International Conference on Applied Energy 2020
Dec. 1 - Dec. 10, 2020, Bangkok / Virtual
Paper ID: 084

IMPACT OF RECYCLED MATERIAL ON BUILDING ENERGY REDUCTION AND CLEAN ENERGY TRANSITION: A CASE STUDY OF RESIDENTIAL BUILDINGS

Minjin Kong [1], Changyoon Ji [2], Hyuna Kang [3], and Taehoon Hong [4*]

1 Graduate Research Assistant, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, Republic of Korea

2 Ph. D. and Researcher, Green Building Research Institute, Korea Appraisal Board, Seoul, Republic of Korea

3 Graduate Research Assistant and Ph.D. Student, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, Republic of Korea

4 Professor, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, Republic of Korea
*Correspondence: hong7@yonsei.ac.kr

ABSTRACT

This paper aims to analyze the impact of recycled materials on energy reduction and clean energy transition of buildings. The life cycle energy of building using virgin materials is compared with that of building using recycled materials, and the energy savings due to recycled materials is calculated. Also, the impact of recycled materials on clean energy transition is verified by calculating the module area of the photovoltaic panel achieving the same amount of energy savings. As results of a case study, replacing virgin to recycled materials reduced 10% of life cycle energy. It means that the use of recycled materials can reduce 10% of module area of PV system for achieving clean energy transition. Recycled materials should be considered for fundamental energy reduction and effective clean energy transition.

Keywords: recycled material, life cycle assessment, life cycle energy, clean energy transition

NOMENCLATURE

Abbreviations	
LCA	Life Cycle Assessment
LCE	Life Cycle Energy
PV	Photovoltaic
RC	Reinforced Concrete
S	Steel
SRC	Steel-Reinforced Concrete

1. INTRODUCTION

Additional insulation materials and renewable energy systems to reduce the operation energy of the building may increase embodied energy of the building. Therefore, recent studies suggested that life cycle energy (LCE) of the building, which can be calculated by life cycle assessment (LCA) method, should be considered for the substantial energy reduction and clean energy transition of buildings [1,2]. That is, building materials with less embodied energy may be the fundamental solution for LCE reduction and clean energy transition [3,4]. Previous studies mentioned that recycling plays critical role in embodied energy reduction [4,5]. Using recycled materials instead of virgin materials as building materials may reduce LCE of building, resulting in less need for renewable energy systems to achieve the clean energy transition of buildings.

To analyze the impact of recycled materials, a case study is conducted for a residential building. First, LCE for case buildings using recycled materials, as well as that using virgin materials, was calculated by LCA. Then, PV module area for clean energy transition is calculated for case buildings using virgin or recycled materials. Finally, LCE and PV module area of each case are compared.

2. MATERIALS AND METHODS

The case study is composed of three steps: (i) Step 1: Calculating life cycle energy of case buildings; (ii) Step 2: Calculating PV module area for clean energy transition of case buildings; and (iii) Step 3: Comparing calculated results of case buildings.

2.1 Step 1: Calculating life cycle energy of building

According to the process-based life cycle energy assessment method defined by Chau et al. [6], LCE of a building is divided into four major phases, which are initial embodied energy, recurring embodied energy, operation energy and demolition energy (Eq. (1)). The energy of each phase is calculated by following Eqs. (2-5), suggested by Kong et al. [1]. First, the initial embodied energy of a building includes energies from building material production, transportation, and construction (Eq. (2)). Second, the recurring embodied energy of a building indicates the energies required for repair and rehabilitation during the maintenance period. Thus, the recurring embodied energy is calculated by multiplying initial embodied energy by maintenance repair and rehabilitation rate (Eq. (3)). Third, the operation energy of the building is calculated by multiplying the lifetime of a building by annual operation energy (Eq. (4)). Fourth, the demolition energy of a building includes not only the deconstruction energy of a building but also transportation, intermediate treatment, and landfill energy of waste materials (Eq. (5)).

