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Determining the optimal occupancy density for reducing the energy consumption of public office buildings: A statistical approach

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ABSTRACT

Due to the various restrictions on the energy performance of public office buildings, it is essential to obtain occupancy information for not only evaluating but also regulating the building energy performance. There is still a lack of information and standard, however, for occupancy density due to the limitations on data collection and the lack of reliable data. Therefore, this study aimed to determine the optimal occupancy density for reducing the energy consumption in public office buildings. Towards this end, this study used various statistical methods, such as correlation analysis, decision tree, and Mann-Whitney *U* test, based on the actual occupancy data from public office buildings in South Korea. This study was conducted in three steps: (i) establishment of the database; (ii) determination of the optimal occupancy density using the statistical approach; and (iii) application of the proposed occupancy density using building energy policies. As a result, it was shown that buildings with an occupancy density above 31.41 m^2/person could save up to 50.3% energy on average compared to those with an occupancy density below 31.41 m^2/person. The analysis results showed that the proposed occupancy density could help in deciding the appropriate occupancy density for reducing the energy consumption of public office buildings.

1. Introduction

To solve the various issues regarding climate change and energy depletion, many countries are striving to reduce their building energy consumption, which accounts for 40% of the total energy used worldwide [1–6]. Among the various impact factors on the building energy performance, the building occupants who actually stay and use energy in the buildings are among the most significant factors affecting the actual building energy consumption [7,8]. Therefore, it is important not only to simulate and predict the building energy performance but also to manage and control the building energy consumption using the occupancy information (e.g., occupant behavior and number of occupants) [8,9]. Especially, in the case of the public office buildings, the importance of the occupants and their information has been widely recognized and investigated to reasonably regulate and reduce the building energy consumption, due to the various government restrictions on the energy performance and use of public office buildings (i.e., regulation of reasonable energy use for public institutions under the Ministry of Trade, Industry, and Energy of South Korea) [10–12]. Due to the diversity of the office space occupants' working behavior and schedule, however, it is difficult to collect occupancy information for analyzing and evaluating the building energy performance. Furthermore, it is even more difficult to obtain accurate and reliable data regarding occupant information [11]. As such, many countries have been facing difficulty establishing and determining any type of standard for office building occupants to reduce their building energy consumption. Instead, the relevant government agencies in major countries have established various standards and criteria for the building occupancy density for other purposes [13–17]. In general, the building occupancy density is classified into two categories according to the included space type: (i) building occupancy density including only the workspace; and (ii) building occupancy density including both the workspace and public community space.

First, many countries recommended minimum criteria of the building occupancy density, often including only the workspace, mainly for building design and planning purposes. However, this building occupancy density only allows to suggest minimum required workspace per person for building design and planning purposes, not considering the building energy consumption [18–23]. In the United Kingdom (UK), Cabinet Office, a department of the UK government, recommended that an 8.3–11.7 m^2 area on average be required for an office space per person [18,19]. Similarly, in the United States (U.S.), General Services Administration (GSA)

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recommended that a 17.6 m^2 area on average be required for an optimum workspace per person [20]. In addition, several companies in the UK and the U.S. provided a tool that can assess and determine the optimal office area per person according to the office's purpose and number of employees [21,22]. Moreover, in South Korea, a 7–17 m^2 area per person is generally recommended for designing and planning public office buildings [23].

Second, some countries provided standards or information of the building occupancy density, often including the workspace and public community space, mainly for building managerial and control purposes. This building occupancy density makes it possible to suggest adequate size of workspace for different managerial purposes including the building energy management [24,25]. In the U.S., an office space of 9.3–37.1 m^2 per person is recommended to be maintained for managing the office building [24]. In addition, in South Korea, a person generally uses the office space of 20.1–56.1 m^2 in the public office building [25].

Accordingly, those who want to reduce the energy consumption of an office building will be confused and will have difficulty making the right decision regarding the building occupancy density when considering only the aforementioned criteria. Especially, there is a risk of increasing the building energy consumption when only the design standard provided by the government for office buildings will be considered, as it suggests only the minimum area required for work efficiency, resulting in an office space design with too many people per unit area [18–25].

Despite the aforementioned limitations and difficulties, many studies have been conducted considering the building occupancy information [26–40]. First, various previous studies analyzed the impact of the occupancy information (e.g., occupancy pattern, number of occupants, and occupancy schedule) on the building energy consumption [20–26]. Menezes et al. [26] and Huovila et al. [27] compared the building energy consumption prediction accuracy when considering the occupancy information and when not considering it. The studies conducted by the aforementioned researchers showed that if the occupancy information would be considered, the building energy consumption prediction accuracy could be increased. Liang et al. [28] developed a model for occupancy schedule learning and prediction in office buildings using data-mining techniques. Yang et al. [29] quantitatively evaluated the energy implication of occupancy diversity from two perspectives: real-time occupancy and long-term occupancy. These previous studies considered the occupancy information for analyzing the building energy consumption but failed to suggest an optimal occupancy density for reducing the building energy consumption.

