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ASSESSMENT OF ENVIRONMENTAL IMPACTS OF RESIDENTIAL DEVELOPMENTS: A CASE IN SAGA CITY

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ABSTRACT: Housing developments are emerging everywhere as part of urban development. Environmental assessment of these housing developments is essential for planning and design of existing and future projects. The paper compares two types of housing construction mainly wooden and structural reinforced concrete construction. The two types of construction will be evaluated in terms of energy usage and air emissions. The main purpose of the study is to calculate and evaluate the air emissions from the two types of housing construction. The life cycle of the two different housing construction types will be traced and the methodology used will be the life cycle assessment (LCA) method. An analysis called the Life Cycle Assessment (LCA) is one method to know and assess the total impact of a particular product to the environment. The study looks into the emitted emissions from the housing construction to its final disposal of a typical residential development in Saga, Japan.

Keywords: Environmental Impact, Residential Development, Sustainable Development, Life Cycle Assessment.

INTRODUCTION

Sustainable development as defined by the Brundtland Commission is “ensuring that development meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987). The report has started a global discussion on sustainable development. This concept has been widely accepted and several studies have been done to be able to assess and practically use the concept in evaluating the needs of nations and their ability to cope. 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. Environmental hazards in lowland areas such as flooding and landslides are some of the problems facing housing developers and planners. To add to that burden are air pollutants from the construction and operation of these housing developments. Recently, Saga City in Japan, a low land area, has seen a sprouting of new residential developments. 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 emissions from the two residential types will be traced from its construction, maintenance, operation and disposal of the houses. Life cycle analysis (LCA) can be a methodology to be able to address this issue. Life Cycle Analysis (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 by-products, their included 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 (1996) 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 (1998) 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, (2000) 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 & Parker, (1991) 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. Gerilla, et al (2005a,c) evaluated the embodied emissions in different types of housing construction and the materials used. They found out that certain materials

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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 it. The main purpose of the study is to compare the two types of residential construction, namely, wooden type and the steel reinforced concrete type (SRC) thru its life cycle.

Following this introduction is the methodology wherein the framework in computing for the emissions of residential housing is discussed. The data collection techniques are also discussed. The third section is the results section, the study's main outcome are presented. The impacts of the calculated embodied emissions are explained in the 4th section. Concluding remarks closes the paper.

METHODOLOGY

This paper follows the Life Cycle Assessment methodology. The flowchart of the method is shown in the figure below.

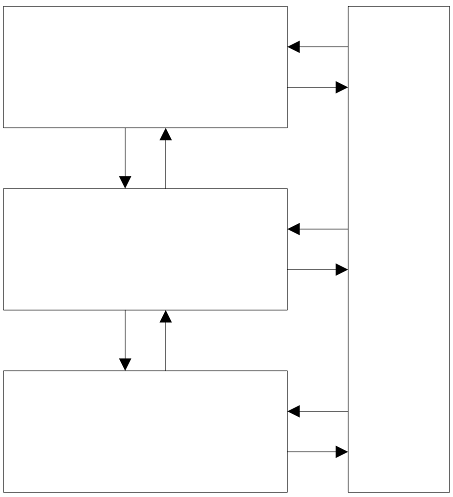

Fig. 1 The phases of life cycle assessment, ISO 14040 (1997)

There are four phases in the Life Cycle assessment methodology. The goal definition and scoping stage defines and limits the objectives of the study. The functional unit as a basis for comparison is also defined. The second stage, Inventory analysis, is a detailed description of the product systems and the inputs and outputs of that system. Inputs and outputs of the system include energy and raw materials used as well as emissions generated. 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 last stage, interpretation, evaluates the results and reports them results as clearly as possible. A recommendation on ways to reduce the impact of the product or service on the environment is also done.

The goal of this paper is to assess the environmental impacts of two different types of housing construction, namely the steel reinforced concrete (SRC) and wooden construction. A comparison of emissions and impacts to the environment is done for the two types of construction.

The study area is a residential development in Saga City, Japan, wherein the types of housing construction were mainly wooden and steel reinforced construction. A questionnaire survey was conducted to know the resident's household characteristics and energy consumption.

