Evaluating critical criteria for green hospital buildings

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Abstract. Greening building is an increasingly important concern and a challenge in construction industry. The purpose of this paper is to evaluate the weights of criteria for green hospital buildings that provides decision-makers the priorities strategy in greening process. AHP was applied in this study to establish the hierarchy structure and evaluate the weight of criteria for green hospital buildings. The result indicated that sustainable site, energy saving, and water efficiency are the top three criteria. In the overall ranking, the top three significant sub-criteria are design of layout, greening of site, and energy saving for façade. The contribution of this study is to help decision-makers understand the relatively important of criteria to make decision for green hospital projects for sustainable development.

1. Introduction
Hospital is one of the public buildings, which has characteristics of high energy consumption, air and waste pollution. For instance, the air conditioning consumption of hospital is the highest of energy consumption, which accounts over 50%, followed by lighting [1]. Against the background of sustainable development, the strategy of green building practices could solve energy and environmental problems in hospitals. Thus, the design and construction of hospital towards green building that has become an important issue.

Several studies have explored the assessment criteria and design of green hospital. Unger, Campion et al. [2] used checklists to evaluate the quantifiable metrics in green healthcare and indicated that the checklists have helped to advance sustainability in healthcare. Wood, Wang et al. [3] used a questionnaire survey to investigate the users’ perceptions of green design elements in hospitals, then they translated the needs to design requirements suitable for implementation. Sahamir and Zakaria [4] investigated green criteria for hospital building development in Malaysia and compared green assessment criteria with different rating systems, there by indicating that energy efficiency is the most important criteria of green hospital building. However, there was rarely research focused on the relative importance of criteria in green hospital building. Consequently, this study applied the Analytic Hierarchy Process (AHP) method to assess the relative importance of criteria for reducing energy consumption and environmental impacts in hospital.

2. Hierarchy model
To consider the local situation and regional development of Taiwan, this paper referenced literature review and the green rating system of US Leadership in Energy and Environmental Design (LEED) to establish the hierarchy structure for green hospital buildings, which was suitable for Taiwan. The AHP method was applied in this study to establish the criteria hierarchy. The hierarchy structure consisted...
main objective, multi-criteria and sub-criteria, as shown in Fig.1. The main objective at first hierarchy level that was green hospital buildings that provided ecology, water-saving, energy-saving, waste reduction and healthy environmental for patient and staff. The multi-criteria at second hierarchy level that contained sustainable site, water efficiency, energy-saving, materials and resources, and indoor environmental quality. Within the 5 criteria, 23 sub-criteria were identified at the third hierarchy level, as shown in Fig1. Therefore, relevant criteria and sub-criteria for green hospital building were identified.

![Hierarchy Structure](image)

**Figure 1.** The hierarchy structure

### 3. Methodology
AHP is one of the multi-criteria decision making (MCDM) methods to help decision-makers dealing with complex problems with multiple criteria, which can formulate hierarchy structure and measure weight for ranking. Several studies have applied AHP method to evaluate the weight of criteria in different fields. Wannakul, Pathumnakul et al. applied AHP method to evaluate the weight of criteria that affecting decision to choose government R&D projects for small and medium-sized enterprises [5]. Ghimire and Kim used AHP methodology to estimate and rank the barriers to developing renewable energy in Nepal [6]. Wang and Perng used AHP method to identify the key indicators affecting customer satisfaction for the interior design industry [7]. Tse-Hsiung and Perng used AHP method to explore the key factors affecting the rent of office buildings in Taipei city [8]. Lin and Perng used AHP method to explore the key indicators in the space design of commercial [9]. In order to achieve the objective in this study, AHP was applied to evaluate the weight of criteria for reducing the energy consumption and improving environmental for hospital. The AHP proceeded as follows [10][11]:

- Construct a hierarchy structure with main objective, multi-criteria and sub-criteria.
- Assess relative importance of criteria by pairwise comparison and build the judgment matrix.
- Evaluate the local and global weight of criteria and confirm the sum of weight is equal to 1.
- Calculate Consistency Index (CI) and Consistency Ratio (CR) of expert evaluation matrix.
- Verify the value of CI and CR is less than 0.1, the expert matrix is regarded as consistency.
- Ranking the local and global weight of criteria for decision-making.

### 4. Analysis result
The analysis data of pairwise comparison questionnaires were collected from 45 experts in Taiwan. Table 1 summarized the local weight of the criteria and sub-criteria from experts’ evaluation. All the
judgment matrixes were verified the calculated value of CI and CR that less than 0.1. Rank columns displayed the priority of the criteria and sub-criteria. As shown in Table 1, the top three importance of criteria are sustainable site (0.28), energy saving (0.25), and water efficiency (0.21). By contrast, indoor environmental quality (0.13), materials and resources (0.12) were less importance of criteria, respectively.

