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Measuring the Capital Energy Value in Historic Structures

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Abstract
A credible model to account for the overall energy benefits with retention of historic buildings has been needed since preservation became national policy in 1966. The initial need to measure energy capital in buildings arose from the two energy crises in the 1970s, with a second need to address the sustainability goals of the 1990s/2000s. Both responses measure overall energy efficiency of historic buildings by attempting to account for the "energy capital." The Advisory Council on Historic Preservation introduced the first model in 1979, focused on measuring embodied energy and it has remained embedded in preservation vocabulary and is a reflexive argument utilized to advocate for the retention of historic structures over new construction. The second model, the life cycle assessment/avoided impacts is a response to the evolving metrics and currency of sustainability. The Preservation Green Lab further matured the capabilities of the life cycle assessment/ avoided impacts model in 2012 with their innovative report, The Greenest Building: Quantifying the Environmental Value of Building Reuse. This thesis evaluates the future of the preservation field to communicate with a common currency regarding retention of historic structures.

Keywords
embodied energy, avoided impacts, sustainability

Disciplines
Historic Preservation and Conservation

Comments
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MEASURING THE CAPITAL ENERGY VALUE IN HISTORIC STRUCTURES

Erika Leigh Hasenfus

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To Mom, Dad and Krista

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Glossary of Terms

BTU: British thermal unit

CO2: Carbon dioxide

EIA: U.S. Energy Information Administration

ACHP: Advisory Council on Historic Preservation

LCA: Life Cycle Assessment

EPA: U.S. Environmental Protection Agency

GHG: Greenhouse Gas Emissions

ICE: Inventory of Carbon Emissions

MJ: Megajoule

EE: Embodied Energy

Chapter I
Introduction

"In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of *Science*, whatever the matter may be."

Lord Kelvin (Sir William Thomson)

Energy Value Within Historic Structures

Historic preservation in the United States evolved from a local movement and desire to preserve sites associated with national identity. With the 1966 National Historic Preservation Act, cooperation between local and federal governments was established.[1] Shortly after, in the 1970s, the country faced two energy crises—each prompted by oil embargoes in oil-producing states. As a result, energy prices increased, the United States experienced shortages of gasoline and fuel oil, and became acutely aware of the country's dependency on foreign oil. These factors produced a push for energy conservation nationwide with the formation of the Department of Energy in 1977 and citizen participation through reductions in air travel, reduced highway speed limits, and to turn down thermostats six degrees as just a few measures. The preservation field responded to these threats with a number of initiatives including, in 1978, *Preservation Briefs 3*—

[1] "Historic Preservation in the United States," ICOMOS, accessed March 31, 2013, http://www.usicomos.org/preservationhttp://www.usicomos.org/preservation.

"Conserving Energy in Historic Buildings" by the National Park Service.[2] This initiative laid the groundwork for the embodied energy argument of retention of existing buildings rather than replacement with new more energy efficient buildings. Embodied energy became the focal point for the preservation field as an argument, focusing on all of the energy that was locked up in a historic building from its original construction. The twenty-first century brought with it a new set of goals and policies to a new problem. The Intergovernmental Panel on Climate Change in their 2007 Fourth Assessment Report, indicates that the:

> "Earth's climate system is unequivocally warming, and it is more than 90% certain that humans are causing most of it through activities that increase concentrations of greenhouse gases in the atmosphere, such as deforestation and burning fossil fuels."[3]

In response to this knowledge, sustainability has emerged and become a household term and it is now nearly impossible to not encounter its efforts, both large and small. However, historically, sustainability when dealing with the built environment has relied heavily on "green technology" and new high performance construction as opposed to preservation projects.

The arguments for retention of historic buildings from an energy value standpoint have evolved around the focus of the energy capital embodied within structures. The environmental avoided impacts approach looks at the environmental impacts that are avoided by rehabilitating an existing structure compared to demolition and new construction. The prior method values energy retrospectively as all the energy stored to

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[2] *Preservation Briefs 3* – "Improving Energy Efficiency in Historic Buildings," was updated in December 2011. The updated version of this report provides an even more comprehensive look at the building envelope and how it can be updated to better manage energy performance.

[3] Intergovernmental Panel on Climate Change, Synthesis Report, Section 1.1: "Observations of climate change," in IPCC AR4 SYR 2007, http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains1.html.

date, while the second method values energy as the capital you would have to spend in the future to upgrade a building.

This thesis explores energy's role in the preservation field, specifically, comparison of the past and emerging methods for how energy value is determined in historical structures. Since the 1970s embodied energy has served as the primary method for determining energy value in historic structures. It has provided the field with the rationale it required for support in not demolishing a structure, but at times, the data yields varied results. Embodied energy as a concept may retain validity, but as sustainability goals and policies advance, so do the methods used to evaluate the capital energy embedded in building systems. For example, the sustainability movement in the past decade began utilizing a carbon dioxide (CO_2) currency, which could antiquate the language and rationale of embodied energy—and make it increasingly difficult for preservation professionals to advocate for the energy capital stored within historic structures.[4]

This thesis further evaluates the strengths and weaknesses of both the embodied energy model and the life cycle assessment/environmental avoided impacts. It addresses the 1979 model, which established by the American Council on Historic Preservation, and the 2012 model, which was established specifically for the field by the Preservation Green Lab a sector of the National Trust for Historic Preservation. Both models create output measurement units in two different sustainability currencies for expressing the

[4] Carbon dioxide (CO_2) currency is defined as the measurement of greenhouse gas emissions into the atmosphere, an environmental indicator of sustainability. CO2 is only one of several greenhouse gases impacting global warming.

energy value of an existing building. Ultimately, this thesis seeks to identify which model provides higher and better rationale for the preservation field.

Bridging the Energy Efficiency Gap

Continually, the preservation field is faced with the challenge of bridging the gap between operational energy and embodied energy when comparing the energy efficiency of historic versus new buildings. Operational energy is defined as the energy used within a building to heat, cool and illuminate as it operates over a typical meteorological year. Operating energy is a vital component when measuring the energy consumption of a building, the ability to integrate and mature the operating energy component into the assessment of the "energy capital" of a building will improve the argument for the preservation field. The embodied energy scheme measured "energy capital" by what had been invested, while the life cycle assessment/avoided impacts scheme measures "energy capital" by what must be spent in the future to improve operating efficiency of an existing building. In both cases the "energy capital" of the historic building is compared to the "energy capital" of the new building.

Methodology

The methodology for this study consists of an overview of the connections between sustainability and preservation, an in-depth evaluation of the embodied energy model and the life cycle assessment/avoided impacts model, followed by a single case study. This thesis examines preservation professionals' reliance on the embodied energy method as definitive data and to draw conclusions about the future fate of historic

structures. Evaluation of the two models is applied and explores future options for the preservation field to advance and remain relevant rather than to denote these past claims and advances.

Industry Interviews

Interviews with industry professionals was conducted to provide insight into what is currently utilized in the preservation field, as well as varying opinions on the future of sustainability currency and how preservation professionals can maintain inclusion in sustainability discussions. Professionals were selected by availability, accessibility and knowledge on the topic.

Case Study

A case study building is presented and used as a basis for comparing both models for evaluating energy value of an existing building. A masonry townhouse in Society Hill, Philadelphia, Pennsylvania was selected due to accessibility and material construction. Embodied energy was assessed using the survey method. Environmental consequences, or the avoided impacts, were measured using the Athena EcoCalculator provided by the Athena Sustainable Materials Institute in Canada.

Findings

The analysis from the Philadelphia case study and interviews with professionals was used to draw conclusions about how preservation practitioners can better handle sustainability conversations, specifically as they relate to energy value in historic

structures. Recommendations are solely for the issue of energy value in historic structures and do not include other facets of sustainability that preservation affects.

Chapter II
Preservation and Sustainability: Inherent Connections

This chapter provides contextual background of the sustainability movement and its connections with preservation by chronicling the histories of eco-conservation and preservation. The evolutions of both fields are also presented on a timeline, highlighting similarities. It then defines embodied energy as it is used today, and presents the development of the rationale for measuring energy capital within a historic structure.

The Early Years: 1970s – 1980s

Growing concern about the scarcity of environmental resources began in the 1970s when dialogue turned towards the notion of limited resources. *Silent Spring,* written by Rachel Carson and published in 1962, is widely accredited with launching the modern American environmental movement. Carson stimulated growing concern about pollution, after she documented detrimental effects pesticides have on the eco-system.[5] Ten years later the publication of *The Limits to Growth*, in 1972 written by Donella H. Meadows, Dennis L. Meadows, Jorgen Randers and William W. Behrens III and commissioned by the Club of Rome, further explored how potential growth interacts with limited finite resources.[6] The environmental movement began to stir and organize as social groups recognized the necessary need to research and educate about the effects humans were having on the earth's eco-system. Both of these publications foreshadowed

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[5] Rachel Carson, *Silent Spring* (Boston: Houghton Mifflin, 1962).
[6] Donella H. Meadows, Dennis L. Meadows, Jorgen Randers and William W. Behrens III., *The Limits to Growth* (New York: Universe Books, 1972).

anxieties that would accumulate as an outcome of the energy crises that were on the horizon for the United States.

The 1970s oil crises initiated a concern for energy consumption after the Organization of Petroleum Exporting Countries (OPEC) arose in the Middle East. In October of 1973, during the Yom Kippur War, Arab members of OPEC raised the price of crude oil by 70 percent and placed an embargo on imports to the United States. As a result, by January 1974 oil prices were quadrupled from what they previously were.[7] Price levels rose to $11.00 per barrel, significantly higher than the $1.80 per barrel that had remained unchanged from 1961 to 1970.[8] At the start of the oil embargo in October 1973, the United States imported about 35 percent of its petroleum supply.[9] The rise in oil prices was preceded by years of negotiations between OPEC and Western oil companies over production and price levels, leaving a destabilized relationship making the oil embargo effective.

The United States was faced with a growing consumption of oil and was reliant on foreign exports; eventually six months later a negotiation to end the embargo was reached in March 1974. By this time the United States had formed The Federal Energy Office in December 1973 to assist in gaining control and responsibility over fuel allocation. With the end of the embargo reached and President Ford taking office, The Federal Energy Administration was created in June 1974. By March 1974, the average

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[7] "1973-74 Oil Crisis," The Bancroft Library, University of California, Berkeley, accessed March 1, 2013, http://bancroft.berkeley.edu/ROHO/projects/debt/oilcrisis.html.

[8] Chairman Alan Greenspan, "Energy" (remarks before the Japanese Business Federation, The Japan Chamber of Commerce and Industry, and the Japanese Association of Corporate Executives, Tokyo, Japan, October 17, 2005), accessed March 1, 2013, http://www.federalreserve.gov/boarddocs/speeches/2005/20051017/.

[9] James L. Williams and A.F. Alhajji, "The Coming Energy Crisis" (submitted to *Oil & Gas Journal* for publication, February 3, 2003).

retail price of gas was at 84 cents per gallon up from 38 cents per gallon previously. These shortages elicited an immediate response from the U.S. government. The years 1974 and 1975 witnessed a blitz of energy conservation acts, including the Emergency Highway Energy Conservation Act, Corporate Average Fuel Economy Standards and the Energy Policy.[10] By this time U.S. attitudes towards energy consumption changed drastically in conjunction with the anxiety that was rising concerning the limited supply of natural resources. Unfortunately this would not be the last time the United States would face an oil crisis in the 1970s.

In the wake of the oil embargo energy conservation in buildings became a cornerstone to future development and research. In his 1974 book, *Energy Conservation in Buildings: Techniques for Economical Design,* C.W. Griffin, Jr., P.E., investigates the role buildings play from an energy usage standpoint and the future energy adaptive qualities and designs buildings will have to incorporate. Griffin cites the Projected U.S. Energy Gap graph from *The Energy Crisis* by Lawrence Rocks and Richard P. Runyon and tables from the National Bureau of Standards data; buildings are one of three major classes of energy consumers. If accounting for percentages for cooling, heating, water supply, sewage, and other usages the construction industry would account for approximately 40 percent of U.S. energy consumption.[11] Conservation of energy within buildings became an integral role in the effort to cut down on energy consumption at broad.

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[10] Richard Wagner, "Finding A Seat At The Table: Preservation And Sustainability," in *Sustainability & Historic Preservation,* ed. Richard Longstreth (Newark: University of Delaware Press, 2011), 4.
[11] C.W. Griffin, Jr., P.E., *Energy Conservation in Buildings: Techniques for Economical Design* (Washington, D.C., The Construction Specifications Institute, Inc., 1974), 3 -10.

1979 marked the second oil crisis of the decade. Recovery after the oil embargo of 1973 – 1974 marked a period of complacency. The United States continued to follow a pattern of increasing oil consumption; an increase of 6 million barrels a day in 1973 to 8 million in 1977.[12] Yet, once again the nation was shook up with rising oil prices and implementation of energy conservation strategies. This time the disturbance was attributed to the Iranian Revolution and the outbreak of the Iran-Iraq War in 1980.[13] In 1979 the price of a barrel of oil was up to around $40.[14] Philip K. Verleger, Jr., from Yale University in his article *The U.S. Petroleum Crisis of 1979,* for the Brookings Institute, states that: "American consumers were told that the cause of the crisis was a decline in Iranian oil production from 5.8 million barrels a day in July 1978 to 445,000 barrels a day in January 1979."[15] The long-term consequences are once again increased prices of gasoline, heating oil and residual fuel oil. The responses to this depletion and scarcity of energy resources forced the nation to enter for a second time a period of energy efficiency and conservation.

In the aftermath of the 1973 oil crisis and preceding the 1979 oil crisis, Richard Stein Associates and researchers at the University of Illinois at Urbana – Champaign released a report *Energy Use for Building Construction* in 1976.[16] This report provided

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[12] Calvin W. Carter, "Assessing Energy Conservation Benefits: A Study" in *New Energy Old Buildings,* ed. National Trust for Historic Preservation (Washington, D.C.: Preservation Press, 1981), 104.

[13] "Introduction" in *Viewpoints*: *The 1979 'Oil Shock:' Legacy, Lessons, and Lasting Reverberations*, (The Middle East Institute, Washington, D.C.), www.mei.edu.

[14] Jahangir Amuzegar, "OPEC's Adaption to Market Changes," in *Viewpoints*: *The 1979 'Oil Shock:' Legacy, Lessons, and Lasting Reverberations (*The Middle East Institute, Washington, D.C.), www.mei.edu.

[15] Philip K. Verleger, Jr., "The U.S. Petroleum Crisis of 1979," (Brookings Papers on Economic Activity, 2,1979), www.brookings.edu.

[16] B.M. Hannon, R.G. Stein, B. Segal, D. Serber & C. Stein. *Energy Use for Building Construction* (Illinois: Energy Research Group Center for Advanced Computation University of Illinois, 1976).

the building industry with energy values for multiple types of building materials as well as embodied energy values for several types of buildings. The evaluation of building materials was based on new construction from 1969. The preservation field utilized this report as a basis for the argument that historic buildings were repositories of embodied energy. Mike Jackson, Chief Architect of the Preservation Services Division of the Illinois Historic Preservation Agency, published an article in 2005 remarking that *Energy Use for Building Construction* is still "the most thorough evaluation of embodied energy of building materials to have been produced in the United States."[17] Jackson, acknowledges the benefits associated with reusing historic structures versus building new, and explains the benefits of expanding the discussion to include environmental benefits, including the topic of embodied energy. Lastly, Jackson highlights the notion that using the data associated with the 1976 *Energy Use for Building Construction* comes with some concerns. First, the building figures in the report underestimate the embodied energy values in older buildings. There was no attempt to calculate the embodied energy of original construction processes. Secondly, the data from 1967 construction processes has changed due to newer and more efficient industrial processes, further reducing the overall embodied energy in materials.[18] The reporting of the embodied energy within building assemblies and materials evoked the research to eventually come from The Advisory Council on Historic Preservation a few short years later.

In the aftermath of the energy crisis, the preservation field began to link energy efficient performance and historic buildings. The 1978 publication of

[17] Mike Jackson, "Embodied Energy and Historic Preservation: A Needed Reassessment," *APT Bulletin* 36, no. 4 (2005): 47-52.
[18] Ibid.

Preservation Briefs 3 – "Conserving Energy in Historic Buildings" by the National Park Service began to discuss the low operational energy usage of historic buildings.[19] In this brief, Baird Smith discusses the three highest energy-consuming systems in buildings: heat, light and ventilation.[20]

Late in the decade, the Advisory Council on Historic Preservation commissioned a study regarding energy conservation and historic structures. The intentions of the Advisory Council on Historic Preservation were to provide a tool for determining the energy value of historic structures. The methodology related to embodied energy used by the ACHP measured:

1. The embodied energy of materials and construction for existing, rehabilitated and new construction. The amount of energy to process and put materials of construction in place.
2. The demolition energy for existing buildings; including the energy to raze, load and haul away building materials.[21]

The resulting report *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples,* performed by consulting firm Booz, Allen & Hamilton, produced four formulas that could be applied to any preservation project to better evaluate the efficiency of building conservation and rehabilitation. This report came at a time when the preservation field needed a response to the energy crises and the policies that emerged as a result.

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[19] Jo Ellen Hensley and Antonio Aguilar revised, *Preservation Briefs 3: Conserving Energy in Historic Buildings,* written by Baird M. Smith and published in 1978, accessed at http://www.nps.gov/hps/tps/briefs/brief03.htm, National Park Service, December 2011.

