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A dynamic energy performance curve for evaluating the historical trends in the energy performance of existing buildings using a simplified case-based reasoning approach

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ABSTRACT

To make the building energy performance certificate more effectively, it is necessary to analyze the historical trends in the energy performance of existing buildings as well as their current status. To achieve this objective, this study aimed to develop a dynamic energy performance curve for evaluating the historical trends in the energy performance of existing buildings using a simplified case-based reasoning (S-CBR) approach. Based on the relationship between the historical trend in the energy performance of a given building and the generalized historical trends (which can be established using the developed S-CBR model), the four types of the dynamic energy performance curves were established. To validate the applicability of the dynamic energy performance curve, an elementary school facility located in Seoul, the capital of South Korea, was selected for model application. The developed dynamic energy performance curve can be used to make the public clearly aware of the historical trends in their building's energy performance, to establish the optimal energy retrofit strategy for their buildings, and to encourage the public to voluntarily participate in their country's energy-saving campaign.

1. Introduction

According to the press releases [1,2], it was reported that more than 40% of global greenhouse gas (GHG) emissions were produced from building sectors of the developed countries such as the United States (US) and countries in the European Union (EU). As part of efforts to reduce GHG emissions from building sectors, the EU established the *Energy Performance of Buildings Directive* (EPBD) in 2002 and issued energy performance certificates (EPCs) for new and existing buildings (Directive 2010/31/EU) [3–8]. The building EPCs can be categorized into two types: (i) the asset rating system, which is an energy-demand-based rating system mainly for new buildings and (ii) the operational rating system, which is an energy-consumption-based rating system mainly for existing buildings [9–13]. Several previous studies analyzed the difference between the asset rating system and the operational rating system [9,12,13]. Based on these studies, it can be determined that the operational rating system is more suitable for evaluating the energy performance of existing buildings, compared to the asset rating system. In addition, the operational rating system can be used to establish the optimal energy retrofit strategy for improving the energy performance of existing buildings. As a typical example, the United Kingdom (UK) issues the display energy certificates (DECs) for existing public buildings, based on the operational rating system [14–18].

Koo and Hong studies analyzed the potential problems that may occur in the process of implementing the UK's DECs to South Korea [19,20]. First, in Koo and Hong study [19], the potential problems were analyzed from the three perspectives (i.e., building category, region category, and space unit size) and then the dynamic operational rating system was developed to reasonably evaluate the current status of the energy performance for existing buildings. Second, in Koo and Hong study [20], the potential problems were analyzed from the comparison criteria and then the dynamic incentive and penalty program was developed to encourage the public to voluntarily participate in the energy-saving campaign. In addition to the aforementioned potential problems that can arise in the process of implementing the UK's DECs to South Korea, it is necessary to analyze the historical trends in the energy performance of existing buildings. In fact, the UK's DECs provide "*the only three-year*" historical data for the operational and letter ratings of "*the only given building*" as the historical trends in the existing building's energy performance [14–18], and thus the potential problems may occur in two aspects: (i) historical period and (ii) comparative reference.

