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A Study on the Estimation Method of the Environmental Load Intensity for Analyzing GHG Reduction Effect of Han-Ok

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Abstract The Korean government recently has rediscovered the potential value of Han-Ok, the Korean traditional house, as an eco-friendly building. In order to objectively verify the environmental performance of Han-Ok as a low carbon green building, this paper suggests the analysis method of GHG emission load of Korean traditional house, based on Life Cycle Assessment, which is commonly abbreviated to "LCA". The environmental impacts caused by building construction and operation can be analyzed through the sum of input and output data from every phase. The study particularly describes the GHG reduction effect by using traditional building materials such as wood products, traditional clay roof tiles, and mud, which are mainly used to construct Han-Ok. Also the study proposes the method for comparative analysis of quantity of GHG emissions in building's entire life cycle so that the data can be used as a reliable basis to optimize the environmental performance of building.

Keywords: Life Cycle Assessment, Life Cycle CO_2, GHG Reduction, Low Carbon Building Material, Han-ok

1. INTRODUCTION

As evolving the environmental point of view from 'Eco-Friendly' to 'Sustainability', which considers environmental, economic and social impacts, many technologies for Low Carbon Green Growth have been developed in the fields of architecture and civil engineering. Especially, construction industry, which is far from being a single activity, heavily causes greenhouse gas (GHG) emissions because of its complicated networks with other related industries. The Korean construction industry covers 35% of the GDP and the one-third of overall carbon emissions in Korea when including production, construction and operation. In consequence, it is necessary to have a nationwide strategy for the Climatic Change Convention in Korea.

The reason why it is important to concern about the environmental performance of Han-Ok, the Korean traditional housing style, is to achieve low carbon and green growth in Korea. Han-Ok as a low carbon green building can be an effective countermeasure for greenhouse gas reduction in the construction field. Han-Ok is an environmentally-friendly building in various aspects such as architectonical methods, materials and landscaping techniques. First of all, Han-Ok has fully adapted to both the continental and the oceanic climate of the Korean Peninsula since the 10th century. The spaces in the house can be classified into two categories depending on functions; heating spaces for winter and cooling spaces for summer. The two oppositional spaces can coexist by adopting passive solar design. Secondly, Han-Ok is mainly constructed with natural building materials such as stones, clay, and wooden materials. Because of the characteristics of construction materials, the building naturally controls indoor temperature, humidity, air quality and ventilation. It means that artificial equipment is less necessary and, as a result, domestic energy consumption can be reduced. Moreover, this raw materials used for construction contain low initial embodied energy, the total environmental load of building can be therefore reduced.

For these reasons, the Korean government recently has rediscovered the potential value of Han-Ok as an eco-friendly building and has encouraged it with policies such as "Han-Style". In addition, according to a recent survey performed by the Ministry of Land, Transportation and Maritime Affairs of Korea, about forty two percent of the respondents chose Han-Ok as a favorite type of residence. The result reflects the tendency that Han-Ok is getting more preferred by housing consumers as increasing interests in 'Well-Being' and 'LOHAS' in Korean housing market. It will be very meaningful to revitalize this old-fashioned housing type for contemporary lifestyles. This research is executed to evaluate the environmental performance level of Han-Ok as a low carbon green building. The basis of environmental analytical measurement is GHG emissions which is attracting worldwide concern in this era of climate change.

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2. METHODOLOGY AND SCOPE

2.1 Methodology

In order to objectively verify the environmental performance of Han-Ok, this paper suggests the analysis method of GHG emissions, based on Life Cycle Assessment, which is commonly abbreviated to "LCA". The procedures of LCA are part of the ISO 14040s series of standards and it is carried out in four distinct phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation. LCA is usually applied as an important tool for evaluating climate change impacts of products. LCA can be an essential part of establishing a baseline carbon footprint, as well as analyzing carbon reduction and environmental benefit. In general, LCA provides a more holistic perspective on a given product, following the key impacts of its manufacture, use, and disposal across all stages of the life cycle.

