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A proposed new weighting system for passive design approach in BEAM Plus

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Abstract

Building environmental assessment method (BEAM) has been practiced by local architects and engineers as references for green building design over the last 20 years. The current version of BEAM Plus v1.2 has introduced the passive design concept to make the rating scheme in line with the state-of-art energy efficient design in the world. However, the introduced passive design approach is criticized for its arguable criteria allocation, unjustified weighting system and incompatibility with the existing whole building energy simulation approach. In view of these flaws, a new weighting system based on different global sensitivity analysis methods, robust energy end-use statistics and a green building case study is proposed in this article. The total available credits of sub-criteria are determined according to the ratio of the cooling and lighting energy consumption in the total end-use energy data of residential buildings. Eventually, the priorities of assessment criteria are derived from the sensitivity analysis of a generic building model based on a simultaneous variation of different design parameters. The results from this research can help stakeholders in a green building project to identify design strategies with the largest impact over building performance and obtain an optimized preliminary design in the early planning stage.

Keywords: Passive design; Sensitivity analysis; Weighting; BEAM; Green building

1. Introduction

Hong Kong is an energy-intensive densely populated metropolis where building sectors alone accounts for more than 90% of the total domestic electricity consumption according to the statistics of the local government. The Building Environmental Assessment Method (BEAM) has been launched since 1996 to encourage sustainable building designs to reduce energy consumption and environmental impacts. BEAM originally constructed its rating system with reference to BREEAM, which is the earliest green building rating scheme in the world [1]. Accompanied by further development of the green building industry,

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BEAM introduced new elements from major assessment schemes over the world including but not limited to LEED, GBL, and CASBEE. Credits or points are awarded to encourage good practices in the life cycle of buildings either based on improved performance or deployed features. A scale of weighting is then applied before summarizing attained credits in each criteria. The weighting system is crucial in a rating scheme because it can re-allocate credits for various assessment criteria.

In spite of the importance of the weighting, there is by far not a satisfactory well-recognized weighting assignment method for assessment schemes. Lee et al proposed a scientific approach that the weighting should be determined by the cost-effectiveness of adopted technologies to achieve a certain performance levels where corresponding credits are awarded [2]. The approach formulated an incentive-crediting scale to attract profit-maximizing investors and was only applied to the energy assessment framework. In order to bring consensus between stakeholders in the whole construction process, a multi-level fuzzy evaluation method is constructed. The weights of each design factor is classified to five grades by the analytic hierarchy process (AHP), which can help decision-makers to prioritize their desirable solutions from multiple design alternatives [3]. The evaluation method was also applied to other green building assessment studies to formulate an indicating system about environmental load, building qualities and economics [4, 5]. Based on a comparison of the structure of major rating tools, it is found difficult to actualize the variable importance of each index. This is the reason why BEAM adopted a weighting system for categories only to avoid an over complicated scheme in CASBEE. With reference to the popular global green building rating tools, Ali and Nsairat developed a unique assessment tool contextualized to conditions in developing regions like Jordan, where inefficient use of resources causes considerable environmental, social and economic issues [6]. In this tool, the assessment items are also weighted by the AHP method with an expert team of stakeholders. Pan et al. argues that the index weight should be concerned with the human expectation and government advocating, which were reflected by a well-designed questionnaire [7]. The index weight was then evaluated for the first-class indicators of green residential areas.

From the above brief introduction, it can be summarized that little research has been conducted to develop an objective weighting system for performance-based criteria in green building rating systems. Such a weighting system can be derived from a comprehensive global sensitivity analyses which require massive computation modelling experiments and validations with case studies. This paper proposed a weighting system for the passive design route in the energy assessment category of BEAM Plus, with application potential to all performance-based criteria in the whole rating scheme.

2. Methodology

2.1. Passive design approach

BEAM Plus for new buildings version 1.2 evaluates the overall sustainability of building design and construction according to four grades as illustrated in Fig.1. The final grade is determined by the weighted subtotal score and weight scores in key categories including the material, energy, indoor environment quality categories and a bonus section of innovation and additions. At the current stage, weighting coefficient for the five categories are allocated according to their respective environmental impacts, while no specific weighting is assigned to sub-criteria included in passive design approach. Among the five category, energy use is attached with the highest weighting factor of 35%, which reflected its large environmental, social and economic impact.

