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Dwelling Selection by Applying VIKOR and Fuzzy AHP Method

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Abstract. The purpose of this study is twofold: first, it is aimed at demonstrating a model of dwelling selection using an integrated VIKOR and fuzzy analytical hierarchy process (FAHP). Second, a selection among alternative buildings and their heating system is made using a proposed VIKOR-fuzzy AHP methodology. Types of building under consideration are composed of traditional singe flat dwelling house and loft flat dwelling house. In this paper, alternatives of heating system include coal based, gas based, biomass based, and combined biomass and gas based systems. Eight criteria are used for making decision. In dwelling decision making problems, data obtained from decision makers are imprecise because the decision makers cannot give exact values for the criteria. This research allows the decision makers to assess the alternative buildings by using linguistic terms. Fuzzy theory is used to address uncertainty in human preferences. Thus, the weights of the selection criteria are determined by pairwise comparison matrices of fuzzy AHP. It was found that one flat dwelling house with coal based heating is the most appropriate alternative buildings.

Keywords: VIKOR, fuzzy AHP, Dwelling, Alternative, Selection, Heating System

1. Introduction

The civil construction industry is one of the greatest sectors in the economy and one of the biggest polluters [1]. The construction sector has not only a major impact on economic activity, employment and growth rates, but has also a substantial impact on the natural environment, the effects of which are evident across the world. Housekeeping was responsible for 12% of the greenhouse gases. In addition with the 5% of the commercial premises, this leaded to a total of 17% of the greenhouse gases. To investigate the influence of different heat systems on the energy performance level, previous study undertook a cost analysis of different heating systems (condensing gas boiler, non-condensing gas boiler, oil boiler, and heat pump) and ventilation systems (C and D). The analysis was performed for three representative types of dwellings in Flanders: a terraced, semi-detached and detached dwelling. The analysis clearly indicated that a condensing gas boiler in combination with the heat exchanger was most advantageous. It was the cheapest heating system and generates the lowest energy level. This made the condensing gas boiler the best choice for all dwelling types. The aim of the study was to search for the cheapest heating system and the heating system generating the best energy level [2]. However, factors such as design complexity speed of construction, durability, environment, aesthetics, construction complexity, and geometric design should be considered in a conceptual design phase [3]

To make right decision in dwelling house construction, decision maker usually has little information and it is usually incomplete. Selection of the dwelling house can be classified as a multi-criteria decision-making (MCDM) problem [4]. One widely used method which can handle both – group decisions and fuzziness – is the fuzzy analytic hierarchy process (AHP) – a further development of Saaty's widely used AHP technique [5,6]. Several researches present the application of the fuzzy AHP, for example, critical decisions in new product development [7]. VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje that means Multi-Criteria Optimization and Compromise Solution) method is one of the most popular methods. A VIKOR method is used to rank alternative. The VIKOR method provides the maximum group utility for the majority and minimum of an individual regret for the opponent. The multi-criteria ranking index is obtained based on the particular measure of closeness to the ideal solution. The VIKOR method is not based the evaluation unit of a criterion function [8,10].

This paper provides a systematic approach to dealing with alternative design of dwelling house. The proposed approach considers both qualitative and quantitative assessments. The assessment of alternative dwelling houses is performed using fuzzy AHP and VIKOR method. The results can be used to evaluate alternative future methods to enhance sustainability. This paper presents an example for being an innovative way of evaluating different dwelling houses, taking into account affects of uncertainty. This study considers fuzziness, which is the main reason for the implementation of the fuzzy AHP and the VIKOR method instead of the classical usage of the AHP or other MCDM methods. The result can be used as information for developers, contractors and designers to develop measures for satisfying all requirements (i.e., cost, time, energy).

