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The Optimal Sustainable Insulation Material by Using MCDM Analysis

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Abstract:
Increasing fuel costs is the new norm, and an increase in energy consumption leads to many troubles, such as a growing of harmful environmental emissions and rise in energy consumption bills. Hence, it's desirable and recommended to estimate the value of energy consumed for buildings in the first design state in order to reduce the impact of these issues, and obtain a sustainable building using thermal insulation for the buildings (walls, roofs, floors...). The purpose of this experimental analysis is to determine the best insulating material among 12 selected materials, as the properties of these materials were analysed based on several criteria. The study focuses on using multiple analysis methods in order to achieve the best results and to eliminate potential inconsistencies of data with available scientific methods. The evaluation is conducted via implementing three multiple criteria decision-making methods (MCDM)the full Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) multiplication, rating the choices and selection the solution nearest to ideal, VIekriterijumsko KOmpromisno Rangiranje (VIKOR) and the method of ordering options by analogy with the optimal method (TOPSIS). In addition to the significance of the criteria, find the weights of the criterion in the analysis by using the correlation between criteria (CRITIC). Results based on pre-established methods showed consistent results, with the highest and worst performing materials identified in buildings. Extruded polystyrene foam (XPS) is ranked the best among other materials. The number of articles related to MCDM isn't that high. Therefore, this study will contribute to filling the gap.

Keywords: *CRITIC; Energy Efficiency; Insulation materials; MCDM Analysis; Multi-MOORA; Sustainable; TOPSIS; VIKOR.*

مادة العزل المستدامة الأمثل باستخدام تحليل القرار متعدد المعايير

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الخلاصة:

تُعدُّ زيادة تكاليف الوقود تحديًا، حيث إنّ زيادة استهلاك الطاقة يؤدي إلى الكثير من المشاكل، مثل تزايد الانبعاثات البيئية الضارة وارتفاع فواتير استهلاك الطاقة. ومن هنا فمن المستحسن والمُوصى به تقدير قيمة الطاقة المستهلكة للمباني في الحالة التصميمية الأولى لتقليل تأثير هذه المشكلات، والحصول على بناءٍ مستدام باستخدام العزل الحراري للمباني (الجدران، الأسطح، الأرضيات، ...إلخ). الغرض من هذا التحليل التجريبي هو تحديد أفضل مادة عازلة من بين (12) مادة مختارة، حيث تم تحليل خواص هذه المواد بناء على عدة معايير. تُركّز الدراسة على استخدام طرق تحليل متعددة من أجل تحقيق أفضل النتائج وإزالة التناقضات المحتملة للبيانات مع الأساليب العلمية المتاحة. أُجري التقييم من خلال تطبيق ثلاثة معايير متعددة لأساليب اتخاذ القرار (MCDM) وهي التحسين الكامل متعدد الأهداف على أساس تحليل النسب (MOORA)، وتصنيف الاختيارات واختيار الحل الأقرب إلى المثالي (VIKOR)، وطريقة ترتيب الخيارات قياسًا على الطريقة المثلى (TOPSIS). بالإضافة إلى إيجاد أوزان المحك في التحليل باستخدام العلاقة الارتباطية بين المعايير (CRITIC). حيث أظهرت النتائج المستندة إلى الأساليب المحددة مسبقًا نتائج متسقة، وتم تحديد المواد الأعلى والأسوأ أداءً في المباني. تم تصنيف رغوة البوليسترين المبثوق (XPS) على أنها الأفضل بين المواد الأخرى. عدد المقالات المتعلقة بـ MCDM ليس مرتفعًا. ولذلك فإن هذه الدراسة سوف تسهم في سد هذه الفجوة.

الكلمات المفتاحية: *كفاءة الطاقة؛ مواد العزل؛ تحليل القرار متعدد المعايير؛ استدامة.*

1. Introduction

Insulating materials are those that offer thermal insulation or reduce heat transfer between objects. When two items are in contact yet have different temperatures, heat transfer can be a concern in a variety of sectors. While there will inevitably be heat transfer between two objects, it can be minimized by using an insulating substance. Instead of absorbing heat radiation, these materials act by lowering thermal conductivity or reflecting it. Compared to other materials, the thermal insulation has a short history, yet humans have been conscious of the value of insulation for a very time period. In the ancient times, people started constructing shelters to safeguard themselves from wild animals and terrible weather (Greenspec, 2023).

