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THE ASSESSMENT OF THE EFFECTIVENESS OF THE THERMAL INSULATION LAYER OF THE FLAT ROOF OF A CLASS A++ INDUSTRIAL BUILDING ACCORDING TO THE MOORA METHOD

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Abstract. The paper presents a multi-objective optimization solution on the basis of ratio analysis and the assessment of the effectiveness of the thermal insulation layer of the flat roof of a class A++ industrial building. The MOORA method was selected for the evaluation of the effectiveness of the middle layer of the thermal insulation material. Five different thermal insulation materials (*Paroc ROS 30*; *EPS100; EPS80N; XPS300; FF-PIR ALK*) were assessed according to 4 objectives: the thickness of the thermal insulation layer; the density; the thermal conductivity coefficient; and the price (the third quarter of 2022) of insulation material. Findings of the performed analytical study suggest that the graphite polystyrene foam *EPS80N* is the most effective thermal insulation material for the flat roof of the nearly zero-energy industrial building. This material scored the highest number of the relative efficiency points (-0.318). The least effective alternative (from the five tested materials) is the rock wool - *Paroc ROS 30* (-0.618 points). The difference between the best and worst alternatives is 51.46 percent.

Keywords: thermal insulation; flat roof; nearly zero-energy industrial building; MOORA method

INTRODUCTION

According to the requirements of the European directive 2018/844, 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. In Lithuania, nearly zero-energy building meet the requirements of A++ Class buildings (STR 2.01.02:2016).

From 2030 all new buildings will have to be zero-emission buildings. A zero-emission building is defined as a building that has a very high energy performance and requires very low amount of energy, which can be fully covered by energy from renewable sources and without carbon dioxide emissions from fossil fuels ('Fit for 55' EU Parliament, 2022).

In the scientific literature, there are a lot of different scientific analyses about the net-zero energy buildings (Hu, 2022; Aviža 2021; Zhao et al. 2022 and others) and the net-zero emission buildings (Moschetti et al., 2022; Liu et al. 2023 and others). However there is a lack of information on the assessment of the effectiveness of the thermal insulation material solutions for the industrial buildings. This study will further investigate a typical flat roof of an A++ Class industrial building. After performing the empirical analysis, the most effective insulation material alternative option of the flat roof will be identified.

The goal of this research is: to perform the assessment of the effectiveness of the thermal insulation layer of the flat roof in an A++ Class industrial building according to the MOORA method.

The objectives of the research are:

1. To analyze the MOORA method for multi-objective assessment.
2. To create a research model by using a typical flat roof detail on corrugated steel supporting structure of an A++ Class industrial building.
3. To perform a multi-objective assessment study of the effectiveness of five different thermal insulation materials.

Research methods: the analysis of technical and scientific sources, empirical modeling, MOORA method.

THE MOORA METHOD

The MOORA method, first introduced by W. Brauers (2004) is such a multi-objective optimization technique that can be successfully applied to solve various types of complex decision making problems in the manufacturing environment. Other researchers (Karuppanna et al., 2016) have compared the MOORA method with other multi attribute decision making (MADM) methods (Table 1).

Table 1

The comparison of the MOORA method with MADM approaches

MADM method	Computational time	Simplicity	Mathematical calculations required
MOORA	a lot less	very simple	minimum
AHP	very high	very critical	maximum
ANP	moderate	moderately critical	moderate
GRA	very high	very critical	maximum
VIKOR	less	simple	moderate
GTA	very high	very critical	maximum
ELECTRE	high	moderately critical	moderate
DEA	very high	very critical	maximum
TOPSIS	moderate	moderately critical	moderate
PROMTHEE	high	moderately critical	moderate

The MOORA method starts with a decision matrix showing the performance of different alternatives with respect to various attributes (objectives). The assessment of the effectiveness by MOORA method consists of several steps (Wankhede et al. 2020; Brauers et al. 2006; Patnaik et al. 2020):

Step 1: To decide the input information data, develop the decision matrix (1):

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix}; \tag{1}$$

where $i = 1, \dots, m$, and $j = 1, \dots$, n.

Step 2: Normalize decision matrix by using Equation (2):

$$X_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}; \; (j = 1 \dots n) \tag{2}$$

Step 3: Weighted normalized decision matrix is formed with the use of Equation (3):

$$v_{ij} = w_j \cdot \bar{x}_{ij}; \tag{3}$$

where w_j shows the weight of the jth criterion.

Step 4: Final preference (y_i^*) values obtained by using Equation (4):

$$y_i^* = \sum_{j=1}^{g} v_{ij} - \sum_{j=g+1}^{n} v_{ij}; \tag{4}$$

where $j = 1, 2, \dots, g$ indicates the criteria to be maximized and $j = g + 1, g + 2, \dots, n$ shows the criteria to be minimized.

