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Post Occupancy Life Cycle Analysis of a Green Building Energy Consumption at the University of Western Ontario in London - Canada

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***Abstract*—**The CMLP building was developed to be a model for sustainability with strategies to reduce water, energy and pollution, and to provide a healthy environment for the building occupants. The aim of this paper is to investigate the environmental effects of energy used by this building. A LCA (life cycle analysis) was led to measure the real environmental effects produced by the use of energy. The impact categories most affected by the energy use were found to be the human health effects, as well as ecotoxicity. Natural gas extraction, uranium milling for nuclear energy production, and the blasting for mining and infrastructure construction are the processes contributing the most to emissions in the human health effect. Data comparing LCA results of CMLP building with a conventional building results showed that energy used by the CMLP building has less damage for the environment and human health than a conventional building.

***Keywords*—**Environmental Impacts, Green buildings, Life Cycle Analysis, Sustainability

I. Introduction

ENVIRONMENTAL degradation, resource depletion and climate change are some of the important environmental sustainability issues that world has been dealing with over the last several years. Industry, including the building sector, started to recognize the impact of its activities on the environment in the 1990s [1]. In 1992, the Agenda 21 [2], was signed at the UN Conference on Environment and Development, in Rio de Janeiro, and proposed key policies for achieving sustainable development that meets the needs of the poor and recognizes the limits of development to meet global needs. Besides, the document proposed several activities to decrease the environmental impact of civil construction such as the need for greater efficiency in the use of energy and resources, minimization of waste generation and sustainable consumption.

According to the United Nations Environment Programme [3], the building sector is responsible for more than a third of the annual global resource consumption, including 12 per cent of all fresh water use, and generates forty per cent of worldwide solid waste.

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The concerns about the enormous ecological footprint of the built environment, gave rise to the development of green initiatives that seek to minimize the damage it causes.

The adoption of the environmentally friendly building techniques can help to reduce energy consumption and greenhouse gas emissions [4]. Furthermore, going green contribute to increase economic savings and occupants health benefits and also are are an important initiative to bring carbon dioxide emissions back to 1990 levels, as required by the Kyoto Protocol; a critical proactive step to combat climate change [5-6].

Rebitzer *et al.* [7] have noted that in order to achieve sustainable development it is important to use reliable tools and methods to quantify the environmental impacts of providing goods, services and products to society. Through the years, a few green building rating systems were emerging to assess and evaluate the performance of green buildings or a specific part of the building from planning, designing, constructing, and operations. Nowadays, the LEED rating system, developed by the U.S. Green Building Council (USGBC), in 2000, to provide a framework of implementing practical and measurable in green building design, construction, operations and maintenance solutions, is the most commonly used tool in the built environment – 23,009 projects certified, among them 10,155 commercial projects and 12,854 residential homes [8].

The USGBC embraces different LEED rating systems according to building types and uses: New Construction, Commercial Interiors, Core and Shell, Existing Buildings and Homes. It classifies green buildings according to their features in six broad categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation and design. Projects can award one certification level - certified level, silver, gold or platinum - depending of the total of points achieved.

This study aim to provide a briefly overview of green buildings thought the literature review of definitions, benefits and barriers; and to present the case of the study of the University of Western Ontario through a presentation of main features and an energy consumption LCA.

II. Life Cycle Assessment Methodology

The life cycle of a building encompasses all the processes from extraction of natural resources, through material production, construction, operation, and demolition. All these processes and related activities consume natural resources and release substances into the natural environment, creating environmental impacts such as climate change, ozone depletion, eutrophication, toxicological stress on ecosystems and human health and the degradation of natural resources, among others. LCA encompasses the collection and evaluation of quantitative data on the inputs and outputs of material, energy and waste flows associated with a product life cycle [7-9-10]. The International Standard Organization (ISO) standardized the LCA in four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation.

In brief, the meanings of these phases are:

- Goal and scope definition: Includes the definition of the product system and functional unit, establishes the context in which the analysis is to be made and identifies the boundaries and environmental effects to be reviewed for the assessment.
- Inventory or life cycle inventory (LCI): Includes data collection and the quantification of relevant inputs and outputs of a product, as energy, water and materials usage and environmental releases.
- Impact assessment or life cycle impact assessment (LCIA): Calculation and interpretation of indicators of the potential impacts associated with such exchanges with the natural environment.
- Interpretation: Evaluates the LCI and LCIA information, checking that the requirements of the application as described in the goal and scope of the study are met.