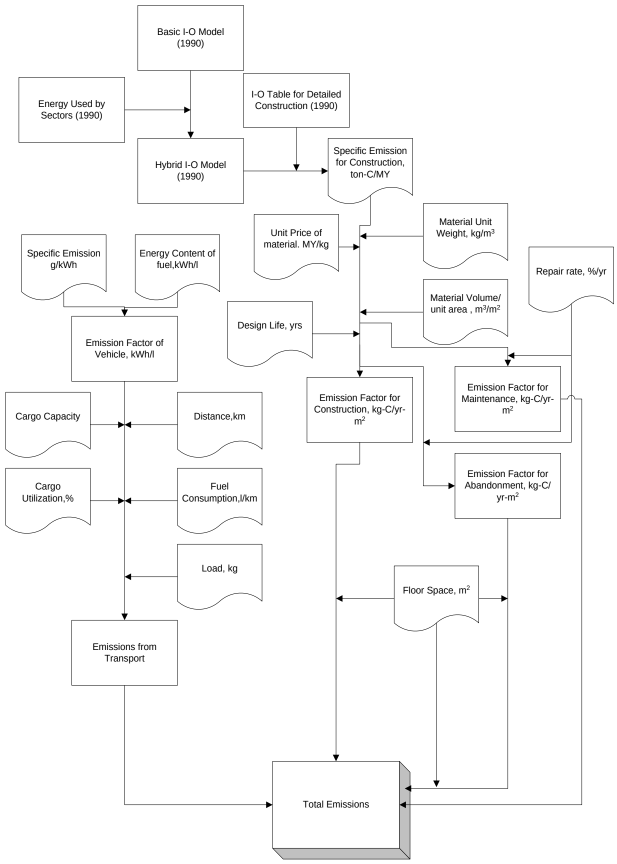

Fig. 2 Flowchart for calculating CO_2 emissions of the residential developments

Figure 2 shows the flowchart on how the emissions were calculated for each type of residential construction. The energy usage tables from the National Institute of Environmental Studies, Japan (NIES) were combined with the basic Japanese I-O tables to produce a hybrid Input-Output matrix (see Gerilla, et al., 2005a for further explanation) The detailed Input-Output Construction was used as a final demand matrix to get the specific emission for construction.

The detailed explanation of the hybrid model and its accompanying specific formula will not be discussed in this paper, but the author refers the reader to another paper which elaborates the hybrid input-output model (Gerilla, 2005a).

The material unit weight, unit price of material and material volume were taken from several architectural data. Emissions from transport were also calculated for each life cycle. Further explanation on how to use the emissions from transport, the reader is referred to (Gerilla, et al., 2005b). Each life cycle stage has a transport component so emission from transport is added to each life cycle stage.

The functional unit is the unit used based on the main function of the system under study. All data will be related to the functional unit (Lindfors, 1995). 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 CO_2 NOx, SOx and suspended particulate matter (SPM) due to data constraints.

EMISSION FACTORS

Emission Factors for Construction, Maintenance and Disposal Phases

The construction phase is defined as the stage wherein all the material inputs needed for the building of a house are selected and calculated. The maintenance phase is generally the stage wherein the house is repaired including all accessories in it like carpets, equipment. The disposal stage is defined as the demolition of the house wherein the building has reached its end life.

The carbon dioxide and nitrogen oxide emission factors for construction, maintenance and disposal are shown in Table 1. The factors were calculated using the flowchart in Figure 2.

Table 1 CO_2 and NOx Emission Factors used for each life cycle stage

Table 2 shows the emission factors used for sulfur oxide and suspended particulate matter. Some factors seem to be almost equal; it is so because of rounding off errors due to space constraints. The values used in the calculation of the total emissions uses the expanded values.

Table 2 SOx and SPM Emission Factors used for each life cycle stage

Emission Factor for the Operation Stage

The emission factors for the operation stage were calculated using the average household energy consumption of the respondents in our questionnaire.

