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LCC and $LCCO_2$ analysis of green roofs in elementary schools with energy saving measures

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ABSTRACT

As the area of urban forests rapidly decrease in size, there is growing interest in green roofs as the only alternative to urban forests. This study aimed to evaluate economic and environmental effects of functional improvement in elementary school facilities by applying various improvement scenarios based on green roof systems (GRSs) with the combination of energy-saving measures (ESMs). A total of 16 possible improvement scenarios from the combination of GRSs and ESMs were developed, and energy modeling (Energy Plus ver. 6.0), based on the (i) characteristics of building, (ii) regional climate, and (iii) season, was performed. Using the energy modeling result, the amount of the CO_2 emission reduction by energy savings and the CO_2 absorption by GRSs' plants was calculated, and a life cycle cost analysis was conducted with the consideration of the life cycle CO_2 ($LCCO_2$). The results of this study can be used (i) to introduce the most appropriate ESMs for the specific facility when applying GRSs, (ii) to decide which location is proper to implement GRSs considering characteristics of regional climate, and (iii) to select energy- and cost-efficient elementary school when applying GRSs.

1. Introduction

The concentration of urban populations, which causes urban climatic and environmental changes such as floods, shortage of underground water, and urban desertification, is causing a rapid decrease in urban forests and worsening environmental pollution day by day [1]. The forest reduction rate in South Korea is 35 times higher than the global average forest reduction rate, and particularly, the area of urban forests in representative metropolitan cities, including Seoul, is 6.78 m^2/person, about two-thirds of the minimal standard (9 m^2/person) recommended by the World Health Organization (WHO). The area of urban forests in Seoul is 4.54 m^2/person, which is relatively smaller than that in Tokyo (5.14 m^2/person), Paris (13 m^2/person), New York (23 m^2/person), and London (27 m^2/person) [2]. Thus, in cities such as Seoul where the urban ecosystem is threatened by excessive urbanization, even the smallest green area must be gradually acquired to improve the micro-climate of the city. In South Korea or Japan, however, where the population is concentrated, there is an extreme lack of urban forests, and it is currently difficult to rapidly expand or improve existing green open spaces. Therefore, green roof systems (GRSs) are considered as the only alternative to acquiring urban forests on the ground [3,4].

As such, some countries are taking various measures to promote GRSs. In Japan, the Tokyo Prefecture has attempted to distribute GRSs by enacting regulations that make GRSs mandatory as of April 2001 for newly built, renovated, and expanded buildings whose land area is 1000 m^2 or larger. Similarly, South Korea is conducting the Green School Project, one of the core projects in the country's Green New Deal Program, which combines green growth and job creation. According to the Green School Project, the South Korean government is implementing the overall repair and renovation of existing elementary and middle school facilities that are severely deteriorated, using eco-friendly techniques, including GRSs [5]. Despite such policy efforts, GRSs both in South Korea and abroad are not being rapidly deployed because of difficulties such as limited budgets, lack of owner commitment of GRSs, higher construction cost compared to the energy-saving effect, and difficulties in repair and maintenance aspect [6].

Therefore, the introduction of GRSs considers not merely the quantitative increase in urban forests, but also their effect on improving the quality of cities and building performance. First, in terms of improving urban environments, GRSs alleviate the thermal island effect, reduce damages from urban flooding, purify the air (emitting oxygen by absorbing CO_2 and heavy metal particles in the air), and help boost bio-diversity. Second, in terms of improving the environment in a building, GRSs improve the building's

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insulation performance, reduce air heating and cooling loads by blocking solar radiation, and prevent the building deterioration.

Various studies have been conducted both in South Korea and other countries on the effects of GRSs. Particularly in line with the recent global efforts to reduce greenhouse gases, previous researchers have been actively investigating GRSs' roles in controlling temperature and alleviating the heat island phenomenon, and reducing CO_2 concentration by the CO_2 absorption capacity of plants.

First, regarding the role of GRSs in controlling temperature and alleviating the heat island phenomenon, it has been reported that the installation of GRSs on a five-story commercial building led to a 0.6–14.5% decline in the building's annual energy consumption. Compared to the 72 W/m^2 heat flux value of a conventional roof, the heat flux value of a roof that a GRS installed is only 2 W/m^2 [7]. Such an effect depends on the height of plants or the leaf area index (LAI), which represents the total leaf surface contained in a volume of unit base [8]. As the LAI changed from 1.5 to 3.5, the building's internal temperature decreased by as much as 3.3 °C, compared to that of the building with a conventional roof. Also in terms of the daily temperature change, the building with the conventional roof showed a difference of 10 °C and more, whereas the building that GRSs installed showed a difference of only up to 5 °C [9,10].

