ICIC Express Letters
Volume **11**, Number **1**, January **2017**

ICIC International ©2017 ISSN 1881-803X
pp. 71–78

GREEN ENERGY RENOVATION DIAGNOSIS AND REHABILITATION FOR RESIDENTIAL COMMUNITIES

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Received June 2016; accepted September 2016

Abstract. *Focusing on the improvement of green energy management of existing residential communities in Taiwan, this research is to develop and establish a green energy management assessment framework that could apply to these communities for their renovation diagnosis and rehabilitation. In this study, through literature reviews and expert interviews, the major criteria and sub-criteria of the initial green energy management assessment framework were determined first. Then, through expert questionnaires, the Delphi method was used to finalize the assessment framework. The final assessment framework consisted of four major criteria and seventeen sub-criteria. The four major criteria are ecological protection, energy conservation, waste reduction and interior environmental quality. Furthermore, in order to easily apply the assessment framework to the existing residential communities, a renovation diagnosis and rehabilitation scoring table was established by using analytic hierarchical process to determine the relative weights of the major criteria and the sub-criteria. Finally, the scoring table was applied to an existing residential community in Taipei, Taiwan to investigate the renovation diagnosis problems encountered and propose the rehabilitation strategies.*
Keywords: Green energy, Green architecture, Renovation and rehabilitation, AHP

1. **Introduction.** Based on the data from Architecture and Building Research Institute, Ministry of Interior, the amount of carbon dioxide emissions of the construction industry has exceeded one quarter of the national total. The CO_2 emission distribution is 9.31% for building materials production, 0.2% for construction, 1.49% for materials transportation, 11.88% for residential daily energy use and 5.94% for commercial daily energy use with a total of 28.82% [1]. It can be seen that the residential communities (buildings) play a key role on energy saving and CO_2 emission reduction policy. Residential buildings have a high daily use of energy consumption. However, in addition to energy conservation, there is a continuous need for safe and effective electricity usage, health care, and a comfortable and convenient living environment in energy management. Therefore, in the field of green buildings, ideal energy management is defined as being ecological, energy-conserving, waste reducing, and healthy (EEWH). In addition, there is a growing importance to apply intelligent high technology in the design of sustainable green buildings to developing a building energy management system (BEMS) or central energy management system (CEMS) [2-4]. However, it is highly unlikely to develop this kind of system in an existing, especially old, residential community, especially when there are a lot of different people living in it.

Chen et al. [5] had studied those factors affecting the application of green architecture to both new and existing residential building development. Here this research is to focus on the existing residential communities in the area of green energy renovation diagnosis and rehabilitation.

The purposes of this research are: (1) Establish a green energy renovation diagnosis and rehabilitation assessment framework that could apply to existing residential communities and determine the major criteria and sub-criteria to be used in the framework, (2) Understand the importance of each major criterion and sub-criterion by finding the relative or absolute weights of major criteria and sub-criteria, and (3) Apply the obtained sub-criteria to the existing residential communities for energy renovation diagnosis and rehabilitation.

This paper, after the introduction (including literature reviews), (1) presents the research methods used, (2) establishes the criteria and sub-criteria to be used in the assessment framework by using the Delphi method, (3) identifies the relative weights of criteria and sub-criteria by using AHP and obtains a scoring table, (4) discusses the weights obtained in the scoring table, (5) performs a case study, and (6) draws the conclusions.

2. **Methodology.** In this study, after the foreign and domestic literature was reviewed and experts were interviewed, the criteria and the sub-criteria to be used in the initial assessment framework were formulated. The final framework was determined by using the Delphi method. The relative weights of criteria and sub-criteria were identified by using the analytic hierarchical process (AHP). In this research, the Delphi and AHP questionnaires were conducted with a panel of 15 professionals in green energy management. They had 13 to 25 years of working experience with an average of 18 years.

The Delphi method is designed to explore opinions of a group of knowledgeable persons in order to gain a consensus on a particular topic without bringing the group together [6]. The Delphi method pools expert judgment in an iterative process that involves anonymity and opportunity to reflect on and respond to other experts' opinions. Questionnaires are mailed to a group of expert panelists, soliciting their opinion on a topic of interest. Researchers then synthesize the results and distribute them to the panelists in additional waves for reflection and comment.

