Comparative Analysis of Greenhouse Gas Emissions Between a Timber-Framed House Based on Korea's Standard Design and a Concrete House with a Converted Structure

Yeonjung Han, Myungsun Yang, and Min-Ji Kim, *

Expanding the concept of medium-to large-scale timber buildings to public buildings and securing data on the environmental benefits of timber construction are necessary for its recognition as a green building. This study aimed to compare the greenhouse gas emissions over the entire life cycle of a timber-framed house based on a standard Korean design and a concrete house designed by converting a timber-framed house. Timber structures reduced greenhouse gas emissions relative to concrete structures, and this effect became more pronounced as the building size increased. Although the largest environmental impact over a building's entire life cycle occurred during the use phase, a significant difference based on the structure was found in the material production phase. The wood structure was found to emit approximately 43 to 50% less greenhouse gas than the concrete structure during the material production phase. The difference in total emissions was the highest in the largest-scale model, at 52.6 tCO_2, showing the greatest effect when a concrete house was replaced with a wooden house. These results can be attributed to the low embodied carbon content of wood and its ability to store carbon ranging from 21 to 34 tCO_2, which delays greenhouse gas emissions.

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*Contact information: Forest Products and Industry Department, National Institute of Forest Science, Seoul 02455, Republic of Korea, *Corresponding author: kimmj9708@korea.kr*

INTRODUCTION

The construction sector accounts for approximately 34% of global energy consumption (UNEP 2022) and has a significant impact on the environment; therefore, efforts are being made to reduce the environmental impact over the life cycle of buildings to achieve carbon neutrality and prevent an increase in the global average temperature. To this end, life cycle assessment (LCA), which quantifies the environmental impact of a building's entire life cycle, has been used as a major analytical method. Early studies on building LCA focused on methods to reduce operational carbon, and results aimed at reducing environmental impact during the use phase have been published (Fay *et al.* 2000; Verbeeck and Hens 2007; Ortiz *et al.* 2009; Passer *et al.* 2012), but after technologies that can mitigate the environmental impact of the use phase, such as zero-energy buildings, were commercialized, the focus shifted to the embodied carbon of buildings (Alwan and Jones 2014; Akbarnezhad and Xiao 2017). This can be interpreted as a need to reduce embodied carbon because even in zero-energy buildings that minimize the environmental

impact during the use phase, the impact of the production and construction phases still accounts for more than 50% of the total (Hafner and Winter 2012).

Wood is a representative building material with low embodied carbon and is attracting attention as a building material for carbon neutrality. Not only are the unique characteristics of wood (easy to process, excellent specific strength, excellent thermal insulation, renewable material, *etc*.) suitable as a building material, but it also stores carbon in its body. Therefore, the more wood is used, the more carbon is stored in the wood, which delays emissions for the duration of its use (Geng *et al.* 2017). The amount of greenhouse gases generated in the production of wood products is less than that of other materials; therefore, from a life cycle perspective, using wood is environmentally advantageous.

Timber construction is a method of using large quantities of wood products with a long lifespan, and many countries consider timber construction to be one of the main policy tools for achieving carbon neutrality (Tupenaite *et al.* 2023). In Japan, the "Wood First Act" was enacted in 2010 to make timber construction of low-rise public buildings mandatory, and in 2021, the existing law was revised to expand the scope to general buildings to promote the expansion of timber construction. In the U.S. Wood Innovation Act, Canada Wood First Act, and New Zealand Wood First Policy and Action Plan, the use of wood in projects or public buildings receiving financial support is mandatory. These policies mandate or encourage the direct use of wood through financial support. Additionally, in New Zealand, France, and Finland, the building industry environment is being restructured to increase the use of materials with low embodied carbon, such as wood, by limiting allowable carbon emissions from buildings.

Korea's land is 67% forested, and many forest resources have reached the wood production stage after the greening project in the 1970s; therefore, it is necessary to expand the use of wood. It is also necessary to continuously expand wood production and use wood in stages to achieve the national 2030 NDC goal. The expansion of wood use requires the expansion of timber construction; however, thus far, the demand for timber construction in Korea is not high, with small houses and buildings still accounting for the majority. Compared with the overseas timber construction market, which is gradually growing from a focus on small buildings to large and high-rise buildings, the Korean timber construction market is in the early stages of demand expansion. Therefore, it is necessary to establish a legal foundation to expand the concept of medium-to large-scale timber buildings, which is still an unfamiliar concept, to public buildings and to secure data on the environmental benefits of timber construction for its recognition as a green building.

