Integrated FAHP-FPROMETHEE for thermal insulation of masonry buildings

Abstract

Purpose- The need for the thermal insulation of masonry buildings in Algeria is no longer debated. This paper proposes an integrated fuzzy multi-criteria decision aid method for the thermal insulation of masonry buildings in order to rank the thermal insulation solutions.

Design/methodology/approach-The proposed method combines the Fuzzy Analytical Hierarchy Process (FAHP) with the Fuzzy Preference Ranking Organization Method for Enrichment Evaluation (FPROMETHEE).

Findings- A case study using the proposed method is detailed in this paper. The building users' preferences obtained by the FAHP had a higher level of consistency, and accuracy. The case study demonstrates how in a highly uncertain field such as thermal insulation of masonry buildings, the FPROMETHEE can prevent the loss of valuable evaluation data, and overcome the difficulty in integrating linguistic assessments of the thermal insulation alternatives.

Originality-The proposed method extends the current knowledge by using the FAHP to consider uncertainties regarding the building users' preferences, and the FPROMETHEE in order to get a complete ranking of the thermal insulation solutions taking into account the uncertainties related to the alternatives' evaluations.

Keywords FAHP, FPROMETHEE, masonry buildings, multi-criteria decision making, thermal insulation, building users' preferences

Paper type Research paper

1 Introduction

The final energy consumption in Algeria has reached 30 million PET (Petroleum Equivalent Tonnes) in 2012. Residential and tertiary sectors represent one of the highest energy consumption with 34% of the total energy production. The existing building stock in Algeria has reached 6.500.000 habitations in 2016, from those 1.050.000 consist of masonry habitations built before 1945 (Denker et al. 2014). The majority of masonry buildings were constructed according to traditional techniques and materials during the French colonial period. Masonry buildings do not meet any current thermal regulations. The Algerian context offers a great opportunity to perform the thermal insulation of masonry buildings, and this for the two following reasons:

1. A political engagement for the energy efficiency of the existing buildings stock. The Algerian energy policy is based on three main actors which are; the national agency for the promotion and the rationalization of the energy use (APRUE), the thermal regulation DTR (Regulatory Technical Documents) provided by the law of 1999, and the national fund for energy management (FNME). In order to reduce greenhouse gases emissions and to mitigate climate change, the government plans to decrease its national energy consumption by 16% by 2020 (Bouamama 2013). For this purpose, the government has launched in 2016 a national energy saving program that aims the insulation of 100.000 houses per year (Denker et al. 2014).
2. A political engagement for the perseveration of masonry buildings. In order to preserve the masonry buildings, the government has implemented a regulation which specifies the responsibilities of the building users in the maintenance of the common areas in the building (Mazouz 2015). Currently, due to the indifference of the building users concerning the preservation of masonry buildings, most of these buildings require an urgent intervention since they present clear elements of aging and degradation (Ibrahim 2013). Therefore, the government, without the involvement of the building users is obliged to take in charge the preservation of masonry buildings by launching interventions. In 2016, the government has started the rehabilitation of 300.000 masonry buildings (Addab 2015).

The thermal insulation of masonry buildings would reduce the energy consumption of the residential sector and guarantee the preservation of masonry buildings. However, the selection of thermal insulation solutions during their renovations is a difficult decision since it simultaneously involves a multitude of criteria including risks related to the heritage preservation (Zagorskas et al. 2014). Furthermore, the preferences of the building users regarding the criteria should be taken into account (Strachan and Banfill, 2012). Another issue is that different uncertainties that can affect the evaluation of the thermal insulation solutions have to be considered. In fact, during the decision process, the evaluation of the insulation solutions in term of different criteria (building performance indicator) can be the result of building simulation tools or simplified design guidelines or expert recommendations based on subjective judgments. Recent studies have revealed that the results are usually difficult to quantify using a set of exact values and that the uncertainties in the evaluations can be important, which makes it crucial to take into account those uncertainties (Mathieu, 2006). Additionally, taking into account the building users' preferences during the decision process involves subjective assessments. A lack of understanding of the building users' concerning the evaluation criteria or the thermal insulation solution may lead to imprecise data in a qualitative manner. Due to the uncertainties of information in the decision process, as well as the vagueness of human judgments, it is usually complicated to make an accurate assessment (Zheng et al. 2009).

This paper proposes an integrated decision aid method for the thermal insulation of masonry buildings with a heritage value. It combines the Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Preference Ranking Organization Method for Enrichment Evaluation (FPROMETHEE). The aim of this method is to rank the thermal insulation solutions using a fuzzy multi-criteria approach. The proposed method takes into account uncertainties concerning the evaluations of the thermal insulation solutions, and uncertainties regarding the building users' preferences.

