Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 42 (2007) 2778–2784
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

An environmental assessment of wood and steel reinforced concrete housing construction

G.P. Gerilla[a,*], K. Teknomo[b], K. Hokao[a]

[a]Department of Civil Engineering, Saga University, 1 Honjo, Saga 840-8502, Japan
[b]Arsenal Research, Giefinggasse 2, Vienna 1210, Austria

Received 20 June 2006; received in revised form 5 July 2006; accepted 21 July 2006

Abstract

Wooden type of housing is ubiquitous in Japan. It is the main structure for housing; however, due to the increase in residential developments, steel reinforced concrete houses are also on the rise. This paper assesses the environmental impacts of these two types of construction. An evaluation of the two types of construction in terms of energy usage and air emissions is done. A comparison of the damage costs due to the generated emissions is also considered. Four types of emissions generated are evaluated, namely carbon emissions (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x) and suspended particulate matter (SPM). The life cycle of the two different housing construction types is traced and environmental impacts are determined. External costs are also calculated. Furthermore, different improvement assessment scenarios are simulated to ascertain several emission reduction possibilities. The study looks into the emitted emissions from the housing construction to its final disposal of a typical residential development in Saga, Japan. Results show that much of the environmental impacts from building a house are on the Global Warming Potential due to high carbon emissions. Moreover, the construction phase generated the highest pollutant emissions from nitrogen oxides, sulfur oxides and suspended particulate matter. Steel reinforced concrete (SRC) construction has a higher environmental impact compared to the wooden type of housing construction. A longer design life for a residential house gives a reduction of about 14% in carbon emissions. Using solar energy for the operation phase has gained a reduction of 73% in the total life cycle carbon emissions.

Keywords: Environmental impact; Residential development; Sustainable development; Life cycle assessment

1. Introduction

Wooden type of housing is ubiquitous in Japan. It constitutes about 77% of all residential houses in Saga prefecture, Japan. Steel reinforced concrete (SRC) comprises about 15% of all residential buildings. The 5-year period starting 1993 shows that there was a 54% increase in SRC type of detached houses compared to about a 3% increase in wooden houses. Due to the increase in residential developments, SRC houses are also on the rise, therefore there is a need to assess the environmental impacts of these two types of housing construction. Housing is one of the areas in urban development that needs to be assessed in terms of its environmental impacts. Housing is a very basic human need that stakeholders in residential development sometimes do not consider the effects of building such residential properties. There is a need to evaluate the environmental impacts of these housing developments; therefore, this paper will study the environmental impacts of two types of the most common residential construction in the area. The two types of construction will be evaluated in terms of energy usage and air emissions. Damage costs due to the generated emissions are also compared. The main purpose of the study is to compare the two types of residential construction, namely, wooden type and the SRC type through its life cycle and assess different improvement scenarios that will lessen the environmental burden from these housing types. Four types of emissions generated are considered, namely carbon emissions (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x) and suspended particulate matter (SPM). The life

*Corresponding author. Tel.: +81 952 28 8830.
E-mail address: glogtek@gmail.com (G.P. Gerilla).

0360-1323/$ - see front matter
doi:10.1016/j.buildenv.2006.07.021

cycle of the two different housing construction types will be traced and environmental impacts considered. A simulation of different improvement assessment scenarios is evaluated. The emissions from the two residential types can be traced from its construction, maintenance, operation and disposal of the houses. Life cycle analysis (LCA) is a methodology able to address this issue. LCA is a procedure to assess the sustainability of a product through consideration of all environmental implications of development, from primary inputs to disposal of final output and byproducts, including wastes. In that respect, LCA can be used to assess an eco-balance of a product. Several studies have been done to evaluate the environmental soundness of buildings and housing. Cole and Kernan [1] evaluated the life cycle energy of a 50,000 ft^2 (4620 m^2) three-story generic office building for alternative wood, steel and concrete structural systems in Canada. Blanchard and Reppe [2] studied the total life cycle energy of a standard house in Michigan. They used the typical LCA methodology to evaluate the embodied energy of the house. On the other hand, Harmaajärvi [3], used the EcoBalance model to study the ecological impacts of eco-villages and he indicated that eco-villages may not be very sound from an ecological point of view. Vieira and Parker [4] examined the energy use in ten Florida developments built in the 1980s and they concluded that increased occupancy increases household energy use. They also mentioned that detached households consume substantially more electricity than attached households. Lee [5] assessed the environmental sustainability of multi-family estates in Korea. He selected and evaluated the sustainability of housing estates based on Korean sustainability indicators and standards. Gerilla et al. [6,7] evaluated the embodied emissions of different types of housing construction and the materials used. They found out that certain materials in housing construction contribute to the increase in embodied CO_2 emissions. These studies did not compare the total embodied emissions from two types of residential housing construction so this paper will try to address that issue.

