METRICS FOR BUILDINGS OR BUILDING OF METRICS: A COMPARISON OF ENVIRONMENTAL FOOTPRINT OF THE TRADITIONAL VS. THE RENEWABLE IN MEDICAL OFFICES

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ABSTRACT

As renewable technologies become a focus in the design process in both architectural education and practice, measuring the environmental impacts of such technologies is gaining attention in education and practice. This paper conducts a Life Cycle Assessment LCA study to model two medical office buildings over a service life of 60 years and its implications on the environment from cradle to grave. It also quantifies and compares the total impacts these 2 buildings have throughout this life span. Both buildings located in Michigan where steel construction is the dominant method of construction for commercial type. Building 1 is a 3-story building with conventional HVAC system. Building 2 is a 1-story LEED certified building that uses a geothermal HVAC system and has more sustainable materials used. The study calculates the environmental footprint of each building per unit area to identify which case has lesser environmental impact (to air, water, and land). The study highlights the importance of setting metrics to measure buildings' sustainability through their environmental burden. This will allow architects to choose more sustainable materials and renewable energy systems based on actual performance. The analysis also provides an assessment to which building component (structure, walls, floors, roofs) contribute *the most* to the total impacts for each case. The outcome also highlights some areas where LEED rating system may fall short regarding the best materials alternatives to be used and in which component of the building. This contributes to reduced impacts through selecting more sustainable alternatives based on its damage to the environment regardless of the certification.

KEYWORDS: Sustainability Metrics, Environmental Impacts Modeling, Climate Change, Building Clean Energy, Geothermal Modeling.

1. INTRODUCTION

Life Cycle Assessment LCA represents a quantitative tool for calculating the environmental burdens (impacts) of products at all stages in their life cycle from cradle to grave. Throughout the life cycle of a building, various natural resources are consumed, including energy resources, water, land, and several pollutants are released back to the global/regional environment. These environmental burdens result in global warming, acidification, air pollution, etc., which impose damage on human health, primarily natural resources and biodiversity. For example, in the United States, the construction and building sector has been estimated to be responsible for roughly 40% of the overall environmental burden (1). The building sector, constitutes 30-40% of the society's total energy demand and approximately 44% of the total material use as well as roughly 1/3 of the total CO2 emission, has been identified as one of the main factors of greenhouse gas emissions (1). There is no doubt that reducing the environmental burden of the construction industry is crucial to a sustainable world.

Most research on the environmental impacts of buildings examines the issues at a relatively broad level though extensive description. For example, Finnveden and Palm (2) stated that the use phase accounts for the majority of the environmental impacts of buildings. Klunder (3) gave a description of environmental issues of dwellings, noting that assessments should focus primarily on components that involve large quantities of materials (e.g., foundation, floors, and walls), but there are also dangerous materials that should be avoided regardless of quantity (e.g., lead). Trusty and Meil (4) have assessed the environmental impacts of an office building, including the structural and envelope elements, which were compared against the annual operational energy. Junnila and Horvath (5) took the same path to quantify the most significant impacts of a high-end office in Europe. However, this study narrows down to the systems and materials that release most emissions for the studied case in order to test better retrofitting or fit out alternatives as building adapts to its future.

Building assembly systems (structural, envelope, floors, and roofs) are rarely studied on individual or as combined systems in LCA studies. Thus, such information and data indicating the significant impacts by building systems would be of great use in design and management of the building life cycle maintenance. Ragheb (6) concluded that that the walls system has the highest percentage of emissions among other components, mainly in global warming, acidification, smog, and respiratory effect in a comparative study of 3 office buildings. This study acknowledges that LCA stands among new metrics to quantify how sustainable our buildings are. It also shows how to build an LCA model for the entire building after multiple successful attempts to model consumer products' environmental profiles.

