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Evolutionary Multi-objective Optimization in Building Retrofit Planning Problem

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Abstract

Energy efficiency has been a primary subject of concern in the building sector, which consumes the largest portion of the world's total energy. Especially for existing buildings, retrofitting has been regarded as the most feasible and cost-effective method to improve energy efficiency. When planning retrofit in public buildings, the most obvious objectives are to: (1) minimize energy consumption; (2) minimize CO_2 emissions; (3) minimize retrofit costs; and (4) maximize thermal comfort; and one must consider these concerns together. The aim of this study is to apply evolutionary multi-objective optimization algorithm (NSGA-III) that can handle four objectives at a time to the application of building retrofit planning. A brief description of the algorithm is given, and the algorithm is examined using a building retrofit project, as a case study. The performance of the algorithm is evaluated using three measures: average distance to true *Pareto*-optimal front, hypervolume, and spacing. The results show that this study could be used to find a comprehensive set of trade-off scenarios for all possible retrofits, thereby providing references for building retrofit planners. These decision makers can then select the optimal retrofit strategy to satisfy stakeholders' preferences.

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Keywords: Building retrofit; CO_2 emissions; Energy consumption; Evolutionary multi-objective optimization; Retrofit costs; Thermal comfort

1. Introduction

The primary energy consumed in the building sector worldwide is 40% of total annual energy consumption, and increasing every year [1]. Also, 30% of greenhouse gases come from the sector, making it the main cause of global warming [2]. Therefore, countries around the world have developed and implemented various policies to reduce the energy consumed in the buildings. For the effective accomplishment of the energy saving policies in the building sector, increasing the energy efficiency of each building is essential [3]. Due to recent reinforcement of legal energy

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efficiency requirements, old buildings built under less regulation have lower energy efficiency than newly constructed ones [4]. For such existing buildings, retrofitting has been regarded as the most feasible and cost-effective method to improve energy efficiency [2].

Recently, government organizations in each country have supported such retrofit [5]. Despite these support policies, decision makers who perform the retrofit have difficulty planning [6]. The reason is because there are multiple objectives to accomplish through the retrofit, and it is difficult to verify how much the different retrofit alternatives satisfy them [7]. Also, there are numerous alternatives; hence, it is difficult to select the appropriate retrofit scenario by comparing all possible alternatives [8]. When planning retrofit in public buildings, the decision maker plans to minimize energy consumption and CO_2 emissions at minimal expense and in maximum comfort [9]. However, these objectives contradict each other and have trade-off relations; it is difficult to find an optimum alternative satisfying all of them [10]. For this reason, generally, the decision maker first sets a limited number of subjective alternatives, then, compares them. Or, the decision maker excludes some and then selects the scenario intuitively [11]. In these processes, the decision maker can only consider a few alternatives, making it difficult to find the best of all [12].

To solve this problem, previous studies have employed multi-objective optimization [13]. Multi-objective optimization is a process to find the optimal solutions that satisfies multiple objectives simultaneously [14]. It can obtain a *Pareto* solution comprising of a set of complementary alternatives [15]. In earlier studies, before selecting the alternative, the decision maker had first defined preference on the objectives to select one scenario among the set complementary alternatives satisfying all objectives [16]. However, the preference may vary with the decision maker, and not all objectives can be compared equally, therefore, it is difficult to provide an accurate preference in real-world problems [17]. Therefore, it has been regarded that it is efficient to derive the set of complementary alternatives via methods with a posteriori articulation of preferences.

The most popular of these is the evolutionary algorithm [18]. The evolutionary algorithm is designed to evaluate multiple alternatives simultaneously through the global search, therefore, it has a high possibility of converging the actual optimal solutions [19,20]. In a few previous studies (e.g. [10,11,21,8,22]) in solving multi-objective optimization in building retrofit planning problem, non-dominated sorting genetic algorithm (hereafter, NSGA-II) was mainly used among the evolutionary algorithms to derive the set complementary alternatives. In addition, these studies considered only three or less objectives. When solving the optimization problem using four or more objectives, the convergence performance of NSGA-II is diminished [23]. In addition, it is more difficult to derive a set of complementary alternatives with four or more objectives because of the difficulty in intuitive selection. For this reason, the reference-point based non-dominated sorting genetic algorithm (hereafter, NSGA-III) was developed based on the reference-point to be more efficient optimization, thereby enhancing the performance of NSGA-II [24,25]. Recently, NSGA-III has shown better performance on the problem of multi-objective optimization with four or more objectives (so-called as many-objective optimization problems) than the previously investigated NSGA-II [26,27].

The aim of this study is to solve the optimization problem in building retrofit planning via an evolutionary multi-objective optimization algorithm, which considers four objectives at a time: (1) minimizing energy consumption; (2) minimizing CO_2 emissions; (3) minimizing retrofit costs; and (4) maximizing thermal comfort. This study applies and evaluates evolutionary multi-objective optimization algorithm, the NSGA-III, which can handle four objectives at a time, to retrofit planning. Section 2 presents some materials on the proposed methodology. Section 3, the data analysis and a discussion of experimental results is provided. Section 4 contains conclusions and suggestions for future research.

2. Building Retrofit Planning via Multi-objective Optimization

Multi-objective optimization is a process of considering a series of constraints to enable the given objective functions to be maximum or minimum, and the alternative process of enabling the objective function to become maximum is called the decision variable. Generally, in the multi-objective optimization, several objective functions show the contradicting relationship on the decision variable; therefore, it is almost impossible to enable perfect optimization on all objective functions at the same time [28,29]. For this reason, to solve the multi-objective problem, the rational "set of solutions" satisfying the acceptable level of objectives is derived [30].