Energy And Buildings Template

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Abstract

Environmental concerns are a big threat to almost all the parts of most of the countries in the world, especially with the growing size of infrastructure. There is a need for attention towards structures with respect to their impact on the environment. The present study is an attempt to assess the ecological imbalance, environmental impacts, and reduction in the overall lifetime of the buildings. Largely, the ecological imbalance is due to the emission of Carbon Dioxide (CO2) into the atmosphere which triggers global warming. The present study also uses Life Cycle Assessment (LCA) as a tool to address the major environmental concerns in the construction of residential buildings. SimaPro 8.4 is used to assess and verify the overall performance of the project in terms of its maintenance and quality. Also, the amount of CO_2 generated due to use of machinery for construction was found to be 3485.01 and the CO_2 emissions due to the manufacturing of building materials were 18629.021 tonnes and were compared with alternate databases. The percentage difference in the value of CO2 emissions when an alternate database was used, was found to be 27%. The embodied energy associated with this building was also calculated and it was found to be 15.65 TJ. An actual building case study constructed using pure cement was chosen to apply the concepts of LCA and compare the results with the alternative materials.

Introduction

The construction sector is damaging the environment by being the primary contributor in generating Green House Gases (GHG). GHG emissions are responsible for global warming. Carbon Dioxide (CO_2) is the principle GHG. The rampant growth of construction sector has therefore led to alarming increase in global warming. As per a report by the UK Green Building Council, the CO_2 content in the atmosphere is estimated to be doubled by 2100. Drainage of natural resources, environmental damage and GHG emissions have become driving factors for initiation of sustainable construction practices. As per C.K. Chau et al. 2015, Life cycle study comprises of three sub-categories: Life cycle assessment (LCA), Life cycle energy assessment (LCEA), and Life cycle carbon emission assessment ($LCCO_2A$).

The building sector accounted for nearly 40% of the world's energy consumption, 30% of raw material use, 25% of solid waste, 12% of land use, and 33% of the related global greenhouse gas (GHG) emissions [SBCI, UNEP 2009]. As per the latest report by India Environmental Change [Jos G.J. Olivier et al., 2016], net annual CO2 emission for India during 2015 increased to 2.47 billion tonnes which was 5.1% more than in 2014. Energy from fossil fuels consumed in the construction and operation of buildings accounts for approximately half of the UK's emissions of carbon dioxide [Ben Stubbs, 2008]. As concluded by Cass and Mukherjee (2011), 90% of GHG emissions throughout the construction phase were due to production of materials. For India alone, CO2 emissions from cement and steel production increased by 4.9% and 2.4% for the year of 2015 as compared to 2014 [Ben Stubbs, 2008].

Hong et al. 2014, analysed GHG emissions during the construction phase of a case study building in China and concluded that building material production and transportation, on-site electricity usage were three of the greatest contributors for GHG emissions. Atmaca et al. 2015 concluded that the operational phase accounted for 79-84% of total energy requirements and 86-93% of total CO2 emissions, over a life span of 50 years, for a residential building each in rural and urban area of Gaziantep (Turkey). As concluded by Bribián et al., building materials are the second most energy consuming for a residential building after heat consumption during the operational phase. Seo et al. 2016, concluded that, for a building complex, materials production accounted for 94.3% of the net CO2 emission and CO2 emissions from the material transportation and on-site construction were merely 2.4% and 4.2% of the total emissions, respectively. They also concluded that choice of input materials and construction process plays a vital role in reducing CO2 emissions.

Bribián et al. 2011, concluded that, the impact of construction materials can be significantly reduced by substituting the use of finite natural resources for waste generated in other production processes, preferably available locally. As concluded by Bansal et al. 2014, the use of autoclaved aerated blocks (AAC) instead of burnt clay bricks in construction of a four storied building proved to be more energy efficient. As per Ortiz et al. 2009, the application of LCA is essential for in building and construction sector and can be utilized as a decision making tool in the construction sector. As concluded by Takano et al 2015, the life cycle energy efficiency increases as the geometrical factors become better for ex. perimeter to area ratio. They also concluded that life cycle energy efficiency of a building increases as the number of floors and stories increase. As concluded by Takano et al 2015, the energy differences between alternate materials were more prominent in the production stage of the building and also that use of recyclable materials greatly influenced the life cycle energy of the building.