The AHP was developed in the early 1970's by T. Saaty. There are six procedures to run AHP: (1) analyzing problem and displaying evaluative factors, (2) constructing the hierarchy, (3) establishing pair-wise comparison matrices, (4) computing eigenvectors and eigenvalues, (5) testing inconsistency of pair-wise comparison matrices, and (6) computing the relative weight of each factor [7].

3. **Establishment of Assessment Framework.** The assessment framework was established first using the Delphi method. Through literature reviews and expert interviews, an initial assessment framework was formulated with four major criteria, including ecological protection, energy conservation, waste reduction and indoor environmental quality along with a total of 22 sub-criteria for the four criteria (see Table 1). The three-level (A: Green energy renovation diagnosis and rehabilitation, B: Criteria, C: Sub-criteria) hierarchical diagram of the final assessment framework is shown in Figure 1. The 22 sub-criteria in the initial framework have been cut to 17. Those sub-criteria cut were considered by the panel as not practical in Taiwan or not important to be implemented.

4. **Identification of Relative Weights of Elements.** After the elements of each level in the hierarchical diagram of the assessment framework have been established, the AHP method was used to identify the relative weights of elements of each level. Two types of pair-wise comparisons matrices had been established: (1) the evaluation matrix of level 2 criteria with respect to the goal; and (2) the evaluation matrix of sub-criteria with respect to the related criterion at level 2. The evaluation matrix of criteria to the goal (**A**) is shown in Table 2. At level 3, four evaluation matrices were required to perform. The evaluation matrices of sub-criteria with respect to the four criteria are shown respectively in Table 3, Table 4, Table 5 and Table 6. The above evaluation matrices were obtained by using Power Choice [8] to analyze the data from AHP questionnaires. Based on the

Table 1. Criteria and sub-criteria of the initial assessment framework

Criteria	Sub-criteria	Descriptions
Ecological Protection	Greening Building Lot	Incorporate green products and processes to improve or restore the building lot.
	Vegetated Roof and Exterior Wall	Design and install vegetation on the roof and exterior wall to create a passive thermal control system that purifies the air, cools the interior during the day and regulates temperature changes at night.
	Permeable Lot	Design the lot such that the built environment is permeable or designed to capture water runoff for infiltration on site.
	Community Friendly Fence	Enhance the community surrounding with recycled or recyclable and preferably, maintenance-free fencing.
	Ecological Retention Pond	Install a pond to manage stormwater runoff to prevent flooding and bring nature's methods of balancing a wetland ecosystem into the backyard water garden.
	Small Community Farm	A community farm is a small area where tenants can grow their own crops. The farm is divided into small pockets of land for shared use among residents.
Energy Conservation	Energy-consuming Equipment	The major energy-consuming equipment or appliances are HVAC units, elevators and lamps. Reduce their energy consumption by replacing them with energy saving units that meet various demands for energy efficiency.
	Solar Thermal Energy System	Reduce consumption of non-renewable energy sources by using solar thermal energy system.
	Roof Thermal Insulation	Design and install roof insulation materials to minimize heat transfer and thermal bridging.
	Solar Photovoltaic Energy System	Reduce consumption of non-renewable energy sources by using solar photovoltaic energy system.
	Rainwater Harvesting	Install a rain harvesting system to collect rainwater for irrigation and other outdoor water uses.
	Wind Power	Wind power is extracted from air flow using wind turbines to produce electrical power.
	Building Energy Management System	A building energy management system (BEMS) is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems.
Waste Reduction	Resource Recycling and Reuse	Reduce consumption of raw materials by converting waste materials into reusable objects to prevent waste of potential useful materials.
	Garden Waste Collection and Garbage Storage	Provide a place for garden waste collection. Provide solid and durable metal or plastic watertight containers with tight-fitting insect and rodent resistant cover for garbage (food waste) storage. The garbage freezer can be used to omit stinky odors.
	Waste Handling, Separation and Storage	Separating different types of waste components is an important step in the handling and storage of solid waste at the source when the waste is placed in storage containers for collection. The air-tight waste compression equipment can be used for storage.
	Sewage Treatment	The process of removing contaminants from household wastewater with or without sewers.
Indoor Environmental Quality	Indoor Sound Quality	Control excess unwanted or unpleasant noise from indoor sources, especially in public space.
	Indoor Lighting Quality	Maximize the efficiency of electric lighting systems through control systems; upgrade electric lighting fixtures to more efficient fluorescent and LED fixtures; provide occupants with appropriate illumination by dividing the building space into different lighting zones.
	Indoor Air Quality	An indoor space with good air quality is one that is low in toxins, contaminants and odors.
	Indoor Thermal Comfort	Indoor thermal comfort includes temperature, humidity, and air speed as well as outdoor temperature design conditions and outdoor humidity design conditions.
	Green Building Materials	Use GBM (Green Building Material) certified materials to do community rehabilitation.

