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Development of a new energy benchmark for improving the operational rating system of office buildings using various data-mining techniques

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HIGHLIGHTS

- This study developed a new energy benchmark for office buildings.
- Correlation analysis, decision tree, and analysis of variance were used.
- The data from 1072 office buildings in South Korea were used.
- As a result, six types of energy benchmarks for office buildings were developed.
- The operational rating system can be improved by using the new energy benchmark.

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ABSTRACT

As improving energy efficiency in buildings has become a global issue today, many countries have adopted the operational rating system to evaluate the energy performance of a building based on the actual energy consumption. A rational and reasonable energy benchmark can be used in the operational rating system to evaluate the energy performance of a building accurately and effectively. This study aims to develop a new energy benchmark for improving the operational rating system of office buildings. Toward this end, this study used various data-mining techniques such as correlation analysis, decision tree (DT) analysis, and analysis of variance (ANOVA). Based on data from 1072 office buildings in South Korea, this study was conducted in three steps: (i) Step 1: establishment of the database; (ii) Step 2: development of the new energy benchmark; and (iii) Step 3: application of the new energy benchmark for improving the operational rating system. As a result, six types of energy benchmarks for office buildings were developed using DT analysis based on the gross floor area (GFA) and the building use ratio (BUR) of offices, and these new energy benchmarks were validated using ANOVA. To ensure the effectiveness of the new energy benchmark, it was applied to three operational rating systems for comparison: (i) the baseline system (the same energy benchmark is used for all office buildings); (ii) the conventional system (different energy benchmarks are used depending on the GFA, currently used in South Korea); and (iii) the proposed system (different energy benchmarks are used depending on the GFA and the BUR of offices). The results of this study showed that the baseline and conventional operational rating system can be improved by using the new energy benchmark of the office building proposed in this study.

1. Introduction

With the increase in energy demand due to rapid industrialization and population growth, a variety of environmental issues such as global warming have been raised. In particular, as the building sector accounts for about 40% of global energy consumption, it has been reported to consume more energy than the industry and transportation sectors. Accordingly, improving energy efficiency in the building sector plays an important role in saving energy and reducing greenhouse gas (GHG) emissions. To ensure and improve energy efficiency in the building sector, many countries such as European Union countries (including the United Kingdom (UK)), the United States (U.S.), and Japan make various efforts through building energy policies [1–3]. Particularly, these countries focus on evaluating the energy performance of a building based on (i) asset rating (i.e., based on the predicted energy demand), and (ii) operational rating (i.e., based on the actual

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energy consumption). In asset rating, the basic energy performance predicted based on the physical characteristics of a building is evaluated. On the other hand, in operational rating, not only are the physical characteristics of a building considered, but its actual energy performance measured in its operational phase is also evaluated [4,5]. Many countries have recently adopted the latter approach, the operational rating, for evaluating the energy performance of a building, such as (i) the UK, through Display Energy Certificates (DECs); (ii) the U.S., through the Energy Star; and (iii) South Korea, through Energy Performance Certificates (EPCs). The aforementioned three operational ratings, DECs in the UK, the Energy Star in the U.S., and EPCs in South Korea, evaluates the energy performance of a building by comparing its actual energy consumption with that of a typical building, which can be referred to as an energy benchmark [6–8].

To calculate the operational rating based on the actual energy consumption, it is very important to reasonably establish an energy benchmark. An energy benchmark, which can be referred to as a relative energy performance standard, determines whether a given building uses energy more efficiently than other similar buildings. Without a rational and reasonable energy benchmark, an error can occur in evaluating the energy performance of a building [9–11]. Accordingly, many studies have been conducted worldwide to develop a reasonable energy benchmark for buildings by using various methods [12–23]. First, Chung et al. [12], Chung and Hui [13], and Xuchao et al. [14] used regression analysis, a simple analytical method, to develop an energy benchmarking model. Second, Yalcintas [15], Yalcintas and Ozturk [16], Hong et al. [17], and Hong et al. [18] used an artificial neural network (ANN), which is a black box method, to develop an energy benchmarking model. Third, Farrou et al. [19], Gao [20], Koo et al. [21], and Koo and Hong [22] used clustering methods such as the *k*-means algorithm and the decision tree (DT) to develop an energy benchmarking model. Fourth, Armitage et al. [23] used analysis of variance (ANOVA) to characterize the current energy performance of public office buildings in the UK based on a database of 2600 DECs.