2 Literature review

2.1 Multi-criteria decision aid method and thermal renovation

The main scientific works available in the literature considering the application of multi-criteria decision aid method in the thermal renovation of buildings were summarized, in putting in evidence the field of application, the method used, the method's category, and comments on the method (see table 1). The multi-criteria decision aid (MCDA) methods were often used in the literature for the thermal renovation of buildings. They can be ranked into two different families according to their aggregation approach; the partial aggregation approach, and the complete aggregation approach. It is possible to say from table 1 that MCDA methods were rarely applied for the thermal insulation of masonry buildings with a heritage value. To the best of our knowledge, none of the existing method takes into account at the same times:

- The risks related to the specificity of the thermal insulation of masonry buildings with a heritage value.
- Uncertainties concerning the evaluation of the thermal insulation solutions.
- Uncertainties regarding the building users' preferences.
- Additional constraints such as the maximum budget allocated to the operation.

This paper proposes an integrated FAHP-FPROMETHEE decision aid method for the thermal insulation of masonry buildings with a heritage value. Mardani et al., (2015) have provided a large state of the art about the applications of fuzzy multiple criteria decision-making in various fields. So far, the FAHP-FPROMETHEE has not been used for the thermal insulation of masonry buildings with a heritage value.

Table 1: Main works available in the literature concerning the application of MCDA methods in thermal renovation of buildings

Authors	Fields of application	MCDA methods and its category	Comments
(Rey 2004)	Thermal renovation of office buildings	ELECTRE Partial aggregation	These approaches use the partial aggregation. They allow taking into account both quantitative and qualitative criteria without having to do any coding. It does not allow compensation between criteria.
(Rutman et al. 2005)	Study of air conditioning systems	ELECTRE Partial aggregation	
(Roulet et al. 2002)	Thermal renovation of office buildings	Rating method Complete aggregation	These approaches use the complete aggregation. They allow the compensation of low score in criteria with good results on several other criteria. Also, it is necessary to carry out a coding to take into account both quantitative and qualitative criteria.
(Blondeau et al. 2002)	Summer ventilation strategies	MAUT Complete aggregation	
(Alanne 2004)	Thermal renovation of residential buildings	knapsack model Complete aggregation	The advantage of this model is to introduce additional constraints in order to treat a portfolio optimization case.
(Kontu et al. 2015)	Selection of heating system for residential buildings	SMAA Complete aggregation	The relevance of these approaches is to take into account the preferences of the building users.
(Medineckiene and Björk, 2011)	Thermal renovation of residential buildings	AHP,SAW,MEW, COPRAS Complete aggregation	
(Zagorskas et al. 2014)	Selection of insulation option for historic buildings	TOPSIS Complete aggregation	The pertinence of this approach is to take into account the risks related to the specificity of the insulation of historic buildings.
(Mathieu 2006)	Thermal renovation of residential buildings	ELECTRE Partial aggregation	This approach integrates uncertainties related to the characterization of existing buildings and the evaluation of renovation scenarios.
(Zheng et al. 2009)	Building energy conservation	FAHP Complete aggregation	This approach integrates uncertainties regarding the decision-makers preferences.

ELECTRE: Elimination and Choice Expressing the Reality; MAUT: Multi-Attribute Utility Theory; MCDA: Multi-Criteria Decision Aid; SMAA: Stochastic Multi-criteria Acceptability Analysis; AHP: Analytical Hierarchy Process; SAW: Simple Additive Weighting; MEW: Multiplicative Exponential Weighting; COPRAS: Complex Proportion Assessment; TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution; FAHP; Fuzzy Analytical Hierarchy Process.

2.2 *Integrated approach Fuzzy HAP- Fuzzy PROMETHEE*

The integrated FAHP-FPROMETHEE decision aid method represents the association of FAHP with FPROMETHEE. This combination enables to take into account the uncertainties concerning the decision makers' preferences, as well as the uncertainties concerning the evaluation of the alternatives regarding the criteria. It also allows considering additional constraints such as the maximum budget allocated to the operation. The integrated FAHP-FPROMETHEE has been successfully implemented in various area as indicated by Mardani et al., (2015). Kafa et al., (2014) applied the integrated FAHP-FPROMETHEE for the evaluation of the sustainability performance of third party reverse logistics providers. Gupta et al., (2012) used FAHP-FPROMETHEE for the selection of logistic service provider for a cement industry while Hashemian et al., (2014) applied it for assessment of supplier process. In order to elaborate in detail the FAHP-FPROMETHEE approach, a presentation of its components (FAHP, and FROMETHEE) is developed below:

2.2.1 *AHP and Fuzzy AHP*

The FAHP method is a combination between the AHP method and the fuzzy numbers. Here, in short words we present the original AHP method, as well as the advantage to combine it with fuzzy set theory and to use FAHP.

