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LIFE CYCLE ASSESSMENT FOR HISTORIC BUILDING REUSE: IS EXISTING BUILDING THE GREENEST BUILDING?

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Abstract
Until now, little has been known about the climate change reductions that might be offered by reusing and retrofitting existing buildings rather than demolishing and replacing them with new construction. This life cycle analysis of Bent’s house building was carried out as an exploratory study to find out whether preserve historical building will have quantifiable environmental impact beyond the cultural benefit that have been known and agreed by public. This research paper provides a comprehensive analysis to date of the potential environmental impact reductions associated with building reuse using Bent’s opera house as a study case. Utilizing a Life Cycle Analysis (LCA) methodology, the study compares the relative environmental impacts and primary energy consumption of historical building, building renovation and new construction over the course of a 75-year life span. Also, this research project illustrates a framework of integrating variety BIM tools in life cycle analysis.

Keywords. *Life Cycle Assessment, Historical Preservation*

1. Introduction – this is an essential section of the paper

Every year, approximately 1 billion square feet of buildings are demolished and replaced with new construction in the United States. The Brookings Institution projects that some 82 billion square feet of existing space will be demolished and replaced between 2005 and 2030 – roughly one quarter of today’s existing building stock.1 Yet, few studies to date have sought to examine the environmental impacts of razing old buildings and erecting new structures in their place. In particular, the climate change implications of demolition and new construction, as compared to building renovation and reuse, remain under examined.

Life Cycle Analysis (LCA) is an internationally recognized approach to evaluate the potential environmental and human health impacts associated with products and services throughout their respective life cycles. " LCA requires life cycle inventory (LCI) data for all materials and processes, a life cycle impact assessment (LCIA) method, and a software tool to do the work. LCI data is the inventory of all flows to and from nature due to a product or process – it's a long list of substances and quantities which involves complex considerations in boundary, allocation methods and so forth. The LCIA method translates those flows into environmental impact potential.." 2

2. Approach and Methodology

According to ISO 14040 standards, and LCA is conducted in four phase. "The first phase, goal and scope definition, establishes the boundary conditions of the systems, defines a functional unit for the system, and enables equivalent comparisons with other products or processes. During the second phase, life cycle inventory (LICI), data is aggregated to determine aggregate inputs and outputs. In the case of a building materials study, this is often the quantity of materials used as well as the emissions associated with the production of those materials. In phase three, Life cycle impact assessment (LCIA), the LCI is translated using characterization factors, into impact categories, such as global warming potential. The fourth and final phase is interpretation, where data and results are analyzed to determine areas of relatively high environmental impacts and recommendations are made for improvements to the system. The four phases often occur in an iterative nature." 4 Quite a few LCA tools and software exist that can be used to assess buildings, for example, BEES, ATHENA, Gabi and Simpro. The USGBC has also started to incorporate LCA into their newest version of LEED through pilot credits, including Pilot Credits 1: Life Cycle Assessment of Building Assemblies and Materials and Pilot Credit 63: Materials and Resources – Whole Building Life Cycle Assessment. 5

2.1 STUDY OBJECT DESCRIPTION

Located in the heart of Median, New York, Bents' Opera House stands prominently at the corner of 444 main street and center street. Completed in 1865, the opera house was built from the now famous medina sandstone, which can also be found in places such Havana, Cuba and was used for London's Buckingham Palace. 6 Named after the property's original owner Don Carlos Bent, the Opera House has a rich and varied history. Given the building's name, it follows that the opera house's main feature was historically its performance space located on the third floor. This was home to variety of uses including plays, shows, commencements, elections, and other public functions. The building has also served as a gathering space for the local men's fraternal order as well as a Bank of America branch. Over time the building fell into disuse but is still considered a significant architectural landmark for Medina. In 1995 it was included in the National Register of historic places as a part of Medina's main street historic district. Bents' house has total 4 floors with square footage of 23000.

