Selection of insulation materials with PSI-CRITIC based CoCoSo method

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Abstract
The performance effect of construction on energy conservation substantially depends upon application of correct materials and energy saving methodologies. A sizable financial impact is accomplished through insulated walls. The criteria explaining the present wall insulating material options may have different values. Furthermore, they may alter in different aspects, i.e. higher values of certain criteria show a preferable status, while for others they denote an inferior status. In this framework, a variant of compromise is needed, which can be situated through multi-criteria assessment methodologies. To diminish the effect of different methodologies on computational results, few diverse techniques can be considered, with descriptions of the mean predicted values. Thus, drawbacks of certain multi-criteria assessment techniques could be compensated through others. A hybrid methodology through the combination of individual techniques will be accurate if there is a relationship between the values determined through diverse methodologies. In this study, the most efficient insulation material used at external walls is selected by using PSI-CRITIC based CoCoSo Method. The analytical results are important both from financial and engineering point of views as the applied methodology is commercially viable and practically implementable. Precise and up-to-date material properties are derived from the leading companies in the sector.

Keywords: PSI, CRITIC, CoCoSo. insulation materials, building, construction material.

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Introduction

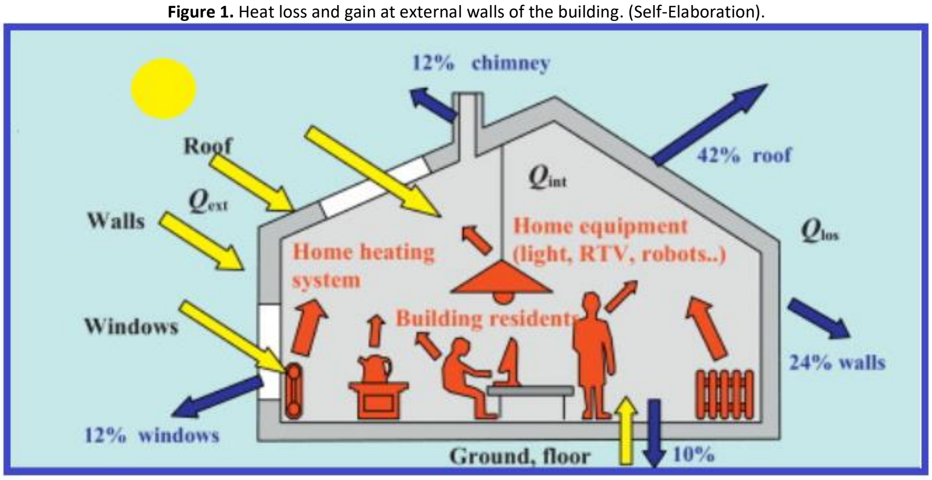
In a world with serious ecological pollution and with diminishing resources, it is clear that sustaining a certain level of life standard will be more and more challenging. As a complex system, constructions play a key role in society and our lives (Biekša et al., 2006). Generally, habitants living in relatively cold zones want to warm their indoor spaces while the ones living relatively hot zones want to cool their indoor spaces. It is known that thermal loss occurs as a result of heat transfer from hot to cold spaces. To overcome this loss in constructions, thermal insulating is supplied to sustain the needed warmth inside the construction (Schiavoni, D'Alessandro, Bianchi, & Asdrubali, 2016). Insulation can keep the inside of a container cold, or it can keep an enclosed space such as inside of a building warm. The thermal insulating can refer either to materials utilized to decrease the heat transfer's ratio, or the processes and methods utilized to decrease the transfer of heat. Thermal insulation purpose is to decrease the transfer of heat between inside and outside of a construction. Generally, the building walls and the external envelope of the building especially apply a prime role in construction, both from an economic perspective and in terms of habitability that they provide.