Objective of the study

Life cycle accounting of any process or a product is imperative as it addresses the parameters in the process that impact or contribute the most towards environmental deterioration. Given the lack of studies conducted on life cycle accounting in the Indian context, this study aims at setting an illustration for a typical residential building in India. This study also identifies the issues associated with a life cycle study during various phases and the possible alternatives that can be suggested. Finally, the study suggests alternate construction materials that can be used to reduce the net impact during the process. An eight storey residential apartment building, under its final stage of construction, at the Hyderabad Campus of BITS Pilani was chosen for this study to address the following objectives:

- Characterization and quantification of the environmental impacts of the various construction materials that have been used for the building.
- Identifying the impacts of self-consolidating concrete mixes with waste materials like fly ash and (ground granulated blast furnace) GGBS.
- Suggesting possible alternatives to reduce these impacts to reduce the overall life cycle impact of the overall process.
- Quantify the greenhouse gas (GHG) emissions from construction materials and from the on-site machinery used during the construction phase.

Methodology

As per C.K. Chau et al. 2015, life cycle study comprises of three sub-categories: Life cycle Impact Assessment (LCIA), Life cycle energy assessment (LCEA), and Life cycle carbon emission assessment (LCCO2A). Any life cycle study is carried out for the life time scale of a product, that is, right from its birth to its demolition or dumping phase. The life cycle phases for the building are illustrated in figure 1 (Flow diagram for the entire process). This scale includes the raw materials extraction for the manufacturing of the product, their transportation to the manufacturing plant, the manufacturing of the materials, transportation of the materials to the construction site, the construction phase, the operation or the use phase of the building, maintenance and repair followed by the end-of-life or demolition phase of the building. As there exists uncertainty when it comes to operational phase and maintenance and repair, it becomes difficult to quantify the impacts of these phases. The impacts during these phases highly depend upon the nature of inhabitant. Hence, for this study, only the cradle to gate system boundary has been investigated. This practice of focusing on a particular area instead of the entire boundary system is called streamlined LCA.

LCA was conducted as per the framework and the norms laid by the ISO 14040 series and the databases used was the Ecoinvent 3.0, (United States Environmental Protection Agency) USEPA and the (Inventory of Carbon and Energy) ICE 1.6 from the university of BATH, United Kingdom. SimaPro 8.0 was used as the LCA tool for the study.

Life Cycle Impact Assessment

Life Cycle Impact Assessment is carried out in 4 stages which are Goal and Scope definition, Inventory Assessment, Impact Assessment and Interpretation.

* Goal and Scope Definition: Defining the purpose of the study, system and functional boundaries of the study.

* Inventory Analysis: Collection of all the input data relation to energy consumption, material usage etc.

* Impact Assessment: Quantification of Environmental impacts and input resources.

* Interpretation: Interpreting the results calculated from assessment stage and recommending suitable improvement measures.

Before carrying out LCIA, it is necessary to define a functional unit. The functional unit considered for this study is cubic meter. This study was carried out for cradle to gate system boundary and it considered the manufacturing of the construction materials and their transportation to the construction site, on-site machinery and electricity usage during the construction phase of the building.

The interpretation stage consists of the following major steps: classification, characterization, normalisation and weighing, of which procedure up-to characterization stage is mandatory and normalisation and weighing are optional, per the ISO 14044. The impact of any product or a process is translated into various impact categories. For LCIA, there are two possible approaches for interpretation of results; the mid-point approach and the end-point approach. The mid-point approach classifies impacts via impact categories such as ozone layer depletion, global warming potential, acidification and eutrophication potential which depicts a complete picture of the impacts. The end-point approach distributes the impacts into categories like damages to human systems, eco-systems and resource depletion, which are easier to convey to the society. However, the mid-point approach reveals more accurate and comprehensive results with a lesser set of uncertainties than compared to end-point approach [Curran MA. Encyclopaedia of ecology. Elsevier; 2008.]. Therefore, mid-point approach for interpretation was used for the impact assessment in this study.

Life Cycle Carbon Emission Assessment (LCCO$_2$A)

During the construction process, there is release of carbon dioxide gas, methane, nitrogenous oxides and many other gases. Carbon emission accounting quantifies the amount of carbon dioxide gas released during the entire life cycle of the product i.e cradle to grave i.e for the initial phase, construction phase, operational phase and the demolition phase(**Figure 2 system boundaries**). Carbon accounting is a form of impact assessment which takes into account the impacts of climate change due to the construction process. The carbon impacts of the operational and the demolition phases are future impacts and thus can only be projected. It becomes difficult to predict the GHG emissions during the operational phase of the building as it depends upon the amount of electricity and heating services used by the residents, the frequency of repair and maintenance work for the building and even the building architecture. Owing to this difficulty and to avoid assumptions and discrepancies, the study mainly focuses on the initial and the construction phase of the building.

