REVISITING THE CASE OF SUSTAINABLE CONSTRUCTION VIA LCA – BUILD NEW OR REUSE?

Authorship and Acknowledgements

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1. Introduction and Research Goals

"The greenest building is the one that is already built" – Carl Elefante, is an elegant maxim for the notion that reusing an existing building is more environmentally sustainable than demolishing and building anew. This belief comes from the fact that new construction uses more materials and hence inflicts more environmental impacts associated with those materials than building reuse. According to Frey et. al. (2011), **reuse of an existing building reduces up to 46% of harmful impacts on the environment** when compared to demolishing and building new. For instance, if Portland, Oregon retrofits and reuses single family homes and commercial office buildings that it is otherwise likely to demolish over the next 10 years, the potential impact reduction would total approximately 231,000 metric tons of carbon dioxide or 15% of the country's carbon dioxide reduction targets over the next decade (Frey et. al 2011).

On the contrary, new buildings are usually more energy and water efficient by virtue of their high performing systems and envelopes, required by current codes. A study of the Commercial Buildings Energy Consumption Survey (CBECS) data reveal that the energy use intensity of buildings constructed between 2000 - 2003 was far less than those constructed between 1920 - 1999 (EIA 2003).

While older buildings can be retrofitted with modern systems, but the ability to bring them up to the energy and water efficiency standards of new buildings may often be impossible or cost prohibitive.

Multiple factors are employed when considering reuse versus new construction. Certainly economics play a role in the decision as do aesthetics, building and land use regulation, historic status and personal taste. Through this research, we have shown that a decision can also be made from an environmental perspective and that environmental impact of reuse versus new construction may be modeled and quantitatively approximated. The paper uses Life Cycle Analysis (LCA) to determine which one of these actions will be more environmentally sustainable in a given case. The bulk of this paper is dedicated to demonstrating this comparison.

Once an objective model is established, the paper will discuss how this comparison can be incorporated into green building certification systems.

2. Green Building Certifications

As the significance of sustainability and green buildings increased in the latter part of the 20th century, green building certifications became an important tool to incentivize and encourage building owners to be sustainable in the design, construction and operation of buildings. Importantly, it gave them the ability to demonstrate green systems and practices in a quantifiable manner.

In addition to providing a path to operational cost containment, it offered them the ability to promote their sustainability to an increasingly environmentally conscious market.

The pioneers of green building certifications in the United States are the **United States Green Building Council (USGBC)** and their Leadership in Energy & Environmental Design (LEED).

Today **Green Globes** and the **Society of Environmentally Responsible Facilities (SERF)** also offer green building certifications. This paper is commissioned by SERF Foundation, a 501 (c) (3)

With regard to reusing an existing building, current green building certifications assume that it is always beneficial to reuse an existing building. There is no requirement to demonstrate the necessity for building reuse from an environmental perspective. For instance, the latest version of LEED (Version 4) awards buildings up to 5 points under Credit 1 of the Materials and Resources Section for building reuse (USGBC 2014). The assumption here is that it is always beneficial to reuse an existing building. Through this research we have attempted to prove why this may not always be the case.

We hypothesize that it is better to demolish and rebuild only if the lower operational energy consumption of the new building would offset any impact related to its materials and demolition.

3. Life Cycle Analysis

International Standard ISO 14040 defines life cycle analysis (LCA) as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a system throughout its life cycle". For a built facility, these would include extraction, manufacture of building materials, transportation, construction, operations and demolition/decommissioning. It is also frequently referred to as the *cradle-to-grave* approach for assessing systems (Curran

2006). Life cycle analysis quantifies environmental performance of the built environment (Athena 2014).

The origins of Life Cycle Analysis can be traced back to the 1960s, when concerns over depleting energy resources led to interest in developing tools that could provide total energy use in the life cycle of a product (Svoboda 1995).

LCA mainly provides quantifiable environmental impacts in the following areas and as shown in Figure 1 below (Bayer et. al. 2010)

- Fossil fuel depletion;
- Global warming potential;
- Acidification potential;
- Human health impacts;
- Eutrophication potential;
- Ozone depletion potential;
- Smog potential.

How LCA Works

There are 4 steps in the LCA process as identified by Bayer et al. (2010). These include:

1. Goal and Scope Definition;
2. Inventory Analysis;
3. Impact Assessment;
4. Interpretation.

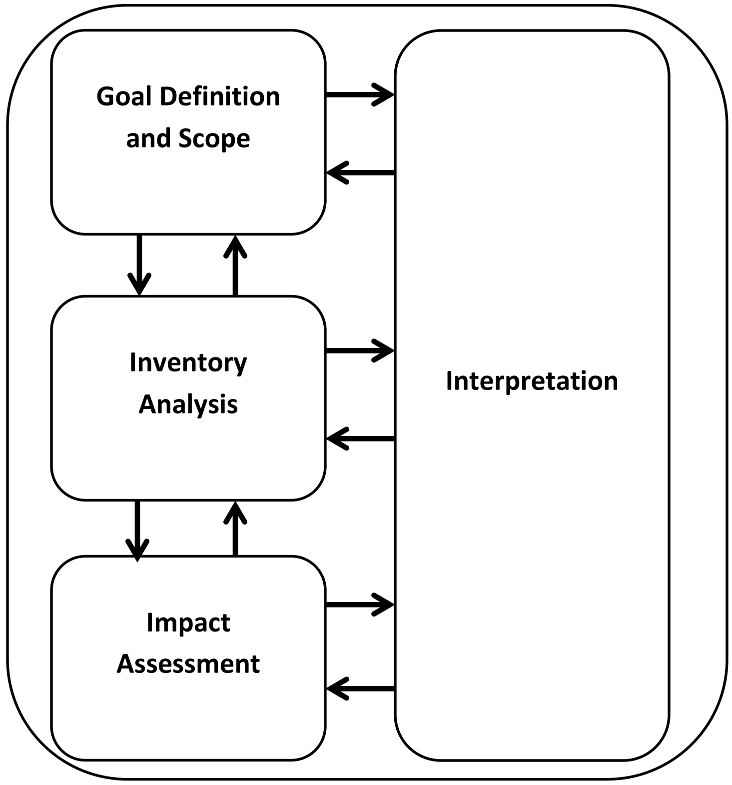

Figure 1: LCA Steps from ISO 14040 (from Bayer et. al. 2010)

Step 1: Goal and Scope Definition

This stage defines the project goals, the depth and details of analysis, defines product boundaries and functional units and identifies impact categories.