2. METHOD AND ASSUMPTIONS

A life-cycle assessment (LCA) framework is selected to analyze the environmental impacts of 2 medical office buildings in Southeast Michigan. Sixty years of use was assumed to be the basic life cycle. LCA is the most appropriate framework for the identification, quantification, and evaluation of the inputs, outputs, and the potential environmental impacts of a product, process, or service throughout its life cycle, from cradle to grave i.e., from raw material acquisition through production and use to disposal, as defined in ISO 14040, 1997(7)(8). The LCA had three main phases; *inventory analysis* for quantifying emissions and wastes, *impact assessment* for evaluating the potential environmental impacts of the inventory of emissions and wastes, and *interpretation* for defining the most significant aspects.

LCA is defined as a systematic, holistic, objective process to evaluate the environmental burdens associated with a product or process. The process identifies and quantifies energy and material usage and environmental releases of the studied system, and evaluates the corresponding impacts on the environment. Identification and quantification of material and energy flows (inputs and outputs) of the case study office buildings were conducted during the design and construction of the building in 2009. The material and energy flows of the building's life cycle were primarily derived from the floor plans and specifications of the 2 buildings. Some emissions data related to different energy and material flows were collected mainly from the actual manufacturers in Michigan. The quality of the data used in the life-cycle inventory was evaluated with the help of a six-dimensional estimation framework recommended by Lindfors et al. (9). The quality target for the LCA was set to be at the level of ''good,'' which means reliability of most recent documented data from drawings, specs sheets, and contractor rep on-site. In life-cycle impact assessment, the magnitude and significance of the energy and material flows (inputs and outputs) were evaluated. The impact categories included were those identified by EPA in 2006 (10) as 'Commonly Used Life Cycle Impact Categories'. Among the 10 listed categories, the impact categories in this paper included:

- Primary Energy (Fossil Fuel) Consumption FFC,
- Resources Use RU,
- Global Warming Potential GWP (Climate Change),
- Acidification Potential AP,
- Eutrophication Potential EP,
- Human Health Respiratory Effect Potential, and
- Photochemical Ozone Creation Potential POCP or Summer Smog
- Ozone Depletion Potential ODP,

The chosen impact categories are also on the short list of environmental themes that most environmental experts agree to be of high importance in all regions of the world and for all corporate functions (11). Furthermore, the used impact categories are consistent with the air and water emissions that the World Bank (12) has recommended to be targeted in environmental assessments of industrial enterprises. The classification, or assigning of inventory data to impact categories, and the characterization, or modeling of inventory data within the impact categories, ISO 1997 (7), were performed using the ATHENA 4.1 life-cycle calculation program (13) which is used to model the 2 buildings. The significance of different life-cycle aspects is evaluated by comparing the environmental impacts of different building elements in every impact category so that the significant environmental impact could be ranked in order of importance. In the life-cycle interpretation section, the results are also examined from the building assembly (foundation, walls, floors, etc.) so that the environmental impact of each system's life cycle can be quantified.

2.1 Case Study Buildings Description

Two medical office buildings located in Southeast Michigan, U.S. are targeted as cases:

Southfield is a new office building. Its construction ended in 2009. The targeted use of the building is mainly medical offices. The building has 29,000 sq ft (2690 m^2) of gross floor area, and a volume of 423,000 cu ft (11978 m^3). The building consists of 3 floors (9700 sq ft each, 14.6 ft average height) plus a partial basement. The structural frame is wide flange (W sections) columns and W sections beams. Floors are metal decking with 2” concrete topping. The exterior walls are brick veneer with steel studs backing. Interior walls are galvanized steel studs with gypsum board facing to receive paints or wall paper. Foundations are cast-in-place concrete. The annual energy consumption is calculated using eQuest 3.64 (14). The estimated natural gas consumption (mainly for water heating) of the building is 45.97 MBtu (1585 Btu/sq ft/year) and this is equivalent to 0.46 kWh/sq ft/year. The estimated electricity consumption is 412,860 kWh/year (14.2 kWh/sq ft/year), which is close to the average in such cold weather in Michigan.