They also began researching thermal insulation. People living in prehistoric times build their houses out of reeds, flax, and other plant materials as well as things made from animal skins and fur. Because their homes were impermanent, they were more inclined to utilize the material they utilized in the clothes, which were simple to procure and prepare. These materials were initially used as human body insulation. The materials used to make plant and animal products can trap a lot of air between their molecules, reducing the amount of heat exchanged.

Later, as agriculture and human longevity made a permanent home necessary, stone homes, earth-sheltered homes (the first bungalow was built in Ooty, India), and cave dwellings (a structure with earth (soil) against the walls, on the roof, or completely buried underground) started to appear. Some ground-protected homes and cave dwellings were constructed simultaneously, and it seems that their intrinsic advantages made them quite popular. They were simple to implement, and an earthen covering provided good defence against wild animals, fire, and conflict. The earthen homes utilize the surrounding soil as a magnificent insulating layer. Consequently, thanks to the earth's enormous density, internal temperature changes occur gradually. The interior has kept the temperature warm during the winter season and cool during the summer season by the earth covering, due to a phenomenon known as thermal lag. During 12th and 13th century, Northern Europeans constructed the houses covered by thatch with 60–80 cm thickness of the straw roof.

Clay and straw were frequently used in the construction of the walls. Thatched dwellings swiftly continued to grow, mainly in the northern regions of Europe and America, because of the dry, hollow fibre of straw and reed, which offered an exceptional level of thermal resistance. Due to the high density of these materials, thermal transport may be slowed down, resulting in a gradual shift in interior temperature. This effect keeps buildings' interiors cool in the summer season and warm in the winter season, and because earth or stone materials are not difficult to obtain, this plan is extremely widespread in many locations, such as the first human insulated house. Russia, Greenland, and Iceland. The first resources that might be used to construct a place where people could get a shelter to protect themselves from inclement climate and to help keep them warm were organic materials. Nevertheless, since organic materials, such as animal and plant fibre, cannot last a very long period, they are unable to meet peoples' long term need for thermal insulation. They then started looking for more durable alternatives (insulationGo, 2023). They stopped using natural materials for thermal insulation in the 19th century and instead processed organic resources to create the first insulated panels. A wide variety of artificial thermal insulation materials, including as rock wool, fibreglass, and foam glass, were produced at the same time that increasing amounts of artificial materials began to appear. Reed panels were first utilized as thermal insulation in accessory buildings in the 19th century. They were well-liked despite their weak hygroscopic capacity, since they were resistant to deterioration. Reed panels with bituminous coatings first debuted around the turn of the 20th century, but their flammability and unreliable nature prevented them from taking off. Insulating panels constructed of bagasse were first manufactured by the US Celotex Company in 1920. (a waste by product of sugar manufacturing). In the construction of residential buildings and the creation of refrigerated railroad wagons, it served as thermal insulation. Later, one or both of the sides were covered with asbestos cement due to their flammability. In the USA, the first attempts at manufacturing roof insulation panels composed of flax were produced. In the USA, polystyrene foam was first produced in 1931. The technique for foaming polystyrene was developed by the Swedish inventors Carl Georg Munters (1897-1989) and John Tandberg (1896-1968) in collaboration. By utilizing their technique, Otis Ray McIntire (1918-1996), an engineer for the Dow Chemical Company, created the first polystyrene foam in 1941. Using chloromethane as a foaming agent, he used an extruder to heat the milk-white polystyrene granulate to 200 C. Extruded polystyrene (XPS) panels with a 98% closed cellular structure were produced as a result of his leading the polystyrene foam through a small opening. The business introduced Styrofoam R, the first polystyrene insulating product, to consumers in 1943. In the 1940s and 1950s, the introduction of plastic foams (polystyrene, polyurethane) sparked a massive upheaval in the market for insulating materials.

From this point on, synthetic insulation materials (such as plastic foams and mineral wool) took the lead in pushing natural materials aside. With the oil crisis of the 1970s, their uptake quickened, and today, 90–95 percent of all thermal insulation material production is made up of artificial materials. The expanded polystyrene foam (EPS) for the first time was technology created in 1950 by engineers at IG Farbenindustrie AG in Germany. Water vapour is given to the polystyrene granulate using pentane as a foaming agent. The raw material's grains get softer as the temperature rises, and pentane’s actions cause the volume of the pearls to increase 20–50 times. Expanded polystyrene foam develops tiny closed cells as a result of this process, which gives it exceptional thermal insulation properties and makes it the perfect material for building insulation.