According the local weight of sub-criteria, indicating that design of layout (0.49), was found to be the most important sub-criteria within the sustainable site, followed by greening of site (0.31) and greening of building (0.2), respectively. Within the water efficiency, water-saving plan (0.27) was found to be the most important sub-criteria, followed by water reuse (0.26). Within the energy efficiency, energy-saving for façade (0.27) was found to be the most important sub-criteria, followed by efficiency air conditioning (0.26). Meanwhile, Table 1 indicated that space flexibility, construction waste reduction, reused and recycled materials (0.22) were the most important sub-criteria within the materials and resources. Within the indoor environmental quality, indoor air quality (0.27) was the most important sub-criteria, followed by noise reduction and ventilation (0.21).

Table 1. Criteria weights.

| Criteria                  | Local weight | Rank | Sub-criteria                      | Local weight | Rank |
|---------------------------|--------------|------|-----------------------------------|--------------|------|
| Sustainable site          | 0.28         | 1    | Design of layout                  | 0.49         | 1    |
|                           |              |      | Greening of site                  | 0.31         | 2    |
|                           |              |      | Greening of building              | 0.20         | 3    |
| Water efficiency          | 0.21         | 3    | Water-saving                      | 0.27         | 1    |
|                           |              |      | Water reuse                       | 0.26         | 2    |
|                           |              |      | Rainwater recycle and recovery    | 0.21         | 3    |
|                           |              |      | Grey-water recycle and recovery   | 0.18         | 4    |
|                           |              |      | Water-saving certified equipment  | 0.08         | 5    |
| Energy-saving             | 0.25         | 2    | Energy-saving certified equipment | 0.11         | 5    |
|                           |              |      | Energy-saving for facade          | 0.27         | 1    |
|                           |              |      | Efficiency air conditioning       | 0.26         | 2    |
|                           |              |      | Lighting-saving                   | 0.20         | 3    |
|                           |              |      | Renewable energy                  | 0.17         | 4    |
| Materials and resources   | 0.12         | 5    | Space flexibility                 | 0.22         | 1    |
|                           |              |      | Reused and recycled materials     | 0.22         | 1    |
|                           |              |      | Green-material certified          | 0.16         | 5    |
|                           |              |      | Use local materials               | 0.18         | 4    |
|                           |              |      | Construction waste reduction      | 0.22         | 1    |
| Indoor environmental quality | 0.13      | 4    | Indoor air quality                | 0.27         | 1    |
|                           |              |      | Noise reduction                   | 0.21         | 2    |
|                           |              |      | Daylighting                       | 0.16         | 4    |
|                           |              |      | Ventilation                       | 0.21         | 2    |
|                           |              |      | Temperature and humidity          | 0.15         | 5    |
Moreover, this study presented the global weight and ranking of sub-criteria, as shown in Fig.2. All the comparison of sub-criteria has been performed. The top five significant sub-criteria were design of layout, greening of site, energy-saving for façade, efficiency air conditioning, and water-saving. The figure clearly showed that design of layout was the most significant sub-criterion, which accounted for 13.69% of the total global weight. In the overall ranking, water reuse, greening of building, lighting-saving, rainwater recycle and recovery, and renewable energy were ranked sixth through tenth, respectively. By contrast, the least significant sub-criterion is water-saving certified equipment, which accounted for 1.7% of the total global weight. The result of ranking may help decision-makers to make effective and efficient decisions in limited budget and time for green hospital buildings.

5. Conclusion
AHP was applied in this study to establish the criteria hierarchy and the relation importance of all criteria for green hospital buildings. The analysis result in this paper indicated that the top three importance of criteria are “sustainable site”, “energy saving”, and “water efficiency” for green hospital building evaluation. “Indoor environmental quality”, “materials and resources” were less importance of criteria, respectively. According the analysis result of sub-criteria, indicating that “design of layout” was found to be the most important sub-criteria within the sustainable site criteria. “Water-saving plan” was found to be the most important sub-criteria within the water efficiency criteria. “Energy-saving for façade” was found to be the most important sub-criteria within the energy efficiency criteria. “Space flexibility”, “construction waste reduction”, “reused and recycled materials” were the most important sub-criteria within the materials and resources criteria. “Indoor air quality” was the most important sub-criteria within the indoor environmental quality criteria. In the overall ranking, the most significant criterion has been discovered as “design of layout”, followed by “greening of site”, “energy saving for façade”, and “efficiency air conditioning”, respectively. By contrast, the last significant criterion is “water-saving certified equipment”. The analysis result of the relatively important and ranking may help decision-makers to make effective and efficient decisions in limited budget and time for green hospital buildings that practical towards sustainable development.
The research limitations in this study include local situation, regional, and the green rating system development in different countries. Therefore, the analysis result in this paper is limited to the green hospital buildings in Taiwan; different countries require individual criteria and analyses for green hospital buildings. Otherwise, there are 23 sub-criteria under 5 main criteria, some more criteria have not been identified and categorized. For future work, the research can be done by using other MCDM methods like Fuzzy AHP, Analytic Network Process (ANP) to dealing with similar or another issue with multiple criteria.

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