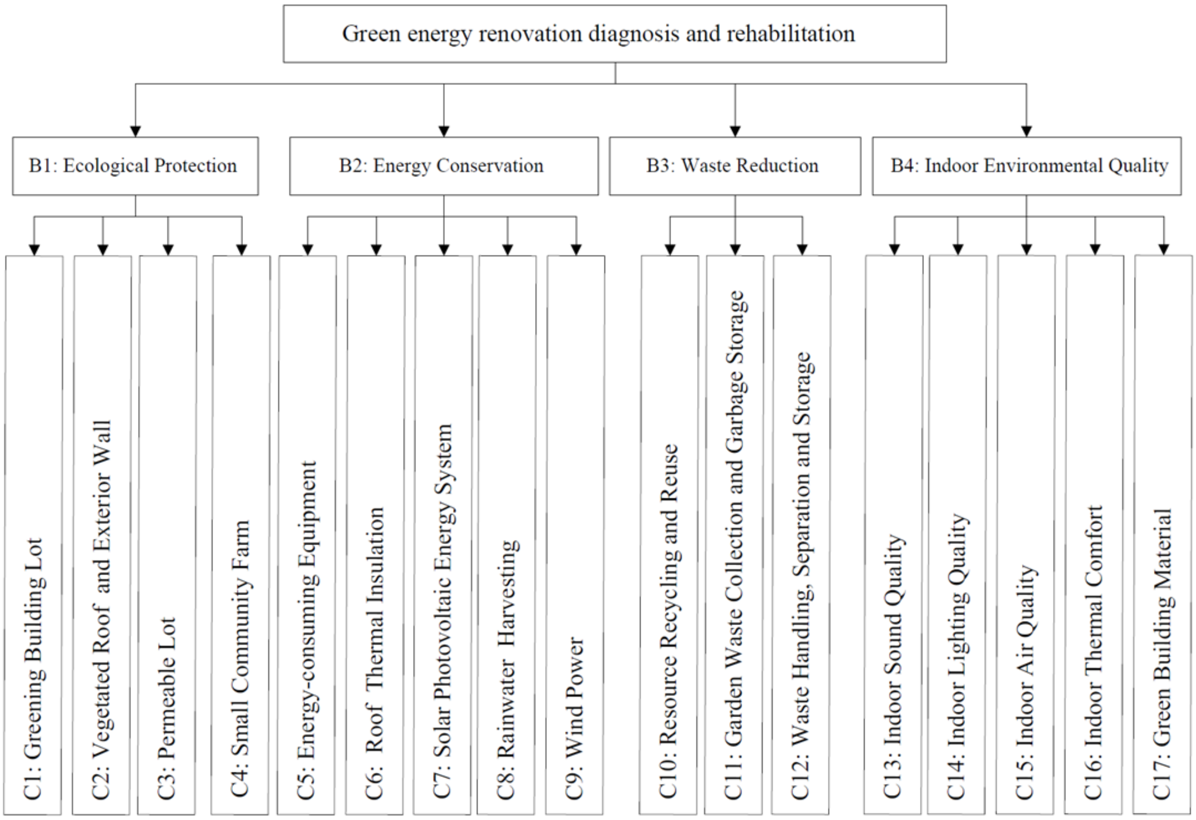

FIGURE 1. Three-level hierarchical diagram of the assessment framework

TABLE 2. Evaluation matrix of level 2 criteria with respect to the goal

A	B1	B2	B3	B4	Geometric Mean	Weights
B1	1.000	0.900	1.700	1.200	1.164	0.235
B2	1.111	1.000	8.900	4.800	2.625	0.530
B3	0.588	0.112	1.000	0.770	0.475	0.096
B4	0.833	0.208	1.299	1.000	0.689	0.139
λ max = 4.27; C.I. = 0.089 ($\fallingdotseq 0$, ok); C.R. = 0.099 (< 0.1, ok)						

