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Life cycle assessment (LCA) of roof-waterproofing systems for reinforced concrete building

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Abstract. In this study, we investigated a life cycle assessment (LCA) of six roof-waterproofing systems [asphalt (C1), synthetic polymer-based sheet (C2), improved asphalt (C3), liquid applied membrane (C4), Metal sheet with asphalt sheet (N1), and liquid applied membrane with asphalt sheet (N2)]for reinforced concrete building using an architectural model. To acquire accurate and realistic LCA results, minimum units of material compositions for life cycle inventory and real data for compositions of waterproofing materials were used. Considering only materials and energy demands for waterproofing systems per square meter, higher greenhouse gas (GHG) emissions could be generated in the order of C1 > N2 > C4 > N1 > C2 > C3 during construction phase. However, the order was changed to C1 > C4 > C3 > N2 > N1 > C2, when the actual architecture model was applied to the roof based on each specifications. When an entire life cycle including construction, maintenance, and deconstruction were considered, the amount of GHG emission was in the order of C4 > C1 > C3 > N2 > C2 > N1. Consequently, N1 was the most environmental-friendly waterproofing system producing the lowest GHG emission. GHG emissions from maintenance phase accounted for 71.4%~78.3% among whole life cycle.

Keywords: life cycle assessment; GHG emission; roof-waterproofing system; reinforced concrete building; architectural model

1. Introduction

Reinforced concrete (RC) structures have been applied to housings and buildings world-widely for a long time. About 66% of total housing types of Japan are the RC structured high-rise housing. RC structure has been applied to the buildings in South Korea more than 90% of them, and the usage of RC structure is still increasing. RC structure is well known as a durable structure system for compression and tension because rebar and concrete can strengthen each weak point of theirs. However, the concrete itself cannot avoid water intrusion, waterproofing-system is essential for the RC building. Many structures built old days without proper design have been cracking and leaking, due to the lack of perfect waterproofing system that can endure until building deconstruction. Therefore, costs for maintenance increased and excessive consumption of material and energy caused severe environmental problems. Durability of RC structure can be rapidly

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deteriorated by water intrusion in the building so that selection of proper waterproofing system is very important. Nevertheless, the ratio of waterproofing system on total construction cost is only accounted as 3-4% (Jang 2002), and their significance for buildings has been overlooked at most of construction sites.

The Intergovernmental Panel on Climate Change (IPCC) issued the report including impacts of climate change and its vulnerability in the recent general assembly. The report showed that all the materials and processes causing imbalance of global energy can be the reason of climate change, and high concentration of anthropogenic greenhouse gas (GHG) in atmosphere is the primary factor (IPCC 2013). Therefore, many efforts have been made to reduce huge amount of GHG emission locally and internationally. Especially, industrial sector (e.g., manufacturing, transportation, construction, etc.), one of the greatest GHG emission source has been doing their best effort in GHG mitigation to avoid the regulation by the IPCC.

Life cycle assessment (LCA) has been well known as a representative method to evaluate the environmental impacts of products and/or processes during their entire life cycle (e.g., material collection, production, use and disposal). The LCA has been widely used as an important decision-making tool because it can suggest tactics lessening the load of environmental contamination (e.g., acidification, ozone depletion, and GHG emissions). Various LCA models have been developed for environmental assessment of buildings (e.g., materials and construction method) and they have been applied to many cases (Kim 2003, Monteiro and Fausto 2012, Hong *et al*. 2012, 2014). For instances, a LCA model has been implemented to investigate the environmental effect of steel-framed building and concrete-framed building (Guggemos and Horvath 2005). Some LCA studies have been conducted to understand the impact of locations, construction materials, and structure types on environmental outputs (Rossi *et al*. 2012, Zhang *et al*. 2013). Environment performance of high-strength concrete used in skyscraper was also evaluated by the LCA model (Marceau and VanGeem 2002). Moreover, optimization scenario for roof-top greening on educational facility was selected by considering both economic and environmental impacts obtained from LCA simulation (Kim *et al*. 2012). This shows that diverse environmental assessments for materials and construction methods can be implemented by the LCA model for the establishment of sustainable buildings. In addition, it is expected that the LCA model can be applied to waterproofing system to minimize the consumption of material and energy. However, few studies have dealt with waterproofing system using LCA models in spite of its significance for building construction.