Hence, we can divide the evolution of thermal insulation materials into five distinct historical eras. Each era started with a crucial advancement in the history of humanity, science, or industry. These were the key factors that transformed the market for thermal insulation materials, resulting to the launch of a brand-new item or the removal of an already-existing one. It is obvious from an analysis of the thermal insulation materials industry that synthetic materials are the most widely used goods. About 50–55% of the manufacturing is made up of products containing mineral wool, while 40–45% of it is made up of plastic foam. The recent century has brought to light that fossil fuels are finite and will eventually run out rather soon. Also, the use of fossil fuels contributes significantly to the critical problem of the twenty-first century known as climate change and global warming by emitting greenhouse gases, particularly CO2.

From here comes the importance of insulating materials in: energy efficiency, and thus saving money, maintaining the building at the appropriate temperature a very long time with no requirement to operate increasing the level of comfort for building occupants while decreasing the consumption of air conditioners over extended periods of time, which reduces the health impact and has less psychological consequence on people since of the noise originating from the operation of these devices, which leads lower the thickness of the concrete walls and ceilings required to lessen the transfer of the heat into the building, and to save the burden on power production stations and distribution networks (Bozsaky, 2010).

In this research, an analytical study has been conducted to determine the best insulating materials from an economic and environmental perspective at the same time. Twelve insulating materials are studied and analysed, aiming to determine which is better in terms of performance. In this analytical paper, the following factors are considered for each of the materials, density, thermal conductivity, global warming potential, photochemical ozone creation potential, acidification potential, eutrophication potential, specific heat capacity, water vapour difference resistance index, cost.

Moreover, in this study three MCDM models have been used to determine the best performance of insulation materials, using three methods though achieving multiple goals. First, get rid of potential inconsistencies. Second, get confirmation of the results.

Finally, have a better multipronged platform to define the solution, as not all models use the same algorithms. The models used are Multi-MOORA, VIKOR and TOPSIS to refine the data and find the best insulation performance.

2. Literature Review

Case study 1- This study used (AHP) and (TOPSIS) and fuzzy ball groups to select insulation materials during building design, thermal conductivity, rate of fire, embodied carbon, specific heat, and density. Geopolymer (foamed, fly ash-based), sheep wool, rock wool, fibreglass, and expanded polystyrene were compared. Foamed coal fly ash geopolymer insulation is the best (Kalaw et al., 2022).

Case study 2-This study evaluates numerous parameters to select a SAW-compatible insulation material. Costs, CO2 emissions, compressive strength, density, thermal conductivity, complexity, durability, time to complete, water vapour diffusion resistance, and flammability class. These were utilized. Styrofoam, rock wool, polyurethane. Efficiency order of insulating materials: RW, PU, EPS. Rock wool was the lightest, most durable, flammable, water vapour diffusion resistant, and lowest carbon dioxide emissivity (Lill et al., 2017).

Case study 3-This study illustrates the aims to update historic residential structures to boost thermal insulation efficiency and reduce energy consumption from European energy production. Cost, duration, energy losses, repayment term, water vapour dispersion. MCDM was used to analyse six examples utilizing SWARA and TODIM methods. Cost, time, payback period, energy losses, and water vapour affect the outcome more (Ruzgys et al., 2014).

Case study 4-Sustainable building design requires material selection. DS ARAS's evidence theory solves sustainable material selection. The four main criteria—economic, social, environmental, and technological—were supplemented by 25 sub-criteria. The case study demonstrates the use of the technical, economic, social, cultural, and environmental criteria weigh 0.327, 0.209, 0.241, and 0.221. These results showed that economic and environmental criteria were most relevant. The proposed approach yielded 0.538 aluminium siding, 0.494 terracotta brick, and 0.494 stone facade scores. The most sustainable choice was 0.482, the highest score (Hatefi et al., 2021).

Case study 5-This study identified cellulose (1), walnut India, cork, flax, hemp, jute, kenaf, mineral wood, fibres, sheep's wool, and cotton as the most effective wall insulation materials by using several criteria evaluation approaches to reduce energy use and financial impact. Density, specific heat, thermal conductivity, transmittance, and thermal wave displacement were compared. The PSI-CRITIC technique and CoCoSo yield financial and engineering results that are realistic and economically feasible. Jute won all three tests (Ulutaş et al., 2021).