2.2 LCA BOUNDARY DEFINITION AND LCI INPUT

The boundaries for this study include material extraction, product processing, delivery, demolition and transportation. Benefit and loads beyond the system boundary such as steel recycling was excluded. This LCA include the environmental impacts of Bent's house's building materials and operational expense. Three models have been built: the first model is based on the original material of historical building (no additional thermal insulation were added); the second model is based on keeping original historical building external walls and roof materials with additional thermal insulation; the third model is based on rebuilding entire building with the same square footage, functions and meeting current international green construction code (Igcc code). Building mechanical, electrical, plumbing system is excluded from material calculation since in the original historic building none of those modern systems existed.

Transportation of the building materials to the construction site, construction waste, and materials used for construction itself (e.g., temporary materials) are included. The functional unit of this study is defined as the entire Bent's Opera House. Operational expenditure includes energy spent on heating, cooling, ventilation, water heating, lighting, and others. The major components of the material analysis, ranging from structural elements to interior flooring are included. "Not included in the study were landscaping elements; interior finishes such as carpet tiling and paints were also not included in this study as they represent a small quantity of the building's total mass. Paint and interior finished represented only 2%- 4% of energy and global warming impacts in previous building LCA studies." 7

Figure 1 Building Materials and Assemblies included in LCA

The analysis take a closer look at the initial materials involved with the Bent's house and also account for replacement materials that included in life cycle B6 stage. (refer to figure 4)Material inventory data was obtained through plans and project information provided by Bero architect and site survey conducted by the researcher, including plans, elevations, sections, code analysis and Revit models. Materials were extracted from material schedule in Revit models, then converted into a excel database. The operational expenditure was obtained through benchmarking method based on CBECS(Commercial Building Energy Consumption Survey) building 2003 database. 8 The operational expenditure's measure unit is KBTU/sf-yr.

2.3 IMPACT ASSESSMENT METHOD

The LCIA phase was conducted using the combination of two impact assessment methods. The material side life cycle primary energy consumption is analyzed using Athena IE4B. The Athena sustainable material institute is the pioneer of whole---building life cycle assessment (LCA) in North America. In 3.3 tools and data, IE4B will be explained in details. The operational side of primary energy consumption is assessed using benchmarking method. The benchmark database is CBECS 2003 survey; the sets of data used in the study include offices and public assemblies.

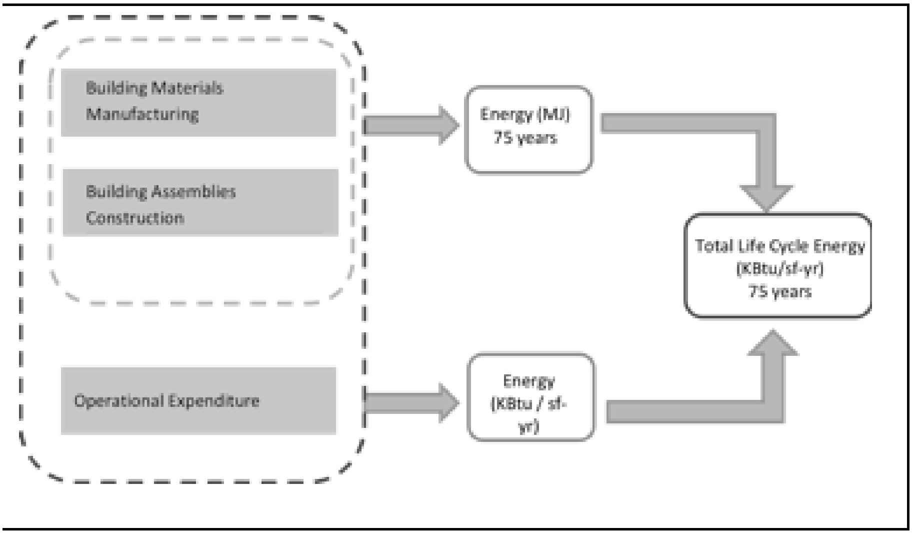

Figure 2 Impact assessment method

The impact assessment categories reported from Athena included global warming, acidification potential, HH particulate, Ozone depletion potential, smog potential, eutrophication potential, energy consumption, air emissions, water emissions, resource use, land emissions. In this study, the researcher focuses on global warming, HH particulate, Ozone depletion potential, smog potential.