The insulation process is one of the most effective routes to protect energy at building as it keeps cool in the summer and warm in the winter. Natural insulation products often surpass many man-made insulation materials when considering the variety of advantages, they bring. They have a variety of features that, when used correctly, can significantly increase a building's efficiency. This results in a considerably more comfortable and tolerable living environment not only during the summer but also throughout the winter. Natural insulation products, unlike artificial fibres, have the ability to release and absorb moisture hygroscopically, hence reducing condensation danger within structure components while maintaining thermal efficiency. This property can also help to reduce the possibility of mold growth in the fabric of the structure. In buildings, many natural insulating products in buildings not only decrease CO2 emissions and heat loss. The natural insulation materials have a heat conductivity that is as low as the desired value, outperforming many artificial insulation materials. They outperform many plastic and artificial fiber insulation solutions acoustically because of a combination of their high density, flexibility, fibrous nature, and ease of cutting and handling. The natural insulation materials are unrivalled in terms of environmental and sustainability benefits. They are generally not detrimental to health because they do not comprise irritating fibres. They are also simple to set up because no special precautions are required. They also have a far smaller environmental impact than artificial insulation, however, it is not fully non-existent.

Description of the problem

Heat loss and gain at external walls of a building is shown in Fig.1 (Lewandowski & Lewandowska-Iwaniak, 2014). The heat flow can be decreased through addressing one or more of the heat transfer's 3 different techniques and is relevant on the functional features of the product used to do this. In building insulation, the *R* value is an evidence of how good a product isolates.

Figure 1. Heat loss and gain at external walls of the building. (Self-Elaboration).



To develop the energy performance, additional insulating materials should be placed in the constructions' exterior walls. The most effective and suitable way to accomplish this is the wall isolation from outside (Šadauskiene, Monstvilas, Stankevičius, & Šadauskienė, 2010). This can be done through pasting or fixing the walls on with insulation materials and then covering the external walls with plaster. Reasoning behind the external wall insulation is as it follows:

- Raising market value (Zavadskas, Raslanas, & Kaklauskas, 2008).
- Developing architectural façade solutions tailored to the specific climate.
- Increasing the level of comfort in a building.
- Extending the service life of a construction and increasing the efficiency of building constructions (Biekša et al., 2006; Šadauskiene et al., 2010; Zavadskas et al., 2008), decreasing energy expenditures.

State of the art

Diverse materials, durability, thermal parameters, and change in weight etc. can be used for this purpose. The building material choice defines the walls' thermal insulation cost. Under current market circumstances, the renovation expenses are paid to the landholder's institutions in majority of the cases (Zavadskas et al., 2008). Hence, they are concerned with the external wall's lower insulation cost. In this framework, finding an optimal solution to this problem becomes an important research issue and a functional trouble. The criteria clarifying the present thermal insulating material options for external walls may be assessed in different ways. In this content, a variant of compromise can be found with the implementation of multi-criteria appraisal methodologies (Brauers, Ginevicius, Zavadskas, & Antucheviciene, 2007; Hwang & Yoon, 1981; Kaklauskas, Zavadskas, Banaitis, & Satkauskas, 2007).

Whatever methodology is used, the effectiveness and the values of the criteria should be cognized. The material properties can be found in manuals, operating conditions, etc. By specialists, the effectiveness of the pre-determined criteria should be identified. There are weight definitions differing in many ways (Ginevičius, Podvezko, & Bruzge, 2008; Lin, Wang, & Yu, 2008; Zavadskas & Vilutiene, 2006). For a practical implementation, some of them are very complex. The others are not accurate enough because they are at very basic levels. In any case, the expert's evolutional accuracy substantially depends on the number of criteria.

When this number increases, a limitation may emerge when a specialist can no longer crosscheck the options and perform intellectual mathematics to identify their weight values. Among different materials, the selection methodologies of the most advantageous material have been in development over lifetime decade. These methodologies characteristically aim at choosing the most proper resolution for a given implementation to meet a series of needs from micro-scale to macro-scale (Ashby, 2005; Ermolaeva, Kaveline, & Spoormaker, 2002; Guisbiers & Wautelet, 2007) below the conceptual design's completion. Generally, material choice occurs in one of the 3 stages below (Dieter, 1986):

(a) The materials requirement analysis. Identify the terms of environment and service that the material must resist, and convert them into the needed product features.
(b) The candidate materials screening. Crosscheck the needed features with a big material feature database to choose many products that look favourable for the implementation.
(c) The candidate materials selection. Analyse the candidate materials to choose the most advantageous material for the implementation.