Huron is another new office building in Southeast Michigan in the U.S., constructed in 2008. The targeted use of the building is mainly medical offices. The building has 21,290 sq ft (1978 m^2) of gross floor area, and a volume of 351,285 cu ft (9947 m^3). The building consists of 1 main floor (16.5 ft high) with no basement. The structural frame is Hollow Structural Steel HSS columns and open web steel joist for roof support. Floors are light reinforced concrete of 1 floor. The exterior walls are brick veneer with steel studs backing. Interior walls are galvanized steel studs with gypsum board facing to receive paints or wall paper. Foundations are cast-in-place concrete. The annual energy consumption is calculated using eQuest 3.64. The estimated natural gas consumption (mainly for water heating) of the building is 34.42 Mbtu (1616 Btu/sq ft/year) and this is equivalent to 0.47 kWh/sq ft/year. The estimated electricity consumption is 183,870 kWh/year (8.6 kWh/sq ft/year). One important factor for Huron office building is that it is a LEED certified building and that might interpret its slightly lower use of electricity because it uses geothermal ground loops in heating and cooling.

In the study, the life cycle of the building was divided into 5 main phases: building materials *manufacturing*, *construction* processes, *operation* phase, *maintenance*, and *demolition*. Transportation of materials was included in each life-cycle phase. The building materials phase included all of the transportation to the wholesaler warehouse. The construction phase included the transportation from the warehouse to the site.

2.2 Building Elements and Materials Phase

The following building element categories were included in the study: *foundation*, structural *frame* (beams & columns), *floors*, external *walls* (envelope), *roofs*, and minor internal elements e.g., doors, partition walls, suspended ceilings, and 2 stairs. The amount of each material used in the building was derived from the bill of quantities, architectural and engineering drawings, and the architect’s specifications. Around 30 different building materials were identified and modeled.

2.3 Building Construction Phase

The *construction* phase of the building included all materials and energy used in on-site activities. Data were modeled for the use of electricity, construction equipment, and transportation of building materials to the site (average 100 mi). Some of the data were collected from the contractor, and were further confirmed by interview with his representative on-site.

2.4 Building Operation Phase

The *use* of the building was divided into mainly heating service (by natural gas) and electrical consumption. For the purpose of energy simulation, the building was estimated to be used 55 hr/week for 60 years. Energy calculations were performed using eQuest, a DOE 2 energy simulation program (14) for electricity use and HVAC heating and cooling loads. All building parameters (dimensions, orientation, walls, windows, etc) were modeled.

2.5 Maintenance and Retrofit Phase

The *maintenance* phase included all of the life-cycle elements needed during the 60 years of maintenance; use of building materials, construction activities, and waste management of discarded building materials. An estimated 75% of building materials was assumed to go to landfill, and 25% was assumed recovered for other purposes such as recycling.

2.6 Demolition Phase

The *demolition* phase included demolition activities on-site, transportation of discarded building materials (75% of the total) to a landfill (50 mi), and shipping of recovered building materials to recycling site (70 mi, on average). The entire building was assumed to be demolished.

3. RESULTS

3.1 Normalization of Results

Since the 2 case studies are of different floor areas, the normalization of results is a must to ensure the validity of the comparison among cases. The results have been normalized per square meter (m^2) of floor area of the 2 buildings. Although the database used in the study (ATHENA) allows some inputs in imperial units, the results of impact assessment, which is more important to the study findings, are presented in metric units. For this reason and for consistency purposes the square meter (m^2) is used as normalization factor instead of the square foot (ft^2).