As per the (Intergovernmental Panel for Climate Change) IPCC norms, carbon accounting is carried out by two methods, which are top-down or long term approach and bottom-up or short term approach. The top-down approach consists of calculating the long life emissions of the product i.e right up to the stage of demolition. Top-down is approach is further classified as the Reference Approach and Sectorial Approach. The top down approaches express the impacts to the economy or various economic sectors rather than actual emissions at the plant. As tis approach estimates the long life impacts, it highly depends upon the service life of the building, which in most cases for a residential building is more than 50 years. Therefore, for a building during its final stage of construction, it is difficult and involves assumptions to estimate the carbon emissions for its service life.

The bottom-up approach consists of the calculation for short term carbon emissions which are those occurring within twenty years of the fuel use. Bottom-up approach takes into account the fuel consumption activities and estimates the amount of carbon dioxide released. It can work effectively if reliable databases are available or relevant data is obtained from the enterprises which consume the fuels. The approach uses the schedule of activities of fuel consuming equipment or the activity level directly correlated with fuel consumption to quantify the carbon emissions. As relevant databases and other datasets are available, the bottom-up approach is used to carry out carbon accounting in this study.

The expression for carbon accounting is given as follows:

$$\text{Carbon Account} = Q_i \times EF \qquad \text{Equation (1)}$$

where Q_i : Quantity of the construction material and EF: Emission Factor.

The amount of carbon dioxide released into the environment represents the respective climate change that occurs. For any process, along with carbon dioxide, there are many gases that are released like methane, nitrogenous oxides like N2O, CFC-11 etc. The impacts of these different gases will vary and hence there is a need to connect these various impacts. Global Warming Potential (GWP) which translates the emissions of a specific gas into its respective carbon dioxide equivalent was used for this study. **The Intergovernmental Panel on Climate**

Change (IPCC) has developed three sets of GWP to account for the impact of a particular GHG with the same amount of CO2 under the constraint of a set time horizon (TH). Therefore, GWP is the integral of the global warming effect of GHG compared with that of CO2 in the same time interval. Three TH are commonly calculated, namely 20 years, 100 years, and 500 years. IPCC's First Assessment Report (Tegart et al. 1990) quoted an atmospheric life-

span of CO_2 to be between 50 and 200 years. Therefore, it is common to use the IPCC 100 TH GWP. For methane, the conversion coefficient is 25 and for nitrous oxide is 298. Hence, the amounts of methane and nitrogenous oxides released are then further converted to equivalent kg CO_2 by using GWP factor. The equation for the conversion is given as follows:

Account = Q*i* x EF x GWP Equation (2)

Therefore, the overall carbon emissions for any process or a product is the net summation of carbon emissions from all the contributing elements in the process. The final expression for carbon emissions is

Overall Account =

=

Equation (3)

The study addresses various emission sources, classifying them as direct and indirect emission sources to comprehensively depict the GHG emissions associated with a construction process.

Life Cycle Energy Assessment (LCEA)

Life cycle energy analysis is an approach that quantifies all energy inputs for a building over its entire

life cycle

. The system boundaries for the energy analysis are illustrated in figure 3. The system boundary comprises of manufacture, usage and demolition phases for the building. The manufacturing phase comprises of the production of the building materials, their transportation to the construction site and energy consumption in the erection of the building. The use phase of the building consists of all energy requirements such as electricity, heating, air conditioning etc. It also comprises of timely maintenance and repair works. Finally, the demolition phase includes the destruction of the building and activities related to the transportation of the materials to recycling plants or landfills.

Embodied energy is thus defined as the energy consumed during the manufacturing of the building. It includes all the energy of the building materials, energy consumption in the construction of the building and also the energy used in maintenance and repairs. The energy of building materials is the energy used in the extraction of raw materials, manufacturing of the materials themselves and their transportation to the construction site.

Embodied energy is classified into two types; the initial embodied energy and the recurring embodied energy. Every building requires maintenance and undergoes repairs due to several reasons. The recurring embodied energy is defined as the energy inputs required for the maintenance and the repairs for any building over its entire life. As the frequency of repairs and maintenance will differ for every building, it is difficult to quantify the recurring embodied energy (Er). The energy of the manufacturing phase is called the initial embodied energy. It is given by the following equation:

Ei = Qi x EM Equation (4)

where Qi: Quantity of the construction material and EM: Energy content of the material per unit of its amount.

