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Life Cycle Assessment of a Domestic Natural Materials Wood House

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Abstract

We conducted a project entitled "Achieving Climate Change Abatement and Comfortable Life by a Partnership between Forestry and Natural Material Housing (NMH) in Urban Areas," which aims to achieve carbon neutral housing by 2050 by linking forest management to the use of domestic wood in environmentally friendly Natural Materials Housing. In this paper, we conduct long term Life Cycle Assessment of CO_2 emissions from afforestation stage to ultimate demolition of the house, encompassing the following stages: afforestation work and log cutting, lumber production, house building, use of the house (with main emissions coming from energy consumption for space heating and cooling, cooking, hot water supply, lighting, and appliances), repair, demolition, and waste treatment. Analysis results indicate that Life Cycle CO_2 emissions from Natural Materials Housing are low, when compared with standard cases.

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Keywords ; LCA, CO_2 emissions, Natural Materials Housing, forestry, wood lumber

1. Prorogue (introduction)

We conducted a project entitled “Achieving Climate Change Abatement and Comfortable Life by a Partnership between Forestry and Natural Material Housing (NMH) in Urban Areas”; the project commenced in 2009 and was implemented through an R&D Program called “Community-Based Actions against Global Warming and Environment Degradation” in RISTEX, JST. The purpose of the project was to attain carbon neutral housing by 2050 and to simultaneously contribute towards comfortable and healthy living by directly linking forest management to the use of domestic wood in environmentally

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friendly NMH. Through the process of directly linking the forest industry to housing construction, we aim to develop a new socio-economic system, based on which the forestry business can survive.

As a case study for the development of this new business model, we conducted an empirical study of one NMH construction NPO and a forestry company in Miyagi prefecture, which manages a lumber mill. This study aims to demonstrate the results of this environmentally friendly business model, as well as a support system for market penetration.

The features of the NMH are as follows: a) completely natural materials, b) domestic wood which dries at low temperatures, c) no use of plywood or laminated wood, d) use of plaster made from ground shells, e) wool insulation, f) natural adhesives, g) no use of any synthetic chemical materials, h) hand-carved traditional wooden structures, i) long-life hard concrete, j) direct purchase of wood from the forestry industry not through markets, and k) direct delivery from lumber mill to construction site.

Using this system, the NMH builder can realize both a reduction in environmental load and cost cutting, and the lumber mill can generate adequate income through additional carving work by highly skilled carpenters. Furthermore, the forestry industry can generate sufficient income with a slightly higher price for log sales. In this way, the direct linkage system creates an environmentally friendly and reasonably priced supply chain of domestic wood and natural materials housing.

We conducted long-term Life Cycle CO_2 ($LCCO_2$) analysis of the NMH direct supply system, from the forestry work stage to demolition.

2. $LCCO_2$ elements and system boundary

The elements of $LCCO_2$ are shown in Table 1. The subject is a domestic wooden natural materials house and the evaluation system boundary extends from nursery trees to final biomass burning of the lumber wood after demolition.

Table 2 shows the system boundary of a NMH, specifically an independent house with two floors and a footprint of 125.86 m^2, in which the amount of wooden material amounts to 30 m^3, a quantity 1.5 times greater than in a typical case. The thermal insulation performance of the NMH is mid-level, i.e., not very high but adequate. Airtight performance is not high but mid-level as well. Q value is 2.08 W/m^2, which is not as high as it could be; however, room temperature is not cold with the operation of a biomass fuel stove and is not hot without the operation of cooling air conditioners. Consequently, the NMH has low CO_2 emissions. The lifetime of the NMH is assumed to be 100 years, longer than in the case of a typical house and much longer than the 22-year period used by Japanese institutions for official monetary value accounting of wooden houses.

3. CO_2 emissions at each stage

3-1 Forestry

We analyzed the case of a company managing a forestry field and lumber mill in Miyagi prefecture, with these forming part of the NMH direct supply chain. For LCA of log production from forests, the evaluation of unit emissions is difficult, because of the very long period of work under changing fundamental conditions. The difficulty of accounting stems from the variability of several elements and conditions, for example by region or by tree types. In the case of the forestry supplying the NMH, the estimation result was 15.4 tCO_2/ha-year and 19.19 $kgCO_2$/log m^3.

3-2 Lumber

For the lumber mill, we compared the case of wood NMH with a large lumber mill for domestic wood and imported wood cases from Russia and the USA (data provided in Oshiro, K. et al., [6]). Emissions from the NMH lumbermill are low; this has a carbon neutral low-temperature drying furnace, which uses biomass fuel from wood waste generated on site. Emissions in the case of imported wood from Russia are large due to the following assumptions: 500 km of long haul travel with heavy-duty diesel trucks, from the forestry site to the railway station, and 4,200 km of transportation over diesel railways to the export harbor. For imported wood from the USA or Canada, total emissions are not so high, due to the low emissions of each element and due to the short distance of transportation by heavy-duty trucks, with the latter assumed to be 100 km to the export harbor.