Step 2: Inventory Analysis

In this stage, the system identified in Step 1 is analyzed for the resources consumed and emissions during its lifecycle. For a complex system such as buildings which consists of many products and materials, it might be wildly impractical to analyze each component. Therefore, to make the analysis practical, the availability of LCA databases and software tools are of utmost importance.

Life Cycle Inventory (LCI) Database

For analysts performing Life Cycle Analysis, the task of calculating the life cycle impacts of each product and material of the building will be excessively cumbersome if not impossible. For instance, the life cycle analysis of reinforced concrete will require the analyst to first determine the life cycle impacts of its constituents namely cement, aggregate, rebar and additives. It may be beyond the knowledge level of a building professional such as an architect or engineer to know how to analyze these materials. Therefore, without inventory databases containing product impact information, LCA will not be practically feasible.

In the US, Life Cycle Inventory (LCI) databases developed by the National Renewable Energy Laboratory (NREL) contains life cycle data for several US products and materials and is one of the most popular LCI databases in the country.

Software Tools

As important as LCI databases are software tools that can quickly access the database and produce information that is specific to a building. In order to use LCA in green building certifications, the practical method is to use software tools. In the absence of software tools, the analyst would have to manually perform calculations using data from the LCI database to find the aggregate impact of products and materials. Such a task would be prohibitively intensive.

For the purpose of this research we have used ATHENA® Impact Estimator, produced by the Athena Sustainable Materials Institute. Currently, this is the only US-based tool that is capable of performing a whole building LCA simulation (Bayer et. al 2010).

Step 3: Impact Assessment

In this step, the results from Step 2 of “product life cycle emissions” and “resources used” are converted to useful information that relates to environmental impacts. For example, if the total life cycle fossil fuel consumption of a building was found to be 10 million BTU of natural gas in Step 2, it could be converted to an equivalent amount of Global Warming potential that the production and use of that amount of natural gas would produce. Or total emissions found in Step 3 could be converted to acidification potential of the land and water.

Step 4: Interpretation

The final step is the interpretations of the results. The use of LCA today is mainly as a decision support tool that helps in choosing between different designs. Therefore the interpretation step involves producing the results in a format that aids in such decision making. The results may be displayed in tables or graphs which may then be weighted for impact categories that is of most interest to the project team and which produces the most meaningful results for a specific situation.

4. LCA for Analysis of Reuse versus New Construction

Several research projects show that building reuse is more sustainable than new construction. According to Frey et. al. (2011), “reuse of buildings with an average level of energy performance consistently offers immediate climate-change impact reductions compared to more energy efficient new construction.” There are two main reasons why researches have arrived at this conclusion: First, when a building is demolished and constructed anew, the existing building must first be demolished (an action that requires energy) and the waste generated from the demolition must be transported to and deposited in a landfill.

Additionally, the construction of the new building requires significantly more new materials, products and systems compared to retrofitting an existing building. All products have the potential to affect the environment through the stages of its life cycle including extraction of raw materials, production, transportation, installation use and disposal/demolition. On the contrary, reusing an existing building reduces such impacts because firstly it eliminates or delays the demolition and associated impacts. Secondly, the materials that would be required to upgrade an existing building to current standards would be a fraction of what it would take to build a new building (USGBC 2009).

Although new construction tends to negatively impact the environment due to reasons mentioned above, it is not always a better environmental decision to reuse an existing structure. Most new buildings have the advantage of higher operational energy efficiency due to better designs of the thermal envelope and use of highly efficient equipment and lighting. They may also have the capability to produce green energy on site through renewable sources such as wind and solar.

However, it may be a challenge to retrofit an existing building to increase its energy efficiency and produce green energy to the levels of new a building. In this research, we hypothesized that **it would make better environmental sense to demolish and rebuild only if the lower operational energy consumption potential of the new building would offset any impact related to its materials and demolition.** To test this hypothesis we performed whole building LCA simulations on two hypothetical buildings using the ATHENA® Impact Estimator:

Both structures were retail buildings in Atlanta, Georgia with similar life spans of 60 years. They were also of the same sizes and dimensions which include a gross floor area of 2,990 square feet and an average height of 12 feet. The first building was assumed to be a new retail building that was built from ground up including complete new foundation and envelope. All the materials, systems and products used in this building were new. The complete bill of materials required to construct this building from the ground up was inputted into the simulation tool. The second building was assumed to be an existing building retrofitted to bring it up to market functionality and physical usability. Other than the materials that were used for retrofit, all other materials were reused from the original structure. The bill of materials that were used for the retrofit was inputted into the simulation tool for the second building. Note that for both buildings, only the structure was analyzed, the site work was not included in the analysis. The reason for this is that the current version of ATHENA® Impact Estimator does not offer the option to include site-work.

The second major difference between the buildings was with respect to their operational energy efficiencies. The energy consumption of the retrofitted existing building was arbitrarily assumed as 12,823 KWH of electricity and 2.57×10^7 BTU of natural gas per year. This energy consumption was assumed as a baseline and maintained constant for the analysis. However the operational energy consumption of the new building was varied as a percentage of the baseline (operational energy consumption of the existing building). Table 1 below shows the energy consumption for both buildings. Refer to Appendix - 1 for complete input data used in the LCA simulation.

