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Implementation of a simple additive weighting method to choose a thermal insulation material for buildings

Using insulation materials is a solution to reduce energy consumption in buildings and structures. Insulation materials are chosen on the basis of economic and technical criteria, such as the energy-saving effect, construction conditions, climatic conditions, durability, price, etc. At present, there are many different methods related to multi-criterial decisio-making; one of them is the Simple Additive Weighting (SAW) method. This paper explains how to apply SAW to solve sequence problems in choosing an insulation material.
Keywords: *multicriterial analysis, SAW method, thermal insulation material, mineral wool, expanded polystyrene (EPS), extruded polystyrene (XPS)*

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INTRODUCTION

Today energy efficiency is key to sustainable development not only in Vietnam, but also around the world. Its mission is to combat climate change in the conditions of depleting global fossil oil resources[1, 2, 3]. Using insulation materials to make buildings and constructions is one of the solutions to reduce energy consumption by air-conditioning and ventilation systems and improve the quality of life inside buildings [1, 2].

The choice of an insulation material affects the insulation capacity, the quality and durability of the structure of exterior building walls. Multi-criterial decision making (MCDM) deals with decisions involving the choice of the best alternative among several potential options to select an insulation material with account taken of the following factors: the energy-saving effect, construction conditions, climatic conditions, the durability and cost of construction.

The authors introduce the Simple Additive Weighting (SAW) method to make a decision on the insulation material used to repair exterior walls of buildings in tropical countries (Vietnam, Indonesia, Thailand, Myanmar, …). The next section of the paper is arranged as follows: Part II, Literature Review surveys research papers about insulation materials and some popular multi-criterial decision-making methods; Part III, Methodology, presents the SAW method; Part IV, Numeric Example applies the SAW method to select insulation materials; and Conclusion is the final part.

LITERATURE REVIEW

Insulation materials have been widely used in Europe and Russia for the purpose of reducing heat loss and saving energy in buildings. Some basic categories of insulation include bulk insulation — vermiculite, perlite and expanded clay gravel, mineral wool (basalt fiber or glass wool), eco-wool, insulation, including foamed polymers (polyfoam, urea formaldehyde foam insulation, expanded polystyrene, extruded polystyrene, and polyurethane foam) [3–6]. The technical strengths and weaknesses of different types of materials are presented by several authors (K.S. Kravchenko, T.I. Ilyasov, G.R. Gafurova and A.G. Dalabaeva). However, in their research works, the method used to evaluate and select insulation materials, if the selected alternatives meet the pre-set criteria, such as insulation efficiency, durability, construction conditions, climatic conditions and material prices, is not provided. In these works, mineral wool, expanded polystyrene (EPS) and extruded polystyrene (XPS) have the following noticeable advantages: low thermal conductivity, durability, fire resistance, efficiency, environmental friendliness, and ease of installation.

However, to choose insulation materials with account taken of constraints such as insulation efficiency, durability, construction conditions, climatic conditions, material price, MCDM is used to choose the best alternative among several potential options. Currently, there are many methods to solve this problem, including the method of simple additive weighting (SAW); the TOPSIS method; electre I and electre II methods, etc. [7–13]. The SAW (Simple Additive Weighting) method is one of the best-known and widely used methods of multi-criterial decision making.

METHODOLOGY

In general, the process of finding the best thermal insulation material can be divided into the following steps:

- analysis of materials according to the criteria;
- standardization of the criteria;

1 QCVN 09:2017/BXD. Building structures utilized energy efficiency. Hanoi, 2017.

2 Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Official Journal of the European Communities. 2003; 65-70.

3 On Energy Saving and on Increasing Energy Efficiency and on Amendments to Certain Legislative Acts of the Russian Federation : Federal Law No. 261-FZ of November 23, 2009.

- determining the criteria weight;
- determining the rating of materials by multiplying the criteria values by weights.

The applied method for determining the integral dimensionless index based on the modified SAW method can be divided into the following stages.

Step 1: selecting initial comparison criteria (it is necessary to make sure that the criteria are not duplicated).

Step 2: setting functional comparison goals (maximum or minimum values).

Step 3: defining the direction of each criterion and translating the criteria not corresponding to the direction of the functional goal (using the reciprocal of the number).

Step 4: determining the value of dimensionless criteria using the following formula:

$$P_{ij} = \frac{C_{ij}}{\sum_{j=1}^{n} C_{ij}} \cdot 100, \qquad (1)$$

where P_{ij} is the dimensionless value of criterion i of option j; C_{ij} is the value of criterion i of option j; n is the number of options, $j = 1, 2, \ldots, n$.