The LCA methodology can be applied in the building sector at different process stages with a variety of purposes. Bribián *et al.* [11] note that architects, engineers and consultants use the LCA in preliminary phases, early design (sketch) and design of a renovation project, to select products or process, to size a project, to set targets at municipal level and choose a building site. Furthermore, Arena and Rosa [12] also highlight that LCA can be applied to buildings to identify opportunities to reduce energy consumption and emissions with negative environmental impacts during building use and operation.

III. Green Buildings

A. Definition and Performance Building Characteristics

The term “green building” is used to describe structures and processes that are environment-friendly, resource-efficient, provide comfort and safety and protects human health, throughout a building's life-cycle. For the United States Environmental Protection Agency: “Green or sustainable building is the practice of creating healthier and more resource-efficient models of construction, renovation, operation, maintenance, and demolition” [13].

Usually, green buildings use construction materials that have low environmental impact, renewable energy, waste recycling, high energy-efficient systems, water conservation, pollution prevention and waste reduction, high durability and decrease in the use of automobiles [14]. Furthermore, green buildings aim to promote occupants physical and mental well-being by maintaining high levels of indoor air quality and comfort through the use of natural ventilation, integration of the natural environment with the building, low-toxicity finishes and furnishings, daylight and adjustable windows and fans that enable personal control over ambient conditions; increasing also the occupants productivity [6-13-15-16].

B. Benefits and Barriers

The are lots of green buildings benefits, among then it can be highlighted: reduction of water and energy cost and maintenance costs, “carbon footprint” reduction, increase of the value from higher net operating income and increase of the public relations for commercial buildings, productivity improvements for occupants, more competitive real estate holdings for private sector owners over the long run, health benefits as less risk of occupants exposure to irritating or toxic chemicals in building materials, furniture, and furnishings; reduction of infrastructure costs and transportation, marketing benefits, and tax benefits and incentives [6-17-18].

Meantime, still there are barriers to the adoption of green buildings. High costs of adopting and investing in green buildings represent the main barrier, roughly, green buildings can cost 0% - 4% more to build than a conventional one, but the green one can provide a wide range of financial, health and social benefits. Normally, this costs are higher when green design is incorporated in the mid of project, when there is a lack of time to research materials and technologies options, and when there is no experience with green buildings. Green buildings can reduce the energy use by an average of 33% giving a feedback in 20 years of the initial cost [18-19].

A study performed by Issa et al. [20] about the reasons for why practitioners are uncertain about adopting green building practices concludes that practitioners are uncertain about green buildings because green buildings consume more time to design and construct than a conventional building, meeting green requirements and standards can be challenging and payback can not be guaranteed.

IV. Description of the Claudette MacKay-Lassonde Pavillon

The CMLP building was inaugurated in 2008 at the University of Western Ontario (UWO) in London, Canada, as a first LEED building from this university. The CMLP was designed with the goal to be a sustainability model due to guidelines that prioritize water, energy and pollution reduction. Furthermore, the \`Eco- laboratory\` concept was develop to make all the building sustainable elements accessible to researchers for demonstration to encourage research in green technologies.

The case of study has a floor area of 43543 Sq Ft and accommodates several research laboratories (40.56% of the total area), graduate student offices, undergraduate student projects, meeting rooms and lounge spaces (see Fig. 1). In 2009, this building received a gold label, according to LEED, as a result of extensive sustainable features in the building combined to modern technologies that emphasize the use of recyclable materials, renewable energy, natural lighting and water reuse.

A. Status of LEED Category Points

The CMLP building achieved 44 points obtaining the gold LEED label for New Constructions. As seen in table 1, the building obtained the total of points in Water Efficiency and in Innovation and Design categories, corresponding a 100% performance in this both categories. Though, at Energy and Atmosphere category the CMLP building achieved 7 points, corresponding a performance of 41.18%.

B. Sustainable Approach of CMLP Building

The sustainable features were grouped in six LEED categories: water efficiency, energy and atmosphere, materials and resources, indoor environmental quality and innovation in design.