Case study 6-This study compares bricks, pumice concrete, and autoclaved aerated concrete (AAC) as hotel wall materials. Analytical hierarchy process. Weight values from material comparisons on cost, density, earth resistance, environmental friendliness, fire resistance, thermal insulation, product quantity, recycling, sound insulation, strength, and void ratio determined model asymmetry. Criteria and findings supported these values. Cost (0.360) drives wall material selection. Sound, thermal, and fire resistance follow (0.124, 0.141, 0.123). Earthquake resistance was 0.009. The model's variance was 0.092, making the analysis sufficient and consistent. This approach analyses better (Uğur & Baykan, 2017).

3. Data and Methodology

The methodology applied in this study, compared the materials to each other from an economic standpoint by using these methods combined. The 12 selected materials were analysed, by using MCDM methods (Multi-MOORA, CRITIC, VIKOR, and TOPSIS ways as described further in the text below.

Table 1: Principle data of insulation materials and criteria

Material	*ρ*	*K*	GWP	POCP	AP	EP	C	μ	Price($/m2)
EPB	85	0.042	0.52	0.0001	0.0024	0.0003	1000	4.00	6.10
ExClay	400	0.900	0.31	0.0002	0.0020	0.0001	1100	5.00	15.85
XPS	37	0.040	3.73	0.0030	0.0300	0.0020	1500	140.00	12.00
PUR	40	0.030	13.70	0.0005	0.0700	0.0020	1450	115.00	3.20
CalSil	115	0.050	1.10	0.0003	0.0020	0.0003	1000	11.50	4.80
Cotton	35	0.040	0.02	0.0008	0.0100	0.0005	1070	1.50	1.90
ICB	110	0.040	-1.46	0.0001	0.0030	0.0003	1900	7.50	1.48
Flax	20	0.040	0.22	0.0003	0.0080	0.0007	1470	1.50	8.28
EPS	15	0.040	2.80	0.0010	0.0060	0.0006	1500	60.00	2.52
CF	75	0.040	1.60	0.0010	0.0100	0.0005	1925	1.50	2.54
WFB	165	0.040	-0.45	0.0004	0.0050	0.0004	1850	7.50	8.60
Coir Fibres	80	0.050	0.60	0.0002	0.0400	0.0010	1450	1.50	3.71

Note. The table is prepared based on the information obtained from the book of Insulating materials: principles, materials, applications (Pfundstein et al., 2012)

3.1. Measurement indicators.

3.1.1. Density(ρ): represents the mass of a material per unit volume. The formula for density is d = M/V, where M represents mass and V is volume. A common unit of measurement for density is grams per cubic centimetre. For example, water has a density of 1 gram per cubic centimetre, whereas the density of the Earth is 5.51 grams per cubic centimetre. In meter-kilogram-second or SI units, density can also be expressed as kilograms per cubic meter. For example, the weight of air is 1.2 pounds per cubic meter. The usual solids, liquids, and gases' densities are listed in textbooks and manuals (Jones, 2020).

3.1.2. Thermal Conductivity (K): The ability of a material to conduct heat. Compared to materials with high thermal conductivity, those with poor thermal conductivity move heat more slowly. For instance, insulating materials like Rockwool or Styrofoam excel in retaining heat, whereas metals frequently exhibit high thermal conductivity and are excellent heat transmitters. As a result, materials with a high thermal conductivity are typically used as heat sinks, while materials with a low thermal conductivity are used as thermal insulation (Toberer et al., 2012).

3.1.3. Global Warming Potential (GWP): The global warming potential (GWP) (CO_2) of a greenhouse gas is the capacity of that gas over time to trap more heat in the atmosphere than carbon dioxide. The 100-year GWP, which is frequently calculated over a 100-year period, is used to describe this. The gas's ability to trap heat while in the atmosphere and how long it stays there before decomposing both have an impact on the global warming potential (GWP). A typical methane molecule lasts 12 years in the atmosphere, but methane (CH_4) decomposes quite quickly. Yet, while having a significantly longer lifetime than CO_2, CH_4 is more effective at capturing heat. Using the aid of GWPs, we can determine how much CO_2 would be required to trap the same amount of heat if 1 kg of a certain greenhouse gas were to capture that amount (Pfundstein et al., 2012).

