Evaluation of energy savings and carbon emission reduction through the replacement of apartment building walls with CLT

In-Hwan LEE[1*], *Beom Yeol* YUN[1], *Sang Joon* LEE[1], *Chul-Ki* KIM[1], *Hyung Woo* LEE[1]

[1]Wood Engineering Division, National Institute of Forest Science

Abstract. In recent years, growing emphasis on sustainable buildings has led to increasing interest in timber housing. Timber houses are recognized as an energy-efficient building type due to their carbon reduction potential and excellent thermal insulation performance; however, achieving Zero Energy Building (ZEB) certification requires addressing various technical and institutional challenges. This study analyzes the key requirements for timber houses to obtain ZEB certification and proposes strategies for energy reduction and the integration of renewable energy systems to meet these requirements. First, domestic and international ZEB certification systems are comparatively reviewed to derive evaluation criteria suitable for timber housing. Subsequently, the applicability of passive design elements—such as high-performance insulation, enhanced airtightness, and optimized window placement—and active technologies, including photovoltaic systems, geothermal systems, and energy management systems, is examined. In addition, case studies are analyzed to assess practical feasibility, and optimal approaches for achieving ZEB certification are suggested by considering economic viability and environmental benefits. The results indicate that an optimal combination of energy-saving technologies tailored to the structural characteristics of timber housing, together with the efficient application of renewable energy systems, is a critical factor in achieving ZEB certification. This study is expected to contribute to the wider adoption of environmentally friendly timber housing and the advancement of sustainable building technologies.

Keywords. Timber housing, Zero Energy Building (ZEB), Sustainable building design, Energy efficiency, Passive and active building systems.

1. Introduction

In response to accelerating climate change, the Korean government has announced a national roadmap targeting carbon neutrality by 2050, along with an interim goal of reducing greenhouse gas emissions by 40% relative to 2018 levels by 2030.[1] Within this policy framework, the building sector has been identified as a major contributor to national emissions, prompting the mandatory adoption of Zero Energy Building (ZEB) certification for public buildings and its gradual expansion to private residential developments. Conventional reinforced concrete construction, which dominates the Korean housing market, is associated with high energy consumption and significant embodied carbon emissions during material production and construction.

Timber construction has emerged as a promising alternative due to its renewable nature, high strength-to-weight ratio, and inherent carbon fixation effect. Wood products store carbon dioxide absorbed during tree growth, effectively functioning as long-term carbon sinks when used in buildings. Previous studies have shown that reinforced concrete emits approximately 635 kg-CO_2e per cubic meter, whereas timber products can store up to 500 kg-CO_2e.[2] Despite these advantages, the application of timber systems in multi-family and high-rise residential buildings remains limited, primarily due to concerns regarding structural performance, fire safety, and compliance with stringent energy certification requirements. Accordingly, systematic research integrating energy performance evaluation and carbon reduction analysis for timber-based ZEBs is required.

2. Overview of zero energy building (ZEB) certification criteria

Under the revised Korean ZEB certification system effective from January 1, 2025, building performance is evaluated based on two primary indicators: (1) the energy self-sufficiency rate and (2) the annual primary energy consumption per unit floor area. For residential buildings, ZEB Grade 5 requires either an energy self-sufficiency rate of 20% or more or a primary energy consumption

* Corresponding author: ih1990@korea.kr

 https://doi.org/10.1051/e3sconf/202671602043

below 90 kWh/m²·y, while ZEB Grade 4 requires primary energy consumption below 70 kWh/m²·y. Higher certification levels, including ZEB Grade 1, demand near-complete energy independence, with primary energy consumption below 10 kWh/m²·y.[5]

Achieving these performance targets necessitates a holistic design approach combining passive design strategies—such as high-performance insulation, airtight building envelopes, and optimized window-to-wall ratios—with active systems including high-efficiency HVAC equipment, building energy management systems (BEMS), and renewable energy technologies. Timber-based construction offers intrinsic advantages for passive energy performance due to the low thermal conductivity and high thermal resistance of wood-based assemblies.[7]

3. Methodology

This study investigates the impact of substituting conventional reinforced concrete external wall systems with Cross-Laminated Timber (CLT) assemblies in a high-rise residential building. CLT was selected due to its structural robustness, dimensional stability, and suitability for mid- to high-rise applications.[3]

3.1 Simulation Model and Assumptions

Energy performance was evaluated using DesignBuilder, a dynamic simulation tool based on the EnergyPlus engine.[4] The reference building model represents a 20-story residential apartment with a typical floor area of 229.37 m² per story(Fig. 1). The building orientation was set to southeast, reflecting common residential layouts in Korea. Operational conditions were defined with a heating setpoint of 20°C and a cooling setpoint of 26°C, and an air change rate of 1.5 ACH was applied to account for ventilation and infiltration(Table 1).