Step 5: determining the importance of each criterion in the comparison.

The use of the Warkentin square matrix and the evaluation of criteria on a scale, the use of the e_{ij} coefficient means the importance of BK_j criterion according to the rules:

- the level is not important when $BK_i << BK_j$

$$L_{ij} = 1;$$

- the level is less important when $BK_i < BK_j$

$$L_{ij} = 2;$$

- the importance levels are equal when $BK_i = BK_j$

$$L_{ij} = 3;$$

- the level of importance when $BK_i > BK_j$

$$L_{ij} = 4;$$

- the level is very important when $BK_i >> BK_j$

$$L_{ij} = 5.$$

Given that:

$$L_{ij} = L_{ji} = 3, \text{ for which } i = j;$$

$$L_{ij} = L_{ji} = 5, \text{ for which } i \neq j.$$

The weight coefficient of each criterion is identified and the results are controlled using formulas (2)–(4).

$$W_i = \frac{L_{ij}}{\sum L_{ij}}, \qquad (2)$$

$$3m^2 = \sum L_{ij}, \qquad (3)$$

$$\sum W_i = 1, \qquad (4)$$

where W_i is the weight coefficient of criterion i for all criteria; L_{ij} is the level of importance of criterion i of option j; m is the number of initial criteria for comparison.

Step 6: determining the dimensionless value for each option using formula (5):

$$V_j = \sum_{i=1}^{m} P_{ij} W_i, \qquad (5)$$

where V_j is the dimensionless value of option j; P_{ij} is the dimensionless value of riterion i of option j; W_i is the weight coefficient of criterion i in all criteria.

Step 7: analyzing and rating the options by the dimensionless values.

A NUMERIC EXAMPLE

The economic and technical criteria, presented in Table 1, are used to calculate and analyze the heat transfer process through the external wall structure into the buildings and to conduct experiments to assess the suitability of three types of materials (extruded polystyrene, expanded polystyrene and mineral wool) to the climate conditions in the Hanoi area. The criteria in Table 1 are used as input

Table 1. Economic and technical criteria

Criterion	Units	Option number 1 (XPS)	Option number 2 (EPS)	Option number 3 (Mineral wool)
Coefficient of thermal conductivity λ	W/(m·C)	0.029	0.041	0.038
Material layer thickness δ	m	0.02	0.02	0.025
Material density ρ	kg/m³	33	10	80
Static load *P*	kg/m²	0.66	0.2	2
Material price	rub/m²	118	53	156
Durability	Years	70	50	40
Fire resistance	—	Abnormal	Abnormal	Perfect
Level of compliance with climate conditions	—	Perfect	Normal	Abnormal
Thermal insulation efficiency	%	59.16	49.10	58.04

data for evaluating, comparing and selecting insulation materials for exterior wall structures and constructions in Vietnam[4, 5] [14–16].

Step 1. Choice of comparison criteria

Table 2 presents the analysis and selection of 7 criteria from the entire set of criteria (Table 1), in which the properties of the criteria are not repeated.

Step 2. Determining the functional targets for comparison

The choice of maximum values is a functional purpose for comparison.

Step 3. Determining the direction of each criterion

According to Table 2, it is necessary to translate the criteria (1, 2 and 3) that are contrary to the direction of the functional goal, using the reciprocal of the number. In addition, the value of criteria 6 and 7 are determined using the method of analysis and the rating scale. The results are shown in Table 3.

Step 4. Determining the value of dimensionless criteria

The value of dimensionless criteria is determined using formula (1), the results are shown in Table 4.

Step 5. Determine the importance of each criterion used for comparison purposes

The level of importance of the criteria is determined by experts.

1. Coefficient of thermal conductivity — very important (λ).

Table 2. Baseline options for comparison

Criterion	Units	Option number 1 (XPS)	Option number 2 (EPS)	Option number 3 (Mineral wool)
Coefficient of thermal conductivity λ	W/(m·C)	0.029	0.041	0.038
Static load *P*	kg/m^2	0.66	0.2	2
Material price	rub/m^2	118	53	156
Durability	Years	70	50	40
Fire resistance	—	Abnormal	Abnormal	Perfect
Level of compliance with climate conditions	—	Perfect	Normal	Abnormal
Thermal insulation efficiency	%	59.16	49.10	58.04

Table 3. Results following the translation of the criteria that are contrary to the direction of the functional goal