3.1.4. Photochemical Ozone Creation Potential (Pocp): The relative capacities of volatile organic compounds (VOCs) to produce ground level ozone are measured using the Photochemical Ozone Creation Potential (POCP) scale. POCP values are typically computed using atmospheric boundary layer models that include thorough illustrations of the chemistry involved in atmospheric VOC degradation. Here, it has been examined how responsive POCP values are to changes in a variety of kinetic and mechanistic parameters. It is demonstrated that the chemical structure and OH reactivity of VOCs allows for the rationalization of their POCP values.

3.1.5. Acidification Potential (AP): relates to how much each substance contributes to acid rain. This comprises a wide range of chemicals, such as sulphur dioxide (SO2), nitrogen oxides (NOx), nitrogen monoxide (NO), and nitrogen dioxide (N2O). One of the key environmental impact indicators of EN, which provides direction for the development of the lifecycle assessment (LCA) methodology used to calculate product environmental footprints, is acidification potential (PEF). For the purposes of calculating, evaluating, and creating environmental product declarations, it is also regarded as one of the essential environmental performance indicators (EPDs). The acidification potential is considered one of non- beneficial criteria for the material, because its increase has negative effects on the environment.

3.1.6. Eutrophication Potential (EP): Phosphate (PO_4)-equivalents are used to express the eutrophication potential. Despite being essential for life, nitrates and phosphates can encourage excessive algal growth and reduce oxygen levels in water when present in large amounts. Eutrophication can thus be defined as an excessive nutrient load in rivers. Its emergence could endanger ecosystems, increase the death of aquatic animals and plants, and cause the extinction of species that rely on low-nutrient settings. For these reasons, it is considered a non-beneficial criterion.

3.1.7. Specific Heat Capacity (C): is the amount of heat required to increase a kilogram of material's temperature by one Kelvin (or one degree Celsius). A good insulator has a greater Specific Heat Capacity due to the longer time it takes for it to heat up (temperature rises) and transmit heat. High specific heat capacity materials could offer thermal mass or thermal buffering (Decrement Delay). This is why it is considered one of the beneficial criteria of insulation materials (Waples & Waples, 2004)

3.1.8. Water Vapour Diff. Resistance Index (μ): water vapour is constantly present in the atmosphere and in construction materials. The molecules of water vapour are continually attempting to disperse evenly throughout all directions. Depending on their microstructure, building materials exhibit a certain resistance to this distribution. The dimensions less resistance factor is calculated by comparing the vapour-tightness of a layer of material that is 1 m thick with a layer of air that is 1 m thick in order to measure this resistance. The diffusion behaviour of building components is determined using the water vapour diffusion resistance index. Several insulating materials have upper and lower values indicated, which might be affected by the manufacturing process or cell structure. Calculations are always performed using the value that is less favourable for the application (Gorjanc et al., 2012)

3.1.9. Price: the amount of money or its equivalent in exchange for which anything is being bought, sold, or otherwise transacted. The price is one of the non-beneficial criteria from an economic point of view, as the materials with the lowest price are considered the best, taking into account the other characteristics of the materials.

3.2 Methodology

The study focuses on using multiple analysis methods targeting to achieve the best results, and to eliminate potential discrepancies of data with available scientific methods. The evaluation is conducted through implementing three multiple criteria decision-making methods (MCDM)the full Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) multiplication, rating the choices and selection the solution nearest to ideal, VIekriterijumsko KOmpromisno Rangiranje (VIKOR) and the method of ordering options by analogy with the optimal method (TOPSIS). In addition to the significance of the criteria, find the weights of the criterion in the analysis by using the correlation between criteria (CRITIC).

This approach includes studying and analysing the properties of materials and furthermore it contributes to the studies conducted previously, and brings more focus in environmental properties.

3.2.1 Multi-MOORA ratio, Data is normalized using:

MCDM attempts to encourage and guide the administrator, leader, or manager to discover their options in the event of complex and challenging scenarios having various standards of measurements, and benchmarks. It is a renowned stringent, well-thought-out, and transparent decision creation process. It includes the selection of the best option from a group of alternatives after weighing them all against frequently at odds criteria.