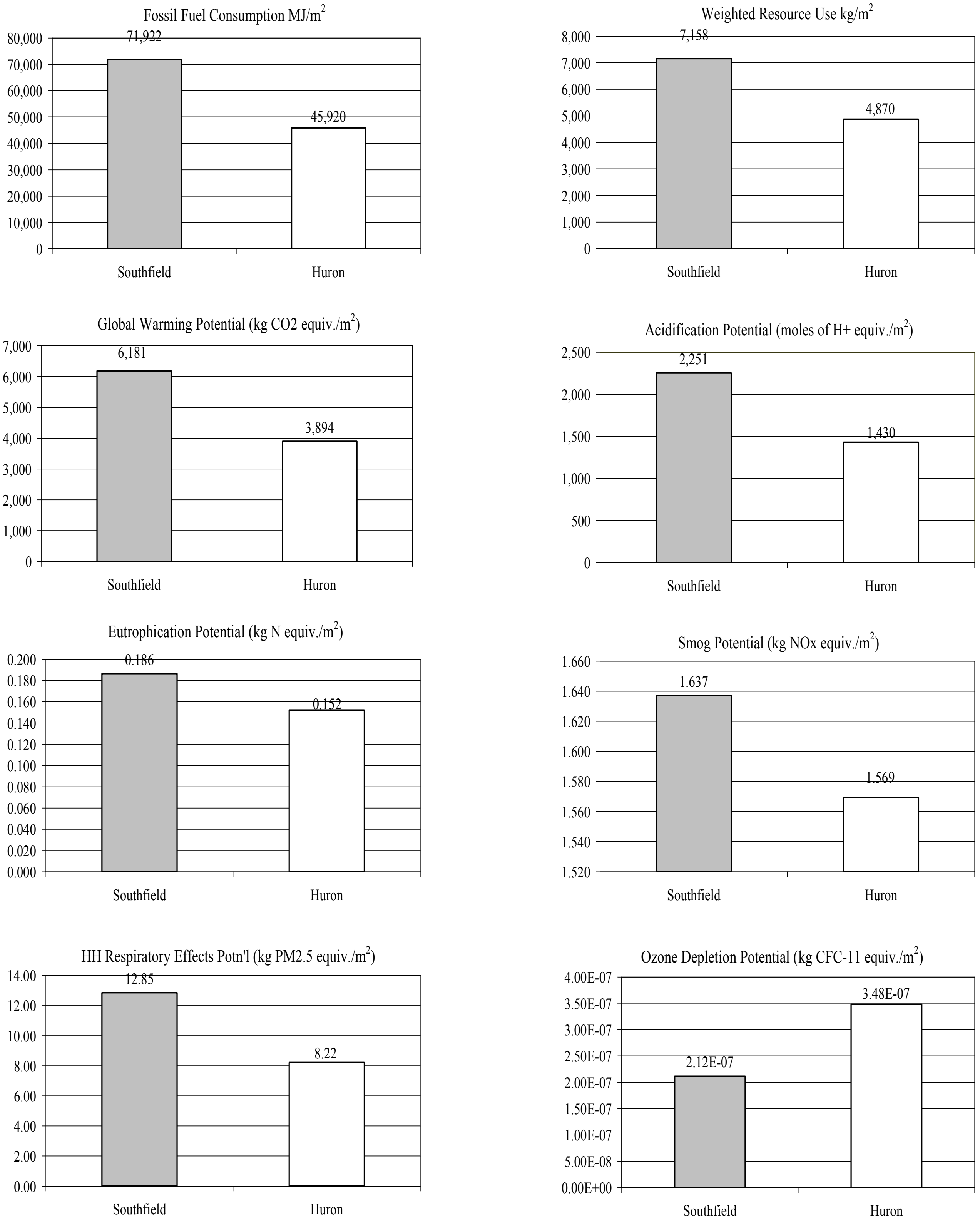

Fig. 1: Environmental Impacts Absolute Values for the 2 case buildings

TABLE 1: BREAKDOWN OF ENVIRONMENTAL IMPACTS BY LIFE CYCLE STAGE

Impact Category	Manufacturing		Construction		Operation		Maintenance		End of Life		Total Impact	
	S. Field	Huron	S. Field	Huron	S. Field	Huron	S. Field	Huron	S. Field	Huron	S. Field	Huron
Fossil Fuel Consumption (MJ)	2683.57	2824.18	99.20	129.97	68456.3	41953.4	456.67	939.04	65.85	73.27	71922.0	45919.9
Weighted Resource Use (kg)	763.48	967.99	2.36	3.06	6342.70	3850.77	32.22	45.96	1.55	1.73	7158.27	4869.51
Global Warming Potential (kg CO2 eq)	189.26	214.79	7.25	9.39	5937.21	3623.52	29.20	41.41	4.50	5.03	6181.21	3894.15
Acidification Potn'l (moles of H+ eq)	76.35	88.55	2.61	3.55	2144.91	1310.64	21.53	26.59	0.66	0.80	2251.08	1430.13
HH Respiratory Effects Potn'l (kg PM2.5 eq)	0.524	0.605	0.003	0.004	12.01	7.33	0.281	0.28	8E-04	9E-04	12.85	8.22
Eutrophication Potential (kg N eq)	0.121	0.104	0.003	0.004	0.055	0.034	0.007	0.01	6E-04	7E-04	0.19	0.15
Ozone Depletion Potential (kg CFC-11 eq)	2E-07	3E-07	2E-10	3E-10	2E-09	1E-09	3E-08	4E-08	2E-10	2E-10	2E-07	3E-07
Smog Potential (kg NOx eq)	0.44	0.707	0.06	0.081	0.99	0.608	0.14	0.157	0.013	0.016	1.64	1.57

3.2 Environmental Impact Absolute Values of the Cases

The overall environmental impact contribution to the life cycle phases of the 2 cases is shown in (Fig. 1). The results show that there are differences between the buildings impacts. Southfield has higher impacts in all categories per unit area (m^2). The values of the impacts of Huron range between 4%-42% *less* in value than Southfield. It should also be noted that ODP is in negative value so Huron bldg is still less in impact for this category when reading Fig. 1. Huron is a LEED certified building (achieved 26 – 32 points according to LEED NC 2.2 rating of 2005). By looking at the nature of the life cycle phases where operation phase has the most impacts on the whole life cycle, Huron case saves significant energy during that phase due to the use of renewable geothermal (earth energy) loop system in its HVAC systems