2.2.1.1 *AHP*

The Analytic Hierarchy Process AHP was developed by Saaty (1982). It is probably the best-known and most widely used multi-criteria making method in various domains. According to Macharis et al., (2004), AHP method is based on three principles: (1) construction of a hierarchy, (2) priority setting, and (3) logical consistency. First, the decision problem is structured and decomposed using a hierarchy with goals into different levels at the top of the hierarchy. A hierarchy has at least three levels: the main objective at the top, the criteria or sub-objectives at the intermediate levels and the considered alternatives at the bottom. Second, the relative priorities of each element in the hierarchy are determined by comparing all the elements of the lower level against the criteria, with which a causal relationship exists. The decision maker uses a pairwise comparison in order to define the relative ‘‘priority’’ given to each element in the hierarchy with respect to the global goal. Lastly, the degree of consistency achieved in the pair-wise comparison is measured by a consistency ratio indicating whether the comparison made is consistent. This procedure is explained in detail in Saaty (1982). The advantage of the AHP method is that it provides specific guidelines to determine the weight of the criteria. However, AHP presents the disadvantage to use the complete aggregation approach, which conducts into a compensation between good and bad scores on criteria. Furthermore, in the pair-wise comparison the AHP method does not take into account uncertainties regarding the humans' judgments.

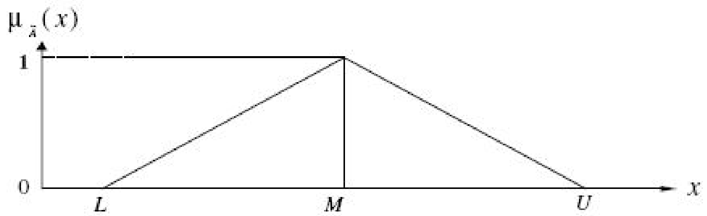
2.2.1.2 FAHP

To overcome the limitations of the AHP method concerning the uncertainties, several researchers have integrated fuzzy theory with AHP method. Van Laarhoven and Pedrycz (1983) were the first to integrate triangular fuzzy numbers in the pairwise comparison matrix of the AHP method and used the FAHP to improve uncertainty. Later, trapezoidal fuzzy numbers were also frequently used in decision making processes (Buckley 1985). The fuzzy set theory was developed by Bellman and Zadeh (1970). The logic of the fuzzy set theory is that an element is defined by a membership function that specifies the degree of membership of the element in a fuzzy set. In order to express the degree of membership function, the unit interval [0, 1] is the most commonly used range. In this paper, triangular fuzzy numbers are applied due to the easiness of their calculations and their efficacy in treating imprecise data in a fuzzy environment. A fuzzy number Ã on R is a triangular fuzzy number (l, m, u) if it is membership function $x \in \tilde{A}, \mu_{\tilde{A}}(x) : R \to [0, 1]$ is equal to as follows (see figure 1) :

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l) & l \leq x \leq m \\ (u-x)/(u-m) & m \leq x \leq u \\ 0 & otherwise \end{cases} \quad (1)$$

Where, the parameters *l*, *m* and *u* respectively express the smallest values, the most possible value, and the largest possible value (Taha and Rostam, 2012).

Figure 1: The membership function of the triangular fuzzy number



FAHP method has been widely applied in various areas (Kubler et al., 2016). For instance, it has been used in logistics (Gupta et al., 2012), and construction (Radziszewska and Szewczyk, 2016). The general FAHP process used in this paper is discussed in step 4 of the methodology section.

2.2.2 PROMETHEE AND FPROMETHEE

The FPROMETHEE method represents the combination between the PROMETHEE method and the fuzzy numbers. Here we succinctly present the original PROMETHEE method, as well as the interest to combine it with fuzzy set theory, and to use FPROMETHEE.

2.2.2.1 PROMETHEE

PROMETHEE methods are multi-criteria decision-making methods that use the partial aggregation. Brans (1986) introduced first PROMETHEE in the form of partial ranking of alternatives. A few years later, several versions of the PROMETHEE methods were proposed to help with more complicated decision-making situations (Macharis et al., 2004). The PROMETHEE methods deal with ranking a finite number of alternatives. Implementing PROMETHEE methods requires specifying for each criterion two types of information; the weights, and the preference functions. The weights (w_j) provide information between the different criteria. They represent the importance of each criterion. The preference functions ($P_j(a,b)$) provide information within the same criterion. They represent for each pair of alternatives "a", "b" the preference intensity of "a" over "b". A multi-criteria preference index is defined as in equation (2).

$$\pi(a,b) = \sum_{j=1}^{k} w_j \times P_j\,(a,b) \qquad (2)$$

Where π (a, b), expresses the preference degree of "a" over "b" regarding all the criteria, it varies from 0 to 1.

Where wj , is the normalized weight assigned to criterion j

The weights and the preference functions are used to compare the actions pairwise in order to establish a comprehensive ranking. This process is explained in details in Macharis et al., (2004). PROMETHEE methods present the advantage to use the partial aggregation approach, which permits to preserve the quality of the information. They do not allow the compensation between good scores on some criteria and bad scores on other criteria. PROMETHEE V allows adding many types of real-life constraints, such as the maximum budget allocated to an operation (Brans, 1992). However, PROMETHEE methods do not provide any specific technique to define the weights of the criteria. Furthermore, PROMETHEE methods do not allow capturing the uncertainties concerning the evaluation of the alternatives regarding the criteria.