To support institutional and market expansion, the environmental advantages of timber construction need to be substantiated quantitatively through life-cycle-based greenhouse gas emission assessments, rather than relying solely on qualitative evaluations. Especially for application in public buildings, robust LCA data reflecting domestic construction practices and material characteristics are essential, as they provide a critical foundation for green building certification frameworks and policy formulation. Nevertheless, comprehensive LCA case studies and databases focusing on timber buildings in Korea are still limited.

Accordingly, the aim of this study was to assess the potential contribution of timber construction to carbon neutrality in Korea by calculating and comparing the greenhouse gas emissions of timber residential buildings and conventionally constructed reinforced concrete (RC) residential buildings.

EXPERIMENTAL

Case Study Building

A total of eight residential buildings were selected as the subjects. First, four types of standard timber houses provided by the Korea Forest Service (KFS)— Farm-25, Farm-41, Rural return-25, and Rural return-32—were selected as the timber building cases. The KFS provides these standard timber house designs to reduce the cost and time required for housing design, promote the use of domestically produced timber through standardized model development, and supply comfortable and safe timber houses (Table 1).

Table 1. Basic Information on the Four Types of Standard Timber-Framed House Designs

Type	Farm-25	Farm-41	Rural return-25	Rural return-32
Area (Attic)	84.24 m^2 (17.95 m^2)	136.08 m^2 (17.95 m^2)	81 m^2 (20.87 m^2)	108 m^2 (20.87 m^2)
Wood usage	26 m^3	41 m^3	26 m^3	30 m^3
Carbon storage	21 tCO_2	34 tCO_2	21 tCO_2	25 tCO_2
Construction cost	192 million KRW	299 million KRW	202 million KRW	274 million KRW

Farm-25





Farm-41





Rural return-25





Rural return-32



Fig. 1. Bird's eye view and interior layouts of Korea Forest Service standard timber-framed house designs by Type

The standard timber houses are classified as Farm type and Rural return type. The Farm type is designed to accommodate rural lifestyles, while the Rural return type is intended for individuals returning to rural areas. Each housing type is further categorized by floor area, and the structural system consists of a combination of post-and-beam (heavy timber) construction and light-frame timber construction (Fig. 1).

These timber houses employ structural members with cross-sectional dimensions in 30 mm increments (*e.g.*, 120 mm, 150 mm, and 180 mm), in accordance with domestic timber production standards. For columns, primary structural members with cross-sectional dimensions of 150 mm × 150 mm were used to ensure structural stability and to expose the internal timber structure through 2 × 6 (140 mm thick) wall assemblies. Similarly, the main beams and columns were designed with 150 mm × 150 mm cross sections, while larger members (≥150 mm) were applied in locations requiring additional structural reinforcement.

For comparative analysis, four RC residential buildings were additionally designed by converting each of the four timber house types into RC structures while maintaining identical interior layouts, spatial configurations, and functional programs. As a result, four timber house types and four corresponding RC house types were analyzed in a one-to-one comparison to evaluate differences in greenhouse gas emissions.

Life Cycle Assessment

LCA was performed based on ISO 14040 and ISO 14044 standards (ISO 2006), quantifying environmental impacts throughout the full life cycle from raw material extraction to disposal.

Goal and scope

The goal of this study was to evaluate and compare the environmental impacts of wooden and concrete houses. Wooden houses were selected from the 84~147m^2 designs included in the standard design drawings, and concrete houses of the same function and size were designed. It was assumed that all materials, except for the main structural parts, such as insulation, exterior materials, and windows, were the same, and only the structural parts were compared and analyzed.

System boundary

The scope of this LCA was cradle-to-grave, and its entire life cycle was largely divided into material production, transportation, construction, operation, and disposal stages. Because wooden and concrete houses were designed to serve the same function, LCA was performed for each building, and the environmental benefits were evaluated

based on the differences in the results. The analysis tool used for the evaluation was a simplified LCA tool developed by Chang *et al.* (2017) for evaluating greenhouse gas emissions from construction. This tool was developed to improve the accessibility of LCA by addressing the limitations of existing commercial tools not specialized for forestry and building analysis. As the tool includes the data required for wooden building analysis, it was used in this study. To ensure the accuracy of the results, the statistical data underlying the stage-specific assumptions used in the analysis tool of Chang *et al.* (2017) were updated using the most recent available statistics and subsequently verified (Table 2).

