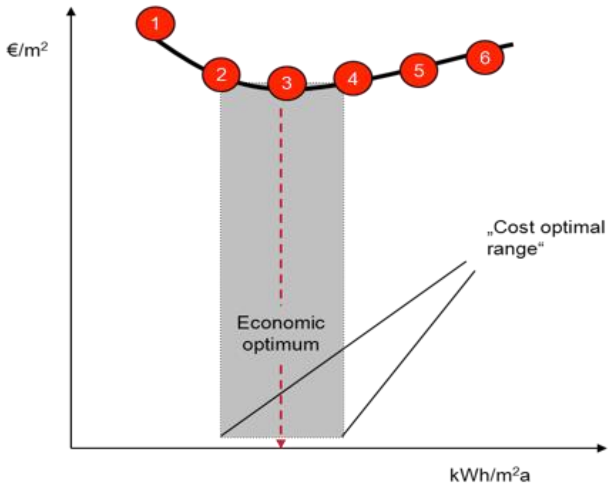

Figure 3. **Different variants on the cost-optimal curve and position of the cost-optimal range (BPIE, 2013)**

Using the cost-optimal methodology, research calculations were performed and optimal values were determined.

THE RESEARCH RESULTS

The required thickness of the thermo-insulation layer (EPS70N) of the sample of a typical public building wall was calculated according to the methodology of the normative requirements for the energy efficiency classes of buildings. The final thickness of the wall was calculated using the approximation method of checking the condition of Eqn (3).

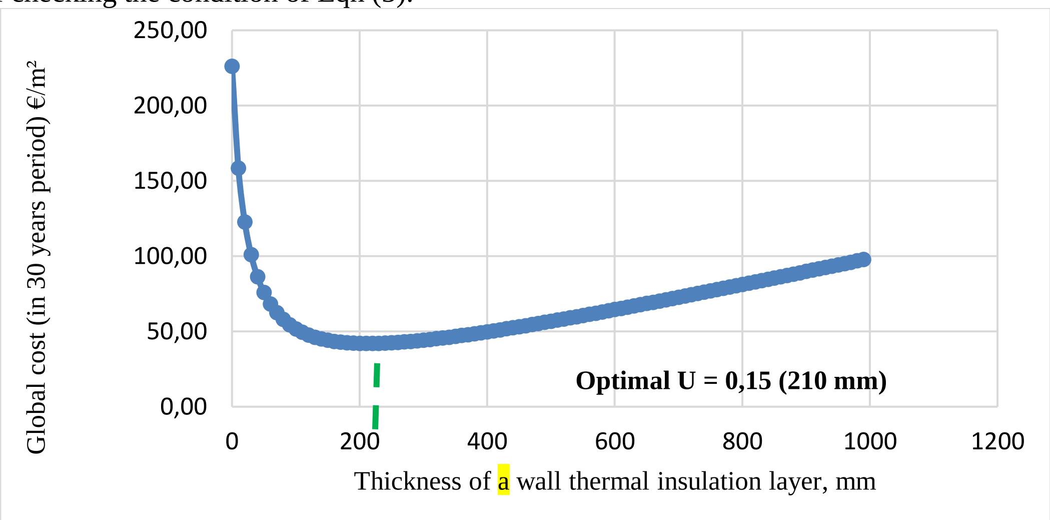

Figure 4. **The optimal heat transfer coefficient of the walls of a public building**

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The optimal heat transfer coefficient of a typical public building wall was calculated according to the global cost (in 30 years period) methodology and Eqn (4). The investigation showed that the optimal *U* value of a modernized public building wall (for district heating system) is equal to 0.15 W/(m^2·K), and the optimal thickness of the thermo-insulation layer (EPS70N) is 210 mm (Fig. 4).

The empirical study showed that the cost-optimal thermal insulation layer for a modernized Lithuanian public building corresponds to building energy efficiency class ‘A+‘. The optimal insulation thickness is from 180 to 240 mm (EPS70N), when the cost optimal range is ±15 % (Fig. 5).

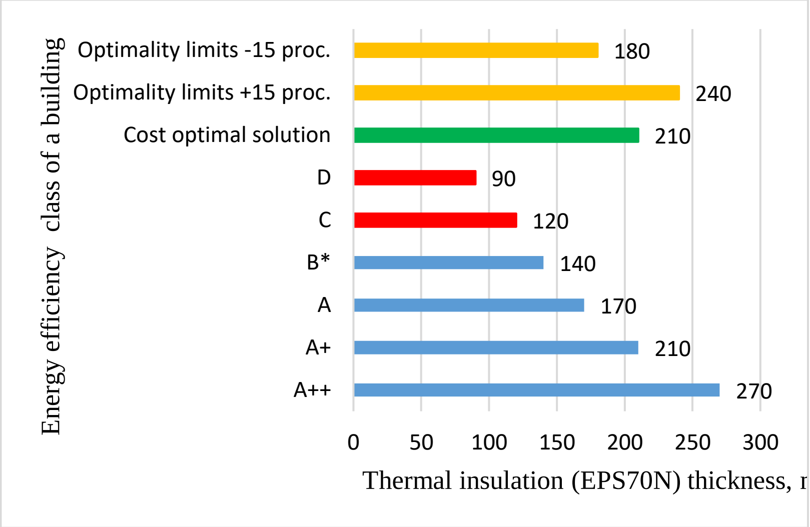

Figure 5. **Cost-optimal thermal insulation (EPS70N) thickness for the district heating**

Taking into account the Lithuanian construction technical regulation No. STR2.01.02:2016, the energy efficiency classes ‘C‘(120 mm) and ‘A++‘ (270 mm) are not the cost-optimal solutions.

CONCLUSIONS

1. The cost-optimal thermal insulation layer in the walls of modernized Lithuanian public buildings corresponds to building energy efficiency class ‘A+‘. The optimal heat transfer coefficient is U=0.15 W/(m^2·K).
2. The cost-optimal insulation thickness for the district heating is from 180 to 240 mm (EPS70N), when the cost optimal range is ±15 %.
3. Taking into account the Lithuanian construction technical regulation No. 2.01.02:2016, the energy efficiency classes ‘C‘(120 mm) and ‘A++‘ (270 mm) are not the cost-optimal solutions.

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