Operation Stage is basically defined as the phase wherein the house is in use by the residents and energy is consumed due to the use of appliances and other equipment for living.

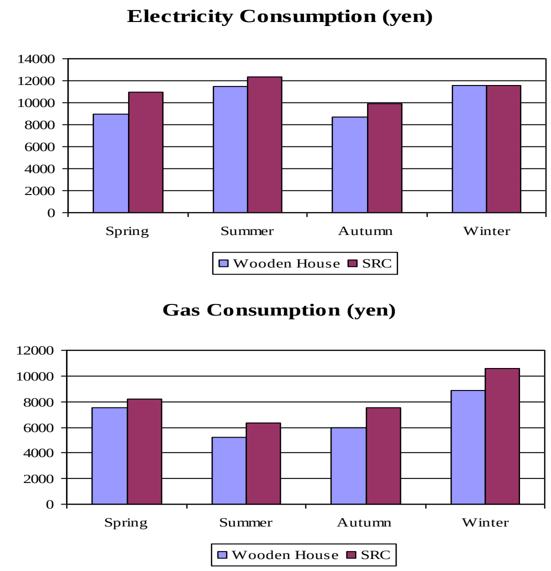

Fig. 3 Average Energy Consumption of households in the study area according to different housing construction types

Figure 3 shows the average energy consumption of the households in the study area. The households basically used electricity, liquefied natural gas and kerosene for heating purposes during winter all throughout the year. It shows that electricity consumption is highest during summer while gas consumption is highest during winter. The electricity consumption in Japan is about 22.1 yen/kWh and gas consumption is on average 208.9 yen/m^3. Kerosene on average was about 61 yen/liter.

The emission factors for each type of pollutant and type of housing construction is shown in Table 3.

These conversion factors were calculated based on the different fuel types in this paper namely kerosene, electricity and natural gas. The results from NIES with some mathematical manipulation to come up with these values in table 3.

Table 3. Conversion Factors for each type of pollutant for the operation stage

TOTAL EMISSIONS

This section presents the results of the life cycle emissions' calculations done on the studied detached housing with a 150 m^2 floor space and a design life of 35 years.

The emission factors from Tables 1 and 2 were used to calculate the total emissions for the construction, maintenance and disposal stages. The average consumption for each residential type were consolidated and converted to energy consumption in kWh and the appropriate conversion factors were used.

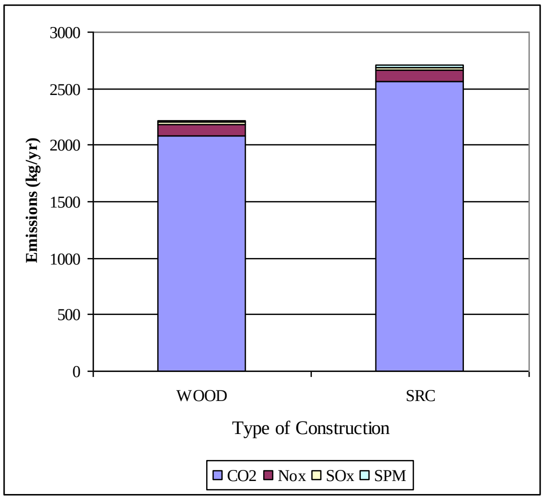

Fig. 4 Total Life Cycle Emissions for Wooden and SRC Type of Construction

Figure 4 shows the total life cycle emissions for the wooden and steel reinforced concrete (src) type of construction. It shows that carbon emissions dominate the other pollutants to air by as much as 93%. NOx emissions are only about 4% of the total emissions calculated while SOx and SPM constitute about 3%. Percentage of emissions for the two types of construction is almost similar.

The total life cycle carbon emissions according to each life cycle stage are shown in Figure 5. The figure presents the percentages of CO2 emissions for each stage in the life cycle. It shows that CO2 emissions for the operation stage were the largest with 79% of the total CO2 emissions. Construction stage was only 12% while maintenance and disposal only had around 9% of the total carbon emissions.

