



Development of a dynamic operational rating system in energy performance certificates for existing buildings: Geostatistical approach and data-mining technique



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HIGHLIGHTS

- Problem analysis of the conventional EPCs was conducted in terms of three issues.
- Three issues consist of the building category, region category and space unit size.
- Dynamic operational rating (DOR) system in EPCs for existing building was developed.
- The DOR can be used as a tool for building energy performance diagnostics.
- The DOR can allow policymakers to establish a reasonable operational rating in EPCs.

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ABSTRACT

The operational rating system in building energy performance certificates (EPCs) has been used for systematically monitoring and diagnosing the energy performance in the operation and maintenance phases of existing buildings. However, there are several limitations of the conventional operational rating system, which can be subdivided into three aspects: (i) building category; (ii) region category; and (iii) space unit size. To overcome these challenges, this study conducted the problem analysis of the conventional operational rating system for existing buildings by using the statistical and geostatistical approaches. Based on the problem analysis, this study developed the dynamic operational rating (DOR) system for existing buildings by using the data-mining technique and the probability approach. The developed DOR system can be used as a tool for building energy performance diagnostics. To validate the applicability of the developed DOR system, educational facilities were selected as the representative type of existing buildings in South Korea. As a result, it was determined that the developed DOR system can solve the irrationality of the conventional operational rating system (i.e., the negative correlation between the space unit size and the CO₂ emission density). Namely, the operational ratings of small buildings were adjusted upward while those of large buildings were adjusted downward. The developed DOR system can allow policymakers to establish the reasonable operational rating system for existing buildings, which can motivate the public to actively participate in energy-saving campaigns.

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1. Introduction

As global greenhouse gas emissions due to the use of fossil fuel have increased, the consequent climate change is threatening the human race [1,2]. It is reported that in developed regions like the United States (USA) and the European Union (EU), about 40% of greenhouse gas emissions come from the building sector. In

South Korea, the building sector accounts for about 24.5% of greenhouse gas emission. Thus, the energy consumption from the building sector is a key factor in global greenhouse gas emissions [3–7].

In order to reduce the greenhouse gas emissions from the building sector, various efforts have been conducted, including political actions (e.g., regulatory and supportive policies) and technical measures (e.g., passive design, active design, and new and renewable energy techniques) [8–11]. For these efforts to be effective, it is necessary to clearly evaluate the actual greenhouse gas emissions from the building sector. That is to say, it is required to establish the reasonable assessment process for evaluating the building

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energy performance, referred to as *building energy performance diagnostics* in this study [12,13].

The EU established the *Energy Performance of Buildings Directive* (EPBD) in 2002 to improve the building energy performance and to reduce the greenhouse gas emissions from the building sector. The EPBD initiated the energy performance certificates (EPCs) for new and existing buildings; accordingly, the building's EPCs should be provided to the building purchasers and renters [14–17]. With this policy in place, all the public can not only recognize the importance of improving the building energy performance, but also how the improvement of the building energy performance can contribute to the climate change problem. Based on the EPBD policy, one of the most representative green-building policies, EU countries including the UK, Germany, and France have established their own building EPCs [18–21]. The building EPCs can be largely subdivided into two types: (i) asset rating that is the energy-demand-based estimation method (or calculation method) (i.e., grading mainly for new buildings), which is mainly affected from the physical properties of a building, such as the building envelope, window-to-wall ratio, thermal insulation, and heating system efficiency; and (ii) operational rating that is the energy-consumption-based measurement method (i.e., grading mainly for existing buildings), which is mainly affected from the occupant behaviors in the operation and maintenance phase of a building [12,13,22].

