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INTRODUCING WEIGHT FACTORS INTO A DECISION MAKING TOOL FOR EVALUATING THE SUSTAINABILITY ASPECTS OF BUILDINGS RENOVATION ALTERNATIVES

- CASE STUDY USING RENOBUILD

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ABSTRACT
Energy efficiency investments have become strategically important for the European Union. In particular, energy efficient renovation and investment in its existing building stock have become a major challenge. Creation of a high-performance building should be carried out according to a holistic and integrated design process, which considers all three aspects of sustainability. The aim of this work is to suggest a mathematical model that considers the weight of each sustainability aspect, to support housing owners in decisions regarding the optimal sustainable renovation alternative. Multi-criteria decision making (MCDM) concerns structuring and solving multiple-criteria decision problems. MCDM has become popular in energy planning as it enables the decision maker to give attention to all the criteria available and make the appropriate decision as per the priority of criteria. In this study, an example explains the suggested numerical system for comparing different renovation alternatives. The suggested method will facilitate the decision making process in renovation projects and allows housing owners to choose the best renovation method according to their companies policies and preferences.

Keywords: energy efficient renovation, sustainable renovation, weighted sum method (WSM), multi-criteria decision making (MCDM)

NONMENCLATURE

Abbreviations	
MCDM	Multi-Criteria Decision Making
WSM	weighted Sum Method
PE	Primary Energy
Symbols	
A	Renovation alternative
C	Criteria
W	Weight Factor

1. INTRODUCTION

Energy efficiency investments have become strategically important for the European Union, since these are the most cost effective way to reduce the EU's dependence and reliance on energy imports costing over €400 billion a year [1]. Energy security and more independence are not the only advantages. Others are competitiveness, social and territorial cohesion, job creation, well-being and greenhouse gas emission reductions. Buildings are central to the EU's energy efficiency policy, as these account for nearly 40% of the final energy consumption and 36% of greenhouse gas emissions [2], and at the same time are long-term assets expected to remain useful for 50 years or more [1]. Some 75-90% of the buildings standing today are expected to remain in use in 2050 [3]. Due to low demolition rates (0.1% per year), low renovation rates (1.2% per year), and moves to highly energy efficient new-build (1%

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additions per year) [3], the energy efficient renovation and investments in its existing building stock have become the challenge for Europe's energy efficiency in buildings. Thus, EU countries carry out energy efficient renovations of at least 3% of the buildings owned and occupied by central governments per year, is one of the adopted policies for improving energy efficiency in the EU [4]. However, improving energy efficiency and reducing carbon emission are not the only goals in building renovation. It is not sustainable to consider them alone in a project. Creation of a high-performance building (consistent with sustainability in its full sense) should be carried out according to a holistic and integrated design process, which considers the three aspects of sustainability (environmental, economic and social aspects).

Thuvander et al., 2012 [5], Cattano et al., 2013 [6] , and Häkkinen and Belloni (2011) [7] have investigated the implementation of renovation processes towards more sustainable buildings. There are several key barriers in addition to the fear of high investment costs and problems with profitability identified by [8]. These are lack of knowledge about sustainability aspects, lack of simplified evaluation tools (for decision making), insufficient knowledge of the quality of the building stocks, and lack of coordination between the goal of energy-saving and other project goals. Consequently, very few housing owners manage to address sustainability aspects throughout a renovation project in a satisfactory manner.

1.1 Novelty and aim of the study

A challenge to promote better decision-making is to find a systematic method that evaluates the three aspects of sustainability of different renovation scenarios, to support the owners in their decisions at an early stage. Ideally, the tool should be comprehensive and easy to use, and at the same time be attractive for adoption by the owners. The housing owners have shown interest in using such a tool, Renobuild. This work suggests an improvement of Renobuild to enhance its applicability for housing owners [9].

Accordingly, the aim of this work is to suggest a mathematical model that considers the weight of each sustainability aspect, to support housing owners using Renobuild in decisions regarding the optimal sustainable renovation alternative.