Table 2. Assumptions and Limitations for Each Life Cycle Stage

Life Cycle Stage		Assumptions and Limitations
Production		If a conversion factor for a representative product's unit weight is unavailable, the unit weight is used.
Construction	Transportation	All material transport is assumed to be by 15-ton trucks over a 30 km domestic land route.
	Construction	Energy input is based on the '2022 Construction Standard Price'.
Operation	Use	Applies 'Total energy consumption by household floor area' from the 'Korea Energy Economics Institute'.
	Maintenance	'Detailed Standards for Long-Term Repair Plan' from the 'Enforcement Rules of the Multi-Family Housing Management Act' are applied, considering repair timing, number, cost, and replacement.
Disposal	Demolition	Assumes crushers, breakers, and excavators for concrete, and LPG cutters for steel frames.
	Transportation	Same as the construction stage, 15-ton trucks over 30 km on domestic land.
	Disposal	Assumes materials are recycled, incinerated, or landfilled, with the ratio calculated based on the type and amount of construction waste.

Life-cycle inventory and impact assessment

The data used in this study included the materials used in the structural parts of the building. The main structural parts were calculated by quantifying the amounts of wood products, ready-mixed concrete, and rebar used in the foundation, slab, wall, and beam. The LCI DB for inputs and outputs used the Ecosystem Information List (http://ecosq.or.kr) and the Korean national LCI DB. The environmental impact assessment was characterized only by greenhouse gas emissions (GWP) among all environmental impact categories. In the evaluation, the stages of production, construction, operation, and disposal were applied based on the standard price, except for the operation stage, and validity was secured using domestic statistical data, such as energy statistics, for the operation stage. However, because there is no separate standard for the life of a building, the life of a reinforced concrete building was set as the standard life of 40 years, according to the standards presented in the Corporate Tax Act Enforcement Regulations.

Sensitivity analysis

To address uncertainty associated with building service life and to evaluate the robustness of the LCA results, a sensitivity analysis was conducted by varying the assumed building service life. All other parameters, including system boundaries, functional units, and inventory data, were kept constant. The building service life was set to 30, 40, and 50

years, reflecting plausible service-life scenarios commonly considered in building LCA studies. Life-cycle environmental impacts were recalculated for each service-life scenario and compared to assess the influence of service life assumptions on the results.

RESULTS AND DISCUSSION

To compare the greenhouse gas emissions of timber-framed and concrete buildings, the concrete building was designed by converting a standard Korea Forest Service timber-framed house design. The biggest difference that emerged from changing to a concrete structure while maintaining the function and size of the timber structure was the wall thickness (Appendices 1 and 2). While a timber structure improves the energy efficiency by placing insulation between structural members, a concrete structure requires insulation to be placed either inside or outside the structural frame. This can result in a smaller clear interior dimension or a larger overall volume. Therefore, to maintain a similar function and size without significantly changing the windows, the clear interior dimensions of the concrete structure were reduced by 63 mm, and the roof was raised to make the interior space as similar as possible. Consequently, the reinforced concrete (RC) building became slightly taller and its roof area increased. For the rural-return type with an attic, the roof height was also raised for the same reason, which resulted in a concrete structure being 0.15 m taller than the wood structure.

The material quantities of the main structural parts of the two final designs, including materials used for foundation construction, are summarized in Table 3. The timber-framed house required significantly less rebar and concrete used exclusively for the foundation construction than the concrete house. For consistency, the quantities of concrete and rebar used for foundation construction were also included in the concrete house. Even after accounting for the volume of wood used by the structural members, the total quantity of materials needed for the wood structure was substantially lower. This difference highlights the efficiency of timber as a building material in terms of overall material volume.

Table 3. Quantities of Building Materials Input into Timber-Framed and Reinforced Concrete (RC) Houses

Type	Area	Timber-framed House				RC House	
		Rebar (ton)	Concrete (m^3)	Wood (m^3)	OSB (m^3)	Rebar (ton)	Concrete (m^3)
Farm-25	84.24 m^2	5.2	49.0	21.3	4.1	9.1	136.0
Farm-41	136.08 m^2	8.1	84.0	33.9	6.4	15.4	220.0
Rural return-25	81.00 m^2	4.8	46.0	21.5	3.9	8.6	114.0
Rural return-32	108.00 m^2	6.2	58.0	25.1	4.6	11.5	148.0