A number of studies have focused on approaches based on simulation for evaluating the efficiency of the outer wall. The simulation tools and numerical modellings were used by Sutheesh and Chollackal to analyse the thermal efficiency of the multilayer insulation (Sutheesh & Chollackal, 2018). Künzel and Holm evaluated the fundamental principles of the established wall models and examples (including necessary data and obtainable results) of guidelines defined through the use of simulation analyses to assist (Künzel & Holm, 2009). Under Italian climate conditions, the efficacy of three separate traditional wall formations was investigated by Stazi and co-workers. The wall efficiencies were researched by CFD Fluent modelling & EnergyPlus tools (Stazi, Vegliò, Di Perna, & Munafò, 2013). Oikonomou et al. assessed the building internal temperature variety during high outer media temperatures by defining the thermal properties of the buildings in London by EnergyPlus simulation (Oikonomou et al., 2012). Ji and co-workers digitally analysed the impact of options such as thickness, emissivity, the density position layout, foil number, material density and foil emissivity. It was established that the best efficacy is accomplished by the specific layer number. As the volume of the sheet raises, the insulation's total conductivity raises owing to the highly conductive metallic foils' dominance (Ji, Zhang, Sunden, & Xie, 2014). The wind-driven rain quantification quest was explored by Blocken and Carmeliet via numerical, experimental, and semi-empirical methods. Based on building science, the authors compared the wind-driven rain quest abstract (Blocken & Carmeliet, 2004). In particular, McLeod and Hopfe explored the drawbacks of dynamic modelling in terms of input points and data sources. Inhomogeneity in structural materials, for instance, makes it difficult to refrain from uncertainty in modelling parameters (McLeod & Hopfe, 2013).

Alifanov and co-workers computed the radiative and thermal features such as emissivity and thermal conductance though the inverse problem method through measuring the thermal flux and temperature (Alifanov, Nenarokomov, & Gonzalez, 2009). Porritt and co-workers used dynamic thermal simulation to analyse the terraced buildings' expertise in the United Kingdom in the late centuries to cope with future thermal waves by embracing different mitigations like ventilation, sun shading, and insulation strategies (Porritt, Shao, Cropper, & Goodier, 2011). In addition to the long-term laboratory experiments, Karamanos and co-workers investigated the efficiency of the stone-wool insulation material under changing temperature and humidity circumstances by modelling (Karamanos, Hadiarakou, & Papadopoulos, 2008). De Wilde and co-workers used the terraced houses' transient modelling utilizing the EnergyPlus programme to equate infinite projections of climate change with variations in the thickness of building materials, occupancy patterns of building, and control settings of HVAC (de Wilde, Rafiq, & Beck, 2008). For the construction assessment based on U-values and RdSAP program's Chartered Institution of Building Services Engineers Guide A, the isolated external building walls were researched utilizing Strube et al.'s simplified steady-state heat loss modelling. The findings obtained were analysed according to the criteria of Passiv Hause Enerphit (Strube, Miller, & Ip, 2012). Orme and co-workers researched thermal and APACHE regression analysis results obtained. For climate scenarios, they demonstrated the various insulation measures' sensitivity (Orme, Palmer, & Irving, 2003). Sanders summarized the existing models for change condensation risk analysis. He addressed the availability of data on material characteristics and proper boundary conditions for modelling purposes (Sanders, 2005).

To assess the thermal efficiency of the multilayer insulation with double aluminized Mylar reflective foil and glass fabric spacer, a numerical modelling was improved with combined conduction and radiation by Bapat et al. (1990). The conduction rose with a raise in layer density owing to the efficient thermal conductivity of the enhanced isolation (Bapat et al., 1990). In Germany, Kunzel and co-workers have examined numerous external insulation build wall facilities with relatively extreme temperature variations and wind-driven rain on multi-story floors (Künzel, Künzel, & Sedlbauer, 2006). In wide Dewar tanks, multilayer insulation has been investigated by (Nast, Frank, & Feller, 2014). A simulation modelling was developed to test the cryogenic fluid boil-off and the thermal conductivity of multilayer insulation.