3. Goal and Scope

3.1. GOAL

There are no original drawings for the historic building; however there are multiple alterations have been done to the interiors. None of the alternation and renovation is well documented. The base of this study is the survey drawings done by Bero Architect and Revit model reconstructed based on the survey drawings and filed measurement conducted by the researcher. Most building assemblies are based on field assessment. The main outcomes of this LCA study are the establishment of materials inventory and environmental impact references of the Bent's house. Exemplary applications of these references are in the assessment of future reconstruction or renovation of the historical buildings similar to Bent's house. Furthermore, the comparisons of environmental impact between preserving historical building with upgraded exterior wall insulation property and reconstructing a new building according to Igcc, can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future historical buildings renovation, reconstruction and demolition projects.

3.1. TOOLS AND DATA

Two main software tools are utilized to complete this LCA study: Revit model to takeoff the materials and the Athena sustainable materials institute's Impact Estimator for Building (IE4B) to assess the life cycle impact. The materials quantify takeoff from Revit model constructed based on survey drawings and field measurement. Using the physical model, the schedule within Revit extracts the three dimensional data and then materials takeoff schedule has been exported out from Reivt as xcel file. The researcher has to simplify the schedule to edit out the non-useful information and made a clear spreadsheet. The useful data include: external walls, interior walls, columns, floors, roofs, foundations. Then the data have been manually inputted into Athena IE4B.

Using the formatted takeoff data, version 5.0.0125 of IE4B software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the Bent's house. Three models were generated based on geometrical information from the same Revit model: 1) The historical building; 2) The renovated version with added insulation in external wall the roof. (The added insulation has a value of R30 on external wall and R40 on roof); 3) New constructed Bent's house.

Table 1 Building Assemblies Included in LCA

Assemblies Makeup			
	Historical Building	Renovation	New Construction
EXTERNAL WALL	Natural solid Sand stone	Natural solid Sand stone with additional fiberglass batt insulation R30	Brick cladding concrete backing with air barrier and fibreglass batt
WINDOWS	Unclad wood window frame double pane glaze no coating air	PVC window fram double glazed no coating air	Fiberglass window grame double glazed sofr coated argon

DOORS	Solid wood door	Solid wood door	Fiberglass exterior door
FLOOR	Plywood decking @15mm with 3.6 kPa	Plywood decking @15mm with 3.6 kPa	Concrete hollow core floor with love load 2.4kPa
COLLUMNS	Softwood lumber with live lad 2.4kPa	Softwood lumber with live lad	Precast concrete with live lad
BEAMS	Glulam	Glulam	Precast concrete
ROOF	Plywood decking @ 15mm without insulation	Plywood decking @ 15mm with R40 insulation and waterproofing	Precast concrete decking with R40 insulation, EPDM cellulose and
FOUNDATION	Concrete @ 200mm with average flyash %	Concrete @ 200mm with average flyash %	Concrete @ 200mm with average flyash %

3.3. BUILDING MODEL

In order to compare preservation, renovation and new construction, three models have been created with reasonable accuracy.

The first step in creating a reasonable building model is to carry out a takeoff of the materials used. The takeoff for Bent's house was based on Revit model we created based on survey drawing provided by Bero Architect. Unfortunately, due the age of the building, many of the actual building assemblies are hard detected, and the researcher made multiple assumptions. The takeoffs for Bent's house were done using scheduling tool in Revit. The area condition is used to compute the surface area and building basic geometry. The count condition is used to compute the number of times the same instance occurs. A few major assumptions were made to complete this project and the assumptions are: the foundation are raft foundation made of caste in place concrete; all floors are same in terms of assembly and load; all columns on all floor are the same.

