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Applying multi-objective genetic algorithms in green building design optimization

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Abstract

Since buildings have considerable impacts on the environment, it has become necessary to pay more attention to environmental performance in building design. However, it is a difficult task to find better design alternatives satisfying several conflicting criteria, especially, economical and environmental performance. This paper presents a multi-objective optimization model that could assist designers in green building design. Variables in the model include those parameters that are usually determined at the conceptual design stage and that have critical influence on building performance. Life cycle analysis methodology is employed to evaluate design alternatives for both economical and environmental criteria. Life cycle environmental impacts are evaluated in terms of expanded cumulative exergy consumption, which is the sum of exergy consumption due to resource inputs and abatement exergy required to recover the negative impacts due to waste emissions. A multi-objective genetic algorithm is employed to find optimal solutions. A case study is presented and the effectiveness of the approach is demonstrated for identifying a number of Pareto optimal solutions for green building design.

Keywords: Building design; Green building; Life cycle assessment; Life cycle cost; Multi-objective genetic algorithm

1. Introduction

Buildings are energy gluttons and have a large impact on the global climate change and other energy-related environmental issues. In Canada, residential and commercial/institutional buildings consume about 30 percent of the total secondary energy use [1]. As a direct result, they are responsible for nearly 29 percent of CO_2 equivalent greenhouse gas emissions. A similar situation is also observed in the United States, where buildings account for 39 percent of the total primary energy consumption and 70 percent of the electricity consumption [2]. About 38 percent of CO_2 emissions, 52 percent of SO_2, and 20 percent of NO_x are produced in the US because of building-related energy consumption.

As the environmental impacts of buildings are acknowledged, it becomes important to consider the environmental performance in building design. Green building is a recent design philosophy which requires the consideration of resources depletion and waste emissions during its whole life cycle [3]. A green building is designed with strategies that conserve resources, reduce waste, minimize the life cycle costs, and create healthy environment for people to live and work.

The successful design of green buildings requires that special attention be paid to the conceptual stage when many potential design alternatives are generated and roughly evaluated in order to obtain the most promising solution. Decisions made in the conceptual stage have considerable impacts on the building performance. For example, simply making buildings the right shape and

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the correct orientation can reduce energy consumption by 30–40% with no extra cost [4]. Currently, designers heavily rely on previous experience or building energy simulation programs to determine appropriate values for design parameters. However, the previous experience might lead to incorrect conclusions because they cannot cover every foreseeable circumstance and cannot reflect the complicated interactions between various parameters. Although many sophisticated energy simulation programs (e.g., DOE, Energy Plus) are valuable to study the impacts of design parameters on building performance, the iterative trial-and-error process of searching for a better design solution is time-consuming and ineffective because of the inherent difficulty in exploring a large design space.

This paper presents the use of an optimization program coupled with an energy simulation program, which allows the design space to be explored in the search for an optimal or near optimal solution(s) for a predefined problem.

The remainder of this paper is organized as follows. Related studies are reviewed in the next section. It is followed by a presentation of exergetic life cycle assessment to evaluate environmental performance of buildings. The optimization model is presented in the fourth section, followed by a brief introduction to the multi-objective genetic algorithm used to solve the optimization problem. A case study is finally presented to illustrate the application of the multi-objective genetic algorithm in green building design.

2. Previous related studies

Many efforts have been made to assist designers in green building design. Integrated simulation environment provided by some tools (e.g., Building Design Advisor [5]) can facilitate the comparison of several design alternatives with respect to different performance criteria, such as daylighting and thermal energy consumption. Some tools such as ATHENA [6] have been developed to assess the environmental performance of a building design by considering a number of environmental impact categories due to its construction. Building performance rating systems such as GBTool [7] can evaluate a broad range of green building related issues and obtain an overall score after weighting aggregation. Recognizing the disadvantage of trial-and-error process to improve the design solution using building simulations, Shaviv et al. [8] combined knowledge-based heuristics and procedural simulation to support low-energy building design. Optimization is another approach adopted in some studies to avoid the trial-and-error problem. It has the distinctive advantage of finding optimum or near optimum building design alternatives. A review of some optimization studies is presented below.

End-use operating energy consumption is the optimization criterion in many studies [9–11]. Heating and cooling energy are covered by Al-Homoud [9] and Coley and Schukat [11] while Wetter [10] enlarged the scope further to include lighting energy consumption into the optimization model. If the operating energy consumption is considered as the only optimization criterion, the proposed building is likely to have excessive amount of insulation and would not be cost-effective. To overcome this problem, life cycle cost has been used as the performance criterion in several studies [12–14].

Since designers rarely consider only one criterion in the decision-making process, multi-objective optimization models have been proposed. Radford and Gero [15] applied dynamic programming in the multi-criteria design optimization with the following four performance criteria: thermal load, daylight availability, construction cost and usable area. Hauglustaine and Azar [16] optimized the building envelope using genetic algorithms. As many as 10 criteria related with code compliance, energy consumption, and cost are considered. Wright et al. [17] applied a multi-objective genetic algorithm to building thermal optimization with emphasis on mechanical system design. Operating energy cost and occupant thermal comfort are the two performance criteria used.

Although the above efforts in optimization studies are significant to explore effective ways for better building design, several limitations may undermine their application in practice. They are discussed below.

2.1. *Difficulty in making cost-effective decisions accounting for environmental performance*

Most previous studies deal with either economical or environmental performance [9–12]. Two approaches were followed in an effort to consider the two criteria simultaneously: (1) one criterion is handled as a constraint [13,14] or (2) the weighted sum technique is used [16]. Both approaches require a priori information from designers: boundary value for the constraint or weights for the performance criteria. With little knowledge about the performance space of the problem in advance, designers may find it difficult to set appropriate values for those required inputs. Furthermore, only one optimal solution is obtained for each run if the two performance criteria are treated separately or coupled together into one meta-criterion. The designer cannot learn about the impact of the marginal change of one criterion on another just from a single optimal solution. Therefore, it is difficult to make cost-effective decisions without knowing the trade-off relationship between economical and environmental performance.