ISSN: 2754-6675

Journal of Chemistry & its Applications

SCIENTIFIC Research and Community

Research Article

Open Access

A Comparative Life-Cycle Assessment of Timber and Brick Residential Buildings in Norway: An Evaluation of Environmental Impacts

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ABSTRACT

Buildings use a fair share of the world's energy and raw materials, and the choice of construction material has a strong effect on their environmental performance. This research examines two 50 m² buildings for the Norwegian cold climate, one timber and one brick, to determine which of the two building typologies is the most environmentally friendly [1]. The paper applies a Life Cycle Assessment (LCA) approach according to the ISO 14040/44 standards, and focuses on the production of materials, their transport, construction, and the operation phase of the buildings [2]. Environmental impacts are quantified with SimaPro 10.1.0.6 software, using the ReCiPe 2016 Endpoint (H) method, which assesses the impact on human health, environment and resource use [3]. These findings support wider use of timber and of optimized masonry for cold-climate housing.

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Received: July 15, 2026; **Accepted:** July 21, 2026; **Published:** July 29, 2026

Keywords: Life Cycle Assessment, ReCiPe 2016, Timber Construction, Brick Construction, Eco-Design, Carbon Emissions

Introduction

The construction sector uses large amounts of raw materials and is responsible for a considerable share of global greenhouse gas emissions [3]. The choice of material for a house (timber, brick or concrete) has a significant impact on the amount of energy and carbon consumed during the life cycle of the building. This is even more relevant in areas with a high percentage of forest cover, such as Norway, which is cold for much of the year, since much of the energy consumption in a building could be related to heating [4].

Wood is a renewable material and is abundant in Norway, while brick and concrete are more widespread in conventional construction and are known to be energy-intensive. Limestone is one of the primary ingredients in cement (which in turn makes up concrete) and is estimated to account for nearly 8% of CO2 emissions worldwide due primarily to the heat and calcination required to produce it [5]. Hence, some researchers began to explore and compare the sustainability of timber structures with concrete or masonry structures in cold climates to understand which option is more sustainable [3-6].

In this paper, a comparative, attributional LCA of two 50 m² residential buildings in Norway, one timber and one brick, is reported. The objective is to determine the building with the lowest life-cycle effects and the most dominant of these effects. The second objective is to assess whether an eco-design modification on the brick building (perforated brick and additional insulation) can decrease its environmental impact. The paper is organized as follows: In Section II, the Methodology is explained, Section III provides the results, Section IV discusses the eco-design scenario, and Section V provides the conclusion.

Methodology

Goal, Scope and Functional Unit

The goal of the study is to compare the environmental performance of a timber and a brick residential building of the same size and function, using a comparative attributional LCA. The functional unit (FU) is calculated as 1 m² of living area over 60 years, so that the results can be scaled and compared without taking into account the overall size of the building. Although the case-study building has a footprint of 50 m², all results are expressed per square meter.

System Boundaries and Inventory

A gate-to-gate approach is followed in the study, starting with the material transport to the site (A4), through the construction phase (A5) and into the operational phase up to B5, with a focus on operational energy. The current scope does not include end-of-life stages (C1-C4). Minor component content, if present, is ignored unless more than 5% of the building content is omitted, consistent with ISO 14040/44 [1]. The primary material quantities used in the two buildings and the transport data are summarized in Tables 1 and 2, respectively.

Table 1: Material Inventory Comparison for Brick and Timber Buildings [6]

Component	Material	Brick (kg/m²)	Timber (kg/m²)
Foundation	Concrete	42.77	35.88
Foundation	Glulam	–	31.31
Floors	Concrete	539.13	267.55
Floors	CLT	–	71.90
Walls	Concrete	125.74	13.77
Walls	CLT	–	28.22
Roof/ceiling	Mineral wool	0.085	0.085
Roof/ceiling	Steel sheet	0.680	0.680

Table 2: Transport Data for Material Delivery (100 km Average Radius, Euro 6 Trucks) [6]

Parameter	Brick building	Timber building
Total transport distance (km)	1 280	2 480
Freight work (tonne-km)	43.99	60.40
Diesel used (L/m²)	1.54	2.11

To make the comparison valid, a number of assumptions were made. The assumption is that all primary materials originate from Norway or neighboring areas. Power supply: Euro 6 diesel trucks are used in transport, and the electricity comes from Norway's electric grid, which is approximately 90-95% hydroelectric [6]. The buildings are assumed to provide the same thermo-functional comfort and structural performance over 60 years, and furniture and appliances are not considered to be part of the system, nor are labor costs.

Impact Assessment Method

The SimaPro 10.1.0.6 was used for the impact assessment, using the ReCiPe 2016 Endpoint (H) method [2,3]. with the World (2010) scope and the hierarchist perspective. This method translates inventory outcomes into three impact areas: human health, ecosystems, resources and, finally, the overall score is expressed in points (Pt), which refer to a thousandth of the average environmental footprint of a European citizen per year. The same approach of normalization and weighting was used, enabling the results from all the impact categories to be compared on one scale.

Results and Discussion

In almost every impact category considered, including climate change, human toxicity, fine particulate matter and fossil resource scarcity, the brick building shows a higher value than the timber building. The only exception is land use, with a higher impact from timber, as brick has about 26.2% of the land-use impact of timber. This is accounted for in terms of the amount of forest area required to generate structural wood, but this is comparatively small to the overall benefit from timber in the other categories.