The steps in the process are: defining the choice problem, in this example, choosing the best insurance business to invest in; assessing the needs; and obtaining the requirements through data collection and decision scenario analysis. Creating objectives and goals, coming up with alternatives, figuring out the necessary criteria, choosing a model, assessing alternatives against criteria, validating solutions against the problem statement or statements, and then putting the solution into practice (Zavadskas et al., 2019).

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^{2}}} \ and\ x_{ij}^{*} \ = 1 - \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^{2}}} \text{(j=1, 2,…)}$$

then choose the highest value among: $y_i^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*}$ the best rank is the biggest value.

-Multi-MOORA reference point, after normalization, the ratios determined in the ratio system are used to determine the Max Objective Ref Point (vector).

(such as r_j= max x_{ij}). This formula is used to produce tchebycheff: $min_i \{ max_j(|r_j - x^*_{ij}\}$

The company with the lowest score is considered to be the one performing the best (Krishnan et al., 2021).

-Multiplication MOORA

Beneficial criteria are essentially increased by one another in the past and divided by unfavourable criteria using: $B_j = \prod_{k=i+1}^{n} x_{kj}$

3.2.2 CRITIC method for weight distribution

Variables or measurement indicators are one of the most crucial components of a decision problem, so it's crucial to specify criteria in order to assess how effectively each choice accomplishes the desired outcomes. The objective weights of relative

The following method was used to calculate each criterion's weight: First, the standard deviation of each criterion was determined: $C_j = \sigma_j \sum_{j'=1}^{N} (1 - p_{ij'})$

Step1: Implementing CRITIC method is to normalize the decision matrix; we normalize the performance measures of the decision matrix to obtain the project outcomes as follows:

$$x_{ij}^{T} = \begin{cases} \dfrac{x_{ij} - x_j^-}{x_j^+ - x_j^-}, x_j^+ = \max\limits_i x_{ij}, x_j^- = \min\limits_i x_{ij} \\ \dfrac{x_j^- - x_{ij}}{x_j^- - x_j^+}, x_j^+ = \min\limits_i x_{ij}, x_j^- = \max\limits_i x_{ij} \end{cases}$$

Step 2: Calculation of the standard deviation for each criterion. Is given by equation

$\sigma_j = \sqrt{\frac{(\sum_{i=1}^{m} x_{ij} - \bar{x}_j}{m-1}}$where $\bar{x}_j$ is the mean score of criterion j and m is the total number of alternatives.

Step 3: Constructing the correlation matrix in this step, also called the calculation of the correlation between criteria, the correlation of each criterion in the normalized matrix is calculated. Naturally, the result will be 1 for each criterion compared to itself.

$$p_{ij\prime} = \frac{cov(x_i, x_{j\prime})}{\sqrt{\sum(x_i - \bar{x_\iota})^2 \sum(x_j - \overline{x_{J\prime}})^2}}$$

Step 4: The conflict shaped by criterion j pertinent to the decision condition defined by the rest of criteria is considered by the below formula

(1-$p_{ij\prime}$)

After calculating all values for the symmetric matrix, we find sums of each row by

$$\sum_{j'=1}^{N} (1 - p_{ij\prime})$$

Step 5: Utilizing the following multiplicative aggregation formula to combine the two metrics mentioned above, determine the amount of information

$$C_j = \sigma_j \sum_{j'=1}^{N} \left(1 - p_{ij'}\right)$$

Step 6: Obtaining weights

First, we find the sums of C_j' from the previous step.

$$c_k = \sum_{k=1}^{n} c_j$$

Step 7: The following equation is used to get the normalized objective weights

$w_j = \frac{c_j}{c_k}$ (Krishnanet al., 2021).

3.2.3 VIKOR Method

The VIKOR technique, also known as ViseKriterijumska Optimizacija VIsekriterijumsko KOmpromisno Rangiranje I Kompromisno Resenje is a multi-criteria optimization approach for reasonably complicated systems. This strategy focuses on ranking and selecting from a collection of options, as well as creating compromise solutions in situations of conflicting criteria, to aid decision-makers in making a final choice. This compromise solution is the most realistic and close to perfect option, and compromise denotes an agreement reached via mutual compromises according to Kusuma and Ginting, (2020).

Step1: Determine the decision matrix of alternatives and criteria with measures

$$F = \begin{bmatrix} f_{11} & .. & f_{1n} \\ : & : & : \\ f_{m1} & .. & f_{mn} \end{bmatrix}$$

Step 2: Determining Criteria Weight (W).