The methods of environmental assessment are largely classified into two ways, Economic Input-Output-LCA and process-based LCA. Economic Input-Output LCA method, which is abbreviated to EIO-LCA, estimates the materials and energy resources for particular service or good, and its environmental emissions as results of the relevant activities in our economy. But the results of any EIO-LCA can be imprecise because certain economic activities or economic sectors could be excluded from system boundary for calculation. On the other hand, the process-based LCA maps every process associated with a product within the system boundaries, and associates energy and material inputs and environmental outputs and wastes in each process. Although this model usually require a great deal of time and cost due to heavy data collections, the results of process-based LCA are more accurate because materials and energy input and emissions output are directly collected by the field survey.

Several studies have been conducted to find out the environmental impact and quantitate it based on LCA methodology in construction sector. Gonzalez et al.[6], for example, calculated the reduction effect of CO2 emissions by selecting different construction materials, Verbeeck et al.[7] developed an evaluation method for life cycle inventory of building. The environmental impacts caused by building can be analyzed through the sum of input data and output data from every phase of entire life cycle. Examples of inputs include fuels or energy, raw materials, time, and water, while examples of outputs include the product component itself, emissions, waste materials, and by-products. The process-based LCA is supported with real measurements of inputs and outputs in each stage of building's life cycle. Therefore, the methodology of the research for this paper follows the process-based LCA.

2.2 Technical scope

The technical scope of the research is follows;

1) Analysis of materials used in a case of Han-Ok-style building, examining the details of construction cost.
2) Life Cycle Inventory development of traditional materials
3) Estimation and Evaluation of GHG emission, according to the life cycle phases such as material production phase, construction phase, building operation phase and demolition phase.

This research work was carried out on 4 cases of real construction projects. The process-based LCA demands intensive, time-consuming effort, so it is reasonable to limit the scope of data collection when a research subject consists of various materials for a long period of use and consequently has complicated input/output system of materials and energy, for instance, a residential building. The research was conducted by extracting significantly influential factors in every phase of life cycle and applying them for data collection scenarios. The table 1 presents the general scope definition for Han-Ok LCA. The scope includes functional unit, reference flow and system boundary. The purpose of the functional unit and the reference flow is to ensure comparability of LCA results. The system boundary defines the unit processes to be included as the key elements in the physical system. The cut-off criteria for initial inclusion of inputs and outputs were determined by cumulatively contributed factors in mass. The research assumed that there was no by-product occurrence in the system, so allocation procedures were excluded.

Table 1. General scope definition for Han-Ok LCA

Categories	Definitions	
Function	Household-dwelling function	
Functional unit	A residential building for one household during 30 years	
Reference flow	Energy and material input to a building for a household during 30 years	
System boundary	Material production phase Construction on site phase Building operation and maintenance phase Disposal and recycling phase	
Input	Raw material & Ancillary input	Cement, clay, sand, gravels, stones, wooden materials, baked roof tiles, steel products
	Energy	Diesel, gasoline, electricity, water, LNG
Output	Final product	Han-Ok building
	Atmospheric emission	GHG emissions
	Solid waste	Waste wood, waste concrete, waste sand, waste roof tiles, waste metal, mixed waste

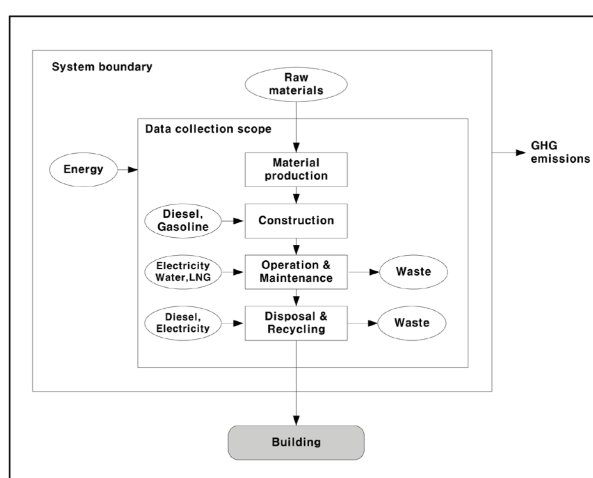

Figure 1. System boundary and reference flow for Han-Ok LCA

3. ANALYSIS OF THE MAIN MATERIALS OF HAN-OK

3.1 Description of the buildings

The 4 analysis subjects were chosen among new construction cases located in Bukchon Hanok Village, Seoul. Bukchon was the residential area for high circles in 19th century, but has changed its urban structure in modern style since 1930s because of the massive construction with standardized materials by Housing operation companies. Han-Ok in Bukchon can be a suitable case for research because it is considered as a new type of urban housing which preserves the traditional beauty of Korea while it also accepts new aspects of modern life style. The cases were generally composed of 2 buildings with 2 main halls, 5 rooms, 1 kitchen, and 2 bathrooms and the average building area is 77.13 m2. The houses were temporarily vacant but installed LNG gas boiler, electric appliance and water supply equipment.