For NASA, test results were used for the planning of large propellant tanks (Nast et al., 2014). The hygrothermal and thermal efficacy of the twenty-year old external wall insulation device was evaluated using laboratory experiments and control, parametric simulations and analysis by Stazi and co-workers (Stazi, Di Perna, & Munafò, 2009). Carabano and co-workers analysed life cycle assessment of thermal insulation materials to evaluate building sustainability (Carabaño, Hernando, Ruiz, & Bedoya, 2017). Bojic and Loveday investigated the impact of the distribution of insulation. They modelled 3-layered structures using climate data from the United Kingdom (Bojić & Loveday, 1997). In North America, external insulation systems for lightweight constructions have been tested by Künzel and Zirkelbach in mild and cold climates using the WUFI programme (Künzel & Zirkelbach, 2006). A transient 3-D and 2-D modelling was carried out by Karagiozis and Kumaran by comparatively early modelling predictions using the IRCINRCC-designed LATENITE process. This approach was used by various extended wall insulation systems to digitally obtain humidity, heat transport, and air (Karagiozis & Kumaran, 1997).

The 3D model of the light weight thermal protection system was improved by Xie and co-workers. The ANSYS simulation programme formed a sandwiched panel and the ANSYS simulation programme subjected it to mechanical and thermal loads. The parametric design language along with the globally convergent process algorithm of moving asymptotes was used for optimization of the minimum weight thermal protection system. The provided thermal conservation device was 0.37 lighter after optimization (Xie, Wang, Sunden, & Zhang, 2013).

Mavrogianni and co-workers used EnergyPlus for London characteristics to obtain complex thermal simulations for the 3456 integrations of dwelling types (Mavrogianni, Wilkinson, Davies, Biddulph, & Oikonomou, 2012). Gupta and co-worker shown on the GPS-based modelling's use for 6 construction archetypes using Bristol, Stockport, and Oxford data (DECoRuM- Carbon Reduction Modelling, Domestic Energy, and Adapt Carbon Counting). By means of dynamic thermal simulation, they compared the shift in overheating with reference to adaptation packages (Gupta & Gregg, 2013). Pavlík and co-worker provided the laboratory modelling for the evaluation of the hygrothermal efficiency of building envelopes to simulate on-site terminology that can be used (Pavlík & Černý, 2008).

Material choice indicates holistic and systematic strategy to arrive at a decision and can dramatically impact the efficiency. For the optimization purposes, a multi-criteria analysis methodology can be utilized. The analysis displays that the maximum financial impact can be provided through insulating the building's external envelope. The external wall insulation's effectiveness depends upon a lot of elements. Specialists point out more than twenty criteria. All of them are not of the same significance. Hence, 5 main criteria were selected. Some of these criteria have inverse relationship which means that the insulation condition becomes more favorable with the increase in values of certain criteria and decrease in others. Through the multi-criteria assessment methodologies, this complex phenomena's quantitative assessment can be meaningfully applied. They can be performed when all the criteria weights and values are understood. To simplify this operation, the mean prediction value should be situated. For the methodologies' integration to be right, it is essential to identify the relation between the values defined through different assessment methodologies.

In order to design an energy-efficient building, this paper is constructed to select an efficient external wall insulation material among various types of insulation materials. For building the external wall, the natural insulation materials are obtained from leading companies in the sector and they are utilized to establish modelling with five primary criteria consisting density, specific heat, thermal transmittance, thermal conductivity, and thermal wave shift attributes. By this research, grouping them in primary categories and determining the related criteria is the new approach obtained. The built modelling is supported by using two multi-criteria decision making techniques.

Methodology

PSI method

PSI (Preference Selection Index) (developed by (Maniya & Bhatt, 2010)) is a method used to determine objective weights of criteria. This method's steps are indicated below (Madić, Antucheviciene, Radovanović, & Petković, 2017).