2. Dwelling Selection Method

Various criteria related to the dwelling selection are introduced. The important criteria are usually associated with cost, material, energy, water. Ten criteria were considered for selecting best alternative for dwelling selection problems [4]. Ten criteria included $x1$ – material, used for construction process (t/m2), $x2$ – energy, used for construction process (GJ/m2), $x3$ – water, used for construction process (m3/m2), $x4$ – energy use for 50 year operation phase (kWh/m2), $x5$ – enclosures with heat losses (m2), $x6$ – CO2 use for 50 year operation phase (kg/m2), $x7$ – price of the apartment (€/m2), $x8$ – labor costs (human hour/m2), $x9$ – Fuel annual price (€/100m2), *and* $x10$ – Price of energy use for 50 year operation phase (Lt/m2). Eight alternatives were determined, namely $A1$ – one flat dwelling house with coal based heating, $A2$ – one flat dwelling house with gas based heating, A3 – one flat dwelling house with biomass based heating, A4 – one flat dwelling house with combined biomass and gas based heating, $A5$ – loft flat dwelling house with coal based heating, $A6$ – loft flat dwelling house with gas based heating, $A7$ – loft flat with biomass based heating, and $A8$ – loft flat dwelling house with combined biomass and gas based heating. Eight alternatives were evaluated by considering ten criteria, simultaneously. To determine these criteria at the same time for finding a final solution, elements of uncertainty involved in these criteria influence the decision making process. Decision makers are not only required to make a decision based on various criteria, they also have to consider conflicting relationships existing between these criteria of which the values are subjectively assessed. The uncertainty and the qualitative human thoughts are difficult to measure in quantitative value for the criteria associated with the dwelling selection [4].

3. Fuzzy AHP and VIKOR Method

A decision-making model should well handle vagueness or ambiguity because of fuzziness and vagueness associated with decision-making problems. This section provides an overview of a fuzzy AHP for addressing uncertainty in the sustainable university of research project assessment. The pairwise comparison considers favorable and adverse effects of uncertainty. The ranges are used to present uncertainty involved in the pairwise comparisons by using parameters l and u to present favorable and adverse effects of uncertainty, respectively.

The fuzzy AHP is one of the effective approaches used to address the uncertainty and vagueness from the subjective perception and the experience of humans in decision-making process. By using the fuzzy AHP, the decision makers are allowed to provide the comparing results by the interval judgement instead of crisp value judgement which makes the decision makers feel more convenient and confident. The effects of uncertainty on the pairwise comparison are qualitatively estimated by the decision maker at a given level regarding their parent in the next higher level, based on the requirement of the comparative judgement principle. The fuzzy AHP integrates these individual effects of uncertainty on the pairwise comparison by combining the calculated ratio-score local priorities according to the requirement of the synthesis of priorities.

In this study, the fuzzy AHP is applied to evaluate the weight factor by using five linguistic terms: equally significant, moderately significant, strongly significant, very strongly significant, and extremely significant of which the numerical ratings are 1, 3, 5, 7, and 9, respectively [6].

The VIKOR method started with the form of L_{p}-$metric$, which was used as an aggregating function in a compromise programming method and applied to the multicriteria measure for compromise ranking. In the proposed approach, the alternatives are denoted as $A_1, A_2, ..., A_i, ..., A_m$, w_j is the weight of the j_{th} criterion, expressing the relative importance of the criteria, where $j = 1,2,...,n$, and n is the number of criteria. The rating (score) of the j th criterion is denoted by f_{ij} for alternative A_i. The form of L_{p}-$metric$ was introduced by Duckstein and Opricovic and is formulated as follows:

$$L_i^p = \left\{ \sum_{j=1}^{n} \left[w_j \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right) \right]^p \right\}^{\frac{1}{p}} \quad 1 \le p \le \infty \quad i = 1,2,...,m \tag{1}$$