both for heating and cooling (eQuest results). Huron bldg uses more roof insulation than Southfield (4.75" vs. 3" thick). This interprets the smog potential total impact of Huron come very close to Southfield (Table 1) and even 61% higher in manufacturing phase because of the extensive release of Nitrogen Oxides (NOx) and VOCs during manufacturing of insulation.

Since the 2 buildings are of typical steel construction, one conclusion on why Southfield case has high impacts absolute values could be the extra partial basement over Huron (no basement). Number of floors (3 vs. 1) is another factor to slightly affect the results because structure has to be designed to support more floors which results in heavier columns and beams. This is supported by the Resources Use impact results (Fig. 1) where the unit area uses more materials in Southfield. The use of steel W-sections (wide-flange) beams and columns as the structure system vs. HSS sections (Hollow Structural Steel) in columns for Huron is also a contributor to other impacts since W-sections have significant embodied energy than the HSS sections.

3.3 Environmental Impact Contribution to Life Cycle Phases

Table 1 summarizes all impacts by life cycle phase. Although the 2 cases are different in floor areas and some architectural features, the contribution of each life cycle to the total impacts seems to follow a similar pattern. The following percentages represent an *average* of the 2 cases:

The *Operation (use) phase* in all buildings dominates the environmental impacts in all impact categories except in Eutrophication Potential (EP) and Ozone Depletion Potential (ODP) which are dominated by the manufacturing phase. Operation phase's share of impacts averages 93% in fuel consumption, 84% in resources use (WRU), 95% in GWP, 93% in AP, and 91% in respiratory effects potential (Table 1). These results are mostly associated with the energy consumed in this phase which results in massive air emissions such as CO_2 (main cause of GWP), SO_2 and NOx (main cause to AP), and effects of particulates ($PM_{2.5}$) on the human respiratory system.

