Environmental Life Cycle Analysis of Office Buildings in Canada

F. A. Amin Ganjidoost and S. A. Sabah Alkass

Abstract—**In order to design sustainable and environmental friendly buildings, the impacts of the building on environment through its life cycle must be analyzed. Life cycle assessment is the best method to achieve this purpose. However, design and construction of office buildings is often not conducted with an assessment of life cycle environmental impacts. This paper presents a framework to assess the environmental emissions of office building through its life cycle stages which are: raw materials acquisition and manufacturing, construction, use / reuse / maintenance and end-of-life (recycle / waste management). The Environmental impact measured in Primary Energy (MJ), Solid Waste (Kg), Air Emission (index), Water Emissions (index), Global Warming Potential(GWP) (Kg) and Weighted Resource Use. Life cycle assessment framework of this study applied to an eight story office building in Canada. Then to observe the performance of the life cycle assessment method of the present study, alternatives to the base office building components are explored. The pre-cast concrete substituted with base office building floor and tilt up concrete with wall components. For the envelope components, triple glazed windows have been chosen to substitute with the windows of the base office. The results showed that the pre-cast and Tilt-up office Building had less impact on environment.**

Index Terms—**Life cycle assessment; office building; sustainability; environmental indicators.**

I. Introduction

Over the last few decades, the idea of sustainability has morphed from concept to a way of life. The depletion of natural resources has led the construction industry to explore alternatives in material selection as well as construction procedures. In the building industry, office Buildings rank number one, consuming more than 40% of total capital expenditures in commercial building market each year [1]. Guggemos (2005) says “Energy use and environmental emissions from office buildings can be reduced through a careful selection of embedded and temporary materials and construction equipment” [2].

Therefore, stakeholders of a project must not only find the quickest way to complete their work but also considering a way which has the least impacts on environment. Dell’lsola (1981) has a definition for the concept of office building which is “building designed for or used as the offices of professional, commercial, industrial, religious, institutional, public, or semipublic persons or organizations” [3]. This definition clearly clarifies the concept of office building. This research is based on the above definition.

II. Life Cycle Assessment (LCA)

“Life Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements” [4].

Cole (1996) have indicated: “The notion of Life-Cycle Assessment (LCA) has been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative materials, components and services” [5]. A life-cycle assessment (LCA) is a systematic, cradle-to-grave process that evaluates the environmental impacts of products, processes, and services. Its quality depends on the life-cycle inventory (LCI) data it uses. This study uses life cycle assessment as a method to assess the environmental impact of buildings.

Many studies have been done in area of life cycle assessment, but few of them were in the field of buildings especially in office building. For example: Canadian wood council in 1996 has done a case study for an office building. For this study, they used Athena institute LCA tool to compare the environmental impacts of wood, steel and concrete. The office building with wood had lower environmental impact [5]. In 2007 Xing, Zhang and Gao developed a life cycle inventory model for office buildings in china. In energy consumption and environmental emissions of the steel-framed and concrete-framed building materials, it was founded that steel-framed building is superior to concrete-framed building because it has life cycle energy consumption 75.1% as that of concrete, and the environmental emissions are less than 35.55% of concrete [6]. Also, CEDST: Construction Environmental Decision Support Tool is another example which looks specifically at the effects of the construction phase of commercial building. It allows designers and contractors to estimate the energy use, environmental emissions, and waste generation associated with the construction of commercial buildings [7].

Guggmos (2005) with using LCA quantified the energy use and environmental emissions during the construction phase of two typical office buildings structural steel frame and cast-in-place concrete frame. The results showed that the concrete has more associated energy use, CO2, CO, NO2, particulate matter, So2, and hydrocarbon emissions due to more formwork used. Larger transportation impacts due to a larger mass of materials, and longer equipment use due to the

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longer installation process. While steel frame construction has more volatile organic compound (VOC) and heavy metal (Cr, Ni, Mn) emissions duo to the painting, torch cutting, and welding of steel members [7]. Seppo Junnila (2004) has done a study on LCA of office building in Europe and U.S. He compare the potential environmental impacts caused by an office building during its life cycle (50 years) using both a multiple case study and LCA methods. The key environmental issues founded for electricity used in outlets, HVAC and lighting, heat in ventilation and conduction and material used in internal surfaces [8]. An interesting tool which called BuiLCA is been developed by Pedro Vieira 2007 at UC-Berkeley. This research developed a user-friendly hybrid LCA tool for office building that can be used to assess the environmental effects of all life cycle phases and the environmental consequences of decisions made over the life cycle of building. Also, this tool can assess the end-of life impacts of construction materials [9]. They applied this methodology to concrete and it has been founded that with increasing 27% of current recycling rate to 50% could lead to 2-3% reduction in global warming potential or equivalent to removing 612,000 cars from U.S. roads annually.