Criterion	Units	Option number 1 (XPS)	Option number 2 (EPS)	Option number 3 (Mineral wool)
Coefficient of thermal conductivity λ	W/(m·C)	34.483	24.390	26.316
Static load *P*	kg/m^2	1.515	5.000	0.500
Material price	rub/m^2	0.008	0.019	0.006
Durability	Years	70	50	40
Fire resistance	—	1	1	5
Level of compliance with climate conditions	—	5	2	1
Thermal insulation efficiency	%	59.161	49.097	58.041

Table 4. The meaning of dimensionless criteria

Criterion	Option number 1 (XPS)	Option number 2 (EPS)	Option number 3 (Mineral wool)
Coefficient of thermal conductivity λ	40.478	28.631	30.891
Static load *P*	21.598	71.274	7.127
Material price	24.985	56.149	18.866
Durability	43.750	31.250	25.000
Fire resistance	14.286	14.286	71.429
Level of compliance with climate conditions	62.500	25.000	12.500
Thermal insulation efficiency	35.575	29.523	34.901

4 TCVN 9258: 2012. Thermal insulation of residential buildings — Standard projects. Hanoi, 2012.

5 TCVN 4605:1988. Heat engineering — Enclosing structures — Standard projects. Hanoi, 1988.

2. Static load — less important (*P*).
3. Material price — important (Pri.).
4. Durability — important (Dur.).
5. Fire resistance — very import (Fir.).
6. Level of compliance with climate conditions — very import (Cli.).
7. Thermal insulation efficiency — important (Eff.).

The results of the application of the Warkentin square matrix used to determine the weight factor of each criterion are shown in Table 5.

Step 6. Finding the dimensionless value

We determine the dimensionless values for each option using formula (1)–(5).

Step 7. Evaluation and rating of options

In order to select the best option, it is necessary to start by identifying the option that has the largest dimensionless value (Table 6).

Option No. 1 (XPS) has the largest dimensionless value of 35.986 and is ranked as the first one;

Option No. 2 (EPS) has a score of 32.943 and is second in the ranking;

Option No. 3 (Mineral wool) has a score of 31.071 and is ranked third.

As it can be seen from the ranking, option No. 1 is the best one, compared to options No. 2 and No. 3.

CONCLUSION

Hence, the use of expanded polystyrene (XPS) in the renovation of the facade of a building in Vietnam not only meets the climate conditions, but also proves the effectiveness of thermal insulation. It also meets the requirements of evaluation of materials in the integral system of parameters. As the studies have shown, we can say that expanded polystyrene (XPS) is the most optimal material for repairing the facade of a building and a structure in a hot and highly humid climate, characterized by long rainy seasons and heavy precipitation.

Table 5. Matrices for determining the weight factor of each criterion

Criterion	λ	*P*	Pri.	Dur.	Fir.	Cli.	Eff.	L_{ij}	W_i
λ	3	5	4	4	3	3	4	26	0.177
P	1	3	2	2	1	1	2	12	0.082
Pri.	2	4	3	3	2	2	3	19	0.129
Dur.	2	4	3	3	2	2	3	19	0.129
Fir.	3	5	4	4	3	3	4	26	0.177
Cli.	3	5	4	4	3	3	4	26	0.177
Eff.	2	4	3	3	2	2	3	19	0.129
Control results: $3\cdot7^2=\sum L_{ij}=147$ and $\sum W_i=1$								147	1

Table 6. The results of determining the dimensionless value of the criterion of options

Criterion	W_i	Option number 1 (XPS)		Option number 2 (EPS)		Option number 3 (Mineral wool)	
		P_{i1}	$P_{i1}W_i$	P_{i2}	$P_{i2}W_i$	P_{i3}	$P_{i3}W_i$
λ	0.177	40.478	7.159	28.631	5.064	30.891	5.464
P	0.082	21.598	1.763	71.274	5.818	7.127	0.582
Pri.	0.129	24.985	3.229	56.149	7.257	18.866	2.438
Dur.	0.129	43.750	5.655	31.250	4.039	25.000	3.231
Fir.	0.177	14.286	2.527	14.286	2.527	71.429	12.634
Cli.	0.177	62.500	11.054	25.000	4.422	12.500	2.211
Eff.	0.129	35.575	4.598	29.523	3.816	34.901	4.511
			35.986		**32.943**		**31.071**