$\sum_{j=1}^{n} w_j=1$

Step 3: Make a normalization matrix by deciding on positive and negative values as the best option for each criterion. The equation normalizes the decision matrix of options and criterion (F).

$N_{ij} = \frac{f^{+}-f_{ij}}{f^{+}-f^{-}}$

You may use the Max and Min functions to calculate the positive and negative values of all possibilities.

f^{+}=max $(\mathrm{f}_1 \mathrm{f}_2, \dots \dots, \mathrm{f}_{\mathrm{mj}})$

f^{-}=min $(\mathrm{f}_1 \mathrm{f}_2, \dots \dots, \mathrm{f}_{\mathrm{mj}})$

Step 4: Determine the normalized data's weighted value for each choice and criterion. This is accomplished by multiplying the normalized data value (N) by the criteria weight value (W) calculated via calculation:

$F_{ij}^{*}=w_j N_{ij}$

Step 5: Calculates the Utility Measure (S) and Regret Measure (R) values. Use the following formula to determine the Utility Measure (S).

$S_j=\sum_{j=1}^{n}\left[w_i \frac{f^{+}-f_{ij}}{f^{+}-f^{-}}\right]$

And the following formula may be used to determine Regret Measure (R).

$R_j=\sum_{j=1}^{n} max_j \left[w_i \frac{f^{+}-f_{ij}}{f^{+}-f^{-}}\right]$

Step 6: Perform a ranking. The sorting results are decided from the lowest value, with a compromise option as the optimal answer. This indicates that the lower the Qi ranking value, the higher the Qi ranking value may be put.

3.2.4 TOPSIS method

TOPSIS method under structure was laid out by Hwang and Yoon (1981) in the early 1980s.

The TOPSIS approach modifies the n-dimensional distance, Euclidean distance (n - number of variables) between the value vectors describing specific alternatives and vectors reacting to ideal and negative-ideal variations when comparing specific variables with one another. The option with the value vector that is farthest from the vector of the ideal solution while remaining closest to the vector of a negative-ideal solution is said to be the best alternative (Kobryń & Prystrom 2016).

Step 1: The process of creating the normalized decision matrix

$$r_{ij} = \frac{x_{ij}}{\sqrt{(\sum x_{ij}^{2})}}$$

Where i =1, ……., m x_{ij} *and* r_{ij} are original and normalization score of decision matrix, respectively

Step 2: Construct the weight normalization decision matrix

$v_{ij} = w_j r_{ij}$

Where w_j is the weight of j criterion.

Step 3: Determine the positive ideal and negative idea solution

Positive ideal

$A^{*} = \{v_1^{*}, \dots \dots, v_n^{*}\}$

Where $v_i^{*}= \left\{\max\,(v_{ij}) if\ j \in J; \min(v_{ij}) if\ j \in J'\right\}$

Negative idea.

$A' = \{v_1', \dots \dots, v_n'\}$

Where $v_i' = \{\min (v_{ij}) if\ j \in J; \max(v_{ij}) if\ j \in J'\}$

Step 4: Make the separation measurements for each option

The difference between the ideal positive alternative is:

$$S_i^* = \left[\sum (v_i^* - v_{ij})^2\right]^{1/2}$$

The difference between the ideal alternative and the ideal is:

$$S_i' = \left[\sum (v_i' - v_{ij})^2\right]^{1/2}$$

Step 5: Determine how near the solution is to the ideal one

$$C_i^* = \frac{S_i'}{(S_i^* + S_i')}$$

$$0 < C_i^* < 1$$

Select the Alternative with C_i^* closer to 1.

4. Results

Table Below are the results of the multi-criteria decision analysis by using three methods Multi-MOORA, VIKOR, TOPSIS, and their Comprehensive

Table 2: Results

Insulation material	Multi-MOORA	VIKOR	TOPSIS	Comprehensive
Expanded Perlite (EPB)	10	11	8	10
Expanded Clay	6	4	5	5
Polystyrene Foam extruded (XPS)	1	1	1	1
Polyurethane Rigid Foam (PUR)	2	2	3	2
Calcium Silicate Foam	7	10	7	7
Cotton	11	12	9	11
Insulation Cork Board (ICB)	12	8	4	8
Flax	8	9	6	6
Polystyrene Expanded (EPS)	3	3	2	3
Cellulose Fibres Boards	5	6	12	12
Wood Fibres insulating board (WF)	9	5	10	9
Coconut -Fibres	4	7	11	4