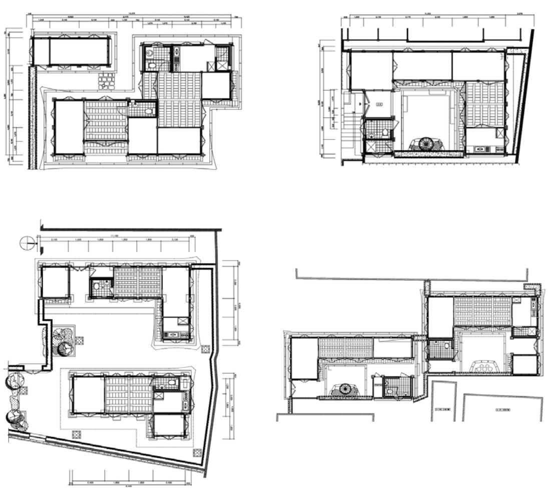

Figure 2. Plans of the analysis subjects

3.2 Weight and volume analysis of the construction materials

The weight and volume analysis is an integral procedure to establish the cut-off criteria. It is realistically impossible to research and collect all the quantitative data for input and output items in the system boundary. Also some items could be in too small quantity to influence significantly to the environment. Therefore, principal materials were selected after the thorough weight and volume analysis based on detailed statements of construction expenses. The principal materials include cement, steel products, wooden products, baked roof tiles, clay, sand, gravels, stones, and granite. The other types of materials include items that input quantity was small, or size and shape information was not clearly stated, for instance, charcoal, straw, seaweed glue or PVC mosquito net.

According to the result of weight and volume analysis of major building materials used for the cases (Table 2), building materials produced from ground such as clay, sand, stones, gravels and granite account for a major percentage of weight as well as volume. Wooden materials, which are mainly used for the structure, account for nearly 6.2% of weight while the traditional clay roof tiles account for around 16.5% of it. Wooden structure, masonry foundation, mud-plastered wall, and tiled roofs are the most important elements that give the own characteristics of a traditional residential building style. These natural resources constitute more than 91% of total building material weight for Han-Ok. (Fig. 3)

Table 2. Average weight and volume by building mate

Materials	Weight		Volume	
	[ton]	[%]	[m3]	[%]
Clay	91.52	20.92%	50.85	18.38%
Baked roof tiles	72.29	16.52%	54.41	10.89%
Granite	66.48	15.19%	31.06	11.22%
Stones	84.64	19.34%	44.51	16.08%
Gravels	30.75	7.03%	18.09	6.54%
Wooden materials	27.21	6.22%	54.41	19.66%
Sand	25.61	5.85%	16.01	5.79%
Cement	7.86	1.80%	5.24	1.89%
Steel products	0.03	0.01%	0.01	0.00%
Other types of materials	31.16	7.12%	26.42	9.55%
Total	437.56	100%	276.72	100%

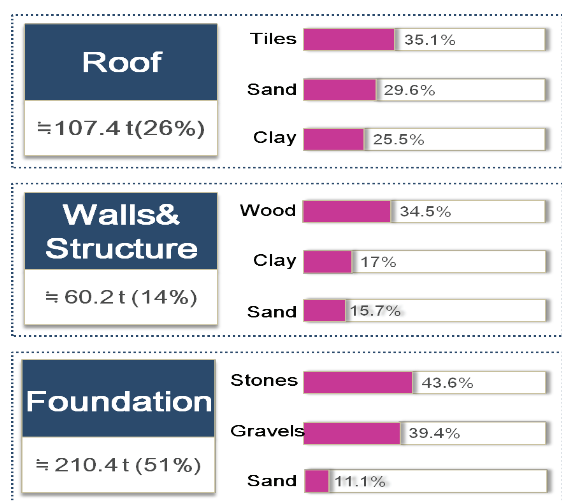

Figure 3. Building material composition by parts

The results of analyzing weight and volume of building materials show that Han-Ok is mainly composed with the low-embodied-energy materials which are transported directly from the nature or undergone simple manufacturing processes. In other words, the building materials of Han-Ok contain low environmental load, compared to modern buildings of steel and reinforced concrete.