In this study, we (1) applied the LCA model tosix waterproofing system (four conventional system and two combinational system), which is suitable for the roof of RC buildings; (2) estimated total GHG emissions (CO_2 equivalent) during their main processes (construction-maintenance-disposal) using real data of material compounds; and (3) suggested tactics to reduce GHG emissions at the stage of waterproofing system selection.

2. Methodology

2.1 Waterproofing system

Waterproofing system is dependent on roof finishing method, position of the building, and type of structural deck. In this study, selection of waterproofing system was limited to the roof of RC building based on architectural engineering guide (Architecture Institute of Korea 2008). The waterproofing system mostly used for roof of RC building in USA, JAPAN, and South Korea is asphalt, synthetic polymer based sheet, improved asphalt, and liquid applied membrane waterproofing system. Therefore, these four waterproofing systems were selected as representative conventional systems (C1, C2, C3, and C4). Additionally, two more combinational waterproofing system [polymer film coated metal sheet with rubberized asphalt sheet (N1) and cement added liquid applied membrane with polyester non-woven fabric reinforced asphalt sheet (N2)] frequently used in South Korea were investigated to compare the results with the conventional systems. Waterproofing systems of C1, C3, and C4 used exposed method for finishing material while that of C2, N1, and N2 did non-exposed method. Waterproofing system considered in this work and their components are summarized in Tables 1 and 2, respectively.

Table 1 Roof waterproofing system for RC building

	Conventional waterproofing system				Combinational waterproofing system	
	C1	C2	C3	C4	N1	N2
Type	Asphalt	Synthetic polymer-based sheet	Improved Asphalt	Liquid applied membrane	Polymer film coated metal sheet with rubberized asphalt sheet	Cement added liquid applied membrane with polyester non-woven fabric reinforced asphalt sheet
Finishing materials	Exposed	Unexposed	Exposed	Exposed	Unexposed	Unexposed

Table 2 Components for each waterproofing system

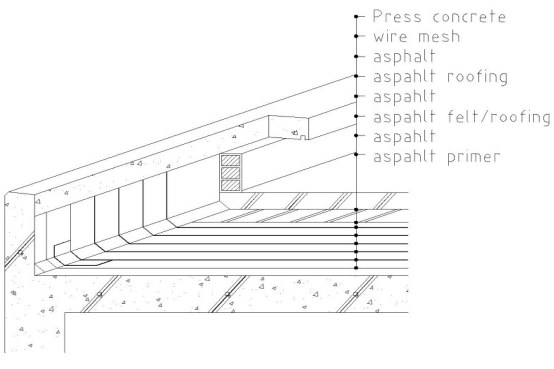
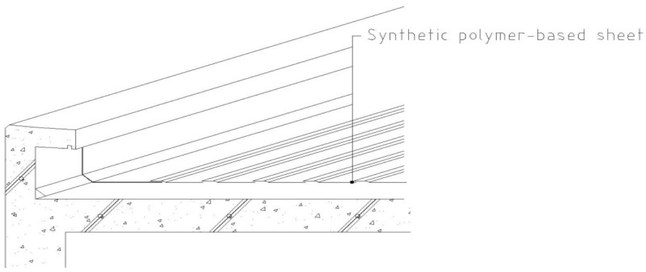
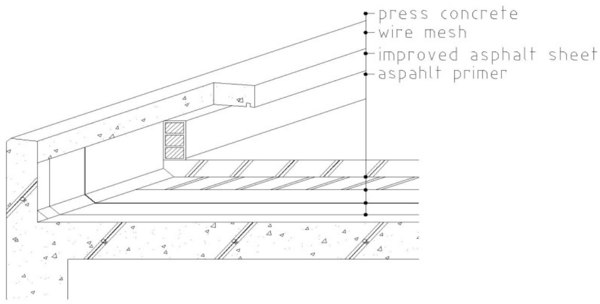
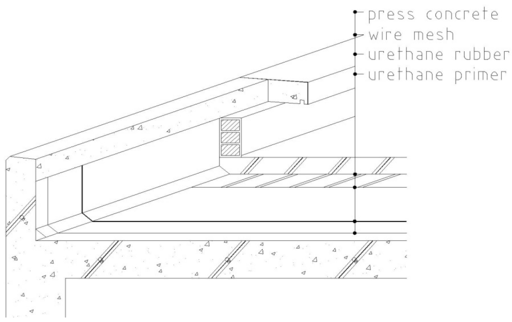
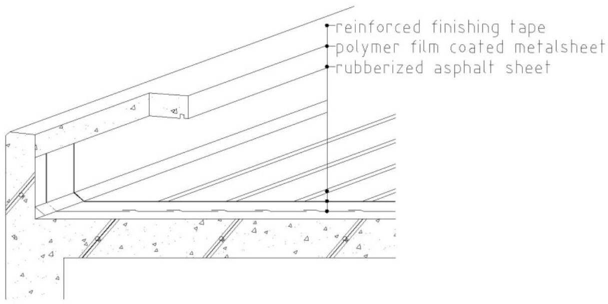
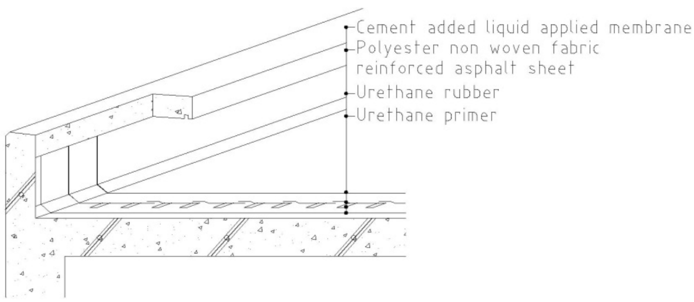
	Components	Section drawing
C1	Asphalt primer, Asphalt, Asphalt roofing, Asphalt felt, Wire mesh, Press concrete, Silicone, Concrete block, Concrete mortar, Diesel	
C2	Synthetic polymer-based sheet, metal sheet, fastener, washer, non-woven fabric, sealing, drain, L-Bar, PVC coil	

