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ESTABLISHMENT OF GREEN ENERGY MANAGEMENT EVALUATION FRAMEWORK IN SUSTAINABLE BUILDINGS

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Abstract. *The development of intelligent management system is influenced by a lot of factors. This research is to develop and establish a green energy management evaluation framework for the future development of intelligent management system to be employed in a university. In this study, through literature reviews and expert interviews, the primary and the secondary evaluation factors of the initial green energy management evaluation framework were determined first. Then, through expert questionnaires, the Delphi method was used to finalize the evaluation framework. The final evaluation framework consisted of four primary factors and nineteen secondary factors. The four primary factors were intelligent management, equipment system, renewable energy, and indoor air quality. Afterward, the analytic hierarchy process (AHP) questionnaires were used to determine the relative or absolute weighted values of these factors. From the obtained relative weights of four primary factors, "equipment system" and "intelligent management" have about the same weights, followed by "renewable energy" and "indoor air quality". The obtained absolute weights of secondary factors can help us understand the priorities to apply those factors in green energy management.*
Keywords: Sustainable buildings, Building energy management system, Intelligent green buildings

1. **Introduction.** Many buildings have a high ratio of energy consumption. However, in addition to energy conservation, there is a continuous need for safe electricity usage, health care, and a comfortable and convenient living environment in sustainable buildings. Therefore, in the field of green buildings, ideal buildings are defined as being ecological, energy-conserving, waste reducing, and healthy (EEWH). EETH is the green building certification system in Taiwan. In addition, there is a growing importance to apply intelligent high technology in the design of sustainable green buildings.

In the development of the building energy management system (BEMS) for intelligent energy-saving buildings, it is crucial to construct both a central monitoring system with an advanced technical solution and an interface control system with various controllers [1]. The BEMS has several important functions, including the monitoring of buildings and architectural equipment. Various functions such as monitoring, printing, and operation contribute towards increasing the overall managerial efficiency of the system. Moreover, the BEMS must have a statistical, graphical display interface so that the data and the related management conditions are presented clearly. In this way, consumers can easily access all kinds of information about the building. Some of the important elements of the BEMS include easy operability, multimedia, data management, automatic control, coordinated control, and operational control related to energy saving and control functions for power outages and restoration [2]. Another important element is the control function for operational optimization of air conditioning mainframes.

Apart from using renewable energies, one should focus more on the ways in which energy sources optimize and distribute energy for accurately understanding energy usage. The building energy management platform can be used to determine the energy consumption information of equipment. That information can then be used to implement automatic environmental monitoring and equipment management, and to reduce energy consumption in buildings and effectively improve the environmental comfort hierarchy so that emission reduction and energy saving can finally be achieved [3]. According to *The Application Technical Manual on Building Energy Conservation* under the direction of the Bureau of Energy, Ministry of Economic Affairs [4], a BEMS includes four main management systems: the building management system (BMS), the building automation system (BAS), the energy management system (EMS), and the modern electricity-integrated automation system based on computing technology. These systems can dispatch information on energy usage and make decisions regarding this usage in the buildings. The decisions are based on the values obtained from each monitoring point in the centralized monitoring system, and ensure that all the important functions, such as electricity utilization and demand management, of various electric facilities are optimized for highest efficiency. The central energy management system (CEMS) is a possible BEMS configuration in which multiple buildings are connected to each other and are connected via the Internet to a central operating unit to allow smooth cooperation among the buildings and increase efficiency.

The green energy management can be achieved through developing a proper energy management program and designing an effective BEMS or CEMS for the program. The development of a green energy management program is influenced by a lot of factors, such as factors associated with energy conservation, intelligent management, and the use of renewable energy. What should be considered in developing such a system is the key to having an efficient and effective green energy management program for different types of sustainable buildings.

This research was intended to establish a green energy management evaluation framework to be used as a basis for the future development of green energy management program in a university. The purposes of this research are: (1) establish a green energy management evaluation framework for the future development of a green energy management program to be employed in a university and determine the primary and secondary factors to be used in the framework, and (2) understand the importance of each primary and secondary factor by finding the relative or absolute weights of primary and secondary factors.