4. LCI DATABASE OF TRADITIONAL BUILDING MATERIALS

In order to estimate the total quantity of GHG emissions from every phase in entire life cycle of a building, it is necessary to specify individual quantity of GHG emissions in product manufacturing phase firstly. Because the environmental information of traditional clay roof tiles and larch lumber does not exist in KLCI[1] database , this paper also developed the life cycle inventory of those materials so that the amount of GHG emissions in material phase can be estimated.

Defining the goal and scope of the LCA has to be preceded before collecting all input and output flows of both product and elementary of the entire manufacturing process from and to the environment. It is because collecting method, quality and contents of data are closely related to the purpose of use. Materials and energy input and emissions output, including solid wastes and atmospheric emissions, were directly collected by the field survey. Then, the analysis of the LCI reports was conducted with LCA software, which is named as TOTAL developed by Ministry of Environment. Table 3 shows the GHG emissions by functional unit of each material for Han-Ok.

Table 3. List of main building materials for Han-Ok and its GHG emissions

Materials	GHG emissions unit	Database sources
Cement	1.06E+00 kg CO_2-eq./kg	KLCI
Concrete Brick	1.23E-01 kg CO_2-eq./kg	KLCI
Clay	7.36E-05 kg CO_2-eq./kg	Ecoinvent
Quicklime	4.03E-02 kg CO_2-eq./kg	Ecoinvent
Sand	3.86E+00 kg CO_2-eq./m^3	KLCI
Gravels	1.13E+01 kg CO_2-eq./kg	KLCI
Stones	1.13E+01 kg CO_2-eq./kg	KLCI
Granite	1.13E+01 kg CO_2-eq./m^3	KLCI
Traditional roof tile	2.46E-01 kg CO_2-eq./kg	Calculated
Wooden materials	8.91E-01 kg CO_2-eq./m^3	Calculated
Steel products	1.43E+00 kg CO_2-eq./kg	KLCI

5. ESTIMATION OF GHG EMISSIONS IN THE LIFE CYCLE OF HAN-OK

Building LCA is a holistic assessment which requires the assessment of all phases such as raw material extraction, manufacture, construction, use and disposal including all intervening transportation steps. The environmental impacts caused by building's existence can be evaluated through the sum of GHG emissions from every phase. The other related studies on building LCA usually suggest dividing the entire building life into 3 phases; construction phase, building operation phase and demolition phase. But this paper proposes to divide into 4 phases; material production phase, construction on site phase, building operation and maintenance phase and demolition and recycling phase. It is because defining building's lifecycle more specifically will be helpful to consider different conditions of activities derived from each lifecycle phase and to make collecting data easier. The table 4 presents contents and sources of data collection in order to ensure the quality of GHG emissions calculation in every phase.

Table 4. Contents and sources of data collection

Unit process	Contents of data	Method	Data sources
Production phase	Building material production	Process-based LCA	LCI DB Statement of construction expenses
Construction phase	Material transportation to construction site	Process-based LCA	LCI DB Statement of construction expenses
	Construction activities with machine	Process-based LCA	LCI DB, IPCC guidance, Statement of construction expenses
Operation & maintenance phase	Electricity consumption	Statistics	Korea National Statistical Office
	Water consumption	Statistics	Korea National Statistical Office
	LNG consumption	Energy simulation	Energy Performance Assessment
	Material production for renovation	Process-based LCA	LCI DB, Standard cycle of maintenance
	Material transportation for renovation	Process-based LCA	LCI DB Statement of construction
Demolition & Recycling phase	Demolition activities with machine	Process-based LCA	IPCC guidance, Field survey
	Waste transportation	Process-based LCA	LCI DB, Field survey
	Recycling operation	Process-based LCA	LCI DB, Carbon footprint label, Korea National Statistical Office
	Waste landfills	Process-based LCA	LCI DB, Carbon footprint label, Korea National Statistical Office
	Waste incineration	Process-based LCA	LCI DB, Carbon footprint label, Korea National Statistical Office

[1] KLCI is Korea Life Cycle Inventory database developed by the Ministry of Environment, the Ministry of Knowledge Economy and the Ministry of Land, Transport and Maritime Affairs.