Table 1: Energy Consumption of New and Existing Building

	Existing Building	**New Building**	0%	5%	10%	15%	20%	25%	30%
Annual Electricity Consumption (KWH)	12,823		12,823	12,182	11,541	10,900	10,258	9,617	8,976
Annual Gas Consumption (BTU)	2.6E+07		2.57E+07	2.44E+07	2.31E+07	2.19E+07	2.06E+07	1.93E+07	1.80E+07

Simulations were run for both buildings with parameters including materials, location, dimensions and operational energy consumption as discussed above. This included one simulation for the existing building with the single energy consumption data and six simulations of the new building with the varying energy consumption data. It must be noted that although the operational energy consumption data was varied for the new building, all the other parameters including location, dimensions and material data were left unchanged.

The simulations produced results of the life cycle environmental impacts of the buildings in impact categories that include fossil fuel depletion, global warming potential, acidification potential, human health impacts, eutrophication potential, ozone depletion potential and smog potential. For the sake of simplicity we only analyzed results of the global warming potential (GWP).

Table 2 below shows the GWP output from the simulations of the new and existing buildings: As may be observed, the GWP of the existing building remains constant because all the input parameters including operational energy efficiency remain constant. However, the GWP of the new building varies along with the decrease in its operational energy consumption.

Table 2: Global Warming Potential of New and Existing Building

%EE*	0%	5%	10%	15%	20%	25%	30%
New Building GWP~	885,922	851,048	816,175	781,301	746,381	711,508	676,634
Existing Building GWP~	727,792	727,792	727,792	727,792	727,792	727,792	727,792

*Percentage increase in energy efficiency of the new building with respect to the existing building

~ Global Warming Potential (expressed as Kg of CO2 Equivalent)

A graph of the global warming potential (kg of CO2 equivalent) of the new and existing buildings is plotted with data from Table 2 as shown in Figure 2 below. The x-axis shows the percentage increase of energy efficiency of the new building over the existing building. The y-axis shows the global warming potential at a given energy efficiency. Since the existing building energy consumption data was constant, its global warming potential was a horizontal line.

Conversely, the plot of the new building's GWP produced a slanting line showing the decreasing GWP, inversely proportional to its increasing operational energy efficiency.

At 0% on the x-axis, the operational energy consumption for both new and existing buildings is the same (See Table 1). This means that the new building consumed 0% less energy than the existing building at that point. Even at this similar energy consumption, the GWP of the new building was significantly higher by virtue of the large amount of materials and demolition related impacts. Upon moving along the positive x-axis (increasing energy efficiency of the new building), GWP of the new building drops with respect to the existing building.

As observed in the graph, at lower differences in energy efficiency, the existing building had a lower global warming potential (GWP). However at a certain break point (22.5% higher energy efficiency in this case), the GWP of both existing and new were equal. Any higher difference in energy efficiency of the new building showed that demolishing and building new was a better choice in terms of global warming potential. For instance at a 30% higher energy efficiency, the new building shows a lower global warming potential compared with the existing building.