TABLE 3. Evaluation matrix of sub-criteria with respect to B1

B1	C1	C2	C3	C4	Geometric Mean	Weights
C1	1.000	1.760	1.540	1.410	1.398	0.343
C2	0.568	1.000	1.030	1.170	0.910	0.223
C3	0.649	0.971	1.000	1.080	0.908	0.223
C4	0.709	0.855	0.926	1.000	0.866	0.212
λ max = 4.01; C.I. = 0.042 ($\fallingdotseq 0$, ok); C.R. = 0.046 (< 0.1, ok)						

relative weights for the four criteria at level 2 and the 17 sub-criteria at level 3, the priority weights and rankings of sub-criteria can be established (see Table 7).

5. **Discussions.** Among the four major criteria, "energy conservation" is the most important criterion with a weight of 53.0%, followed by "ecological protection", "indoor environmental quality" and "waste reduction". The result indicates that "energy conservation" is the key criterion to be considered first. This is due to the fact that it has an immediate impact on energy consumption of a community and it can be easily applied to the existing residential community. The ecological protection criterion has a weight of

Table 4. Evaluation matrix of sub-criteria with respect to B2

B2	C5	C6	C7	C8	C9	Geometric Mean	Weights
C5	1.000	1.750	1.530	1.420	1.020	1.311	0.260
C6	0.571	1.000	1.160	1.090	1.140	0.962	0.190
C7	0.654	0.862	1.000	1.090	1.200	0.941	0.186
C8	0.704	0.917	0.917	1.000	0.970	0.895	0.177
C9	0.980	0.877	0.833	1.031	1.000	0.941	0.186
$\lambda\max = 5.05$; C.I. $= 0.012$ ($\fallingdotseq 0$, ok); C.R. $= 0.013$ (< 0.1, ok)							

Table 5. Evaluation matrix of sub-criteria with respect to B3

B3	C10	C11	C12	Geometric Mean	Weights
C10	1.000	0.570	0.340	0.579	0.151
C11	1.754	1.000	0.170	0.668	0.174
C12	2.941	5.882	1.000	2.586	0.675
$\lambda\max = 3.03$; C.I. $= 0.016$ ($\fallingdotseq 0$, ok); C.R. $= 0.017$ (< 0.1, ok)					

Table 6. Evaluation matrix of sub-criteria with respect to B4

B4	C13	C14	C15	C16	C17	Geometric Mean	Weights
C13	1.000	0.409	0.733	0.286	0.530	0.539	0.102
C14	2.447	1.000	1.900	0.625	1.267	1.298	0.246
C15	1.364	0.526	1.000	1.133	0.952	0.950	0.180
C16	3.500	1.599	0.882	1.000	1.456	1.484	0.281
C17	1.886	0.789	1.050	1.687	1.000	1.014	0.192
$\lambda\max = 5.14$; C.I. $= 0.034$ ($\fallingdotseq 0$, ok); C.R. $= 0.031$ (< 0.1, ok)							