Second, regarding the CO_2 absorption capacity of plants and the effects on the microclimate improvement of the GRSs, the use of field measures, chamber experiments, and numerical simulation showed that plants can reduce the CO_2 concentration in the environment by absorbing CO_2 during the day. On a sunny day, GRSs may lower the CO_2 concentration in nearby regions by as much as 2% [11,12].

The previous study considered only the effects of GRSs without consideration to the related factors such as the characteristics of building or regional climate. For example, although one study conducted some case studies which categorized the types of buildings, it did not analyze the characteristics of energy usage in each building. This approach made it difficult to analyze the characteristics of building that cause the difference of energy consumption [13]. From the perspective of decision makers, it has been difficult to determine what type of GRSs is most appropriate for the building because the characteristics of building and the regional climate should be considered together to maximize energy saving effects. Therefore, the relationship between the characteristics of building or regional climate and the energy-saving effect of GRSs needs to be clarified.

This study focused on the energy-saving and greenhouse gas reduction effect of GRSs with various scenarios considering the energy performance of a building which is affected by the combination of energy saving measures (ESMs) and different regional climates. To achieve this, one type of GRS was applied to the case study, because the purpose of this study is to analyze energy saving and greenhouse gas reduction effect of GRS in terms of characteristics of building and regional climate, not to select the optimum alternative among various type of GRSs. Furthermore, life cycle cost (LCC) and life cycle CO_2 ($LCCO_2$) analyses were performed to quantitatively analyze the effects of various ESMs.

This study is organized as follows: (i) selection of educational facility for case study; (ii) selection of green roof systems (GRSs) and energy saving measures (ESMs); (iii) analysis of the energy consumption characteristics in case study; (iv) analysis of the energy saving effect of GRSs with the combination of ESMs based on the results of energy simulation; (v) case study: LCC and $LCCO_2$ analysis of GRSs and ESMs scenarios. And it is shown in Fig. 1.

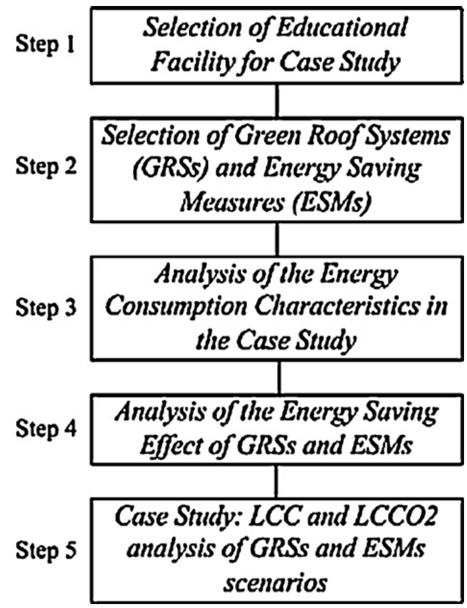

Fig. 1. Research framework.

2. Research framework

This study aimed to examine the economic and environmental effect of the installation of GRSs in educational facilities. To consider various effects of GRSs, the following analyses were performed: (i) an analysis of the effect of GRSs based on the application of various combinations of ESMs; and (ii) an analysis of the effect of GRSs based on different climatic characteristics in different regions. This study also aimed to conduct LCC and $LCCO_2$ analyses of a project selected as a case study. The detailed research process is as follows.

First, using the *2009 Statistical Yearbook of Education*, published by the Korea Ministry of Education, Science, and Technology, data on the energy consumption of educational facilities in South Korea were collected and analyzed. Based on the results of the analysis, an elementary school facility was selected because of the highest amount of CO_2 emission due to energy consumption and a case study was selected based on the region, the service life, energy consumption, etc.

Second, through extensive literature review and interviews with experts in the field of green roofs, a type of GRS was selected as appropriate to the selected case project. Also, the properties of the soil and plants were examined to collate basic data for energy simulation, and ESMs that were applicable to educational facilities both in South Korea and abroad were surveyed. The ESMs that were used in this study were selected first based on the literature review, and finally based on interviews with experts. By combining the ESMs that were selected as such, improvement scenarios were established.

Third, as a preliminary process for analyzing the energy-saving effect of each improvement scenario, energy modeling for the selected case studies was performed using Energy Modeling (Energy Plus ver. 6.0). The coefficient of variation of the root mean square error (CV (RMSE)) equation was used to evaluate the reliability of the modeling result.

Fourth, the energy-saving effect of each improvement scenario was analyzed by applying the established energy model to the established improvement scenarios. The amounts of heating and cooling energy saved by region, by varying climate conditions of the identical improvement scenarios were also compared. Based on the results, the relationship between GRSs and ESMs in terms of their energy-saving performance was analyzed.