Step 1: Decision matrix (*D*) is structured with Eq. (1).

$$D = [d_{ij}]_{m\times n} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \tag{1}$$

In above matrix, d_{ij} denotes the performance of ith option on jth criterion.

Step 2: Values in this matrix are normalized by utilizing equations two (for beneficial criteria) and three (for cost criteria) Eq. (2) and (3).

$$d_{ij}^* = \frac{d_{ij}}{max(d_{ij})} \tag{2}$$

$$d_{ij}^* = \frac{min(d_{ij})}{d_{ij}} \tag{3}$$

Step 3: The average of normalized value of jth criterion is obtained with Eq. (4).

$$\bar{d}_j^* = \frac{\sum_{i=1}^{m} d_{ij}^*}{m} \tag{4}$$

Step 4: Preference variation value (PV_j) for jth criterion is calculated with Eq. (5).

$$PV_j = \sum_{i=1}^{m} (d_{ij}^* - \bar{d}_j^*)^2 \tag{5}$$

Step 5: The deviation (δ_j) in preference value is computed for each criterion with equation Eq. (6).

$$\delta_j = (1 - PV_j) \tag{6}$$

Step 6: With Eq. (7), the weights of criteria (w_{jPSI}) are calculated as,

$$w_{jPSI} = \frac{\delta_j}{\sum_{j=1}^{n} \delta_j} \tag{7}$$

CRITIC method

CRITIC method (developed by (Diakoulaki, Mavrotas, & Papayannakis, 1995)) is also utilized to identify the criteria' objective weights (Jahan, Mustapha, Sapuan, Ismail, & Bahraminasab, 2012). This method is a correlation technique that utilizes the standard deviation of criteria values of alternatives for each column, as well as correlation coefficients of all paired columns to identify contrasts of the criteria (Žižović, M., Miljković, B., & Marinković, 2020). This method's steps are explained below (Jahan et al., 2012).

Step 1: Decision matrix (D), which is indicated in equation 1, is constructed.

Step 2: This matrix is normalized by utilizing Eq. (8) (for beneficial criteria) and Eq. (9) (for cost criteria).

$$t_{ij} = \frac{d_{ij} - min(d_{ij})}{max(d_{ij}) - min(d_{ij})} \quad (8)$$

$$t_{ij} = \frac{max(d_{ij}) - d_{ij}}{max(d_{ij}) - min(d_{ij})} \quad (9)$$

Step 3: The weights of criteria (w_{jCR}) are calculated with Eq. (10).

$$w_{jCR} = \frac{k_j}{\sum_{e=1}^{n} k_e} \quad (10)$$

In above equation, k_j denotes the quantity of information stored in jth criterion. This value is computed with Eq. (11) (Madic & Radovanović, 2015).

$$k_j = \sigma_j \sum_{e=1}^{n} (1 - f_{ej}) \quad (11)$$

In Eq. (11), σ_j denotes the standard deviation of jth criterion and f_{ej} denotes the correlation coefficient between eth criterion and jth criterion. The objective weights of criteria obtained by utilizing PSI and CRITIC methods are combined by using Eq. (12) (Zavadskas & Podvezko, 2016).

$$w_{jCO} = \frac{w_{jPSI} w_{jCR}}{\sum_{j=1}^{n} w_{jPSI} w_{jCR}} \quad (12)$$

In equation 12, w_{jCO} denotes the criteria' combination weights.

CoCoSo method

CoCoSo method (developed by (Yazdani, Zarate, Zavadskas, & Turskis, 2019)) is a technique that combines simple additive weighting method and exponentially weighted product modelling. This method is utilized to rank the insulation materials. The CoCoSo's steps are indicated below.

Step 1 and *Step 2* of CRITIC method and CoCoSo method are the same. Therefore, these steps will not be indicated again.