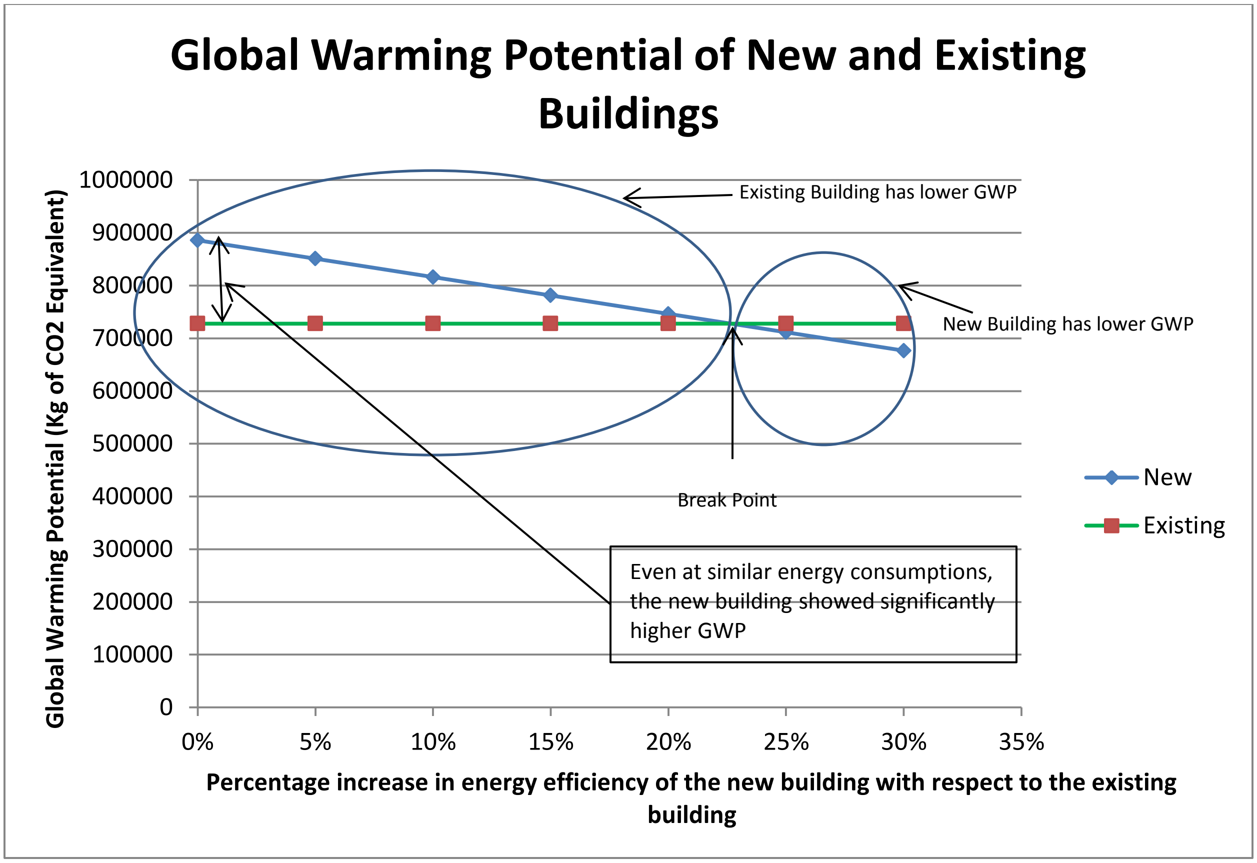

Figure 2: Global Warming Potential Comparison of New Construction and Reuse

A tool such as this is very useful to compare environmental impacts of a new building versus reuse. In green building certification (GBC) when applicants have a choice between reuse versus new construction, they may use this tool to demonstrate which choice was more environmentally sustainable. The guidelines for implementing this tool in GBCs are discussed in the following section.

5. Guidelines for Implementation in Green Building Certifications

The above analysis and subsequent results provide a useful tool that can be incorporated into green building certification systems to evaluate and quantify the sustainability of building reuse. This puts this essential component of sustainability on par with other, more readily quantifiable comparisons

In the following discussion, we have suggested methods to implement the tool into green building certification systems. As discussed previously, the tool we developed can be used to make a case for both new construction as well as existing building reuse.

Case for New Construction

In order to justify demolishing an existing building and constructing a new building in its place, we determined that the increased energy efficiency should compensate for the environmental impacts due to the higher amount of materials used (the amount of materials required for new construction is far greater than retrofitting an existing building). The process to demonstrate that the new building is a better environmental choice is shown in Figure 3 and discussed following:

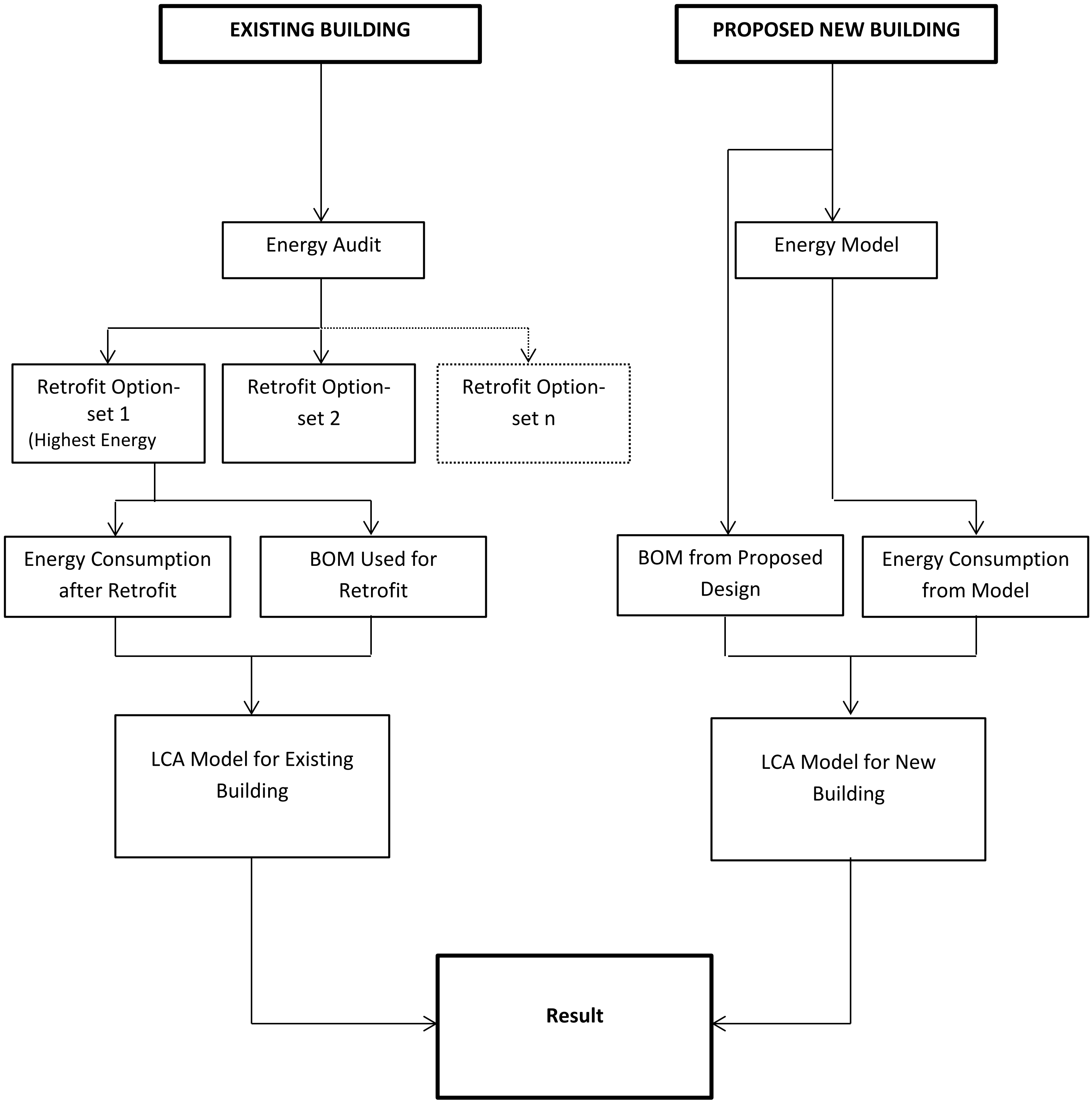

Figure 3: Process Flow to Make the Case for New Construction

Step 1: The applicant must perform an energy audit on the existing building through a third party who may provide them with a list of retrofit measures to increase energy efficiency. The measures should represent the maximum energy savings that are physically practical to implement. For instance, if the auditor provides three sets of options for retrofit (with different energy saving outcomes and cost), the option-set with the highest energy saving potential must be selected. Subtract this energy savings from the existing energy consumption to obtain the energy consumption after retrofit.