Energy consumption in the demolition phase of the building is called the demolition embodied energy (DE). The energy consumed in the use phase is called operational embodied energy (OE). Electricity usage, HVAC (heating, ventilation, air conditioning), lighting are included under operational embodied energy. This form of energy is highly dependent upon the weather conditions, the behavior of the inhabitant and required level of the comfort and thus is difficult to predict. Thus, the study only evaluates the initial embodied energy for the building.

The summation of all the energies is called the life cycle energy for the building. It is given by the following equation

Case Study

Description of Project

The building chosen for the study is an

eight-storey

residential apartment building which is a part of the extension plan for faculty and staff housing at the Hyderabad campus of BITS Pilani. Each floor consists of two of each type of apartment, Type B, and Type C respectively. The specifications of each apartment are presented in Figure 1 and Figure 2. There are also service and main lifts. The entire building was made up of Reinforced Cement Concrete (RCC) as the load-bearing structural component and AAC blocks were used for masonry work.

Scope of the account

The study covered the impacts for the cradle to gate boundary system for environmental impact assessment, carbon accounting and energy accounting for the building. It covered impacts arising from manufacturing of the construction materials, their transportation to the construction site and the machinery used for the erection of the building. It also articulates the direct and indirect emissions of GHG arising from all of these activities.

Data Collection

To maintain the accuracy of the process data, the authors enlisted help from the project manager, site engineers, and contractors. Further details were extracted from the documents like the schedule of work, bill of quantities, activity log, etc. Priority was allocated to different sources based on the authenticity of the data. Table 1 depicts the data source and the priority allocated to the respective data sources.

Building Relevant Data

The quantities and specifications for the materials used for the construction of this building were extracted from the BOQ obtained by the project manager. Table 2 represents the materials used and their respective quantities. The transportation distances for all the materials have been selected after consulting with the projected manager.

The machinery used during the construction process is also significantly responsible for contributing to the CO_2 release. Various types of machinery that are generally used during a construction process are bulldozers, concrete mixers, concrete pumps, cranes etc. So, for this study, a certain set of diesel operated machinery was selected after consulting with the site engineer. Table 3 represents the machinery used, their purpose and the machine capacity.

Quantification of the GHG emissions

The quantification of the emissions occurring from the activities occurring during the construction period () will be in accordance with the ISO 14064 series, for both direct and indirect emissions. All the emission factors related to the manufacturing of building materials and transportation has been taken from the Ecoinvent 3.0 database and data related to the machinery has been taken from IPCC 2006 and company website.

Majority of machinery or construction equipment run on fossil fuels like diesel or petroleum and some on electricity. Naturally, they are bound to emit various gases like carbon dioxide, xmethane, nitrogenous oxides, (Chlorofluorocarbon) CFCs etc. The IPCC 2006 guidelines have suggested emission factors for types of machinery running on diesel. The calorific values and emission factors (or more correctly, the carbon content) of fuels, being the intrinsic properties of fuels, depend from country to country and location to location as the source of extraction of these fuels varies.

Therefore, there arises a need for employment of correction factors to closely relate the dataset suggested by IPCC guidelines to the

fuel

data of a respective country. Therefore for India, the net calorific value for diesel is 10,800 kCal/kg or 45187 kJ/kg (1 kCal/kg = 4.184 kJ/kg) as per. Therefore, the correction as per (CHINA paper) is depicted in the equations below:

Corrected emission factor = EF_{IPCC} x Cdiesel Equation (6)

where EFI_{PCC}: Default emission factor from the IPCC guidelines and Cdiesel: Net calorific value for diesel oil.

The default emission factors from the IPCC guidelines are 74100, 4.15, and 28.6 kg/TJ for CO_2, CH_4, and N_xO respectively. As per equation 6, the corrected values for diesel oil are as follows:

Corrected EFCO2 = 74100 kg CO2/TJdiesel x 45187 kJ/kg_{diesel} x 10-9 = 3.35 kgCO2/kgdiesel

Corrected EFCH4 = 4.15 x 45187 x 10-9 = 3.35 kgCO2/ kg_{diesel}

Corrected EFNxO = 28.6 x 45187 x 10-9 = 3.35 $kgCO2/kg_{diesel}$

As for the building materials, manufacturing of building materials are the second largest contributors after the operational phase. Due to lack of database in the Indian context, the quantification of GHG emissions becomes difficult. Therefore, for this case study, the Ecoinvent 3.0 database was adopted for the emission factors. Although these factors are developed in Switzerland, they still give an estimate as to which parameters contribute more to the construction process. For the transportation of the construction materials, the distances were assumed as per the data are given by the project manager. Emission factors for transportation were also taken from Ecoinvent database and were in terms of (tonnes-km) tkm. As for the construction phase of the building, the data for machinery used in the construction and their use schedules were all obtained from the site engineer. The emissions from the machinery usage were calculated as per the IPCC norms and methodology as described earlier.