Step 3: The sum of the weighted comparability (E_i) and power weight of comparability (C_i) sequences are computed respectively with Eqs. (13) and (14):

$$E_i = \sum_{j=1}^{n} (w_j t_{ij}) \quad (13)$$

$$C_i = \sum_{j=1}^{n} (t_{ij})^{w_j} \quad (14)$$

Step 4: Aggregated appraisal scores ($a_{i\alpha}$, $a_{i\beta}$, $a_{i\gamma}$) are calculated with Eqs. (15), (16) and (17), respectively:

$$a_{i\alpha} = \frac{C_i + E_i}{\sum_{i=1}^{m} (C_i + E_i)} \quad (15)$$

$$a_{i\beta} = \frac{E_i}{min(E_i)} + \frac{C_i}{min(C_i)} \quad (16)$$

$$a_{i\gamma} = \frac{\lambda (E_i) + (1-\lambda)(C_i)}{((\lambda) max(E_i) + (1-\lambda) max(C_i))} \quad (17)$$

In equation 17, λ $(0 \leq \lambda \leq 1)$ is generally accepted as 0.5.

Step 5: For each alternative, the last score (a_i) is calculated as in Eq. (18):

$$a_i = \left(a_{i\alpha} a_{i\beta} a_{i\gamma}\right)^{1/3} + +\frac{1}{3}\left(a_{i\alpha} + a_{i\beta} + a_{i\gamma}\right) \qquad (18)$$

The option having the highest score is identified as the best option.

Results

In this paper, the alternatives for uncommercial-natural insulation are assessed with respect to 5 criteria named Density, Specific Heat, Thermal Transmittance, Thermal Conductivity, and Thermal Wave Shift. Only Specific Heat criterion is noted as a beneficial criterion and the other criteria are considered as cost criteria. Decision matrix including insulation materials that were utilized to decrease the heat energy transfer and the selected criteria are indicated in Table 1.

Table 1. Properties for natural insulation (Schiavoni et al., 2016).

Thermal insulation material	Density (kg/m^3)	Specific heat (kj/kg K)	Thermal conductivity (W/ mK)	Thermal transmittance (W/m^2 K)	Thermal wave shift (h)
Cellulose(1)	70	2	0.039	0.296	11.1
Coir	105	1.5	0.043	0.318	11.0
Cork	130	2.1	0.040	0.302	12.6
Flax	30	1.6	0.040	0.302	9.8
Hemp	90	1.7	0.040	0.302	11.2
Jute	35	2.4	0.038	0.290	10.3
Kenaf	100	1.7	0.030	0.241	12.0
Mineralized wood fiber	533	1.8	0.065	0.425	15.7
Sheep wool	20	1.8	0.038	0.290	9.6
Cotton (recycled)	25	1.6	0.039	0.296	9.7

First, PSI method is implemented to this matrix to obtain objective weights of criteria. The PSI method's results are shown in Table 2.

Table 2. The Results of PSI Method. (Self-Elaboration).

Results	Density (kg/m^3)	Specific heat (kj/kg K)	Thermal conductivity (W/m K)	Thermal transmittance (W/m^2 K)	Thermal wave shift (h)
PV_j	0.939	0.118	0.152	0.098	0.131
1-PV_j	0.061	0.882	0.848	0.902	0.869
w_{jPSI}	0.017	0.248	0.238	0.253	0.244

After the implementation of PSI method, CRITIC method is applied to the Decision Matrix to obtain the criteria' objective weights. After this process, the weights of criteria obtained in PSI method and the weights of criteria obtained in CRITIC method are combined by utilizing equation 12. The weights of criteria obtained in CRITIC method and the combination weights (w_{jCO}) of criteria are represented in Table 3.

Table 3. The weights of criteria obtained in CRITIC method and the combination weights of criteria. (Self-Elaboration).

Results	Density (kg/m^3)	Specific heat (kj/kg K)	Thermal conductivity (W/m K)	Thermal transmittance (W/m^2 K)	Thermal wave shift (h)
w_{jPSI}	0.017	0.248	0.238	0.253	0.244
w_{jCR}	0.135	0.433	0.121	0.125	0.185
w_{jCO}	0.009	0.498	0.135	0.149	0.209

After obtaining the combination weights, CoCoSo method is applied to the Table 1 (decision matrix) to rank the alternatives. By using equations 8 and 9, the normalized matrix is achieved. This matrix is presented in Table 4.