III. Study Methodology

This section represents the methodology of the present research. The impacts of office building on environment are carried out as following approach:

A. *Life Cycle Assessment (LCA) Approach*

The environmental impact of the office building thought its life cycle is carried out in three steps:

a) Data collection of office building

b) Emission quantification, using the LCA tool: Athena impact estimator

c) Results of the LCA process: environmental indicators

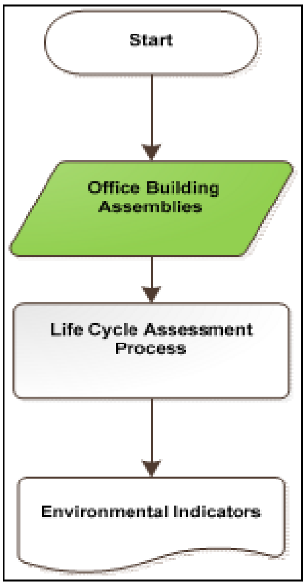

Fig. 1. Framework of Life Cycle Assessment Process

B. *Athena Impact Estimator*

The Athena sustainable material institute [10] has developed software called Athena impact estimator for analysis of the environmental implications of industrial, institutional, commercial and residential designs–both for new buildings and major renovations. Life cycle inventory of this software allows user to compare the environmental impacts of the building materials and assemblies through the life cycle of the building from the raw material acquisition to the end of life of the building. Athena software offers five categories of the assemblies including foundations, mixed beams and columns, floors, roofs and walls. For the other components, there is an option which called extra basic materials. The user can add the other components into this section. This system does not include the capability of an operating energy simulation, but allows user to input the result of a simulation to calculate the fuel cycle burdens and relate them to the overall results. The user may compare the results of the analysis in different summary measurements of: primary energy, water emissions, air emissions, solid waste, acidification potential, eutrophication potential, global warming potential, human health respiratory effectpotential, ozone depletion potential, weighted raw resource use, and photochemical smog potential.

The environmental indicators used in the study methodology based on the Athena Sustainable Material Institute are described as following:

• Primary Energy (MJ)

Primary energy or embodied energy is the amount of energy associated with raw material acquisition, processing, manufacturing, transportation and assembly of product or buildings materials.

• Solid Waste (Kg)

The solid waste generates during the extraction of raw materials, manufacturing, construction and disposal of the product or buildings materials. The solid wastes measured by Athena are the wastes of wood, concrete, steel, blast furnace slag and blast furnace dust.

• Air Emissions (index)

The Athena measures the emissions of the buildings materials or products from the extraction of material to the end of life. The air emissions of the products or buildings materials measured by Athena include sulphur oxides, nitrous oxides, carbon monoxide, hydrogen chloride, hydrogen fluoride, metals, methane, particulate and volatile organic compounds.

• Water Emissions (index)

Water emission is the quantity of water use associated with the building material process, including the liquid waste material which deposited into water bodies. The considered factors into water emission index include aluminum, ammonia and ammonium, biochemical and chemical oxygen; chlorides cyanides dissolved organic compounds, dissolves solids, iron, nitrates, metals, phenols phosphates, sulphates, sulphides, suspended solids and polymer aromatic hydrocarbons.

• Global Warming Potential (Kg)

The Global warming is defined as climate changes that cause an increase in the average temperature of the earth's atmosphere. This climate changes is the results of the increasing greenhouse gases emission into the atmosphere. The major cause of global warming is CO2. Carbon dioxide is the common equivalent reference measure of the GWP.

• Weighted Resource Use (Kg)

The Athena measures the amount of raw resource used in its mass and/or volume such as kilograms. The Athena accounted resources are coal coarse aggregate, fine aggregate, gypsum, iron ore, limestone, sand, shale, clay, ash, scrape steel, semi cementitious materials, uranium and wood fiber.

IV. Case Study

An eight story office building in Canada used as a case study to demonstrate the mechanism of the research method [11]. This building has a total gross area of 54,000 SF. This part represents a description of the base office building's components and alternative of the base office building.

A. Base Office Building

For the purpose of this study the targets are initially set at the impact level of the base office building. Then the possibility of improvements to these impact levels will explore. The size of the building is 60'*100' and the height of the floor to floor is 12'. The foundation is concrete spread and strip footings with 4'' concrete slab on grade and normal soil condition. The type of the building's columns is steel with wide flange. The floors consists of composite steel frame and deck with concrete slab. The roof is steel beams, opens web joist and deck.