Table 2 Continued

	Components	Section drawing
C3	Asphalt primer, Improved asphalt sheet, Butane gas, Wire mesh, Press concrete, Silicone, Concrete block, Concrete mortar, Diesel	
C4	Urethane primer, Urethane rubber, Wire mesh, Press concrete, Silicone, Concrete block, Concrete mortar, Diesel	
N1	Rubberized asphalt sheet, Polymer film coated metal sheet, reinforced finishing tape, Silicone, Anchor, Fixed disk	
N2	Urethane primer, Urethane rubber, Polyester non-woven fabric reinforced asphalt sheet, Cement added liquid applied membrane, Steel holder, Silicone	

2.2 LCA modeling

LCA modeling was carried out using the commercial software, Simapro v. 7.0 based on ISO 14040 method (ISO 2006). Environmental impacts with different waterproofing system were estimated by the CML2001 method (CML 2002). Life cycle inventory (LCI) data used for modeling were obtained from Eco-invent database. Realistic data for each waterproofing system were collected from specifications and minimum unit of materials were assembled for LCI to acquire precise results for LCA modeling. LCA framework is composed of four stages: (1) Definition of goal and scope; (2) LCI analysis; (3) life cycle impact assessment; and (4) life cycle interpretation. Functional unit, system boundary, and quality criteria for inventory data is established on the first stage. Input and output data of all the material and energy during entire life cycle processes are listed at the second stage. Afterwards, environmental impact of buildings, materials, and construction method on global warming can be investigated with different impact factor. Finally, a key environmental factor highly affecting global warming can be analyzed based on assessment results.