4.1 Multi-Mora Result:

The MOORA multiplication method had realistic and logical results. This method showed Polystyrene Foam extruded (XPS) scoring 1565.0334 as the top performing insulation material, Polyurethane Rigid Foam (PUR) scoring 682.2965333 as the second best, then Polystyrene Expanded (EPS) scoring 0.857304 in third, Cellulose Fibres Boards was 0.11001375 in fourth, Coconut Fibres of 0.06197184 in fifth, Calcium Silicate Foam scored 0.02513808 in sixth, and Flax scored 0.003373968 in seventh, and Expanded Perlite (EPB) scored 0.002588352 in eighth, and Expanded Clay scored 0.000480431 in ninth, cotton scored 0.000213465 in tenth, and Insulation Cork Board (ICB) scored -0.007620872 in eleventh, finally Wood Fibres insulating board(WF) scored -0.177197625 was the worst.

4.2 VIKOR Result:

VIKOR had Polystyrene Foam extruded in first at a Qi of 0.029735, and immediately behind it Polyurethane Rigid Foam Qi of 0.081012 in second, Polystyrene Expanded Qi 0.639706 in third, Expanded Clay Qi 0.654900 in fourth, and Coconut -Fibres Qi 0.895391 in fifth, and Wood Fibres insulating board Qi 0.911899 in sixth, and Calcium Silicate Foam Qi 0.924778 in seventh, and Cellulose Fibres Boards Qi 0.929145 in eighth, and Flax Qi 0.967157 in ninth, and Insulation Cork Board Qi 0.977851 in tenth, Cotton was the worst performing at a Qi of 0.980776, and Expanded Perlite second worst at 0.979396.

4.3 TOPSIS Results:

TOPSIS had Polystyrene Foam extruded in first at a score of 0.55330, and immediately behind it Polystyrene Expanded scoring 0.53438 in second, Expanded Clay scored 0.52384 in third, Insulation Cork Board scored 0.49554 in fourth, and Calcium Silicate Foam scored 0.48202 in fifth, and Expanded Perlite scored 0.48139, and Flax scored 0.47987 in seventh, and Polyurethane Rigid Foam scored 0.47916 in eighth, and cotton scored 0.47517 in ninth, and Wood Fibres insulating board scored 0.46499 in tenth, Coconut -Fibres was the worst performing at a score of 0.44096, and Cellulose Fibres Boards second worst at 0.45165. These results are close to the previous methods.

4.4 Comprehensive Results:

All the results of the three methods were combined. The result in all methods was that extruded polystyrene is the best performing material. Followed by Polyurethane Rigid Foam (PUR), Polystyrene Expanded (EPS), Coconut -Fibres, Expanded Clay, Flax, Calcium Silicate Foam, Insulation Cork Board (ICB), Wood Fibres insulating board, Expanded Perlite (EPB), Cotton, Cellulose Fibres Boards. We can say that the results were very realistic and logical.

5. Conclusion

The significance of this research in identifying the best performing insulation material among the 12 selected materials, by using MCDM methods (Multi-MOORA, CRITIC, VIKOR, and TOPSIS ways), the economic, social, and sustainable implications of this is critical to say the least. Extruded polystyrene foam was found to be the best performing material in this analysis. Extruded polystyrene is classified as a type of foam insulation board that has several economic benefits.

- Energy Efficiency: XPS insulation helps reduce the amount of energy required to heat and cool a building by reducing heat loss and air leakage. As a result, homeowners and businesses will have cheaper energy costs, which can save them a lot of money over time.
- Durability: XPS is a strong, long-lasting material that can handle challenging environmental conditions as well as large weights. Because of this, it needs less upkeep and replacement over time, which lowers the overall cost of building maintenance.
- Economical: When compared to other forms of insulation, XPS is an economical insulation material. Compared to other insulating materials such as rigid foam or spray foam, it has a relatively cheap cost per R-value (a measure of heat resistance). This means that using less material to get the same amount of insulation will ultimately result in a lower project cost.
- Environmental Benefits: Because XPS is recyclable and can be utilized in other goods, less waste is disposed of in landfills. Additionally, XPS's energy efficiency lowers greenhouse gas emissions, making the economy more sustainable.

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