Step 5: Ranking of the alternatives are obtained by ranking (y_i^*) values in descending order.

THE RESEARCH MODEL

The research model was created by using a typical flat roof detail on corrugated steel supporting structure used in Lithuania in A++ Class industrial buildings. The research assessed the efficiency of the middle thermal insulation layer. Tested layer - no 3 (Figure 1).

The required heat transfer coefficient of an A++ Class industrial roof - U=0.15 W/m²K and the thickness of the different thermal insulation materials was calculated according to the Technical Regulations of the Construction STR 2.01.02:2016. The buildings were considered to be of fire resistance class 2.

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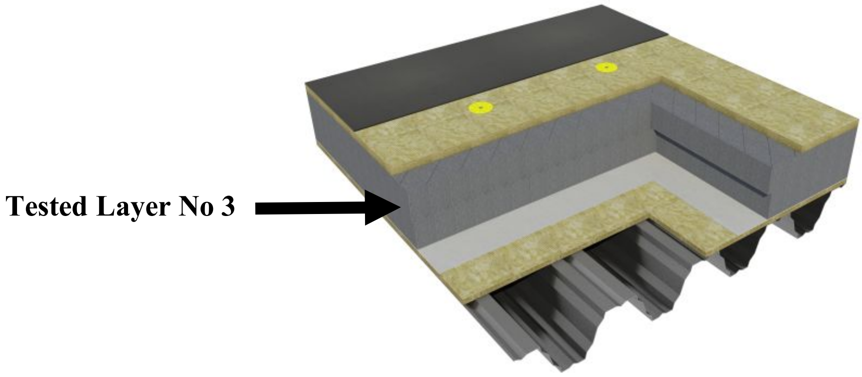

Figure 1. **Research model - flat roof of an A++ Class industrial building (for explanation of layers, see Table 2). Source: https://finnfoam.lt/**

Table 2

The layers of a flat roof

No	Roof layer	Thickness, mm
1	Roof membrane	-
2	Rockwool Paroc ROB 80	30
3	Thermal insulation (TESTED LAYER)	110-180
4	Vapour barrier	-
5	Finnfoam FF-PIR	30
6	Supporting structure (Corrugated Steel)	-

In this assessment study, 5 different thermal insulation materials: rockwool, conventional polystyrene, graphite polystyrene, extruded polystyrene and also polyisocyanurate (PIR) insulation products were tested.

The MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) method was chosen for the multi-objective assessment of the effectiveness of the thermal insulation alternatives.

THE RESEARCH METHODOLOGY AND OUTCOMES

In the first stage, a decision-making matrix (Table 3) is compiled and five different thermal insulation materials (*Paroc ROS 30*; *EPS100; EPS80N; XPS300; FF-PIR ALK*) are assessed according to four objectives, taken from the technical specifications of manufacturers: the thickness of the thermal insulation layer; the density; the thermal conductivity coefficient and the price of insulation materials (the third quarter of 2022). The significance of all attributes (objectives) is assumed to be equal.

Table 3

Decision-making matrix

Tested alternatives (thermal insulation materials)	Attributes (objectives)			
	The layer thickness, mm	***The density, kg/m³***	***Design value of the thermal conductivity coefficient, W/mK***	***The price of the thermal insulation, €/m²***
Paroc ROS 30	180	120.00	0.038	29.27
EPS100	170	18.50	0.037	16.83
EPS80N	150	16.50	0.033	15.24
XPS300	160	32.00	0.035	25.16
FF-PIR ALK	110	35.00	0.024	30.61
Significance	0.25	0.25	0.25	0.25

In the second step, the decision-making matrix is normalized (Table 4).

Table 4

Normalized decision-making matrix

Tested alternatives (thermal insulation materials)	Attributes (objectives)			
	The layer thickness, mm	*The density, kg/m³*	*The design value of the thermal conductivity coefficient, W/mK*	*The price of the thermal insulation, €/m²*
Paroc ROS 30	0.52	0.91	0.50	0.54
EPS100	0,49	0.14	0.49	0.31
EPS80N	0,43	0.13	0.44	0.28
XPS300	0.46	0.24	0.46	0.46
FF-PIR ALK	0.32	0.27	0.32	0.56

In the third step, the weighted normalized decision matrix is formed (Table 5).

Table 5

Weighted normalized decision-making matrix

Tested alternatives (thermal insulation materials)	Attributes (objectives)			
	The layer thickness, mm	*The density, kg/m³*	*The design value of the thermal conductivity coefficient, W/mK*	*The price of the thermal insulation, €/m²*
Paroc ROS 30	0.13	0.23	0.13	0.13
EPS100	0.12	0.04	0.12	0.08
EPS80N	0.11	0.03	0.11	0.07
XPS300	0.11	0.06	0.12	0.12
FF-PIR ALK	0.08	0.07	0.08	0.14

In the fourth and fifth steps, the contribution index is calculated and then the ranking of the alternatives are obtained (Table 6).

