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Article

A DFuzzy-DAHP Decision-Making Model for Evaluating Energy-Saving Design Strategies for Residential Buildings

Kuang-Sheng Liu [1], Sung-Lin Hsueh [2,*], Wen-Chen Wu [2] and Yu-Lung Chen [2]

[1] Department of Interior Design, Tung Fang Design University, No.110 Dongfang Road, Hunei Distract, Kaohsiung City 82941, Taiwan; E-Mail: kliu1219@yahoo.com.tw

[2] Graduate Institute of Cultural and Creative Design, Tung Fang Design University, No.110 Dongfang Road, Hunei Distract, Kaohsiung City 82941, Taiwan; E-Mail: s8886191@ms35.hinet.net (W.-C.W.); 1962chen9966@gmail.com (Y.-L.C.)

* Author to whom correspondence should be addressed; E-Mail: hsueh.sl@msa.hinet.net; Tel.: +886-9-32883292; Fax: +886-7-6931234.

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Abstract: The construction industry is a high-pollution and high-energy-consumption industry. Energy-saving designs for residential buildings not only reduce the energy consumed during construction, but also reduce long-term energy consumption in completed residential buildings. Because building design affects investment costs, designs are often influenced by investors' decisions. A set of appropriate decision-support tools for residential buildings are required to examine how building design influences corporations externally and internally. From the perspective of energy savings and environmental protection, we combined three methods to develop a unique model for evaluating the energy-saving design of residential buildings. Among these methods, the Delphi group decision-making method provides a co-design feature, the analytical hierarchy process (AHP) includes multi-criteria decision-making techniques, and fuzzy logic theory can simplify complex internal and external factors into easy-to-understand numbers or ratios that facilitate decisions. The results of this study show that incorporating solar building materials, double-skin facades, and green roof designs can effectively provide high energy-saving building designs.

Keywords: energy-saving design; solar building materials; double-skin facades; the Delphi method; analytical hierarchy process (AHP); fuzzy logic theory

1. Introduction

Building construction and operation contribute to more than one-third of the carbon emissions in the United States [1]. In addition, greenhouse gas emissions are caused by building construction. A total of 82%–87% of greenhouse gas emissions are from the embodied greenhouse gas emissions of building materials, 6%–8% are from the transportation of building materials, and 6%–9% are caused by the energy consumption of construction equipment [2]. Building construction contributes anthropogenic CO_2 emissions [3,4]. Although the construction industry is a significant indicator of economic development, it consumes a significant amount of energy and produces substantial pollution [5–9]. Construction has been blamed for causing various environmental problems, ranging from excessive consumption of global resources for construction and building operations to polluting the surrounding environment [10]. Based on estimations by the United Nations Environment Programme, the building sector accounts for 30% to 40% of global energy use [11]. Thus, improving construction practices to minimize their detrimental effects on the natural environment is an emerging issue [12,13]. The environmental impact of construction, green buildings, recycling, and eco-labeling of building materials has attracted the attention of building professionals worldwide [14–16].

The trend of developing green industries has resulted from policy pressure related to climate change, customer demand, and sustainable environmental protection. In addition, development of the green industry has become an effective method for promoting economic recovery and increasing employment levels [17]. Environmental protection and development of the green industry in the EU is particularly specific and active. In the E.U. Green Book, corporate social responsibility is a major tool for creating new jobs and sustaining economic development [18]. Thus, people are becoming increasingly convinced of the importance of corporate social responsibility, which is also an important factor for companies to achieve profits and stimulate socioeconomic development [19,20]. Many companies have recognized that corporate social responsibility is a source of future business opportunities and competitive advantages [21,22]. Therefore, green innovation for companies is not only a method of fulfilling corporate social responsibilities, but also a strategy to sustainably manage and create competitive advantages [23,24]. Recently, the energy-saving measures promoted by the construction industry include green supply chain management [25–27], green procurement [28], and green building design [29,30]. This issue is gaining importance in countries worldwide, and becoming a goal of policy objectives. For example, green building design projects in Taiwan are being given area ratio rewards, and additional green building-related guidelines and regulations are planned for the future. However, this is likely to cause problems in the management of traditional builders, building material suppliers, real estate developers, and architectural designers. Green transformation of the entire supply chain for both the upstream and downstream of the construction industry is an important development strategy for companies to create competitive advantages and sustainable operations.

Developing energy-saving design strategies for buildings requires a cross-disciplinary and cross-expertise design thinking model. Numerous factors are involved when considering energy-saving designs, particularly for large-scale carbon-neutral community building developments; examples include the use of renewable energies [31], eco-designs [32], solar energy [33–35], lighting [36], compressed shopper waste (CSW) blocks [37], waste disposal [8], air-conditioning facilities [38], ventilation designs [39,40], shading designs [41], heating systems [42,43], green roofs [44], building envelopes [45], and wall insulation for buildings and double-skin facades [46–48]. Therefore, comprehensive preparation in integration and design is required to demonstrate effectiveness. In addition, the energy-saving design of buildings may cause multiple issues in construction projects, including increased construction costs, increased complexity of contracting and procurement, greater difficulty integrating construction interfaces, influences on building quality, necessities of cross-disciplinary specialties, and influencing project progress. These also cause decision-makers to alter investment decisions regarding the energy-saving designs of buildings. However, because the green transformation of industries is a trend in future development, investment decision-makers should be prepared in advance to increase their company's competitive advantage. According to Pacheco, saving energy is a high-priority goal for developed countries. Therefore, energy-efficient measures are being increasingly implemented in all sectors [43]. To ensure the global environmental security of the future, green procurement is implemented when awarding international construction contracts in countries throughout the world, which significantly affects the operation of construction industries in developing and undeveloped countries.

