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Development of low carbon durability design for green apartment buildings in South Korea

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ABSTRACT

A number of studies have evaluated life-cycle CO_2 emissions and related emission-reduction technologies that can contribute towards a low carbon construction industry; specific attention has also been paid to apartment buildings. There has also been much focus on long-life building technologies as a major means to reduce carbon emissions from the construction industry. These developments are accompanied by a need to develop models for quantitative evaluation of building service life and of life-cycle CO_2 emissions. This study thus aims to evaluate service life and life-cycle CO_2 emission reductions, and to develop a low carbon durability design for apartment buildings, utilizing green technologies to satisfy these twin goals.

To this end, three types of green technology groups that could be applied to apartment buildings were selected. Furthermore, a method to estimate the service life of apartment buildings was applied to evaluation measures of CO_2 emissions, in order to identify evaluation measures for CO_2 emission reduction performance and service life. The life cycle of apartment buildings was divided into four phases: construction, operation, maintenance, and disposal phases, with CO_2 emission evaluation measures considered for each phase.

A case study was also analyzed in order to validate the reliability of the proposed low carbon durability design. The study result showed that it is possible to analyze the characteristics of life-cycle CO_2 emission reductions and the service life of apartment buildings using green technologies; 36 technologies capable of satisfying the 40% life-cycle CO_2 emission reductions target and the 100-year service life target were selected.

1. Introduction

Much effort has been paid to the management of CO_2 emission by many nations to cope with climate change because CO_2 emission has been regarded as a main cause of global environment disasters that occurred in recent years. As per the Kyoto Protocol of the United Nations Framework Convention on Climate Change, CO_2 has, since 2005, been targeted as the main culprit of global warming. To this end, the European Union has used the Energy Performance of Building Directive (EPBD) to cope with climate changes and to achieve CO_2 emission reduction by countries [1,2]. South Korea has also been making efforts to achieve the target reduction in CO_2 emissions of 37% below business-as-usual (BAU) by 2030, through the INDC (Intended Nationally Determined Contributions) voluntary reduction program, which was formulated in response to this environmentally friendly trend [3]. Typical examples of related initiatives include discussion of mandatory CO_2 emission reduction agendas for each industry and the enforcement of environmental regulations, such as the "energy and green gas target management system" [4].

The construction industry in South Korea accounts for 40% of total energy consumption; it is therefore considered a main target for reducing CO_2 emissions, not only because it is a mass consumption industry, but also because of its relation to many other industries [5,6]. The industry has acknowledged this role and has made efforts to reduce CO_2 emissions from buildings by using low-emission green building technologies [7,8]. In particular, much attention has been paid to reducing the use of construction materials and to life-cycle CO_2 (hereafter referred to as $LCCO_2$); key requirements for this sector include long-life building construction and the development of technology to enable evaluation of the durability of design and quantitative assessment of $LCCO_2$ emissions, taking into consideration the target service life of buildings [9,10].

However, existing CO_2 emission evaluation techniques focus on evaluating CO_2 emissions based on energy consumption during a building's operational phase, failing to consider CO_2 emissions during the construction phase and use of green building technologies.

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Moreover, evaluation of life cycle CO_2 emissions does not take into account the durability of buildings, making it difficult to quantitatively calculate the effects of durability design on CO_2 emission reductions [11,12].

This study thus aims to evaluate reductions in $LCCO_2$ emissions during different building life cycles, taking into account target service life. The study also seeks to develop a low carbon high durability apartment building design, using green technologies that satisfy the goal of CO_2 emission reduction.

To achieve these goals, three types of typical green technologies that can improve durability and reduce CO_2 emissions were selected. Furthermore, a service life estimation technique for apartment buildings was applied to a measure of CO_2 emissions evaluation, in order to develop a measure to evaluate a building's performance in relation to CO_2 emissions and service life. The building life cycle of apartment buildings was divided into four phases: construction, operation, maintenance, and disposal; this allowed development of evaluation measures for each phase. We also evaluated the reliability of the developed measure through case study analysis.