Figure 2 illustrates the greenhouse gas emission results for both wood-framed and concrete structures. For wood-framed structures, the type of Farm-25 emitted 185.0 tCO_2 and the Farm-41 emitted 230.2 tCO_2. Similarly, the Rural return -25 emitted 183.4 tCO_2, which is comparable to the farmhouse type, whereas Rural return -32 emitted 203.3 tCO_2. When converted to emissions per unit area, the area type of 25 emitted 2.2 to 2.26 tCO_2, the area type 32 emitted 1.88 tCO_2, and the area type 41 emitted 1.69 tCO_2. This demonstrates a clear trend in which the greenhouse gas emissions per unit area decrease as

the scale of the building increases. For concrete structures, the Farm-25 and Farm-41 emitted 218.8 tCO_2 and 282.9 tCO_2, respectively. In the rural return types, the area type 25 emitted 208.2 tCO_2 and the area type 32 emitted 237.1 tCO_2.The trend in greenhouse gas emissions per unit area for concrete buildings decreased as the building size increased, with area types 25 to 41 showing a progression from 2.57 tCO_2 (~ 2.6 tCO_2) to 2.20 tCO_2 and 2.08 tCO_2, respectively. In summary, while both structural types showed a reduction in emissions per unit area with increasing scale, wood structures consistently maintained lower emission levels than their concrete counterparts. However, the difference in total emissions was the highest in farm-41 type, showing a reduction of 52.6 tCO_2. This indicates that replacing a concrete house with a wood-framed house had the most significant effect in this model.

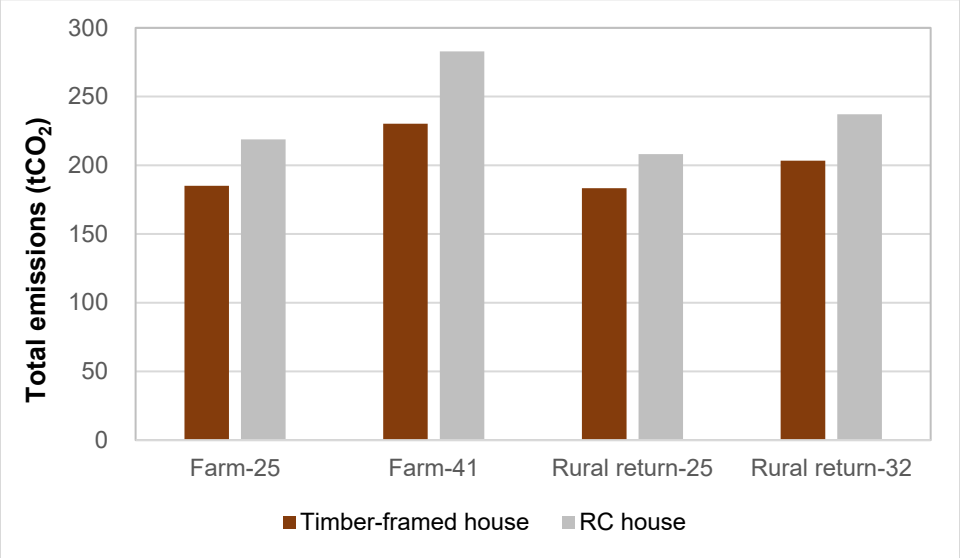


Fig. 2. Global warming potential assessment results of timber-framed and concrete (RC) houses

Analyzing greenhouse gas emissions across the entire life cycle of a building revealed that the highest impact came from the use, material production, and disposal stages (Fig. 3). The use stage, which has the most significant impact, utilized energy consumption statistics based on the building scale; therefore, its influence was not dependent on the building's structural components. Thus, the most meaningful stage in this study was the material production stage because it directly reflected the difference between the two structural types. It is well known that timber products require less energy than rebar or concrete. A comparison of greenhouse gas emissions during the production stage of both structures showed that wood structures emitted approximately 43 to 50% less greenhouse gas than concrete structures. This finding underscores the environmental efficiency of using timber as a building material.

The sensitivity analysis showed that variations in assumed building service life resulted in systematic changes in absolute life-cycle emission values across all building types (Fig. 4.). When compared to the baseline scenario of 40 years, reducing the service life to 30 years led to a decrease in total emissions of approximately 20%, whereas extending the service life to 50 years resulted in an increase of approximately 20%. Despite these changes in magnitude, the relative comparison between building systems remained consistent across all service-life scenarios, indicating that the main conclusions of the study are robust with respect to uncertainties in building service life.