[20] *Preservation Briefs 3* – "Improving Energy Efficiency in Historic Buildings," was updated in December 2011. The updated version of this report provides an even more comprehensive look at the building envelope and how it can be updated to better manage energy performance.

[21] Allen & Hamilton Booz, "Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples," (Advisory Council on Historic Preservation, 1979).

Interim Years: 1980 - 1990

The 1980s marked a period of exploration for renewable energy sources. Geothermal energy was the focus of research during the 1970s and 1980s, but with oil prices dropping again in the 1980s, interest waned in securing alternate resources.[22] A response to the conservation era of the 1970s, from The National Trust for Historic Preservation came in 1981 in the form of a book, *New Energy From Old Buildings,* the result of a national symposium on energy conservation and its relationship to preservation, defines this period and discusses the role of preservation and how it would have to as well as the rest of the nation go through a transition period. The introduction by Michael L. Ainslie, President of the National Trust for Historic Preservation, cites "energy questions surfaced with urgency following the Arab oil embargo and subsequent rapidly rising energy costs in the 1970s; preservation, it seemed, would have to take a back seat to other more pressing national concerns."[23] Calvin W. Carter in his contribution paper, "Assessing Energy Conservation Benefits: A Study," an overview of the importance of the study produced by the ACHP, *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples,* is given noting specifically, that the "study should profoundly influence the preservation movement and perhaps revolutionize the way effects on the built environment are evaluated."[24] Lastly, William I. Whiddon in his contributing paper, "The Concept of Embodied Energy," defines embodied energy and defines U.S. energy consumption for new buildings as more than 5

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22 Nancy Stauffer, "Underground heat: an omnipresent source of electricity," *The MIT Energy Research Council*, accessed March 3, 2013, http://web.mit.edu/erc/spotlights/underground_heat.html.

23 Michael L. Ainslie, "Foreword" in *New Energy Old Buildings,* ed. National Trust for Historic Preservation (Washington, D.C.: Preservation Press, 1981), 15-16.

24 Calvin W. Carter, "Assessing Energy Conservation Benefits: A Study" in *New Energy Old Buildings,* ed. National Trust for Historic Preservation (Washington, D.C.: Preservation Press, 1981), 103.

percent. After calling out data regarding the U.S. consumption of energy as it relates to building construction, Whiddon cites:

> "Historic preservation has the potential for displacing a large fraction of the energy used directly at the job site and embodied in construction materials. As new and existing buildings are made increasingly efficient in the ways they use energy, embodied energy becomes an even more significant fraction of the energy investment required in the use of buildings."[25]

New Energy from Old Buildings is a grand effort to promote the energy value of historic buildings. This book is an indicator of the leadership and insight from individuals to link energy value of historic structures and the eventual impending sustainable goals and policies of the 1990s/2000s. It is within the following years that the preservation industry would celebrate and define historic structures as "repositories of embodied energy" and gain recognition for energy efficient qualities.[26]

Internationally, 1983 marked a year with progress to address the growing concern of resource depletion. The United Nations set up the Commission on Environment and Development, also known as the Brundtland Commission, named after its Chair Gro Harlem Brundtland. The Brundtland Commission was formed specifically to address several spheres of sustainable development. The outcome in 1987 was *Our Common Future*, commonly known as the Brundtland Report, a comprehensive document defining sustainable development. Many reference the second chapter of *Our Common Future*, wherein sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own

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[25] William l. Whiddon, "The Concept of Embodied Energy" in *New Energy Old Buildings*, ed. National Trust for Historic Preservation (Washington, D.C.: Preservation Press, 1981), 113.
[26] Ibid, 35.

needs."[27] The development of this report, introduced a new concept: "sustainable development." This approach has been one of the most successful approaches seen internationally. This definition implies limiting consumption, thereby utilizing tactics of smart growth. Sections of the Brundtland Commissions report addressed the notion of smart growth in conjunction with addressing technological advances. Technology at this time should aim to be more energy efficient. Lastly, the Brundtland report gave birth to the well-known diagram of sustainability. The diagram introduced the concept of sustainability reaching beyond environmental protection and incorporating social equity and economic growth. The overlapping branches of the diagram visually displays how all three work together to define sustainability (Figure 1). Today, this concept of sustainability is understood as the three "pillars." The Brundtland Report eventually became integral in future discussions about sustainability and climate change, setting up an integrated platform for the next several decades.

[27] Gro Harlem Brundtland and World Commission on Environment and Development, *Report of the World Commission on Environment and Development: "Our Common Future"* (New York: United Nations, 1987).

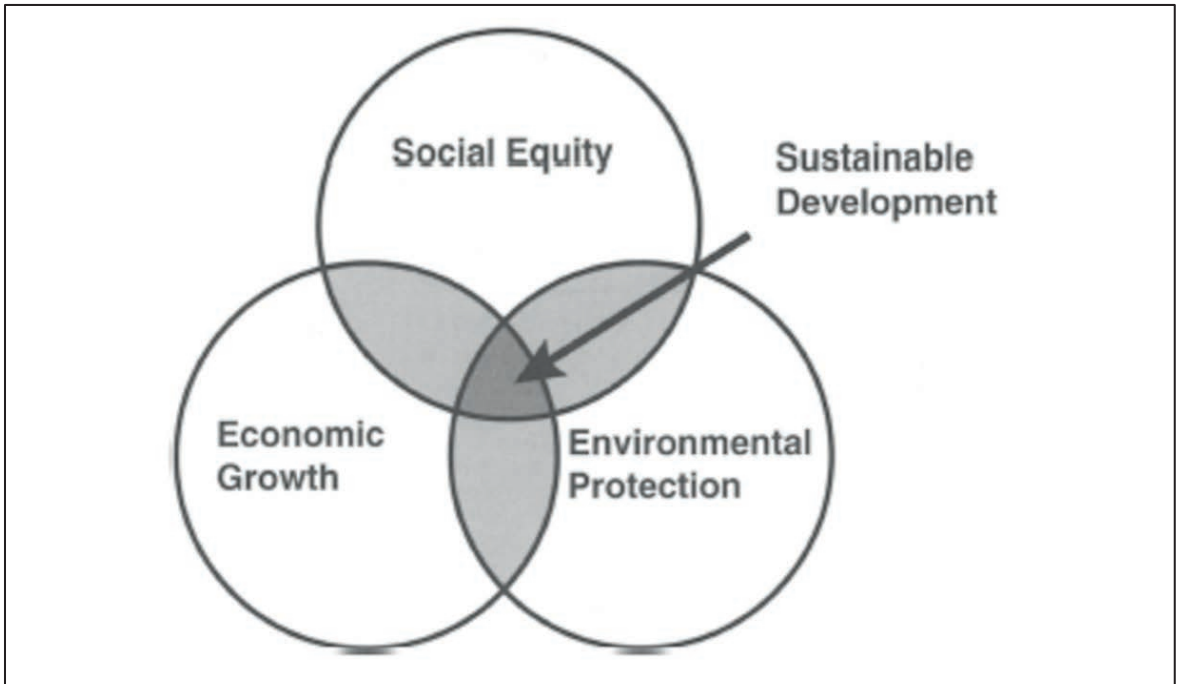

Figure 1. Sustainable development theory. (Julian Agyeman and Tom Evans, "Toward Just Sustainability in Urban Communities: Building Equity Rights with Sustainable Solutions, *Annals of the American Academy of Political and Social Science,* Vol. 590, Nov. 2003).

Building Recycling and Resource Conservation: 1990 – 2012

After lying dormant for several years the nation's energy concerns re-emerged in the 2000s. The issue of energy policy once again became a growing concern and building efficiency and performance emerged with public and private initiatives. Cheap oil had become an economic fact of the past. Green initiatives were taking hold and it was becoming increasingly apparent that they were not going to dissipate as a trend might in the near future. Jean Carroon, Bayard Whitmore and Karl Stumpf, in *Designing for Building Performance: The Management of Change* (2006), remark "the surge in green building in the last five years is the most dynamic trend in construction since the introduction of steel."[28] Another major development in sustainable thinking was the

[28] Jean C. Carroon, Bayard Whitmore and Karl Stumpf, "Designing for Building Performance: The Management of Change," *APT Bulletin* 37, no. 4 (2006): 38.

acceptance of carbon emissions. Carbon emissions and tracking your carbon footprint became imperative in order to move in common business affairs. N. Lior, Editor-in-Chief, ENERGY, The International Journal at the University of Pennsylvania, signifies the movement into a new relationship with sustainability when he states "quantification of sustainability is a vital first step in human attempt to attain it."[29] As a nation the movement of tracking and quantifying our impact on the fragile eco-system is apparent.

Awareness of building efficiency and association with quantifying impacts on the eco-system affected the future development in the building industry. Building and developing "green" became a goal for the industry. In 1993 Rick Fedrizzi, David Gottfried and Mike Italiano established The U.S. Green Building Council with a mission "to promote sustainability in the building and construction industry."[30] The U.S. Green Building Council gave birth to the green rating system, LEED. LEED is defined as:

> "The most widely recognized and widely used green building program across the globe. LEED is certifying 1.6 million square feet of building space each day in more than 130 countries. LEED is a certification program for buildings, homes and communities that guides the design, construction, operations and maintenance. Today, nearly 50,000 projects are currently participating in LEED, comprising more than 8.9 billion square feet of construction space."[31]

LEED provided the groundwork for the building industry to begin designing with sustainable incentives in mind. But, for the preservation industry this created a gap between what already exists and new sustainable (green) construction. This posed the question: How would historic structures fit into a world of limited resources? The U.S.

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[29] N. Lior, "About sustainability metrics for energy development," (A paper, University of Pennsylvania Department of Mechanical Engineering and Applied Mechanics), 1.
[30] "USGBC History," U.S. Green Building Council, accessed September 10, 2012, http://new.usgbc.org/about/history.
[31] "About USGBC," U.S. Green Building Council, accessed September 10, 2012, http://new.usgbc.org/about.

Green Building Council established an innovative system to provide incentives for building in a sustainable manner, but it has some systematic flaws. Existing buildings do not fit into the rating system cleanly. This has created a gap, providing incentives and accolades for certain levels of certification, when existing historic buildings cannot attain the same certification as easily. A full review of rating systems is not provided in this thesis because it is beyond the scope, but Patrice Frey's 2007 Masters Thesis at the University of Pennsylvania addresses LEED for historic buildings.[32]

In 1997, in Kyoto, Japan a treaty was negotiated to address the global implications of climate change. The agreement set international binding goals of greenhouse gas emission reduction targets.

> "The Kyoto Protocol is a legally binding agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990 (but note that, compared to the emissions levels that would be expected by 2010 without the Protocol, this target represents a 29% cut). The goal is to lower overall emissions from six greenhouse gases – carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, HFCs, and PFCs – calculated as an average over the five – year period of 2008 – 12. National targets range from 8% reductions for the European Union and some others to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland."[33]

The agreement went into force in February 2005. While this was a global initiative to demand reduction of greenhouse gases from nations across the world, it did not demand participation. The United States signed the Protocol in 1998 under the Clinton administration, but they did not ratify it in the United States. In 2001 the Bush Administration rejected the Kyoto Protocol. A year later in 2002, Bush announced a U.S.

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[32] Patrice Frey, "Measuring Up: The Performance of Historic Buildings Under the Leed-NC Green Building Rating System" (Masters Thesis, University of Pennsylvania, 2007).
[33] "Kyoto Protocol," United Nations Framework Convention on Climate Change, accessed September 3, 2013, http://unfccc.int/kyoto_protocol/items/2830.php.

policy for climate change that relied on domestic, voluntary actions to reduce greenhouse gas emissions of the U.S. economy by 18 percent over 10 years.[34] The United States may not have ratified the Protocol, disengaging from any binding international agreement, but the Protocol did initiate domestic demands to reduce greenhouse gas emissions.

Awareness of the need to reduce greenhouse gas emissions transferred the sustainability initiative from an energy crisis to a climate of mitigation. Discussions became based around how to reduce greenhouse gas emission - specifically, for the purposes of this thesis, within the building sector. The *Buildings Energy Data Book*, an online resource produced by The Buildings Technologies Program within the U.S. Department of Energy provides a comprehensive view of where the U.S. stands on energy consumption for residential and commercial buildings. Some of the most current data indicates that in 2010, the building sector in the U.S. accounted for about 41 percent of primary energy consumption. As a comparative, total building energy consumption in 2009 was 48 percent higher than in 1980.[35] The growth in building energy consumption is attributed to population growth. Over the last several years, buildings have continually been marked as the largest energy consumption sector over transportation and industrial, as energy consumption by buildings continues to be a growing concern the preservation community can gain traction on the argument of reusing historic buildings. In 2007, Carl Elefante coined the phrase "the greenest building is the one that is already built," in his

[34] Armin Rosencranz, "U.S. Climate Change Policy under G.W. Bush," *Golden Gate University Law Review* 32, issue 4 (2002), accessed http://digitalcommons.law.ggu.edu/ggulrev/vol32/iss4/4.
[35] United States Department of Energy, "Buildings Energy Data Book," last modified March 2012, http://buildingsdatabook.eren.doe.gov/default.aspx.

popular article.[36] The development of this popular slogan emphasizes the sentiments of the preservation industry. As a nation we cannot continue to build our way to sustainability, as the data from the U.S. Department of Energy indicates. Elefante's article emphasizes the similarities in end goals that historic preservation and sustainable design have. This one line has become the framework for an argument for many to defend the value of energy embodied in historic buildings.

Following on the heels of Elefante's article the idea of utilizing a method of life cycle assessment, the science behind environmental footprinting buildings began to gain popularity. Wayne B. Trusty, the former President of the Athena Sustainable Materials Institute, discusses in *Renovating vs. Building New: The Environmental Merits,* two approaches, the benchmarking approach of comparing demolition versus new construction and estimating the environmental impacts that are avoided by saving an existing building.[37] Trusty, looks at two scenarios, the first is the minimum avoided impact case, which involves saving only the structural system of a building while the rest is demolished or replaced. The second scenario is the maximum avoided impact case, which involves saving the envelope as well as the structure. Trusty concluded that life cycle assessment should be used for renovation projects as a decision support methodology, if the appropriate data and tools are available.

In 2010, *The Greenest Building Is The One That Is Never Built: A Life-Cycle Assessment of Embodied Effects for Historic Buildings,* by The Athena Sustainable Materials Institute and Morrison Hershfield Consulting Engineers, examined a life cycle

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[36] Carl Elefante, "The Greenest Building Is…One That Is Already Built," *Forum Journal: The Journal of the National Trust for Historic Preservation* 21, no. 4 (2007).

[37] Wayne B. Trusty, "Renovating vs. Building New: The Environmental Merits," The Athena Sustainable Materials Institute, 2004.

analysis and whole building energy simulation, in assessing the material and operational environmental effects of renovating an existing building compared to new construction. The results from this study are:

1. The most notable conclusion is that tools and methods are available to more accurately understand the material and operational environmental impacts of existing historical buildings as compared to alternative new constructions.
2. An understanding of the environmental impacts of historic buildings and comparable new buildings requires numerous assumptions. Accordingly, the methodology presented should only be used by persons knowledgeable of building energy use and building envelopes and capable in the use of the various tools suggested.
3. Renovated historic buildings can function comparably to new buildings using common environmental measures such as energy intensity and global warming contributions.[38]

The results from this study provide insight into how a life cycle assessment approach can be applied to historic buildings transitioning the arguments preservation can utilize when advocating for the reuse of buildings. The results and goals of this study transitions to align with the goals of sustainability creating a common language or currency.

In 2012, after the nation had been operating with green incentives and examining life cycle assessments, the Preservation Green Lab, part of the National Trust for Historic Preservation published, *The Greenest Building: Quantifying the Environmental Value of Building Reuse.* This report was a new innovative report for the preservation field around which to build its sustainability framework. The report examines the climate change reductions that can occur from reusing existing buildings over demolition and replacing them with new buildings.

[38] Mark Lucuik, Wayne Trusty, Allison Huffman and Alexandra Prefasi, "The Greenest Building Is the One That Is Never Built: A Life-Cycle Assessment Study of Embodied Effects for Historic Buildings" (paper presented at ASHRAE Buildings XI Conference, 2010).

Stated within the first several pages of the report:

> "This groundbreaking study concludes that building reuse almost always offers environmental savings over demolition and new construction. Moreover, it can take between 10 and 80 years for a new, energy-efficient building to overcome, through more efficient operations, the negative climate change impacts that were created during the construction process."[39]

This report provides preservation professionals with innovative data to confront the new era of sustainability discussions by confronting the issue looking at greenhouse gas emissions and savings over demolition and new construction. While this report is innovative it does have several follow up questions that will be outlined in Chapter IV. From a building standpoint, this model broke ground for the industry to potentially move into new territory and have a more universally accepted model for discussing reuse of existing buildings.

Today, we operate in an era in which global warming is difficult to argue against. Assessments and innovative concepts are being created to help mitigate future damage to resources. Preservation has numerous sustainable attributes that make it a cohesive partner to sustainability, but the future of where the framework lies will depend largely on leadership from within the preservation community to set universal standards to base conversations and programs.