The heat released from buildings is the largest contributor (89% to 96%) of global heat emissions [49]. People cannot ignore the high CO_2 emissions, which have already caused serious climate change and environmental damage, from various industries that consume energy. The environmental risks pose serious problems to individual and societal decision-making [50], and are serious issues that must be urgently addressed. The interactive relationships between people and society directly affect the level of concern individuals, families, and companies have for the environment. O'Neill stated that environmental protection is a national education project of personal and social responsibility that can be used in various specific institutional contexts and missions [51]. Education on social responsibility and policy promotions can help reduce the effects of anthropogenic CO_2 emissions. In addition, Hediger stated that corporate social responsibility is a strategy that acts as insurance against risks to corporate reputations, predicts damage to profits and corporate values, and satisfies external demands [52]. In the construction industry, a strategy of developing green supply chains, green procurement, green design, and green buildings is a manifestation of corporate social responsibility. Burtraw [53] noted that subsidies on green energy can aid in the return of the value of CO_2 emission allowances to households. Currently, Taiwan provides multiple subsidies for residential energy-saving measures. Therefore, the strategic approach of residential building developers for the energy-saving design and construction of residential buildings is a developmental strategy that matches the interior and exterior of a company. Investment decision-makers require objective assistive decision-making models to evaluate the influence of decision-making projects on the interior and exterior of their companies to provide recommendations that enable the best decision to be reached. For this study, we applied the group decision-making technique [54,55] to examine criteria suitable for this study. The multi-criteria decision-making technique [56,57] featured in the analytical hierarchy process (AHP), was used to verify the relative importance of each criterion. The quantifying ability of fuzzy logic theory was used to establish a model that evaluates energy-saving designs of residential buildings [1,58]. This enables effective resolution of energy-saving issues related to residential buildings during the early stages of design. In addition, the factors evaluated in this model consider corporate social responsibility, attitudes toward environmental protection, and long-term energy-saving factors after the completion of the residential buildings. This model shows the potential importance of each evaluating factor in the early design stages, which can provide professionals with decision-making references during the design stages of energy-saving residential buildings.

2. Model Overview

The Delphi method is used to provide implicit expert assistance in research that is highly professional and objective. The Delphi method was developed by the U.S. RAND Corporation to assist management in predicting future events. However, its application scope is not restricted to predicting future events [1,58]. In this study, we explain the Delphi method as a group decision-making technique, including its uses, underlying assumptions, strengths and limitations, potential benefits to qualitative higher education research, and key considerations in its use. Use of the method was demonstrated in a recent national study to develop management audit assessment criteria that can benefit increases in research reliability [54].

The AHP method was first proposed by Saaty and has been extensively used to solve multi-criteria decision-making problems. AHP is also commonly applied to social, policy, and engineering decision-making issues [59,60]. AHP is employed in research for enhancing sustainable community development [58], the estimation and selection of building investments [61], maintenance selection problems [62], project management [63], maintenance strategy selections [64], evaluations of advanced construction technologies [65], decision-support systems in the housing sector [64], urban renewal proposals [66], and sustainable urban energy environment management [67].

Fuzzy set theory was developed by Professor Zadeh at the University of California, Berkeley, in 1965; it is the optimal quantitative tool for addressing fuzzy phenomena and fuzzy language. Fuzzy logic theory based on fuzzy sets is primarily used to express and quantify certain fuzzy concepts that cannot be clearly defined. This theory can provide excellent results when dealing with fuzzy language expressions. Fuzzy logic can manage vague information in natural human language, such as uncertainty, complexity, and tolerance for imprecision [68,69]. Fuzzy logic theory is extremely suitable for highly complex and difficult-to-quantify policy evaluations, especially group decision-making issues [70], such as the sustainable and efficient use of energy during corn production [71].

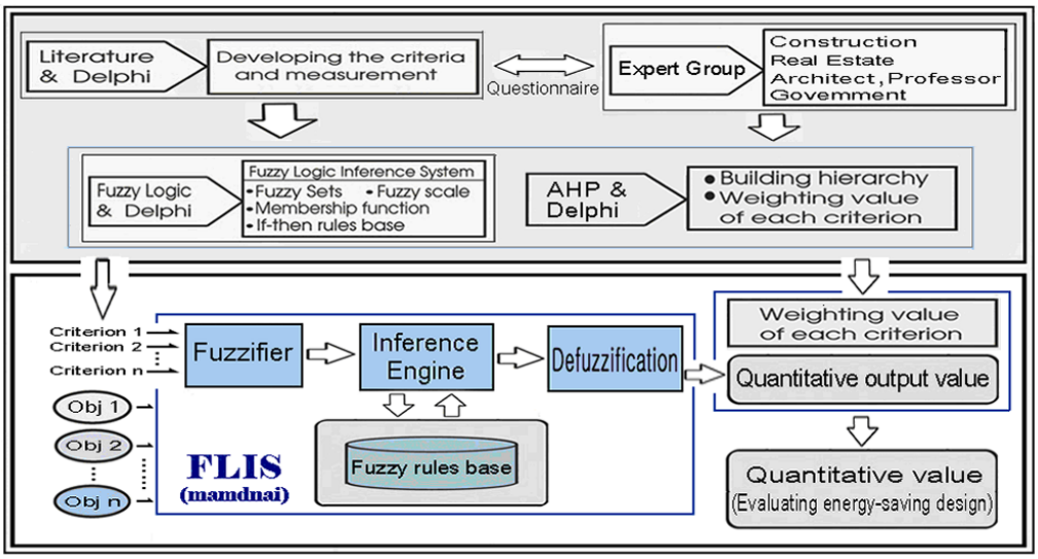
After determining the model evaluation factors using the Delphi method, we then applied fuzzy logic to build the model. During the model-building process, a rigorous inference system should first be completed to ensure effective and correct implementation and application of the evaluation model. The steps for building the fuzzy logic inference system are as follows:

1. Define the fuzzy quantitative interval value and the high, moderate, and low quantitative values;
2. Define the output score for fuzzy quantitative intervals and the quantitative high, moderate, and low values;
3. Define the membership functions of various evaluation factors and output scoring values;
4. Define the semantic logic of the inference system relevance (effect) to describe the inter-relationship logic of various scenarios based on various high, moderate, and low quantitative values;
5. Establish a rule base and inference system according to the semantic logic of various scenarios to use as the knowledge rule base for evaluating model inferences.

For this study, we developed a model that combines the Delphi method, AHP, and fuzzy logic theory. This model was highly rigorous and reliable because of the expert assistance we employed to examine the content, and form group decisions during the modeling process. Diagrams of these stages are shown in Figure 1. The 15 Delphi experts who assisted in this study had over 15 years of practical work experience in related fields; three experts were from the construction industry, three were from the real estate industry, three were architects, three were scholars, and three were from the public service sector. The group decision-making data collected from the Delphi experts provided the required information for a fuzzy logic model. In a Delphi Fuzzy- (DFuzzy) and Delphi AHP- (DAHP) model environment, appropriate criteria must first be selected from complex factors, and then each criterion hierarchy must be completed. After the quantitative natural language membership functions are selected, the fuzzy sets and fuzzy scale sets, the fuzzy logic inference systems (FLIS) of the "IF-THEN rule base" and the DFuzzy-DAHP models can function.

This model incorporates multiple characteristic benefits from DFuzzy, DAHP, Fuzzy-AHP, and DFuzzy-AHP, and its purpose is to address complex decision-making issues. Related studies have applied DFuzzy to human resources (HR) [72], maintenance strategy selections [73], and the reuse selection of historic buildings [74]. Researchers that have applied DAHP include Tavana and Liao [75,76]. Studies that have applied Fuzzy-AHP include those investigating optimum maintenance strategies [77], enhancing sustainable community developments [58], and evaluating the rankings of alternatives [78]. One study that applied DFuzzy-DAHP is mentioned in [79]. Models built by applying DFuzzy, DAHP, Fuzzy-AHP, and DFuzzy-DAHP all provide quantified group decision-making analysis, among which DFuzzy-DAHP is the most objective and rigorous.

Figure 1. Framework of the evaluation model.



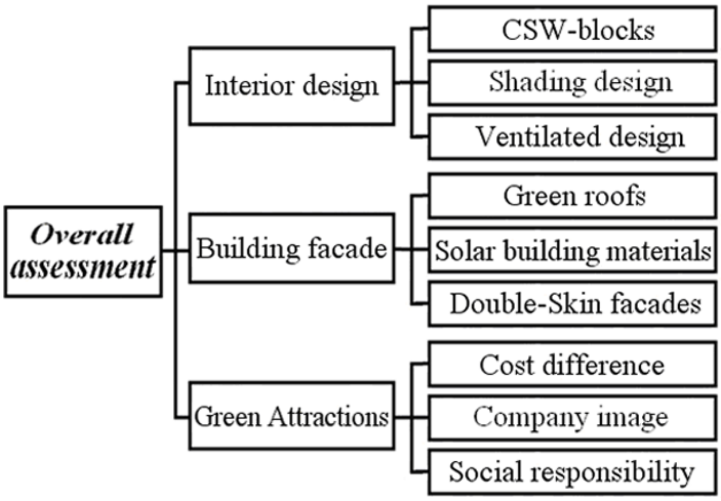
3. Developing the Criteria and AHP Hierarchical Framework

This study completed the Delphi process in 6 months, and confirmed the criteria required for model building. Three main criteria for residential building energy-saving designs have received universal approval from experts; these criteria are interior design, building facades, and green attractions. These criteria contain nine sub-criteria, namely CSW blocks, shading designs, ventilation designs, green roofs, solar building materials, double-skin facades, cost differences, company images, and social responsibilities. Because building regulations in Taiwan do not enforce the implementation of green buildings and green procurement, they remain in the rewards and promotions stage. Most non-public sector building projects continue to follow traditional design and construction methods during construction. In this study, we obtained a consensus among Delphi experts on the energy-saving designs of residential buildings. Green transformation is believed to be an issue that companies must soon address. Therefore, investment decision-makers for residential building projects must reduce profits and increase green investments to adapt to changes in the investing environment. Faced with customer demand, green attractions are gradually having value-adding effects on company images with continuous policy and education promotions. This also highlights the social responsibility of green residential building projects, which benefits the sustainable operation of the company. The AHP framework of the criteria required for model building in this study, as determined by using the Delphi method, is shown in Figure 1. Delphi experts unanimously agree that of the nine criteria, increased costs are more likely to be recognized by real estate developers and, thus, facilitate evaluations prior to the implementation of energy-saving designs. The relative weight of numerous evaluation factors can be determined using the AHP process.

