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The air emission assessment of a South Korean apartment building's life cycle, along with environmental impact

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ABSTRACT

In South Korea, 86.4% of residential buildings are apartment buildings. A typical apartment building generates a significant amount of air emissions during its life cycle, from building material production, construction, operation, and demolition, to recycling and disposal, along with transportation activities at two stages. In order to measure the life cycle air emission production of an apartment building, this study assesses seven types of air emissions and then demonstrates the application of the proposed methodology to a recently constructed apartment building in Busan, South Korea. The results of the study indicate that a proto-typical 25-storey apartment building produces 10,642,215.14 kg of CO_2, 326,393.29 kg of CO, 9401.8 kg of CH_4, 8444.57 kg of NO_X, 2877.47 kg of SO_2, 603.95 kg of NMVOC, and 27.05 kg of N_2O during its entire life cycle. In addition, this study assesses the environmental impact of apartment building materials, using the life cycle assessment software tool Gabi. From the environmental impact analysis and the carbon footprint analysis, it is found that the steel and concrete have the largest influence on global warming potential, acidification potential, and eutrophication potential.

1. Introduction

South Korea is currently the ninth largest source of carbon dioxide emissions in the world [1]. In response to the demonstrated impact of carbon dioxide emissions on global warming, and in an effort to comply with the international Kyoto Protocol treaty, the South Korean government has made effort commitment to decrease the annual air emissions in all industries [2]. One of the largest industries in South Korea, the construction industry, consumes approximately 40% of the raw materials and 30% of the energy [3], with approximately 23% of the carbon dioxide emissions occurring in the Korean building sector [4]. With the goal of reducing carbon emissions in the building sector by up to 48 million tons by the year 2020 [5], the Korean government has recently established and implemented various policies to reduce the environmental impacts of buildings through increasing the energy efficiency of buildings [6].

Largely due to the Kyoto Protocol, the current Korean government's policies vis-à-vis the building sector is focused on carbon emission reductions. However, the building sector produces not only carbon emissions but also other air emissions. Some of the various air pollutants released into the atmosphere during construction are carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_X), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC), and nitrous oxide (N_2O). All these contribute to environmental impact potential – global warming potential, acidification potential, eutrophication potential, and ozone depletion potential [7].

In response to the government's increasing concern about environmental issues in the building sector, several research studies have investigated the environmental impacts of buildings in South Korea in terms of energy requirements and carbon emission production using a life cycle assessment approach [8]. Typically, the life cycle assessment of a building considers energy consumption and carbon emissions in five stages – building material production, building construction, building operation, building demolition, and building material disposal and recycling – along with transportation activities from both a building material manufacturer to a construction site and from the building site to a landfill site. However, to date little research has been conducted to estimate a building's air emissions from the life cycle perspective in South Korea.

Most of the existing research has focused on the operation stage, which accounts for 80% of the total energy consumption in a

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building's life span [8]. However, the results of those studies cannot provide accurate data on energy consumption and carbon emissions of a building's life cycle because the researchers fail to include either a construction stage or a demolition stage. To be comprehensive, it is necessary to assess the entire life cycle of a building, from building material production to building material disposal. By evaluating a building's entire life cycle, data will be available for designers and environmental policy makers to use in planning to mitigate the environmental impact of a building.

Since residential buildings utilize a large amount of energy and produce a large amount of carbon emissions in the global building sector, it is necessary to focus specifically on the residential building sector in order to mitigate the environmental impact of the overall building sector [9]. As a reflection of South Korea's having the third-highest population density in the world, the most common type of residential building is the high-rise apartment building, constituting 86.4% of the total residential sector in South Korea [10]. Since the construction demand of an apartment building is expected to continuously increase in the future [10], it can be expected that apartment buildings will continue to utilize a large amount of the raw materials and the energy and produce a large amount of carbon emissions in South Korea.

In order to reduce the environmental impact of the building sector, it is necessary to first quantify the environmental impact of buildings [8]. Thus, it is reasonable to investigate the life cycle of the largest component of this sector, apartment buildings. The objective of this study is to analyze seven types of air emissions in the entire life cycle of an apartment building in South Korea, from building material production to building material disposal and recycling, as well as to assess their environmental impact. The results of this study can then be used as reference data for designers and environmental policy makers to estimate air quality in order to create more sustainable apartment buildings.