Conclusion

Review of where modern sustainability grew from reveals that a credible model to account for the overall energy benefits with retention of historic buildings has been needed since preservation became national policy in 1966. A dependable model allows

[39] Preservation Green Lab, "The Greenest Building: Quantifying the Environmental Value of Building" Reuse (Washington, D.C., The National Trust for Historic Preservation, 2012), VI.

for the fair comparison of the energy capital in historic structures compared to new construction. The initial need to measure energy capital in buildings arose from the two energy crises in the 1970s, with a second need to address the sustainability goals of the 1990s/2000s. Both responses measure overall energy efficiency of historic buildings by attempting to account for the "energy capital."

The Advisory Council on Historic Preservation introduced the first model in 1979, and it has remained embedded in preservation vocabulary and is a reflexive argument utilized to advocate for the retention of historic structures over new construction. The second model, the life cycle assessment/avoided impacts is a response to the evolving metrics and currency of sustainability. The Preservation Green Lab further matured the capabilities of the life cycle assessment/avoided impacts model in 2012 with their innovative report, *The Greenest Building: Quantifying the Environmental Value of Building Reuse.*

Chapter III will examine the Advisory Council on Historic Preservation model in-depth, followed by a similar in-depth examination of the life cycle assessment/avoided impacts model in Chapter IV.

Historic Preservation & Sustainability

A Timeline

Sustainability Evolution

1962: *Silent Spring*, Rachel Carson

1970: First Earth Day
Environmental Protection Agency Formed

1972: *The Limits to Growth*, Club of Rome Report

1973: OPEC oil embargo

1974: Federal Energy Administration Act signed

1977: The Department of Energy Organization Act signed

1979: Second oil crisis begins, Iranian Revolution

1987: *Our Common Future,* Brundtland Commission report

1993: U.S. Green Building Council established

1997: The Kyoto Protocol

2002: UN World Summit on Sustainable Development

2007: Intergovernmental Panel on Climate Change Fourth Assessment Report

2013: President Obama commits U.S. to 17% reduction below 2005 greenhouse gas emissions levels by 2020

Historic Preservation Evolution

1966: National Historic Preservation Act

1971: Executive Order for the Protection and Enhancement of the Cultural Environment

1978: Preservation Briefs 3 – *Conserving Energy in Historic Buildings*

1979: Advisory Council on Historic Preservation report released

1981: *New Energy from Old Buildings*

1994: *Guiding Principles for Sustainable Design,* The National Park Service

1998: *Sustainable Design and Historic Preservation,* Sharon C. Park

2004: Association of Preservation Technology formed Technical Committee on Sustainable Preservation

2009: Preservation Green Lab formed, The National Trust for Historic Preservation

2012: *The Greenest Building: Quantifying the Environmental Value of Building Reuse* published

Chapter III
Embodied Energy and the ACHP Model

The response to the two oil crises from the Advisory Council on Historic Preservation in the late 1970s represents recognition from the preservation industry to determine and define a credible calculus for the overall energy benefits of existing buildings. The identification of embodied energy as a quantitative measurement to account for the energy capital stored in historic buildings was a conservation associated response, aligning with conservation synergies that were evident across the nation. Embodied energy exploits the value of commitment to resources that already exist.

Decisions about how to quantify and calculate embodied energy were studied by The Advisory Council on Historic Preservation (ACHP) prior to the release of *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples,* with extensive research by Richard Stein Associates. The result, a comprehensive approach to equate embodied energy in historic buildings provided a tool and argument for the preservation field to respond to the energy crisis that was occurring. This chapter defines embodied energy as a term and provides the methodology and calculations behind the Advisory Council on Historic Preservation 1979 report. A discussion of deterioration, maintenance and material replacement is included to examine the fundamental role of these processes in a buildings service life. Lastly, it gives an evaluation of the embodied energy concept as it relates as an attempt to measure and account for the "energy capital" represented by an existing building.

Embodied Energy Defined

Understanding "embodied energy" is imperative before analyzing how preservation professionals use the term when establishing the "energy capital" represented by historic structures. Embodied energy is commonly defined as:

> "the total energy resource committed to produce a specific result, whether a service or a product. It included the energy for extracting and processing raw materials, manufacturing components, and installation. It includes the transportation energy used throughout the entire production cycle and the energy consumed by the service activities that support the process. It includes the energy resources that become physically part of the finished product."[40]

The Advisory Council for Historic Preservation in their 1979 report, *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples,* defined embodied energy as: "the energy, measured in fossil fuels, that was consumed to make any product, bring it to market, put it to use, and then to dispose of the product at the end of its useful life."[41] This definition will be used throughout the duration of this thesis when discussing embodied energy.

The First and Second Law of Thermodynamics provide the basis for examining embodied energy in resources. The quality of a resource will determine and affect its utility and value within a system, by raising the quality of a resource will impose its own set of environmental demands. Carl Stein in *Greening Modernism* displays this law through the life cycle of a brick. The brick has the same amount of material as an equivalent lump of clay in the ground. But, the brick in the brick wall has substantially more value than the unprocessed soil. In order for the clay in the ground to become a brick it has to undergo a number of processes including: extraction of the raw clay,

[40] Carl Stein, *Greening Modernism* (New York: W.W. Norton & Company, 2010): 98.
[41] Allen & Hamilton Booz, "Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples," (Advisory Council on Historic Preservation, 1979).

transportation, crashing and separation of the clay, shaping, firing in the kiln, transportation to the job site and assembly in the wall. As a result, the brick has higher environmental demands associated with it. In order to raise the quality of the clay to that of a brick, energy has been added. As the brick weathers or deteriorates by natural processes, or it is demolished the resources and energy that were added to the material will be lost.[42]

The term entropy as it relates to thermodynamics is typically applied to states of energy, stating that it is a resource at the same level or state as its surroundings, therefore having no utility.[43] Entropy is a measure of molecular disorder and energy spent to get from one state to another. Entropy is part of the Second Law of Thermodynamics, stating that things move from a state of order to disorder, unless new energy is introduced in the form of regular maintenance. Energy is applied to construct a building and overcome the disorganized state of building materials; this energy is necessary to overcome the entropic forces to organize the building materials. When buildings are demolished the state of the materials drops to that of the material in the landfill; making all of the resources that were embodied during the making of the building now entropic; they can not be reapplied.[44]

Deterioration, repair and maintenance

Deterioration of materials and assemblies as a building witnesses the passage of time is an inevitable consequence of the Second Law of Thermodynamics. Sam Harris notes that "the combination of building material properties and environmental conditions create

[42] Stein, *Greening Modernism,* 98.
[43] Ibid, 121.
[44] Ibid.

requisite components that perpetuate materials deterioration, hence building failure."[45] Specifically correlated to deterioration and preservation, Harris addresses the role denial plays when approaching the inevitable fact that deterioration will occur, by stating preservation professionals think, "deterioration is indicative of an error or poor judgment, and if we exercise proper care and judgment in the remediation, deterioration will not occur again."[46] This is fundamentally untrue and deterioration affects all materials and all buildings. Buildings begin deteriorating at construction completion, slowly at first, then accelerating the pace before slowing once again. At some point, the functionality of the material or assembly is lost, and service life ends, although some residual embodied energy may remain. Building owners slow deterioration rate by preventative maintenance, or offset deterioration with repairs and replacements, incrementally increasing the embodied energy, approaching the original values (Figure 2).

[45] Samuel Y. Harris, PE, AIA, Esq., *Building Pathology Deterioration, Diagnostics, and Intervention,* (John Wiley & Sons, Inc., New York, 2001): 12.
[46] Ibid, 13.

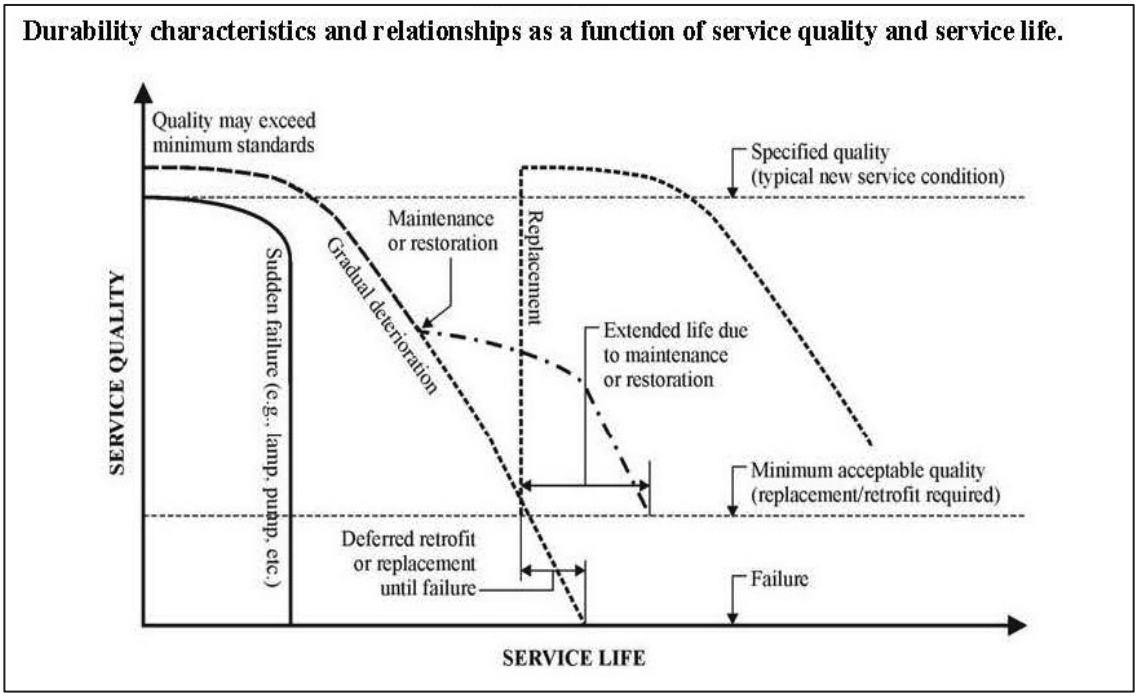

Figure 2. Ted Kesik graph durability characteristics and relationships as a function of service quality and service life. (Courtesy of "Differential Durability, Building Life Cycle and Sustainability").

It is self-evident that historic buildings that have been standing for over fifty years have witnessed deterioration to a degree, some buildings more than others. As the building envelope begins to deteriorate, the residual embodied energy associated with the materials diminishes.

The dilemma with Ted Kesik's graph from an embodied energy assessment is that the materials embodied energy reaches a limit of zero when it reaches a "minimum acceptable quality" of service life.[47] In reality, materials do not reach an embodied energy of zero when they begin to fail or have been deemed failed.

[47] Graph taken from, Ted Kesik and Ivan Saleff. "Differential Durability, Building Life Cycle and Sustainability," 10th Canadian Conference on Building Science & Technology, May, 2005, Ottawa Canada, 38-47.

Adapting the concept of service life and service quality from Kesik, the below graph depicts a material as it begins to fail and what would happen once it crosses the threshold of functionality (Figure 3).

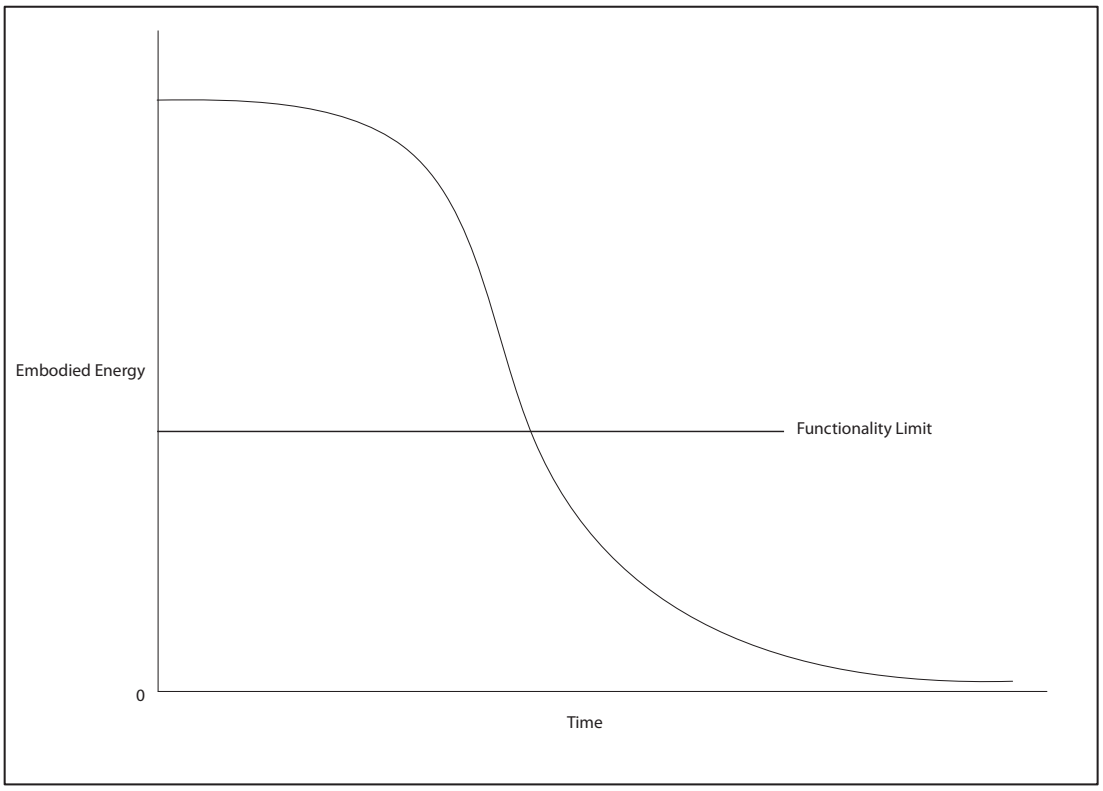

Figure 3. Material embodied energy vs. service life. (Image created by author).

Here, the line behaves as an asymptote, "a line whose distance to a given curve tends to zero."[48] Even if a material turns to dust, it still maintains some minute level of embodied energy.

Advisory Council on Historic Preservation Model

In 1979, the Advisory Council on Historic Preservation published *Assessing the Energy Conservation of Historic Preservation: Methods and Examples* (a report

[48] "Asymptote," Merriam – Webster Dictionary, accessed February 15, 2013, http://www.merriam-webster.com/dictionary/asymptote.

produced by Booz, Allen and Hamilton), instituting the term and concept of embodied energy for the preservation field. The concept that historical buildings have energy embodied in them from initial construction was the driving force of development for this report. Mathematical equations were developed to compute how much energy is embodied within existing structures by computing embodied energy in an equivalent structure, as well as an equation which computes how much energy would be involved in demolishing and replacing them. The report states, "This study provides the Council with another tool for determining the total worth of threatened properties, and, in particular cases, whether retention and continued use are in the public interest."[49] As outlined in the previous chapter, the report was defined from a push towards energy valuation and an energy conservation crisis. This pursued to fill that call by strongly stating, "energy conservation is an important concern, and one that needs careful consideration in decisions affecting the built environment."[50]

Assessing the Energy Conservation of Historic Preservation: Methods and Examples identifies three case studies of how embodied energy calculations in conjunction with demolition and new construction calculations can be utilized to provide quantitative outcomes. These case studies were used to set examples of how equations can be utilized and translated into historic properties. The research established embodied energy values in existing construction, energy required for demolition and energy required for new construction. Three existing structures were chosen: Lockefield Garden

[49] Booz, "Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples," 3.
[50] Ibid, 3.

Apartments (Indianapolis, Indian), the shell of a Washington, D.C. carriage house and The Grand Central Arcade (Seattle, Washington).[51]

The report concluded that the Lockefield Garden Apartments represents over 550 billion BTUs of energy embodied in its construction, equivalent to 4.5 million gallons of gasoline.[52] The Washington, D.C. carriage house embodied over 1 billion BTUs of energy within its materials, equivalent to about 8000 gallons of gasoline.[53] Lastly, the Grand Central Arcade required only one-fifth as much energy for rehabilitation materials and construction activity, compared to the materials and activities needed to build a new facility.[54] The "savings" equaled more than 90 billion BTUs, or over 700,000 gallons of gasoline. The conclusion from the three case studies is that "rehabilitation of existing buildings, rather than demolition and new construction, results in a net energy investment 'savings' over the expected life of the structure."[55]

The Advisory Council of Historic Preservation developed tools for assessing the potential energy conservation value that preservation provides. The below are outlined tools from the Booz, Allen and Hamilton report.

1. Embodied Energy of Materials and Construction for Existing, Rehabilitated, and New Construction – The amount of energy required to process and put materials of construction in place. Embodied energy increases with the amount of processing and is not recoverable.
2. Demolition Energy for Existing Buildings – The amount of energy required to raze, load, and haul away building construction materials.
3. Annual Operational Energy for Existing, Rehabilitated and New Construction – The amount of energy required to operate the facility.

[51] Ibid, 11-12.
[52] Ibid, 11.
[53] Ibid, 11.
[54] Ibid, 12.
[55] Ibid, 14.