2.2.2.2 FPROMETHEE

Incorporating fuzzy set theory into PROMETHEE method allows capturing the uncertainties concerning the evaluation of the alternatives regarding the criteria. Goumas and Lygerou (2000) were the first to propose the combination of PROMETHEE method with triangular fuzzy numbers for the interpretation of linguistic variables. Later, Fuzzy-PROMETHEE has been successfully implemented in various areas such as industry (Motlagh et al., 2015), customer reviews (Peng et al., 2014), and logistics (Gupta et al., 2012). In this work, we adopt the Fuzzy-PROMETHEE method as it is described by Gupta et al.,(2012). In this approach, all the data concerning the multi-criteria evaluation of the alternatives are directly converted to a linguistic scale in order to take into account the uncertainties regarding these assessments. The Fuzzy-PROMETHEE process used in this paper is discussed in detail in step 5 of the methodology section.

3 Methodology

This section presents an integrated FAHP-FPROMETHEE method to rank different insulation solutions. The proposed method consists of the following steps:

Step 1 Full investigation on the building

A comprehensive investigation of the current situation of the building and the main characteristics of the site was carried out. The data collection concerned the following aspect:

- The implantation of the building and the climate zone.
- The internal organization (plans, sections).
- The plan of facades with full details.
- The area and volume of the building.
- The methods of construction of the building and the openings (load bearing elements, walls, nature of the connections, roof, flours, and windows type).
- The energy consumption and the technical equipment's.

Furthermore, data concerning the building exploitation (the number of occupants, the occupancy scenario, the calculation set point temperature for the heating needs and for the cooling requirements, windows opening hours) were obtained through interviews with the building users. This first step should help to define if the building presents a real opportunity for energy improvement. If not the process stops here with only few recommendations.

Step 2 Alternative generations

Once the investigation on the building was completed, the user of the method has formulated a set of thermal insulation alternatives. The proposed method takes into account only the insulation of the building envelope (roof insulation, wall insulation, windows insulation etc).

Step 3 Evaluation criteria

The thermal insulation solutions were evaluated on a multi-criteria basis. During this step, the user of the method through direct interviews with the building users has defined the objective of the operation (the energy consumption decrease), and the constraint of the operation (the investment cost). The number of users to be interviewed depends on the case study (e.g. in our case study, the building has 4 flat, consequently, 4 building users were interviewed). Furthermore, the user of the method has integrated the risks related to the architectural, and the hygrothermal specificities of masonry buildings (the risk of the loss of building historic aesthetic features, and the risk of the fabric decay). The evaluations were as follow:

- The investment cost was calculated in Algerian dinars.
- The energy consumption decrease was expressed with the heating and air conditioning annual need decrease, and was evaluated under TRANSYS (Solar Energy Lab University of Wisconsin-Madison).

- The risk of the fabric decay was evaluated in terms of moisture accumulation in walls under the WUFI software (The Fraunhofer Institute for Building Physics).
- The risk of the loss of building historic aesthetic features was evaluated by means of subjective judgments.

Subsequently, according to the results of the evaluation of alternatives in terms of the selected criteria, all the data were converted to linguistic scales in order to take into account the uncertainties regarding these assessments.

Step 4 Calculating criteria weight via FAHP

The building users have expressed their preferences concerning the criteria though FAHP method. The method follows the steps described next as indicated in Gupta et al., (2012).

Step 4.1 Pairwise comparisons of the criteria:

First, each building user had to perform pairwise comparisons of the criteria regarding the global objective (thermal insulation) through a fuzzy linguistic (qualitative) scale. The linguistic scale permits to take into account uncertainty concerning the building user's preferences. Linguistic variables express a human statement that can be divided in a number of linguistic criteria for example, "Strongly more important," "Weakly more important," "Just equal," "Strongly less important" and "Weakly more important". For instance, table 2 presents the linguistic judgments of the pairwise comparison of the criteria for one building user involved in the process.

Table 2: linguistic judgments of the pairwise comparison of the criteria for one building user

	Energy consumption decrease	Investment cost	Risk of the loss of building historic aesthetic features	Risk of the fabric decay
Energy consumption decrease	Just equal (JE)	Equally less important (ELI)	Strongly more important (SMI)	Strongly more important (SMI)
Investment cost	Equally more important (EMI)	Just equal (JE)	Strongly more important (SMI)	Strongly more important (SMI)
Risk of the loss of building historic aesthetic features	Strongly less important (SLI)	Very strongly less important (VSLI)	Just equal (JE)	Weakly more important (WMI)
Risk of the fabric decay	Strongly less important (SLI)	Very strongly less important (VSLI)	Weakly less important (WLI)	Just equal (JE)

Later, triangular fuzzy numbers (l, m, u) were used to specify the linguistic values of these comparisons, as presented in Gupta et al., (2012). For example, Just equal is converted to (1, 1, 1), and equally more important is converted to (0.5, 1, 1.5), and so on.