3.1. Weighting Value of Each Criterion

The hierarchical framework for each criterion is shown in Figure 2. Two levels were established for overall assessment. The first level comprises the following three criteria: interior designs, building facades, and green attractions. Each main criterion was then divided into three sub-criteria. Because AHP questionnaires frequently result in invalid responses, AHP is time-consuming. According to Hseuh, more than one year is required to complete the AHP [1].

Figure 2. AHP hierarchical framework for each criterion.



We invited professionals to assist with the AHP questionnaires and obtained complete and valid questionnaire data. We adopted a strict attitude when completing the AHP. The experts who assisted with the 52 valid questionnaires during the AHP all had a minimum of 15 years of experience in their related fields. The scholars were a vice chancellor, a dean, and a senior professor at universities ranked among the top five universities in Taiwan. The industry experts included one construction expert, one real estate expert, one architect, a CEO, and a project manager with a master's degree. The research period for this study was from November 2011 to August 2012 to allow for the completion of the AHP. Tables 1–4 show the relative weight calculations for each sub-criterion for each level. Table 5 shows the relative weight for each criterion in the overall assessment.

Table 1. Weighting value of the main criteria: comparison of the interior design, building facades, and green attractions.

Attributes	Interior design	Building facade	Green Attractions
Interior design	1	1/2	1/5
Building façades	2	1	1
Green attractions	5	1	1
Eigenvector	0.14	0.37	0.49

Table 2. Weighting value of interior design: comparison of CSW blocks, shading design, and ventilation design.

Attributes	CSW blocks	Shading design	Ventilation design
CSW blocks	1	1/3	1/6
Shading design	3	1	1
Ventilation design	6	1	1
Eigenvector	0.11	0.4	0.49

Table 3. Weighting value of building facades: comparison of green roofs, solar building materials, and double-skin facades.

Attributes	Green roofs	Solar building materials	Double-skin facades
Green roofs	1	1/3	1
Solar building materials	3	1	1
Double-skin facades	1	1	1
Eigenvector	0.2	0.6	0.2

Table 4. Weighting value of green attractions: comparison of cost difference, company image, and Social responsibility.

Attributes	Cost difference	Company image	Social responsibility
Cost difference	1	1	1
Company image	3	1	1
Social responsibility	3	1	1
Eigenvector	0.14	0.43	0.43

Table 5. Weighting value of each criterion.

Main Criteria (*wi*)	Subcriteria (*wi*)	*wi*	*Wi*%
Interior design (0.14)	CSW blocks (0.11)	0.015	1.5%
	Shading design (0.40)	0.056	5.6%
	Ventilation design (0.49)	0.069	6.9%
Building facades (0.37)	Green roofs (0.20)	0.074	7.4%
	Solar building materials (0.60)	0.222	22.2%
	Double-skin facades (0.20)	0.074	7.4%
Green attractions (0.49)	Cost difference (0.14)	0.069	6.9%
	Company image (0.43)	0.211	21.1%
	Social responsibility (0.43)	0.211	21.1%
$Wi = wi \times 100\%$		1.001	100.1%

3.2. Developing a Fuzzy Logic Inference System

The fuzzy logic inference method can be separated into two systems, that is, the Mamdani and the Sugeno systems. Typically, output from the Mamdani system is continuous, whereas that for the Sugeno system is discrete. To understand the change in continuous output, we adopted the Mamdani system. In addition, multiple types of membership functions existed; the membership functions commonly used include triangular functions and bell-shaped functions [80,81]. Therefore, triangular functions and bell-shaped functions were also adopted in this study for fuzzy set membership functions. The bottom section of Figure 1 shows the FLIS schematic diagram for the DFuzzy-DAHP decision-making model proposed in this study. The FLIS system was divided into the following four main parts: a fuzzifier, inference engine, fuzzy rule base, and defuzzification. The membership function and fuzzy range of the fuzzy set for each criterion must first be defined. The membership function and fuzzy range of the fuzzy set for the output value corresponding to each scenario must also be defined. After further completing the definition of the IF-THEN rule base in the FLIS system, the FLIS is then capable of inferences and quantified computations.

Fuzzy logic belongs to the field of artificial intelligence and can be used to process the complex and imprecise semantic meanings of people. For example, the expression "very good" does not have a "0" or "1" logical relationship. In a fuzzy decision environment [82], the membership function is used to define the degree of goodness. Fuzzy set theory expands traditional mathematical dichotomy theory (set value is 0 or 1) to an infinite number of continuous set values (between 0 and 1). This also renders fuzzy logic convenient for processing variables and inferences in language [83]. For this study, we applied fuzzy logic to define the evaluation content, which included risk factors, such as consumer-oriented future green energy requirements, corporate social responsibilities, corporate profitability, changes in operational environments, and policy changes. These influencing factors benefit decision-making for the overall project and investment risk considerations. Decision-making analysis of investments does not focus solely on profits. A company must understand the objective changes in demands in the external environment to form appropriate operating decisions, and to ensure the sustainable operation of the company. Once the FLIS system for the evaluation content examined in this study is complete, design evaluations of energy-saving residential building projects can be represented using easy-to-understand numbers or ratios. The potential importance of each criterion is also simultaneously presented, providing the decision-maker with additional information to facilitate decision-making.