> Operational energy depends upon: Climate; Occupancy characteristics; and Physical design of the building.[56]

The report defined how the methods could be performed in a number of projects. The methods are defined as follows:

1. Existing Energy Investment in Materials and Construction – Calculate the embodied energy of materials and construction for the existing building.
2. Energy Investment in Rehabilitation Materials and Construction versus New Materials and Construction – Compare the embodied energy of rehabilitation materials and construction with the corresponding quantity for new construction which provides the same level of service. If razing an existing building would be necessary for new development, then Demolition Energy should be added to the embodied energy of materials and construction for the comparable new building.
3. Annual Operational Energy for the Rehabilitation versus Annual Operational Energy for a Comparable New Facility – Compare the estimated amount of energy needed annually to operate the rehabilitated facility with the corresponding estimated energy required for operation of comparable new construction which incorporates contemporary energy conservation standards in the same climatic region.
4. Rehabilitation Total Energy Investment versus Total Energy Investment for a Comparable New Building – Combine Embodied Energy of Materials and Construction and Annual Operation Energy over a pre-determined life expectancy for the rehabilitated structure and a comparable new building. This comparison reveals the net energy "savings" of preservation.[57]

These methods are more than just calculating "capital energy" invested in original construction of a building, but they have limitations and at times produce varied results making universal acceptance within the preservation industry arduous.

The methodology of the report looks at embodied energy of materials and construction for existing, rehabilitated and new construction. The embodied energy

[56] Ibid, 8.
[57] Ibid, 9.

calculation includes the amount of energy to process and put materials of construction into place. The calculations referred to and cited in this thesis are the embodied energy calculation for existing buildings.

The first model is the building concept model. This model is the simplest and least detail-oriented, lending it to be the least exact or have the lowest resolution. The report states that "results are generally correct but not precise," a later discussion of where the data is derived from will provide feedback on the term "precise."[58] This model states that embodied energy is measured by assessing the building type and gross square footage. A single calculation is conducted to provide a result.[59] This model is currently available on the Internet at websites such as www.thegreenestbuilding.org, operated by the May T. Watts Appreciation Society. The concept model as a formula is expressed as:

> Embodied Energy Investment = {Gross floor area of historic building x invested energy per square foot specific to the building type from Exhibit 1}

The second model is the building survey model. This method is an intermediate model compared to the concept model and is deemed to "be the most useful."[60] This model can provide refined results with some additional data over and above that needed for the building concept model. Embodied energy is determined using a rough survey of primary material quantities and applying their respective energy values. The survey model formula is expressed as:

> Embodied Energy Investment = {Energy used in construction + Energy invested in materials}

[58] Ibid, 19.
[59] Ibid.
[60] Ibid, 20.

The third and final model is the building inventory model. This model is the most complex and provides the most precise results.[61] Embodied energy is determined by conducting a detailed inventory of material quantities and an analysis of energy embodied in each material type. The inventory model formula is expressed as:

Embodied Energy Investment = {Energy used in construction + Energy Invested in Materials}

An evaluation of the data inputs for the above formulas is further explored to pinpoint the rationale behind the embodied investment argument. The variance for historical structures may be obvious as structures were originally built in varying centuries with varying building technologies that utilized varying energy outputs. A closer inspection will identify where data not only is originated from, but how this provides a barrier when discussing sustainability in current context.

Data Input Derivation

It is important to understand the basis and origins of the data and numeric quantities in *Assessing Energy Conservation for Historic Preservation: Methods and Examples*. The Advisory Council on Historic Preservation report introduced a standard into the industry that is still put into practice thirty-four years later. Fine print within the ACHP report references another report, *Energy Use for Building Construction* from 1976. This report prepared for the U.S. Energy Research and Development Administration provides a study of patterns of embodied energy through different

[61] Ibid, 21.

construction industries.[62] The data is derived from the embodied energy of building materials of typical building assemblies, and of new construction. The numeric and the embodied energy per unit of material are based on new construction materials from 1967. In order to account for direct and indirect energy flows, the average figures are broken down by building type, by the industry sector that supplies the materials and by components within each sector.[63] The report breaks down construction into forty-nine categories and identifies the energy inputs associated with each. These measurements also include the direct energy used at the building site. The embodied energy total includes the embodied energy of the materials plus the direct energy of construction used at the site. The breakdown of the forty-nine categories is, seventeen are new building; five are building maintenance, repair and alteration; and the remaining twenty-seven are non-building construction and repair. Importantly, the report includes the embodied energy in over a thousand materials. The report highlights that 70 percent of embodied energy in new construction is attributed to manufacture of basic construction and components, the remaining 30 percent is allocated to delivery and installation, including direct fuel purchases, administration, transportation of materials, furnishings and construction equipment.

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62 The United States Department of Energy published this research in 1981 as "Handbook of Energy Use for Building Construction."

63 Direct energy is defined as energy consumed in onsite and offsite operations, such as construction, prefabrication, assembly, transportation and administration.
Indirect energy is defined as energy consumed in manufacturing the building materials, in renovation, refurbishment and demolition processes of the buildings.

Evaluation

The Advisory Council on Historic Preservation report has become an embedded argument within the field as a link to the sustainability conversation. The sustainability movement has shifted the currency from conserved "capital energy" in a measurement of gallons of gasoline saved to CO_2 emission equivalent currency. The preservation field has rendered initiatives to participate and work collaboratively with the building sector to identify strong links between the benefits of building reuse over demolition and new construction. The 1979 ACHP report laid the groundwork for quantifying the energy value of preserving historic structures, giving preservationists conversation arguments to confront modern issues. Yet, as we enter further into sustainability initiatives that have filtered into planning policies, business initiatives and every day life, the 1979 model may pose as a deterrent rather than a benefit.

The ACHP model has collided with modern technology in the aspect that one can easily sign onto a website and be given numbers in a matter of seconds. Pencil and paper mathematical calculations are no longer deemed necessary if a computer can generate it. Such technology obviously cuts down on the time it takes to generate these numbers when the concept model can be performed almost instantaneously in the work field. The ability to provide quantifying information instantaneously is prudent in some cases, but looking at how valid that estimated information is when it has already been highlighted that data is from 1967 construction reports and factors such as recurring embodied energy and deterioration are not accounted for. If an exact high-resolution calculation of embodied energy were to be accounted for, a building history would have to be obtained to account for maintenance, restoration and other interventions that have occurred. This

process would be time consuming and could lose effect if not able to provide information in a deadline-driven situation.

The ability of the preservation industry to respond to what was occurring in the country during the 1970s was an educated and contemporary response. The notion to observe and relate that current events had an effect not only on the economy, but on the building sector as well and to respond with the solution that energy conservation could be qualified through reuse of existing buildings was tapping into the drivers that were taking hold of major decisions of the time. The argument of inherent low energy features and the energy capital already invested in historic structures was a logical response to a frenzy of energy conservation talk. The 1981 Preservation Week campaign logo by The National Trust for Historic Preservation provided a visual for the idea that energy capital in existing buildings can be equated to gasoline or oil conservation. Providing an image of a building as a gasoline can was timely and current as the nation was recovering from an energy crisis. A response from the preservation industry in order to continue successfully performing the work that preservation sets out to do by preserving cultural heritage, was necessary in order to not get pushed aside by policies and new innovative technologies that were going to solve the energy crisis. A threat was seen to the industry, and a response was enacted.

The ACHP model was innovative at the time, and today can still provide vast visual savings. However, at what point does the industry respond to the new wave of energy efficiency and green building design solutions to lower carbon emissions? The answer to this question may be apparent with the mere mention of the Preservation Green Lab, National Trust for Historic Preservation's recent study. Yet, as an industry many

still apply the ACHP model and are not comfortable or aware that the data the ACHP model provides is becoming more antiquated as the sustainability currency is a moving target.

To express what embodied energy is fundamentally accounting for in a formula would be the following equation (Figure 4).

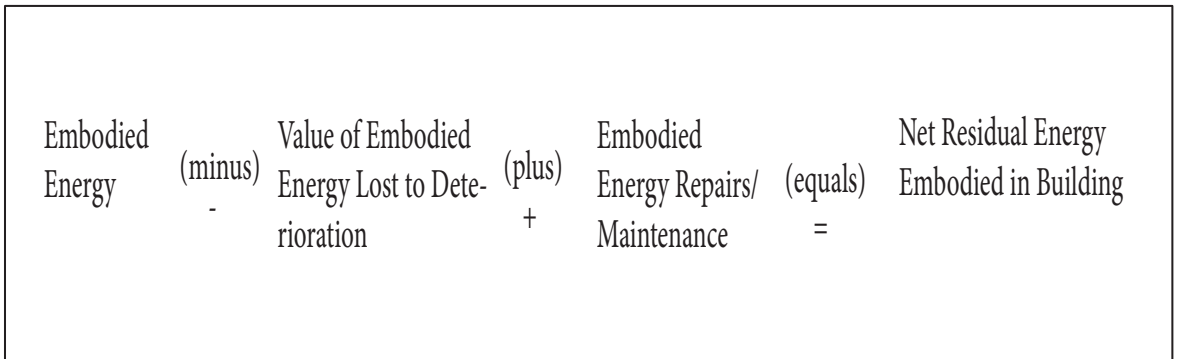

Figure 4. Formula to express embodied energy. (Courtesy of author).

This equation implies that embodied energy starts off with the total energy that is invested in the building at original construction minus the value of embodied energy lost due to deterioration (an inevitable natural process), plus the embodied energy from repairs and maintenance (reoccurring embodied energy), equals the net residual energy embodied in the building. What you are left with, the net residual energy embodied, is the true current capital value in a building. Residual value is based on the original energy value. Inclusion of loss due to deterioration and the addition of reoccurring embodied energy are both processes that must be accounted for if seeking to quantify the true capital value.

Applied in comparison to economics, the same equation can be expressed starting with the original capital investment, minus the losses due to depreciation, plus the added

investment while ownership is maintained, equals the residual current value of investment (Figure 5).

Embodied Energy	(minus) -	Value of Embodied Energy Lost to Deterioration	(plus) +	Embodied Energy Repairs/ Maintenance	(equals) =	Net Residual Energy Embodied in Building
Original Capital Investment	(minus) -	Losses Due to Depreciation	(plus) +	Added Investment While Own	(equals) =	Residual Current Value

Figure 5. Comparative formulas embodied energy and economics. (Courtesy of author.)

Expressing the "capital energy" as a formula for embodied energy breaks down the actual losses and gains that are involved when evaluating a building.

Conclusion

Evaluation of the embodied energy method of quantifying the energy value of a historic building reveals that there are fundamental flaws to the equation. The need to quantifying energy capital of historic buildings rose out of the 1970s oil crises and embodied energy was deemed the highest and best valuation process at the time. The embodied energy method does not account for inevitable processes that occur to every building such as deterioration and maintenance, therefore not accounting for the true current capital value of the building.

Chapter IV will evaluate the life cycle assessment/avoided impacts methodology of evaluating the capital energy of a historic structure. The current report, *The Greenest*

Building: Quantifying the Environmental Value of Building Reuse by the National Trust for Historic Preservation will be examined as well as the Athena Sustainable Materials Institute tools that are available.

Finally, an evaluation of the life cycle assessment/avoided impacts approach will be provided. In subsequent chapters a case study will inform an understanding of the application of the embodied energy method and the life cycle assessment/avoided impacts method to a historic structure.

Chapter IV
Life Cycle Assessment of Historic Structures

This chapter examines in-depth the role life cycle assessments have previously had in historic preservation and evaluates what the future role could be for life cycling within historic structures. A definition of life cycle assessment as it relates to buildings is provided. The National Trust for Historic Preservation report *The Greenest Building: Quantifying the Environmental Value of Building Reuse* will be reviewed, and the barriers that it reveals will be discussed. Lastly, the avoided impacts approach will be highlighted with explanation of the Athena Institute of Sustainable Materials' role in the discourse of this topic. Finally, an evaluation of the life cycle assessment will provide insight into how different parties have affected the development of a template for historic buildings and life cycle assessments.

The Age of Building Cycling

Science has and continues to provide research that proves climate change will have an inevitable impact globally in the coming years. As a response, countries around the world have made commitments to reducing greenhouse gas emissions and are taking advanced steps through research to educate the public with current information. However, it is vital that this conversation of sustainability and energy efficiency be relevant across all sectors and that a source of a common language exists. This will prevent preservation and green building professionals, who are addressing the issue of

climate change, from having to break the language barrier between them—and ultimately allow both sectors to work towards a mutually beneficial goal.

There have been tensions between the preservation community and the green building sector for years, as many journal and scholarly articles point out. Some of these articles are a bit dated, but they still highlight the friction between the two industries. Wayne Curtis, in his article *A Cautionary Tale,* bluntly describes the sentiments of some outside the field of preservation when he quotes: "Yesterday's buildings solved yesterday's problems; new buildings were needed to solve the problems of today – and tomorrow."[64] But this justification is not a solution to the problem of sustainability; it will only create further damage and provoke the already fragile state that our natural resources are in. Instead, the buildings of yesterday will have to become new again in order to avoid more environmental chaos and continuing down the road of demolition and new construction.

While preservation is not the sole solution to sustainability, it can be an integral part. The Whole Building Design Guide, in its 2012 article "Sustainable Historic Preservation," endorses the notion that "preserving a building is often called the ultimate recycling project."[65] The article goes on to detail inherent sustainable features within historic structures such as sustainable sites, water efficiency, water use reduction, energy and atmosphere, on-site renewable energy, green power, materials and resources and indoor environmental quality. These features provide the preservation industry with measures to fight the stigma that historic buildings are inefficient and require corrective

[64] Wayne Curtis, "A Cautionary Tale," *Preservation* (January/February 2008), accessed March 14, 2013, http://www.preservationnation.org/magazine/2008/january-february/cautionary-tale.html.
[65] "Sustainable Historic Preservation," Whole Building Design Guide a program of the *National Institute of Building Sciences,* accessed February 2, 2013, http://www.wbdg.org/resources/sustainable_hp.php.

measures. The reality is that using these features highlights the similarities and overlap in sustainability goals and preservation. Beginning with the notion that historic buildings can be recycled for modern usage is a much more effective starting point.

Life Cycle Assessment Defined

Life cycle assessment is defined by the United States Environmental Protection Agency as:

> A technique to assess the environmental aspects and potential impacts associated with a product, process, or service by:
> - Compiling an inventory of relevant energy and material inputs and environmental releases;
> - Evaluating the potential environmental impacts associated with identified inputs and releases;
> - Interpreting the results to help you make a more informed decision.[66]

The promotion of LCA models helps industries, individuals, private associations and interested parties "make more informed decisions through a better understanding of the human health and environmental impacts of products, processes, and activities."[67]

The LCA process is governed under the International Organization for Standardization (ISO) 14000, a series of international standards addressing environmental management. ISO 14000, provides "practical tools for companies and organizations looking to identify and control their environmental impact and constantly improve their environmental performance."[68] These standards set forth international groundwork for industries to enhance their already focused efforts towards a sustainable future. ISO

[66] United States Environmental Protection Agency, "Life Cycle Assessment (LCA)," accessed March 2, 2013, http://www.epa.gov/nrmrl/std/lca/lca.html.
[67] Ibid.
[68] "ISO 1400 – Environmental Management," International Organization for Standardization, accessed March 2, 2013, http://www.iso.org/iso/home/standards/management-standards/iso14000.htm.

14040 defines life cycle assessment as "a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle."[69] *ISO Focus,* the online publication produced by the International Organization for Standardization provides insight into globalization and environmental management case studies and issues.

The United States Environmental Protection Agency delivers a general definition of LCA, but specifically for buildings, the American Institute of Architects, in their publication *AIA Guide to Building Life Cycle Assessment in Practice,* delineates the differences between life cycle of a manufacturing process and the life cycle process of a building. For a building the life cycle stages are defined as:

> **Materials Manufacturing:** Removal of raw materials from earth, transportation of materials to the manufacturing locations, manufacture of finished or intermediate materials, building product fabrication, and packaging and distribution of building products.
> **Construction:** All activities related to the actual building project construction.
> **Use and Maintenance:** Building operation including energy consumption, water usage, environmental waste generation, repair and replacement of building assemblies and systems, and transport and equipment use for repair and replacement.
> **End of Life:** Includes energy consumed and waste produced due to building demolition and disposal of materials to landfills, and transport of waste materials. Recycling and reuse activities related to demolition waste also can be included and have a 'negative impact.'[70]

For the building industry, defining the stages helps professionals actively design buildings with reduced negative environmental impacts. Life cycle assessment as a tool helps assist with this process by understanding "the energy use and other environmental

[69] Ibid.
[70] "AIA Guide to Building Life Cycle Assessment in Practice," Guide prepared by Georgia Institute of Technology (Washington, D.C.: The American Institute of Architects, 2010), 14.

impacts associated with all life cycle phases of the building: procurement, construction, operation, and decommissioning."[71]

Life Cycle Assessment and Historic Preservation

Life cycle assessment (LCA) for buildings is a way to quantify the amount of energy it is consuming and producing, as well as its environmental and cost impact. LCA is based on the fact that all stages of a product or building create environmental impacts on water, land and air, and eventually impact human health. LCA provides an arena to determine trade-offs when designing a building that might affect another phase of the assessment; for example, will increasing recycled material create a future disposal problem? This way of thinking doesn't determine if a building is a success or failure, but provides a way of thinking to create the best possible outcome.