The pairwise comparison matrix for each building user was obtained as shown in equation (3).

$$\tilde{A}_d = (\tilde{a}_{ij})^d_{n\times n} = \begin{bmatrix} A_1 & (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ A_2 & (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_3 & (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix} \quad (3)$$

Where $\tilde{a}_{ij}$is the relative importance of i^{th} criterion over j^{th} criterion as assigned by dth building user. Where d = 1, 2, , ,D and "D" is the number of total the building users.

Step 4.2 Obtaining the weighted comparison matrices:

Table 4 indicates the weighted comparison matrix for all building users, this matrix was defined as per the as per the following equations:

$$\widetilde{(b_{ij})}_{n\times n} = (l_{ij}, m, u_{ij}) = \sum_{d=1}^{d=D} w_d \times (\tilde{a}_{ij})^d_{n\times n} \; for \; i \leq j \quad (4)$$

For $i \leq j$ and w_d = individual weight of the d_{th} building user (all the building users had the same weight in this paper) and:

$$\widetilde{(b_{ij})}_{n\times n} = \widetilde{(b_{ji})}^{-1}_{n\times n} = \left(\frac{1}{u_{ji}}, \frac{1}{m_{ji}}, \frac{1}{l_{ji}}\right) \; for \; i > j \quad (5)$$

Step 4.3 Find the sum of each row of the fuzzy comparison matrix by fuzzy arithmetic operations as shown in equation 6:

$$\tilde{S}_{ri} = \sum_{j=1}^{j=n} \tilde{b}_{ij} = \left(\sum_{j=1}^{j=n} \tilde{l}_{ij}, \sum_{j=1}^{j=n} \tilde{m}_{ij}, \sum_{j=1}^{j=n} \tilde{u}_{ij}\right) \quad (6)$$

Where $\tilde{S}_{ri}$ is the sum of ith row.

Step 4.4 Find the sum of all the rows as per the following equation:

$$\tilde{S}_t = \sum_{i=1}^{i=n} \tilde{S}_{ri} \quad (7)$$

Step 4.5 Divide the sum of each row by the sum total of all the rows as per the following equation:

$$\tilde{S}_t = \tilde{S}_{ri} \times [\tilde{S}_t]^{-1} \quad (8)$$

To obtain the estimates for the vectors of weights under each criterion, it was required to determine the degree of possibility of greatest or least fuzzy number among the several fuzzy synthetic extents.

Step 4. 6 Compute the degree of possibility of $\tilde{S}_i \geq \tilde{S}_j j$ *by the following equation*

$$V(\tilde{S}_i \geq \tilde{S}_j) = \begin{cases} 1 & if\ m_i \geq m_j \\ \dfrac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)} & if\ l_j \leq u_i\ \ i,j = 1,\dots,n;\ \ j \neq i \\ 0 & others \end{cases} \quad (9)$$

Step 4.7 Computing degree of possibility:

The degree of possibility of $\tilde{S}_i$ over all other (n - 1) fuzzy numbers was calculated through equation 10:

$$V(\tilde{s}_i \geq \tilde{s}_j | j, \dots . n; j \neq i) = \min V(\tilde{s}_i \geq \tilde{s}_j), \quad i = 1, \dots, n \quad (10)$$

$$\text{If } d'(A_i,) = \min V(\tilde{s}_i \geq \tilde{s}_j)$$

Then for *j=1,…,n*; *j ≠ i* , the weight vector is given by equation 11 :

$$W' = (d'(A_1,), (d'(A_2,), \dots, (d'(A_n,))^T \quad (11)$$

Normalizing the weight vector, we get the weights of the criteria as indicated in equation 12:

$$W = (d(A_1,), (d(A_2,), \dots, (d(A_n,))^T \quad (12)$$

Where *W* and *W'* are non-fuzzy numbers and are the weights of the criteria.