$$LCE_B = IEE_B + REE_B + OE_B + DE_B \quad (1)$$

$$IEE_B = \sum [Q_b \times (EE_b + tE_b + cE_b)] \quad (2)$$

$$REE_B = \sum [Q_b \times R_b \times (EE_b + tE_b + cE_b)] \quad (3)$$

$$OE_B = aOE_B \times L_B \quad (4)$$

$$DE_B = dE_B + \sum [Q_w \times (tE_w + wE_w)] \quad (5)$$

Here, LCE_B refers to life cycle energy of the building, IEE_B refers to the initial embodied energy of a building, REE_B refers to the recurring embodied energy of the building, OE_B refers to operation energy of a building, DE_B refers to demolition energy of a building, Q_b refers to quantity of building material, EE_b refers to the embodied energy of building materials, tE_b refers to the transportation energy of building materials from plant to site, and cE_b refers to construction/installation energy of building materials, R_b refers to maintenance repair and rehabilitation rate of building material, aOE_B refers to annual operation energy of a building, and L_B refers to lifetime of a building, Q_w refers to the quantity of waste materials, tE_w refers to the transportation energy of waste materials, and wE_w refers to the intermediate treatment/landfill energy of waste materials.

The process of producing recycled materials is different from that of virgin materials. Thus, the system boundary for calculating embodied energies of virgin and recycled materials should be considered differently.

Saghafi and Hosseini [5] have defined factors that should be considered for calculating embodied energies of virgin and recycled materials. Referring to the previous study, this study also defines the system boundary for the embodied energy of both virgin and recycled materials. A virgin material starts from raw material extraction to final processing (Eq. (6)). On the other hand, for recycled materials, the process of transporting and recycling recyclable materials, which are produced from deconstructed buildings, should be additionally considered (Eq. (7)).

$$EE_{b(v)} = xE_{b(v)} + tE_{b(v)} + pE_{b(v)} \quad (6)$$

$$EE_{b(r)} = xE_{b(r)} + tE_{b(r)} + rE_{b(r)} + pE_{b(r)} \quad (7)$$

Here, $EE_{b(v)}$ refers to the embodied energy of virgin material, $xE_{b(v)}$ refers to extraction energy of raw material, $tE_{b(v)}$ refers to transportation energy of raw material, $pE_{b(v)}$ refers to production energy of virgin material, $EE_{b(r)}$ refers to the embodied energy of recycled material, $xE_{b(r)}$ refers to raw material extraction energy, $tE_{b(r)}$ refers to the transportation energy of recyclable material and raw material, $rE_{b(r)}$ refers to recycling energy of recyclable material, and $pE_{b(r)}$ refers to production energy of recycled material.

2.2 Step 2: Calculating module area of PV system for clean energy transition

Carbon emission can be reduced by replacing fossil fuel-based energy with clean, renewable energy. This is known as clean energy transition and replacement ratio is known as transition ratio. In South Korea, government stipulated a mandatory transition ratio for the clean energy transition of the building energy consumption. Renewable energy system such as PV system must be installed in the building in order to generate enough renewable energy to achieve mandatory transition ratio [1]. Since LCE of building using recycled materials is different from that of building using virgin materials, renewable energy required for clean energy transition may differ. Based on the mandatory transition ratio and specifications of PV system, PV module area for the building is calculated using Eq. (8) [1].

$$MA_{PV} = \frac{TR \times LCE_B}{[L_B - (TR \times EPBT_{PV})] \times gE_{PV}} \quad (8)$$

Here, MA_{PV} refers to module area of PV system, TR refers to mandatory transition ratio, L_B refers to lifetime of a building, $EPBT_{PV}$ refers to the integrated energy payback time of PV system during the lifetime of a building, and gE_{PV} refers to energy generation of PV system.

2.3 Step 3: Comparing calculated results

Impact of replacing building material from virgin material to recycled material can be analyzed by comparing LCE of building using recycled materials and LCE of building using virgin material. Module area of PV system required for mandatory transition ratio of building will be proposed as absolute value.