Manufacturing phase has the highest impact in the ozone depletion at 87%, and in eutrophication at 65%. These results are mainly due to the release of CFCs and Halon (main cause of ODP) to air specifically in this phase. Also, these results demonstrate that this phase has the highest releases of water pollutants such as heavy metals, nitrogen and phosphorous compounds (main cause of EP) during manufacturing processes of different building materials.

The operation and manufacturing phases are somewhat balanced in the smog potential (POCP) impact category. Operation phase contributes to 49% of this impact and manufacturing contributes to 35%. The results reflect the influence on Nitrogen releases, whether to air or to water, in these two categories.

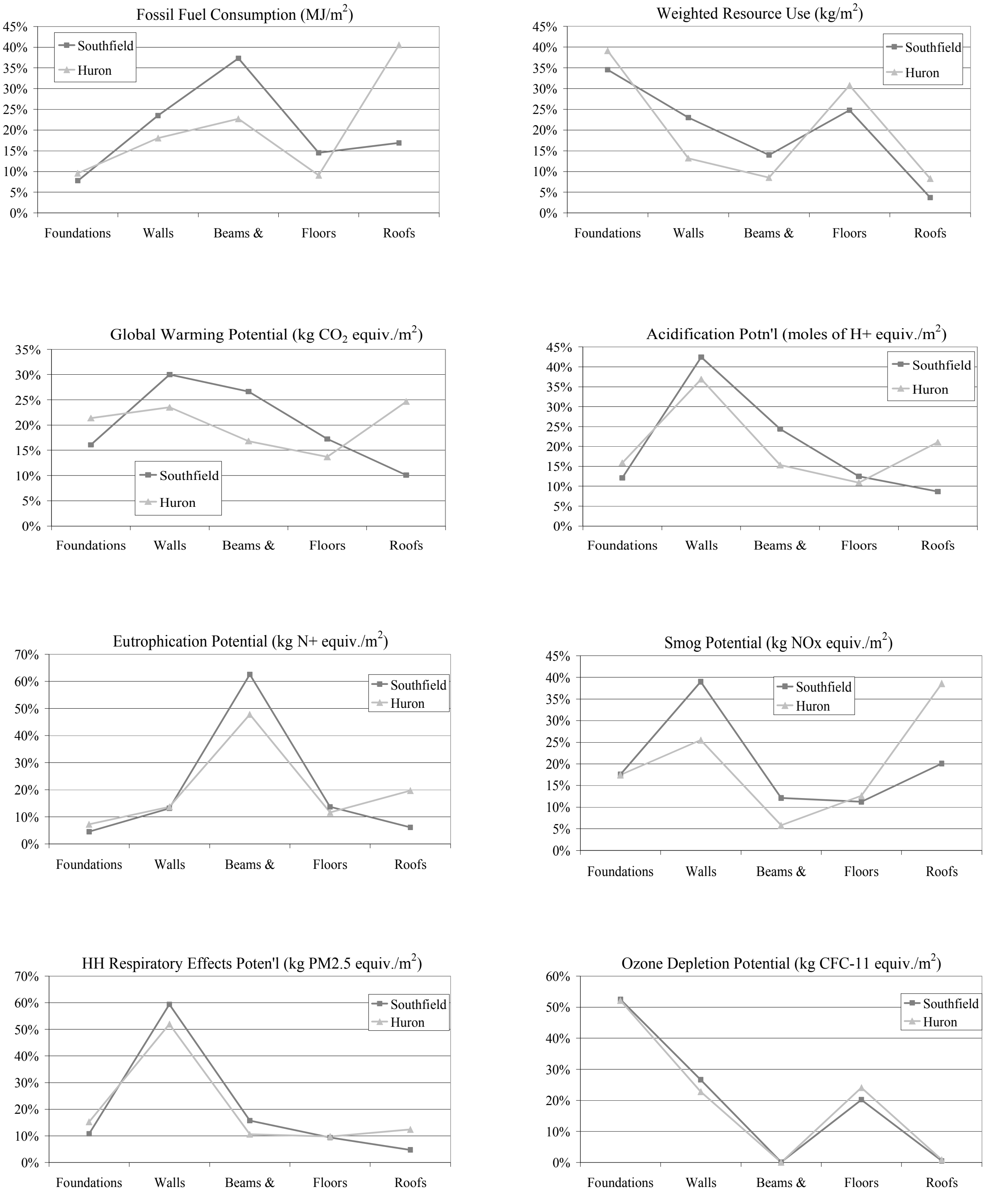

Fig. 2: Environmental Impact Contribution by Building Assembly Systems

3.4 Environmental Impact Contribution to Bldg Assembly Systems

The overall environmental impact contribution to building assembly systems (foundations, structure, walls, floors, roof) of the 2 cases are presented in (Fig. 2). Although the 2 buildings have different architectural features (mainly number of floors, floor height, windows to wall ratios, and slight difference in insulation R-values, the contribution of each assembly system to the total impacts seems to follow a similar pattern. The following percentages represent an *average* of the 2 cases:

Walls system in all buildings dominates the environmental impacts in global warming (26%), acidification (40%), smog potential (35%), and respiratory effect potential (57%) categories. A major factor of these impacts attributed to the use of insulation materials which cover large areas of building facades. Other factor is the embodied energy of metals such as steel and anodized aluminum in windows and curtain walls.

Structure (beams and columns) system of the buildings dominates the impacts in fossil fuel consumption (31%), eutrophication (56%) categories. These results attributed to the massive embodied energy of steel sections and the associated water emissions during manufacturing processes.