Table 7. Sub-criteria priority weights and rankings

A	Criteria	Relative Weights	Sub-criteria	Relative Weights	Absolute Weights	Rank
Green energy renovation diagnosis and rehabilitation	B1: Ecological Protection	23.5%	C1: Greening Building Lot	34.3%	8.06%	6
			C2: Vegetated Roof and Exterior Wall	22.3%	5.24%	8
			C3: Permeable Lot	22.3%	5.24%	8
			C4: Small Community Farm	21.2%	4.98%	10
	B2: Energy Conservation	53.0%	C5: Energy-consuming Equipment	26.0%	13.78%	1
			C6: Roof Thermal Insulation	19.0%	10.07%	2
			C7: Solar Photovoltaic Energy System	18.6%	9.86%	3
			C8: Rainwater Harvesting	17.7%	9.38%	5
			C9: Wind Power	18.6%	9.86%	3
	B3: Waste Reduction	9.6%	C10: Resource Recycling and Reuse	15.1%	1.45%	16
			C11: Garden Waste Collection and Garbage Storage	17.4%	1.67%	15
			C12: Waste Handling, Separation and Storage	67.5%	6.48%	7
	B4: Indoor Environmental Quality	13.9%	C13: Indoor Sound Quality	10.2%	1.42%	17
			C14: Indoor Lighting Quality	24.6%	3.42%	12
			C15: Indoor Air Quality	18.0%	2.50%	14
			C16: Indoor Thermal Comfort	28.1%	3.91%	11
			C17: Green Building Materials	19.2%	2.67%	13

23.5%. Its four sub-criteria are generally used in green architecture. The third ranked criterion, indoor environmental quality, has a weight of 13.9%. Although its sub-criteria have low priority weights, they should be implemented to have a healthy community. The fourth ranked criterion, waste reduction, has one sub-criterion (Waste Handling, Separation and Storage) with a high priority weight. It is because this sub-criterion is essential to a community and its implementation is cost effective. In general, the sub-criteria in energy conservation criterion should be implemented in the residential communities as soon as possible.

6. **Case Study.** In order to easily apply the assessment framework to the existing residential communities, a renovation diagnosis scoring table (see Table 8) was established based on Table 7. For the sake of letting a user give the score to a sub-criterion easier, the absolute weight in the table is changed to an altered weight. Depending on how serious a sub-criterion is, the user can give a sub-criterion a score from 0 to 10. The score for each sub-criterion is equal to its altered weight times its given score. An exemplary study case, the Fuh-Shih-Bao residential community in Taipei city, is presented to show how it was used to do renovation diagnosis. The sub-criteria scores for the Fuh-Shih-Bao community

TABLE 8. Renovation diagnosis scoring table

A	Criteria	Sub-criteria	Altered Weights	Given Score	Sub-criterion Score
Green energy renovation diagnosis and rehabilitation	B1: Ecological Protection (24.0%)	C1: Greening Building Lot	0.806	6.8	5.48
		C2: Vegetated Roof and Exterior Wall	0.524	5.6	2.93
		C3: Permeable Lot	0.524	NA	0
		C4: Small Community Farm	0.498	NA	0
	B2: Energy Conservation (53.0%)	C5: Energy-consuming Equipment	1.378	5.8	7.99
		C6: Roof Thermal Insulation	1.007	5.6	5.64
		C7: Solar Photovoltaic Energy System	0.986	3.0	2.96
		C8: Rainwater Harvesting	0.938	5.0	4.69
		C9: Wind Power	0.986	3.0	2.96
	B3: Waste Reduction (10.0%)	C10: Resource Recycling and Reuse	0.145	NA	0
		C11: Garden Waste Collection and Garbage Storage	0.167	7.0	1.02
		C12: Waste Handling, Separation and Storage	0.648	7.0	4.54
	B4: Indoor Environmental Quality (13%)	C13: Indoor Sound Quality	0.142	7.2	1.02
		C14: Indoor Lighting Quality	0.342	7.5	2.57
		C15: Indoor Air Quality	0.250	7.0	1.75
		C16: Indoor Thermal Comfort	0.391	7.8	3.05
		C17: Green Building Materials	0.267	6.8	1.82
				Total Score	48.42

How to fill the table:

1. Give each sub-criterion a score from 0 to 10.
2. Sub-criterion score = Altered weight × Given score
3. Total score is an indicator of the green energy management maturity of a residential community.

Rehabilitation criteria:

1. No Rehabilitation: Sub-criterion given score >= 7
2. Some Rehabilitation: 4 < Sub-criterion given score < 7
3. Immediate Rehabilitation: Sub-criterion given <= 4
4. If it is impossible to do rehabilitation for a sub-criterion, enter NA for the sub-criterion score.

are also shown in Table 8. The rehabilitation strategies for green energy management are shown in Table 9.