2. RENOBUILD

SP Technical Research Institute of Sweden has developed methodology and tools called Renobuild, in addition to the Life Cycle Cost (LCC) analysis tool developed by Älvstranden Utveckling AB [9]. The aim of the development of the Renobuild methodology was to develop an instrument for evaluating various renovation options for an individual building or an area with several buildings with regard to economic, environmental and social aspects. The result can be used as a support for decision makers when choosing renovation measures. The methodology aims to help property owners and other decision makers to consider the aspects of sustainability in the renovation of existing buildings in a simple and transparent manner. This will lead to reduced energy use and thus less climate impact, while at the same time it will maximize the positive social effects of the measures at a reasonable cost. Thus, Renobuild is unique as it concerns mainly renovation projects, and also considers the three aspects of the sustainability.

Renobuild has some limitations as it is in a development process. An example of these limitations is the problem of finding appropriate input data. For Renobuild, this becomes a problem when analyses are carried out in early stages, as there are often many uncertain inputs and many estimates must be made. Furthermore, to be able to carry out the analysis with accurate results, a relatively extensive basis of data is required, which can mean significant work for a property owner. But this is necessary to be able to compare sustainability aspects between different alternatives. The results of Renobuild consider that the three aspects of sustainability have equal importance, which is not necessarily true from an owner perspective.

3. WEIGHTED SUM METHOD (WSM) IN MULTI-CRITERIA DECISION MAKING (MCDM)

MCDM or MCDA are well-known acronyms for multiple-criteria decision-making and multiple-criteria decision analysis. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria [10].

MCDM helps a decision maker to quantify particular criteria based on its importance in the presence of other objectives. There are three steps in utilizing any decision-making technique involving the numerical analysis of alternatives:

Determine the relevant criteria and alternatives.

If there is a set with alternatives.

$$A= \{A1, A2, A3……, An\}, \qquad \text{(Eq 1)}$$

a set of criteria C can be established such that

c= {c1, c2, c3………cn} (Eq 2)

Attach numerical measures to the relative.

Process the numerical values to determine a ranking of each alternative.
It is possible to form them as a matrix

$$\begin{array}{c} \\ \boldsymbol{A_1} \\ \vdots \\ \boldsymbol{A_n} \end{array} \begin{array}{c} \begin{array}{ccc} \boldsymbol{c_1} & \cdots & \boldsymbol{c_m} \end{array} \\ \begin{bmatrix} \mu_{11} & \cdots & \mu_{1m} \\ \vdots & \ddots & \vdots \\ \mu_{n1} & \cdots & \mu_{nm} \end{bmatrix} \end{array} \quad \text{(Eq 3)}$$

Where $\mu_{ij} \in [0, 1]$, i= {1,2,3….n}, j={1,2,3…….m} represents the satisfaction of criterion cj by alternative Ai. A higher value of μij means that alternative A satisfies criterion cj in a better way.
If wj is the weight of importance associated with cj

$$\text{AWSM\_score} = \text{Max} \sum_{j=1}^{m} \mu_{ij*} \, w_j \quad \text{(Eq 4)}$$

AWSM-score is the WSM score of the best alternative, m is the number of decision criteria, μij represents the satisfaction of criterion cj by alternative Ai, and Wj is the weight of importance of the criterion cj.

The weighted sum model (WSM) is probably the oldest and most commonly used approach in MCDM, especially in single dimensional problems [11].

In single-dimensional cases, where all the units are the same, the WSM can be used without difficulty. MCDM has become popular in energy planning as it enables the decision maker to give attention to all the criteria available and make appropriate decision as per the priority of criteria [10].

In the renovation process, the owner will choose between different renovation measures based on the environmental, social and economic impact of these alternatives. Different renovation alternatives have different scores regarding their performance in each sustainability aspect. However, the sustainability aspects are not equally important from the owners' perspective. This work suggests the WSM to be a suitable method to help property owners in their final decision regarding the best renovation alternative from their own perspective. The following chart explains the proposed method in this work.

The suggested method can be adopted in the final stage of a decision-making process; the following example will explain the suggested numerical system.