Step 5 FPROMETHEE and PROMETHEE V

According to PROMETHEE theory, preference functions (Pj(a,b)) should be specified for each criterion. The preference function type IV (Level criterion) was chosen in this paper as it is indicated in Brans et al., (1986). It is the most suitable preference function for dealing with qualitative information. The weights and the preference function of the building users were used to compare the actions. First, the leaving flow and the entering flow were calculated:

The leaving flow Phi+ (Ø+) represents a strength measure. It is a number between 0 and 1; this means that for a given action if the leaving flow is 1 the action is preferable to all the others actions on all the criteria, and if the leaving flow is equal to 0 this means that the action does not represent any advantage over the other actions. Phi+ is calculated with equation (13).

$$\emptyset^+(\mathrm{a}) = \frac{1}{\mathrm{n}-1} \sum_{\mathrm{b} \neq \mathrm{a}} \pi\,(\mathrm{a}, \mathrm{b}) \quad (13)$$

The entering flow Phi- (Ø-) represents a weakness measure. It is a number between 0 and 1, where 0 is the best solution and 1 the worst one. Phi- is calculated with equation (14).

$$\emptyset^{-}(a) = \frac{1}{n-1}\sum_{b\neq a}\pi\,(a,b) \qquad (14)$$

Secondly, the net flow Phi (Ø) was calculated. It represents the difference between the two flows as shown in equation (15). The net flow allows establishing a comprehensive ranking of actions.

$$\emptyset(a) = \emptyset^{+}(a) - \emptyset^{-}(a) \qquad (15)$$

Additional constraints were introduced through PROMETHEE V. A binary variable (0-1) xi was associated with each action “ai”: xi = 1 means that the action “ai” is selected, xi = 0 means it is not. The aim is to select the actions so that the sum of the Phi (Ø) of these actions is maximum as shown in equation (16).

$$\max\sum_{i=1}^{n}\emptyset\ (a_i)x_i \qquad (16)$$

4 Case study

In this section, the case study approach was chosen in order to test the applicability of the proposed method for the thermal insulation of masonry buildings. This approach has been widely used in the literature for the same purpose (Medineckiene and Björk, 2011), (Zagorskas et al. 2014). The case was selected as a pilot study by the government. It is the building number 11 Boulevard Matta, Oran, Algeria. It is a neoclassical colonial collective building constructed in masonry between the late 19 the century and early 20 the century. An investigation on the building was carried out (step1). The building has 4 flats occupied by 4 different users. The apartments are distributed two per each floor. The total building volume is 2.320 m3. The floor- area is 580 m2. The building is equipped with four individual heating systems and four individual air conditioning systems. The annual heating and electricity consumption of the building is about 66.332 kWh. The roof is built in vaulted brick floor and metal beams; it has a U-value of 1.69 W/m2K. Exterior masonry walls have a thickness of 55 cm and a U-value of 1.19 W/m2K. The windows are all single glazed with a U value 5.68 W/m2K. Then the user of the method has formulated a set of thermal insulation alternatives and evaluated them in terms of the various criteria (step 2 and step 3 see table 3).

Table 3: Evaluation table

Code	Actions (Thermal renovation solutions)	C1	C2	C3	C4
A1	Exterior insulation of the main facade with 10 cm of expanded polystyrene	Medium	Good -very good	Very high	Very high
A2	Exterior insulation of the main facade with 10 cm of cellular concrete	Medium	Medium	Very high	Low
A3	Exterior insulation of the main facade with 10 cm of wood fiber	Medium	Good -very good	Very high	Low
A4	Exterior insulation of the main facade with 6 cm of lime hemp plaster	Bad-medium	Good	Very low	Very low
A5	Exterior insulation of the secondary facade and courtyard with 10 cm of expanded polystyrene	Medium	Very good	Medium	Very high.
A6	Exterior insulation of the secondary facade and courtyard with 10 cm of cellular concrete	Medium	Good	Medium	Low
A7	Exterior insulation of the secondary facade and courtyard with 10 cm of wood fiber	Medium	Very good	Medium	Low
A8	Exterior insulation of the secondary facade and courtyard with 6 cm of lime hemp plaster	Bad-medium	Very good	Very Low	Very low
A9	Exterior insulation of the roof with 10 cm of expanded polystyrene	Medium-good	Bad-medium	Very low	Low
A10	Exterior insulation of the roof with 10 cm of wood fiber	Medium-good	Bad-medium	Very low	Low
A11	Exterior insulation of the roof with 15 cm of expanded polystyrene	Good	Bad	Very low	Low
A12	Exterior insulation of the roof with 15 cm of wood fiber	Good	Bad	Very low	Low
A13	Double glazing window installation	Very good	Very bad	Medium	-
A14	Double windows installation	Good - very good	Very bad	Very low	-
A15	Secondary glazing installation	Medium	Medium	Very low	-

C1: Energy consumption decrease; C2: Investment cost; C3: Risk of the loss of building historic aesthetic features, C4: Risk of the fabric decay

The normalized criteria weights (wj) were determined using FAHP (step 4). First, four different users performed a pairwise comparison of the criteria through linguistic (qualitative) preferences regarding the global objective (thermal insulation) as indicated in table 2. Then, the linguistic preferences were converted to triangular fuzzy numbers (Step 4. 1). Table 4 indicates the results of steps 4.2, 4.3, 4.4, and 4.5. Using equations (4) and (5), the weighted comparison matrix for all the building users is obtained (Step 4.2). Then, the sum of the individual row (Step 4.3) and the sum total of all the rows (Step 4.4) are respectively calculated through equation (6) and equation (7). After, using equation (8), the sum of each row is divided by the sum total of all the rows (Step 4.5).