3.3. Defining the Fuzzy Set of the Input and Output Factors in Fuzzy Logic

For the three main criteria, the interior design criterion is composed of three sub-criteria, namely CSW blocks, shading designs, and ventilation designs. The building facades criterion is composed of three sub-criteria, namely green roofs, solar building materials, and double-skin facades. The last main criterion, green attraction, is also composed of three sub-criteria, namely cost differences, company images, and social responsibilities. Before the FLIS system can be constructed, the membership function, fuzzy set, and fuzzy range of each criterion must be defined. In addition, the membership function and fuzzy range for the fuzzy set containing the output value must also be defined. When the evaluation factors were quantitatively defined in the fuzzy set, the IF-THEN rule base of the FLIS system was used to perform the appropriate quantification process on the evaluation factors in various scenarios. Because the evaluation factor has various levels of influence on the evaluation of energy-saving designs of residential buildings, definitions of the membership function, fuzzy set, and fuzzy range are required to complete the variable computation and inferences from various input scenarios through the IF-THEN rule base [68,83], which presents the corresponding output evaluation, result.

The definition of the fuzzy set and fuzzy range for each sub-criterion of the three main criteria, and the fuzzy set and fuzzy range definition of the corresponding output values, are shown in Tables 6–8. The measurement scale defined in fuzzy logic is an arbitrarily defined fuzzy scale. For example, in the cost difference sub-criterion of green attractions, 60% profitability indicates a good outcome, 30% profitability indicates an ordinary outcome, and 10% profitability indicates a poor outcome. However, whether 40% is good or ordinary is defined by the membership function in the fuzzy logic scale according to its membership levels in good or ordinary. Defuzzification in FLIS then shows the results for the quantified output values. These problems are often difficult for traditional evaluation models to process.

Table 6. Definition of the input and output fuzzy set and fuzzy range for the interior design criteria.

Input Scenario			Fuzzy output value	
Criteria	**Value range**	**Fuzzy sets**	**Description**	**Fuzzy sets**
CSW blocks	30%	Good	Quantitative value	Good (90%)
	20%	Ordinary		Ordinary (75%)
	10%	Poor		Poor (60%)
Shading design	90%	Good		
	70%	Ordinary		
	50%	Poor		
Ventilation design	90%	Good		
	60%	Ordinary		
	40%	Poor		

Table 7. Definition of the input and output fuzzy set and fuzzy range for the building facades criteria.

Input Scenario			Fuzzy output value	
Criteria	**Value range**	**Fuzzy sets**	**Description**	**Fuzzy sets**
Green roofs	90%	Very good	Quantitative value	Very good (90% ↑)
	75%	Good		Good (80% ↑)
	60%	Ordinary		Ordinary (60%)
	45%	Poor		Poor (45% ↓)
	30%	Very poor		Very poor (30% ↓)
Solar building materials	40%	Good		
	25%	Ordinary		
	10%	Poor		
Double-skin facades	30%	Good		
	20%	Ordinary		
	10%	Poor		

Table 8. Definition of the input and output fuzzy set and fuzzy range for the green attractions criteria.

Input Scenario			Fuzzy output value	
Criteria	**Value range**	**Fuzzy sets**	**Description**	**Fuzzy sets**
Cost difference	50%	Good	Quantitative value	Good (80% ↑)
	35%	Ordinary		Ordinary (55%)
	20%	Poor		Poor (30% ↓)
Company image	80%	Good		
	60%	Ordinary		
	40%	Poor		
Social responsibility	90%	Good		
	70%	Ordinary		
	50%	Poor		

3.4. Input Scenario and Output Mapping

The insertion of the input scenarios into FLIS first undergoes the IF-THEN rule base inference before the defuzzified result is quantified in the output value. This model has 99 input scenarios. The main criterion interior design comprises three sub-criteria, each of which has three fuzzy sets (three scenarios for each fuzzy evaluation: good, ordinary, and poor, or high, moderate, and low); thus, there are 3 × 3 × 3 = 27 scenarios. The structure of the main criterion green attractions is the same as that for interior design; therefore, it also has 3 × 3 × 3 = 27 scenarios. However, green roofs in three sub-criteria of the main criterion building facade comprise 5 fuzzy sets, and the other two criteria contain three fuzzy sets. Therefore, there are 5 × 3 × 3 = 45 scenarios. The overall evaluation contains 99 scenarios, and each criterion in the scenario has a varying degree of influence on the energy-saving design strategy of residential buildings. In addition, the 99 evaluation scenarios comprise multiple properties and measurement units to handle the complex evaluation problem. The 3D mapping relationship chart for the input scenarios in the three main criteria and output is shown in Figure 3. This computation model is difficult to achieve manually. In addition, the fuzzy rule base is similar to the human brain in the overall FLIS. When the inference rules of FLIS are constructed, FLIS is then capable of inference computations.

Providing the decision-maker allocates an input value to each evaluation factor, FLIS can automatically calculate a quantified performance evaluation value. Fuzzy logic is categorized as artificial intelligence; its scientific reasoning and computing mechanism is widely adopted for quantificational decision-making. Fuzzy logic possessed substantial objectivity and adaptability. The reasoning and computing of scenarios input into the FLIS are shown in Figure 4.