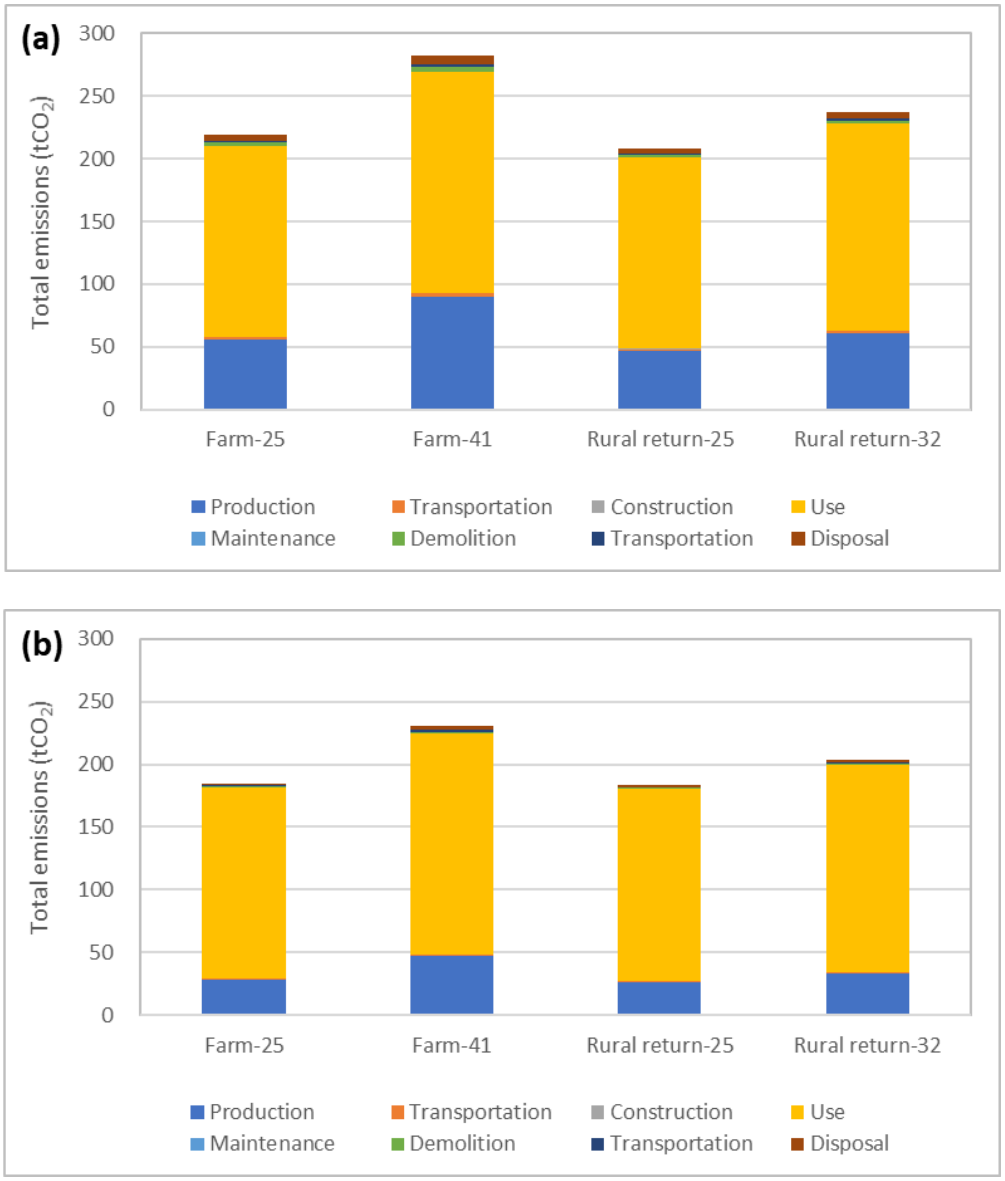


Fig. 3. Contribution of each life cycle stage to greenhouse gas emissions: (a) Concrete house, (b) Timber-framed house

The results of this study are consistent with those of many previously reported studies (Andersen *et al.* 2022; Hegeir *et al.* 2022), which found that timber construction has a lower environmental impact than concrete construction. Andersen *et al*. (2022) conducted an LCA of mid-rise apartment buildings using concrete and cross-laminated timber (CLT) as structural materials. The results indicated that the CLT building received a lower impact score in 11 of the 18 impact categories, including global warming. The climatic advantages of CLT buildings, specifically their impact on global warming, were highlighted, emphasizing the importance of considering timber as a building material. This study also confirmed that operational energy had the greatest impact, followed by the embodied impact of the materials. Chen *et al*. (2022) reported that large-scale timber buildings have a lower impact on global warming than concrete buildings. They suggested considering the transportation distance of raw materials because longer distances can add

to the environmental burden and diminish the advantages of using timber. They recommended that regulations and policies encourage the use of locally sourced timber. Similarly, Mofolasayo (2022) reported that timber construction had a lower environmental impact in 9 of 10 impact categories and suggested that although wood is an eco-friendly material, it is necessary to consider the difference in LCA results owing to improvements in the environmental footprint of concrete and technological developments.