Within the energy category, 22 credits, which account for 47.7% of maximum available credits in this category, are assigned to the passive design approach for annual energy use assessment. The passive design credits are further allocated to sub-criteria including site planning/building orientation, building envelope (i.e. Overall Thermal Transfer Value), natural ventilation, daylight (i.e. vertical daylight factor), active building systems (i.e. HVAC, lighting and vertical transportation). Among these sub-criteria, the active building system should be excluded from the classification of passive designs, while others have to be adjusted in both assigned credits (i.e. weightings) and type of design strategies. According to previous research conducted by the authors, passive design parameters can be divided into the building layout, envelope thermophysics, building geometry and infiltration and air-tightness [8-10].

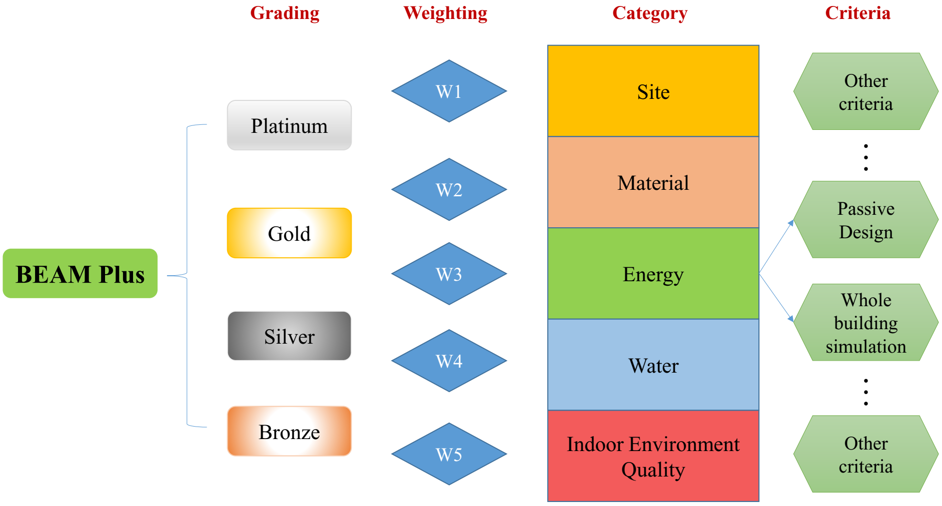

Fig. 1. Framework of BEAM Plus assessment scheme

2.2. Global sensitivity analysis

To determine the weighting coefficients based on the contribution of different design strategies to the variation of building performance, the global sensitivity analysis (SA) is applied to a generic building model constructed based a prototype of public rental housing (PRH) in Hong Kong [11, 12]. Referring to a review study conducted by Wei Tian [13], the global SA has the sampling-based, screening-based and variance-based approach. Given the complication of a building model, three representative methods from each approach including the standardized rank regression coefficient (SRRC), Morris and Sobol, are adopted for this research.

SRRC is derived from a linear multidimensional regression model as expressed by Eq. (1):

$$\hat{y} = \beta_0 + \sum_{j=1}^{k} \beta_j x_j \tag{1}$$

where β_j is the regression coefficient determined by minimizing Eq. (2):

$$\sum_{i=1}^{N} (y_i - \hat{y}_i)^2 = \sum_{i=1}^{N} \left[y_i - \left(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij} \right) \right]^2 \tag{2}$$

R^2 value (coefficient of determination) is then calculated by Eq. (3) to assess the correlation between the input and output

$$R^2 = \frac{\sum_{i=1}^{N} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{N} (y_i - \bar{y})^2} \tag{3}$$

SRC can be calculated by the below equation:

$$SRC_j = \frac{\beta_j \sigma_x}{\sigma_y} \tag{4}$$

Sobol is especially suitable for non-linear and non-additive model analysis, where the first-order and total order sensitivity indices are calculated according to Eq. (5) and Eq. (6):

$$S_i = Corr(Y, \mathrm{E}(\mathrm{Y} \mid \mathrm{X}_i)) \tag{5}$$

$$S_{Ti} = S_i + \sum_{j \neq i}^{k} S_{ij} + \cdots + S_{i \cdots j \cdots k} \tag{6}$$

Morris can only provide qualitative measurement of the ranking between design strategies, so that it is only used as a validation of the raking orders.