- Sustainable sites: A few strategies was established for reduction of site impacts during the building construction. The construction disturbance was reduced to 50% through the increase of the useable floor space within building footprint and due to the decrease of work area during construction. A decrease of 25% in storm water runoff was reached through the use of permeable paving in courtyard and the use of a rainwater collection from roof in underground cistern; and a improvement of 80% in removal of sediments in storm water was achieved through a inline sedimentation control. Besides, the urban heat side effect was reduced in 90% through a increase in the landscape space, the adoption of a green roof and highly reflective roof surfaces.
- Water efficiency: With the adoption of strategies that aimed to reduce the water use, it was eliminated 100% of municipal water use for irrigation through the use of drought-tolerant plant materials and the use of essential irrigation from rainwater cistern; and was reduced 65% of municipal water use indoors through the use of rainwater cistern for toilet, ultra low-flow faucets and dual-flush toilet.
- Energy and atmosphere: There was a reduction in the total of energy use by 48% because of the use of high performance windows and insulation – the walls have a polyiso insulation due to higher energy efficiency performance compared to other building insulation products, high efficiency HVAC systems, energy recovery from laboratory exhaust systems, 1 kW wind turbine, 1 kW photovoltaic array, high efficiency lighting systems, natural ventilation systems for link and bridge areas and advanced building automation systems and controls. A ground source heating and cooling system from ground floor common areas is in process of installation.
- Materials and resources: A significant reduction of resource use was reached through the use of high recycled content in building, including cement, steel and interior finishes; use of local building materials, including masonry, roofing and paving and use of high durability materials (the building was designed to last over 100 years based on CSA Durable Standard). Moreover, 75% of construction waste was diverted from landfill. The cement company involved in the CMLP project used Supplementary Cementing Materials (SCM) in Portland cement to produce more durable and sustainable concrete infrastructure as seen in Table 2. For every portion of Portland cement replaced by SCMs there is an improvement in the environmental footprint of concrete [21].

All Ready-Mix raw materials came from within the 800 kilometer specified radius and concrete and concrete raw materials were shipped by truck. All replacement values use the LEEDs "base mix" formula for Portland cement content. Predominantly slag and flyash were used as SCM at CMLP building, however, for some columns at lounge area were used three specific mixes to demonstrate three different SCM's for the students as a educational purpose. These mixes are different from the typical mix designs used in the rest of the building, one is a High Slag mix (approx. 60-65%), the other one was poured with High Flyash mix (approx. 35-40%) and the last one was poured using an 8% Silica Fume mix.

- Indoor environmental quality: An improvement in the indoor environment was ensured through the control of products and odors during construction; use of ventilation levels controlled by occupancy of spaces, low volatile organic compounds (VOC) interior finishes, individual room controls and daylight access to occupied spaces.
- Innovation in design: It was implemented in CMLP building some important solutions to keep a high building performance, as: a display to control the building operation and energy use, a tracking water use, a monitoring structural loading, a monitoring performance of variety of green roof vegetation types drought resistant, a monitoring of recycling activities, an indoor living wall and an aquarium, and a control of natural ventilation systems through sensors that can open the windows when the carbon dioxide (CO_2) level increases.

The rainwater is collected by green roof, filtered and stored in water tank. At water tank a part of the rainwater goes to the toilets and a part feds the fish tank and the indoor living wall.The fish tank pumps and lighting system are activated by renewable electricity generation. The green roof monitoring aims to quantify the green roof performance through the temperature measurement and the soil moisture control. A study using monitoring data of November 2009 concluded that the green roof decreases the daily temperature fluctuation, helping to reduce the urban heat island, and attenuates the storm water runoff [22].

V. Post occupancy preliminary analysis of energy

An energy audit undertaken by The University of Western Ontario was made during a period of 24 months from January, 2008 to December, 2009 – to provide energy efficiency data of the whole university campus during all different seasons. The audit estimated the energy used for heating, cooling and lighting and energy used by pumps, lights, fans, computers, domestic hot water, personal plug load and other electronics. The energy costs were estimated in this study.

As shown in Fig. 2, the CMLP Estimated energy breakdown graphic of 2009 indicates that heating system was responsible for 61% of the total energy use in the building, and the light system and fans were responsible for 10.80% and 10.50%, respectively [23].