The figure also shows that carbon emissions for the operation stage in the SRC type of house was lower by

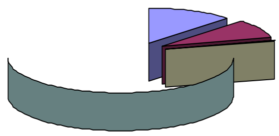

Fig.5 Total Life cycle carbon emissions for each life cycle stage

about 4% compared to the wooden type of house while carbon emissions from construction was about 3% higher than in wood. Carbon emissions from maintenance and disposal for the steel reinforced concrete type are higher than that of the wooden type. Total carbon emissions for SRC type are much higher than the wooden type.

Nitrogen oxide emissions for each life cycle stage of the two types of constructions are shown in Figure 6.

The figure shows that for nitrogen oxides, the biggest contributor to this pollutant is the construction stage with an almost 88% contribution from wood while from SRC it had an 87% contribution. NOx emissions from SRC are about 7% higher than NOx emissions from wood. The NOx emissions from the operation stage in the SRC type of house is about 1 % higher than the NOx emissions from the wooden type of residence. The NOx emissions from disposal in an SRC type of house is about 0.07% higher compared to that of a wooden type of house.

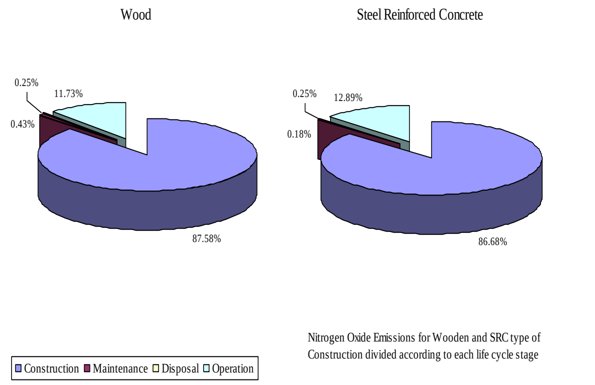

Fig.6 Total Life cycle nitrogen oxide emissions for each life cycle stage

The sulfur oxide emissions for each type of construction are shown in Figure 7. The figure represents the percentages of emissions for each life cycle stage. It can be seen that the construction stage contributed to about 58% of the total emissions from a wooden house construction while the operation stage was about 41%. One per cent of the total SOx emissions come from the maintenance of wooden housing.

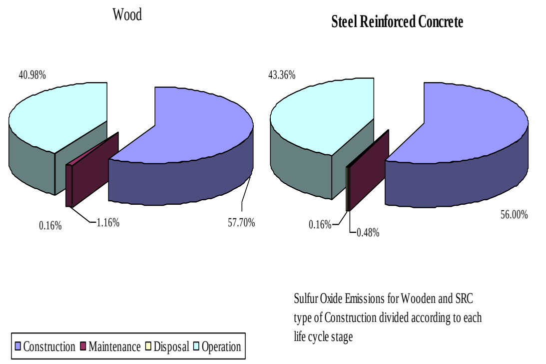

Fig.7 Total Life cycle sulfur oxide emissions for each life cycle stage

Suspended particulate matter (SPM) emissions of the detached residential houses in the study generally come from the construction phase. Figure 8 presents the SPM emissions for each life cycle stage. About 92% of the total SPM emissions are generated in the construction phase both for the wooden type and the SRC type. SPM from the operation stage only consists of about 7% and 8% for wood and SRC, respectively. SPM emissions from maintenance and disposal of an SRC type of house had the same percentage. While SPM emissions from maintaining a wooden house is about 0.4% higher than SPM emissions from disposing of the house.

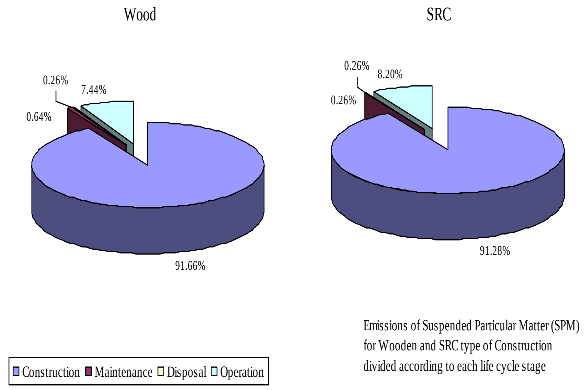

Fig. 8 Total Life cycle suspended particulate matter emissions for each life cycle stage

The next section explains the impacts of the computed air emissions.