Several previous studies have reported the difference between the asset rating and the operational rating [22–26]. Kelly et al. [22] analyzed the difference between the asset rating (which was established using the SAP and RdSAP) and the operational rating (which was established using the actual energy consumption). In the UK, the asset rating was established for new or existing buildings using the government's standard assessment procedure (SAP) or the government's reduced-data SAP (RdSAP), and the operational rating was established for existing buildings using the actual energy consumptions. Majcen et al. [23] compared the theoretical energy performance of Dutch dwellings and their actual energy performance. Branco et al. [24] analyzed the difference between the theoretical energy performance of multifamily complex in Switzerland and their actual energy performance, focusing on the complete technical system which combined the optimized envelope and electrical equipment with the several renewable energy systems. Hass and Biermayr [25] investigated the rebound effect of the energy consumption for residential space heating in Austria, resulting in the rebound effect between 20% and 30%.

Meanwhile, the other studies analyzed the effect of building EPCs on the rental and capital values [27–29]. Amecke [27] analyzed the effect of building EPCs on purchasers of owner-occupied dwellings in German, resulting that the effectiveness of EPCs was limited. Fuerst and McAllister [28] analyzed the impact of building EPCs on the rental and capital values of UK commercial property assets, resulting that there is no evidence of a significant relationship between the building energy performance and the rental and capital values.

As mentioned above, most of the previous studies have mainly focused on the analysis of the difference between the estimated energy performance (i.e., asset rating) and the actual energy performance (i.e., operational rating) and some studies analyzed the effect of building EPCs on the rental and capital values. Although most of the previous studies have emphasized the importance of the operational rating in the building EPCs as a tool for building energy performance diagnostics, they have not sufficiently considered the limitations of the conventional operational rating system and have not clearly suggest the way to improve the conventional operational rating system. Therefore, this study was designed to fill the knowledge gap. That is to say, this study aimed to highlight what the potential problems of the conventional operational rating

system would be, why the potential problems may arise, and how the potential problems can be solved. Towards this end, this study was conducted as follows.

- This study analyzed the potential problems of the conventional operational rating system for existing buildings by using the statistical and geostatistical approaches, which was conducted as a preliminary investigation. The potential problems can be subdivided into three aspects: (i) building category; (ii) region category; and (iii) space unit size.
- Based on the problem analysis, this study developed the dynamic operational rating (DOR) system for existing buildings by using the data-mining technique and the probability approach, which was designed as a solution to the possible problems. The developed DOR system can be used as a tool for building energy performance diagnostics. In general, *dynamic* means energetic or capable of change, while *static* means stationary or fixed.

2. Materials and methods

As a part of such green-building policies, South Korea enacted the building EPCs under the *Act on the Promotion of Green Buildings* in February 2013 [30]. Building EPCs in South Korea were established based on the display energy certificate (DEC) in the UK [31]. However, EPCs in South Korea should be differentiated from the UK's DEC, because they differ from the UK's DEC in terms of several aspects such as the building types, building sizes, building's energy usage patterns, and regional distribution [32,33]. Based on this background, the following criteria were considered in establishing the scope of this study.

- *Public buildings*: This study aimed to analyze the potential problems that may arise in implementing the UK's DEC to existing buildings in South Korea. Accordingly, this study should select the same type of building to which the UK's DEC is applied. Since the UK's DEC is used for public buildings [31], this study focused on public buildings in South Korea.
- *Building category*: When the UK's DEC establishes the operational ratings for existing buildings, they use the subcategories of the building category [31]. Thus, this study selected the educational facilities among the various public buildings because the educational facilities can be categorized further into various subtypes.
- *Region category*: In order to consider the difference in regional weather [31], the UK's DEC adjusts the category benchmark using the heating degree days over a 12-month period. This study focused on the educational facilities located in all the regions of South Korea to consider the region category.

To achieve the research objective, this study was conducted in three steps (refer to Fig. 1): (i) step 1: data collection and analysis; (ii) step 2: problem analysis of the conventional operational rating system for existing buildings by using the statistical and geostatistical approaches; and (iii) step 3: development of the DOR system for existing buildings by using the data-mining technique and the probability approach.

2.1. Step 1: Data collection and analysis

In order to conduct the problem analysis of the conventional operational rating system for existing buildings and to develop the DOR system for existing buildings as a tool for building energy performance diagnostics, data collection and analysis were conducted in three steps: (i) variable definition and data collection; (ii) data unification; and (iii) data filtering.

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