3. Results and discussions

3.1. Sensitivity study with Sobol

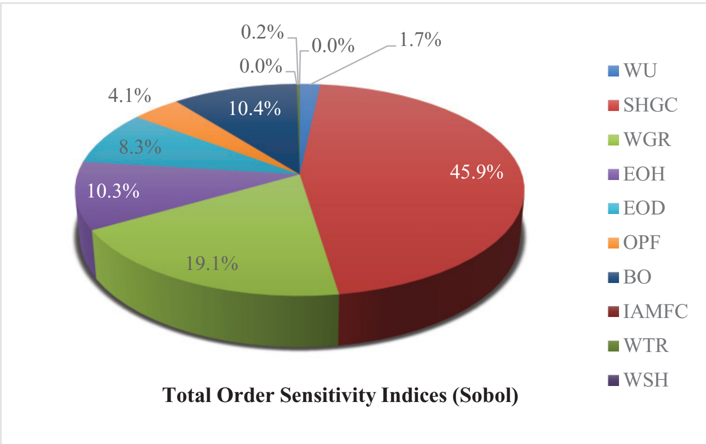

Fig. 2. Sensitivity indices of selected design parameters based on Sobol

Fig. 2 shows obtained total sensitivity indices of 10 selected passive design factors based on 5632 simulation runs. Selected design factors include the window U-value (WU), solar heat gain coefficient (SHGC), window to ground ratio (WGR), overhang projection ratio (OPF), building orientation (BO), external obstruction height (EOH), external obstruction distance (EOD), infiltration air mass flowrate coefficient (IAMFC), wall thermal resistance (WTR), and wall specific heat (WSH). All the input parameters except IAMFC and WSH are determined to make important contributions to the variation of the total cooling and lighting energy consumption.

3.2. Sensitivity study with Morris

Although the Morris method cannot quantify the relative importance of design factors, it only needs 110 runs in this case to conduct the global SA, leading to much less computation cost compared to variance-based methods. As shown in Fig.2, the sample mean value is used to qualify the ranking of major influences from different inputs, while the standard deviation indicates interactions and non-linear effects. Morris sensitivity indices validated that SHGC and WGR were the top two critical factors. However, BO ranking the third place based on Sobol indices became a less important input. This can be a result of the reduced sampling size adopted by the Morris method. Therefore, the variation in the importance of the input factors should be further validated through case studies.

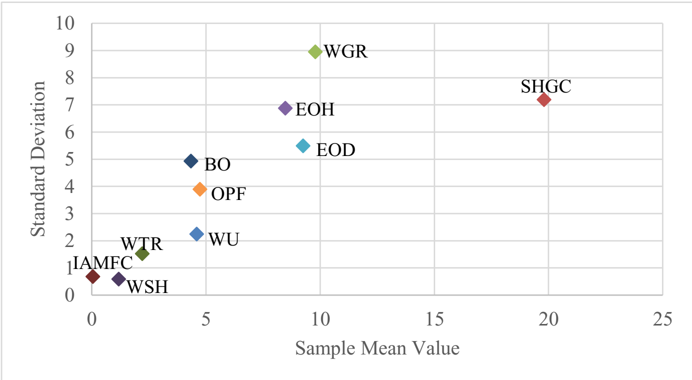

Fig. 3. Sensitivity indices of selected design parameters based on Morris

4. Conclusions

The weighting coefficient for each passive design strategies specified in the current BEAM plus scheme should be obtained from their relative importance over the building cooling and lighting energy use. Global sensitivity analysis methods were proved to be effective approaches to derive the raking orders of different design factors. Window transmittance and geometry are validated as the two most influential factors over the total energy consumption. The findings from this paper can provide potential frameworks for the weighting system of performance-based criteria in green building rating tools.

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