Table 4. The normalized matrix. (Self-Elaboration).

Thermal insulation material	Density (kg/m^3)	Specific Heat (kj/kg K)	Thermal Conductivity (W/mK)	Thermal Transmittance (W/m^2 K)	Thermal Wave Shift (h)
Cellulose(1)	0.903	0.556	0.743	0.701	0.754
Coir	0.834	0	0.629	0.582	0.770
Cork	0.786	0.667	0.714	0.668	0.508
Flax	0.981	0.111	0.714	0.668	0.967
Hemp	0.864	0.222	0.714	0.668	0.738
Jute	0.971	1.000	0.771	0.734	0.885
Kenaf	0.844	0.222	1.000	1.000	0.607
Mineralized wood fiber	0	0.333	0	0	0
Sheep wool	1.000	0.333	0.771	0.734	1.000
Cotton (recycled)	0.990	0.111	0.743	0.701	0.984

Discussion

By using equations 13 and 14, the sum of the weighted comparability (E_i) and power weight of comparability (C_i) are obtained. In these equations, the combination weights of criteria are used. Table 5 represents the sum of the weighted comparability and power weight of comparability.

Table 5. The sum of the power weight of comparability and weighted comparability. (Self-Elaboration).

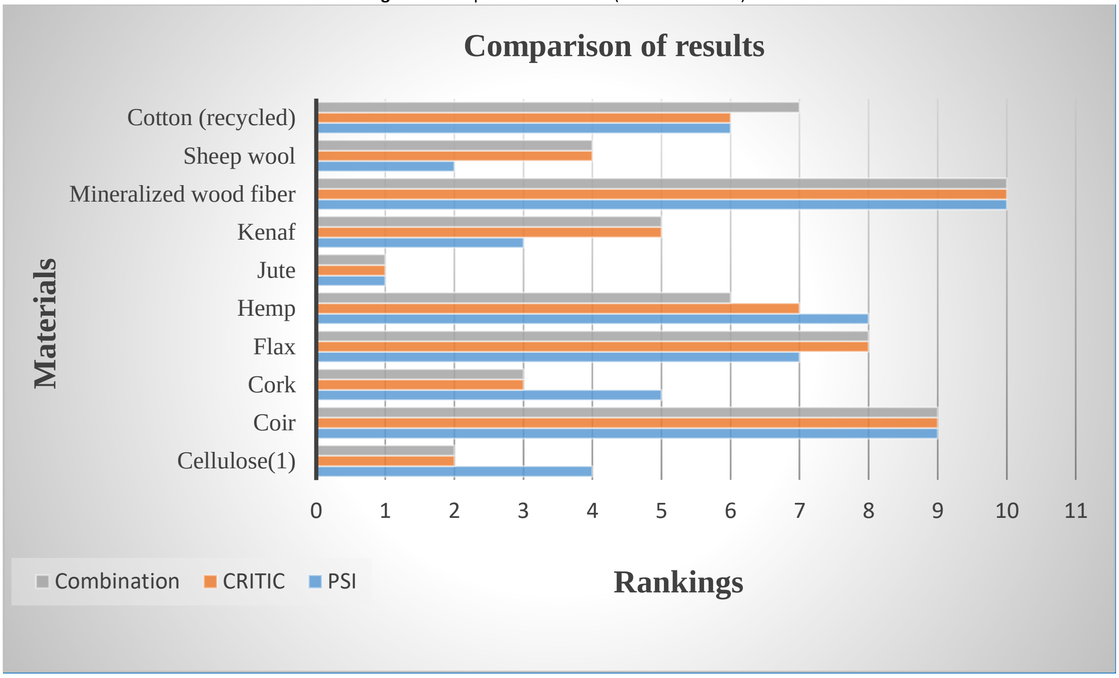
Thermal insulation material	E_i	C_i
Cellulose (1)	0.647	4.597
Coir	0.340	3.807
Cork	0.641	4.580
Flax	0.462	4.225
Hemp	0.468	4.307
Jute	0.905	4.895
Kenaf	0.529	4.372
Mineralized wood fiber	0.166	0.578
Sheep wool	0.597	4.499
Cotton (recycled)	0.475	4.240