REFERENCES

1. Kazarnovskiy V.A., Nguyen Tien Nam. Increase of efficiency of thermal insulation of wall external enclosing designs, as a result of use of mineral wool at repair in climatic conditions of Vietnam. Real Estate: Economics, Management. 2019; 3:70-75. URL: https://www.elibrary.ru/item.asp?id=41520080 (rus.).
2. Nguyen Tien Nam, Grabovyy P.G. Using expanded polystyrene to repair the thermal insulation of enclosing structures of external walls of buildings in Vietnam. Real Estate: Economics, Management. 2020; 4:43-48. DOI: 10.22227/2073-8412.2020.4.43-48 URL: https://www.elibrary.ru/item.asp?id=44803577 (rus.).
3. Kravchenko K.S., Segaev I.N. Analysis of heaters for thermal insulation of buildings and structures. Scientific and Practical Electronic Journal Alley of Science. 2018; 4(20):242-246.
4. Ilyasov T.I., Smorodova O.V. Thermal insulation of building walls. New Information Technologies in Science : collection of articles of the international scientific and practical conference. Part 3. Ufa, April 18, 2017. Ufa, 2017; 74-78. (rus.).
5. Gafurova G.R., Smorodova O.V. Heat-shielding properties of external fences of buildings. Modern Conditions for the Interaction of Science and Technology : collection of articles of the international scientific and practical conference. Part 1. (Kazan, February 3, 2017). Ufa, 2017; 33-36. (rus.).
6. Dalabaeva A.G., Seitkozhina M.S., Kibatollaeva A.A., Smorodova O.V. Thermal insulation of the outer walls of buildings. Alley of Science. 2017; 6:259-263. URL: https://www.elibrary.ru/item.asp?id=28844669 (rus.).
7. Chen C.T. Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems. 2000; 114(1):1-9. DOI: 10.1016/S0165-0114(97)00377-1
8. Rudnik K., Kacprzak D. Fuzzy TOPSIS method with ordered fuzzy numbers for flow control in a manufacturing system. Applied Soft Computing. 2017; 52:1020-1041. DOI: 10.1016/j.asoc.2016.09.027
9. Giner-Santonja G., Aragonés-Beltrán P., Niclós-Ferragut J. The application of the analytic network process to the assessment of best available techniques. Journal of Cleaner Production. 2012; 25:86-95. DOI: 10.1016/j.jclepro.2011.12.012
10. Yue Z. TOPSIS-based group decision-making methodology in intuitionistic fuzzy setting. Information Sciences. 2014; 277:141-153. DOI: 10.1016/j.ins.2014.02.013
11. Ivanushkin S.V., Chechevatova O.Yu. Methodical approach to the definition of domestic best available technologies. Izvestiya Instituta inzhenernoy phiziki. 2015; 2(36):77-79. URL: https://www.elibrary.ru/item.asp?id=23412940 (rus.).
12. Kryukov S.V. System analysis: theory and practice. Rostov-on-Don, Southern Federal University Publishing House, 2011; 228. (rus.).
13. Panova S.A., Tishaeva I.R. System model for identification of best available technology (BAT). Bulletin of MITHT. 2014; 9(5):83-85. URL: https://www.elibrary.ru/item.asp?id=22978751 (rus.).
14. Nguyen Tien Nam, Grabovyy P.G. Study of water-absorption properties of the insulation material utilized for repair of external enclosures of buildings in the climate of Vietnam. Real Estate: Economics, Management. 2020; 2:55-65. DOI: 10.22227/2073-8412.2020.2.55-60 URL: https://www.elibrary.ru/item.asp?id=44822025
15. Nguyen Tien Nam, Grabovy P.G., Kazarnovsky V.A. The change in mass of insulating materials in the Vietnamese climate conditions. IOP Conference Series: Materials Science and Engineering. 2020; 869(5):052026. DOI: 10.1088/1757-899X/869/5/052026
16. Nguyen Tien Nam, Grabovy P.G. The research of moisture sorption characteristics in mineral wool under the Vietnamese climate conditions. IOP Conference Series: Materials Science and Engineering. 2021; 1030(1):012008. DOI: 10.1088/1757-899X/1030/1/012008

Реализация простого аддитивного весового метода для выбора теплоизоляционного материала в зданиях

Использование теплоизоляционных материалов является решением для снижения энергопотребления в зданиях и сооружениях. При выборе теплоизоляционных материалов используются экономико-технические критерии: эффект энергосбережения, состояние конструкции, климатические условия, долговечность, цена материала и т.д. В настоящее время существует множество различных методов, связанных с многокритериальной проблемой принятия решений, одним из них является метод простого аддитивного взвешивания (SAW). В этой статье объясняется, как применять SAW для решения проблем последовательности при выборе изоляционного материала для каждой альтернативы по всем атрибутам.