Step 2: Perform energy simulation for the proposed new building (it is assumed that the new building plan has been developed) using an industry accepted simulation tool, preferably DOE2, BLAST or EnergyPlus to obtain energy consumption of the new building. It must be noted that ATHENA® Impact Estimator does not perform energy simulation. However, it allows users to manually enter annual energy consumption data for the building being analyzed. Therefore, in order to obtain annual energy consumption users may need to either develop a separate energy model if the building is a proposed new building or from past utility bills if the building is existing.

Step 3: Run separate LCA models for the new and existing buildings using the following inputs:

<u>Inputs for Existing Building LCA model:</u>

Energy Consumption – Use energy consumption data (after retrofit) obtained in Step 1.

Bill of Materials – Use the bill of materials that will be necessary to implement retrofits determined in step 1.

Inputs for proposed New Building LCA model:

Energy Consumption - Use energy consumption data obtained in Step 2.

Bill of Materials – Use bill of materials from the proposed new building designs.

Results: Demonstrate through the LCA modeling results that life cycle environmental impacts (of select impact categories) of the proposed new building will be lower than that of the retrofitted existing building.

Case for Reuse of Existing Buildings

In order to justify reusing an existing building in place of constructing a new building in its place from a life cycle environmental perspective, we determined that a hypothetical replacement new building must show a worse environmental impact. Therefore, the biggest challenge will be to develop guidelines for such a hypothetical new building. It is very important to insist on the use of prescribed guidelines to eliminate the ability of applicants to influence the outcome.

In the following section, the guidelines to develop a hypothetical new building have been listed (green building certification systems may modify them based on individual circumstances). Subsequently, the process to implement this hypothetical new building to make a case for the reuse of an existing building has also been described. Figure 4 demonstrates this process.

Guidelines for the hypothetical new building

Size, Shape Fenestration and number of Floors – Assume all of these parameters to be the same as the existing building

Energy Consumption – Perform energy simulations based on the baseline building simulations as prescribed in section G2 of ASHRAE 90.1 2007. The need to develop this separate energy model has been discussed previously.

Bill of Materials – This could be done in one of several ways. The applicant could either commission a design professional to actually design a hypothetical new building of the exact size, shape, fenestration and number of floors as the existing building. Then calculate bill of materials from this design. However, such an approach can be extremely expensive.

A second option would require the certification provider to perform preliminary research to provide standard bill of materials data for buildings of different sizes. The applicant in their simulations will then use these predetermined inputs. A third option would be to input all the materials that are present in the existing building.