3.3.1 Columns and Beams

The column and beam takeoffs were completed mainly using Revit count condition. The floor to floor height and live load were taken from

Bero’s code analysis document. The supporting span and supported Span are both 4 meter. (refer to table 1)

3.3.2 Floors

All floors within the building are wood trust made of plywood. The surface area of the slab was computed using the area condition in Revit. The computed areas were then convert into rectangular slabs of equivalent surface area with spans of 4 meters and 8 meters as those are close to the IE4B span limits. The length and span of the idealized rectangular slabs were then inputted into the IE4B. A rectangular slab 20 meters by 10 meters results in an equivalent surface. The concrete strength and live load were taken from code analysis document and entered into the IE4B. (refer to table 1)

3.3.3 Roofs

All roof in Bent’s house are assumed to be made of plywood as well since we could not get onto the roof top. Decking thickness assume to be 15mm with love load at 2.4kPa, then those date have been manually put into IE4B. Other assumptions include: the bitumen was standard modified, the insulation were not added when the building was originally being constructed.

3.3.5 Walls

The external wall types used in Bent’s house are as follows: natural sandstone walls. The lengths of the external walls are calculated by scheduling from Revit model. There are no rebar in the exterior wall. Interior partition wall are excluded from the material takeoff due to the lack of historic documents on interior layout and multiple alternation through the years. The windows for all walls were modeled as being unclad wood window frames double glaze even though many of the windows are, in fact, wood frames. The window schedule in Revit model was used to find the number of windows relate to a specific wall, in the schedule the researcher was able to schedule window counts per each wall. The number of windows was then put in Athena with related square footage of a single window in order to compute the total window area relate to a given wall. Like windows, the number of doors within each respective wall was calculated using schedule function in Revit model, then manually input the data into Athena. Exterior doors were assumed to be solid wood frame door.

3.3.6 Assumptions

It is important to put in perspective that there is some uncertainly related to the accuracy of the Bill of Materials due to the assumptions mentioned in the previous section. Firstly, the roof material and construction is based on the assumption from similar building built around same period since it is difficult to get on the roof without professional equipment. Secondly, the live load is assumption based on the current building code. This might lead to many of the live loads being overestimated. This, in turn, likely led to a slight over estimation. Thirdly, due the lack of choice in Athena, all windows are chosen as double pane which is different from actual single pane glass. This led to overstatement the materials use and environmental impact in the end.

3.4 ALTERNATIVE OPTIONS

After the base building---historic building data has been manually put into Athena, two alternative sets have been created based on the baseline building: Renovated building; New constructed building update 2012 Igcc standard.

In the renovated building version: external wall were added with additional R30 insulation; windows were replaced with fiberglass window frame with double pane glass; roof were added additional R40 insulation; floors, columns and foundation were kept the same as base line building.

In the new construction: external wall were added with additional R30 insulation; windows were replaced with fiberglass window frame with double pane glass; roof were added additional R40 insulation; wood columns have been replaced by precast concrete columns; floors and foundation were kept the same as base line building.

3.5 BUILDING OPERATIONAL EXPENDITURE (ENERGY USAGE)

Benchmarking method has been used to determine the total site energy intensity. The data set is coming from U.S. National CBECS (Commercial Building Energy Consumption Survey) 2003 version; the location is set to has =<2000 CDD, 5500-7000 HDD; size as 0-25000 sqft; operation hour as 0--90 hours/week and building was built before 1920. In order to capture as much as buildings that comparable to Bents' house, during benchmarking, the building type has been set as Administrative/professional office, Bank/other finical, Culture, Mixed-use office, and other public assembly, recreation, social/meeting. Total 19 buildings have been found in the CBECS database with median energy usage intensity (EUI)at 66.7 kBTU/sf---yr. And this number is being used to calculate the total site energy consumption for the historical building in the life span of 75 years. The same benchmarking process has been

4. Results and Findings

4.1 LIFE CYCLE ENERGY CONSUMPTION

The researcher compared the results from the three models with the goal of providing information related to building reuse and renovation benefit. IE4B produce results for the following mid---point impact measures: total primary energy consumption, non---renewable energy consumption and fossil fuel consumption. In this study, researcher only focuses on primary energy primary energy consumption. Total Primary energy consumption is measured in mega---joules (MJ). The primary energy includes all energy, "used to transform or transport raw materials into products and buildings, including inherent energy contained in raw of feedstock materials that are also used as common energy sources." 10 In addition, the impact estimator also includes indirect energy such as processing, transporting, converting and delivering fuel and operating energy.