Higher data of energy used by heating, comparing to other utilities, could be explained by the increase of the use of heating system during long periods of low temperatures during winter and autumn, ranging from 5 to 6 months at London, Ontario [24]. The Fig. 3 presents the historical of energy use by CMLP during these 24 months. The energy used by heating system and domestic hot water (DHW) is represented in Fig. 3 by steam and it reached almost 350,000 kWh in January 2009 and 300,000 kWh, in December 2009.

However, making a comparison with energy consumption in the year of 2009 between two other buildings, both conventional, at the same university (see table 3) – Spence Engineering Building (SEB) and Medical Science Building (MSB) - with an area of 207,153 sq ft and 162,849 sq ft respectively, and using as functional unit kWh/sq ft, as show in table 4, the CMLP building is the one who spend less energy with lighting system and with domestic hot water (DWH), comparing to both conventional buildings.

The comparison results indicates that both heating and cooling systems are higher at the CMLP building, however, the ground source heating and cooling system in process of installation will help to improve this performance.

VI. Life Cycle Assessment of Energy Use

A. Study Objectives, Scope and Definitions

The main goal of this study is to investigate the environmental effects of the energy used by the CMLP building using the LCA methodology. For this purpose, the CMLP building life cycle operation and maintenance stages will be analyzed; however for this analysis it will be embodied other important processes derived of the energy generation as mining, fuel transportation, electricity generating and transmission, steam, infrastructure and waste disposal. It was established he functional unit as kWh/ft$^{2.}$

B. Inventory of inputs and outputs

The electricity input and output inventories were gathered taking into account the supply mix for Ontario energy generation, which is composed of 55% nuclear energy, 13.6% natural gas, 8.3% coal, 20.4% hydroelectricity and 2.7% of wind and other renewable [25-26]. Heating water is supplied by condensing boilers rated at 85%. Chilled water is supplied by chillers with coefficients-of-performance of the chillers equal to 8. A brake-down of annually energy consumption by CMLP building by source is presented in Table V.

The inputs/outputs databases used in the study comprise data for all the life cycle stages of energy production.

The systems examined included fuel mining and transportation, electricity generation and transmission, steam production for heating and waste disposal. In addition, inputs and outputs regarding the infrastructure for energy generation and transportation were accordingly allocated.

Table VI shows the inputs/outputs databases used for this study, which were provided by the SimaPro 7 software.

C. Life Cycle Impact Assessment (LCIA) and Normalization Data

The EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) was used to perform the impact assessment characterization of potential environmental and human stressors. Furthermore, the characterized results were normalized using normalization values developed by the US EPA based on the impact categories in the TRACI method (see Table 7). Although an optional step within the ISO standardized LCA methodology, normalization is important to better understand the relative significance of each impact indicator, to check for inconsistencies in the LCIA results and to prepare results for additional procedures, such as grouping, weighting, and life cycle interpretation [27].

VII. LCA Results

Through the SimaPro simulation was obtained the impacts of the environment and human health results of CMLP building related to energy used annually for operation and maintenance of the building. These results were gathered and normalized using EPA's normalized values as presented in Table 8. The impact categories most affected were found to be human health cancer and non cancer effects, as well as ecotoxicity (See Fig. 4). Amongst these categories, the non-carcinogenic effects was found to be most significant impact for the CMLP building, with estimated emissions of 89.64 kg of toluene eq/sq ft (See Table 8).

The Simapro life cycle assessment results indicate that the main processes contributing to the non-carcinogenic impact category are the natural gas extraction, uranium milling for nuclear energy production, and blasting for mining and infrastructure construction (See Fig. 5).

VIII. Discussion

The significant solutions deployed in the conception and design stages of CMLP building achieved a satisfactory current level of sustainability that can be noted by benefits as: reduction of water use, reduction of energy use (especially by lighting system), reduction of natural resources and others.

With the LCA approach, it was possible to evaluate the data of energy used by the CMLP building, providing an evaluation in terms of operation and maintenance of the building.

It is possible to conclude that the impact categories most affected by the energy consumption of the CMLP building were found to be human health cancer and non cancer effects, as well as ecotoxicity.