2. **Methodology.** In this study, foreign and domestic literature was reviewed, experts and scholar were interviewed to formulate the primary and secondary factors to be used in the initial evaluation framework. The final evaluation framework was determined by using the Delphi method. The relative weights of primary and secondary factors 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 [5]. The Delphi method has been used in a wide range of decision making studies because of its ability to sidestep some of the limitations of group decisions, which are often slow, expensive, redundant, affected by the differential status of members, and dominated by one or a few individuals [6]. The Delphi format reduces many of these shortcomings by providing a structured format, systematic procedures, clear communication, feedback, and anonymity. 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 opinions 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 developed in the early 1970's by T. Saaty has gained wide popularity and acceptance throughout the world. It is a multi-objective multi-criteria decision-making approach which employs a pair-wise comparison procedure to arrive at a scale of preferences among sets of alternatives [7]. 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 [8]. Chen et al. [9] had used the above two methods to study the application of green architecture to residential buildings.

3. **Establishment of Evaluation Framework.** The evaluation framework was established first using the Delphi Method. Through literature reviews and expert interviews, an initial evaluation framework was formulated with four primary factors, including "intelligent management", "equipment system", "renewable energy" and "indoor air quality" along with a total of 23 secondary factors for the four primary factors. In order to validate the integrity and completeness of the evaluation framework, four rounds of expert questionnaires had been conducted when the opinions of the respondents were converged. The three-level (A, B, C) hierarchical diagram of the final evaluation framework is shown in Figure 1.

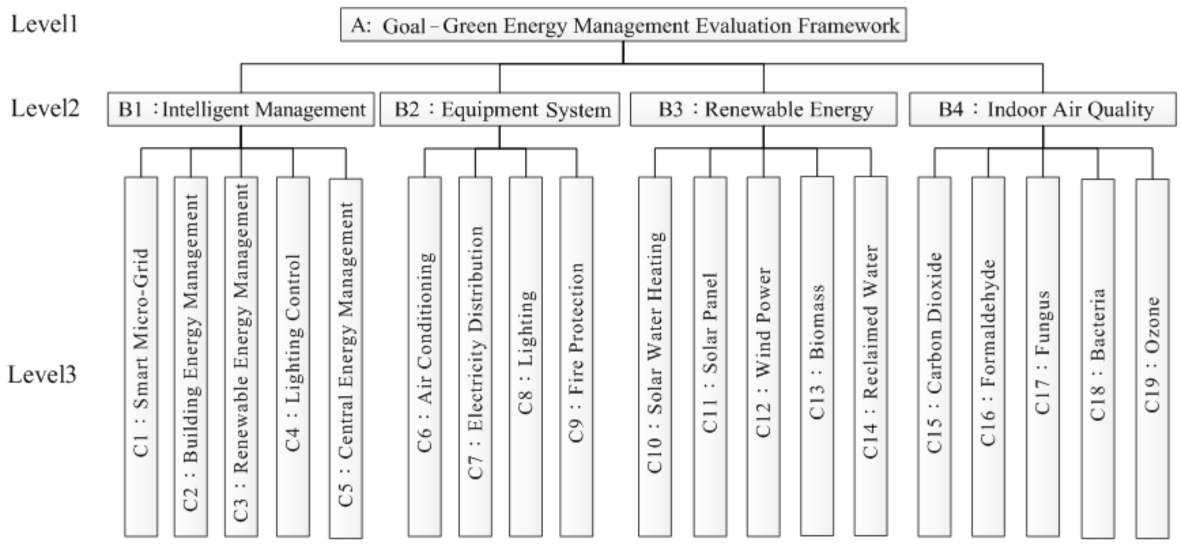

FIGURE 1. Three-level hierarchical diagram of the assessing framework

The 23 secondary factors in the initial framework have been cut to 19. Those secondary factors cut (hydroelectricity, geothermal energy and marine energy in renewable energy, elevator in equipment system) were considered by the panel as not practical in a university campus. The description of secondary factors is given below.