ENVIRONMENTAL IMPACTS

The impact assessment is the third component of the LCA. It aims to analyze and assess the environmental impacts of the interventions identified in the inventory analysis (Lindfors, 1995). The impact assessment is divided into three subsequent sub-components: classification, characterization and valuation. Classification is a qualitative step, wherein the different inputs and outputs of the system are assigned to different impact categories. Characterization is a quantitative step wherein the relative contribution of each input and output to its assigned impact categories is assessed. Valuation is either a quantitative or qualitative step in which the relative importance of the different potential environmental impacts from the system are weighed against each other, the use of this sub component is an optional step.

Each type of pollutant can be grouped together to see the effects they have on the environment. Carbon dioxide, CO_2 is a greenhouse gas, which can cause global climate warming that may have disastrous effects. The Global warming potential is measured relative to the effect of 1 kg of CO_2. Sulfur dioxide, SO2 and nitrogen oxides are two of the pollutants, which cause acidification when mixed with water in the air. Acid rain is one effect of acidification, which causes plants to wither and buildings corroded. NOx also causes eutrophication, a phenomenon that depletes the nutrients of the soil, thereby decreasing agricultural productivity. The eutrophication potential is measured relative to the effect of 1kg of phosphate. The pollutants in the study cause detrimental health effects as shown in the figure.

NOx when inhaled affects the respiratory system and it increases susceptibility to infections among others, SOx, likewise affects the lungs. Suspended particulate matter (SPM) is both cancer inducing and irritates the throat and eyes as well. The human toxicity potential is measured as the human body weight that would be exposed to the toxicologically acceptable limit by 1 kg of substance (UNEP, 1996).

Figure 9 shows the final result from the calculations of impact assessment. It can be seen that much of the environmental impacts from building a house is on the Global Warming Potential because much of the emissions come from carbon emissions. It can also be seen that acidification of the air due to the sulfur oxide emissions also contribute to the environmental impact. It is also noted that Human Toxicity potential that is detrimental to human health had a higher value than eutrophication.

The environmental impacts are the same for Wooden or SRC type of housing. It is noted however, Steel Reinforced Concrete construction has a higher environmental impact compared to the wooden type of housing construction.

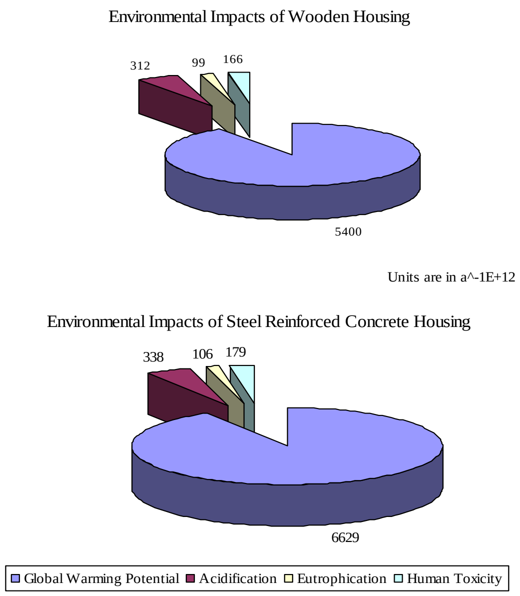

Fig 9. Environmental Impacts of the Calculated Emissions

CONCLUDING REMARKS

Carbon emissions were the highest pollutants from the two types of housing construction. Carbon emissions from the operation phase of both types of housing were the highest. For the other pollutants studied, NOx, SOx and SPM, the construction phase generated the highest pollutant emissions. Much of the environmental impacts from building a house is on the Global Warming Potential because much of the emissions come from carbon emissions. Steel Reinforced Concrete (SRC) construction has a higher environmental impact compared to the wooden type of housing construction.

Studies on the lowering of emissions from CO2 and other types of pollutants are recommended.

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