2. Methodology

LCA is one method to know and assess the total impact of a particular product to the environment. The life cycle model starts from the acquisition of raw materials to the transport of these materials to the manufacturing plant for production. From manufacturing, it is transported to the end user. The products are salvaged as waste. The LCA framework starts with goal definition and scoping which defines and limits the objectives of the study. The next stage in the methodology is the Inventory analysis wherein a detailed description of the product systems and the inputs and outputs of that system are traced. Within the impact assessment, there is a need to characterize the pollutants in terms of the impact they give to the environment, then an indexing or valuation is done to combine the results together into one value. The goal is to appraise two different housing types and to show the impact of these types on the environment. All data will be related to the functional unit [8]. The functional unit used for this study is kilogram of emission per year per square meter. This means that each kilogram of pollutant emitted is attributed to the floor space of the house and its design life. The emissions are limited to carbon emissions (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x) and SPM due to data constraints. The inventory analyses for this study used the input–output tables to get the specific emissions of the different construction types. Fig. 1 shows the flowchart of the calculation procedure.

The hybrid input–output model developed by Gerilla et al. [6] was used together with basic input–output tables for construction to obtain the specific emissions for each housing construction type. Emissions from transport were also calculated for each life cycle. The transport emissions for each life cycle stage are included in the calculations of total emissions. Further explanation on how to use the emissions from transport, the reader is referred to Gerilla [9]. A questionnaire survey was conducted to know the residents' energy consumption for different seasons in a year. The average consumption for each residential type was consolidated and converted to energy consumption. Inaba and Sagisaka [10] presented the life cycle inventory of Japanese electricity grid mixes in 1998. The conversion factors from this study were used for the calculation of the emissions in the operation phase. Total emissions to air from the construction, maintenance and disposal were estimated using the models shown in Eqs. (1.1)–(1.3), respectively.

$$EF_c = \frac{(E_s * W_u * V_a * P_u)}{Y}, \tag{1.1}$$

$$EF_M = \left(\frac{E_s * W_u * V_a * P_u * K}{100}\right) * \left[\left(\frac{Y_m}{Y}\right) + 1\right], \tag{1.2}$$

$$EF_A = \left(E_s * W_u * V_a * D_p\right) * \left[\frac{1}{Y} - \frac{K}{Y_m * 100}\right], \tag{1.3}$$

where EF_c is the pollutant emission factor for construction (kg-pollutant/yr m^2), EF_m is the pollutant emission factor for maintenance (kg-pollutant/yr m^2), EF_A is the pollutant emission factor for disposal (kg-pollutant/yr m^2), E_s is the specific emission (kg-pollutant/'000¥), W_u is the unit weight (kg/m^3), V_a is the material volume/unit area (m^3/m^2), P_u is the unit price of material ('000¥/kg), Y is the design life, Y_m is the refurbishing/rebuilding cycle (yr), K is the temporary repair rate for preventive maintenance (%/yr), D_p is the unit price of discarded material ('000¥/kg).

Eq. (1.1) shows the total pollutant emission factor for the construction stage. It is based on the specific emissions taken from the hybrid input–output model, the properties of the materials used in construction, the unit price of the material and the design life of the residential house. Eq. (1.2) presents the total emission factor from the