The degree of possibility of $\tilde{S}_i \geq \tilde{S}_j$j where $i, j = 1, \dots, n;\ j \neq i$ is computed (Step 4.6). For example, the calculations for the degree of possibility of $\tilde{S}_1 \geq \tilde{S}_2, \tilde{S}_1 \geq \tilde{S}_3, \tilde{S}_1 \geq \tilde{S}_4$ are presented below:

As $l_j \leq u_i, V(\tilde{S}_1 \geq \tilde{S}_2) = \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)} = \frac{0.317 - 0.314}{(0.317 - 0.328) + (0.328 - 0.314)}$ =0.97

As $m_i \geq m_j, V(\tilde{S}_1 \geq \tilde{S}_3) = 1$

As $m_i \geq m_j, V(\tilde{S}_1 \geq \tilde{S}_4) = 1$

Therefore, the weight vector W' computed as in equation, (10) and (11) is:

$d'(C_1) = V(S_1 \geq S_2, S_3, S_4) = \min(1.00, 1.00, 0.97) = 0.97$

Similarly, the calculated values for d' (C_2), d' (C_3), d' (C_4) were (1, 0.74, 0.72). After normalizing, the criteria weights (wj) according to the building users preferences' were as follow: the energy consumption decrease (0.283), the investment cost (0.290), the loss of building historic aesthetic features (0.217), the risk of the fabric decay (0.210).

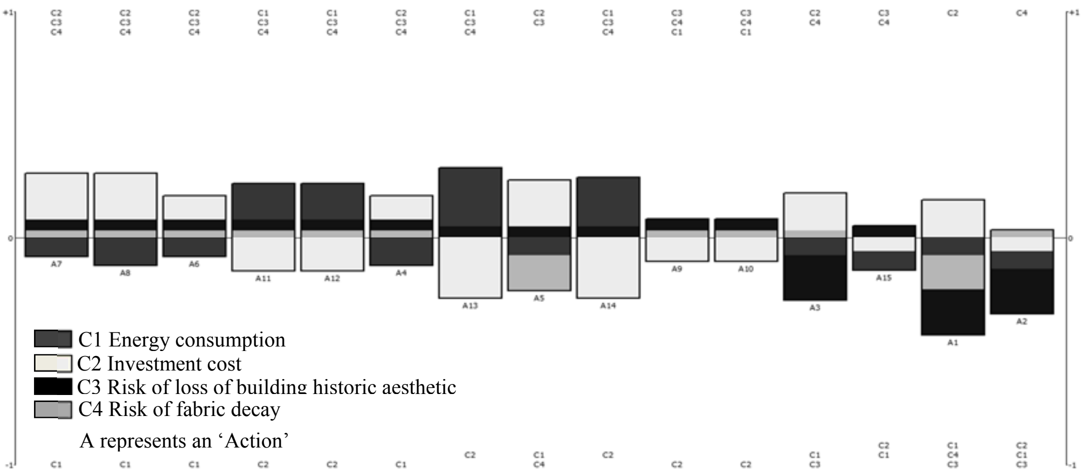
Table 4: Weighted comparison matrix for all building users

	C1	C2	C3	C4	Sum of row elements	Dividing each row sum by sum total of all rows
C1	(1, 1, 1)	(0.667,1.04,1.62)	(1.5,2,2.5)	(1.5,2,2.5)	(4.66,6.04,7.62)	((0.328,0.328,0.317)
C2	(0.475,0.833,1.25)	(1, 1, 1)	(1.5,2,2.5)	(1.5,2,2.5)	(4.47,6.,7.25)	(0.314,0.328, 0.302)
C3	(0.433,0.616,1)	(0.391,0.533,1)	(1, 1, 1)	(0.761,1.166,1.75)	(2.58,3.31,4.75)	(0.181,0.180,0.197)
C4	(0.433,0.616,1)	(0.433,0.616,1)	(0.625,0.958,1.37)	(1, 1, 1)	(2.49,3.19,4.37)	((0.175,0.173,0.182)
Sum total of all rows =					(14.2,18.37,23.99)	

C1: Energy consumption decrease; C2: Investment cost; C3: Risk of the loss of building historic aesthetic features, C4: Risk of the fabric decay

The calculations of step 5 were performed under Visual PROMETHEE software (VP Solutions and Mareschal, 2012). A complete ranking FPROMETHE according to the building users' preferences was calculated. For this purpose, three additional constraints (number of actions to select, incompatibilities between actions, maximum budget available) were added since there were 15 alternatives and only 4 could have been selected simultaneously, the maximum budget available was about 16.000 US dollar. These constraints were taken into account through PROMETHEE V method. According to the building users' preferences, the results indicate that action A7 has a phi net flow of 0.204 followed by action A11 with a phi net flow of 0.093, action A4 with a phi net flow of 0.062, and action A13 with a phi net flow of 0.039. These are the preferred actions to all the other actions. Details of these preferences are shown on figure 2. Please note that the ranking and the criteria weights' are specific to this case and are not to be considered applicable to other buildings.