While the defined role of life cycle assessments is to better understand the environmental implications that are associated with new buildings, LCA is also relevant to historic preservation as it can be utilized to assess the environmental values and benefits associated with reusing a building. LCA methodology delves into the important question brought up previously of "how green is an existing building?" This approach to examining existing structures shifts the focus from solely embodied energy, which makes up a portion of an LCA, to a whole building approach and brings to the forefront a spectrum of environmental values. This method allows preservation professionals to approach the topic of building reuse with a stronger understanding of a building on a whole environmental scale, instead of a single energy outlay. As building professionals

[71] Ibid.

begin to utilize the LCA approach and it becomes routine to perform one for building diagnostics, it would suit the preservation industry to communicate and relate with the same method.

Development of the LCA Approach for Preservation

In June 2009, a group of experts in building science, historic preservation and life cycle assessment met in Washington D.C. to discuss the need to better understand the environmental value of reusing historic buildings.[72] The symposium was organized by the National Trust for Historic Preservation and was sponsored by National Trust Trustee Daniel Thorne. The objective was to develop "a research agenda that, when completed, strengthens Life Cycle Analysis methodology, data, and tools and furthers the understanding and use of LCA in dialogue and public policy related to the preservation of historic buildings."[73] This was the initial step in creating a common language for preservationists to utilize LCA methods in an effective manner. A summary of the symposium recommends that a primer on LCA be developed to further the education and bridge the language gap between historic preservation, architecture and LCA communities. The rationale behind this is that LCA is generally not understood among the preservation industry, but if preservation professionals are educated to understand how to use LCA and what it can accomplish, it will serve as a better tool. The U.S. Life Cycle Inventory (LCI) database, run by The National Renewable Energy Laboratory, the principal laboratory for the U.S. Department of Energy's Office of Energy Efficiency and

[72] Wayne Trusty (former president of the Athena Institute of Sustainable Materials) telephone discussion, January 29, 2013.
[73] Meeting Summary from Symposium, National Trust for Historic Preservation, June 8-9, 2009.

Renewable Energy, exists to measure the energy and material flows in and out of the environment that are associated with a material, component or assembly.[74] A recommendation was to develop LCA data for traditional materials and techniques for renovations and rehabilitations that could eventually become part of the U.S LCI database and made available for practitioners. Part of this was also to provide research on service life, along with data on existing building stock, to define and prioritize retrofit actions. The last recommendation and goal was to create an LCA renovation assessment tool. This tool would be used to compare rehabilitation and new construction, as well as between various rehabilitation options. The goal of this recommendation is to target areas of greatest benefit, develop policies that support real environmental performance, identify how to support existing policy instruments and address the issue of diminishing virgin materials. This symposium was an initial think tank that gave way to the methods that are currently available and, with further education and development, could become vital tools in the sustainability approach for the preservation industry.

The Greenest Building: Quantifying The Environmental Value of Building Reuse

In January 2012, the Preservation Green Lab, National Trust for Historic Preservation released a report in response to several of the recommendations from the June 2009 symposium. The report, *The Greenest Building: Quantifying The Environmental Value of Building Reuse*, looked at the environmental impact reductions when comparing rehabilitated buildings to new construction through an LCA framework. This framework enables the preservation industry to look at key "variables such as

[74] U.S. Department of Energy, "U.S. Life Cycle Inventory Database Roadmap," (prepared by the National Renewable Energy Laboratory (NREL), August 2009).

building life span and operation energy efficiency that may affect the decision to reuse buildings versus build new."[75] There were three key objectives of the study:

1. To compute the life cycle environmental impacts of buildings undergoing rehabilitation and compare to those generated by the demolition of existing buildings and replacement with new construction.
2. Determine which stages of a building's life contribute most significantly to its environmental impacts.
3. Assess the influence of building typology, geography, energy performance, and life span on environmental impacts throughout a buildings life cycle.[76]

The findings stated:

> "Building reuse almost always yields fewer environmental impacts than new construction when comparing buildings of similar size and functionality, reuse and retrofit are best in areas where coal is the driving energy source, and climate implications of demolition and new construction compared to renovation and building reuse."[77]

Greenest Building Approach

The approach and methodology used in this study were based on actual case-study buildings, both in renovation and new-construction scenarios, to determine material inputs for the LCA model. A key outcome in these case studies was quantifying the amount of time needed for a newly built structure to recoup energy outlays initially spent in the construction process by using efficient building operations.

Phase I of the study was a review of existing literature on building LCA, energy use, and U.S. building stock. Interviews with industry leaders in the preservation and

[75] Preservation Green Lab, "The Greenest Building: Quantifying the Environmental Value of Building Reuse" (The National Trust for Historic Preservation, 2011), 15.
[76] Ibid, X.
[77] Ibid, 61.

building reuse fields were conducted. Lastly, this phase included the development of LCA methodology and a pilot case was created to test the LCA process.[78]

Phase II of the study was informed by the results of the pilot LCA; next steps included careful consideration of the building types selected for the study. Six building types were identified: single-family residential, multifamily residential, commercial office, urban village mixed-use, elementary school, and warehouse. The selected buildings within these six types were comparable in terms of size, program and construction typology.[79]

Phase III involved in-depth analysis of each case study building. A full LCA was run on each reuse/renovation and demolition/new construction scenario. Additionally, the LCA was run across four cities to represent four different climate regions within the United States. Lastly, sensitivity analysis was conducted to determine how specific changes to inputs affected the final outcomes. From this data, conclusions were drawn to record key findings from the study.[80]

The Greenest Building: Quantifying The Environmental Value of Building Reuse, can be downloaded from the Internet at The National Trust for Historic Preservation website and referred to for a full scheme.

[78] Ibid, 25-34.
[79] Ibid, 25-34.
[80] Ibid, 25-34.

Results and Key Findings

The results from the LCA reflect the environmental value of building reuse and renovation compared to demolition and new construction. Three key findings from the study are:

- Building reuse almost always yields fewer environmental impacts than new construction when comparing buildings of similar size and functionality.
- Reuse of buildings with an average level of energy performance consistently offers immediate climate change impact reductions compared to more energy efficient new construction.
- Materials matter: The quantity and type of materials used in building renovation can reduce, or even negate, the benefits of reuse.[81]

The results revealed by this study provide preservation with another set of arguments besides the inherent features within historic structures. These findings also broach the topic of operational energy, as many argue new, green, energy-efficient operating systems outweigh the benefits of energy lost through demolition and new construction. The immediate carbon savings associated with building reuse and renovation compared to new construction proves that by reusing structures, initial carbon outlays can be avoided and communities can reach carbon-reduction goals quicker.

Further Research

Further research is always necessary to mature and fine-tune a new approach or tool. One of the topics that require additional research is improving the life cycle inventory data. Similarly discussed in the 2009 symposium, the need for a U.S. database to represent operations and provide data still stands. However, since the LCA

[81] Ibid, 61.

methodology remains somewhat in its infancy, this could take time to develop. Evaluation of the durability of building materials is also needed. In determining the rate at which building materials will be replaced over a set life cycle, additional information regarding material durability would make this input more precise. Lastly, a deeper understating of building energy consumption and material impacts is needed. The LCA approach used in this study does not take into account specific comparisons between materials. While additional research is necessary, this study provided the initial groundwork that advanced the preservation field in energy efficiency debates.[82]

Avoided Impacts

The avoided impacts concept is derived from the idea that energy embedded in a historic structure is already sunk—meaning that there is no inherent or future energy savings associated with preserving a building because the energy expenditure used to create the building occurred in the past, as did the environmental impacts associated with creating the building. This viewpoint takes the accounting of embodied energy and sets it aside, since it already happened. Instead, it looks at the reuse of buildings to be only the environmental impacts that are avoided by not demolishing and building new. This methodology has been done in prior studies, such as the U.K. study by the Empty Homes Agency, *New Tricks with Old Bricks: How Reusing Old Bricks Can Cut Carbon Emissions*, which utilized it to understand the environmental value of existing homes.

[82] Ibid, 91.

Athena Sustainable Materials Institute & LCA Measures

Understanding the life cycle assessment (LCA) method is just the first step; preservation professionals need to be able to obtain software or access templates to utilize the methodology. Making these systems accessible and easy to operate needs to be an essential aspect of disseminating the LCA approach. One reliable source currently is the Athena Sustainable Materials Institute. The Athena Sustainable Materials Institute began in 1989 at Canada's National Wood Products Research Institute in Forintek. It was there that researcher Jamie Meil conversed with Wayne Trusty about widening the environmental dialogue regarding forest products. From this discussion, research guidelines in alignment with the International Organization for Standardization (ISO) for LCA and data for structural and building envelope materials were produced. The research report from this data was published under Building Materials in the Context of Sustainable Development, and this report was globally accepted as credited work, especially in Europe where LCA was already established. This report marked the first significant effort in Canada to develop LCA application in the construction sector.[83]

This work was not dubbed the "Athena Project" until the mid 1990s, and at this point the data was available in spreadsheets for North American designers. In 1997, the Athena Institute was cofounded by Wayne Trusty (who later became President of the Institute). The same year, the spreadsheets were developed into software with funding from the Climate Change Secretariat of the Canadian government. In 2002, it was released under the name Environmental Impact Estimator (and is currently called the

[83] "About ASMI," Athena Sustainable Materials Institute, accessed November 16, 2012, http://www.athenasmi.org/about-asmi/history/.

Athena Impact Estimator for Buildings.) A second tool, the Athena EcoCalculator for Assemblies, was developed in 2007, and aims to provide pre-determined LCA results for specific building construction typologies. Today, the Athena Institute is still a reliable source providing software, research and valuable information in way of life cycle assessments for the building industry.

Evaluation

The life cycle assessment/avoided impacts approach of evaluating existing buildings' environmental benefits versus new construction provides a different currency of data to work with versus embodied energy outputs. While the language of sustainability related to energy is based around carbon emissions and carbon footprints, preservation professionals now have breached a barrier that historically divided life cycle assessment advocates and non-users.

Observing the environmental impacts that are avoided by recycling a building versus demolition amplifies the argument for preservation. The argument that has existed prior concerning the inherent sustainable features of preservation and the ability for historic structures to adapt to modern energy efficient standards has more credibility when observed from a broad environmental standpoint. The notion of looking beyond the recoup of energy outlay that was invested in a building during construction and to the full life cycle spectrum is a stronger case.

Expressing the capital energy of an existing structure in a formula for what is accounted for in the present day capital energy required for a new energy efficient building would be just the total embodied energy spent today.

Expressing the formula for what the capital energy required for an existing building would be the embodied energy spent today, minus the embodied energy needed to improve the existing structure, equals the energy spent or the avoided impacts (Figure 6).

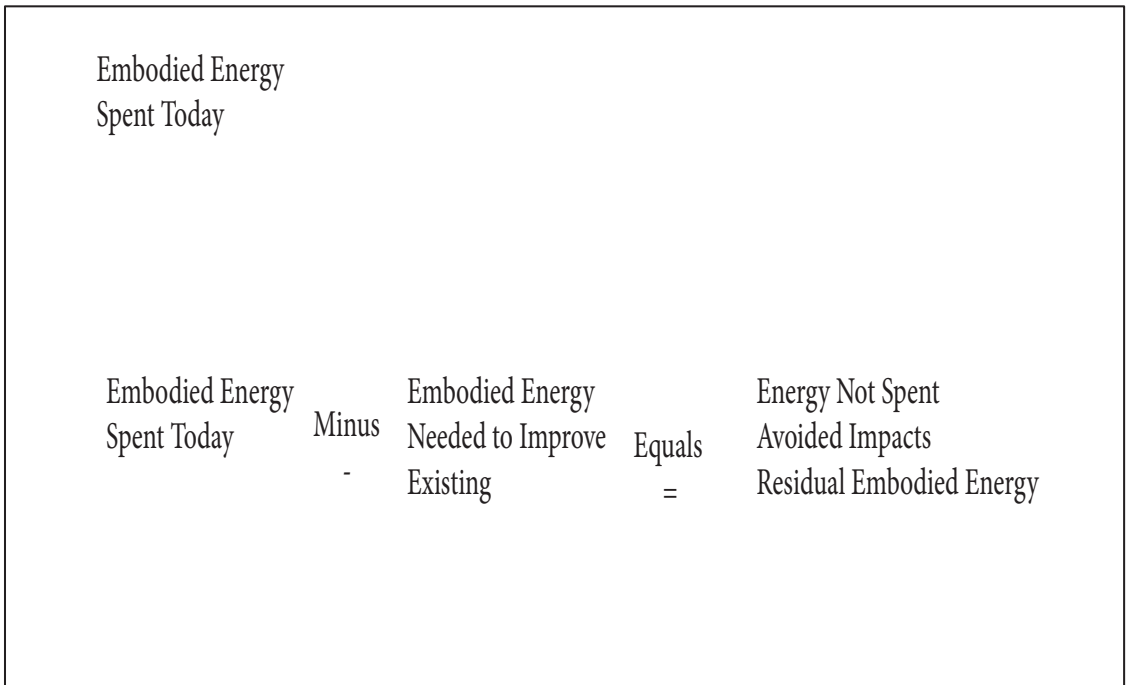

Figure 6. Avoided impacts formula.

The formula for life cycle assessment/avoided impacts accounts for the energy in the future. Accounting for the energy in the future, closes the gap that exists between the energy that was spent at initial construction and the energy added for a replacement building.

Conclusion

The life cycle assessment/avoided impacts model is in alignment with the sustainability goals and policies of the 1990s/2000s. Outputs are quantitative in a currency that has the ability to be transient throughout the sustainability community. The

methodology and results produced by the National Trust for Historic Preservation were innovative and exemplary in the response to provide the preservation field the tools and knowledge with how to build the argument beyond solely embodied energy when examining energy value in historic structures.

Chapter VI is a case study that applies the two approaches identified in this thesis to a historic structure in Philadelphia, Pennsylvania. The application of the two approaches results in an exploration to determine which model produces an output that is the highest and most effective tool for the preservation industry to communicate with.

Lastly, a conclusion chapter will discuss the method that best serves the preservation field going forward. The conclusion chapter incorporates input from several industry professionals as well as the future implications of each model.

Chapter V
Case Study

"There is a tremendous impact to the environment when we construct something new, so avoiding new construction may be the most eco-conscious approach to our environment."
Athena Sustainable Materials Institute

Introduction

This case study compares the Advisory Council on Historic Preservation embodied energy method with the life cycle assessment/avoided environmental impacts model. The case study, a historic residential structure in Philadelphia, Pennsylvania applies the two models and evaluates the outputs to determine which case is the best tool to be employed for preservation professionals when discussing building renovation, restoration and rehabilitation over demolition and new construction. Limitations and restraints within this study will be noted.

The case study & building

The case study building is located at 402 South Front Street, Philadelphia, Pennsylvania (Figure 7). It is a three and a half story, brick Federal style residential building. The building is historically significant as the John Clement Stocker House. John Clement Stocker was a wealthy influential merchant and his son, J.C. Stocker II was a prominent Philadelphia citizen. It is speculated that Francis Trumble Joiner, the original owner from 1768 - 1791, initially constructed the building between 1768 and 1795. No original plans are known to exist, but five early documents of the Mutual Assurance Society note that the building and its additions in 1795 were "twenty seven

feet front, fortytwo feet deep and three stories high. The staircase being eighteen feet by ten feet, three stories high, kitchen twenty feet by fifteen feet and three stories high."[84] The property passed out of the Stocker family ownership in 1866. In 1936 the building, along with several surrounding structures, became part of a fish processing plant. Alterations to the front building facing Front Street during this time included removal of brick partitions; the first floor being covered in concrete and ceramic tile; four fireplaces bricked-in; all of the carved woodwork removed; and a large shop window may have replaced the two probable original windows. The Historical American Building Survey (HABS) documented the building in 1962.[85]

As it stands today, the building is three-and-a-half stories tall and features three bays on the primary east façade. It was built in the Federal style, and the east façade is brick with black glazed headers laid in a Flemish bond. The belt courses on the primary façade are marble, with a molded marble base course and lintels. The building measures 27 feet with a depth of 100 feet. The entrance is currently approximately two feet above grade with a marble stoop and pediment doorway framed by two columns. The primary façade windows are double-hung sash windows, , the third floors are three-over-three, second floor are four-over-four. There is a dormer that is arched and has a pediment with a gable roof. Two original chimneys on the south wall exist. A modern single flue chimney exists on the north wall. The piazza in the rear of the building (west) measures 18 feet by 11 feet. The site is a city street in Society Hill neighborhood of Philadelphia,

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[84] Historic American Buildings Survey, John Clement Stocker House No. PA-1068, National Park Service, 1962.
[85] Ibid.

Pennsylvania. The south lot has been demolished exposing a stucco finish on the south façade. An adjoining building is located to the north.

The interior has lost the majority of the original millwork with only plainer work remaining. The interior of the building recorded by HABS in 1962 notes that the flooring throughout seems to be pine, with the boards running east to west. At the time of surveying concrete had replaced the floor in the ground level of the house. The major interior partitions are brick from basement through the attic. All of the staircases have been removed or relocated. The fireplace openings have been closed with brick. Additionally, floor levels in the piazza have been altered.

The foundations of the building are rubble. The basement partitions have three centered arches. The wall construction is brick with 1-foot thick party walls, and 1'6" on east and west elevations. The roof of the front building is a double pitch to the street and back slope about 8/12. Roof appears to be covered in asphalt shingles. The piazza has a shed roof, which is also covered in asphalt shingles.

Figure 7. 402 South Front Street. (Image by author).