Results

Impact Assessment from SimaPro

Impact assessment results for materials are relative to each other. Figure 5 represents the impacts assessment results for two types of masonry used Normal Fired Clay Brick and AutoClaved Aerated Block (AAC) masonry. Fired clay brick are the ones that are most commonly used in the construction sector. It is clear that fire clay bricks contribute way more than the AAC blocks with respect to every impact category. Their higher contribution implies that their production leads to more emissions into the atmosphere (Global Warming and HH criteria pollutants), into the air (Eutrophication and Smog) and requires more energy input (Natural Resource Depletion). Figure 6 validates this observation as CO2 emissions by fired clay brick are way higher than AAC blocks. (Global warming is measured in terms of CO_2 emissions).

The life cycle assessment results for three concrete mixes, Conventional concrete, concrete with fly ash and concrete with GGBS, are shown

is

Figure 7. As observed, concrete mix with GGBS contributes lowest to the global warming potential but highest in eutrophication and smog potentials. This can be accounted by the fact the GGBS handling and air cooling

requires

resources which lead to these activities. Although GGBS contributes positively with respect to ecological toxicity, its overall negative impact supersedes it owing to its high contribution in eutrophication and smog impact categories. Thus if only global warming potential is being considered as the decision making parameter, GGBS is the optimal choice. But if overall contributions are evaluated, fly ash is the optimal choice, as its overall contribution is relatively lower with respect to GGBS. Figure 8 validates this observation as GGBS concrete mix is the lowest contributor

in

CO2 emissions.

After investigating for the most optimal concrete mix design, the overall environmental impact of these concrete mixes in combination with alternate masonries is to be evaluated. Life cycle studies are carried for two cases: 1) Alternate concrete mixes using normal Fire Clay Brick masonry and 2) Alternate concrete mixes using AAC masonry. Figure 9a and 9b represent the overall environmental impacts for all three combinations for the building. For case 1, the approximate scores of Conventional concrete, FA mix and GGBS mix with Clay Brick for global warming are 120,115 and 110 respectively. For case 2, the scores for Conventional concrete, Fly Ash mix and GGBS mix with AAC masonry for global warming are 60, 55 and 25 respectively. Thus, the environmental impact is significantly reduced if supplementary material like GGBS and FA are used. But, as seen earlier, overall scores are needed to be considered before making the decision. Hence, use of FA with AAC masonry serves as the optimal choice.

In reference to table 1, life cycle assessment for all the building materials is carried out. For the all material inputs, three cases have been considered. 1) Material inputs with conventional concrete and AAC masonry, 2) Material inputs with Fly ash concrete mix and AAC masonry and 3) Material inputs with GGBS concrete mix and AAC masonry. The relative distribution of impacts of these cases is shown in Figures 10a, 10b, and 10c. For all three cases, Steel, Concrete, Italian Marble, and AAC masonry are found to make the most significant contribution to all impact categories followed by granite flooring and paint. For other materials like sand and Kota stone, the impact is relatively negligible. For global warming impact category, case 1 has the highest score followed by case 2 and case 3. Therefore, if only global warming is to be addressed, case 3 is the optimum choice.

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Carbon Accounting

Indirect emissions - For manufacturing of construction materials

Using the mentioned data for the building, databases, and equations, the net GHG emissions have been calculated. Figure 2 shows indirect GHG emissions. The contribution of each building material towards CO2 generation is shown in Figure 11. The total CO2 emissions in figure 11 are 1030.742 tonnes. Concrete leads the contribution followed by steel and AAC masonry. Construction materials like paint and safety grill contribute relatively less as compared to the other materials. For steel, the main component in steel manufacture is coking coal. When coal is burnt at high temperatures or carbonized in an oven until it becomes coke. This coke is then cooled and used in the blast furnace. Coking coal contributed up to 50% of the energy sources used for the production of steel followed by electricity (35%). Obtaining of coke from coal releases high amounts of carbon dioxide and other air emissions like naphthalene, coke dust, and sulfur. For concrete, cement manufacturing process is the leading cause of CO_2 release to the environment. In the cement production process, the clinker burning process is the leading cause of environmental emissions and energy drainage. For every mole of clinker produced the balance is emitted to the air in the form of CO_2 waste. The reaction is as follows:

For various alternate masonry considered, the emissions arising from the masonry alternative utilized for the same building are shown in table 5. Conventional fired clay brick masonry has the highest emissions while sand lime masonry has the lowest.