Second, several previous studies predicted and evaluated the occupancy information to more accurately evaluate the building energy performance [33–37]. Dedesko et al. [33] developed a method of assessing the human occupancy (i.e., number of occupants and duration of their presence in the building) and occupant activity (i.e., number of occupant movements through the room doorways) in hospital patient rooms. Aerts et al. [34] developed a probabilistic model that generates realistic building occupancy sequences, including (i) at home and awake, (ii) sleeping, and (iii) absent, to identify the typical occupancy patterns and to link these with various socioeconomic variables. Ryu and Moon [35] and Luo et al. [36] developed a building occupancy prediction and evaluation model to improve the accuracy of the conventional simulation model. Ryu and Moon [35] proposed an indoor environmental data-driven model for building occupancy prediction using machine learning techniques. Luo et al. [36] evaluated the performance of an agent-based building occupancy simulation model using the occupancy simulator. These methods considered the detailed building occupancy patterns and developed models with more realistic and reliable results, but they still could not overcome the limitation of not proposing detailed occupancy density guidelines for energy saving. Overall, the results of these previous studies were not sufficient to establish and determine the optimal occupancy density for reducing the building energy consumption, despite the fact that the occupancy density has a great effect on the building energy consumption, and controlling it would lead to benefits from the reduction of the building energy consumption. Especially, in South Korea, most of the previous studies analyzed the occupancy load density in the event of a fire or a natural disaster without considering any energy aspect [39,40].

Therefore, it is necessary to determine the relationship between the occupancy density and the building energy consumption, and to propose an optimal occupancy density, which can help save energy. Towards this end, this study aimed to determine the optimal occupancy density for reducing the energy consumption of public office buildings through various statistical methods, such as correlation analysis, decision tree (DT) analysis, and Mann-Whitney *U* test. This study focused on analyzing the optimal occupancy density for public office buildings because as mentioned earlier, such buildings' energy performance is often restricted and controlled by the government to reduce their energy consumption. To determine the optimal occupancy density for public office buildings using statistical methods, this paper was conducted in three steps: (i) establishment of the database; (ii) determination of the optimal occupancy density using the statistical approach; and (iii) application of the proposed occupancy density using building energy policies. Fig. 1 shows the framework of this study.

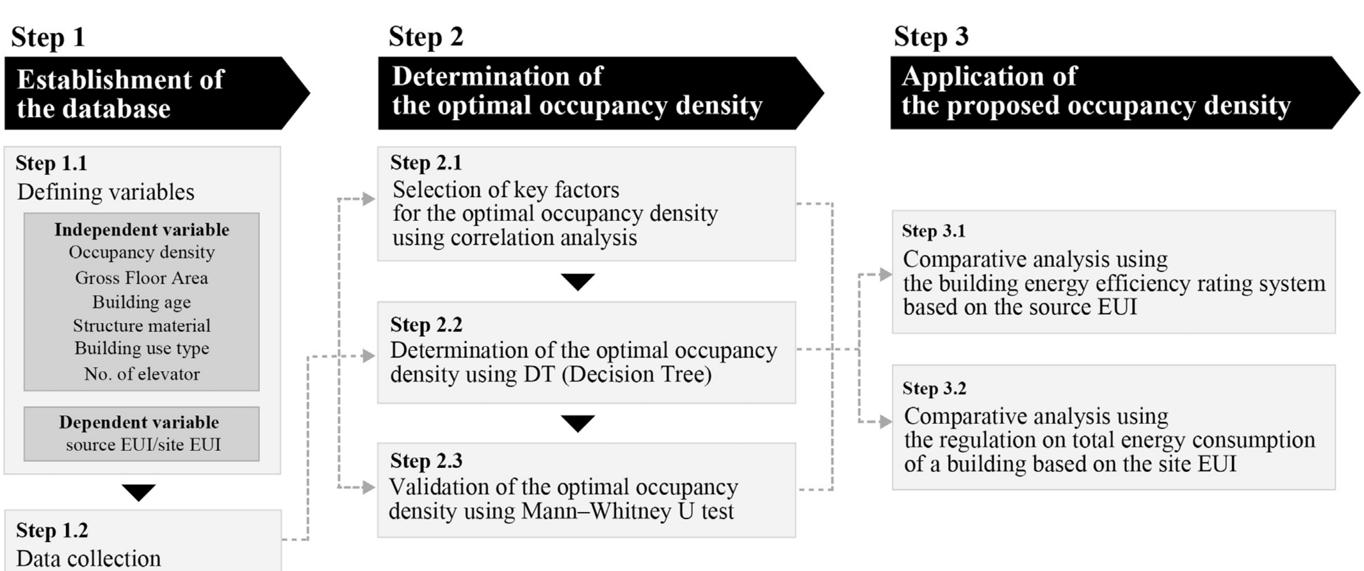

Fig. 1. Research framework.