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A fuzzy multi-criteria decision making approach to assess building energy performance

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ABSTRACT

Due to an increasing demand for energy and rising energy prices, efficiency in energy consumption is fast-becoming a topic of significance. The building and construction sector has seen an increase of approximately 30–40% of overall energy consumption occurred; this has exceeded other major sectors such as industry and transport. Given the number of buildings and the cost of energy required to support these buildings, the developing of new approaches in the construction sector will be likely. This situation forces the various stakeholders to implement energy rating procedures to assess buildings' energy performance. The most commonly utilized building environment assessment method currently used in Europe is the Building Research Establishment Environmental Assessment Method (BREEAM). Parallel to Europe, Turkey started its National Building Energy Performance Calculation Methodology (BEP-TR) in 2010. BREEAM and BEP-TR like other methods, require a lot of detailed and particular information in order to be implemented, and the procedure is fairly complicated. In addition, decision support systems can involve assessments, developed as a result of imprecise data in a qualitative manner. "Fuzzy set theory" can play a significant role in this kind of decision-making situation. This paper examines a "fuzzy multi-criteria decision making (MCDM)" approach in order to analyze BEP-TR. This approach was applied to categorize alternative buildings according to their overall energy performance. Results are discussed in terms of developing a new and practical building rating system.

1. Introduction

Expanding human population, growing complexities of civilization, economic growth, industry, and other related issues are forcing countries to demand more energy sources. The fact that the world has limited resources requires countries to study energy and energy policies in detail. As a result of fossil fuel formation over the course of millions of years, alternative energy sources such as wind, biofuels, solar thermal and photovoltaic sources, are increasingly being considered as fuel sources. Another consideration in meeting this increased energy demand is to reduce energy consumption by improving energy efficiency.

Energy consumption of the building and construction sector accounts for around 30-40% of total primary energy use worldwide; consequently this sector contributes a great deal to greenhouse emissions and global warming [1]. In addition, this sector accounts for the use of approximately 40% of the world's natural resources extracted in industrialized countries; 12% of available potable water, and the production of 45–65% of the waste later sent to landfills [2]. Due to the projected increase of the global population from 6.5 billion in 2005 to approximately 9.0 billion in 2035, these figures are expected to continue to grow [3]. In light of this consideration, organizations have been investing significant resources to create sustainably built environments, stressing sustainable building renovation processes to reduce energy consumption and carbon dioxide emissions [4].

Those who design and operate buildings need methods to evaluate the environmental impacts of their actions. Various rating methods, referred to as building rating systems (BRS), have been developed as important tools in measuring and evaluating the environmental performance of a building. The Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) are the two most widely recognized environmental assessment methodologies used globally in the building and construction industry today.

BREEAM was launched in the UK in 1990 to provide an environmental assessment and labeling mechanism for buildings [5,6]. There are nine different sections/criteria, including management, health and well-being, energy, transport, water, materials, waste, land use and ecology, and pollution. There are also sub-criteria (not

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Table 1
Major building rating systems and weightings.

BREEAM (building fit-out only where applicable to scheme)		LEED (for existing buildings)	
Section	Weighting (%)	Section	Weighting (%)
Health and wellbeing	17	Indoor environmental quality	15
Energy	21	Energy and atmosphere	35
Transport	9	Sustainable sites	26
Water	7	Water efficiency	14
Materials	14	Material and resources	10
Management	13	Innovation in operations	6**
Waste	8	Regional priority	4**
Pollution	11		
Innovation	10*		

* Design innovations can add a maximum of 10% onto the score.
** In addition to 100 points in LEED's five credit categories, projects can earn up to 10 bonus points.

Table 2
Certification levels for BREEAM and LEED.

BREEAM	% Score	LEED	% Score
Unclassified	<30	Uncertified	<40
Pass	≥30	Certified	≥40
Good	≥45	Silver	≥50
Very Good	≥55	Gold	≥60
Excellent	≥70	Platinum	≥80
Outstanding	≥85		

mentioned in this paper). Each criterion consists of a number of issues; each issue is scored and each criterion is weighted for the overall evaluation of a building. The building is then categorized and labeled according to its score. Table 1 shows the corresponding scores for each category [7].