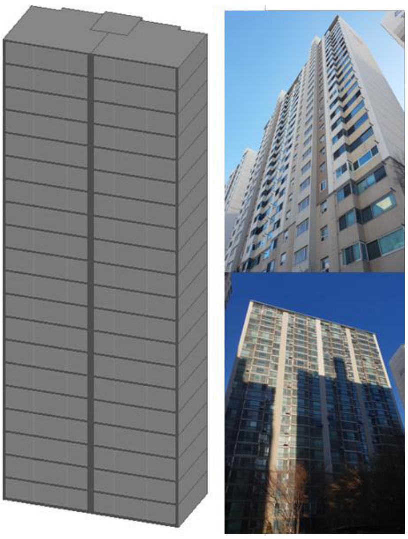

Fig. 1. A 20-story apartment building with a reference model featuring a net floor area of 229.37 m² per floor.

Table 1. Residential apartment building model

Building type	Apartment	
Floor area (m²)	229.37	
Number of floors	20	
Air change rate	1.5	
Azimuth	Southeast	
Window	20 mm multilayer glass	
Heating equipment	Gas boiler / Gas	
Air-conditioning	System air conditioner / Electric	
Setpoint temperature	Heating (°C)	20
	Set back (°C)	18
	Cooling (°C)	26
	Set back (°C)	28

3.2 Material Scenarios

Scenarios Two material scenarios were compared: (1) a baseline reinforced concrete structure and (2) a CLT-integrated structure in which the external wall system was replaced with CLT panels while maintaining equivalent structural performance. Thermal properties of the wall assemblies were defined based on material data from the literature and manufacturer specifications(Fig. 2).

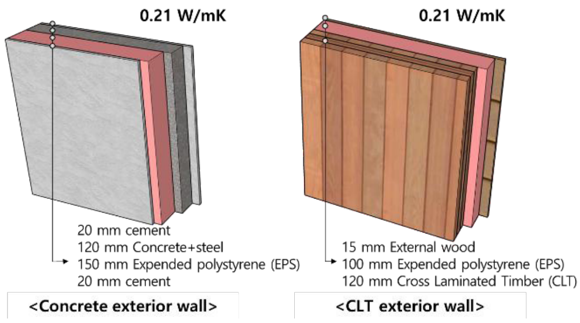

Fig. 2. Wall assemblies of the target building and detailed specifications of each wall assembly

3.3 Embodied Carbon Assessment

An embodied carbon assessment was conducted to quantify the environmental benefits of material substitution. Carbon emissions associated with material production were calculated in terms of kg-CO_2e, focusing on the external wall systems where material replacement effects are most pronounced.

4. Results and discussion

4.1 Analysis of Heating and Cooling Energy Demand in CLT Buildings

Analysis Results of Building Heating Energy Demand
– The analysis shows that the apartment with concrete exterior walls requires 168,776.47 kWh, while the

apartment with CLT exterior walls requires 163,113.86 kWh.

– By replacing the concrete exterior walls with CLT exterior walls, the building heating energy demand was reduced by approximately 3.35%(Fig. 3).

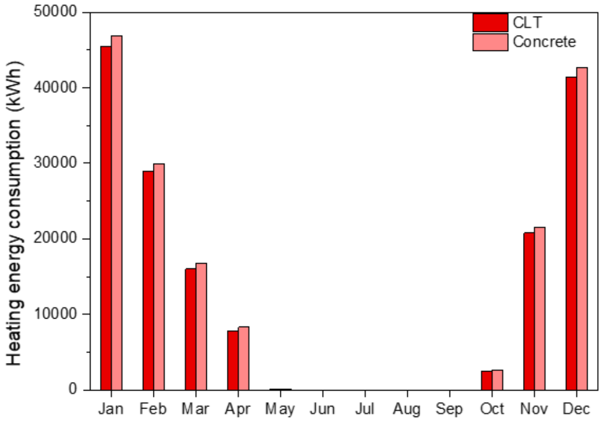

Fig. 3. Analysis Results of Building Heating Energy Demand

Analysis Results of Building Cooling Energy Demand

– The analysis shows that the apartment with concrete exterior walls requires 93,445.81 kWh, while the apartment with CLT exterior walls requires 92,119.53 kWh.

– By replacing the concrete exterior walls with CLT exterior walls, the building cooling energy demand was reduced by approximately 1.41%(Fig. 4).