3.1. **Intelligent management (B1).** The "intelligent management" primary factor includes the following secondary factors:

1. **Smart Micro-Grid (C1):** Smart Micro-Grid Systems are modern, small-scale versions of the distributed energy systems. Established by the community being served, Smart Micro-Grid Systems achieve specific local goals, such as reliability, carbon emissions reduction, diversification of energy sources, and cost reduction. Like the bulk power grid, Smart Micro-Grid Systems generate, distribute, and regulate the flow of electricity to consumers, but do so locally.

2. **Building Energy Management (C2):** 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.
3. **Renewable Energy Management (C3):** The renewable energy management system is used to monitor the renewable installation and export the data to any reporting application. The system can be maximized later by integrating it to a future BEMS system.
4. **Lighting Control (C4):** Lighting control systems reduce energy usage and cost by helping to provide light only when and where it is needed. Lighting control systems typically incorporate the use of time schedules, occupancy control, and photocell control. Some systems also support demand response and will automatically dim or turn off lights to take advantage of utility incentives. Lighting control systems are sometimes incorporated into larger building energy management systems.
5. **Central Energy Management (C5):** The central energy management system is a possible BEMS configuration in which multiple buildings are connected to each other and are connected via the Internet to a central operating unit to allow smooth cooperation among the buildings and increase efficiency. Increased cooperation among different buildings through the BEMS allows for additional increased energy efficiency, as functions of the different buildings can be coupled. Advances in information technology make monitoring via the Internet possible.

3.2. **Equipment system (B2).** The "equipment system" primary factor includes the following secondary factors:

1. **Air Conditioning (C6):** An air conditioning system, or a standalone air conditioner, provides cooling and humidity control for all or part of a building. Air conditioned buildings often have sealed windows, because open windows would work against the system intended to maintain constant indoor air conditions.
2. **Electricity Distribution (C7):** An electricity distribution system distributes electricity from different energy sources and satisfies electricity demand, consumption and peak load of a community.
3. **Lighting (C8):** Lighting is the deliberate use of light to achieve a practical or aesthetic effect. Lighting includes the use of both artificial light sources like lamps and light fixtures, as well as natural illumination by capturing daylight.
4. **Fire Protection (C9):** Hydrant Systems & Sprinkler Systems, Water Mist Fire Suppression, Wet & Dry Risers, Fire Alarm & Voice Evacuation Systems, Gas Suppression System, Public Address System, CCTV Access Control.

3.3. **Renewable energy (B3).** The "renewable energy" primary factor includes the following secondary factors:

1. **Solar Water Heating (C10):** Solar water heating is the conversion of sunlight into renewable energy for water heating using a solar thermal collector. Solar water heating systems are designed to deliver hot water for most of the year. However, in winter there sometimes may not be sufficient solar heat gain to deliver sufficient hot water. In this case a gas or electric booster is used to heat the water.
2. **Solar Panel (C11):** Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaics convert light into electric current using the photovoltaic effect.
3. **Wind Power (C12):** Wind power is extracted from air flow using wind turbines to produce electrical power. Wind power as an alternative to fossil fuels, is plentiful,

renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, and uses little land. The net effects on the environment are generally less problematic than those from nonrenewable power sources.

4. **Biomass (C13):** Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials which are specifically called lignocellulosic biomass. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel.
5. **Reclaimed Water (C14):** Reclaimed water or recycled water, is former wastewater (sewage) that is treated to remove solids and impurities, and used in sustainable landscaping irrigation, to recharge groundwater aquifers, to meet commercial and industrial water needs, and for drinking.