Table 1 LCCO$_2$ Elements and System Boundary

Elements	Boundary
Forestry(Log Wood)	NurseryTree, Soil Preparation,Mowing,Pruning,Thinning, Felling,Log Haul
Lumbermill work	LumberCutting,Drying,Carving,Lumber Haul
House Building	Material Production, Fabrication, Carrying to Construction Site
Daily Life	Space Heating and Cooling, Hot Water Supply, Cooking,Lighting,Appliance
Repair	Interior,Exterior Decoration replacements in asssumed periods
Demolition	Haul to Inert type and Controlled type sanitary land fill site, disposal and recycling
Wood Re-use	Column and Beam re-use
Carbon Absorption	Net CO2 emissions reducing after decucting carbon fixsation

Table 2 LCCO$_2$ System Boundary of Natural Material House

Elements	Given Specification
Forest Work	JapanCeder 70yesar-old wood in Miyagi Pref. felling 1630 trees/ha,thinning twice,
Lumbermill Work	Biomass fuel low temperature Drying, cutting ** work direct delivery to house building site
House Building	Natural wood,Tradirtional connencting hund carving, lumber Rich Specification(30m3/house) 150%of standard case, size 125.86m^{2},Wall insulation100mm,middle level air tightness, Q Value 2.08W/m^{2}K
Daily Life (Energy Use)	Bio Pellet stove space heating, same as standard specification for others
Repairing	House life 100years, repair of iquipment every 20 years, interior and sashes every 40 years
Demolition	Partly Recycle, same as Standard case by Chikada(2003)
Re-use of Lumber	assumed 100%recycling of column and beam
Carbon Fixation by Wood	dencity 0.4, Water content (weight) ratio 15%, Carbon content (weight) ratio 0.5

3-3 House construction

CO_2 emissions in the NMH case are 359 kgCO^2/m^2, 23% lower than the 465.5 kgCO^2/m^2 generated by a standard wooden house (a typical case taken from “Construction Input/Output Table for 2005). Based on this I/O table, a conventional wooden house appears to have lower emissions, 77% of the average for all types of constructions, whereas the value for non-wooden structures is 129% of the average. This means that average CO_2 emissions of a wooden house are 60% those of non-wood houses, while emissions in the NMH case are 59% of the average for all types and 46% of the average for non-wood houses.

3-4 Repair and demolition

CO_2 emissions of repair and demolition are small and do not constitute the main environmental load of the demolition process because the direct damage to the natural environment caused by disposal is more severe.

3-5 Daily life in NMH

In building LCA, 70% to 80% of energy consumption on a daily basis is for space heating and cooling, lighting, and appliances. In case of housing, the share of cooking and hot water supply for baths and showers is large. In terms of insulation performance, NMH does not display a high level of air tightness but aims for adequate air tightness, with a Q value of approximately 2 W/m^{2}K. However, in many cases, NMH provides a comfortable (sufficiently warm but not hot) indoor environment with low energy consumption. In this analysis case, a biomass pellet stove was used for space heating and other energy uses were at a general level, but total energy demand per household was low enough to achieve a low level of energy demand. We measured indoor air temperature and humidity. We can report that no dew condensation was observed in any part of the NMH. The other paper Takaguchi et al will be reporting these findings in detail.

4. Life cycle CO_2 emissions of NMH

Comprehensively, through all the above LCA stages, life cycle CO_2 emissions ($LCCO_2$) of NMH were evaluated based on lifetime assumptions. Fig 5 shows a comparison of $LCCO_2$ for the NMH case and for a standard LCA case study conducted by the Architectural Institute of Japan. Estimated gross $LCCO_2$ of NMH is 27 kg CO_2/m^2/year, 54.9% of the standard case, which was 50.86 $kgCO_2/m^2$/year in 2005. Net emissions, when factoring in the recycled use of wood, which is very limited in the case of long-term use of a house (100 years) and the fixed carbon effect though wood growth, is 26 $kgCO_2/m^2$/year.

If we assume a 100-year period of use of a built house, the share contributed by construction emissions would be small, half those resulting in the case of a 50-year period of use. Even when considering retrofitting, the construction emission share becomes smaller with longer-term use of the house. Meanwhile emissions in daily life, mainly through energy use for electricity, would become smaller as a result of several kinds of effort or innovation. In the 100-year life NMH case, the emission share of daily life energy use is 79%, while that of the standard case (assuming a short lifetime of 30 years) is 76%. As a result, the CO_2 emissions share across elements is not altered much by energy saving and by longer life use of the house. The results of this comparison indicate that daily life energy use and the $LCCO_2$ total in the NMH case are 57% and 55% of the standard case, respectively.

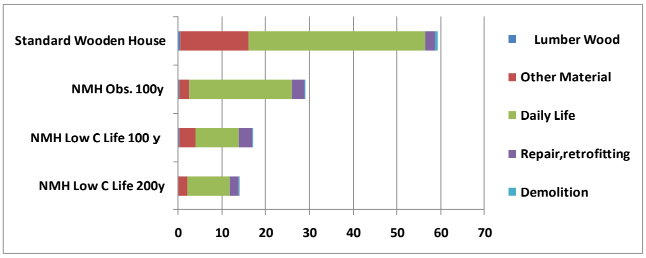

Fig 1 LCCO2 of Natural Material House

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Biography

Professor Yutaka Tonooka, Dr. of Engineering, Professor of Saitama University, Faculty of Economics, Department of Social Environmental Design, Japan, was a Visiting Professor of Imperial College London to 2011, Emeritus Visiting Professor of Dalian Institute of Technology, China, Emeritus Visiting Professor of Xi'an Jiaotong University, China, Visiting Researcher of Waseda University, Chair of Global Environment Committee in Architectural Institute of Japan, Head of NPO Partnership between Forestry and Natural Material Housing

Research Field: Energy and Environment, Emission Inventory, Social System Design