3. CASE STUDY

To verify the impact of the recycled materials, a case study was conducted. This study selected a residential building, which is designed as three structure types (i.e., reinforced concrete (RC), steel reinforced concrete (SRC), and steel (S)), as a case building. For three cases, the LCE and PV module area for clean energy transition are calculated by using Eqs. (1)-(8).

3.1 Calculating life cycle energy of case buildings

Quantities of building materials for the case buildings are necessary to calculate the LCE of the buildings. This study considered a standard residential building, rather than an actual building. As shown in Table 1, the national preliminary calculation standard defines the quantity of materials required per unit floor area when constructing three types of residential buildings [6]. Thus, this study used the quantity of building materials by structure type presented in Table 1.

Table 1 Quantity of building materials for residential buildings

Building material	Quantity (Q_b) (unit/m^2)			unit	kg/unit
	RC	SRC	S		
Concrete	0.550	0.450	0.250	m^3	2300
Formwork	4.800	3.800	1.300	m^2	12.54
Steel rebar	0.057	0.053	0.021	ton	1000
Steel section	0	0.040	0.055	ton	1000
Plate glass	0.450			m^2	12.25
Aluminum sash	1.000			number	9.153
Glass wool panel	4.680			m^2	2.400
Plastic sheet	4.215			m^2	2.840
Polybutylene pipe	0.301			kg	1.000

Building materials in Table 1 could be as either virgin materials or recycled materials. That is, LCE of case building using recycled materials is calculated based on the assumption that the recycled material is used for building materials instead of virgin material. In South Korea, Good Recycled product (GR) certification is implemented and it defines standard distribution ratio between raw and recyclable materials for certification [7], as shown in Table 2. Therefore, amount of recyclable materials for the recycled material was calculated based on the distribution ratio in Table 2.

Table 2 Distribution ratio of recycled materials

Building material	Distribution ratio (%)	Recyclable material
Concrete	50	Recycled aggregate
Formwork	60	Recycled plastic
Steel rebar	30	Steel scrap
Steel section	30	Steel scrap
Plate glass	50	Recycled cullet
Aluminum sash	80	Aluminum scrap
Glass wool panel	50	Recycled cullet
Plastic sheet	60	Recycled plastic
Polybutylene pipe	60	Recycled plastic

Next, the embodied energy of virgin and recycled materials was calculated based on the national life cycle inventory database, using Eqs (6)-(7) [8]. To calculate the energies for transportation, construction and installation, the fuel efficiency of transportation equipment, transportation distance, and equipment efficiency are required. This study calculated the energies for transportation, construction and installation of building materials by applying the quantity of materials to model of Tae et al. [9]. Maintenance repair and rehabilitation rate of building materials refers to Kong et al. [1]. Korea government provides annual statistics showing the energy consumption of residential building [10]. This study assumed the average energy consumption (114.2 kWh/yr·m^2) in the statistics as the annual energy consumption of case buildings. Also, lifetime of case buildings was assumed as 40 years [11]. Finally, the deconstruction energy of building and transportation, intermediate treatment and landfill energies of waste materials are calculated by applying the quantity of materials to model presented by Cha et al. [12].

3.2 Calculating module area of PV system

South Korea government has set the national goal of clean energy transition as 30% mandatory transition ratio for the dissemination and proliferation of renewable energy systems [1]. PV system in the research includes PV panel, balance of system and power converter. EPBT of PV system, with expected lifetime of 25 years, was calculated based on input material data to produce 1m^2 module area of PV system [14]. Energy generation of the PV system was calculated using RETScreen [14] (Table 3).

Table 3 Information of PV system

Module	TR (%)	$EPBT_{PV}$ (yr)	gE_{PV} (kWh/m^2·yr)
sC-Si	30	10.78	218.6

4. RESULTS AND DISCUSSION

Table 4 shows LCE (kWh) of three case building. Replacing virgin materials to recycled materials decreased initial embodied and recurring embodied energies for minimum 67.9% and maximum 62.0%.