Table 6 represents the amount of methane and nitrogenous oxides released in the manufacturing of the construction materials. Calculated as per the aforementioned methodology, table 6 represents the CO2 equivalents for methane and nitrogenous oxides. Therefore, the total CO2 releases to the environment due to the manufacturing of building materials is 18629.021 tonnes.

Indirect emissions - Carbon accounting for the transportation of Construction Materials

The amount of releases to the environment also depends upon the distances from which the construction materials are obtained. Table 7 represents the assumed the type of vehicle used in the transportation of various construction materials.

The distances from where the construction materials are transported play an important role, both environmentally as well as economically. Figure 11 represents the contribution of emissions from transportation of various materials. The amount of CO2 released during transportation is 127.67 tonnes. Transportation vehicle capacity and its efficiency, the distance of the construction site form the manufacturing plant and the amount of material are factors affecting the CO2 emissions. Concrete, with 4876.8 tonnes of CO2, leads the contribution it is required in the highest amount during construction.

As per equation 1 and 2, Table 8 represents the total methane and nitrogenous oxides released during the transportation of building materials and also the respective net CO2 equivalents. The total CO_2 emissions during the transportation of construction materials is 190.861 tonnes.

Therefore, the net emissions arising from the indirect emission sources; manufacturing of building materials and transportation of building materials is 18819.882 tonnes. The manufacturing of building materials contributes dominatingly with 98.9% of the total indirect emissions. Therefore, selecting alternate building materials with lower carbon content and selecting nearby product suppliers can be regarded as an effective strategy to reduce the emissions. Also, it is required to compare these results with other available literature.

Direct emissions - Carbon accounting for the on-site construction machinery used

The machinery used during the construction process is also significantly responsible for contributing in the CO2 release. Various types of machinery that are generally used during a construction process are bulldozers, concrete mixers, concrete pumps, cranes etc. So, for this study, a certain set of diesel operated machinery was assumed. Table 9 represents the machinery used, their purpose and the machine capacity.

Table 10 represents the total CO2, CH4 and NxO emissions arising due to the usage of the diesel operated equipment. It also represents the net total equivalent emissions, calculated as per the methodology described earlier, arising due to the on-site machinery used.

Therefore, the total CO2 emissions accounting for the direct emissions is 3485.01 tonnes. Thus, use of machinery and equipment in the erection of a building contribute significantly higher than the transportation of building materials.

Carbon accounting using alternate database

One of the drawbacks bottom-up or shot term carbon accounting approach is that it is dependent on the database used for extracting the emission factors. A database developed in a particular country if from the information available for that country. For example, the manufacturing of steel in London will be different than that in Hyderabad, as the source of raw materials is different, the technology used is different and the fossil fuels used are from different sources. Therefore, the net carbon dioxide generated in the production of 1 ton of steel in London will be different than that for the 1 ton of steel produced in India. Similarly, for other construction materials, the values of these factors vary.

Thus, to study the impact of the change in the database on the emissions, alternate databases were used. Therefore in this study, the (Inventory of carbon and energy) ICE 1.6 database published by University of BATH (United Kingdom) has been used as an alternate database to the Ecoinvent 3.0 (European) database. As the methodology for calculating the carbon emissions remains the same, i.e the bottom-up approach, the same equations can be used again. Therefore, following the same set of IPCC norms (equation 1 and 2) and using the ICE 1.6 database, the total CO2 emission for the manufacturing of construction materials was calculated to be 1423.67 tonnes. The percentage change with respect to the CO2 emissions from the Ecoinvent database was found out to be 27%.

As a change in the database impacts the emissions from manufacturing of construction materials, the similar impact is observed for the vehicles used for transportation. For the transportation of building materials, the alternate database that was used in the study was the USEPA (United States Environment Protection Agency) database. Keeping the bottom-up approach constant and following the IPCC norms, the total CO2 emissions resulting from the transportation of building materials is 139.9 tonnes. The percentage change with respect to the CO_2 emissions from the Ecoinvent database was found to be 27%.