3.4. **Indoor air quality (B4).** The "indoor air quality" primary factor includes the following secondary factors:

1. **Carbon Dioxide (C15):** Carbon dioxide is an important greenhouse gas and burning of carbon-based fuels since the industrial revolution has rapidly increased its concentration in the atmosphere, leading to global warming. Higher carbon dioxide concentration was demonstrated as an indicator of poor air quality in the office building.
2. **Formaldehyde (C16):** Formaldehyde is colorless and has a characteristic pungent, irritating odor. Exposure to formaldehyde is a significant consideration for human health. It was known to be a human carcinogen.
3. **Fungus (C17):** Fungi can break down manufactured materials and buildings, and become significant pathogens of humans and other animals. Pathogenic fungi are fungi that cause disease in humans or other organisms.
4. **Bacteria (C18):** The most common fatal bacterial diseases are respiratory infections, with tuberculosis alone killing about 2 million people per year. Tuberculosis is spread through the air when people who have an active tuberculosis infection cough, sneeze, or otherwise transmit respiratory fluids through the air. There are many bacteria of health significance found in indoor air and on indoor surfaces. A large fraction of the bacteria found in indoor air and dust are shed from humans. Among the most important bacteria known to occur in indoor air are Mycobacterium tuberculosis, Staphylococcus aureus, Streptococcus pneumoniae.
5. **Ozone (C19):** Ozone is a pale blue gas with a distinctively pungent smell. Its odor is sharp, reminiscent of chlorine, and detectable by many people at concentrations of as little as 10 ppb in air. Ozone is a potent respiratory hazard and pollutant near ground level.

4. **Identification of Relative Weights of Elements.** After having establishing the elements of each level in the hierarchical diagram of the evaluation framework, 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 primary factors with respect to the goal; and (2) the evaluation matrix of secondary factors with respect to the related primary factor at level 2. The evaluation matrix of primary factors to the goal (**A**) is shown in Table 1. At level 3, four evaluation matrices were required to perform. The evaluation matrices of secondary factors with respect to the four primary factors are shown respectively in Table 2, Table 3, Table 4 and Table 5. Based on the relative weights for the four primary factors at Level 2 and the 19 secondary factors at Level 3, the priority weights and rankings of secondary factors can be established (see Table 6).

TABLE 1. Evaluation matrix of level 2 primary factors with respect to the goal

A	B1	B2	B3	B4	Geometric Mean	Weights
B1	1.000	1.600	1.300	0.770	1.125	0.278
B2	0.625	1.000	1.550	2.030	1.184	0.292
B3	0.769	0.645	1.000	1.610	0.945	0.234
B4	1.299	0.493	0.621	1.000	0.794	0.196
CR = 0.083556; C.I. = 0.00752						

TABLE 2. Evaluation matrix of secondary factors with respect to B1

B1	C1	C2	C3	C4	C5	Geometric Mean	Weights
C1	1.000	0.429	0.733	0.286	0.530	0.544	0.103
C2	2.332	1.000	1.900	0.635	1.267	1.290	0.244
C3	1.364	0.526	1.000	1.123	0.952	0.949	0.180
C4	3.500	1.574	0.890	1.000	1.436	1.477	0.280
C5	1.886	0.789	1.050	0.697	1.000	1.017	0.193
CR = 0.029567; C.I. = 0.0331							

TABLE 3. Evaluation matrix of secondary factors with respect to B2

B2	C6	C7	C8	C9	Geometric Mean	Weights
C6	1.000	1.660	1.440	1.410	1.355	0.333
C7	0.602	1.000	1.130	1.170	0.945	0.232
C8	0.694	0.885	1.000	1.080	0.903	0.222
C9	0.709	0.855	0.926	1.000	0.866	0.213
CR = 0.00426; C.I. = 0.0038						

TABLE 4. Evaluation matrix of secondary factors with respect to B3

B3	C10	C11	C12	C13	C14	Geometric Mean	Weights
C10	1.000	1.650	1.530	1.420	1.120	1.320	0.261
C11	0.606	1.000	1.260	1.090	1.140	0.990	0.196
C12	0.654	0.794	1.000	1.190	1.200	0.942	0.186
C13	0.704	0.917	0.840	1.000	0.870	0.861	0.170
C14	0.893	0.877	0.833	1.149	1.000	0.944	0.187
CR = 0.010827; C.I. = 0.0097							