Neither operation energy nor demolition energy has been changed by replacing virgin materials with recycled materials since the same operation energy is used, and quantities of waste materials were regardless of building material replacement. LCE are decreased to minimum 87.2% and maximum 86.1%. As embodied energy of recycled concrete is higher than virgin concrete, RC-building with the highest concrete quantity showed the lowest LCE reduction of 12.8% compared to S-building of 13.9% reduction.

Table 4 LCE result of residential building (kWh)

Structure		IEE_B	REE_B	OE_B	DE_B	LCE_B	(%)
RC	Virgin	1960	1119	4568	49.01	7695	100
	Recycled	1566	525.6		49.01	6708	87.2
SRC	Virgin	1992	1119		41.85	7720	100
	Recycled	1559	525.6		41.85	6694	86.7
S	Virgin	1522	1119		24.70	7233	100
	Recycled	1112	525.6		24.70	6230	86.1

Using Eq. (8), module area (m^2) for the unit floor area of three major structure types are calculated as Table 5. S-building using recycled materials showed the lowest module area of $0.267m^2$ compared to $0.330m^2$ of SRC-building using virgin materials.

Table 5 Module are of PV system (m^2)

Structure		MA_{PV}
RC	Virgin	0.329
	Recycled	0.287
SRC	Virgin	0.330
	Recycled	0.286
S	Virgin	0.310
	Recycled	0.267

Using recycled materials instead of virgin materials can reduce LCE of building for approximately 10%. Therefore, less renewable energy systems are required to satisfy the national clean energy transition goal. Considering cost of renewable energy systems, these results prove that using recycled materials has economic and environmental contributions.

5. CONCLUSIONS

Using recycled material in the construction industry has been shown to be essential for substantial building energy reduction and clean energy transition. Therefore, recycling should be considered for a national policy perspective. However, the impact of solid waste and resource depletion are neglected in the study. If considered, the necessity of recycling will be more emphasized.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT; Ministry of Science and ICT) (NRF-2018R1A2A1A19020868).

REFERENCE

[1] Kong M, Hong T, Ji C, Kang H, Lee M. Development of building driven-energy payback time for energy transition of building with renewable energy systems. Appl Energy 2020;271:115162.

[2] Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy Build 2010.

[3] Chastas P, Theodosiou T, Bikas D. Embodied energy in residential buildings-towards the nearly zero energy building: A literature review. Build Environ 2016.

[4] Thormark C. A low energy building in a life cycle - Its embodied energy, energy need for operation and recycling potential. Build Environ 2002.

[5] Saghafi MD, Hosseini Teshnizi ZS. Recycling value of building materials in building assessment systems. Energy Build 2011.

[6] Chau CK, Leung TM, Ng WY. A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. Appl Energy 2015.

[7] Resources circulation Industry Promotion Association. Good Recycled Products Information System 2020.

[8] Korea National Cleaner Production Center. National LCI DataBase n.d. (accessed February 3, 2020).

[9] Tae S, Shin S, Woo J, Roh S. The development of apartment house life cycle CO2 simple assessment system using standard apartment houses of South Korea. Renew Sustain Energy Rev 2011.

[10] Ministry of Land, Infrastructure and Transport Statistics System. Energy consumption of residential building 2018.

[11] Ministry of Strategy and Finance. Enforcement Decree of the Corporate Tax Act. South Korea: Ministry of Strategy and Finance; 2019.

[12] Cha GW, Hong WH, Kim JH. A study on CO2 emissions in end-of-life phase of residential buildings in Korea: Demolition, transportation and disposal of building materials. Key Eng. Mater., 2017.

[13] Ministry of Trade Industry and Energy. Energy calorie conversion standard n.d.

[14] Hong T, Lee M, Koo C, Jeong K, Kim J. Development of a method for calculating the rooftop solar photovoltaic (PV) potential by analyzing the available rooftop area using Hillshade analysis. Appl Energy 2017.