2.2.1 Functional unit

Roof of an architectural model representing a typical single family home for four family members was demonstrated in Fig. 1. Therefore, functional unit was set to be 100 m^2 roof because living space per one person is 25 m^2. The width, length, and height of architectural model were 10 m, 10 m, and 3.75 m, respectively. The thickness of the wall was 200 mm and the height of roof parapet was assumed to be 450 mm. For non-exposed waterproofing method, the height of inner

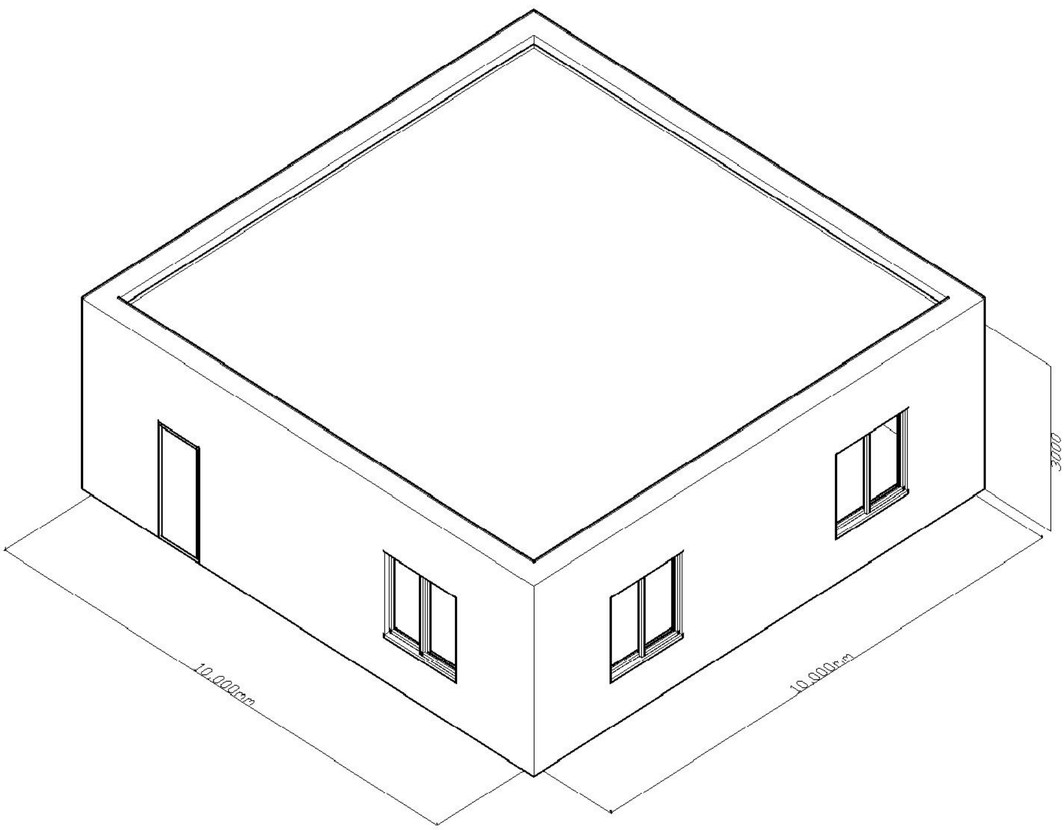
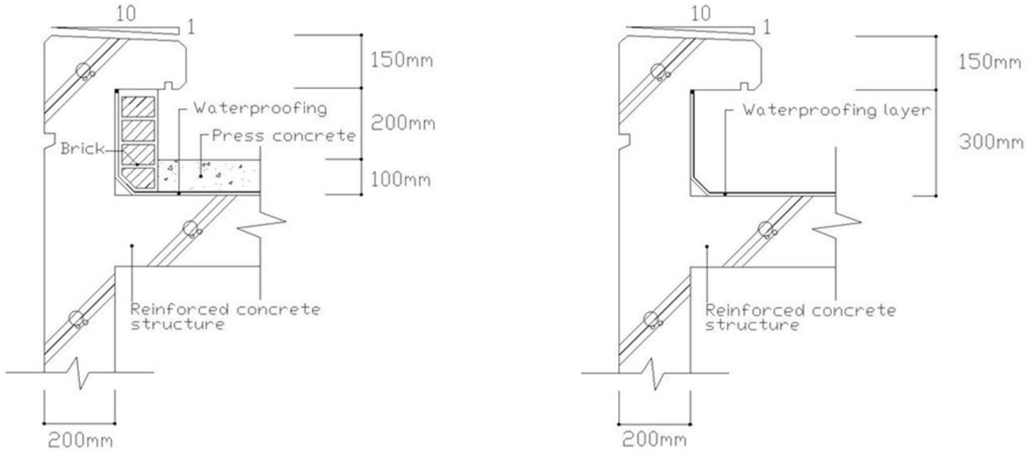