The results showed the non-carcinogenic effects as most significant impact for the CMLP building, with main contribution natural gas extraction, uranium milling for nuclear energy production, and blasting for mining and infrastructure construction process.

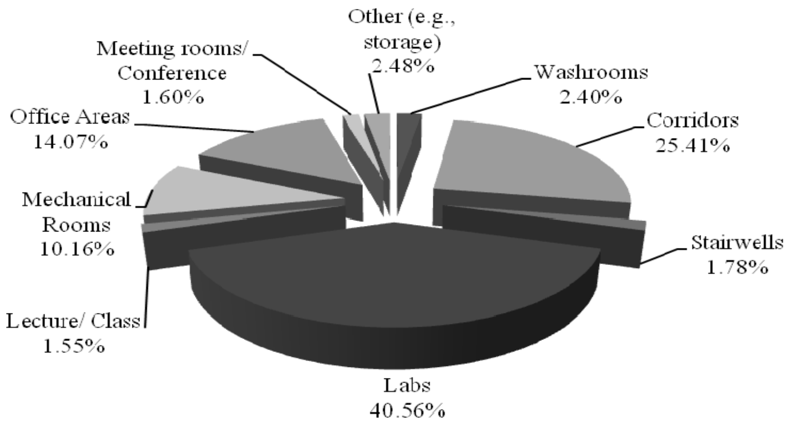

Fig. 1 Building space allocation

TABLE I
POINTS ACHIEVED AT LEED CATEGORIES

Categories	Points achieved	Total of category points	Performance (%)
Sustainable Sites	9	14	64.29
Water Efficiency	5	5	100
Energy and Atmosphere	7	17	41.18
Materials and Resource	8	14	57.14
Indoor Environmental Quality	10	15	66.67
Innovation and Design	5	5	100

TABLE II
CONCRETE MIXES USED FOR CMLP PROJECT

Mix Number	Concrete design strength at 28 days (Mpa)	% Portland cement used	% SCM used	Portland cement reduction (as a percentage)	Volume
1	15	89.9	10.1	20.2	50
2	20	75.3	24.7	49.4	450
3	30	61.3	38.7	77.4	430
4	25	72.2	27.8	55.6	100
5	25	90.1	9.9	19.8	60
6	30	66.5	33.5	67	1600
7	32	77	23.0	46	15

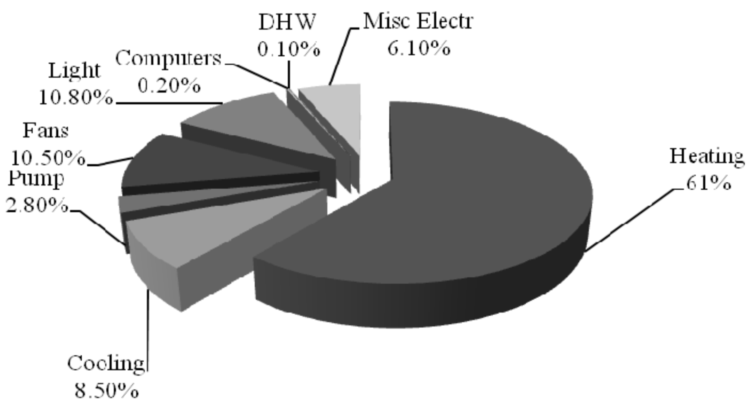

Fig. 2 CMLP Estimated energy breakdown in 2009 (UWO, 2010)