B. Athena Building Assemblies

The version four of the Athena impact estimator software offers five types of building assemblies. For the foundation, the Athena considers the only concrete footing with concrete slab on grade. For the wall assemblies, Athena has seven types of concrete block, cast in place, concrete tilt up, curtain, steel stud, wood stud and insulated concrete form. It offers 7 types of column and 5 types of Beam. Also, eleven types of floor and roofing systems are considered. Extra basic materials have defined for the types of the assemblies which do not exist in the five types of the building assemblies. For example for the triple glazed windows, since the Athena offers only double glazed windows; therefore, an extra layer of glazing can added to the extra basic materials. The environmental impact of the mechanical and electrical systems of the building does not accounted in Athena software. So in the present case study, the impacts of the mechanical and electrical systems on environment have not investigated.

C. Alternatives of the Base Office Building

To observe the performance of the life cycle assessment method of the present study, alternatives to the base office building components are explored. Two types of the alternatives are chosen from the structural components, the pre-cast concrete substituted with base office building floor and tilt up concrete with wall components. For the envelope components, triple glazed windows have been chosen to substitute with the windows of the base office.

V. Results and Discussion

In this section the results of the environmental life cycle analysis of base office building and alternatives are presented.

A. LCA Results of Base Office Building

The results of the energy consumption of the base office through its life cycle shows that the foundation accounts for 0.7%, walls for 70%, beams & columns for 1%, roofs for 9%, floors for 19% and extra basic materials for 0.3% of total energy consumption in base office. The total consumption of the weighted resource use is 6624239.805 kg. The foundation accounts for 2.5%, walls for 39%, beams and columns for 7.85%, roofs for 8.43%, floor for 42.26% and extra basic materials for 0.02% of the total weighted resource consumption of base office construction materials. The total solid waste emissions are 726519.24 kg. The foundation accounts for 1.3%, walls for 64.6%, beams and columns for 0.4%, roofs for 1.85%, floor for 31.7% and extra basic materials for 0.15 %. of the total solid waste materials emissions. From the total air emissions of the base office's construction materials, the foundation accounts for 0.6%, and walls for 73.3%, beams and columns for 1.11%, materials for 0.2 %. The foundation accounts for 0.82%, walls for 69%, beams and columns for 1.44%, roofs for 9.18%, floor for 20.26% and extra basic materials for 0.3 %. of the water emissions of base office's construction materials through its life cycle.

B. LCA Results of Alternatives Base Office Building

This section represents the comparison results of Athena Life Cycle Environmental Impact of three alternatives of Pre-cast office, Tilt up office and Triple glazed windows with base office building. These results have been compared in six categories of global warming potential, primary energy, solid waste, weighted recourse use, water emissions and air emissions provided by Athena impact estimator version 4. Although the results of Athena life cycle environmental impact of each alternatives can represent separately, but it is most productive if the environmental impacts results of the changes to the base office building compared categories with the base office building. The results of life cycle assessment (for four environmental indicators) by assembly groups of alternatives are figured out in Fig. 2 to 5.