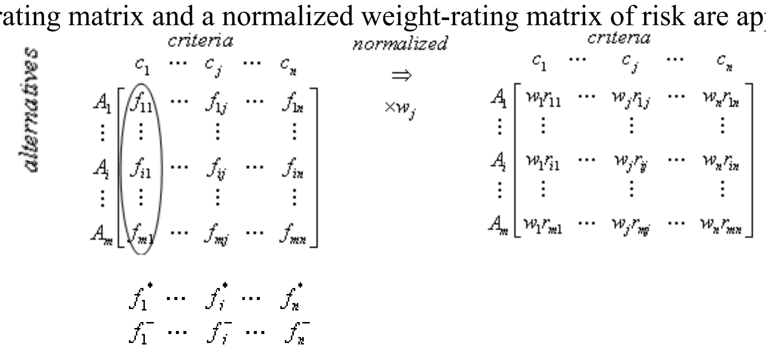
The VIKOR method is developed from the above form of L_{p}-$metric$. In addition, it uses $L_i^{p=1}$ (as S_i in Eq. (2)) and $L_i^{p=\infty}$ (as Q_i in Eq. (3)) to obtain the ranking measure [13-16]

$$S_i = L_i^{p=1} = \sum_{j=1}^{n} \left[w_j \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right) \right] \tag{2}$$

$$Q_i = L_i^{p=\infty} = \max_j \left\{ w_j \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right) \middle| j = 1,2,..., n \right\} \tag{3}$$

The compromise ranking algorithm VIKOR includes the following steps.

Step 1 Consider the best f_j^*, and the worst f_j^- values of all criterion functions, $j = 1,2,...,n$. In addition, an original rating matrix and a normalized weight-rating matrix of risk are applied as follows:



(Original data) (Normalized data)

where, $r_{ij} = \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right)$, f_j^* is the aspired/desired level and f_j^- is tolerable level for each criterion.

Step 2 Calculate the values S_i and Q_i, $i = 1,2,...,m$, applying the relations

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \tag{4}$$

$$Q_i = \max_j \left\{ w_j r_{ij} \middle| j = 1,2,...,n \right\} \tag{5}$$

Step 3 Calculate the index values R_i, $i = 1,2,...,m$, using the relation

$$R_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(Q_i - Q^*)/(Q^- - Q^*) \tag{6}$$

where $S^* = \min_i S_i$ (or setting the best $S^* = 0$) $S^- = \max_i S_i$ (or setting the worst $S^- = 1$) $Q^* = \min_i Q_i$ (or setting the best $Q^* = 0$), $Q^- = \max_i Q_i$ (or setting the worst $Q^- = 1$, and $0 \le v \le 1$, where v is introduced as a weight.

Step 4 Prioritize the alternatives, sorting by the value of $\left\{ S_i, Q_i, \ and \ R_i \middle| i = 1,2,...,m \right\}$, in decreasing order. Propose as a compromise the alternative $\left(A^{(1)} \right)$ which is ranked first by the measure $\min\left\{ R_i \middle| i = 1,2,...,m \right\}$ if the following two conditions are satisfied: Condition 1. Acceptable advantage: $R\left(A^{(2)}\right) - R\left(A^{(1)}\right) \ge 1/(m-1)$, where $A^{(2)}$ is the alternative with second position in the ranking list by R; m is the number of alternatives. Condition 2: Acceptable stability in decision making: Alternative $A^{(1)}$ must also be the best ranked by $\left\{ S_i \ or/and \ Q_i \middle| i = 1,2,...,m \right\}$. The compromise-ranking method is applied to obtain the compromise. Because of the fact that the solution provides maximum group utility of the majority (represented by min S, Eq. (4)), and minimum individual regret of the opponent (represented by min Q, Eq. (5)), the solution is acceptable. The weight stability intervals for the given compromise solution can be obtained from the VIKOR algorithm regarding the input weights provided by the experts [8].