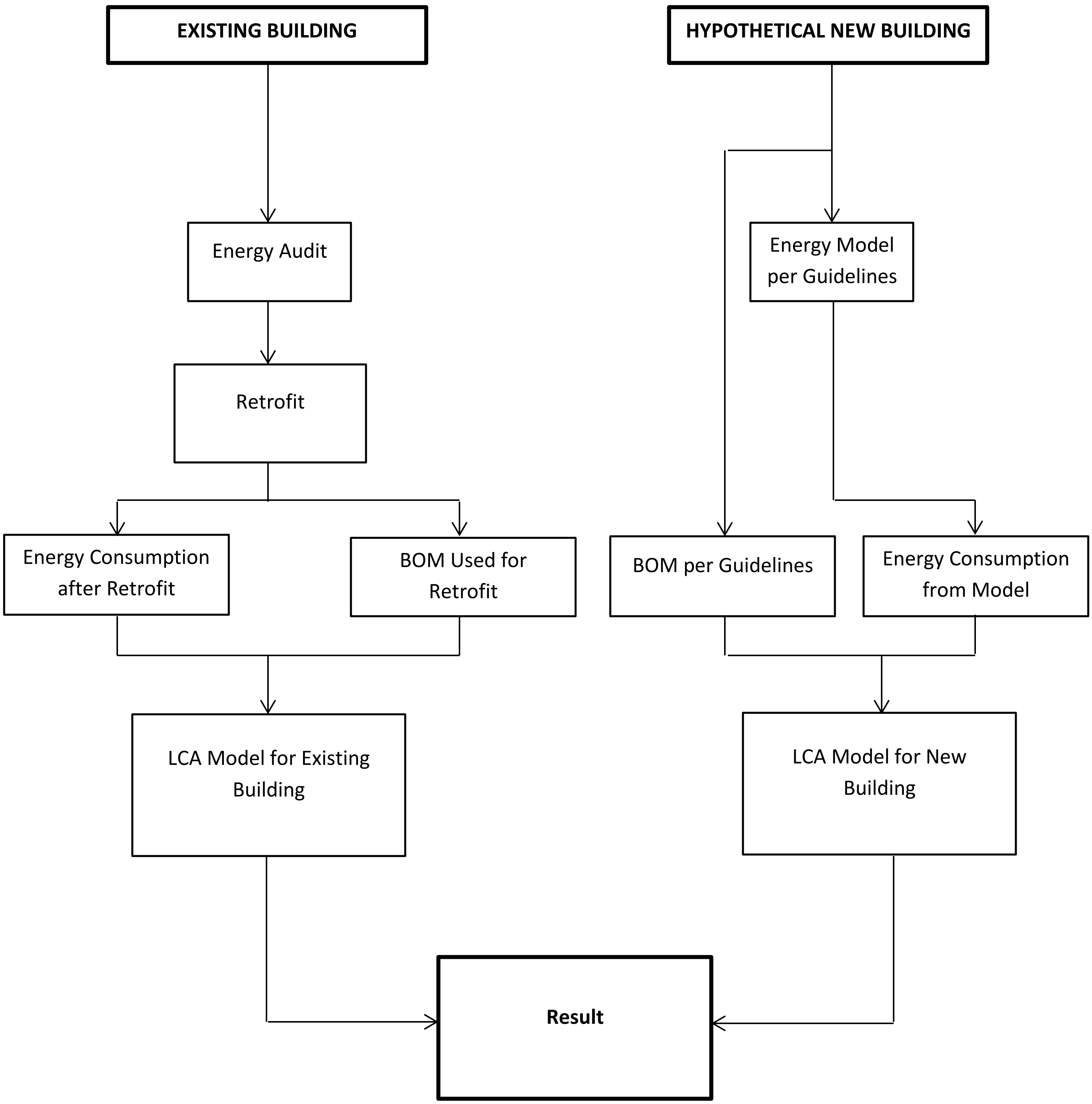

Figure 3: Process flow to make the Case for Existing Buildings

Case for reuse

Once the applicant has developed an LCA model for a hypothetical new building using the above guidelines, the case for reuse can be made using the following steps

Run separate LCA models for the new and existing buildings using the following inputs:

<u>Inputs for Existing Building LCA model:</u>

Energy Consumption – Use energy consumption data from past utility bills. If the existing building has undergone energy improvements, use energy consumption estimate after improvements.

Bill of Materials – Use the bill of materials that will be necessary to implement energy improvements if any.

<u>Inputs for proposed New Building LCA model:</u>

Energy Consumption - Use energy consumption data developed from the guidelines mentioned previously.

Bill of Materials – Use bill of materials from the guidelines listed previously.

<u>Results:</u> Demonstrate through the LCA modeling results that life cycle environmental impacts (of select impact categories) of the existing building will be lower than that of the proposed new building.

6. Conclusion

Research has shown that reusing an existing building has many environmental benefits. However, newer buildings are usually better performing than existing buildings by virtue of their superior systems and envelope. By the use of LCA, this research has shown how to compare new versus reuse to determine which one is more environment-friendly in a given situation. It also provided guidelines for the incorporation of this comparison into green building certification systems.

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Appendix 1 – LCA Simulation Input Data

LCA simulation was performed on ATHENA® Impact Estimator. The inputs used for the simulations are listed below:

Existing Building

Location: Atlanta, Georgia

<u>Operational Energy Consumption (after retrofit)</u>:

Electricity: 12,823 KWH per year

Natural Gas: 2.57 x 10^7 BTU per year

<u>Building Size, Dimensions and Lifespan:</u>

Area: 2990 SF

Average Building Height: 12 feet

Lifespan: 60 years

<u>Bill of Materials:</u>

Material	Quantity	Unit	Mass Value	Mass Unit
1/2" Fire-Rated Type X Gypsum Board	7167.6	sf	6.0043	Tons (short)
Double Glazed Soft Coated Argon	3430	sf	5.688	Tons (short)
Expanded Polystyrene	1344	sf (1")	0.0991	Tons (short)
Extruded Polystyrene	4233.6	sf (1")	0.5333	Tons (short)
FG Batt R20	3053.4	sf (1")	0.0842	Tons (short)
GAF Everguard© white TPO membrane 80 mil	14877.7778	sf	3.0231	Tons (short)
Water Based Latex Paint	734.4	Gallons (us)	2.2983	Tons (short)

New Building

Location: Atlanta, Georgia

Operational Energy Consumption (Various):

Annual Electricity (KWH):

262,049 209,639 157,229 104,819 52,410 0

Natural Gas (cubic feet)

18,357 14,686 11,014 7,343 3,671 0

Building Size, Dimensions and Lifespan:

Area: 2990 SF

Average Building Height: 12 feet

Lifespan: 60 years

Bill of Materials:

Material	Quantity	Unit	Mass Value	Mass Unit
1/2" Fire-Rated Type X Gypsum Board	7167.6	sf	6.0043	Tons (short)
Aluminum	1.9167	Tons (short)	1.9167	Tons (short)
Cedar Wood Tongue and Groove Siding	8416.32	sf	5.4817	Tons (short)
Concrete 20 MPa (flyash av)	83.9843	yd3	164.5637	Tons (short)
Concrete 30 MPa (flyash av)	221.5507	yd3	434.119	Tons (short)
EPDM membrane (black, 60 mil)	163.5217	lbs	0.0818	Tons (short)
Expanded Polystyrene	1414.0731	sf (1")	0.1043	Tons (short)
Extruded Polystyrene	4233.6	sf (1")	0.5333	Tons (short)
FG Batt R11-15	966.4899	sf (1")	0.031	Tons(short)

FG Batt R20	3053.4	sf (1")	0.0842	Tons (short)
GAF Everguard© white TPO membrane 80 mil	14877.7778	sf	3.0231	Tons (short)
Galvanized Decking	6.1629	Tons (short)	6.1629	Tons (short)
Galvanized Sheet	0.1365	Tons (short)	0.1365	Tons (short)
Galvanized Studs	2.4887	Tons (short)	2.4887	Tons (short)
Glazing Panel	9.5549	Tons (short)	9.5549	Tons (short)
GluLam Sections	1612.4322	ft3	19.9957	Tons (short)
Hollow Structural Steel	2.5299	Tons (short)	2.5299	Tons (short)
Nails	0.0043	Tons (short)	0.0043	Tons (short)
Ontario (Standard) Brick	3517.5	sf	43.5867	Tons (short)
Open Web Joists	10.2129	Tons (short)	10.2129	Tons (short)
Rebar, Rod, Light Sections	2.3278	Tons (short)	2.3278	Tons (short)
Screws Nuts & Bolts	0.1082	Tons (short)	0.1082	Tons (short)
Softwood Plywood	5.3799	msf (3/8")	2.6026	Tons (short)
Solvent Based Alkyd Paint	0.1558	Gallons (us)	0.0005	Tons (short)
Spandrel Panel	0.1896	Tons (short)	0.1896	Tons (short)
Water Based Latex Paint	734.4	Gallons (us)	2.2983	Tons (short)
Welded Wire Mesh / Ladder Wire	0.565	Tons (short)	0.565	Tons (short)