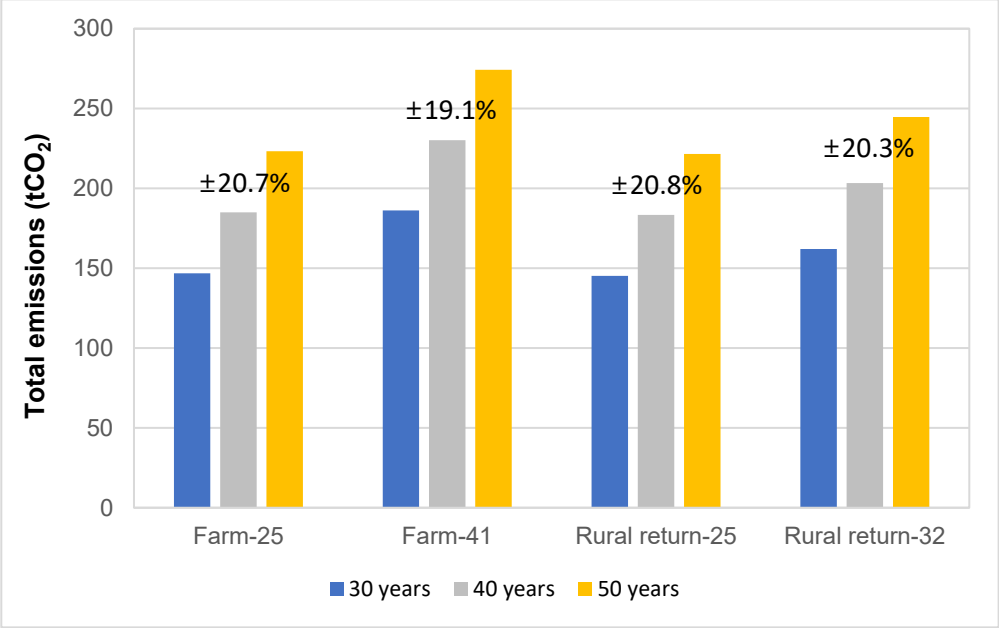


Fig. 4. Sensitivity of life-cycle emissions to building service life, shown as percentage change relative to the 40-year baseline scenario

It has been argued that using timber is advantageous for creating climate-friendly cities to achieve the common global goal of carbon neutrality (Lan *et al.* 2025; Yayla *et al.* 2025). This is not only because timber construction, as the result of this study, has lower greenhouse gas emissions than concrete construction, but also because timber inherently stores carbon. While this study evaluated only the difference in emissions throughout a building's entire life cycle, excluding the carbon stored within the timber, it is important to note that, as presented in Table 1, the amount of timber used in construction stores ranges from 21 to 34 tCO_2. This means that even if the timber slowly decomposes over the lifespan of the building, carbon remains stored until the building is dismantled and disposed of, thereby significantly delaying emissions.

With recent efforts to establish regulations on greenhouse gas emissions from buildings, it is becoming crucial to develop national baselines for environmental impacts through a comprehensive life cycle assessment. To achieve this, it is necessary to accumulate baseline data by conducting impact assessments of buildings at various scales. In particular, for timber construction, a methodology must be developed to incorporate the carbon storage capacity of the timber into the life cycle assessment, fully reflecting the eco-friendly characteristics of the material.

The results of this study should be interpreted in light of several limitations. The analysis was based on standardized housing designs to minimize assumptions and ensure consistency in the comparative LCA; however, this approach may not fully represent the

variability of actual constructed buildings. In addition, the study considered a limited range of building sizes, which constrains the generalization of the observed emission trends across different construction scales. Future research should therefore extend the analysis to real residential buildings and a broader range of building sizes to better capture material-specific emission patterns and improve the applicability of the results.