Energy Account

By applying corresponding emission factors from the ICE 1.6 database and using the bottom-up approach, the embodied energies for the building materials have been calculated. Figure 13 represents the contribution of various construction materials to the embodied energy. The total energy content of building materials is 15.65 TJ.

Steel and concrete lead the contribution as the number of energy sources required for their production are quite high. Production of clinker in cement manufacturing is the leading cause of high energies of concrete. Clinker production requires energy from petroleum and as high amounts of concrete are required for any building, concrete production leads to high energy consumption. In case of steel production, coal is required for producing coke. In the production of steel, this coking coal contributes more than 50% energy-wise. Therefore, burning of coal for the production of steel accounts for higher amounts of energy. Masonry (the type of masonry used in the building) follows after steel and concrete. As in the actual building construction, AAC masonry has been used instead of conventional brick masonry. The masonry is then followed by paint and marble usage as they show a significant amount of energy content. In case of sand (3%) and rubble (1%), the embodied energy is close to negligible. This is because, it was assumed that no process was used to extract sand and rubble, for example, blasting of rocks for rubble and only for their transportation resources were utilized. Although the embodied energy content for aluminum per kg is more than that for steel, the quantity of aluminum that was used in this building (as per Bill of Quantities) was comparatively lesser than the steel quantity. Therefore, the contribution of steel is significantly higher. Therefore, it is imperative to choose materials with lesser energy content. One of the leading contributors in terms of energy is steel. However, steel is one of those materials which, currently does not have a viable alternate substitute with lesser energy content which even satisfies in terms of engineering properties like structural strength. Hence, the steel type used for construction is unlikely to be changed. Building materials like concrete and masonry are also materials contributing heavily in terms of life cycle energy emissions. But unlike steel, alternate concrete mixes and masonry are available which even satisfy the structural requirements with respect to a conventional concrete mixture. Hence, concrete and masonry are the two building materials where lower energy content substitutes can be employed to reduce the energy content of a building. Therefore, using alternate concrete mixes and masonry can serve as an energy efficient strategy.

Discussions

To sum up, out of all the building materials used for construction, production of steel, concrete, and masonry leads to higher environmental implications with respect to the production of other building materials. Thus these three form the platform to implement alternative and greener substitutes, in order to bring down the overall environmental impacts. The AAC masonry had a lower environmental impact score with respect to conventional brick masonry. Using AAC masonry instead of conventional brick masonry would significantly reduce the environmental impact score for the building. As seen, using alternate concrete mixes like a concrete mix with fly ash and concrete mix with GGBS significantly reduce the environmental impacts. Therefore, implementing alternate concrete mixes and alternate masonry would ultimately reduce the overall life cycle impact of the building.

Further, the building material production cause for a comparatively higher amount of net CO2 release than their transportation to the site and even than the construction equipment used for the erection of the building. Production of building materials like cement and steel involves a large amount of fossil fuel energy use and as they are the primary construction materials used in any building, their energy and carbon content has a high impact on the life cycle properties of the building. As a result, using materials with lower carbon content would significantly reduce the GHG emission arising from these construction materials. Also, in this study, the impact of usage of construction equipment like a concrete mixer and concrete pumps was also studied. Concrete mixers and pumps are widely used at the majority of construction sites in India and hence, quantifying GHG emissions arising from them is of extreme importance. It is seen that GHG emissions resulting from them are even more than those from the transportation of construction materials. Therefore, careful utilization of these types of equipment is necessary as they add to the life cycle emissions of a building which can be done by implementation of appropriate construction management strategies.

Also, the production of building materials involves extraction of raw materials, for example, extraction of iron from iron ore for steel production. These extraction processes are carried out by using the energy generated by the burning of fossil fuels. As seen, production of building materials possesses high energy content. Therefore, the material choices that are made for a building determine the energy content of the building. Smart and effective choices in selecting construction materials are thus required to bring down the energy consumption. As for any building, there is not much that can be done to bring down the energy consumption and GHG emissions, once the operational or the use phase begins. Therefore, choosing greener materials for construction is imperative which can be only done at the start of the project or during the design phase of the building.