Research Procedure

The data that was collected from the site included a basic site visit to collect building dimensions, identification of observable materials and where applicable material quantities. The current function is a private residence; interior access was not permissible. Historic American Buildings Survey architectural drawings from 1962 were

available through the Library of Congress. Elevation, section and plans were utilized to obtain unattainable field dimensions as well as interior plan dimensions.

ACHP Embodied Energy Analysis

The survey level methodology for the embodied energy analysis was used for this case study. The survey method calculator is accessed through www.thegreenestbuilding.org website. The survey method looks at major material components of the structure and calculates the embodied energy of each individual element, which utilizes the 1979 Advisory Council on Historic Preservation, *Assessing Energy Conservation for Historic Preservation: Methods and Examples* data sets for calculation (Table 1). The data sets include, extraction of raw material, manufacturing, transportation and physical construction. The survey method was reviewed in-depth in Chapter III. The information that was gathered from the site visit and through observation of the building was used to determine material quantities. Several assumptions were necessary for structural materials that were not visible; all assumptions will be noted.

Mary T. Watts Appreciation Society, website thegreenestbuilding.org generates British Thermal Unit (BTUs) results based on the square footage of materials used in original construction. Several of the inputs are approximations since exact square footage of material is difficult to obtain (Figure 8). The results from the survey method yield 9,831,024 BTUs.

Energy Embodiment of Primary Materials	
Material Category	Embodied Energy per Material Unit
Wood Products	9,000 BTU/BDFT
Paint Products (450sf/gal.)	1,000 BTU/sq. ft.
Asphalt Products	2,000 BTU/sq. ft.
Glass Products: Windows	15,000 BTU/sq. ft.
Glass Products: Plate	40,000 BTU/sq. ft.
Stone & Clay Products: Concrete	96,000 BTU/cf
Stone & Clay Products: Brick	400,000 BTU/cf
Primary Iron & Steel Products	25,000 BTU/lb
Primary Non-Ferrous Products	95,000 BTU/lb

Table 1. Energy embodiment of primary materials. Table from *Assessing Energy Conservation for Historic Preservation: Methods and Examples,* 1979.

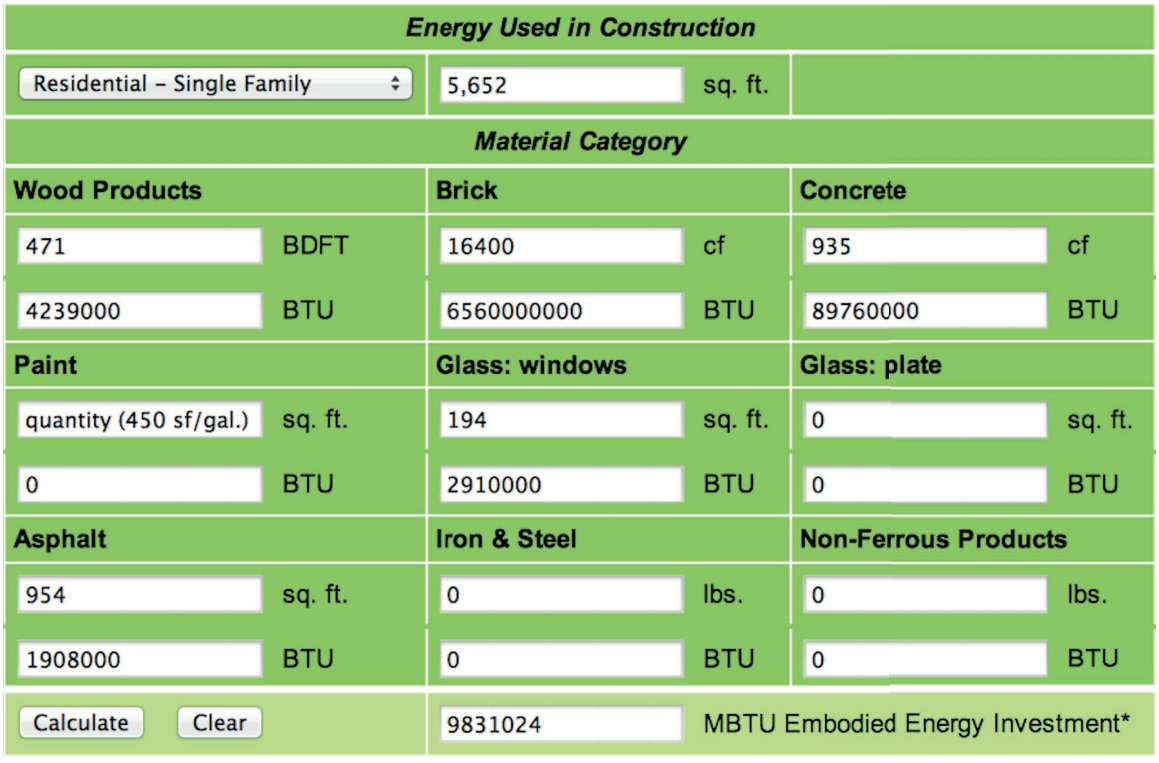

Figure 8. Survey method energy used in construction. (Courtesy of www.thegreenestbuilding.org).

The result of 9,831,024 BTUs is put into the Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator, 9,831,024 BTUs is equivalent to 706 metric tons of CO_2 or CO_2 equivalent. To humanize these results further that is equivalent to the CO_2 emissions from the energy use of 39.1 homes for one year. This number will be relevant when comparing to the results from the LCA approach.

Barriers

The barriers associated with the embodied energy approach to quantifying value in historic structures are first the access. While the embodied energy calculator is accessible for free via the Internet, it is not a downloadable interactive document. An extra paper and pencil calculation to get BTUs is necessary. Only one tangible comparison is offered, gallons of gas. Time intensity for this approach is low. For the gross square footage calculation it took approximately one hour to perform take offs of existing plans. Calculating material amounts and quantities for the survey model took approximately one to two hours. Converting output BTUs to equivalent gallons of gas took approximately ten minutes. While the time demand for this approach is low, the feasibility and estimated outputs of the results needs to be examined.

Avoided Impacts/Environmental LCA

The Athena EcoCalculator, available through the Athena Sustainable Materials Institute and developed in association with the University of Minnesota and Morrison Hershfield Consulting Engineers, is a comprehensive tool that utilizes pre-defined building assemblies that have been previously assessed in the Athena Impact Estimator

for Buildings. The EcoCalculator is a structured excel spreadsheet workbook, with tabs for various construction assemblies on each; individual worksheet specific assembly information is included. The user has to enter the specific square footage of assemblies for specific project. All life cycle stages are taken into account: resource extraction and processing; product manufacturing; on-site construction of assemblies; all related transportation; maintenance and replacement cycles over an assumed building service life of 60 years; and the demolition and transportation of non-metal materials to landfill.[86] The EcoCalculator is used to estimate the avoided environmental impacts by not constructing a new building on the site of 402 South Front Street.

The process consisted of determining square footage necessary for building assembly pre-defined by the analysis template. Replacement assembly and material inputs were derived to fit as close to what is currently in place at 402 South Front Street. Designed to be readily-applied, the EcoCalculator template can be used without outside consulting or specialty help, and the results are considered to be reasonable approximations as opposed to precise estimates. A detailed step-by-step process for the 6.0 Analysis Template that was used can be found in Appendix 1:

- Use of the Athena EcoCalculator to estimate embodied environmental impacts, and global warming potential measured in terms of CO_2 equivalence.
- Estimated avoided impacts associated with demolition of the existing building and construction of new buildings of essentially same size, designed to serve the functions currently being served by the renovated buildings.

[86] Athena EcoCalculator, Athena Sustainable Materials Institute, accessed December 4, 2012, http://www.athenasmi.org/our-software-data/ecocalculator/.

Proposed Replacement Building

- Three and a half stories with full basement
- Same 5,652 square footage as the existing building
- Height of 9 foot wall between intermediate floors
- Similar interior configuration to what Historic American Buildings Survey documented in 1962.
- 11.8% window to wall ratio – not consistent with the EcoCalculator 20% window to wall ratio assumption. EcoCalculator has a built in window to wall ratio of 20%. The actual window to wall ratio for building site was calculated and entered into assembly worksheet.
- Exterior brick cladding on elevations visible from street, metal siding for the remainder.

Results

The EcoCalculator provides results for eight indicators of climate change impacts The classification of the eight impact categories: fossil fuel consumption (MJ), global warming potential (GWP) in tonnes CO2eq, acidification potential, human health criteria, eutrophication potential, ozone depletion potential and smog potential. These impact measures can be evaluated to determine which assemblies provide the lowest negative impact by entering the square footage into different assemblies.

Fossil Fuel Consumption: The estimated amount of fossil fuel energy used in the extraction, processing, transportation, construction and disposal of each material. Measured in megajouls (MJ).
Global Warming Potential: The estimated amount of greenhouse gases created. Measured in mass units of carbon dioxide equivalents.
Acidification Potential: The estimated amount of acid-forming chemicals created. Measured in moles of hydron(H+) equivalents.
Human Health Criteria: The estimated amount of airborne particles that can lead to asthma, bronchitis, acute pulmonary disease, etc. Measured in mass units of 10 micron particulate matter.
Aquatic Eutrophication Potential: The estimated amount of water-nutrifying substances that can lead to proliferation of photosynthetic aquatic species. Measured in mass units of Nitrogen equivalents.
Ozone Depletion Potential: The estimated amount of ozone-depleting substances (CFC's, HFC's, and halons) created. Measured in mass units of CFC-11 equivalents.

Smog Potential: The estimated amount of chemicals that could produce photochemical smog and ground-level ozone when exposed to sunlight. Measured in mass units of ozone equivalents.

The results summary from the EcoCalculator are accounted for across the eight climate change indicators (Figure 9).

Athena EcoCalculator Results

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	Human Health Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
Foundations & Footings	2,835	116,276	12	2,955	39	2,412	85	690
Columns & Beams	0	0	0	0	0	0	0	0
Intermediate Floors	5,652	141,998	7	5,936	78	7,792	6	2,590
Exterior Walls	1,804	225,567	19	6,255	65	3,610	77	1,096
Windows	195	79,657	7	4,466	121	1,820	22	598
Interior Walls	2,060	79,102	5	1,412	46	1,532	20	275
Roof	954	187,700	11	4,640	54	7,192	2	1,285
TOTALS		830,302	61	25,663	403	24,358	212	6,533

Figure 9. Athena EcoCalculator Results. (Template courtesy of athenasmi.org).

The total avoided impacts for global warming potential (GWP) were compiled and the inclusion of calculating the global warming potential for whole building demolition was added on as an avoided impact if you are reusing an existing building (Table 2).

Total Avoided Impacts Summary

Building Component	**GWP Total (Tonnes CO2eq)**
Foundations & Footings	12
Intermediate Floors	7
Exterior Walls	19
Windows	7
Interior Walls	5
Roofs	11
Whole Building Demolition	42
Total	**103**

Table 2. Total avoided impacts summary. (Table derivation courtesy of athenasmi.org).

The assembly groups were also represented by the percentage contribution from each assembly to the eight climate change indicators (Figure 10).

Percentages by assembly groups
(these results are shown in the pie charts below)

Fossil Fuel Consumption	Global Warming Potential	Acidification Potential	Human Health Criteria	Eutrophication Potential	Ozone Depletion Potential	Smog Potential
14%	20%	12%	10%	10%	40%	11%
0%	0%	0%	0%	0%	0%	0%
17%	12%	23%	19%	32%	3%	40%
27%	31%	24%	16%	15%	36%	17%
10%	12%	17%	30%	7%	11%	9%
10%	8%	6%	11%	6%	9%	4%
23%	18%	18%	13%	30%	1%	20%

Figure 10. Percentages by assembly groups. (Courtesy of Athena EcoCalcuator).

Out of the eight climate change indicators, global warming potential is the indicator that can be translated into a carbon dioxide equivalent. Global warming potential as defined by the Environmental Protection Agency:

> "was developed to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. The definition of a GWP for a particular greenhouse gas is the ratio of heat trapped by one unit mass to the greenhouse gas to that of one unit mass CO_2 over a specified time period."[87]

The Intergovernmental Panel on Climate Change officially calculates the GWP. Using GWP as a key environmental impact is beneficial since it is measured in terms of CO_2 equivalence.

The entire building GWP results were than entered into the United States Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator. This free tool provides user-friendly tangible results. Translating measurements the calculator

[87] United States Environmental Protection Agency, "Global Warming Potentials," http://www.epa.gov/outreach/scientific.html.

humanizes data to an understandable concept. The avoided GWP impact of 402 South Front Street is equivalent to the CO_2 emissions from 10,475 gallons of gasoline consumed, or emissions from the electricity use of 14 homes for one year, or CO_2 emissions from the energy use of 4.8homes for one year, or carbon sequestered annually by 76.6 acres of U.S. forests.

Barriers

With any model there are particular barriers in the system. When calculating the square footage for the Exterior Walls assembly there is a built in 20 percent window to wall ratio. The model automatically accounts for the 20 percent ratio. For the residential structure undertaken in this study the actual window to wall ratio is 11.8 percent. In order to make up for the 8.2 percent difference the actual window to wall ratio was determined for the model. Understanding that the model makes an assumption for the window to wall ratio and how to correct that to make results a finer tuned estimate was a barrier overcome to make the model operate at an optimal level.

Time and user building construction knowledge is the second barrier. While this template is accessible, it does require the user to have some basic architectural building construction knowledge. Basic knowledge is necessary to understand how to choose appropriate building assemblies. Time expenditure was heavier on this approach versus embodied energy. Organization and selection of proper assembly systems took approximately two to three hours. Computation and take offs from plans and elevations took approximately two to three hours. Input of square footage into model took approximately one to two hours. Synthesis and calculation of GWP Total including

GWP related to demolition calculation took approximately one to two hours. Of the two approaches tested this approach is more time demanding.

Outcomes

A comparison of the results from the embodied energy approach and the avoided impacts approach reveal the difference in output measurement and retrograde comparison results. Historically, the preservation field has relied on the embodied energy outputs of BTUs and comparable measures of gallons of gas when discussing the energy capital in existing structures. But, with the development of the LCA/avoided impacts approach outputs in the form of GWP or carbon dioxide equivalent emissions can be utilized to still maintain the gallons of gas comparison and also relying on a government run source to generate comparable outputs. The avoided impacts approach is more time and labor intensive, it does provide results that are more comprehensive. The outputs are still energy outputs but, are in a CO_2 emissions equivalent making it easier to utilize the EPA calculator.

The environmental avoided impacts model lends itself to a currency that is interdisciplinary. Decisions of whether to rehabilitate a building or demolish and construct new require the input of many different professional disciplines. Communicating in a currency that is interdisciplinary such as GWP and CO_2 emissions is more effective than championing a position that is dated or dismissed. The environmental avoided impact incorporates not just emissions from CO_2, but also human health, acidification, water, etc. These additional outputs allow the preservation

professional access and ability to discuss potential depleted resources with a way to save them.

Conclusion

This case study identifies and applies two ways to approach quantifying the energy capital in historic structures. Both provide quantitative results, but with different units of measurements. The EcoCalculator measured the energy capital in terms of eight climate change indicators and focused on global warming potential, while the embodied energy ACHP model measured the energy capital in BTUs. The approach needs to produce results that are in a currency that has the potential to communicable across the sustainability community.

The final chapter of this thesis will offer an evaluation of the two approaches that have been identified and place them in the larger field of preservation to determine which provides the most effective results as an argument. The contribution of the preservation field to the continued protection of historic structures within a sustainability circle needs a current and effective argument to have leverage.

Chapter VI
Evaluation

The role that historic preservation plays within sustainability and the goal to reduce greenhouse gas emissions is already on its way to adapting to modern sustainability goals and policies. Just as Richard Moe, President of the National Trust for Historic Preservation noted in 2008 at the Trusts' annual meeting,

> "The preservation movement has periodically reinvented itself: It started with a focus on iconic landmarks, then took up the benefits of adaptive use before going on to emphasize the social values of preservation in building stronger communities. Now we're on the threshold of a new phase."[88]

A new phase is needed to shift and adapt to the discussions and challenges that sustainability has posed. This chapter discusses the fundamental differences between the embodied energy approach and the LCA/environmental avoided impacts approach. The pros and cons of each system have been identified throughout this thesis. This chapter draws conclusions as to why the LCA/avoided impacts model values existing buildings in an appropriate manner for the preservation industry. Application of the two approaches on a broader scale to the preservation field initiates a conversation about the urgency that is underlying in the preservation field to begin adapting to and educating about the LCA/avoided impacts approach.

Retrospective Value and Future Value

Fundamentally, when measuring embodied energy, capital energy is viewed retrospectively. We are accounting for energy that already happened in the past, i.e. sunk cost. We are valuing a building currently in terms of energy that was expended

[88] Wayne Curtis, "A Cautionary Tale," *Preservation*.

historically and not taking into account that a building declines over the years. This method does not account for the simple and unavoidable fact that the building has been used and that materials wear out after time. The LCA/avoided environmental impacts approach views the energy value of the building as the future potential energy savings. It looks at what total replacement with a comparable new building would require and accounts for the building declining over the years.