5.1 Production phase

Production phase includes from excavation of raw material to manufacture of marketable construction products. Because of the complicated manufacturing procedures, putting various raw materials, construction products already have certain amount of environmental load or initial embodied energy before being used in construction site.

The GHG emissions in production phase can be measured by the multiplication of the quantity of construction material and GHG emissions unit of each material. The average quantity of GHG emissions of the case studies in material production phase is 24,784.78 kg-CO2 totally. (Table 5)

Table 5. Average GHG emissions in material production phase of studied cases

Materials	Average GHG emissions [kgCO$_2$eq]	Percentage [%]
Cement	7,950.44	32.08%
Clay	4.02	0.02%
Sand	193.88	0.78%
Gravels	295.12	1.19%
Stones	523.74	2.11%
Quicklime	664.41	2.68%
Granite	268.05	1.08%
Concrete brick	608.89	2.46%
Baked adobe brick	965.37	3.90%
Traditional roof tiles	9,817.01	39.61%
Wooden materials	2,884.98	11.64%
Steel products	273.13	1.10%
Other types of materials	335.72	1.35%
Total	24,784.78	100 %

5.2 Construction phase

Construction phase is largely divided into two steps; transportation of building materials to construction site and execution of construction activities with machines. Therefore, the quantity of GHG emissions in construction phases can be estimated with the sum of GHG emissions in both two steps.

In the case studies, the transport vehicles were dump trucks and trailer and the individual GHG emissions unit is based on KLCI database. The haulage distance of materials to the construction site was various, depending on the proximity of the site to a preferred material supplier centre. After researching types of vehicles and transport distance of each material, the total GHG emissions result, as shown on the Table 6, is 3,490.41 kg-CO2eq during the transportation step.

Contrary to contemporary construction activities, which are generally executed with many different types of specialized construction machines, most of works are executed by manpower during the construction of Han-Ok. In the case studies, mechanized equipments were used only for concrete casting. The fuel used for concrete pump car was diesel and for concrete compactor was gasoline. Capacity and efficiency (L/hour) of the machines were based on the standard quantity per unit. The calculation result of GHG emissions by construction machines is 57.76 kg-CO2eq. (Table 7) The analysis of GHG calculation in the construction phase shows that more than 98% of GHG emissions occurred during building material transportation. In other words, the result implies the importance of using local materials.

Table 6. GHG emission by material transportation

Materials	Vehicle	Distance [km]	GHG emissions [kg-CO$_2$-eq]
Cement	Truck 2.5ton	20	14.22
Deformed bar	Trailer20ton	20	0.01
Sand	Truck 2.5ton	20	263.14
Gravels	Truck 2.5ton	20	159.24
Stones	Truck 2.5ton	20	753.01
Clay	Truck 2.5ton	20	224.36
Roof tiles	Truck 2.5ton	300	1,247.78
Wooden materials	Truck 2.5ton	230	387.97
Granite	Truck 15ton	50	248.29
Others	Truck 2.5ton	20	192.38
Total			3,490.41

Table 7. GHG emission by construction activities

Activities	Equipment	Energy	GHG emissions [kg-CO2-eq]
Concrete Compacting	Compactor	Gasoline	1.45
Concrete Casting	Concrete pump truck	Diesel	3.71
Transporting ready-mixed concrete	Truck mixer	Diesel	52.61
Total			57.76

5.3 Operation and maintenance phase

Operation and maintenance phase is the occupation period of a building, including repair works, renovations or extensions of building. In this phase, the GHG emissions can be measured by the sum of the energy used during the operation and additional materials used for repair works which depend on the cycle of maintenance.