In general external walls of the historical Bent's house represented the highest total primary energy consumption; nearly accounts for 85% of energy consumed through life cycle stage A through C. The secondary is floors assembly, accounts for 6%. In renovation building, external wall accounts for 78% total primary energy consumption and roof assembly rise to the second, consume 12% of the total energy. In the new construction, the external wall assemblies still rank the first, however it only account for 54% of the total primary energy consumption, all other categories have substantial increase in percentage: Beams and columns assembly rank the second representing 32% consumption; roof assembly account for 8% and it is third highest energy consumption category.

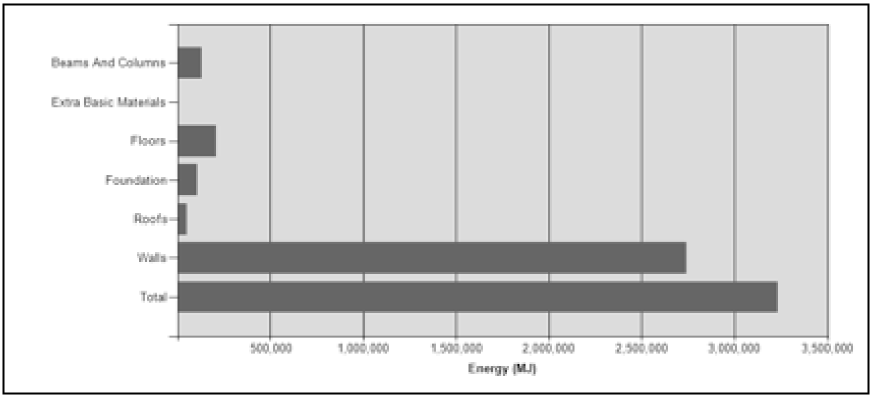

Figure 3 Total primary energy summary for Historical building by assembly groups

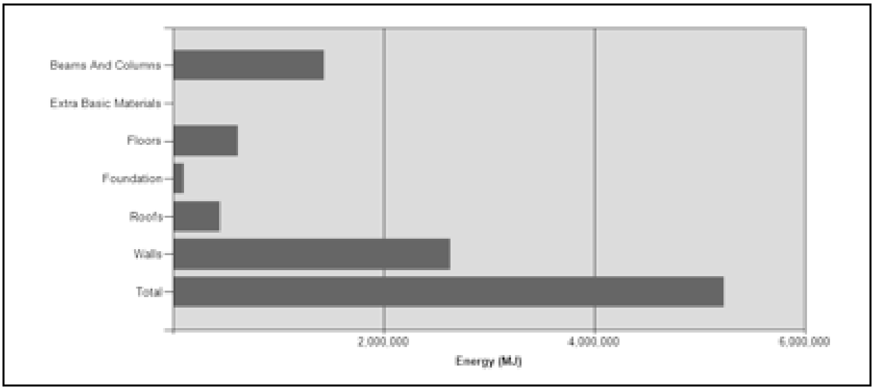

Figure 4 Total primary energy summary for new construction by assembly groups

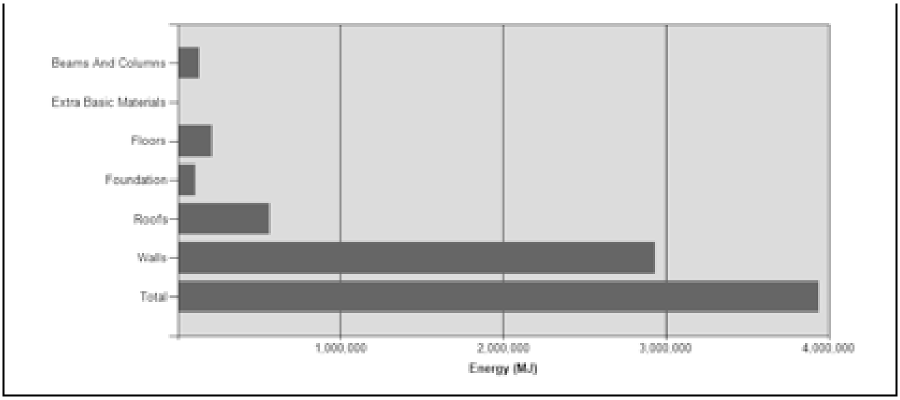

Figure 5 Total primary energy summary for renovation by assembly

And consistently, within material primary energy consumption, operational energy is much higher than embodied energy. In terms of total operational energy(in life cycle stage B6),[11] the historic Bents' house consume almost twice the energy in the entire life span compare to renovation and new construction building. And in the stage A1---A3, the new construction has slight higher energy consumption compare