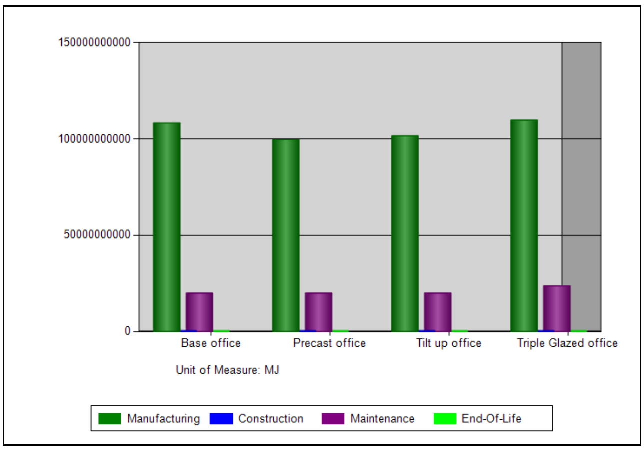

Fig. 2. Comparison of global warming potential by life cycle stages

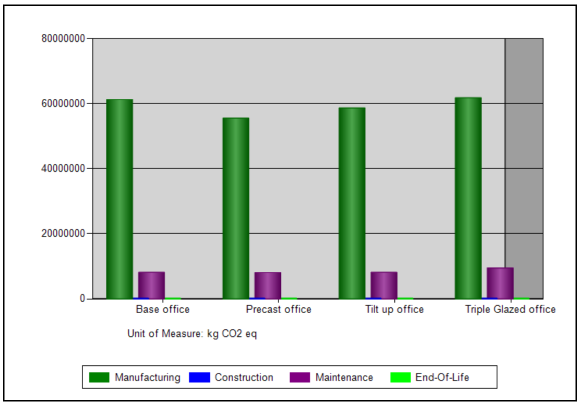

Fig. 3. Comparison of energy consumption by life cycle stages

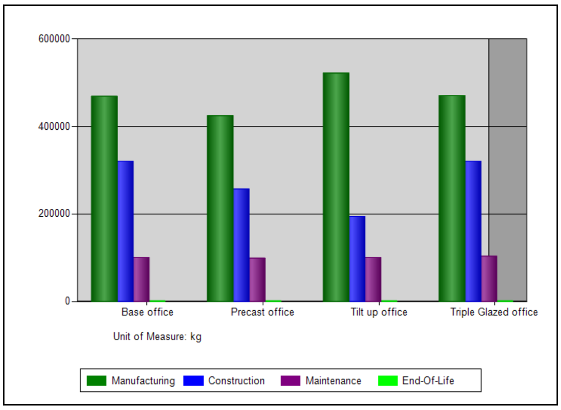

Fig. 4. Comparison of Solid waste by life cycle stages

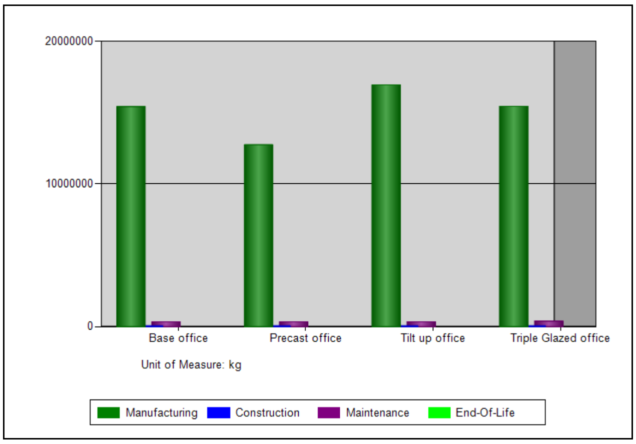

Fig. 5. Comparison of Weighted resource use by life cycle stages

The environmental impacts of the base office building and three alternatives of pre-cast, tilt-up and triple glazed windows measured by life cycle stages has been explored in Table I.

TABLE I: ENVIRONMENTAL INDICATORS SUMMARY MEASURE BY LIFE CYCLE STAGES

	Primary Energy (MJ)	Solid Waste (kg)	Weighted Resource Use (kg)	Global Warming Potential (Kg)	Air Pollution (Index)	Water Pollution (Index)
Base Office	22536626	726519	6624239	1391509	36468868	1.086e+11
Pre-cast Office	20120840	617209	4673594	1180705	34129195	9.97e+10
Tilt-up office	18813709	607929	7632554	1274214	34819309	9.53 e+10
Triple Glazed office	22693704	730830	6697881	1445916	39974017	1.38e+11

Changing from base office to pre- cast floors resulted in decrease of 11% of primary energy, and also, 17% decrease in changing to tilt-up walls. While substitution of triple glazed windows led to increase of 0.7% in primary energy. Substituting of the base office to pre-cast office led to a 15% decrease, and 16% decrease for changing to tilt-up office while Substation with TGW resulted in 0.6% increase. The result of substitution of base office with pre-cast office led to 29% decrease of weighted resource use of construction materials, 15% increase for tilt-up office, and 1% increase in changing to triple glazed windows. The base office produces 1391509.262 kg Co2. Substitution with pre-cast office led to 15% decrease in global warming potential, and 8% decrease in changing to tilt-up office. Substitution of triple glazed windows resulted in 4% increase of global warming potential. Changing to pre-cast office led to 6% decrease in air pollution. Also, the pollution of tilt-up office on air is 4.5% less than base office, but TGW has 10% more pollution on air in comparison with base office. Comparing with base office both of the pre-cast office and tilt-up office have less water pollution. The water pollution of pre-cast office decreased in 8% and tilt-up office in 13%, while for triple glazed windows increased by 27%.

VI. CONCLUSION AND FUTURE WORKS

The study reviewed the concept of life cycle assessment. Also, this work reviewed previous studies in life cycle assessment of office buildings. Methodology of the research applied to an eight-story office building case study to demonstrate the application of system. Two structural components and one envelope component were compared basis of the six environmental indicators. The result of the case study was found the optimum alternatives of pre-cast and tilt-up office buildings which have the lower environmental impacts. Stakeholders of a project must not only find the quickest way to complete their work but also considering a way which has the least impacts on environment. Although the result of case study was shown pre-cast and tilt-up office building have lower impacts on environment, there are several other factors to consider when selecting the best method applicable to the project. This study had only one objective, mitigating impacts of office building on environment throughout its life cycle. To consider multi objective in the methodology such as minimizing life cycle costing can open a new research title for future works.

Finally, the variables of the case study analysis were limited to consideration of two structural and one envelope components. Increasing the number of variables can results more accurate selection of optimum solution since the project stakeholders are considering more alternative.

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