Figure 3. 3D mapping relationship diagram for input and output scenarios.

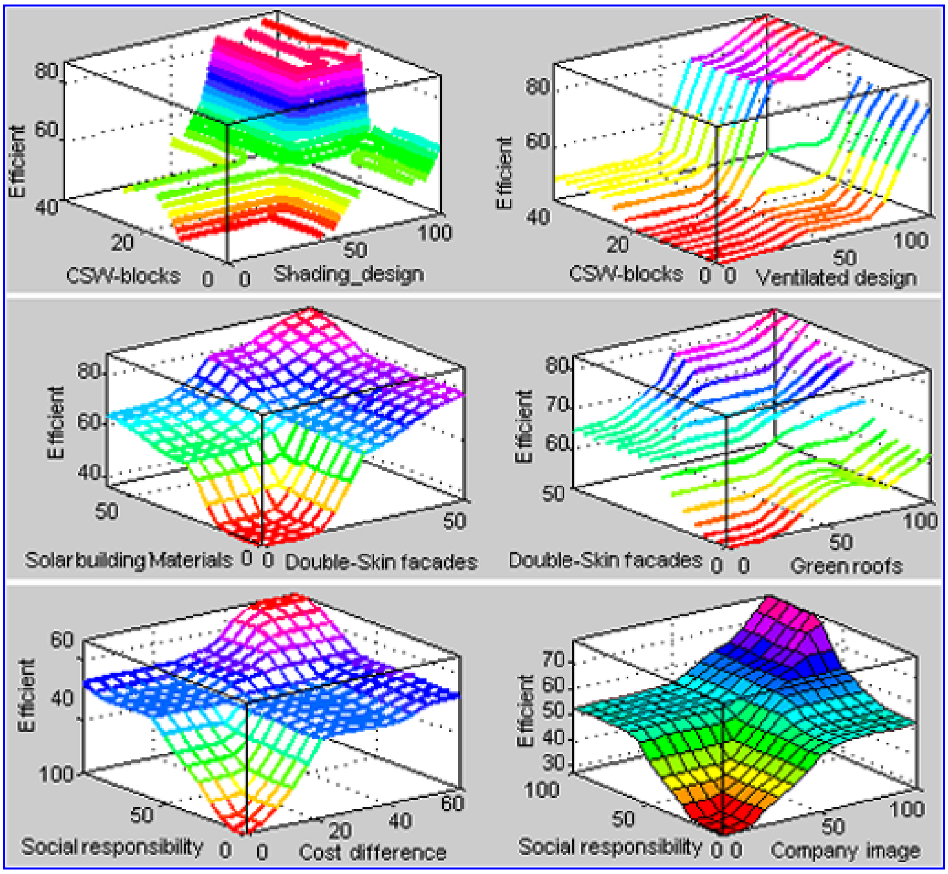
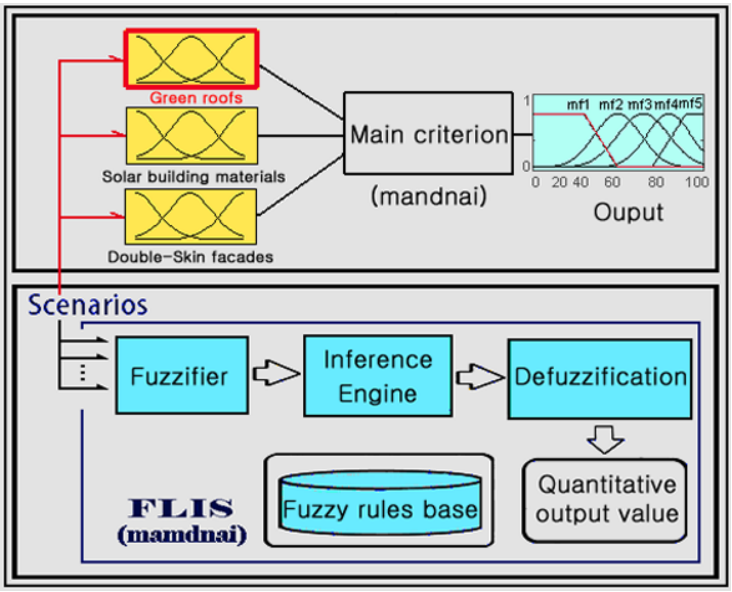


Figure 4. The reasoning and computing of scenarios input into the FLIS.



3.5. Calculation of the Comprehensive Quantified Evaluation Value

The three main criteria function were first defined as follows: y_1 represents interior design, and $f(y_1)$ represents the fuzzy quantified output value of interior design; y_2 represents building facades, and $f(y_2)$ represents the fuzzy quantified output value of building facades; y_3 represents green attractions, and $f(y_3)$

represents the fuzzy quantified output value of green attractions. Once these definitions were completed, the weighting values derived from AHP, and the fuzzy quantified output values derived from FLIS (yi), could be used to calculate the quantified magnitude value of the level of energy-saving design compliance of the residential building project, which equals $\Sigma f\ (yi) \times (wi)$. The model also shows the potential importance of each criterion. Thus, the decision-making information is easy for the decision-maker to obtain. The optimum and worst quantified output values from FLIS computations are shown in Table 9. In addition, the input scenarios in Table 9 can be either quantified values or imprecise semantic meanings in natural language, such as good (high), ordinary (moderate), and poor (low). Because fuzzy logic can compute language variables and infer quantified language [68,83], this model can provide decision-makers the ability to further compare the magnitude of quantified values from scientific calculations prior to conducting project evaluations. This enhances the efficiency and effectiveness of decision-making, which reduces the risk of forming wrong decisions.