2. Literature review

Since the early 1990s, there have been various studies on the environmental performance of buildings in environmentally advanced nations using life cycle analysis (LCA) methodology. Table 1 shows the main building LCA evaluation programs and their characteristics [13–16]. Eco-Quantum is the world's first building LCA-based computer program and was developed by the IVAM Environmental Research Institute in Netherlands; it evaluates various aspects, such as the effects of energy consumption during the building life cycle, maintenance during the operational phase, differences in the durability of building-related parts, and recycling rates [17]. Becost, developed by the VTT Research Institute in Finland, is a web-based program that is utilized in marketing and system management, and uses data relating to environmental effects throughout the building life cycle, including during building material production, transportation, construction, maintenance, and disposal [18]. Envest, developed by BRE, is used to evaluate the LCA of building materials from the early phase of building design. Web-based Envest2 was developed in 2003. Analysis results produced by Envest provide information relating to both environmental performance and economic feasibility, through mean measured values of environmental effects (referred to as Eco-point) and whole-life cost analysis results [19]. LISA, developed in Australia, offers advantages in terms of ease of analysis of environmental performance during the building material production phase by utilizing life cycle inventory (LCI) databases (DBs) for various materials; it also uses simple input methods, thereby reducing evaluation time and effort [20]. GEM-21P, developed by the Shimizu Corporation in Japan, calculates energy input per unit area, relating this to building purpose; it utilizes the corporation's statistical buildings data, enabling multiple reviews of energy reduction technologies at the early planning phase [21]. In South Korea, SUSB-LCA and BEGAS were developed by the Sustainable Building Research Center. SUSB-LCA employs direct input of building materials and energy usage, together with an estimation model. SUSB-LCA can evaluate life-cycle energy, carbon emissions, and cost. It is also an evaluation program that allows a case comparison between target and alternative buildings [22,23]. On the other hand, BEGAS can evaluate the effects of buildings on global warming, and evaluation results are used in a program related to global warming evaluation for Green Building Certificate (G-SEED), a green building certification program in South Korea; the program quantitatively evaluates greenhouse gas emissions during the building material production process through quantitative information on main building materials. The main building materials are identified when the cumulative sum of greenhouse gas emissions produced in building materials exceeds 95%, with this related to the cut-off criterion established in ISO 14040 (ready-mixed concrete, steel bars for reinforced concrete, beams) [24–26].

Technologies for reducing $LCCO_2$ emissions are essential during the preliminary building design phase, especially when considering the difficulties involved in implementing building design changes after completion. These difficulties are also due to the nature of the building industry and its trigger effects on CO_2 emissions and energy performance, as a consequence of inter-linkages with other building life cycle stages (such as the selection of construction materials and building operation). After analyzing the above-listed evaluation techniques, it was noted that Eco-Quantum, Becost, LISA, GEM-21P, and SUSB-LCA do not permit quantitative service life estimation and require available input information only after the construction phase. They are therefore limited in the extent to which they can provide a measure of $LCCO_2$

Table 1
Building life cycle assessment tools and their features.

Category	Nation	Organization	Year	Evaluation target	Main features
Eco-Quantum	Netherlands	IVAM Environmental Research	1996	Houses, offices	• World's first building LCA decision-making tool • Easy analysis during early design phase, scoring 12 environmental effects • Automatically converted into environmental indices
Becost	Finland	VTT	2003	All buildings	• Prediction of environmental effects during the life cycle from the early design phase • Input of structure type and material, land area, and endurance period • Provides various evaluation and analysis results for each phase
Envest2	UK	BRE	2003	House	• Comfortable user accessibility via web-based evaluation • LCA evaluation tool for building materials at early design phase • Evaluated via ECOPOINT, a unique index within the program
LISA	Australia	University of Newcastle	2003	All buildings	• Consists of simple design interfaces • Comfortable analysis ability for material production due to use of LCI DB • CO_2 can be analyzed using a simple checklist-style input method
GEM-21P	Japan	Shimizu Corporation	2008	All buildings	• Utilization of CO_2 emission unit data from the AIJ, continuous DB update • Calculation of CO_2 emissions through building use purpose and size data • Evaluation during life cycle: material, construction, operation, maintenance, disposal
SUSB-LCA	Korea	Sustainable Building Research Center	2007	All buildings	• Can evaluation building LCE, $LCCO_2$, and LCC • Utilization of CO_2 emission unit data through input-output analysis table • Evaluation at construction documents phase
BEGAS	Korea	Sustainable Building Research Center	2013	Apartment buildings	• Evaluation of six types of green gases, targeting main building materials • Utilization of LCI DB of building materials constructed via direction cumulative method • Evaluation linked with green building certificate systems