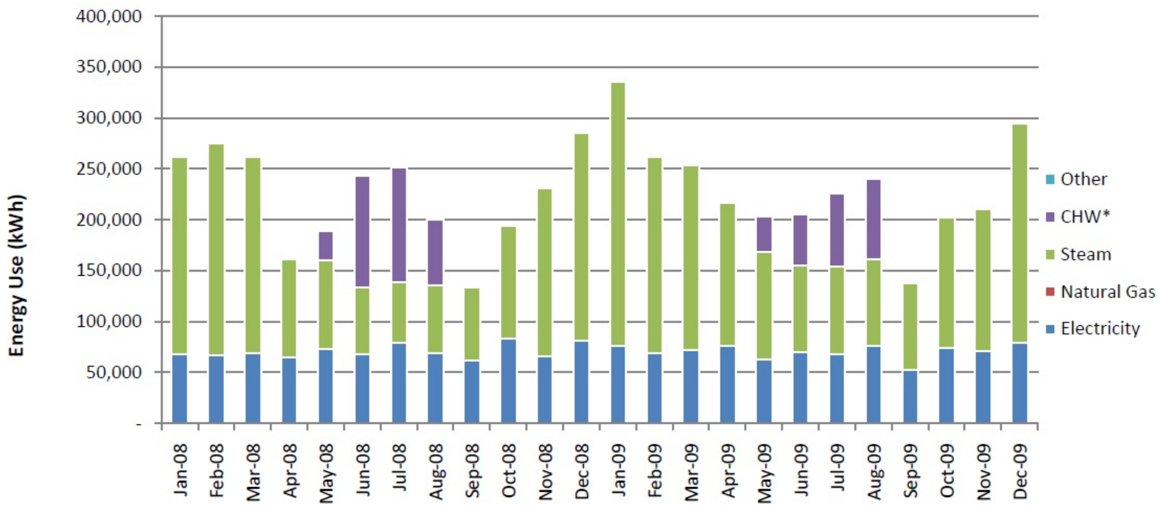

Fig. 3 Historical CMLP energy use (UWO, 2010).

TABLE III
BUILDING INFORMATION

Building	Area (sq ft)	Type
Claudette MacKay Lassonde Pavilion – CMLP	43,543	Green building (LEED gold)
Spencer Engineering Building – SEB	207,153	Conventional
Medical Science Building – MSB	162,849	Conventional

TABLE IV
ENERGY CONSUMPTION IN THE YEAR OF 2009 (KWH/SQ FT) (UWO, 2010)

Building	Heating	Cooling	Lights	DHW
CMLP	39.05	5.33	6.93	0,032
SEB	34.542	4.82	8.99	0,069
MSB	29.22	5.25	8.36	0,065

TABLE V
BREAKDOWN OF ANNUALLY ENERGY CONSUMPTION BY SOURCE

Input datas	CMLP
Steam	39 kWh/Sq ft
Nuclear	13.2 kWh/ Sq ft
Gas	3.26 kWh/ Sq ft
Coal	1.992 kWh/ Sq ft
Hydro	4.896 kWh/ Sq ft
Wind	0.648 kWh/ Sq ft

TABLE VI
INPUT DATA AT SIMAPRO.

	Process	Database
Electricity	Nuclear at power plant pressure water reactor	Ecoinvent
	Natural gas at power plant	Ecoinvent
	Wind power plant 800kW	Ecoinvent
	Hydropower at power plant	Ecoinvent
	Hard coal at power plant	Ecoinvent
Steam	Process steam from natural gas, heat plant, consumption mix, at plant, MJ	ELCD

TABLE VII
SUMMARY OF NORMALIZED VALUES FOR TRACI IMPACT CATEGORIES FOR 1999 ON A PER CAPITA BASIS (BARE ET AL., 2006)

impact category	normalized value air per capita	normalized value water per capita	total normalized value per capita	normalized unit per capita
acidification	$7.44 \times 10^{+03}$	NA	$7.44 \times 10^{+03}$	H^+ equiv/yr/capita
ecotoxicity	$7.29 \times 10^{+01}$	9.24×10^{-01}	$7.38 \times 10^{+01}$	2,4-D equiv/yr/capita
eutrophication	$5.15 \times 10^{+00}$	$1.28 \times 10^{+01}$	$1.80 \times 10^{+01}$	N equiv/yr/capita
global warming	$2.45 \times 10^{+04}$	NA	$2.45 \times 10^{+04}$	CO_2 equiv/yr/capita
human health cancer	2.52×10^{-01}	6.30×10^{-03}	2.58×10^{-01}	benzene equiv/yr/capita
human health noncancer	$1.32 \times 10^{+03}$	$1.52 \times 10^{+02}$	$1.47 \times 10^{+03}$	toluene equiv/yr/capita
human health criteria	$7.63 \times 10^{+01}$	NA	$7.63 \times 10^{+01}$	PM2.5 equiv/yr/capita
ozone depletion	3.11×10^{-01}	NA	3.11×10^{-01}	CFC-11 equiv/yr/capita
photochemical smog	$1.21 \times 10^{+02}$	NA	$1.21 \times 10^{+02}$	NO_x equiv/yr/capita
fossil fuel depletion	NA	NA	4.08×10^{-02}	surplus mega-Joules of energy/yr/capita