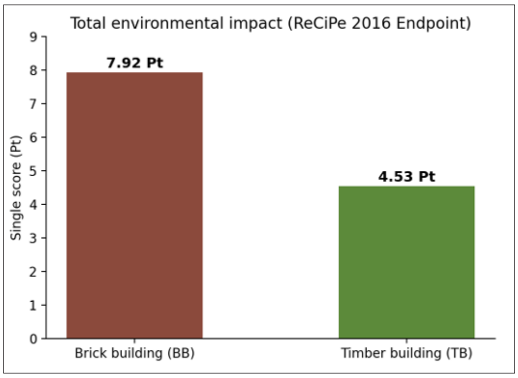

Figure 1: Total Single Score for the Brick and Timber Buildings (ReCiPe 2016 Endpoint)

As shown in Fig. 1, the total single score of the brick building is 7.92 Pt, compared with 4.53 Pt for the timber building, a difference of about 44%. In both cases, the human health category is the main contributor, driven mostly by greenhouse gas emissions and fine particulates released during material production.

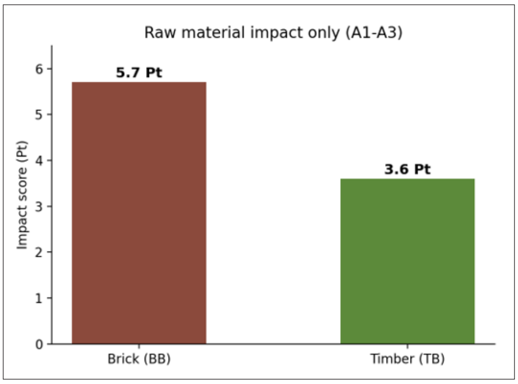

Figure 2: Impact Score of Raw Materials only, Excluding Transport and Operational Energy

When only the raw material stage is considered (Fig. 2), the difference is smaller but still noticeable: 5.7 Pt for the brick building against 3.6 Pt for timber. A closer look at the network results shows that concrete is the single most damaging material in both scenarios; it is responsible for 5.32 Pt out of 7.92 Pt in the brick building, and 2.39 Pt out of 4.53 Pt in the timber building. This matches earlier findings that cement production is a major source of embodied carbon in construction [5].

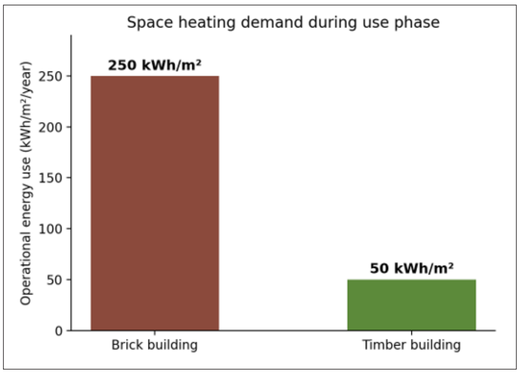

Figure 3: Operational Space-Heating Demand for the Two Buildings

Operational energy is another major difference between the two designs. As Fig. 3 shows, the brick building requires about 250 kWh/m² per year for space heating, while the timber building requires only around 50 kWh/m², about 80% less. This is a result of the better thermal performance of the timber envelope, and it has a large effect over a 60-year lifespan, since heating is repeated every year while embodied impacts occur mostly once.

Eco-Design Improvement of the Brick Building

Because of brick construction showed the higher impact overall, an eco-design scenario was performed to see if it could be improved without changing the main material. In this scenario, solid bricks (density around 1700 kg/m³) were replaced with perforated bricks (density around 800-900 kg/m³), and extra rock-wool insulation, about 14-16 cm thick, was added to keep the same thermal comfort in the Norwegian climate [7].

Table 3 shows that the wall material was reduced from 125.74 kg/m² of concrete/brick to 56.58 kg/m², with 1.414 kg/m² of rock wool added, which is a wall mass reduction of more than 50%. This lighter wall lowers the emissions related to material production and transport, since less material needs to be manufactured and moved to the site.

Table 3: Wall Material Comparison Between the Standard and Eco-Design Brick Building [7]

Wall material	Solid brick (BB)	Eco-brick (BBE)
Concrete/brick material (kg/m²)	125.74	56.58
Rock-wool insulation (kg/m²)	–	1.414
Approx. wall mass reduction	baseline	> 50%

The SimaPro results for this eco-design scenario (full assembly BBE) show a slightly better total score than for the standard brick building (full assembly BB) in all the three endpoint categories, but the improvement is not as great as would be achieved if the full assembly was switched to timber. Even after the redesign, human health remains the most important category in both instances, with over 95% of the total impact being attributed to this category, indicating that the type and quantity of ceramic materials used is still relevant. Despite this, it is the eco-brick scenario that shows that there is some potential for effectively reducing the mass of a conventional masonry building, improving the insulation, and making a meaningful contribution to improving the environmental performance of the building; where timber construction is limited by regulation or the availability of the timber, this can be a viable course of action.

Conclusion

This study compared the environmental performance of a timber and a brick residential building of the same size, in the context of Norway's cold climate. The overall performance of the timber building was better, achieving an impact score approximately 44% lower than the brick building, primarily because of lower operational heating demand and also lower embodied impact from concrete. The only category in which timber did worse was land use due to the amount of forest required to produce timber. An eco-design version of the brick building with rock-wool insulation, using perforated bricks, has significantly lowered the mass of the wall, and provided a modest, but significant improvement over normal brick, but not as high performing as timber.

The findings indicate that as long as regulations and material supply deem it feasible, timber should be used for small residential structures in cold regions and eco-brick solutions may be an appropriate option when timber isn't. Some limitations in the study were: end-of-life processes were not included, secondary databases were used for some material data and maintenance behaviour was not modeled in detail more than 60 years. Future work may expand the boundary to include the end-of-life stage and repeat the analysis with variations of the national electricity mix to check the sensitivity of the results [8].

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