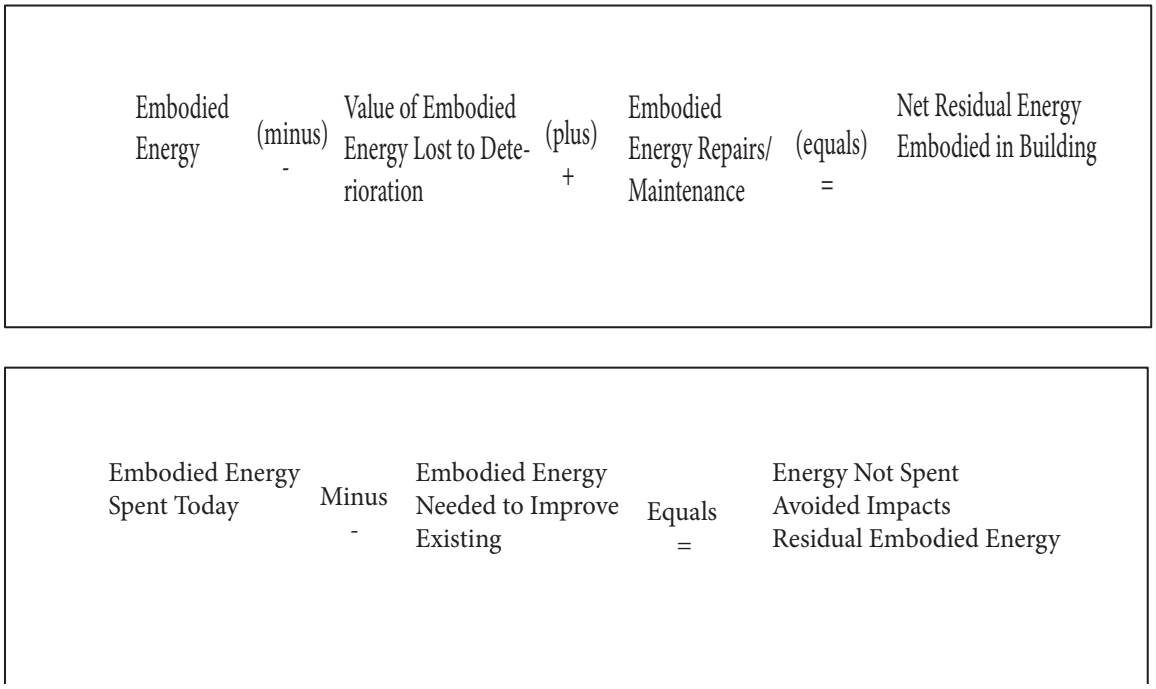

Figure 11. Formulas for Capital Energy

Placing the two equations previously discussed side by side for a comparison reiterates exactly what each approach is accounting for when taking the present day current value of capital energy in a building. Examining the resulting unit of measurement indicates which is a common currency to effectively communicate and align with modern sustainable goals and policies. The embodied energy model produces results that are measured in BTUs and commonly translated to gallons of gasoline. The life cycle

assessment/avoided impacts model produces results in a metric of CO_2 and GWP. The gallons of gasoline measure is reminiscent of the oil crises and a period of conservation goals. Gallons of gasoline were the common currency for the 1970s and 1980s. The CO_2 and GWP measurement is a current measure of sustainability used across the board and provides a multi-faceted language to communicate with. In terms of the preservation field utilizing a common currency to communicate with professionals driving sustainability the life cycle assessment/avoided impacts model provides these communicable measurements.

Implications of continued use of embodied energy model

Examining what could potentially occur if the preservation field continues to rely on the embodied energy model as an argument for the reuse of historic buildings has elements of urgency. Sustainability goals and policies are continually evolving and are a moving target, communicating in a common currency has already been noted as an un-negligible position. If the preservation field continues to hold onto the embodied energy argument moving forward it could be used as a tool for dismissing historic buildings. Continued usage of the embodied energy model places the preservation field in its own silo working out of alignment with the sustainability community.

Turning towards a noted individual in the preservation field, Mike Jackson, previously mentioned for his 2005 article advocating embodied energy, his position has changed. Since the *Greenest Building: Quantifying the Environmental Value of Building Reuse* was published in 2012, Jackson recognizes the importance of this tool for the preservation field. An advocate of this methodology recognizes the future potential in

utilizing CO_2 the common currency, and translating this to carbon credits and the reuse of historic structures. Jackson notes that this is reframing the embodied energy question into a modern era.[89]

A recent study, published in 2013, *Midcentury (un)Modern: An Environmental Analysis of the 1958-73 Manhattan Office Building,* by Terrapin Bright Green LLC, and primary authors William Browning, Alice Hartley, Travis Knop and Curtis B. Wayne look at the need for a segment of New York City's building stock to be overhauled due to them not being able to meet modern sustainability goals. The type of building examined was curtain wall commercial office buildings built in New York City from the 1950s through the 1970s. These structures were built during a period where energy consumption was a non-issue and single-glazed curtain wall exteriors were a modern technology of the time. These structures pose a problem for the future of New York City as they are no longer desirable locations for Class A office space due to their low floor heights, tight column spacing obstructing daylight and many have their original inefficient mechanical systems. A case study building (675 Third Avenue) was chosen to represent this group of buildings in New York City and several scenarios were applied to the building. Integral Group, the engineering firm hired to work on this first established a baseline model to simulate the buildings current condition; they came within six percent of the actual source energy records of the building. After the baseline was determined, they applied retrofitting the building with advanced energy efficiency measures as one scheme and designing a replacement building on the site as the second scheme. The results cited that if well maintained, older buildings could achieve better-than-average

[89] Mike Jackson, email message, October 26, 2012.

energy efficiency. Energy use per square foot in a consistent well-maintained prototype building was 10 percent less than the national average derived from Commercial Buildings Energy Consumption Survey data. Deep retrofitting of early curtain wall structures could in theory lower their energy use by more than 40 percent, although this is unlikely to happen for structural and financial reasons. Additionally, the savings sound great, but due to the low ceilings, poor layout and other deterring features this building type would still not achieve Class A occupancy. The high performance replacement building it could be possible to increase occupancy while reducing absolute energy use. The replacement building for the site had a 5 percent lower total source energy usage and the embodied energy required to dismantle the existing building and construct a new one would be offset in 15.8 to 28 years. The replacement model added 44 percent to the zoning floor area of the existing building, a strategy for accommodating a growing population and creating a market-based incentive for building owners.[90]

Embodied energy is discussed in the study as a component to the buildings total energy impact from a life cycle perspective. Citing the data by Richard G. Stein and Dr. Bruce Hannon, *Energy Use for Construction,* as a source for embodied energy calculations. It is noted that the embodied energy in 675 Third Avenue is a sunk cost; the energy has already been expended and preservation professionals should be "careful in just using that as an argument for retaining an existing building."[91] Applying the Stein data to 675 Third Avenue, results show that improvements have brought the annual source energy use down to 209.7kBTU per square foot. Using the Stein data 1,642kBTU

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[90] Terrapin Bright Green, *Midcentury (un)Modern: An Environmental Analysis of The 1958-73 Manhattan Office Building* (New York: Terrapin Bright Green, 2013), 17.

[91] Terrapin Bright Green, *Midcentury (un)Modern: An Environmental Analysis of The 1958-73 Manhattan Office Building* (New York: Terrapin Bright Green, 2013).

per square foot as the total embodied energy, the building consumes an equivalent amount of energy every 8 years. Over its 46-year operating life the amount of energy consumed is already equivalent to it being rebuilt 5.8 times. This study deems that the best way to determine embodied energy is to use a range between the Stein data and the more current data for newer buildings. This would take into account the number of practices that have changed. Lastly, it is noted that since embodied energy data varies significantly among sources, "it seems reasonable to conclude that arguments in favor of preservation based embodied energy are limited in their usefulness, as approximate benchmarks against which operating energy over the lifecycle of a structure might be evaluated."[92] While this dismisses and weakens the argument for utilization of solely embodied energy calculations there could potentially be an argument for life cycle assessment/avoided impacts. Consideration of how much of the existing building could be saved and the avoided environmental implications from reusing specific assemblies would introduce the preservation field into the discussion in a relevant manner.

In conclusion, the preservation field needs to move towards the LCA/avoided impacts model and begin transitioning away from talking about embodied energy. Embodied energy is giving the field a tool that is easily dismissed and working against the end goal of building reuse. The currency of embodied energy is no longer in circulation and it is utilizing a measurement that is not tradable or communicable in current sustainability discussions.

[92] Ibid, 27.

Final Words

The role of the preservation field within sustainability will continue to evolve and adapt as sustainable strategies and goals are continually developing. This thesis has emphasized the importance of the preservation field to stay abreast with the currency that is associated with sustainability. While embodied energy methods evolved from an energy conservation heavy approach to sustainability within buildings, new approaches are being developed to examine the built environment in a holistic manner moving forward. The role and CO_2 unit of measurement of the life cycle assessment going forward will become more refined and mature as further research is performed. It is with keenness that the preservation field should approach the ability to utilize environmental avoided impact methods when discussing and evaluating historic structures. The ability to bolster the relationship between preservation and sustainability should be the responsibility of the preservation field. While this is one very small aspect of sustainability on a whole, it further adds value to historic structures when discussing energy.

The core aim of sustainability is to safeguard the eco-system for future generations to have the same access as we do now, preservation professionals should adapt to this role as they have taken on the role of safeguarding structures, landscapes and cultures for years. The ability to break down resistance to reuse structures that currently exists is possible. Communicating in a common currency and avoiding operating in a silo will allow professionals to be successful at the reuse of historic structures. The value of energy in buildings both historic and new will be up for discussion for years to come

as we attempt to reduce greenhouse gas emissions and reach a carbon neutral state, finding a way to value buildings in a modern era is essential.

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Appendices

Appendix 1
A 1.1

Template from *A Life Cycle Assessment Study of Embodied Effects For Existing Historic Buildings* by the Athena Sustainable Materials Institute.

6.0 Analysis Template
Taken from Athena Institute/Morrison Hershfield Limited: LCA for Existing Historic Buildings

1. Obtain floor plans, elevations and information regarding the history of the building, specifically repairs and renovations completed.
2. Visit the site to confirm the accuracy of drawings and verify the scope of the renovations. Review the site and building location for constraints or limitations that may impact the design of the new building, such as building immediately adjacent to the existing. Review typical construction assemblies for the geographical area (i.e. prevalent construction practices and assemblies that are being used in new buildings).
3. Determine assembly areas for the replacement building: structural (footprint by number of floors); exterior wall areas (based on existing wall lengths and new building height (3m per floor)); window areas (based on 20% window to wall ratio); area of interior walls; roof area (based on footprint).
4. Download the free version of the Athena EcoCalculator for Assemblies from the website www.athenasmi.org for the relevant geographic region and building height: low-rise (under 4 storeys) or high-rise (5 storeys and above).
5. Select assemblies from the EcoCalculator for the new building based on the construction used in the geographical location, size of building, type of building, site, etc. The following assembly categories are available: Columns and Beams, Intermediate Floors, Exterior Walls, Windows, Interior Walls, Roofs.
6. After selecting a major category (e.g. Exterior Walls), enter the square footage of each type of exterior wall assembly for the new building in the yellow column. More than one assembly type may be entered in each category. The impact totals will indicate their combined environmental impact.
7. Due to underlying assumptions inherent within the EcoCalculator, a 20% window to wall ratio must be used. To do so, take 20% of the total exterior wall area of the new building. The result becomes the square meterage to be entered in the yellow column of the Windows assembly category.
8. After entering assemblies for each category, the small chart at the top of the screen will indicate the environmental impacts by building component within each category as well as for the whole building.
9. In order to calculate demolition effect factors, determine the functional square footage of the new building by multiplying the number of floors in the buildin

Appendix 1.1 Continued

10. by the total roof area. The functional square footage of the building should then be multiplied by the following factors:

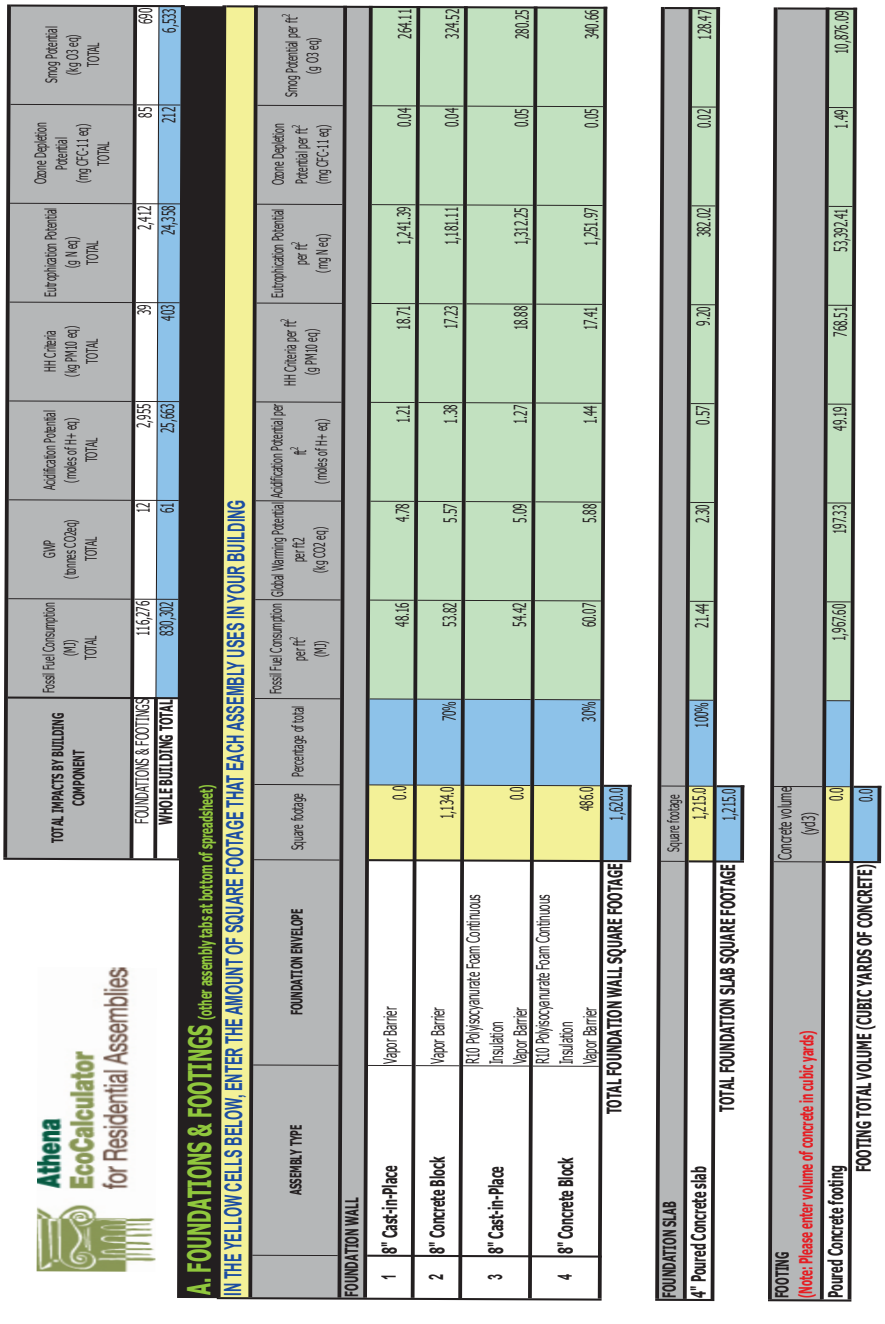
    Primary Energy related to demolition = functional square footage of building x .14 GJ/m2 (140MJ/m2)

    Global Warming Potential related to demolition = functional square footage of building x 0.08 Eq. CO2 tonnes/m2

11. The GWP results from the new building can then be entered into the United States Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator.

Appendix 2
Athena Sustainable Materials Institute
EcoCalculator Inputs

A 2.1 Foundations and Footings



Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
FOUNDATIONS & FOOTINGS	116,276	12	2,955	39	2,412	85	690
WHOLE BUILDING TOTAL	830,302	61	25,663	403	24,358	212	6,533

A. FOUNDATIONS & FOOTINGS (other assembly tabs at bottom of spreadsheet)

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ASSEMBLY TYPE	FOUNDATION ENVELOPE	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (Kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
FOUNDATION WALL											
1	8" Cast-in-Place	Vapor Barrier	0.0		48.16	4.78	1.21	18.71	1,241.39	0.04	264.11
2	8" Concrete Block	Vapor Barrier	1,134.0	70%	53.82	5.57	1.38	17.23	1,181.11	0.04	324.52
3	8" Cast-in-Place	R10 Polyisocyanurate Foam Continuous Insulation Vapor Barrier	0.0		54.42	5.09	1.27	18.88	1,312.25	0.05	280.25
4	8" Concrete Block	R10 Polyisocyanurate Foam Continuous Insulation Vapor Barrier	486.0	30%	60.07	5.88	1.44	17.41	1,251.97	0.05	340.66
	TOTAL FOUNDATION WALL SQUARE FOOTAGE		1,620.0								

FOUNDATION SLAB	Square footage								
4" Poured Concrete slab	1,215.0	100%	21.44	2.30	0.57	9.20	382.02	0.02	128.47
TOTAL FOUNDATION SLAB SQUARE FOOTAGE	1,215.0								

FOOTING (Note: Please enter volume of concrete in cubic yards)	Concrete volume (yd3)								
Poured Concrete footing	0.0		1,967.60	197.33	49.19	768.51	53,392.41	1.49	10,876.09
FOOTING TOTAL VOLUME (CUBIC YARDS OF CONCRETE)	0.0								

Note:
Pier and beam foundations can be modeled in the Columns and Beams tab.