TABLE VIII
IMPACT CHARACTERIZATION AND NORMALIZED EFFECTS FOR THE CMLP BUILDING

Impact category from TRACI methodology	Unit	Results	Normalized value per capita/ year	Normalized results
Global warming	kg CO2 eq	14.48171973	24500.00	0.00059
Acidification	H+ moles eq	2.19937476	7440.00	0.00030
Carcinogenics	kg benzen eq	0.00822738	0.26	0.03189
Non carcinogenics	kg toluen eq	89.64005074	1470.00	0.06098
Respiratory effects	kg PM2.5 eq	0.01009614	76.30	0.00013
Eutrophication	kg N eq	0.00205920	18.00	0.00011
Ozone depletion	kg CFC-11 eq	0.00000099	0.31	0.00000
Ecotoxicity	kg 2,4-D eq	2.53969805	73.80	0.03441
Smog	g NOx eq	0.01411451	121.00	0.00012

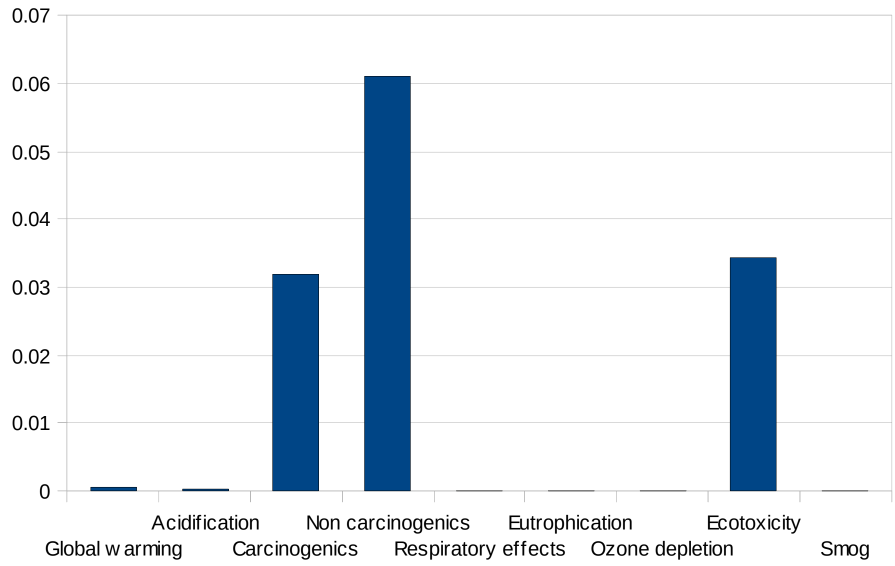

Fig. 4 Normalized effects for the CMLP building

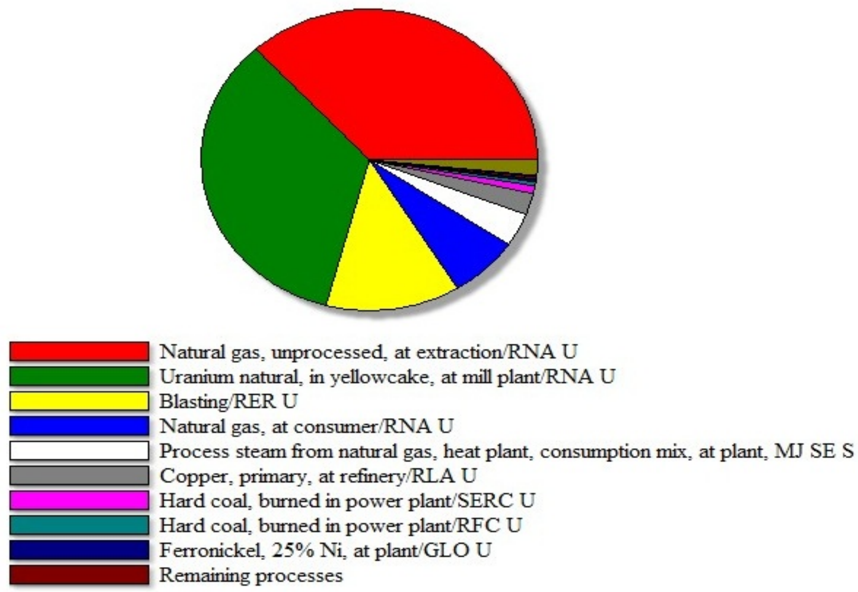

Fig. 5 Characterization of process contributions in the effect of non- carcinogenics