Especially, collecting precise data of energy use during the entire building operation period is so difficult that it is recommended to estimate the energy use with certain assumptions. This paper suggests examining annual consumption of electricity, water and LNG as references. Only annual LNG consumption was calculated by energy simulation program and annual consumption of electricity and water were derived from official statistics. The sum of each multiplication of energy source and its GHG emissions unit will be the quantity of the GHG emissions during building operation. The total GHG emission during building occupation period (30 years) is 287,136 kg-CO2eq. (Table 8)

Table 8. GHG emissions by energy consumption in operation period

Energy	GHG emissions	unit	Annual consumption	Annual GHG emissions [kg-CO_2-eq]	GHG emissions for 30 years [kg-CO_2-eq]
Electricity	4.95E-01	kg CO_2/kWh	3,265.30 kWh	1,616	48,490
Water	3.32E-01	kg CO_2/m^3	530 m^3	176	5,279
LNG	2.74E+00	kg CO_2/m^3	40.80 m3/m^2	7.778.91	233,367
Total					287,136

Moreover, environmental impact by maintenance activities can be assumed by the amount of additional materials for repair, according to the standard cycle of maintenance on the regulation . Because of the unique architectonic condition of Han-Ok, the structural parts did not have any regulations on the maintenance cycle, so extra surveys were conducted with the help of specialized constructors in traditional building. The coefficient of parts is determined as repair rates per year and it can be applied to hypothetically calculate the entire quantity of materials used for repair during the life cycle of building.(Table 9) The GHG emissions by maintenance can be described as the sum of multiplication of two factors; quantity of each materials and its GHG emissions unit. Also it is necessary to consider GHG emissions by materials transportation for repair. The total GHG emission for 30 years by maintenance activities is 12,719.70 kg-CO2eq. (Table 10)

Table 9. Coefficients of repair cycle by parts of Han-Ok

Categories	Parts	Coefficient [%/year]	Basis
Structure	Roof	1.67	Estimated
	Wooden skeleton	1.25	Estimated
	External wall	2.00	Estimated
Window	Wooden	5.00	Regulation
	Aluminum	4.00	Regulation
Finishing	Plaster	4.00	Regulation
	Paper (wall, ceiling)	10.00	Regulation
	Tile	5.00	Regulation
	Paper (floor)	10.00	Estimated
	Wooden floor	4.00	Regulation
Others	Insulation	2.00	Regulation
	Waterproofing	5.00	Regulation

Table 10. GHG emissions by maintenance activities in operation period

Categories	Parts	GHG emissions [kg-CO_2-eq]	%
Material transportation		2,136.40	16.8%
Building exterior	Roof	8,244.06	64.8%
	Exterior wall	1,255.26	9.9%
	Structure	388.04	3.0%
Building interior	Ceiling and interior wall	440.71	3.5%
	Doors and Windows	255.23	2.0%
Total		12,719.70	100%

5.4 Disposal and Recycling phase

In disposal and recycling phase, after completing its physical and social function, building is dismantled and the construction waste is transported to be recycled or buried. Because of the difficulty of collecting precise data, it is also recommendable to calculate quantity of materials, according to suppositional conditions. (Table 11) The recycling rate of each waste item is based on the statistics of wastes in Korea. Disposal and recycling phase can be divided into 4 sub-steps such as dismantling building, transporting waste, recycling procedure and waste landfill/incineration. GHG emissions calculation for dismantling and transporting step is based on fuel consumption of vehicle and mechanized equipment. The calculation for the rest steps is based on GHG emission unit of Korean Carbon Footprint Label. Table 13 presents GHG emissions of each step and the total quantity of GHG emissions in this phase is 6,091.84 kg-CO2.

Table 11. Average quantity of recycling waste, landfills and incineration of studied case

Categories	Recycling rate	Recycling waste [kg]	Landfills and incineration [kg]
Waste wood	97 %	51.99	1.77
Waste concrete	97 %	87.58	2.99
Waste sand	97 %	331.47	11.31
Waste roof tiles	97 %	75.05	2.56
Waste metal	97 %	0.25	0.01
Mixed waste	0 %	0.00	34.09
Total		546.33	52.73

Table 12. GHG emissions in disposal and recycling phase

Procedures	GHG emissions [kg-CO2-eq]	Percentage
Dismantling	3.69	0.06%
Transporting waste	1,217.08	19.98%
Recycling	2,423.75	39.79%
Landfill	1,080.58	17.74%
Incineration	1,366.74	22.44%
Total	6,091.84	100.00%