to historic building and renovation building. In IE4B operational energy is refer to B6 stage and include: energy primary extraction, production, delivery, and use. And those usages are only related the building materials and assemblies. We need make very clear the "Material operational energy" is different from "Building Operational Energy Use" which we described in 3.6. "Building Operational Energy Use" includes the energy used to provide space heating, cooling, ventilation, water heating and etc. for the occupancy.

Through the comparison result, the researcher has three major findings: Identifies the operational cost is most important the stage through the entire building material life span in terms of total primary energy consumption.

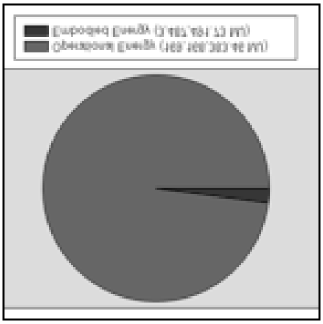

Figure 6 Historic Bent's House

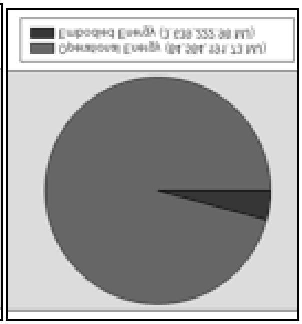

Figure 7 Renovation

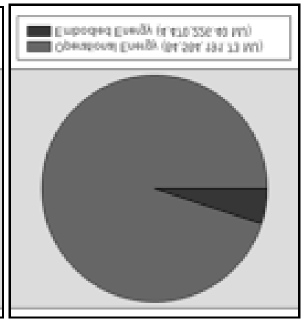

Figure 8 New construction

From stage A-C, historical building has slightly higher material primary energy use in end of life stage C and A4-A5 comparing to renovated building. Beside those stages, historical building has lower primary energy consumption throughout entire life cycle, only 87% comparing to new construction and 97% of renovated building. New construction material has sustainable high primary energy beyond building life span of 75 years that is almost 21 times of historic building. It represents a high waste of new construction materials after the building use life has been terminated.