Table 6

Ranking alternatives

Tested alternatives (thermal insulation materials)	Contribution index	Ranking
Paroc ROS 30	-0.618	5
EPS100	-0.357	2
EPS80N	-0.318	1
XPS300	-0.407	4
FF-PIR ALK	-0.366	3

Upon completion of the multi-objective MOORA assessment, the scores of efficiency were calculated for each thermal insulation material (Figure 2).

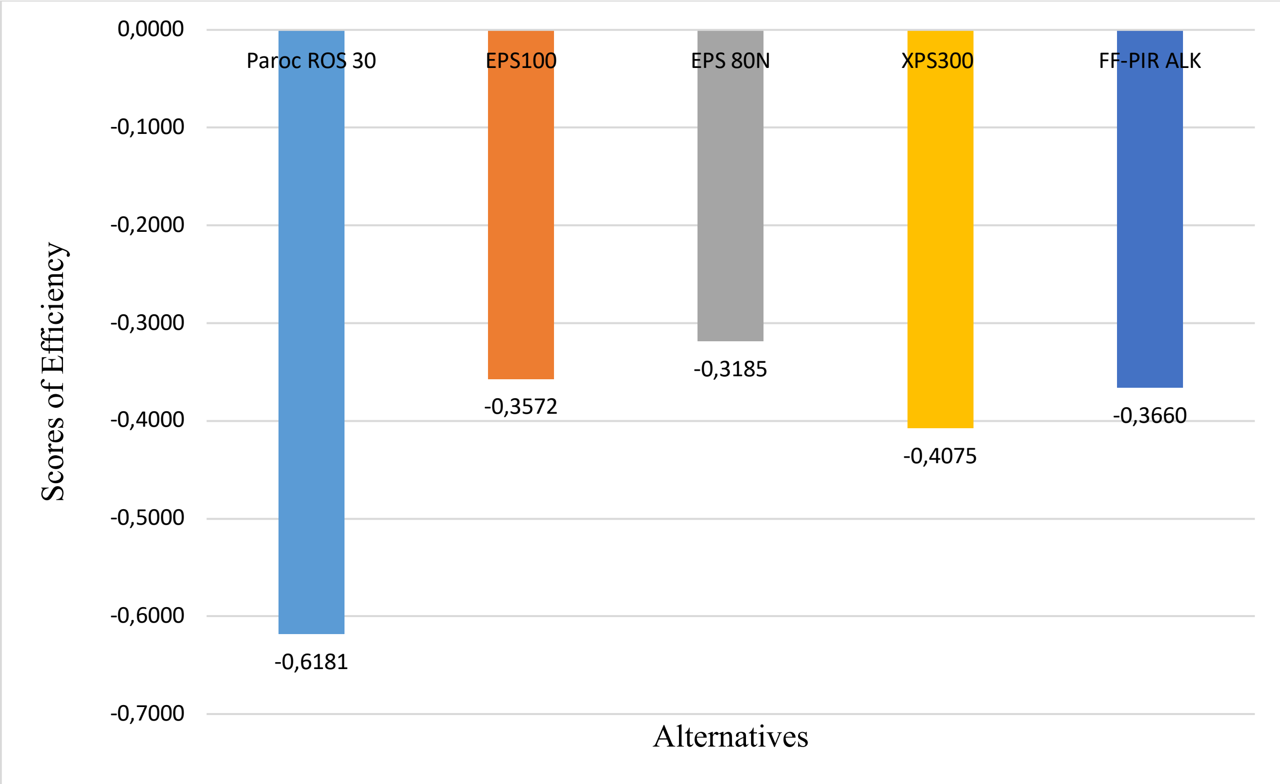

Figure 2. **The assessment of the efficiency of the flat roof thermal insulation layer**

An empirical study shows that the most effective middle thermal insulation layer for a flat roof of an industrial A++ Class building is the graphite polystyrene foam *EPS80N*, the least effective is rock wool *Paroc ROS 30* (-0.6181 points).

CONCLUSIONS

1. After assessing by the MOORA method, it was revealed that the most effective thermal insulation of a flat roof of a Class A++ industrial building (taking into account five material alternatives and four proportional objectives) is the graphite polystyrene foam – *EPS80N*. This alternative scored the highest number of the relative efficiency points (-0.318).
2. The least effective alternative (from the five tested materials) is the rock wool - *Paroc ROS 30* (-0.618 points). The difference between the best and worst alternatives is 51.46 percent.

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