4. Dwelling Selection Framework and Demonstrative Application

To select apartment for living, a case study on the dwelling selection was present [4]. A fuzzy game theory was used to develop an assessment model, considering ten criteria namely, *x*1 – material, used for construction process (t/m2), *x*2 – energy, used for construction process (GJ/m2), *x*3 – water, used for construction process (m3/m2), *x*4 – energy use for 50 year operation phase (kWh/m2), *x*5 – enclosures with heat losses (m2), *x*6 – CO2 use for 50 year operation phase (kg/m2), *x*7 – price of the apartment (€/m2), *x*8 – labor costs (human hour/m2), *x*9 – Fuel annual price (€/100m2), *and x*10 – Price of energy use for 50 year operation phase (Lt/m2). This approach had combined fuzzy set theory with game theory. It was used in design concept appraisal. This study proposes a dwelling selection framework. To demonstrate an application of the proposed approach to the alternative buildings, this study considers eight design alternatives [4]:*A*1 – one flat dwelling house with coal based heating, *A*2 – one flat dwelling house with gas based heating, A3 – one flat dwelling house with biomass based heating, A4 – one flat dwelling house with combined biomass and gas based heating, *A*5 – loft flat dwelling house with coal based heating, *A*6 – loft flat dwelling house with gas based heating, *A*7 – loft flat with biomass based heating, and *A*8 – loft flat dwelling house with combined biomass and gas based heating. This study classifies the main criteria into cost, energy, pollution, and resources. Ten sub-criteria [4] are classified based on these four criteria.

Table 1: Weight of criteria

C	Weight of criteria evaluated by respondent									No.
	1	2	3	4	5	6	7	8	$\bar{x}$	
x1	0.08	0.12	0.11	0.13	0.09	0.12	0.11	0.14	0.11	4
x2	0.08	0.12	0.11	0.13	0.08	0.11	0.10	0.12	0.11	5
x3	0.08	0.12	0.11	0.13	0.07	0.10	0.10	0.11	0.10	7
x4	0.11	0.10	0.14	0.11	0.09	0.08	0.11	0.09	0.10	8
x5	0.10	0.11	0.12	0.11	0.13	0.14	0.15	0.14	0.12	1
x6	0.12	0.07	0.01	0.01	0.10	0.05	0.01	0.01	0.05	10
x7	0.11	0.12	0.13	0.13	0.10	0.11	0.12	0.12	0.12	3
x8	0.10	0.11	0.11	0.11	0.13	0.14	0.15	0.14	0.12	2
x9	0.12	0.05	0.04	0.04	0.13	0.06	0.04	0.05	0.07	9
x10	0.11	0.10	0.14	0.11	0.09	0.09	0.11	0.09	0.10	6

To apply fuzzy AHP, the comparison structure among criteria was developed. Experts with a vast experience of the apartment construction were the participants of this study. There were eight respondents including developer, contractor, designer, and consultant. The years of experiences accumulated by all participants are more than 150 years of experience in the apartment construction. In-depth interviews with organized questionnaires were used to collect data.

After using the fuzzy AHP to calculate weights of criteria, the experts were asked to rate alternatives with respect to each criterion. For prioritizing alternatives, according to the VIKOR method, the calculated data along with the final values of *Ri* were presented. In this study, eight alternatives were ranked. Based on Eqs. (1), (4), (5) and (6), the following calculations are considered for L_i^p ,*Si* , *Qi* ,*Ri* ; *i* =1, 2, 3, 4,5,6,7, and 8. The final ranking of eight alternatives was determined based on ten criteria. The obtained results were verified based on two conditions in Step 4 so that the final ranking and compromise solution can be achieved. The acceptance advantage (Condition 1) is satisfied. Table 2 show results obtained from the proposed evaluation framework using ten criteria. Raw data was obtained from Medineckiene, et.al. [4].

Based on results obtained from the fuzzy AHP method, the most important criterion was the enclosures with heat losses and was followed by labor costs and price of the apartment. The least important criteria was CO2 use for 50 year operation phase and was followed by fuel annual price and energy use for 50 year operation phase, respectively. It was found that the one flat dwelling house with coal based heating was the best alternative. It was followed by the one flat dwelling house with gas based heating and the one flat dwelling house with biomass based heating, respectively. The worst alterative was one flat dwelling house with combined biomass and gas based heating and was followed by loft flat dwelling house with combined biomass and gas based heating and the loft flat dwelling house with gas based heating, respectively.