Fig. 1 Roof of the architectural model



(a) (b)

Fig. 2 System boundary to estimate total GHG emission from each waterproofing system: (a) non-exposed waterproofing method; (b) exposed waterproofing method

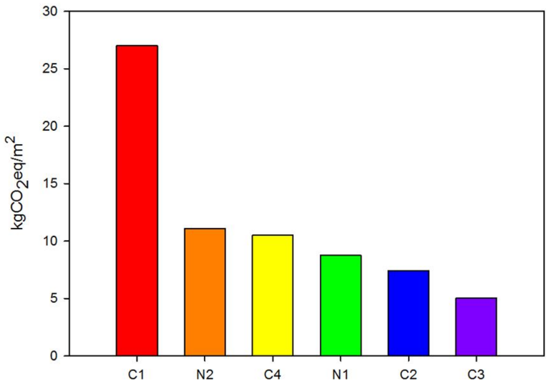
wall from roof slab was set to be 300 mm with press concrete of 100 mm and ornamental cap of 150 mm. In case of exposed waterproofing method, the same architectural section model used for non-exposed one was applied. Drainage hole (75 mm for 100 mm/hr rainfall) is necessary for roof larger than 200 m^2, however, it was not considered in this study due to negligible hole area compared to 100 m^2 roof.

2.2.2 System boundary and life span

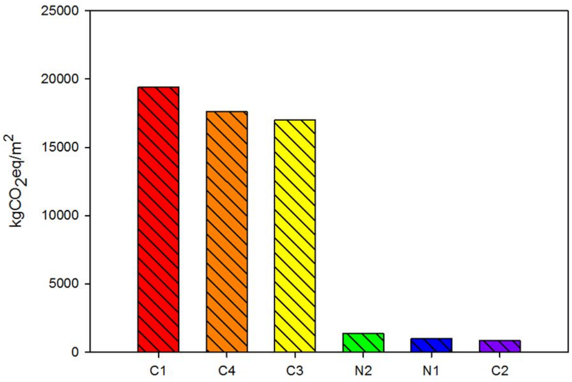
System boundary to estimate total GHG emission from each waterproofing system is illustrated in Fig. 2. Three phases of waterproofing system (construction-maintenance-disposal) were considered for the estimation of GHG emission while acquisition of raw material and transportation were excluded in this study. Materials and energy required for construction machine were included for the construction phase. All materials, fuels, waste treatment required during the life cycle of building were considered for the maintenance phase. Finally, fuels used for building destruction and waste treatment were taken into account for the disposal phase. Life span expectancy of RC, masonry, and steel-frame building is usually 30-50 years. Life span expectancy of RC building was set to be 50 years in this work because previous relevant LCA studies typically used the same value (Hoff 2011).

3. Results and discussion

The amounts of GHG emissions from six different waterproofing systems were in the order of C1 (27.0 $kgCO_2eq/m^2$), N2 (11.1$kgCO_2eq/m^2$), C4 (10.5$kgCO_2eq/m^2$), N1 (8.77$kgCO_2eq/m^2$), C2 (7.39 $kgCO_2eq/m^2$), and C3 (5.04 $kgCO_2eq/m^2$) when only construction materials for waterproofing system was considered as an environmental load, i.e., subsidiary material and energy was excluded from system boundary (Fig. 3(a)). However, GHG emissions from construction phase were totally different when waterproofing system was applied to the actual architectural model by



(a)



(b)

Fig. 3 GHG emission from construction phase of waterproofing system: (a) previous method; (b) present method