Table 13. GHG emissions by environmentally influential factors

Phases	Influential factors	GHG emissions [kg-CO_2-eq]	Contribution rate	Cumulative contribution rate
Operation & Maintenance phase	LNG consumption	233,367.21	69.81%	69.81%
Operation & Maintenance phase	Electricity consumption	48,489.71	14.51%	84.32%
Production phase	Material production	24,784.78	7.41%	91.73%
Operation & Maintenance phase	Maintenance	12,719.70	3.81%	95.54%
Operation & Maintenance phase	Water consumption	5,279.00	1.58%	97.12%
Construction phase	Material transportation	3,490.41	1.04%	98.16%
Demolition & Recycling phase	Recycling	2,423.75	0.73%	98.89%
Demolition & Recycling phase	Incineration	1,366.74	0.41%	99.29%
Demolition & Recycling phase	Waste transportation	1,217.08	0.36%	99.66%
Demolition & Recycling phase	Landfill	1,080.58	0.32%	99.98%
Construction phase	Construction activities	57.76	0.02%	100.00%
Demolition & Recycling phase	Dismantling	3.69	0.00%	100.00%
Total		334,280.41	100.00%	

6. CONCLUSION

This paper presents the quantity of GHG emissions by using traditional building materials such as wood products, traditional clay roof tiles, and sand, which are main materials of Han-Ok construction. This paper also proposes the method to comparatively analyze environmental impact in different phases of building's entire life cycle so that the data can be used as a reliable basis to optimize the environmental performance of building.

The case studies focus on the quantitative analysis of environmental load of Han-Ok, according to the GHG emissions as criteria. The cases of buildings were located in Bukchon Hanok Village and the total GHG emissions during 30 years lifecycle of Han-Ok were estimated as 334,280.41 kg-CO2eq and about 4,333 kg-CO2eq per 1m2. According to the analysis of influential factors by contribution percentage, as shown on the Table 14, the quantity of GHG emissions by LNG consumption for heating is the highest, covering approximately 70% of total GHG emissions. The 97% of GHG emissions is from energy consumption and building materials production, while the GHG emissions from the construction phase and demolition/recycling phase are less considerable. It is because the major components of the building were made of natural materials and the most of construction works were executed by manual. The analysis result also implies that the quality of thermal insulation and air-tightness should be improved primarily to reduce the entire environmental load of Han-Ok. In other words, further study on a practical way of GHG emissions reduction in a building should focuses on technologies to enhance building thermal performance, such as insulation system or effective air conditioning system.

REFERENCES

Soo-Am Kim, Chang-U Chae, Dong-Woo Cho, Gun-Ho Lee, Geun-Soo Park, Sung-Hee Kim, et al, The Environmental Performance Assessment and Revitalization Strategy for Han-Ok, Korea Institute of Construction Technology, 2010

Chang-U Chae, Seung-Eun Lee, Yoon-Gyu Lee, Young-Sun Jung, Dae-Hee Chang, Eun-Mee Park, et al, The Environmental Load Unit Composition and Program Development for LCA of Building, Korea Institute of Construction Technology, 2004

Chang-U Chae, Soo-Hyun Kim, Jong-Woo Shim, Kang-Hee Lee, Tak Huh, An Environmental Assessment Method of Sustainable Building Materials and Recycling Techniques, Korea Institute of Construction Technology, 2000

Sung-Wan Kim, Jong-Sung Lee, A study on the estimation of energy consumption throughout an apartment life cycle (I), Korea National Housing Corporation, 1998

J. Cha, Life Cycle Inventory Analysis of Larch Lumber and Evaluation of Greenhouse Gas Reduction Potential of Wooden House, 2009

Gonzalez M, Navarro J, Assessment of the decrease of CO2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact. Building and Environment 2006, 902-909

Verbeeck G, Hens H, Life cycle inventory of buildings; A calculation method. Building and Environment 2010, 1037-1041

Kellenberger D, Althaus H, Relevance of simplifications in LCA of building components. Building and Environment 2009, 818-825

Cole R. Energy and greenhouse gas emissions associated with the construction of alternative structural systems. Building and Environment 1999, 335-348

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