The study encompassed the assessment of life cycle impact for a building, the GHG emissions associated with the building and the embodied energy consumption for the residential eight-storey building. Throughout the entire process of this study, there were various problems identified that are needed to be addressed to improve further research. Firstly, the data relevant to the building were extracted from the bill of quantities. However, some of the data had to be estimated based on the building drawings and plans. Due to confidentiality of the construction firm, there were difficulties in collecting the data and in some cases had to be assumed. Due to unavailability of accurate data like the distance of transportation of construction materials, they had to be assumed. Working hours of machinery and their schedules were obtained from the bills and site engineer (Data priority table). Secondly, due to unavailability of the database in the Indian context, the material characteristics in the foreign database were thoroughly examined and were then chosen to represent the equivalent material in the Indian context. Therefore, there is a need to develop a database for India, in order to accurately carry out life cycles studies. Due to unavailability of datasets, confidentiality of firms and reluctance from contractors to give details pertaining to site leads to various assumptions and these assumptions lead to uncertainties in the life cycle study.

Conclusion

This study evaluated three major sub-categories of life cycle studies which are Life cycle Impact Assessment (LCIA), Life cycle energy assessment (LCEA), and Life cycle carbon emission assessment (LCCO2A). As construction sector is one of the largest contributors in energy consumption, it has led to several consequences like heavy emissions of GHG in the environment. Hence, a lot of scientists and researchers are now focusing on quantifying these emissions and impacts and are trying to bring them down. This study was carried out under the ISO 14064 guidance to evaluate the environmental impacts, the GHG emissions and the embodied energy for an eight-storey residential building in India.

For LCIA, the impact of various construction materials for the building were calculated using SimaPro 8.4 as an LCA tool. Use of AAC masonry instead of normally fired brick clay reduced the environmental impact significantly. Although sand-lime bricks have the lowest impacts than other alternatives, they are not used as they fail to satisfy structural requirements. As fired clay brick are denser than AAC blocks, for the given volume, their impact is much higher. If global warming was the main decision-making parameter, the most suited concrete mix was GGBS mix and the most suited masonry was AAC bricks. But, if the overall contributions to all the impact categories are considered, the mix with fly ash proved to be the most suitable option as GGBS production contributed heavily in eutrophication. Materials like steel, concrete, AAC masonry and Italian marble had most significant impacts on the building followed by paint and granite.

For LCCO_2A, the production of the building materials results in the release of various GHGs in the environment which affects the climate by causing global warming. In this study, the GHG emissions during production of various building materials were evaluated and it was found that concrete, steel, and masonry were the highest contributors. It was found that conventional fired clay brick was ranked highest in terms of net CO_2 emissions and AAC masonry was ranked third. It was also found that production of building materials contributed

98.9% to the indirect emissions arising from a building construction. Also, the machinery and equipment used in the erection of the construction site contributed more than that by the transportation of building materials. Implementing alternate technologies and employing greener materials for concrete and masonry would reduce the overall carbon dioxide emissions. Therefore, smartly using construction management tactics and wise usage of machinery would help reduce the life cycle emissions for a building. It was also found that there was a 27% difference for CO_2 emissions when the database was changed from Ecoinvent to ICE 1.6. This reveals that quantification of CO2 emissions highly depends on the dataset utilized. Hence, with respect to the Indian context, it is necessary to develop a dataset which would give a more accurate picture of life cycle emission for a building.

LCEA, for any building, is the energy content for that building. It helps in determining the parameters involved in the process which possess largest energy content i.e the parameters whose production involves highest energy consumption. For this study, it was found the concrete and steel are the construction materials which have the highest energy content. Therefore, alternate concrete mixes which possess greener materials like fly ash can be utilized to reduce the overall energy content of the building. Also, among the various types of masonry, conventional brick masonry possessed the highest energy content with 11878.75 MJ and AAC ranked fourth with embodied energy as 2966.7 MJ. Therefore, if AAC masonry were to be used, it would save up to 75% of the energy consumption i.e 75% decline in the usage of fossil fuels.

To summarize, this study only evaluated the manufacturing phase and the construction phase. Although the results have been obtained using Ecoinvent database, a foreign database, the study still gives an idea about which are the parameters that are responsible for the impacts. Thus, if these parameters are known, changes can be implemented and thus the overall impact and emissions and energy consumption can thus be reduced. Therefore, LCA can be used as a decision-making tool in selecting appropriate construction materials and practices. Use of recyclable materials can be beneficial as they save on energy consumptions and CO2 emissions both. Hence, the choice of materials and their sources should be given proper importance during the design phase of the building itself. Wisely choosing the construction materials and obtaining materials from nearby sources rather than far away distances will help in reducing the impact significantly.

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