Roofs system in all cases has also significant impacts (second to beams and columns) in fossil fuel consumption (27%), in global warming GWP (17%), and comes second to walls in smog potential (29%). A major factor of these impacts attributed to the manufacturing of roof insulation materials and to some extent the roof membrane (black EPDM rubber).

Foundations system dominates the cause of ozone depletion at (58%). This high ratio associated with the release of CFCs during manufacturing of paint and cement. Since foundation is the heaviest system among others, it also dominates the Resources Use (RU) at (40%) (Fig. 2)

It is also important to mention that the *roof* system of Huron building has high potential impacts over Southfield roof system. Albeit a LEED certified, the impact of Huron roof is due to the use of thicker insulation layers which interprets the annual energy saving it has using the eQuest model. It uses 1.5 times the insulation used in Southfield bldg. Another note that slightly affect the results is that Huron has one-floor plan where the ratio of *roof area/floor area* in m^2 is equal to 1 (the roof cover the whole area of the building). On the other hand, Southfield building has 3 floors where the ratio of *roof area/floor area* in m^2 is $1/3^{rd}$. (the roof cover one third of the whole area of the building). In conclusion to this important point, roof has significant impacts as an assembly system and a minor change in its material flow with more environmental friendly alternatives (especially insulation) would render significant reduction of those impacts.

4. CONCLUSION

The purpose of the study was to quantify and compare the potential environmental impact caused by 2 medical office buildings' life-cycle phases. The study determined the life-cycle phases contributing most to the impact and defines the significant environmental impacts of the building. The study also examined the building assembly components that most contribute to its life cycle impact. The study found that roof and wall systems to have significant environmental impacts due to the use of insulation and membrane materials. The outcome has shown how to build LCA as emerging metric for a whole building. LCA also showed reliability to choose better alternatives during the maintenance (modification) phase of the building when renewing insulation for example.