CONCLUSIONS

1. The results of this study showed that timber construction had a significant effect on reducing greenhouse gas (GHG) emissions compared to concrete construction. Specifically, in the material production stage, timber structures were found to emit approximately 43 to 50% less greenhouse gas than concrete structures.
2. The GHG reduction effect of wooden construction became more apparent as the scale of the buildings increased. The difference in total emissions was the highest in the largest-scale model, reaching 52.6 tCO_2, indicating that replacing a concrete building with a timber building can achieve the greatest GHG reduction effect.
3. Timber construction not only had lower emissions but the timber itself also had the ability to store carbon. Depending on the amount of timber used in the study, 21 to 34 tCO_2 of carbon was found to have a significant effect on delaying greenhouse gas emissions over the lifespan of timber buildings. Therefore, it is imperative to develop a methodology for life cycle assessment that reflects the carbon storage capacity of timber.

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APPENDIX

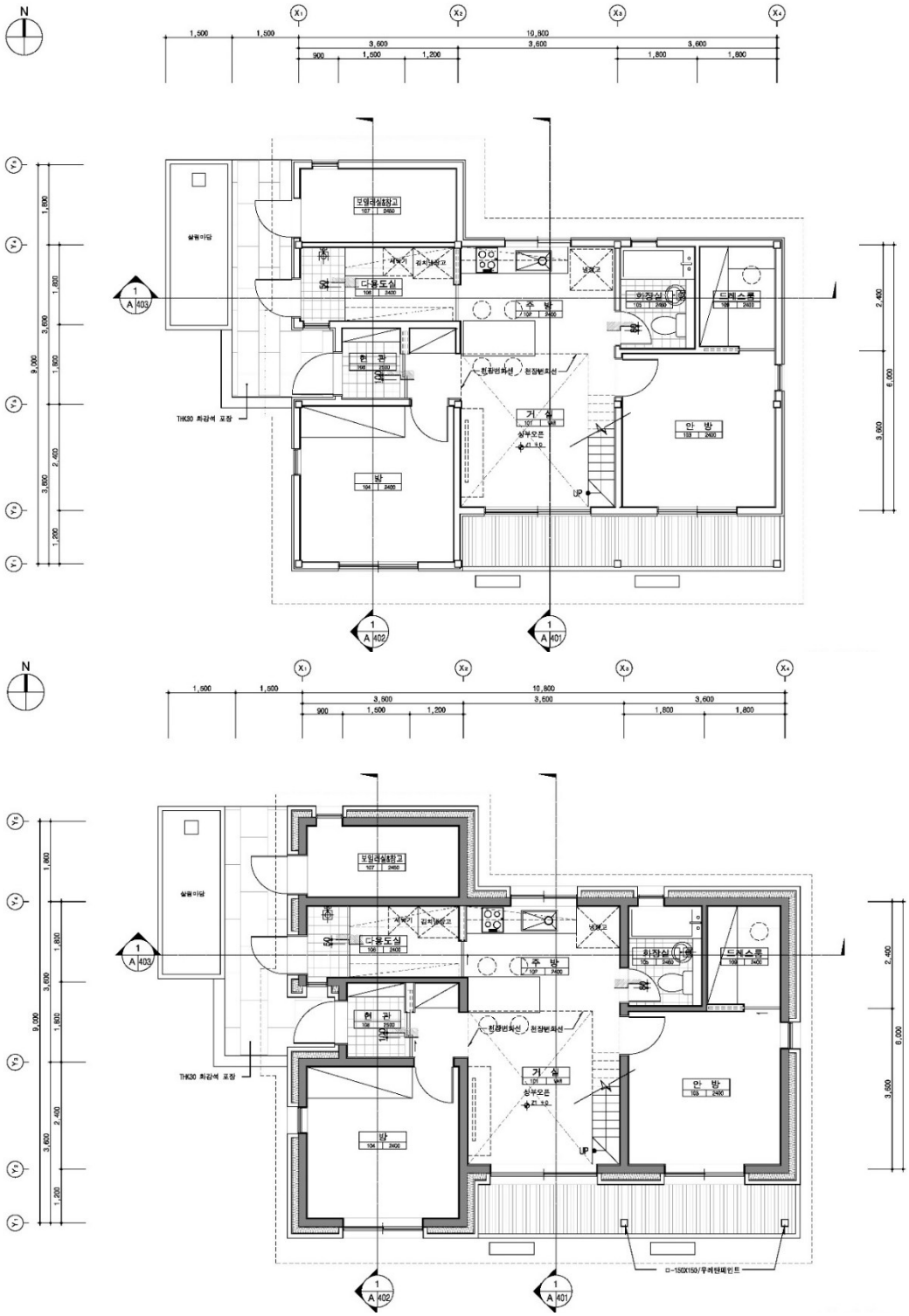


Fig. A1. Floor plans for the Farm-25 timber-framed house (top) and concrete house (bottom)