It is important to know strengths and weakness of the alternative dwelling houses in order to make an industry and researchers aware of potential strengths and weakness so they know what steps to take. The strengths and weaknesses of alternatives can be identified as shown in Table 3. The major strength of the best alternative was enclosures with heat losses and was followed by labor costs and material, used for construction process. The weakness of the best alternative was price of the apartment and was followed by the energy use for 50 year operation phase and the Price of energy use for 50 year operation phase. To overcome the major weakness of the best alternative, the designers should learn how to reduce prices based on alternative 6 and 7, loft flat dwelling house with the gas based heating or biomass based heating. To improve the worst alternative, the designers should learn how to reduce prices based on alternative 6 and 7, loft flat dwelling house with the gas based heating or biomass based heating.

Table 2: Results obtained from the integrated VIKOR and fuzzy AHP method

Criteira	A1	A2	A3	A4	A5	A6	A7	A8	f*j	f-j	w
x1	1.6	2.1	1.8	2.3	1.5	1.9	1.7	2.2	1.5	2.3	0.110
x2	31.5	41.3	35.4	45.3	27.1	35.5	30.5	39.1	27.1	45.3	0.105
x3	51.4	67.4	57.8	73.8	41.7	54.5	46.9	60	41.7	73.8	0.102
x4	7969	7054	8843	7317	5903	5149	6408	5586	5149	8843	0.102
x5	308	308	308	308	362.5	362.5	362.5	362.5	308	362.5	0.123
x6	2966	1522	314	257	2194	1112	228	196	196	2966	0.049
x7	869	886.9	897.4	932.2	724.6	739.1	747.8	776.8	724.6	932.2	0.118
x8	1005	1012	1010	1004	1220	1229	1209	1202	1004	1229	0.121
x9	800.6	317.1	211.4	268.2	800.6	317.1	211.4	268.2	211.4	800.6	0.067
x10	3586	3174	3979	3293	2656	2452	2884	2514	2452	3979	0.103
$w_1 r_{i1}$	0.014	0.082	0.041	0.110	0.000	0.055	0.027	0.096			
$w_2 r_{i2}$	0.025	0.082	0.048	0.105	0.000	0.049	0.020	0.069			
$w_3 r_{i3}$	0.031	0.082	0.051	0.102	0.000	0.041	0.017	0.058			
$w_4 r_{i4}$	0.078	0.053	0.102	0.060	0.021	0.000	0.035	0.012			
$w_5 r_{i5}$	0.000	0.000	0.000	0.000	0.123	0.123	0.123	0.123			
$w_6 r_{i6}$	0.049	0.024	0.002	0.001	0.036	0.016	0.001	0.000			
$w_7 r_{i7}$	0.082	0.092	0.098	0.118	0.000	0.008	0.013	0.030			
$w_8 r_{i8}$	0.001	0.004	0.003	0.000	0.116	0.121	0.110	0.106			
$w_9 r_{i9}$	0.067	0.012	0.000	0.006	0.067	0.012	0.000	0.006			
$w_{10} r_{i10}$	0.076	0.049	0.103	0.057	0.014	0.000	0.029	0.004			
Sj	0.423	0.479	0.449	0.559	0.376	0.425	0.375	0.505			
Qj	0.082	0.092	0.103	0.118	0.123	0.123	0.123	0.123			
S	0.131	0.284	0.201	0.500	0.004	0.136	0.000	0.355			
Q	0.000	0.122	0.253	0.430	0.500	0.500	0.500	0.500			
Rj	0.131	0.406	0.454	0.930	0.504	0.636	0.500	0.855			
No.	1	2	3	8	5	6	4	7			