Life Cycle Cost Analysis (LCCA) is used to calculate the life cycle cost, related to the energy efficient renovation measures of each alternative, which helps to assess the economic aspect of sustainability. In the suggested method, primary energy is used as an index for the environmental aspect of sustainability since it is a measure on the use of energy resources. Primary energy is calculated according to Swedish building regulations (BBR). A questionnaire including maximum 10 questions is used to quantify the social aspect of sustainability; each positive answer gives one point out of totally 10.

To clarify the suggested method in this work, an imaginary example is given. If there are four different scenarios for a renovating building, Table 1 shows the final results of the performance of each alternative.

Table 1. The final results of the performance of four different alternatives (scenarios) for renovating a building.

Studied aspects	**Studied alternatives**			
	Alt1	**Alt2**	**Alt3**	**Alt4**
Primary Energy [kWh/(m²·a)]	70	80	67	75
Economy [€/m2]	250	265	235	285
Social [points]	5	6	4	6

A minimum requirement of each aspect can be defined by following the Swedish building regulations' (BBR) and the owner's own requirements. Consequently, scores of each alternative can be calculated, as Table 2 shows.

Table 2 The scores of each renovation alternative in relation to minimum requirements

Studied aspects	**Min requirement**	**Scores**			
		Alt1	**Alt2**	**Alt3**	**Alt4**
Primary Energy [kWh/(m²·a)]	**80 [kWh/(m²·a)]**	1,14	1,00	1,19	1,07
Economy [€/m2]	**300 [€/m²]**	1,20	1,13	1,28	1,05
Social [points]	**5 [points]**	1,00	1,20	0,8	1,20

The weight factors are subjectively quantified, depending on the owner perspective. The method in this work suggests that the owner should choose the weight factor for each aspect of sustainability between [0,1] so that the total sum of factors is 1.

Table 3 gives an example of an owner's weight factors and the weighted scores and final scores have been calculated for each renovation alternative.

Table 3 the final weighted scores of each alternative.

Studied aspects	weight factors	weighted Scores			
		Alt1	Alt2	Alt3	Alt4
Energy	0,40	0,46	0,40	0,48	0,43
Economy	0,40	0,48	0,45	0,51	0,42
Social	0,20	0,20	0,24	0,16	0,24
Final scores		**1,14**	**1,09**	**1,15**	**1,09**

4. DISCUSSION AND CONCLUSION

For the weighting factors considered in this example and according to Table 3 and Eq 4, the alternative which has the highest final score is Alt 3. However, Alt3 does not comply with the minimum requirement of the social aspect as can be noted from Table 2, it has a value less than 1 regarding the social aspect. Thus, Alt1 is the best renovation alternative in this example. Other weight factors would have given other results.

The suggested method in this study facilitates the decision making process in renovation projects and allows the housing owners to choose the best renovation method according to own preferences though considering authority requirements or recommendations.

The final scores of renovation alternatives are totally based on the housing owners' choice of the weight factors. No recommendations are provided for choosing the weight factors; housing owners choose them depending on their company policies. The choice of weight factors opens discussion about prioritizing sustainability aspects, internally in the company and externally between the companies in the building sector.

Primary energy is used to assess the environmental aspect of sustainability, LCCA was used for the economic part and a questionnaire for the social part. In the social questionnaire it is easy to alter contents and the number of questions. Other criteria could be added or substituted in each category if there are case specific aspects which the housing owners prefer for comparing the renovation alternatives. For example, life cycle assessments of the associated carbon emissions of each renovation alternative could have been used as an environmental criteria. In the near future, the Swedish building regulations (BBR) will most probably have a requirement regarding carbon emissions related to building projects.

In a future work, it is planned to apply the proposed method in a renovation project to evaluate sustainability aspects of different renovation scenarios. Stora Tunabyggen AB, the public housing company in Borlänge municipality, began a renovation project in the Tjärna Ängar area where three multi-family buildings were renovated with different renovation packages [E2B2 grant no]. The proposed method in this work will be applied to compare the three buildings from the owner's perspective.

A qualitative study is also planned to investigate how various Swedish building owners, private and public, evaluate the importance of each sustainability aspect in renovation projects.

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