Table 9. The rehabilitation strategies for Fuh-Shih-Bao residential community

Criteria	Sub-criteria	Rehabilitation Descriptions
Ecological Protection	C1: Greening Building Lot	Grow a variety of plants in the outdoor yard and improve the uneven ground surface to create a much better recreation space to be used by the residents.
	C2: Vegetated Roof and Exterior Wall	Grow a variety of plants for rooftop gardening to serve several purposes for the building, such as absorbing rainwater, providing insulation, and reducing carbon dioxide (CO_2) emissions.
	C3: Permeable Lot	There was no room to make the lot permeable since the basement had been designed in such a way to occupy the whole lot.
	C4: Small Community Farm	There was no unoccupied space (vacant lot) available to set up a small community farm.
Energy Conservation	C5: Energy-consuming Equipment	The community public area has adopted T8 fluorescent illumination with a total of 107 lamps. If they are replaced by T5 lamps, a 30% of energy can be saved. The lobby has adopted 40W incandescent illumination with a total of 8 light bulbs. If they are replaced by 3W LED downlights (3W), a 94% of energy can be saved. The emergency lights have used 10W incandescent illumination with a total of 25 lamps. If they are replaced by 3W LED lights (3W), a 70% of energy can be saved. Install high efficient lighting systems and check the illuminances in public areas. Provide enough but not too much illumination.
	C6: Roof Thermal Insulation	Use the same improvement strategies in B2.
	C7: Solar Photovoltaic Energy System	Install a 4kWp solar photovoltaic panel on the top of the roof water storage tank to generate electrical power to be used in public space.
	C8: Rainwater Harvesting	Install downspout diverters to change the natural rainwater flow of spouts toward the rain barrels or on its way to the plants in the outdoor yard.
	C9: Wind Power	Install a wind power electricity generator on the rooftop to be used as an auxiliary power supply if financially feasible
Waste Reduction	C10: Resource Recycling and Reuse	The community has no extra space to set up a resource recycling station.
	C11: Garden Waste Collection and Garbage Storage	The community has no extra space for garden waste collection. Provide solid and durable metal or plastic watertight containers with tight-fitting insect and rodent resistant cover for garbage (food waste) storage.
	C12: Waste Handling, Separation and Storage	Different types of wastes are classified and clearly labelled. They should be placed in easily identified storage containers for collection. The community has no extra space to set up waste compression equipment for storage.
Indoor Environmental Quality	C13: Indoor Sound Quality	Replace hard floor tiles in public space by sound absorbing tiles to effectively reduce ambient noise level.
	C14: Indoor Lighting Quality	Some areas in the basement have low illuminances. They should install extra lighting fixtures.
	C15: Indoor Air Quality	Install Carbon Monoxide detectors to measure CO levels over time and use the CO levels to control the number of exhaust fans and the amount of time to be activated to control vehicle exhaust pollution concentration in the basement.
	C16: Indoor Thermal Comfort	Although the mid-size community does not have a large public space and its lobby has a front and back door with good ventilation, it is suggested that a thermo-hygrometer is installed to help effectively monitor indoor temperature and humidity.
	C17: Green Building Materials	The ceilings in the community lobby or public space, if remodeled, should be replaced GBM certified ceiling materials or painted using GBM certified paints. Purchase furniture made from recycled simulated wood materials if they are to be replaced.

7. **Conclusions.** The establishment of a green energy renovation diagnosis and rehabilitation assessment framework that could apply to existing residential communities is influenced by a lot of criteria. This research established the criteria and sub-criteria to be used in the assessment framework for green energy management by Delphi method. Then, AHP was used to identify the relative weights of criteria and sub-criteria. From the relative weights of criteria, the energy conservation criterion has the greatest impact on the renovation diagnosis. The priority weights of sub-criteria can help us understand the importance of each sub-criterion to the green energy management. Finally, a scoring table was established to perform renovation diagnosis and rehabilitation of existing residential communities. The scoring table was applied here only to the Fuh-Shih-Bao residential community. However, they can also be applied to other similar communities. The results obtained from those applications can be further studied to improve the established assessment framework.

Acknowledgment. This work was partially supported by National Science Council, Taiwan, under grant NSC101-2221-E-216-040, which is greatly acknowledged. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

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