By using equations 15-18, the results of CoCoSo method and the ranking of alternatives. Table 6 indicates the results of CoCoSo method. According to Table 6, the ranking of thermal insulation materials are as follows: Jute, Cellulose (1), Cork, Sheep wool, Kenaf, Hemp, Cotton (recycled), Flax, Coir, and Mineralized wood fiber. Among these insulation materials, the best one is reported to be Jute. The weights of criteria obtained in PSI method and the weights of criteria obtained in CRITIC method are used in equations 13 and 14 to compare the conclusions of the combination weights-CoCoSo method. Figure 2 represents the comparison of results.

Table 6. The conclusions of CoCoSo method. (Self-Elaboration).

Thermal insulation material	$a_{i\alpha}$	$a_{i\beta}$	$a_{i\gamma}$	a_i	Rankings
Cellulose(1)	0.116	11.851	0.904	5.365	2
Coir	0.091	8.635	0.715	3.972	9
Cork	0.115	11.785	0.900	5.335	3
Flax	0.103	10.093	0.808	4.612	8
Hemp	0.105	10.271	0.823	4.694	6
Jute	0.128	13.921	1.000	6.228	1
Kenaf	0.108	10.751	0.845	4.895	5
Mineralized wood fiber	0.016	2.000	0.128	0.875	10
Sheep wool	0.112	11.380	0.879	5.163	4
Cotton (recycled)	0.104	10.197	0.813	4.657	7

Figure 2. Comparison of results. (Self-Elaboration).



As it can be seen from the Figure 2, the Jute material has been determined as the best material in all three cases. The rankings of Jute, Coir and Mineralized wood fiber materials have not changed in all three cases. The rankings of other materials have changed at least once. Considering these three cases, the rankings are combined with dominance theory (Brauers & Zavadskas, 2010) to achieve the final rank of the materials. The final rankings of material with respect to dominance theory are as follows: Jute, Cellulose (1), Cork, Sheep wool, Kenaf, Cotton (recycled), Flax, Coir, and Mineralized wood fiber. In this study, robust results were obtained by using two types of criteria weighting (PSI and CRITIC) methods.

Conclusions

Isolation products are used to retard the heat energy's flow by decreasing loss of heat or gain from vessels, tanks, ductwork, pipe, and walls. Isolation materials can assist mechanical structures to decrease pollutants' emissions to the atmosphere and also operate within ecological criteria. The insulation material professionals mention many criteria. Not all of them are of the same significance. Thus, five important main criteria were selected. Their values change in diverse directions and of diverse dimensions. This implies that when some of their values rise, the problem gets better, whereas when the values of some other parameters are increased, the condition worsens. By hybrid multi-criteria assessment methods, these complicated phenomena's quantitative assessment can be meaningfully performed.

In this study, PSI-CRITIC based CoCoSo Method of multi-criteria evaluation was used in selecting the most efficiency natural thermal insulation material for the external walls of a building. The most commonly used thermal insulation materials' primary features are assessed. All of the findings were analysed utilizing the applied hybrid multi-criteria decision making approach to determine material solutions' clear view by each criterion's relative significance. This article can be used as a reference for the producers and users in terms of determining the most efficient natural option while choosing an insulation material.

In this study, the classic CRITIC method is used. Žižović and his colleagues (2020) changed the normalization and aggregation process of the CRITIC method to overcome the limitations of this method. Future studies may use this modified CRITIC method to overcome the limitations of the classical method. In this study, completely objective data were used in the evaluation process. Future studies may receive data from experts to determine the weights of criteria. Thus, more detailed research could be done by the inclusion of the subjective weights of criteria in the evaluation process. In addition, uncommercial-natural insulation materials were only included in the evaluation in this study. Future studies may create a more inclusive study by adding commercial insulation materials in the evaluation process.

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