Ключевые слова: *многокритериальный анализ, метод SAW, теплоизоляционный материал, минеральная вата, пенополистирол (EPS), экструдированный пенополистирол (XPS)*

СПИСОК ИСТОЧНИКОВ

1. Казарновский В.А., Нгуен Тиен Нам. Повышение эффективности теплоизоляции стеновых наружных ограждающих конструкций при реализации ремонтных работ на примере Вьетнама // Недвижимость: экономика, управление. 2019. № 3. С. 70–75. URL: https://www.elibrary.ru/item.asp?id=41520080
2. Нгуен Тиен Нам, Грабовый П.Г. Применение пенополистиролов при ремонте теплоизоляции стеновых наружных ограждающих конструкций во Вьетнаме // Недвижимость: экономика, управление. 2020. № 4. С. 43–48. DOI: 10.22227/2073-8412.2020.4.43-48 URL: https://www.elibrary.ru/item.asp?id=44803577
3. Кравченко К.С., Сегаев И.Н. Анализ утеплителей при теплоизоляции зданий и сооружений // Аллея науки. 2018. № 4 (20). С. 242–246. URL: https://www.elibrary.ru/item.asp?id=34975059
4. Ильясов Т.И., Смородова О.В. Тепловая изоляция стен зданий // Новые информационные технологии в науке : сб. ст. Междунар. науч.-практ. конф. Ч. 3. (г. Уфа, 18 апреля 2017 г.). Уфа, 2017. С. 74–78.
5. Гафурова Г.Р., Смородова О.В. Теплозащитные свойства наружных ограждений зданий // Современные условия взаимодействия науки и техники : сб. ст. Междунар. науч.-практ. конф. Ч. 1. (г. Казань, 3 февраля 2017 г.). Уфа, 2017. С. 33–36.
6. Далабаева А.Г., Сейткожина М.С., Кибатоллаева А.А., Смородова О.В. Теплоизолирование наружных стен зданий // Аллея Науки. 2017. № 6. С. 259–263. URL: https://www.elibrary.ru/item.asp?id=28844669
7. Chen C.T. Extensions of the TOPSIS for group decision-making under fuzzy environment // Fuzzy sets and systems. 2000. Vol. 114. Issue 1. Pp. 1–9. DOI: 10.1016/S0165-0114(97)00377-1
8. Rudnik K., Kacprzak D. Fuzzy TOPSIS method with ordered fuzzy numbers for flow control in a manufacturing system // Applied Soft Computing. 2017. Vol. 52. Pp. 1020–1041. DOI: 10.1016/j.asoc.2016.09.027
9. Giner-Santonja G., Aragonés-Beltrán P., Niclós-Ferragut J. The application of the analytic network process to the assessment of best available techniques // Journal of Cleaner Production. 2012. Vol. 25. Pp. 86–95. DOI: 10.1016/j.jclepro.2011.12.012
10. Yue Z. TOPSIS-based group decision-making methodology in intuitionistic fuzzy setting // Information Sciences. 2014. Vol. 277. Pp. 141–153. DOI: 10.1016/j.ins.2014.02.013
11. Иванушкин С.В., Чечеватова О.Ю. Методический подход к определению отечественных наилучших доступных технологий // Известия Института инженерной физики. 2015. Т. 2. № 36. С. 77–79. URL: https://www.elibrary.ru/item.asp?id=23412940
12. Крюков С.В. Системный анализ: теория и практика. Ростов н/Д : Изд-во Южного федерального университета, 2011. 228 с.
13. Панова С.А., Тишаева И.Р. Системная модель наилучшей доступной технологии // Вестник МИТХТ им. М.В. Ломоносова. 2014. Т. 9. № 5. С. 83–85. URL: https://www.elibrary.ru/item.asp?id=22978751
14. Нгуен Тиен Нам, Грабовый П.Г. Исследование характеристики водопоглощения материала утеплителя, применяемого для ремонта наружного стенового ограждения зданий

в условиях Вьетнама // Недвижимость: экономика, управление. 2020. № 2. С. 55–65. DOI: 10.22227/2073-8412.2020.2.55-60 URL: https://www.elibrary.ru/item.asp?id=44822025

15. Nguyen Tien Nam, Grabovy P.G., Kazarnovsky V.A. The change in mass of insulating materials in the Vietnamese climate conditions // IOP Conference Series: Materials Science and Engineering. 2020. Vol. 869. Issue 5. P. 052026. DOI: 10.1088/1757-899X/869/5/052026

16. Nguyen Tien Nam, Grabovy P.G. The research of moisture sorption characteristics in mineral wool under the Vietnamese climate conditions // IOP Conference Series: Materials Science and Engineering. 2021. Vol. 1030. Issue 1. P. 012008. DOI: 10.1088/1757-899X/1030/1/012008

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