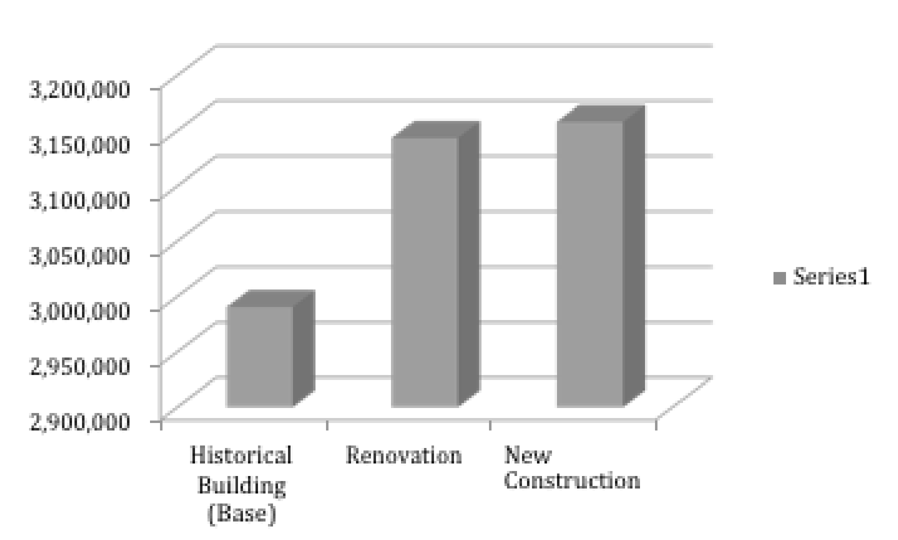

Figure 9 Comparison of Total Primary Energy By Life Cycle Stage

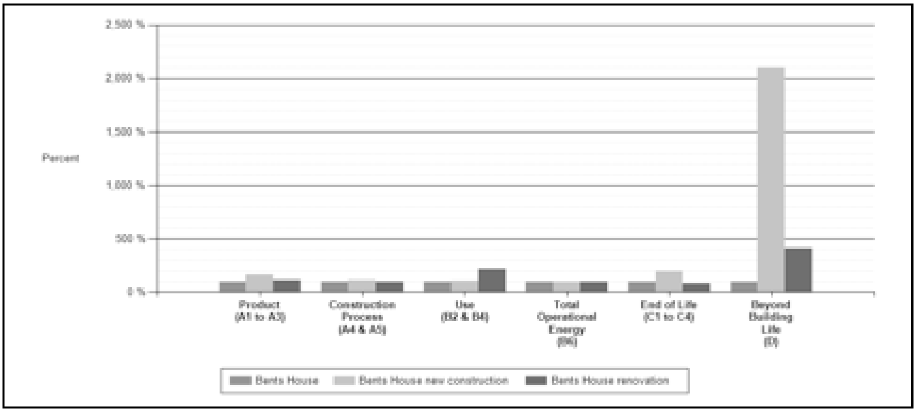

Figure 10 Overall Energy Consumption per year in life span of 75 years

4.1.4 Material primary energy consumption + Building energy expenditure Due the insufficient thermal properties of historical building exterior building envelope and long heating period in Rochester, NY, historical building consume more building operational energy. However, because of the higher embodied energy embedded in the new construction materials the overall energy usage of historical building is still less than renovated building and new construction.

4.2. LIFE CYCLE ENVIRONMENT IMPACT

In this study, researcher focus on the following mid-point impact measures: global warming potential, human health particulate, ozone depletion, and smog potential. In global warming potential (GWP): New construction has about 1.3 times potential than historic building and 1.21 times than renovation building through A-C life cycle stages. In smog potential: New construction has about 1.45 time potential than historic building and 1.44 times than renovation building through A-C life cycle stages. In HH Particulate Potential: New construction has about 3.0 time potential than historic building and 1.78 times than renovation building through A-C life cycle stages. In Ozone Depletion Potential: New construction has about 1.1 time potential than historic building and 1.19 times than renovation building through A--C life cycle stages.

5. CONCLUSION

This study looked at both embodied energy of major building materials and assemblies and building operational energy consumption in building life span of 75 years in upper state New York. The study was done as the comparison between three different models: Historical, Renovated and New construction. It is important to note the result is consistently: the new construction will have bigger primary energy consumption even though the advanced HVAC system might offset some building energy consumption in operational phase. The assumption is: the longer the building life span and closer three model estimation will become, the payback period of using modern advanced materials in order to reduce operational cost will most likely exceed the building functional life span, that is typical 60 years.

As more and more buildings are target to become more energy efficient, we should not disregard the primary energy of the materials and building assemblies play important role when we decide whether to retrofit or reuse an existing historical building verse demolishing old building and building a new one. Many studies in the past have large focused on operational phase energy, as that building life cycle phase typically dominated analyses. We now need to reconsider the important interplay between building materials and use phase performance to truly design and operate any buildings.

This study analyzed the life cycle environmental impacts of the materials phase of three models: Historic Bents' house, Renovated version and New construction compare the impact results. New construction has more negative impact in all aspects studied in this research: Global Warming Potential, Smog Potential, Ozone Depletion Potential and HH Particulate Potential. Life cycle assessment is necessary aspect for evaluation for building reuse to understand how the embodied energy of materials is allocated during a building's use phase and whether building a new high-performance building could have even bigger and negative environmental impact.

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