A 2.2
Columns and Beams

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
COLUMNS & BEAMS	0	0	0	0	0	0	0
WHOLE BUILDING TOTAL	830,302	61	25,663	403	24,358	212	6,533

B. COLUMNS AND BEAMS (other assembly tabs at bottom of spreadsheet)

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ASSEMBLY TYPE Column / Beam	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all column and beam systems (excluding raised floor):				4.81	0.25	0.09	0.52	211.51	0.00	7.86
Assumes LOAD-BEARING exterior wall										
1	Hollow Structural Steel column / Glulam beam	0.0		6.46	0.35	0.12	0.75	168.03	0.00	10.19
2	Hollow Structural Steel column / LVL beam	0.0		6.28	0.35	0.12	0.64	175.16	0.00	7.48
3	Hollow Structural Steel column / Wide Flange Steel beam	0.0		9.57	0.51	0.18	0.78	428.53	0.00	11.12
4	LVL column / Glulam beam	0.0		2.06	0.11	0.04	0.43	42.23	0.00	6.56
5	LVL column / LVL beam	0.0		1.87	0.11	0.03	0.32	49.36	0.00	3.85
6	LVL column / Wide Flange Steel beam	0.0		5.16	0.26	0.09	0.46	302.73	0.00	7.50
7	Wood column / Glulam beam	0.0		1.91	0.10	0.03	0.42	44.42	0.00	6.95
8	Wood column / LVL beam	0.0		1.73	0.10	0.03	0.31	51.55	0.00	4.23
9	Wood column / Wide Flange Steel beam	0.0		5.01	0.26	0.09	0.45	304.92	0.00	7.88
10	Wide Flange Steel column / Glulam beam	0.0		4.92	0.25	0.09	0.60	234.53	0.00	10.12
11	Wide Flange Steel column / LVL beam	0.0		4.73	0.25	0.09	0.49	241.66	0.00	7.41
12	Wide Flange Steel column / Wide Flange Steel beam	0.0		8.02	0.40	0.14	0.64	495.03	0.00	11.06
	TOTAL SQUARE FOOTAGE	0.0								

	24" TALL FOUNDATION PIERS (Note: Please enter number of piers)	# of Piers								
13	Wood Pier	0.0		37.15	2.50	0.18	2.48	259.79	0.00	27.33
14	Concrete Block Pier	0.0		399.02	44.17	9.99	135.66	6,989.47	0.27	2,502.59
	TOTAL NUMBER OF PIERS	0.0								

	FOUNDATION BEAMS (Note: Please enter total linear feet of beams)	Length of Beams (ft)								
15	Wood Beam	0.0		30.38	1.94	0.60	6.16	1,127.87	0.00	118.20
16	Glulam Beam	0.0		45.32	2.28	0.74	10.17	789.73	0.00	166.53
17	LVL Beam	0.0		42.42	2.40	0.77	7.35	1,085.94	0.00	89.64
18	Wide Flange Steel Beam	0.0		137.65	6.94	2.42	10.92	8,494.32	0.00	189.80
	TOTAL LENGTH OF BEAMS	0.0								

A 2.3
Intermediate Floors

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
INTERMEDIATE FLOORS	141,998	7	5,936	78	7,792	6	2,590
WHOLE BUILDING TOTAL	830,302	61	25,663	403	24,358	212	6,533

C. INTERMEDIATE FLOORS

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	FLOOR STRUCTURE	INTERIOR OR CRAWL SPACE CEILING	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all intermediate floor assemblies:					**48.75**	**3.25**	**1.73**	**15.05**	**2,668.60**	**0.00**	**616.91**
1	Wood I Joist w/ OSB Decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		29.54	1.51	2.49	19.31	3,130.87	0.00	1,308.58
2	Wood I Joist w/ Plywood Decking	1/2" Gypsum Board,2 Coats Latex Paint	5,652.0	100%	25.12	1.27	1.05	13.85	1,378.66	0.00	458.24
3	Steel Joist w/ OSB Decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		60.27	3.90	2.37	18.96	3,697.35	0.00	938.00
4	Steel Joist w/ Plywood decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		55.83	3.66	0.93	13.49	1,945.06	0.00	87.66
5	Wood Joist w/ OSB Decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		28.88	1.52	1.87	17.32	2,399.30	0.00	930.03
6	Wood Joist w/ Plywood decking	1/2" Gypsum Board,2 Coats Latex Paint			24.46	1.28	0.43	11.85	647.10	0.00	79.70
7	Wood Truss w/ OSB Decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		32.90	1.88	1.97	17.87	2,551.75	0.00	938.31
8	Wood Truss w/ Plywood Decking	1/2" Gypsum Board,2 Coats Latex Paint	0.0		28.48	1.64	0.52	12.40	799.54	0.00	87.97
9	Wood I Joist w/ OSB Decking	R19 Cavity Insulation Vapor Barrier	0.0		75.41	5.24	3.41	26.26	5,067.46	0.00	1,354.42
10	Wood I Joist w/ Plywood Decking	R19 Cavity Insulation Vapor Barrier	0.0		70.99	5.00	1.96	20.80	3,215.24	0.00	504.09
11	Steel Joist w/ OSB Decking	R19 Cavity Insulation R12 Continuous Insulation Vapor Barrier	0.0		123.61	8.57	3.57	26.51	5,811.72	0.00	1,058.20
12	Steel Joist w/ Plywood decking	R19 Cavity Insulation R12 Continuous Insulation Vapor Barrier	0.0		119.17	8.33	2.13	21.05	4,059.43	0.00	207.86
13	Wood Joist w/ OSB Decking	R19 Cavity Insulation Vapor Barrier	0.0		74.74	5.25	2.79	24.27	4,335.88	0.00	975.88
14	Wood Joist w/ Plywood decking	R19 Cavity Insulation Vapor Barrier	0.0		70.33	5.02	1.34	18.80	2,583.68	0.00	125.55
15	Wood Truss w/ OSB Decking	R19 Cavity Insulation Vapor Barrier	0.0		78.77	5.61	2.88	24.82	4,488.34	0.00	984.15
16	Wood Truss w/ Plywood Decking	R19 Cavity Insulation Vapor Barrier	0.0		74.35	5.37	1.44	19.35	2,736.13	0.00	133.82
17	Wood I Joist w/ OSB Decking	Vapor Barrier	0.0		18.48	1.04	2.35	10.47	2,949.52	0.00	1,284.19
18	Wood I Joist w/ Plywood Decking	Vapor Barrier	0.0		14.06	0.81	0.91	5.01	1,197.31	0.00	433.86
19	Steel Joist w/ OSB Decking	Vapor Barrier	0.0		49.21	3.44	2.23	10.12	3,516.00	0.00	913.61
20	Steel Joist w/ Plywood decking	Vapor Barrier	0.0		44.77	3.20	0.79	4.66	1,763.72	0.00	63.27
21	Wood Joist w/ OSB Decking	Vapor Barrier	0.0		17.82	1.06	1.73	8.48	2,217.95	0.00	905.65
22	Wood Joist w/ Plywood decking	Vapor Barrier	0.0		13.40	0.82	0.29	3.02	455.75	0.00	55.32
23	Wood Truss w/ OSB Decking	Vapor Barrier	0.0		21.84	1.41	1.82	9.03	2,370.40	0.00	913.92
24	Wood Truss w/ Plywood Decking	Vapor Barrier	0.0		17.43	1.18	0.38	3.57	618.19	0.00	63.59
		TOTAL SQUARE FOOTAGE	5,652.0								

Note:
Floors 1-8 represent floors with finished, uninsulated interior ceilings.
Floors 9-24 represent unfinished floors over crawl spaces, and the vapor barrier is used as ground cover.
Floors 9-16 are insulated and should be used in conjunction with uninsulated foundation walls in the Foundations & Footings tab.
Floors 17-24 are uninsulated and should be used in conjunction with insulated foundation walls in the Foundations & Footings tab.

A 2.4
Exterior Walls

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
EXTERIOR WALLS	225,567	19	6,255	65	3,610	77	1,096
WHOLE BUILDING TOTAL	830,302	61	25,663	403	24,358	212	6,333

D. EXTERIOR WALLS

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	WALL TYPE	WALL ENVELOPE	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential (per ft² (g O3 eq)
Average across exterior wall assemblies:					117.94	8.08	3.05	40.35	3,374.40	0.04	711.61
8" CONCRETE BLOCK					118.10	9.43	2.75	41.75	2,170.52	0.06	528.86
1	Concrete Block	Clay Brick Cladding w/ 1" Air Space R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	1,804.0	100%	125.04	10.36	3.47	36.14	2,001.12	0.04	607.27
2	Concrete Block	Metal Cladding R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		168.74	13.80	4.28	46.98	4,371.95	0.15	633.49
3	Concrete Block	2 Coat Stucco Over Porous Surface R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		79.41	6.97	1.80	32.01	1,547.82	0.04	424.32
4	Concrete Block	Vinyl Siding R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		114.50	8.29	2.66	31.49	1,788.37	0.07	440.87
5	Concrete Block	Cedar Bevel Siding R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		101.12	8.01	2.13	32.58	1,835.06	0.04	504.14
6	Concrete Block	Exterior Insulated Finishing System R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		123.08	8.45	2.27	62.86	1,776.37	0.04	523.99
7	Concrete Block	Fiber Cement Siding R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		97.72	8.98	2.59	41.45	2,126.86	0.05	539.20
8	Concrete Block	Natural Stone Cladding R5 XPS Continuous Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		135.16	10.53	2.81	50.48	1,916.63	0.04	556.15
INSULATED CONCRETE FORMS					161.90	13.66	3.91	53.44	2,625.48	0.10	795.50
9	Insulated Concrete Form (R20)	Clay Brick Cladding w/ 1" Air Space 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		167.02	14.35	4.53	50.63	2,375.89	0.08	868.88
10	Insulated Concrete Form (R20)	Metal Cladding 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		210.72	17.79	5.34	61.47	4,746.72	0.19	895.10
11	Insulated Concrete Form (R20)	3 Coat Stucco Over Metal Mesh 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		139.17	11.71	3.08	48.02	2,089.75	0.08	717.69
12	Insulated Concrete Form (R20)	Vinyl Siding 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		156.48	12.28	3.72	45.98	2,163.14	0.12	702.49
13	Insulated Concrete Form (R20)	Cedar Bevel Siding 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		143.10	12.00	3.19	47.07	2,209.83	0.08	765.76
14	Insulated Concrete Form (R20)	Fiber Cement Siding 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		139.70	12.97	3.65	55.95	2,501.63	0.09	800.81
15	Insulated Concrete Form (R20)	Natural Stone Cladding 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		177.14	14.51	3.87	64.97	2,291.40	0.08	817.76
2x4 STEEL STUD WALL w/ SHEATHING					179.21	8.40	3.03	39.51	3,957.80	0.02	600.41
		Clay Brick Cladding w/ 1" Air Space									

A 2.5
Windows

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (Kg O3 eq) TOTAL
WINDOWS	79,657	7	4,466	121	1,820	22	598
WHOLE BUILDING TOTAL	839,302	61	25,663	403	24,358	212	6,533

E. WINDOWS

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	FRAME TYPE	DOUBLE GLAZING TYPE	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all window types:					**581.65**	**50.16**	**32.93**	**663.29**	**10,460.33**	**0.23**	**3,536.73**
1	Aluminum - Operable	Low E, Argon Filled	0.0		970.35	81.47	61.54	878.94	13,053.55	0.36	5,363.77
2	Vinyl-clad Wood - Operable	Low E, Argon Filled	0.0		406.55	36.39	21.95	571.20	8,883.99	0.15	2,850.44
3	Vinyl - Operable	Low E, Argon Filled	0.0		540.36	44.80	25.28	580.35	10,559.17	0.28	2,859.84
4	Wood - Operable	Low E, Argon Filled	194.6	100%	409.34	37.99	22.95	622.68	9,353.60	0.11	3,107.86
		TOTAL WINDOW SQUARE FOOTAGE	194.6								

Note:
Sliding glass door areas should be input as windows on this page

A 2.6
Interior Walls

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
INTERIOR WALLS	79,102	5	1,412	46	1,532	20	275
WHOLE BUILDING TOTAL	830,302	61	25,663	403	24,358	212	6,533

F. INTERIOR WALLS

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ASSEMBLY TYPE (16" o.c. walls modeled as Load Bearing, 24" o.c. as Non Load bearing)	WALL ENVELOPE (applied to both sides of the assembly)	Square footage	Percentage of total	Fossil Fuel Consumption per ft² (MJ)	Global Warming Potential per ft2 (kg CO2 eq)	Acidification Potential per ft² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per ft² (mg N eq)	Ozone Depletion Potential per ft² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across interior walls:					**40.52**	**2.49**	**0.71**	**21.95**	**841.67**	**0.01**	**125.07**
1	**Steel Stud 1-5/8 x 3-5/8 16" o.c.**	1/2" Gypsum Board, 2 Coats Latex Paint	0.0		39.26	2.08	0.59	19.11	966.18	0.00	66.20
2	**Steel Stud 1-5/8 x 3-5/8 24" o.c.**	1/2" Gypsum Board, 2 Coats Latex Paint	0.0		32.00	1.53	0.47	18.49	683.16	0.00	58.19
3	**Wood Stud 2 x 4 16" o.c.**	1/2" Gypsum Board, 2 Coats Latex Paint	1,610.0	78%	27.56	1.19	0.40	18.69	518.43	0.00	66.05
4	**Wood Stud 2 x 4 24" o.c.**	1/2" Gypsum Board, 2 Coats Latex Paint	0.0		26.62	1.12	0.38	18.43	471.99	0.00	60.98
5	**Concrete Block**	1/2" Gypsum Board, 2 Coats Latex Paint	450.0	22%	77.17	6.53	1.69	35.00	1,548.57	0.04	373.92
	TOTAL INTERIOR WALL SQUARE FOOTAGE		2,060.0								

A 2.7
Roofs

Athena EcoCalculator for Residential Assemblies

TOTAL IMPACTS BY BUILDING COMPONENT		Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	HH Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg O3 eq) TOTAL
ROOF		187,700	11	4,640	541	7,192	2	1,285
WHOLE BUILDING TOTAL		830,302	61	25,663	403	24,358	212	6,533

G. ROOFS

IN THE YELLOW CELLS BELOW, ENTER THE AMOUNT OF SQUARE FOOTAGE THAT EACH ASSEMBLY USES IN YOUR BUILDING

	ROOF TYPE	ROOF ENVELOPE	Square footage	Percentage of total	Fossil Fuel Consumption per m² (MJ)	Global Warming Potential per m² (kg CO2 eq)	Acidification Potential per m² (moles of H+ eq)	HH Criteria per ft² (g PM10 eq)	Eutrophication Potential per m² (mg N eq)	Ozone Depletion Potential per m² (mg CFC-11 eq)	Smog Potential per ft² (g O3 eq)
Average across all roof types:					209.30	12.67	4.73	56.98	7,109.38	0.01	1,051.97
WOOD I-JOIST					224.59	13.87	4.54	58.05	7,179.51	0.01	729.68
1	Wood I Joist w/ Plywood Decking	Clay Tile R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		224.65	14.78	5.10	60.31	6,531.70	0.00	824.02
2	Wood I Joist w/ Plywood Decking	Asphalt Shingles, Fiberglass Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		202.67	11.62	3.77	52.88	6,156.62	0.00	678.66
3	Wood I Joist w/ Plywood Decking	Asphalt Shingles, Fiberglass Felt based, 30 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		193.22	11.45	3.71	51.94	6,136.61	0.00	666.83
4	Wood I Joist w/ Plywood Decking	Asphalt Shingles, Organic Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		218.91	11.96	3.89	54.39	6,180.46	0.00	690.37
5	Wood I Joist w/ Plywood Decking	Asphalt Shingles, Organic Felt based, 30 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		201.70	11.63	3.78	52.72	6,146.29	0.00	670.94
6	Wood I Joist w/ Plywood Decking	Metal Roofing R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		209.08	14.02	4.67	56.53	7,299.30	0.05	740.20
7	Wood I Joist w/ OSB Decking	Clay Tile R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		228.18	14.97	6.25	64.68	7,933.47	0.00	1,504.28
8	Wood I Joist w/ OSB Decking	Asphalt Shingles, Fiberglass Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		206.20	11.81	4.92	57.25	7,558.39	0.00	1,358.93
9	Wood I Joist w/ OSB Decking	Asphalt Shingles, Fiberglass Felt based, 30 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	954.0	100%	196.75	11.64	4.86	56.31	7,538.38	0.00	1,347.10
10	Wood I Joist w/ OSB Decking	Asphalt Shingles, Organic Felt based, 20 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		222.44	12.15	5.05	58.76	7,582.23	0.00	1,370.64
11	Wood I Joist w/ OSB Decking	Asphalt Shingles, Organic Felt based, 30 year R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		205.23	11.82	4.93	57.09	7,548.06	0.00	1,351.21
12	Wood I Joist w/ OSB Decking	Metal Roofing R38 Cavity Insulation 1/2" Gypsum Board + 2 Coats Latex Paint	0.0		207.61	14.20	5.82	60.90	8,701.07	0.05	1,420.46
STEEL JOIST					271.06	17.35	5.18	65.24	8,831.01	0.01	719.69

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