Appendix 2 – LCA Simulation Output Data

The results of LCA simulation performed on ATHENA® Impact Estimator for both the new and existing buildings are listed below

New Building Table – 0% Lower Operational Energy Consumption

	PRODUCT			CONSTRUCTION PROCESS		
Summary Measures	Manufacturing	Transport	**Total**	Construction -installation Process	Transport	**Total**
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
281878.2141	6362.249309	142864.18	**8860091**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	11626.833	**717133**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	95.29119	**5839.341**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	11.356365	**893.1388**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.9648924	**141.919**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	4.755E-09	**6.26E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	470.46093	**30451.78**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
2033021.323	162911.4432	8571850.6	**10767783**
176040.56	12271.62632	697609.98	**885922.2**
1260.361054	57.66070579	5717.4714	**7035.493**
852.7878448	1.776674784	681.38192	**1535.946**
125.408519	4.153681387	57.893545	**187.4557**
0.002783853	4.89583E-07	2.853E-07	**0.002785**
17121.0427	2039.019502	28227.656	**47387.72**

New Building Table – 5% Lower Operational Energy Consumption

	PRODUCT			CONSTRUCTION PROCESS		
Summary Measures	Manufacturing	Transport	**Total**	Construction -installation Process	Transport	**Total**
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
281878.2141	6362.249309	135722.3	**8431578**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	11045.608	**682259.4**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	90.527577	**5553.524**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	10.78867	**859.0771**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.9166575	**139.0249**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	4.517E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	446.94299	**29040.7**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
2033021.323	162911.4432	8143337.9	**10339271**
176040.56	12271.62632	662736.47	**851048.7**
1260.361054	57.66070579	5431.6546	**6749.676**
852.7878448	1.776674784	647.32019	**1501.885**
125.408519	4.153681387	54.999448	**184.5616**
0.002783853	4.89583E-07	2.71E-07	**0.002785**
17121.0427	2039.019502	26816.579	**45976.64**

New Building Table – 10% Lower Operational Energy Consumption

	PRODUCT			CONSTRUCTION PROCESS		
Summary Measures	Manufacturing	Transport	**Total**	Construction-installation Process	Transport	**Total**
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
281878.2141	6362.249309	128580.42	**8003066**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	10464.382	**647385.9**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	85.763964	**5267.707**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	10.220974	**825.0154**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.8684225	**136.1308**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	4.28E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	423.42504	**27629.63**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
2033021.323	162911.4432	7714825.1	**9910758**
176040.56	12271.62632	627862.95	**816175.1**
1260.361054	57.66070579	5145.8378	**6463.86**
852.7878448	1.776674784	613.25847	**1467.823**
125.408519	4.153681387	52.105351	**181.6676**
0.002783853	4.89583E-07	2.568E-07	**0.002785**
17121.0427	2039.019502	25405.502	**44565.56**

New Building Table – 15% Lower Operational Energy Consumption

Summary Measures	PRODUCT Manufacturing	PRODUCT Transport	PRODUCT Total	CONSTRUCTION PROCESS Construction-installation Process	CONSTRUCTION PROCESS Transport	CONSTRUCTION PROCESS Total
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE Replacement Manufacturing	USE Replacement Transport	USE Operational Energy Use Annual	USE Total	END OF LIFE De-construction Demolition	END OF LIFE Transport	END OF LIFE Total
281878.2141	6362.249309	121438.54	**7574553**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	9883.1572	**612512.4**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	81.000351	**4981.891**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	9.653279	**790.9536**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.8201876	**133.2367**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	4.042E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	399.90709	**26218.55**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS Non-Transport	TOTAL EFFECTS Transport	TOTAL EFFECTS Operational Energy Use	TOTAL EFFECTS Total
2033021.323	162911.4432	7286312.3	**9482245**
176040.56	12271.62632	592989.43	**781301.6**
1260.361054	57.66070579	4860.0211	**6178.043**
852.7878448	1.776674784	579.19674	**1433.761**
125.408519	4.153681387	49.211253	**178.7735**
0.002783853	4.89583E-07	2.425E-07	**0.002785**
17121.0427	2039.019502	23994.425	**43154.49**

New Building Table – 20% Lower Operational Energy Consumption

Summary Measures	PRODUCT Manufacturing	PRODUCT Transport	PRODUCT Total	CONSTRUCTION PROCESS Construction-installation Process	CONSTRUCTION PROCESS Transport	CONSTRUCTION PROCESS Total
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE Replacement Manufacturing	USE Replacement Transport	USE Operational Energy Use Annual	USE Total	END OF LIFE De-construction Demolition	END OF LIFE Transport	END OF LIFE Total
281878.2141	6362.249309	114287.8	**7145508**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	9301.1561	**577592.3**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	76.230428	**4695.695**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	9.0847646	**756.8428**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.7718882	**130.3387**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	3.804E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	376.35515	**24805.43**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS Non-Transport	TOTAL EFFECTS Transport	TOTAL EFFECTS Operational Energy Use	TOTAL EFFECTS Total
2033021.323	162911.4432	6857267.8	**9053201**
176040.56	12271.62632	558069.36	**746381.6**
1260.361054	57.66070579	4573.8257	**5891.847**
852.7878448	1.776674784	545.08588	**1399.65**
125.408519	4.153681387	46.31329	**175.8755**
0.002783853	4.89583E-07	2.282E-07	**0.002785**
17121.0427	2039.019502	22581.309	**41741.37**