2. Literature review

Using an energy analysis software tool, Koroneos and Kottas assess the environmental impact of the annual energy consumption in a model house in Greece [11]. This study affirms that climate conditions and building material types have a strong effect on energy consumption. In the evaluation of the air and water pollutants resulting from the production of fuel used in homes, the study reveals that the production of heating oil causes two major environmental effects: metal contamination and acidification. However, the Koroneos and Kottas study considers the greenhouse effect generated from the heating oil and electricity consumption in only the operation stage of the model house.

Cheng et al. investigate conventional and green building materials to estimate indoor emission sources of volatile organic compounds in an experimental chamber [12]. The study illustrates that green building materials exhibit fewer primary emissions of volatile organic compounds, including BTEX and carbonyls, as well as fewer secondary emissions due to ozone reaction than do conventional building materials. However, the study focuses on volatile organic compounds in only the construction material production stage.

For the life cycle assessment of residential dwellings in Spain, Ortiz et al. estimate the environmental impacts of energy consumption in the pre-construction and the operation phases in six categories: climate change, acidification potential, human toxicity, depletion of abiotic resources, terrestrial ecotoxicity, and stratospheric ozone depletion [13]. The results of the study indicate that the pre-construction phase has the largest impact of terrestrial ecotoxicity, and the use phase has the largest impact of acidification potential and the second largest impact of depletion of abiotic resources. Although the study provides six categories of environmental impacts, the study does not consider the construction stage, the demolition stage, or the disposal stage of a residential dwelling's life cycle.

Cuellar-Franca and Azapagic conduct a life cycle assessment study for the UK residential sector to evaluate the impacts of energy use on the environment [14]. The study illustrates that energy consumption in the use phase contributes all the environmental impacts except ozone layer depletion over a 50-year lifetime. Further, the insulation materials used in the construction phase make the largest contribution to ozone layer depletion. Although the study considers the life cycle of a residential house from a construction material production phase to a recycling phase, the study focuses mainly on the environmental impacts from carbon emission produced in the life cycle of a residential house.

Xing et al. develop a life cycle inventory model to estimate the environmental impacts of two types of building structures, concrete and steel, for an office building [15]. The study demonstrates that a steel-framed building produces 48.1% less carbon emissions and requires 24.9% less energy consumption than a concrete-framed building. Among greenhouse gases and major pollutants, a concrete-framed building emits almost two times the amount of sulphur oxides. The study suggests that the steel-frame building is a preferable building structure in terms of energy savings and environmental protection. However, the study focuses mainly on the construction and operation stages of an office building.

Using an input–output analysis technique, Acquaye and Duffy estimate the intensities of energy consumption and greenhouse gas emissions in the Irish construction sector [16]. The results of the analysis reveal that carbon dioxide has the largest impact on greenhouse gas and that the other pollutants, such as nitrous oxide and methane, have negligible contributions. However, the study does not consider greenhouse gas emissions in the operation or disposal phase in the Irish construction sector.

Radhi investigates the potential impact of cooling electricity consumption on global warming in UAE residential buildings [17]. The study demonstrates that thermal insulation and thermal mass can play an important role in decreasing the potential impact of global warming by reducing energy consumption and carbon emissions. However, the study focuses solely on global warming in the operation stage of a residential building's life cycle.

Zhang et al. investigate the air emission source of a building's six life cycle phases in Hong Kong [7]. The results of the life cycle assessment reveal that more than 98% of carbon dioxide, nitrous oxide, sulphur dioxide, nitrogen oxide, and non-methane volatile organic compounds are emitted only in the operation and maintenance stage. Although the study considers all major air emission pollutants in a building's entire life cycle, the study does not incorporate all emission factors of the major pollutants emitted in Hong Kong.

Scheuer et al. conduct a life cycle assessment of a university building to evaluate five environmental impacts: global warming potential, ozone depletion potential, acidification potential, nutrification potential, and solid waste generation [18]. The study shows that the environmental impacts are mainly affected by the primary energy consumption at the operation stage over a 75-year life span. Although the study considers the entire life cycle of a commercial building, the results of the study do not include the recycling stage.

Using life cycle assessment software, SimaPro, Desideri et al. assess the entire life cycle of a zero energy consumption educational building from building material production to building material disposal. The results of the study show that technical plants using the renewable energy systems have low environmental impacts. Although the study investigates an entire life cycle of a building, the study does not specify the types of air emissions produced in a construction process, a demolition process, or a