The study also acknowledges the relationship between LCA and LEED rating system. LCA results demonstrated that a Huron medical building (LEED certified) has significant lower energy consumption for an office building. This is mainly due to using renewable geo-thermal HVAC system during the operation phase in which most of the impacts would occur. One shortcoming though was the use of tighter envelope and thicker insulation without considering the negative impact of using such insulation alternative (polyisocyanurate) which is notorious in air emissions. This resulted in that the roof system of the LEED building had the highest impact in most categories. The LCA method in this study opens the way for more testing of LEED certified buildings with high ratings e.g. gold or platinum using LCA impact analysis to verify their environmental performance. This helps to narrow down on the sensitive area of design and material choices (e.g. insulation) that LEED falls short by awarding points for overall energy savings without looking at the significant environmental impact of material alternatives that achieve this saving. The study was also unique in modeling the building with the U.S. electricity grid which depends on coal as resource at 45%, DOE, EIA 2009 (15). This rendered more outcome reliability than modeling with Canadian or European grids which depends more on hydro power.

5. REFERENCES

(1) U.S. Department of Energy. (2002). *''Why is sustainable building important?''* Technical Rep., [http://www.ecy.wa.gov/programs/swfa/cdl/ Benefits.htm], Washington Department of Ecology, Washington, D.C

(2) Finnveden, G., and Palm, V. (2002). *''Rethinking producer responsibility.*'' Int. J. of Life Cycle Assessment, 7(2), 61

(3) Klunder, G. (2001*). ''Environmental impact of Dutch dwellings: Priorities for reduction and benefits of sustainable construction.''* Towards sustainable building, N. Maiellaro, ed., Kluwer, Dordrecht, The Netherlands, 109–134

(4) Trusty, W., and Meil, J. (2000). *''The environmental implications of building new versus renovating an existing structure.''* Proc., CIB Int. Conf. on Sustainable Building 2000, Conseil International de Batiment pour la Recherche, l'Etude et la Documentation, Aeneas Technical Publishers, Boxtel, The Netherlands, 104–106

(5) Junnila, S. and Horvath, A (2003). *"Life-cycle environmental effects of an office building*". Journal of Infrastructure Systems, Vol. 9, Iss. 4, pp. 157-166

(6) Ragheb, A. (2011). *"Towards Environmental Profiling of Office Buildings Using Life Cycle Assessment"*, A PhD dissertation, University of Michigan, Ann Arbor

(7) ISO. (1997). ''Environmental management, life cycle assessment, principles and framework.'' *SFS-EN ISO 14040*, Geneva

(8) ISO 14043 (1998). *Environmental Management – Life Cycle Assessment - Life Cycle Interpretation.* International Organization for Standardization, Geneva, Switzerland

(9) Lindfors, L.-G., et al. (1995*). ''Nordic guidelines on life cycle assessment.''* Rep. Nord 1995:20, Nordic Council of Ministers, Copenhagen, Denmark

(10) U.S. EPA, Env. Protection Agency (2006), *Life Cycle Assessment: Principles and Practice*, EPA/600/R-06/060 May 2006

(11) Schmidt, W.-P., and Sullivan, J. (2002). *''Weighting in life cycle assessments in a global context.*" Int. J. of Life Cycle Assessment., 7(1), 5–10

(12) World Bank. (1998). ''Industrial estates, pollution prevention and abatement handbook.'' *Draft Technical Background Document*, Environmental Dept., Washington, D.C

(13) ATHENA, Impact Estimator 4.1 (2010). Athena Sustainable Materials Institute, Morrison Hershfield Consulting Engineers. Ottawa; Merrickville, Ontario, Canada

(14) eQuest 3.64 (2010), US DOE interface, Energy Design Resources, Camarillo, CA

(15) U.S. DOE, Energy Information Administration (2009), Electric Power Industry 2009: Year in Review, [http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html], accessed Jan 2011