New Building Table – 25% Lower Operational Energy Consumption

	PRODUCT			CONSTRUCTION PROCESS		
Summary Measures	Manufacturing	Transport	**Total**	Construction-installation Process	Transport	**Total**
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
281878.2141	6362.249309	107145.92	**6716996**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	8719.9308	**542718.8**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	71.466815	**4409.879**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	8.5170692	**722.7811**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.7236532	**127.4446**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	3.566E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	352.83721	**23394.36**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
2033021.323	162911.4432	6428755.1	**8624688**
176040.56	12271.62632	523195.85	**711508**
1260.361054	57.66070579	4288.0089	**5606.031**
852.7878448	1.776674784	511.02415	**1365.589**
125.408519	4.153681387	43.419193	**172.9814**
0.002783853	4.89583E-07	2.14E-07	**0.002785**
17121.0427	2039.019502	21170.232	**40330.29**

New Building Table – 30% Lower Operational Energy Consumption

	PRODUCT			CONSTRUCTION PROCESS		
Summary Measures	Manufacturing	Transport	**Total**	Construction-installation Process	Transport	**Total**
Fossil Fuel Consumption (MJ)	1571784.542	48450.141	**1620235**	96444.37055	83772.484	**180216.9**
Global Warming Potential (kg CO2 eq)	162420.064	3486.6256	**165906.7**	8774.012398	6433.6646	**15207.68**
Acidification Potential (kg SO2 eq)	1007.656924	16.99626	**1024.653**	60.37210661	29.763553	**90.13566**
HH Particulate (kg PM2.5 eq)	624.1031161	0.5167652	**624.6199**	12.65467902	0.9223632	**13.57704**
Eutrophication Potential (kg N eq)	34.37167457	1.2190888	**35.59076**	2.641027945	2.1480675	**4.789095**
Ozone Depletion Potential (kg CFC-11 eq)	0.002660232	1.394E-07	**0.00266**	6.11408E-05	2.564E-07	**6.14E-05**
Smog Potential (kg O3 eq)	11241.32625	601.11347	**11842.44**	1304.825217	1052.447	**2357.272**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
281878.2141	6362.249309	100004.04	**6288483**	82914.19601	24326.569	**107240.8**
19042.31693	480.6521587	8138.7055	**507845.3**	-14195.8332	1870.6839	**-12325.1**
119.6146811	2.254971189	66.703202	**4124.062**	72.717342	8.6459217	**81.36326**
211.687388	0.069518022	7.9493738	**688.7193**	4.342661684	0.2680283	**4.61069**
83.86294521	0.162468326	0.6754183	**124.5505**	4.532871236	0.6240568	**5.156928**
6.22495E-05	1.91708E-08	3.329E-09	**6.25E-05**	2.31526E-07	7.456E-08	**3.06E-07**
2144.385609	79.73889962	329.31926	**21983.28**	2430.505626	305.72016	**2736.226**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
2033021.323	162911.4432	6000242.3	**8196175**
176040.56	12271.62632	488322.33	**676634.5**
1260.361054	57.66070579	4002.1921	**5320.214**
852.7878448	1.776674784	476.96243	**1331.527**
125.408519	4.153681387	40.525095	**170.0873**
0.002783853	4.89583E-07	1.997E-07	**0.002785**
17121.0427	2039.019502	19759.155	**38919.22**

Existing Building Table

Summary Measures	PRODUCT Manufacturing	PRODUCT Transport	PRODUCT Total	CONSTRUCTION PROCESS Construction-installation Process	CONSTRUCTION PROCESS Transport	CONSTRUCTION PROCESS Total
Fossil Fuel Consumption (MJ)	235398.4937	972.6042	**236371.1**	7594.266609	5737.1332	**13331.4**
Global Warming Potential (kg CO2 eq)	14732.56339	71.876173	**14804.44**	400.7462312	441.28908	**842.0353**
Acidification Potential (kg SO2 eq)	103.3371725	0.3450412	**103.6822**	2.729030236	2.0390719	**4.768102**
HH Particulate (kg PM2.5 eq)	13.51076585	0.0105459	**13.52131**	0.307362596	0.0632179	**0.370581**
Eutrophication Potential (kg N eq)	5.486286225	0.0247906	**5.511077**	0.218289582	0.1471831	**0.365473**
Ozone Depletion Potential (kg CFC-11 eq)	0.000318219	2.867E-09	**0.000318**	1.71091E-06	1.759E-08	**1.73E-06**
Smog Potential (kg O3 eq)	801.166705	12.200469	**813.3672**	45.5830917	72.101686	**117.6848**

USE				END OF LIFE		
Replacement Manufacturing	Replacement Transport	Operational Energy Use Annual	**Total**	De-construction Demolition	Transport	**Total**
263115.2058	4421.43587	142864.18	**8839387**	0.000524903	861.7169	**861.7174**
14133.27245	336.1983969	11626.833	**712079.5**	0.000588439	66.287584	**66.28817**
99.49053052	1.56973199	95.29119	**5818.532**	6.3767E-07	0.3062674	**0.306268**
51.87996462	0.048477319	11.356365	**733.3104**	1.81965E-08	0.0094956	**0.009496**
52.25039089	0.113161663	0.9648924	**110.2571**	7.46473E-05	0.0221071	**0.022182**
0.000324491	1.34044E-08	4.755E-09	**0.000325**	1.4847E-15	2.642E-09	**2.64E-09**
787.3568179	55.50624887	470.46093	**29070.52**	1.5881E-05	10.829631	**10.82965**

TOTAL EFFECTS			
Non-Transport	Transport	Operational Energy Use	**Total**
506107.9667	11992.89021	8571850.6	**9089951**
29266.58266	915.6512364	697609.98	**727792.2**
205.5567339	4.26011254	5717.4714	**5927.288**
65.69809309	0.131736786	681.38192	**747.2117**
57.95504135	0.30724244	57.893545	**116.1558**
0.000644421	3.6502E-08	2.853E-07	**0.000645**
1634.10663	150.638034	28227.656	**30012.4**