Remark: $x1$ – material, used for construction process (t/m2), $x2$ – energy, used for construction process (GJ/m2), $x3$ – water, used for construction process (m3/m2), $x4$ – energy use for 50 year operation phase (kWh/m2), $x5$ – enclosures with heat losses (m2), $x6$ – CO2 use for 50 year operation phase (kg/m2), $x7$ – price of the apartment (€/m2), $x8$ – labor costs (human hour/m2), $x9$ – Fuel annual price (€/100m2), *and* $x10$ – Price of energy use for 50 year operation phase (Lt/m2), $A1$ – one flat dwelling house with coal based heating, $A2$ – one flat dwelling house with gas based heating, A3 – one flat dwelling house with biomass based heating, A4 – one flat dwelling house with combined biomass and gas based heating, $A5$ – loft flat dwelling house with coal based heating, $A6$ – loft flat dwelling house with gas based heating, $A7$ – loft flat with biomass based heating, and $A8$ – loft flat dwelling house with combined biomass and gas based heating, w is weight of criteria, f*j is the best value, and f-j is the worst value.

Table 3: Ranking strengths of alternatives

Ranking	A1	A2	A3	A4	A5	A6	A7	A8
	Alternatives							
1	x5 – enclosures with heat losses (m2),	x5 – enclosures with heat losses (m2),	x5 – enclosures with heat losses (m2),	x5 – enclosures with heat losses (m2),	x1 – material, used for construction process (t/m2),	x4 – energy use for 50 year operation phase (kWh/m2),	x9 – Fuel annual price (€/100m2),	x6 – CO2 use for 50 year operation phase (kg/m2),
2	x8 – labor costs (human hour/m2),	x8 – labor costs (human hour/m2),	x9 – Fuel annual price (€/100m2),	x8 – labor costs (human hour/m2),	x2 – energy, used for construction process (GJ/m2),	x10 – Price of energy use for 50 year operation phase (Lt/m2).	x6 – CO2 use for 50 year operation phase (kg/m2),	x10 – Price of energy use for 50 year operation phase (Lt/m2).
3	x1 – material, used for construction process (t/m2),	x9 – Fuel annual price (€/100m2),	x6 – CO2 use for 50 year operation phase (kg/m2),	x6 – CO2 use for 50 year operation phase (kg/m2),	x3 – water, used for construction process (m3/m2),	x7 – price of the apartment (€/m2),	x7 – price of the apartment (€/m2),	x9 – Fuel annual price (€/100m2),

Remark *A*1 – one flat dwelling house with coal based heating, *A*2 – one flat dwelling house with gas based heating, A3 – one flat dwelling house with biomass based heating, A4 – one flat dwelling house with combined biomass and gas based heating, *A*5 – loft flat dwelling house with coal based heating, *A*6 – loft flat dwelling house with gas based heating, *A*7 – loft flat with biomass based heating, and *A*8 – loft flat dwelling house with combined biomass and gas based heating.

5. Conclusion

This paper presents an application of a multi-criteria decision making (MCDM) model for evaluation alternatives, dwelling house in this case, for the dwelling selection problem. For this purpose, an integrated methodology is structured, in which the the VIKOR uses the fuzzy AHP result weights as input weights. Finally, an application example of the dwelling house selection regarding ten criteria is demonstrated. The applicability and suitability of the proposed methodology are presented. The quantitative and qualitative evaluation can be conducted for searching the suitable level which in turn increases the complexity of the design evaluation.

A quantitative method for coping with multiple decision criteria is propose. It is suitable for assisting a decision maker during the conceptual design of dwelling project. The proposed method employs the fuzzy AHP method to perform the pairwise comparison and calculate the weights of criteria. The VIKOR method is used to compute the total score of the criteria. In this way, the proposed method accurately examines uncertainty involved in the pairwise comparisons and the calculation of the weights and total score of the criteria in a simply manner.

It is important to know strengths and weakness of the design alternatives. Any pitfall of existing assessment methods could eliminate by using the proposed framework. The result can be used as information for developers, designers, and contractors to develop a suitable design for dwelling house construction. In addition, results obtained from the developed evaluation framework make a construction industry and researchers realize the potential strengths and weakness so they can provide managerial implications to improve the design criteria and construction methods.

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