Table 9. The optimal and worst output value for each subcriterion.

Main Criteria	Subcriterion	Optimal	Worst	Case 1	Case 2
Interior design (y_1)	CSW blocks	Good	Poor	Good	Good
	Shading design	Good	Poor	Ordinary	Good
	Ventilation design	Good	Poor	Good	Good
Output value (%)		90.2	39.9	87.2	90.2
Building façades (y_2)	Green roofs	Very good	Very poor	Poor	Very good
	Solar building materials	Good	Poor	Ordinary	Good
	Double-skin facades	Good	Poor	Poor	Good
Output value (%)		88.5	20.4	51.9	88.5
Green Attractions (y_3)	Cost difference	Good	Poor	Good	Poor
	Company image	Good	Poor	Ordinary	Good
	Social responsibility	Good	Poor	Ordinary	Good
Output value (%)		82	31.4	57.7	62.7

4. Case Study

For this case study, a residential building project in Taiwan was used. The foundation was oriented to face south. Because the solar building materials are influential to residential building planning, the sunlight conditions must be modeled before planning to achieve design efficiency. Taiwan is located along 23.5° N latitude, as shown in Figure 5. The angle of elevation of sunlight in the four seasons in Taiwan and the changing relationship of the angle of azimuth are described.

(a) Each day, the elevation angle of sunlight increases from 0° at sunrise to the highest point at noon, returning to 0° at sunset. The angle of azimuth begins from the maximum value at sunrise, moving to 0° by noon before again reaching the maximum positive value at sunset.
(b) In one year, the range of variation for the angle of azimuth over one day changes from ±115.6° in the summer to ±64.4° in the winter. The value is 90° in the spring and autumn. The range of variation for the elevation angle changes from 90° in the summer to 43.6° in the winter. The buildings facing north in Taiwan receive minimal hours of sunlight in one year, whereas buildings facing south receive sunlight throughout the entire year.

(c) The horizontal face of the building receives numerous hours of sunlight in every season of the year.

(d) Excluding direct sunlight at noon in the summer (solar elevation angle at 90°), the angle of elevation changes in for the other seasons. Therefore, the angle of elevation and angle of azimuth are important aspects for building plans designed with solar building materials.

Case 1 is shown in Figure 5 and is an example of an ordinary traditional residential building design plan. Case 2 is shown in Figure 6. In this case, saving energy was considered before planning, and the company was required to sacrifice profit to improve green building construction. This action shows corporate transformation and the practice of social responsibility.

The results in Table 9 show not only the optimum and worst quantified output values of the three main criteria, but also the fuzzified quantified output values of the two residential building design cases after FLIS calculation, as shown in Figure 7. Because the evaluation content of energy-saving design in this evaluation model includes comprehensive evaluations of factors, such as corporate image and social responsibility, the quantified output values in Table 9 and the weighting values of each criterion in Table 5 can be used to calculate the value of $\Sigma f(yi) \times (wi)$ in Cases 1 and 2.

Figure 5. Traditional residential building planning designs for Case 1.

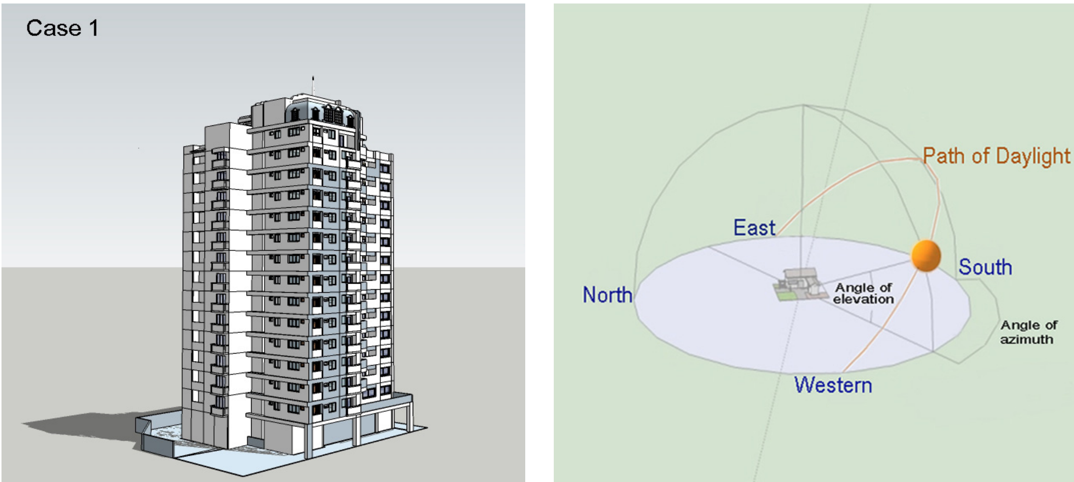


Figure 6. Design concepts for Case 2.

Figure 7. Quantified output values calculated by FLIS for Cases 1 and 2.