5. **Discussions.** Among the four primary factors, "equipment system" is the most important factor with a weight of 29.2%; followed by "intelligent management", "renewable energy" and "indoor air quality". However, the weight of "intelligent management" is very close to "equipment system". The result indicates that "equipment system" and "intelligent management" are the two key factors to have a successful energy management. This maybe is due to the fact that "equipment system" consumes energy while "intelligent management" can save energy. However, the third and fourth ranked primary factors, "renewable energy" and "indoor air quality", are considered to be best implemented in the later stage of the green energy management development. The obtained absolute weights of secondary factors can help us understand the priorities to apply those factors in green energy management. In general, the secondary factors with high priority weights (C6, C4, C7, C2, C8, C9, C10) can be immediately implemented in developing the green energy management system, those factors with low priority weights (C5, C15, C3, C11, C14) should be adopted as soon as possible, and those factors with much lower

Table 5. Evaluation matrix of secondary factors with respect to B4

B4	C15	C16	C17	C18	C19	Geometric Mean	Weights
C15	1.000	1.670	1.540	1.050	1.326	1.326	0.262
C16	0.599	1.000	1.170	1.260	1.240	1.018	0.201
C17	0.649	0.855	1.000	0.930	0.960	0.869	0.172
C18	0.658	0.794	1.075	1.000	1.070	0.903	0.178
C19	0.952	0.806	1.042	0.935	1.000	0.944	0.186
CR = 0.012721; C.I. = 0.0114							

Table 6. Secondary factors priority weights and rankings

A	Criteria	Relative Weights	Sub-criteria	Relative Weights	Absolute Weights	Rank
Green Energy Management in Sustainable Buildings	B1: Intelligent Management	27.8%	C1: Smart Micro-Grid	10.3%	2.86%	19
			C2: Building Energy Management	24.4%	6.79%	4
			C3: Renewable Energy Management	18.0%	4.99%	10
			C4: Lighting Control	28.0%	7.78%	2
			C5: Central Energy Management	19.3%	5.36%	8
	B2: Equipment System	29.2%	C6: Air Conditioning	33.3%	9.74%	1
			C7: Electricity Distribution	23.2%	6.79%	3
			C8: Lighting	22.2%	6.49%	5
			C9: Fire Protection	21.3%	6.22%	6
	B3: Renewable Energy	23.4%	C10: Solar Water Heating	26.1%	6.10%	7
			C11: Solar Panel	19.6%	4.57%	11
			C12: Wind Power	18.6%	4.35%	13
			C13: Biomass	17.0%	3.97%	14
			C14: Reclaimed Water	18.7%	4.36%	12
	B4: Indoor Air Quality	19.6%	C15: Carbon Dioxide	26.2%	5.14%	9
			C16: Formaldehyde	20.1%	3.95%	15
			C17: Fungus	17.2%	3.37%	18
			C18: Bacteria	17.8%	3.50%	17
			C19: Ozone	18.6%	3.66%	16

priority weights (C12, C13, C16, C19, C18, C17, C1) should be seriously considered if sufficient funding is available.

For the comprehensive and effective green energy management of a university, after reviewing all the primary and secondary factors, it is suggested that "central energy management" in "intelligent management", all the factors in "equipment system", "solar water heating" in "renewable energy", and "Carbon Dioxide" in "indoor air quality" should be adopted. In this green energy management system, "Lighting control" and "Building Energy Management" have been incorporated into "Central Energy Management".

6. **Conclusions.** The development of green energy management is influenced by a lot of factors. This research established the primary and secondary factors to be used in the evaluation framework for green energy management in a university by Delphi method. Then, AHP was used to identify the relative weights of primary and secondary factors. From the relative weights of primary factors, "equipment system" and "intelligent management" are the two key factors to have a successful energy management. The obtained absolute weights of secondary factors can help us understand the priorities to apply those factors in green energy management. In general, the secondary factors with high priority

weights can be immediately implemented in developing the green energy management system. The obtained results will be used as a basis to plan the hardware and software system to be installed for the future development of green energy management program in a university.

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