Figure 2: Details of the Phi net flow computation for building users



As indicated on figure 2, details of the Phi net flow computation for the building users highlight the good and weak characteristics of each action with bar. These bars were shaded to reveal each criterion in an action. Each part is equivalent to the influence of one criterion to the Phi net flow score of the action. Positive (upward) parts correspond to good characteristics while negative (downward) parts correspond to weaknesses. The balance between positive and negative slices is equal to the Phi score. Actions were ranked from left to right according to the FPROMETHEE complete ranking (without the additional constraints). As shown on figure 2, action (A7) had very good features in the investment cost (C2), good features in both the risk of the loss of building historic aesthetic features (C3) and the risk of fabric decay (C4). However, it had weak features in the energy consumption decrease (C1). Also, action (A11) had very good features in the energy consumption (C1), good features in the risk of the loss of building historic aesthetic features (C3) and very weak features in the investment cost (C2). Action (A4) demonstrates good features in the investment cost (C2), the risk of the loss of building historic aesthetic features (C3) and fabric decay (C4). However, it had very weak features in the energy consumption decrease (C1). Finally, action (A13) revealed very good features in the energy consumption decrease (C1), good features in the risk of the loss of building historic aesthetic features (C3) and very weak features in the investment cost (C2).

5 Discussion

The MCDA approaches used for the thermal renovation considered that building users express strict preferences as argued by Kontu et al., (2015) and Medineckiene and Björk, 2011). However, the proposed method extends the current knowledge by using the FAHP to consider uncertainties regarding the preferences of building users. The FAHP shows that the building users considered respectively the criteria investment cost and energy consumption decrease as very important. While the criteria risk of the loss of building historic aesthetic features and the risk of the fabric decay were respectively less important. Therefore, it is necessary to motivate the dwellers about the heritage preservation and help them to balance between their need for the energy efficiency and the preservation of the cultural heritage. The results indicate that the criteria weights obtained by FAHP had a higher level of consistency, and accuracy. Most of the MCDA applied in the thermal renovation field uses the complete aggregation approach or the partial aggregation methods ELECTRE. The originality of the proposed method is to use FPROMETHEE in order to get a complete ranking of the thermal insulation solutions taking into account the uncertainties related to the alternative evaluations. Furthermore, the proposed method does not allow the compensation between criteria contrary to the complete aggregation approaches proposed by Zagorskas et al., (2014) and Kontu et al., (2015). In fact, the results indicate that the selected actions do not represent a high risk for the preservation of the case study building, despite the fact that the criteria risk of the loss of building historic aesthetic features and the risk of the fabric decay were respectively the least important criteria. This implies that the best thermal insulation solutions are not those that have the best performance in the criteria with the highest weight but they are those that represent the best compromise. This agreed with researches carried out by Macharis et al., (2004) which argued that partial aggregation approaches do not allow compensation between criteria. Additionally, the method offers the possibility to introduce additional constraint through PROMETHEE V, which is very useful for real life problems when the number of actions or the available budget is limited according to Brans, (1992). The validity of the method was assessed by the building users; they all agreed on the selected thermal insulation solutions. The method described in this article is universal, and can always be applied for selecting thermal insulation solutions when masonry buildings or other types of buildings are considered.

6 Conclusions

This paper considers the thermal insulation of masonry buildings with a heritage value as a complex decision involving different criteria including risks related to the heritage preservation. The paper has an innovative value due to the proposal of an integrated FAHP-FPROMETHEE to rank different thermal insulation solutions. The application of the proposed method on a real case study showed that it was possible to get a full ranking of the alternatives. The ranking of the thermal insulation solutions and the criteria weights' are specific to this case and are not to be considered applicable to other buildings. The preferences of building users obtained by the FAHP had a higher level of consistency, and accuracy. The case study demonstrates how in a highly uncertain field such as thermal insulation of masonry buildings, the FPROMETHEE can prevent the loss of valuable evaluation data, and overcome the difficulty in integrating linguistic assessments of the thermal insulation alternatives. However, the proposed method has several limitations. The FAHP-FPROMETHEE method requires judgments between each pair of criteria. The use of the method is pertinent only for the insulation of the building envelope. The method evaluates each alternative individually but does not take into account the combination of solutions. Furthermore, the developed method in its actual form is expected to be used by a facilitator who would help the building users to choose the best solutions. However future improvements such as an automatic version of the proposed method would facilitate its use for the building users. From a more global aspect, the extensive application of any outcomes of the method might be challenging and further social awareness is required to achieve a smooth operation in applying the agreed outcomes. For further research, all these limitations could be taken into account.

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