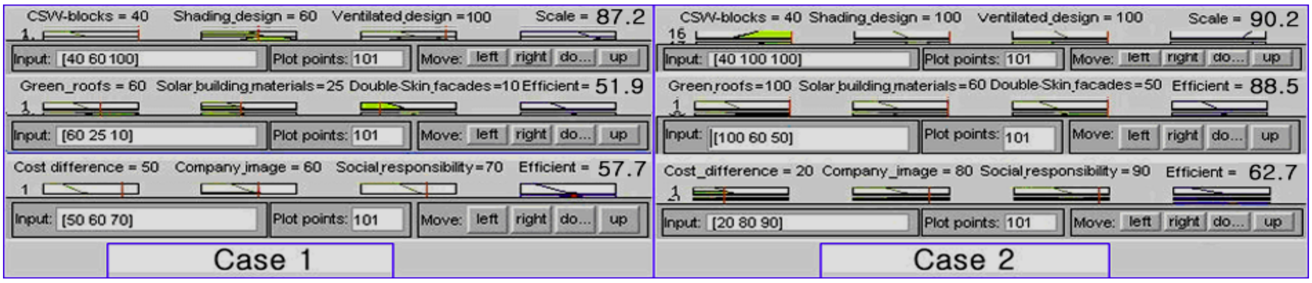


Table 10 shows that the Σ*f* (*yi*) × (*wi*) value of Case 2 was 76.16, which is higher than the value of Case 1, 59.75. The comprehensive evaluation of energy-saving design in Cases 1 and 2 shown in Table 10 indicates that Case 2 is the superior design proposal, which can serve as a decision-making reference in the early design stages. The design concept for Case 2 considered the various levels of influence of the evaluation factors in Table 10, and generated a comprehensive design decision consideration. This includes the use of solar shading panels, solar panels on the exterior walls, solar panels on the roof of the building, double-skin facades, and green roofs. The solar panel and plant cover area on the roof of the building approached 90%. In addition to enhancing the solar power generating efficiency, this effectively lowers the room temperature. The carbon sequestration effect of the green roof provides environmental benefits.

Residential buildings are an important indicator of economic progress. In addition, the residential sector is responsible for a significant portion of global energy consumption [43]. Reducing residential energy consumption is an issue that everyone should prioritize. Both newly built and older residential buildings can attain energy consumption savings through energy-saving design approaches. However, building projects that use energy-saving designs have increased construction costs, which directly impacts profits for investors.

Table 10. Comprehensive evaluation of energy-saving design for Cases 1 and 2.

Subcriteria (*wi*)	**Case 1**			**Case 2**		
	Scenario	***f* (*yi*)**	***f* (*yi*) × *wi***	**Scenario**	***f* (*yi*)**	***f* (*yi*) × *wi***
CSW blocks (0.015)	Good	87.2	1.31	Good	90.2	1.35
Shading design (0.056)	Ordinary		4.88	Good		5.05
Ventilation design (0.069)	Good		6.02	Good		6.22
Green roofs (0.074)	Poor	51.9	3.84	Very good	88.5	6.55
Solar building materials (0.222)	Ordinary		11.52	Good		19.65
Double-skin façade (0.074)	Poor		3.84	Good		6.55
Cost difference (0.069)	Good	57.7	3.98	Poor	62.7	4.33
Company image (0.211)	Ordinary		12.18	Good		13.23
Social responsibility (0.211)	Ordinary		12.18	Good		13.23
Σ*f* (*yi*) × (*wi*)		59.75			76.16	

The use of green building materials increases construction complexity and affects building progress, which creates disinterest in general builders and land developers in energy-saving design planning for residential building projects. This not only affects the promotion of green building policies by the public sector, but also affects technological upgrading in the industry. Although companies are understandably oriented toward seeking profits, company decision-makers must be capable of judging the changing external environment and proposing recommendations to avoid risks. Haleblian [84] stated that the awareness-motivation capabilities of firms influence the timing of competitive action. Managers may occasionally sacrifice profits to improve their relative competitive standing [85]. The results for the main criterion of green attractions in this study show that sacrificing profit and assuming social responsibility can improve corporate image, which benefits sustainable operations and competitive advantages. According to Fernando [20], social responsibility enhances reputation, which improves the profitability of the firm.

5. Conclusions

Whether working on public construction projects or various types of private construction projects, the construction industry is closely related to the lives of citizens. Although the construction industry provides economic development, it also causes environmental pollution. Various strategies of the construction industry, such as low-carbon construction, green buildings, zero-energy development, and carbon-neutral construction, can achieve the goals of project development through designs. Because the issue of carbon neutral design and construction is gaining attention, the construction industry should plan ahead for the green transformation. Company decision-makers should not consider risk analysis of decision-making as mere considerations of investment costs and profit; instead, decision-making analysis requires decision-making models that are objective and scientific to examine the future influence of project activities on both the interior and exterior of the company. Only in this manner can the effectiveness of a decision be enhanced. The model proposed in this study considered the lowest profit of the company, investing reduced profit into energy-saving design configurations. Considering multiple factors simultaneously, including corporate social responsibility, environmental protection, and reducing the energy consumed by residents, the model is highly adaptive. The model also benefits company image and improves intangible values, such as company reputation. Immediately adapting to carbon neutral construction methods is not easy for traditional residential building constructors. They are unwilling to sacrifice profits, which renders the effects of green building policy promotion in Taiwan insignificant. The model developed in this study enables decision-makers to understand multiple factors of corporate operation, including external environmental influences. From the various levels of influence from each criterion, decision-makers can develop strategies suitable for gradually improving the energy-saving decisions of projects during the early design stages.

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