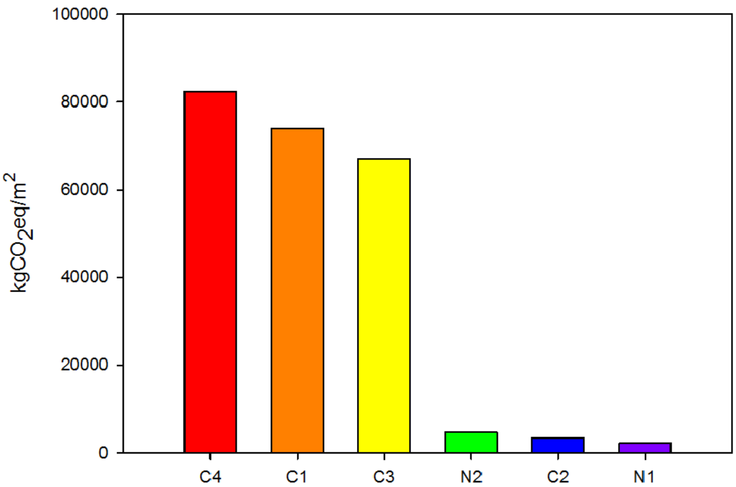


Fig. 4 GHG emission from maintenance phase of waterproofing system

considering the factors previously ignored (e.g., barrier and press concrete) (Fig. 3(b)). The highest amount of GHG was generated from C1 (19,400$kgCO_2eq/m^2$) and followed by C4 (17,600 $kgCO_2eq/m^2$), C3 (17,000 $kgCO_2eq/m^2$), N2 (1,360 $kgCO_2eq/m^2$), N1 (980 $kgCO_2eq/m^2$) and C2 (833 $kgCO_2eq/m^2$). This suggests that configuration of input and output data within proper system boundary is essential to obtain precise LCA simulation results.

GHG emission from maintenance phase with actual architectural model is represented in Fig. 4. Most of GHG emissions was emitted from C4 (82,400 $kgCO_2eq/m^2$) and followed by C1 (73,800 $kgCO_2eq/m^2$), C3 (67,200 $kgCO_2eq/m^2$), N2 (4,700 $kgCO_2eq/m^2$), C2 (3,340 $kgCO_2eq/m^2$), and N1 (2,340 $kgCO_2eq/m^2$). Total GHG emission from entire life cycle of waterproofing system (construction-maintenance-disposal) is illustrated in Fig. 5. It was the C4 (110,000 $kgCO_2eq/m^2$) that generates the most significant amount of GHG emissions during entire life cycle and C1 (103,000 $kgCO_2eq/m^2$), C3 (94,000 $kgCO_2eq/m^2$), N2 (6,270 $kgCO_2eq/m^2$), N1 (4,270 $kgCO_2eq/m^2$),

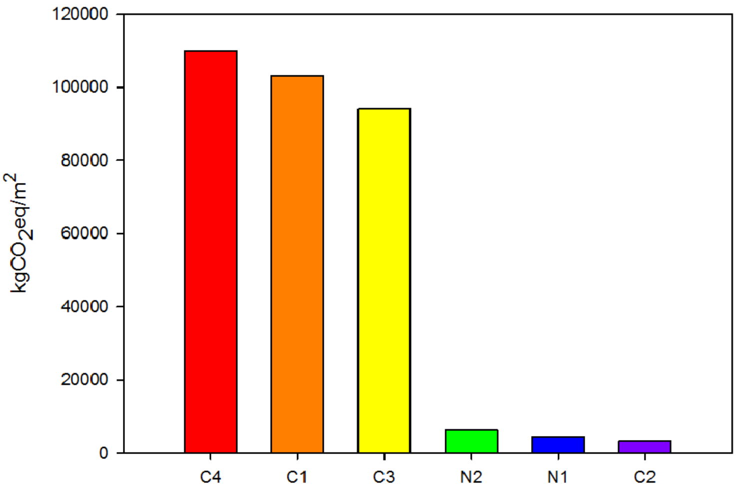


Fig. 5 Total GHG emission from entire life cycle of waterproofing system

and C2 (3,460 $kgCO_2eq/m^2$) was followed. Consequently, N1 and C2 produced relatively less GHG emission for the roof of RC building than other waterproofing system.