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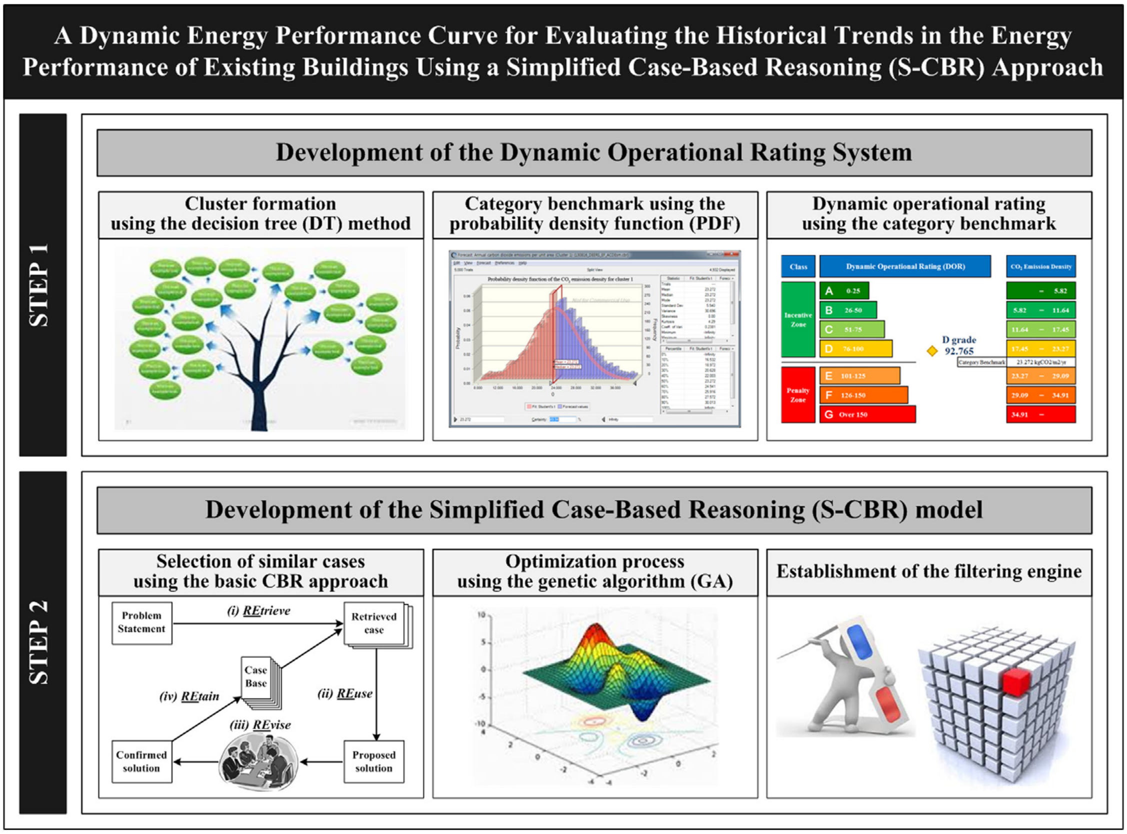

Fig. 1. Research framework.

(i) *Historical period*: If "*the only three-year*" historical data for the operational and letter ratings of a given building are provided as the historical trends in the building EPCs, they are too short time for the public to clearly recognize the overall historical trends in their building's energy performance. Therefore, the historical trends in the energy performance during the "*whole life cycle*" of a given building should be provided for the public to be clearly aware of the overall historical trends in their building's energy performance.

(ii) *Comparative reference*: If the three-year historical data for the operational and letter ratings of "*the only given building*" are provided as the historical trends in the building EPCs, the public cannot be clearly aware of the relative positions of the historical trends in their building's energy performance. This is because there is not the comparative reference to be compared with the historical trends in their building's energy performance. Therefore, the "*generalized historical trends*" (i.e., the maximum value, average value, and minimum value) should be provided as the comparative reference for the public to clearly recognize the relative positions of the historical trends in their building's energy performance. The developed S-CBR model can be used to establish the "*generalized historical trends*" as the comparative reference.

Meanwhile, several previous studies conducted the time-series forecasting of the energy consumption, which can be categorized into three types of methodologies: (i) linear approaches such as multiple regression analysis [21,22] and the autoregressive integrated moving average model [23,24]; (ii) non-linear approaches such as artificial neural networks [25–27]; and (iii) hybrid approaches that combine linear approaches with non-linear approaches [28–30]. These previous studies considered the historical trends in the energy consumption, but they were not related to the operational rating in the building EPCs. Namely, the previous studies are limited in reasonably evaluating the energy performance of existing buildings from the macroscopic perspective and in clearly establishing the optimal energy retrofit strategy for their buildings.

To overcome these challenges, this study developed a dynamic energy performance curve for evaluating the historical trends in the energy performance of existing buildings using the simplified case-based reasoning (S-CBR) approach. The following criteria were established to develop the dynamic energy performance curve in this study. The South Korean government has issued the building EPCs under the *Act on the Promotion of Green Buildings* from February 2013 [31], which was based on the UK's DECs for public buildings [32]. Therefore, this study focused on public buildings, particularly an elementary school facility (building's subcategory) located in Seoul, the capital of South Korea (region's subcategory) [19]. In addition, based on the 1999–2010 energy consumption data provided in the *Educational Statistical Yearbook* [33–43], this study developed the dynamic energy performance curve for existing buildings in two steps: (i) the development of a dynamic operational rating system for existing buildings using the data-mining technique and the probability approach and (ii) the development of the S-CBR model by combining the basic CBR approach with the optimization process (refer to Fig. 1).

2. Materials and methods

2.1. Data collection and analysis

This study collected the 1999–2010 energy consumption data and the project characteristics for elementary school facilities located in Seoul, South Korea. Based on the collected data, this study developed the dynamic energy performance curve for