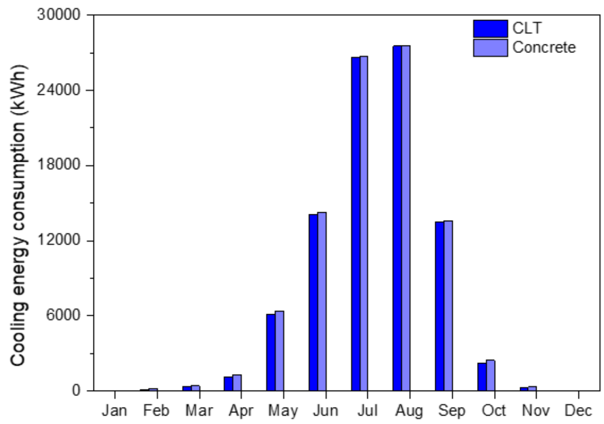

Fig. 4. Analysis Results of Building Cooling Energy Demand

Analysis Results of Building Heating and Cooling Energy Demand

– The combined heating and cooling energy demand of the apartment with concrete exterior walls is 262,222.28 kWh, whereas that of the apartment with CLT exterior walls is 255,233.39 kWh.

– By replacing the concrete exterior walls with CLT exterior walls, the total building heating and cooling energy demand was reduced by approximately 2.66%(Fig. 5).

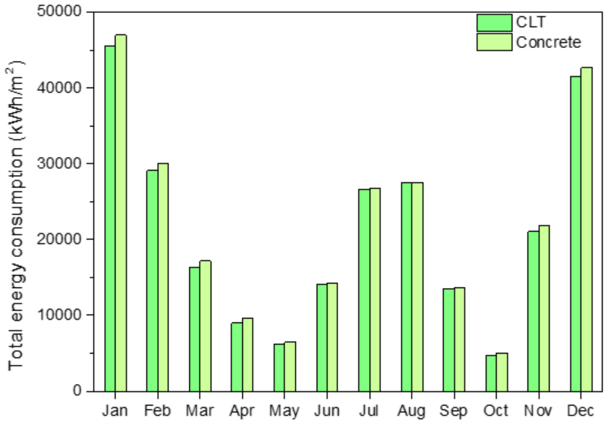

Fig. 5. Analysis Results of Building Heating and Cooling Energy Demand

4.2 Energy Performance Analysis

Simulation results indicate that the CLT-integrated building achieved a primary energy consumption of 55.63 kWh/m^2·y, compared to 57.16 kWh/m^2·y for the reinforced concrete baseline. Although the absolute difference in operational energy consumption is modest, the CLT model clearly satisfies the requirements for ZEB Level 4 certification. The improved thermal performance of CLT wall assemblies contributes to reduced heating demand, particularly during winter operation.[6]

4.3 Carbon Reduction and Environmental Impact

The embodied carbon analysis reveals substantial environmental benefits from material substitution. When the reinforced concrete used in the exterior walls was replaced with CLT, the embodied carbon emissions of the material itself decreased from 253,732 kg-CO_2e to 3,879.2 kg-CO_2e, corresponding to a reduction of approximately 98.5%(Table 2,3). Replacing reinforced concrete in exposed external walls with CLT reduced embodied carbon emissions from 291,106.9 kg-CO_2e to 67,662.4 kg-CO_2e, corresponding to a reduction of 76.8%(Table 4,5).[8] In addition, the reduced material mass of CLT systems lowers transportation-related emissions and construction-stage environmental loads. These results underscore the importance of considering embodied carbon alongside operational energy performance when evaluating ZEB strategies.

Table 2. CO_2-equivalent emissions of concrete (exterior wall) materials

	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)	Mass (kg)
Cement/plaster/mortar – concrete	**4,975.3**	**253,724**	**253,724**	**1,335,389.5**
[1]_XPS Extruded Polystyrene - CO2 Blowing	1,007.7	11,640.4	38,720.3	4,041.8
Cement/plaster/mortar - gypsum plasterboard - 0.16 W/mK	5,982.9	11,487.2	12,444.5	95,726.8
Cement/plaster/mortar - cement plaster	5,982.9	40,013.8	40,013.8	210,599.1
EPS 50 mm	6,192.4	18,577.2	24,224.7	7,430.9
Painted Oak	5,85.3	0	0	14,340.7
Gypsum Plasterboard	9,475.4	25,583.7	27,715.6	213,197.2
Urea Formaldehyde Foam	6,192.4	19,223.2	20,735.1	10,799.6
XPS Extruded Polystyrene - CO2 Blowing	6,192.4	127,772.6	425,021.3	44,365.5
EPS Expanded Polystyrene (Standard)	4,975.3	27,985.8	36,493.5	11,194.3
Cast Concrete	12,384.8	107,004.7	107,004.7	1,337,559.3
Cast Concrete (Lightweight)	6,192.4	59,447.1	59,447.1	743,088.5
Fibreboard	6,192.4	12,316.7	12,799.7	24,150.4
Asphalt 1	6,192.4	12,353.9	12,353.9	247,076.9
Total		727,130.2	1070,698	4,298,960.5