The US Green Building Council (USGBC) formed its major green building code known as LEED in 2000 [8]. LEED provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions. It validates that a building is designed and constructed to achieve high performance in key areas of human and environmental health. Buildings are scored according to the criteria and weights shown in Table 1 [9]. Extra "innovation" credit can be applied for instances where a design can demonstrate a reduction in a building's impact on the environment in an innovative way.

The individual credits are added up and then weighted in line with Table 1 to give a final rating. The building must meets all prerequisites and can achieve the minimum number of points necessary to earn the certified level. The certification levels for BREEAM and LEED are explained in Table 2 [7,9].

Although the BREEAM and LEED systems are more commonly applied in industry, there are other national rating systems. The Taiwan Architecture and Building Research Institute developed a similar system named "Green Building Evaluation and Labeling System" (GBELS). GBELS uses nine criteria including biodiversity, greenery, soil water content, daily energy savings, carbon dioxide emission reduction, waste reduction, indoor environment, water resource, and sewage and garbage improvement [10]. The Green Building Tool (GBT) is an evolving assessment system sponsored by National Resources Canada. Comprehensive Assessment System for Building Environmental Efficiency (CasBee) in Japan, Minergie in Switzerland, National Australian Built Environment Rating System (NABERS) in Australia, DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) in Germany, Green Rating for Integrated Habitat Assessment (GRIHA) in India are examples for BRS [11].

These methods used in different countries require expertise to assess the energy performance of buildings and the process is generally performed by external experts, resulting in a cost for each assessment. The originality of this paper lies in the way the owner-occupiers' viewpoint is included in the assessment process. These stake-holders can easily apply the model proposed herein to assess the energy performance of a building without the help of the external experts. In addition, as seen in the process of BREEAM, LEEDS, BEP-TR and other evaluation systems, energy performance of buildings consist of multiple criteria.

Multi-criteria decision making (MCDM) comprises a finite set of alternatives, among which the decisions makers (DMs) must select, evaluate or rank according to the weights of a finite set of criteria. The multi-criteria nature of the buildings' energy performance assessment problem makes MCDM methods ideal to cope with the complexity of the problem. DMs consider many criteria simultaneously, with various weights, then evaluate the alternatives. Some methods apply to the evaluation of qualitative criteria while others are suitable for quantitative criteria. But the buildings' energy performance assessment problem requires both qualitative and quantitative criteria. These methods also involve subjective assessments, resulting with imprecise data in qualitative manner. Due to the availability and uncertainty of information in the decision process, as well as the ambiguities of human feeling and recognition, it is often difficult to make an exact evaluation and convey the feeling and recognition of objects for DMs. "Fuzzy set theory" can play a significant role in this kind of decision situation [12,13]. Hence since DMs generally fail to make a good numerical prediction for criteria, evaluation is expressed in linguistic terms. Fuzzy linguistic models permit the translation of verbal expressions into numerical ones. Thereby, when dealing quantitatively with imprecision in the expression of the importance of each criterion, some multi-criteria methods based on fuzzy relations are used [14]. As a result, a MCDM method based on fuzzy logic is proposed to assess practically the energy performance of buildings. For this aim, National Building Energy Performance Calculation Methodology of Turkey (BEP-TR) is analyzed as a MCDM problem. There are seven criteria: location and climate data, geometrical shape, building envelope, mechanical systems, lighting system, hot water system and renewable energy and cogeneration in BEP-TR [15].

Since there is a set of criteria which affect each other in the BRS, the Analytic Network Process (ANP), as a well-known MCDM method, is better able to analyze the impact of each criterion on every other criterion using pair-wise comparisons [16]. It should be noted that experts who participate in this evaluation process cannot always explain their judgments about certain attributes such as quality or performance with distinct and discreet scales. The fuzzy set theory enables them to explain their evaluations in linguistic terms. This problem is further analyzed by using ANP based on the fuzzy set theory in this paper.

The remainder of this paper is organized as follows: Section 2 describes buildings' energy performance in Turkey. Main characteristics of the fuzzy set theory and fuzzy ANP (FANP) method are detailed in Sections 3 and 4, respectively. The steps of the proposed