Likewise, many countries continue to conduct various researches to establish a more accurate and reasonable energy benchmark and improve the operational rating system for buildings. However, the energy benchmark of office buildings used to calculate the operational rating in South Korea (i.e., EPCs) has the following limitations. First, the energy benchmark lacks clear criteria. The energy benchmark was established based on three elements of office buildings: (i) type, (ii) region, and (iii) size [24,25]. However, the specific standards for determining such elements are unclear. For example, according to the EPCs in South Korea, the energy benchmark of a given building can be referred to as the average energy consumption per unit area of office buildings with the "same type, region, and size". Nonetheless, there is no clear definition of what constitutes as "same" in type, region, and size among buildings used as the energy benchmark, making it ambiguous and unreliable. Second, the energy benchmark was established without considering other variables that may affect the energy consumption of office buildings, other than their type, region, and size. Therefore, the energy benchmark and the operational rating of office buildings should be established based on reasonable and equitable criteria, in which the characteristics of office buildings in South Korea are reflected. Particularly, with the recent increase in living standards, the number of multi-purpose office buildings equipped with facilities, such as retail stores, sauna baths, and sports centers, has been increased dramatically in South Korea. Since the energy consumption patterns of a building vary greatly depending on the building use, the differences in uses within a building can have a great effect on its energy consumption. Therefore, various building uses within a multi-purpose office building should be considered when evaluating the energy performance of the office building [26,27].

Toward this end, this study aims to develop a new energy benchmark for improving the operational rating system of office buildings in South Korea. To develop a reasonable and rational energy benchmark for office buildings, this study used various statistical methods such as correlation analysis, DT analysis, and ANOVA. This study was conducted in the following three steps: (i) Step 1: establishment of the database; (ii) Step 2: development of the new energy benchmark; and (iii) Step 3: application of the new energy benchmark for improving the operational rating system (refer to Fig. 1).

2. Materials and methods

2.1. Step 1: Establishment of the database

The database on the energy consumption of office buildings was established to develop the new energy benchmark for office buildings in four steps: (i) defining variables; (ii) data collection and matching; (iii) data filtering; and (iv) data unification and standardization. This study was limited to the Gangnam district, which is most crowded with office buildings in Seoul, and the data obtained from a total of three years (2012–2014) was used.

2.1.1. Step 1.1: Defining variables

To establish the database for developing the new energy benchmark of the office building, the independent and dependent variables determining the energy performance of an office building should be defined. Many previous studies and applications of the operational ratings in leading countries have considered various key energy performance factors and indicators for establishing the new energy benchmark of the existing building [10,28–30]. According to these literatures, various key factors that affect the energy consumption of office buildings can be mainly categorized into: (i) the region, (ii) the building size, (iii) the building characteristics, and (iv) the type of building use. The region, in which the building is located, should be taken into account to consider the local weather, especially air temperature, which can highly influence the energy performance of the building. The building size, generally represented by the total building floor area, should be taken into account since the energy consumption of a building tends to increase as the building size becomes larger. The building characteristics such as the building age, occupancy density, operation hours, and the number of computers should be taken into account since they cause different energy consumption patterns. The type of building use, which can be represented by the floor area allocated to a certain purpose (i.e., residential, commercial, office, educational, etc.) inside a building, should be taken into account to consider various building uses within an office building for evaluating the energy performance of the building. Among these four key energy performance factors, the region was not taken into account for defining the independent variables, since this study used building data in Gangnam district, which has a county-level area with 39.50 m^2, not big enough to be influenced by the weather. Accordingly, this study defined the independent variables including (i) the building floor area, (ii) the building characteristics, and (iii) the building use ratio (BUR).

First, this study used the following three categories of the building floor area as the independent variables: (i) the gross floor area (GFA); (ii) the GFA for calculating the floor area ratio (GFA_{FAR}); and (iii) the useful floor area (UFA). The GFA can be defined as the total floor area inside the building envelope, including the ground floor, basement floor, and parking area. The GFA_{FAR}, a term used only in South Korea, can be defined as the total floor area inside