TABLE IX
IMPACT CHARACTERIZATION AND NORMALIZED EFFECTS FOR THE MSB

Impact category from TRACI methodology	Unit	MSB Impacts results	Normalized value per capita/ year	MSB Impact Results Normalized
Global warming	kg CO2 eq	17.77	24500	0.000726
Acidification	H+ moles eq	3.65	7440	0.000491
Carcinogenics	kg benzen eq	0.01	0.26	0.031889
Non carcinogenics	kg toluen eq	159.92	1470	0.108786
Respiratory effects	kg PM2.5 eq	0.02	76.30	0.000230
Eutrophication	kg N eq	0.003431	18	0.000191
Ozone depletion	kg CFC-11 eq	0.000002	0.31	0.000006
Ecotoxicity	kg 2,4-D eq	4.55	73.80	0.061653
Smog	g NOx eq	0.02	121	0.000165

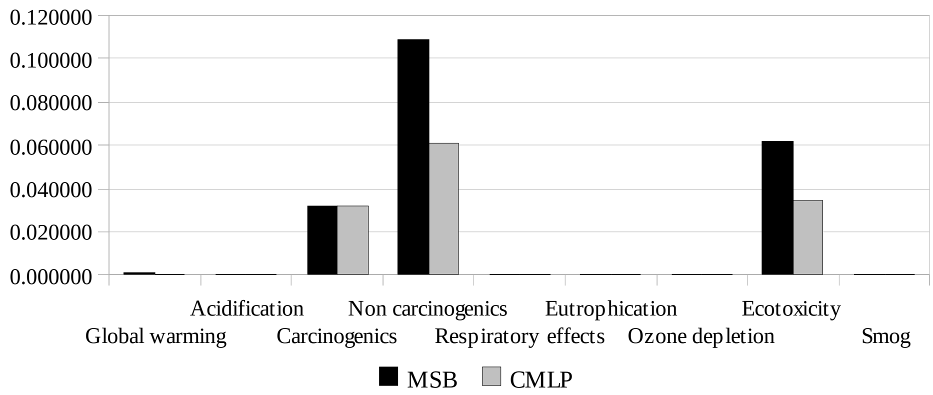

Fig. 5 Normalized effects for the CMLP building and MSB

However, comparing the MSB LCA of energy used results to the CMLP life cycle assessment of energy used results, using the SimaPro simulation (see Fig. 5), it is possible to affirm that non-carcinogenic and ecotoxicity effects are higher for MSB and the carcinogenic effects are similar between both.

IX. Conclusion

Green buildings are mentioned as a possible solution to decrease the high environmental effects of civil construction worldwide through the use of sustainable features, for example: materials with low environmental impacts, renewable energy, waste recycling, high energy-efficient systems, water conservation, pollution control and waste reduction. The literature review presented many environmental benefits of green building, and also benefits for building occupants, and was discussed some barriers to the adoption of green buildings.

This paper presented an analysis of the sustainable features of a green building at the University of Western Ontario, London, Ontario, Canada and measured the environmental impacts of energy used by this building. Based on this, it is possible to conclude that the sustainable features that contributed the CMLP building to achieve the LEED gold label were important for achieved a good environmental performance either. These can be notice through the strategies for reduction of site impacts during the building construction, strategies for reduction of water use, reduction of resource use, use of a tracking water use, monitoring structural loading, monitoring performance of variety of green roof vegetation, monitoring of recycling activities, an indoor living wall and an aquarium, and a control of natural ventilation systems through sensors that can open the windows when the carbon dioxide (CO2) level increases, and reduction of energy.

Moreover, this good environmental performance can be perceived through the LCA. The results of LCA indicated that there are some environment and human health impacts caused by the energy consumption of the CMLP building, however, comparing to a conventional building, these environmental and human heath impacts are lower for the CMLP building.

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