The percentage contribution of each phase on total GHG emission is demonstrated in Table 3. Among the phases, it was the maintenance that significantly influence on total GHG emissions for

Table 3 The percentage contribution of each phase on total GHG emission

Waterproofing system type	Phase	Disposal ($kgCO_2eq$)	Construction ($kgCO_2eq$)	Total ($kgCO_2eq$)	Percentage (%)
C1	Construction		1.94E + 04	1.94E + 04	18.8
	Maintenance	2.53E + 04	4.85E + 04	7.38E + 04	71.4
	Disposal	1.01E + 04		1.01E + 04	9.8
	Total	3.54E + 04	6.79E + 04	1.03E + 05	100
C2	Construction		8.67E + 02	8.67E + 02	20.3
	Maintenance	2.20E + 02	3.12E + 03	3.34E + 03	78.3
	Disposal	6.12E + 01		6.12E + 01	1.4
	Total	2.82E + 02	3.99E + 03	4.27E + 03	100
C3	Construction		1.70E + 04	1.70E + 04	18.1
	Maintenance	2.47E + 04	4.25E + 04	6.72E + 04	71.4
	Disposal	9.87E + 03		9.87E + 03	10.5
	Total	3.45E + 04	5.95E + 04	9.40E + 04	100
C4	Construction		1.76E + 04	1.76E + 04	16
	Maintenance	2.96E + 04	5.28E + 04	8.24E + 04	75
	Disposal	9.86E + 03		9.86E + 03	9
	Total	3.94E + 04	7.04E + 04	1.10E + 05	100

Table 3 Continued

Waterproofing system type	Phase	Disposal ($kgCO_2eq$)	Construction ($kgCO_2eq$)	Total ($kgCO_2eq$)	Percentage (%)
N1	Construction		9.80E + 02	9.80E + 02	28.3
	Maintenance	3.01E + 02	2.04E + 03	2.34E + 03	67.5
	Disposal	1.47E + 02		1.47E + 02	4.2
	Total	4.48E + 02	3.02E + 03	3.46E + 03	100
N2	Construction		1.36E + 03	1.36E + 03	21.7
	Maintenance	6.24E + 02	4.08E + 03	4.70E + 03	75
	Disposal	2.08E + 02		2.08E + 02	3.3
	Total	8.32E + 02	5.44E + 03	6.27E + 03	100

waterproofing system (minimum 67.5% for N1 and maximum 78.3% for C2). This indicates that maintenance phase is the most important for environmental load and considerable amounts of GHG emission can be reduced by selecting waterproofing system having longer duration. In previous studies, GHG emissions have been estimated by assuming that main component of each waterproofing system can represent entire components. Additionally, the usage of fuel for construction equipment and demands of subsidiary materials and ingredients during the construction have been ignored for LCA modeling. For example, Lee (2010) reported that the amount of GHG emission from C4 is higher than C1 and C2 during construction phase (Lee 2010). This is because all of waterproofing systems were assumed as exposed system. However, C2 is constructed by unexposed system for easy maintenance while C1 and C4 are constructed by exposed system for protection of waterproof layer. This indicates that previous works have neglected standard specifications of waterproofing system for LCA modeling as well as overlooked use of proper data due to the lack of information for material composition. In this study, however, limitations previously mentioned were overcome by: (1) adopting standard specifications for waterproofing system; (2) considering factors previously missed; and (3) collecting suitable database (minimum units of material components). Therefore, the results obtained from this work can provide more accurate data of GHG emission from various conventional and combinational waterproofing system. Moreover, the method used to estimate GHG emission from entire life cycle of waterproofing system can be applied to other system with same procedures. Appropriate decision-making would be suggested for the selection of waterproofing system if we both consider economic and environmental factors based on comprehensive understanding of building characteristics with specifications.

4. Conclusions

In this study, we estimated total GHG emissions from representative waterproofing system (four conventional and two combinational) for the roof of RC building by using LCA approach. LCA modeling was implemented with specific data for each waterproofing system, which is obtained from manufacturers and licensed patents. All of LCI data for the components and ingredients of waterproofing system were analyzed by the smallest unit. In addition, detailed factors for waterproofing system (fuel consumption for construction machine, subsidiary material and energy demand for the system) were considered for the estimation of GHG emission within system boundary. The results of GHG emission from waterproofing system would be helpful for building owners, building designers, and contractors to make a right decision. This is because it can provide significant information on environmental impact of waterproofing system throughout the entire life cycle process. By comparing both economic and environmental factors, the best option for sustainable waterproofing system could be recommended. Additionally, the method introduced in this work could be applied to other waterproofing system and further to different construction units and sectors. For future work, massive data for repair cycle and ratio are recommended to obtain more precise estimation results.

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