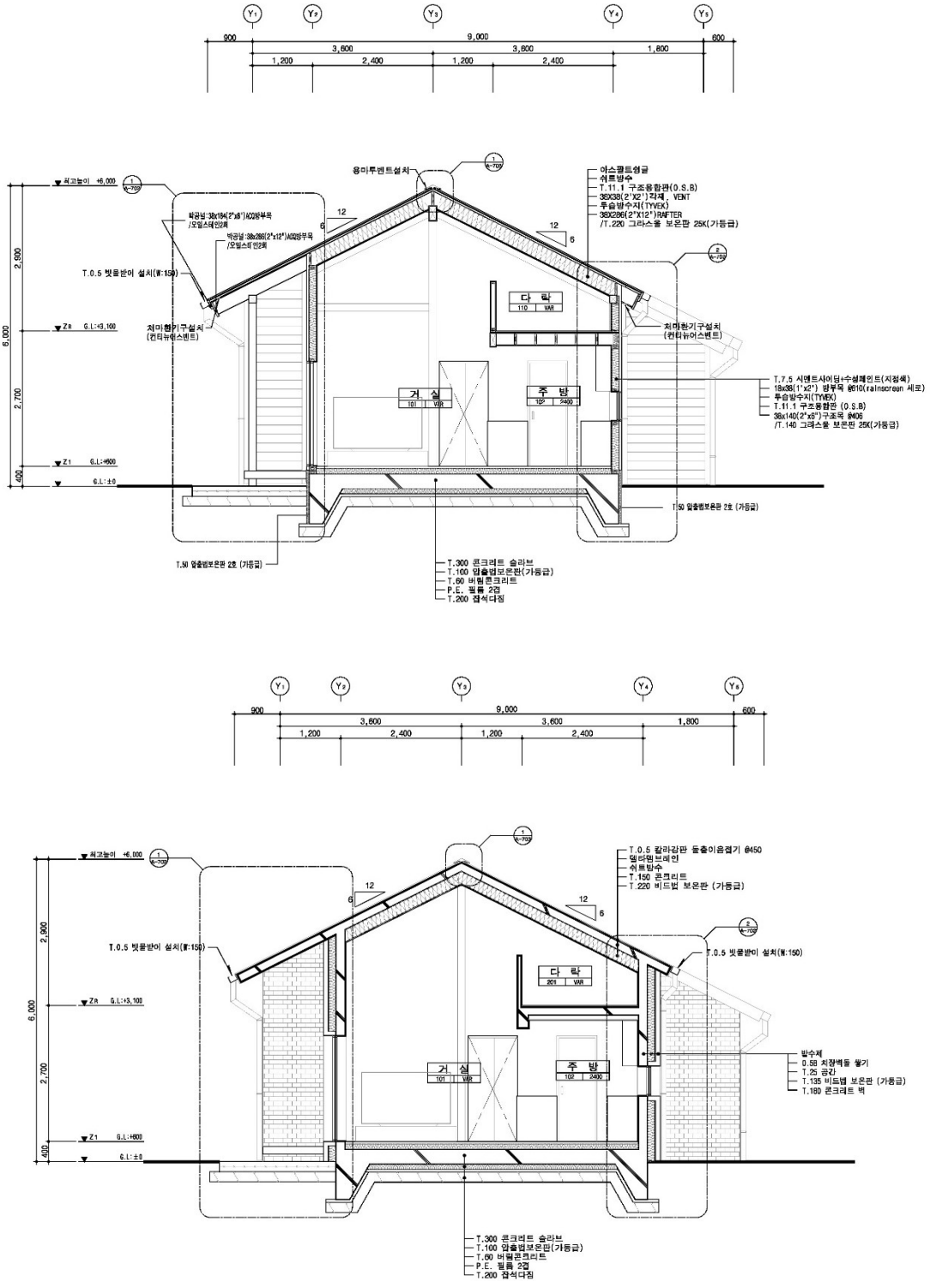


Fig. A2. Cross-sections of timber-framed house (top) and concrete house (bottom) of farm-25