Table 3. CO_2-equivalent emissions of CLT materials

	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)	Mass (kg)
Cross Laminated Timber (CLT)	**4,975.3**	**3,879.2**	**3,879.2**	**387,921.1**
[1]_XPS Extruded Polystyrene - CO2 Blowing	1,007.7	11,640.4	38,720.3	4,041.8
Cement/plaster/mortar - gypsum plasterboard - 0.16 W/mK	1,007.7	1,934.7	2,096	16,122.8
Cement/plaster/mortar - cement plaster	1,007.7	6,739.3	6,739.3	35,470.2
Cement/plaster/mortar - concrete	1,007.7	42,733.5	42,733.5	224,913.3
EPS 50 mm	6,192.4	18,577.2	24,224.7	7,430.9
Fibreboard including MDF	4,973.3	26,408.5	27,303.7	44,760.1
Painted Oak	5,86.6	0	0	14,371.4
Gypsum Plasterboard	9,475.4	25,583.7	27,715.6	213,197.2
Urea Formaldehyde Foam	6,192.4	19,223.2	20,735.1	10,799.6
XPS Extruded Polystyrene - CO2 Blowing	6,192.4	127,772.6	425,021.3	44,365.5
EPS Expanded Polystyrene (Standard)	4,973.3	27,975.1	36,479.5	11,190
Cast Concrete	12,384.8	107,004.7	107,004.7	1,337,559.3
Cast Concrete (Lightweight)	6,192.4	59,447.1	59,447.1	743,088.5
Fibreboard	6,192.4	12,316.7	12,799.7	24,150.4
Asphalt 1	6,192.4	12,353.9	12,353.9	247,076.9
Total		503,589.8	847,253.6	3,366,459

Table 4. CO_2-equivalent emissions of concrete exterior walls

	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)
Exposed wall (Concrete)	**4,975.3**	**281,803.2**	**291,106.9**
Cavity	4,737.7	25,583.7	27,715.6
Semi-exposed wall	1,007.7	63,047.9	90,289.2
Roof	6,192.4	211,890.2	509,621.9
Floor	6,192.4	144,805.2	151,964.6
Total	23,690.8	727,130.18	1,070,698.18

Table 5. CO_2-equivalent emissions of CLT exterior walls

	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)
Exposed wall (CLT)	**4,975.3**	**58,262.8**	**67,662.4**
Cavity	4,737.7	25,583.7	27,715.6
Semi-exposed wall	1,007.7	63,047.9	90,289.2
Roof	6,192.4	211,890.2	509,621.9
Floor	6,192.4	144,805.2	151,964.6
Total	23,690.1	503,589.73	847,253.64

5. Conclusions

This study demonstrates that wood-frame construction utilizing mass timber such as CLT is a technically viable and environmentally superior approach for achieving ZEB certification in residential buildings. CLT-based building envelopes enable compliance with ZEB Level 4 energy performance criteria while delivering significant reductions in embodied carbon. These findings support the expansion of timber construction as a key strategy for meeting national carbon neutrality targets. Future research should focus on integrating renewable energy systems, such as photovoltaic and geothermal technologies, and optimizing building-scale energy management to achieve higher ZEB certification levels, including ZEB Grades 1 and 2, in timber-based urban housing developments.

References

1. Oh, H., Hong, I., & Oh, I. (2021). South Korea's 2050 carbon neutrality policy. East Asian Policy, 13(01), 33-46.
2. Cho, S. H., & Chae, C. U. (2016). A study on life cycle CO2 emissions of low-carbon building in South Korea. Sustainability, 8(6), 579.
3. Cho, S. H., & Chae, C. U. (2016). A study on life cycle CO2 emissions of low-carbon building in South Korea. Sustainability, 8(6), 579.
4. Dodoo, A., Gustavsson, L., & Sathre, R. (2014). Lifecycle primary energy analysis of low-energy timber building systems for multi-storey residential buildings. Energy and Buildings, 81, 84-97.
5. Kim, Y., & Yu, K. H. (2020). Study on the certification policy of zero-energy buildings in Korea. Sustainability, 12(12), 5172.
6. Tettey, U. Y. A., Dodoo, A., & Gustavsson, L. (2014). Effects of different insulation materials on primary energy and CO2 emission of a multi-storey residential building. Energy and buildings, 82, 369-377.
7. Santamouris, M., & Vasilakopoulou, K. (2021). Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. e-Prime-Advances in Electrical Engineering, Electronics and Energy, 1, 100002.
8. Guardigli, L., Monari, F., & Bragadin, M. A. (2011). Assessing environmental impact of green buildings through LCA methods: Acomparison between reinforced concrete and wood structures in the European context. Procedia Engineering, 21, 1199-1206.