THE UNIVERSITY OF CHICAGO

BUILDING ENERGY EFFICIENCY: CAN OLD BUILDINGS REPLACE THE NEW?

AN EXAMINATION OF CHICAGO'S BUILDING STOCK

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INTRODUCTION

Commercial and residential buildings account for nearly 40% of all carbon emissions within the United States, the largest of any sector within our country.[1] The powering and heating of buildings through fossil fuels serves as the primary source of emissions.[2] However, these rates only take into account the amount of CO_2 produced as a result of operating a building; if one were to track the indirect energy usage needed to manufacture and demolish a structure, the carbon emission rates would be nearly 15% greater.[3] Chicago, in particular, attributes roughly 70% of their carbon emissions to building operations.[4] Targeting energy efficiency as one of the key areas of carbon reduction is vital in the face of climate change. As the world population becomes increasingly urbanized, with a projection of 70% of the global population moving into urban areas by 2050[5], prioritizing building energy efficiency becomes a necessity. An increasing population results in an increased demand for infrastructure, such as commercial and residential buildings. Ensuring sustainable and energy efficient infrastructure now will have far-reaching benefits for the future. Targeting this sector can help make significant strides in mitigating climate change, given the present large-scale energy usage.

While new development is anticipated as population increases, cities must also take a look at their existing building stock and evaluate their present usage and conditions. In Chicago,

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[1]"Buildings and Climate Change." U.S. Green Building Council. Accessed October 16, 2018. https://www.eesi.org/files/climate.pdf.
[2] Ibid.
[3] Yim, Stephen, S. Ng, M. Hossain, and James Wong. "Comprehensive Evaluation of Carbon Emissions for the Development of High-Rise Residential Building." *Buildings* 8, no. 11 (2018): 147. doi:10.3390/buildings8110147.
[4]"Energy Efficient Buildings." Energy Efficient Buildings. Accessed October 16, 2018. http://www.chicagoclimateaction.org/pages/buildings/12.php.
[5]"World's Population Increasingly Urban with More than Half Living in Urban Areas | UN DESA Department of Economic and Social Affairs." United Nations. July 10, 2014. Accessed October 16, 2018. http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html.

nearly 70% of the existing buildings are 50 years or older.[6] While older buildings constructed from wood masonry have a lifespan of about 120 years, new modernist buildings using reinforced concrete, steel and glass tend to have a much shorter lifespan of 60 years.[7] This paper seeks to address the question as to whether or not we should be focusing our development goals on historic preservation and retrofits, or on new sustainable design. While newly developed infrastructure may implement materials and design attributes that reduce carbon emissions and that are low-impact, the longevity of the building is an important attribute to take into account when considering the sustainable nature of a structure. Older buildings may not be as up to date in materials and efficiency, however the bulk of the structure already exists and will continue to exist for years to come, preventing the need for demolition. While older Chicago buildings may be reaching the end of their lifespan, placing an emphasis on restoration and making efforts to retrofit these structures can further extend their utility. We must ask, then, is it better to retrofit an older, historic structure? Or to replace these pre-existing buildings with newer and more energy efficient ones?

A new standard, created by the United States Green Building Council (USGBC), encouraged and evaluated environmentally friendly and sustainable buildings. "LEED, or Leadership in Energy and Environmental Design, is a green certification program for building design, construction, operations and maintenance".[8] LEED was launched in 2000, and has since

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[6] Census Bureau. "American Housing Survey (AHS) Table Creator." US Census Bureau. Accessed October 16, 2018. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html#?s_areas=a16980&s_year=m2017&s_tableName=Table0&s_byGroup1=a4&s_byGroup2=a1&s_filterGroup1=t1&s_filterGroup2=g1&s_show=S.

[7] O'Connor, Jennifer. *Survey on Actual Service Lives for North American Buildings*. Canadian Wood Council. October 2004. Accessed October 16, 2018. http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf.
Presented at Woodframe Housing Durability and Disaster Issues conference, Las Vegas, October 2004

[8] "Better Buildings Are Our Legacy." About USGBC. Accessed October 16, 2018. https://new.usgbc.org/about.

become the primary standard for energy efficient and sustainably designed infrastructure. While not required for all construction, many cities and lawmakers have created policy and incentives using the LEED standard rating system. As of 2009, the state of Illinois requires all newly constructed or renovated state-owned or state-funded buildings to have at least a silver LEED certification.[9] State legislature is thus capable of making a market for sustainable design and green buildings. Though they may not be able to mandate the private sector in the same way, promoting this standard of environmentally conscious infrastructure can impact future constructions and incentivize companies to adopt a similar practice and mindset.

Similar to LEED certification, ENERGY STAR is an energy efficiency certification backed by the U.S. Environmental Protection Agency (EPA). Since 1992, ENERGY STAR has provided certified energy efficient products to consumers, as well as helped "measure and track the energy performance of hundreds of thousands of commercial buildings across the nation."[10] In order to be certified as an ENERGY STAR structure, a building must adhere to certain EPA energy performance standards. However, not all buildings that receive an ENERGY STAR rating are ENERGY STAR certified. A certification is similar to LEED in that indicates a certain efficiency level. In fact, to be ENERGY STAR certified, a building must have a rating of 75 or higher, meaning that it performs better than at least 75 percent of buildings of similar type and size nationwide. The rating system is based on a ratio and percentile calculation ranging from 0 to 100. Each year certifications are administered by a verified third-party, and due to their percentile calculation, certification status can change annually. This forces buildings to keep up

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[9] "Executive Branch | (20 ILCS 3130/) Green Buildings Act." Illinois Compiled Statutes. July 24, 2009. Accessed October 16, 2018. http://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=3109&ChapterID=5.
[10] "About ENERGY STAR." ENERGY STAR OVERVIEW. Accessed April 10, 2019. https://www.energystar.gov/about?s=footer.

their energy performance each year to continually be recognized for certification. Therefore, a building of any age can be considered ENERGY STAR certified, so long as it continuously remains up to date in terms of its energy performance.

This paper aims to evaluate the resiliency and environmentally friendly nature of historic preservation and sustainable development by surveying the office building stock within the city of Chicago. Through an evaluation of the operational energy consumption post-development, this paper will address the relation of each building practice and their overall efficiency. Considering each building's ENERGY STAR rating as an indicator for sustainability and efficiency, this paper will model several variables to illustrate whether a relationship exists between the age of a structure and its building design, with respect to its energy efficiency. However, it must be noted that the operational energy is not the only aspect that contributes to a building's resilience; the materials and construction process that make up each structure's embodied energy also hold significance. The energy needed to demolish a building in order to replace it with a new one can also contribute to the energy life cycle of a structure. One must take a holistic approach when considering the efficiency of a building.

HISTORY

Cities are composed of immense networks and interconnected infrastructure. The dense nature of cities limits the need for expansion and promotes economic and environmental benefits. However, as population growth continues and more people migrate toward cities, we have to limit the urban sprawl and concentrate our developmental efforts to existing infrastructure. Presently, there is more disused land and unused space between buildings and industrial wastelands than there is land for new development.[11] Revitalizing these areas and repurposing them for our current needs can help mitigate our carbon footprint, all while increasing density and accommodating growth.

By evaluating commercial structures in urban environments like Chicago, a comparison can be made about the energy savings resulting from improved building efficiency for historic buildings versus newly developed structures. The aim of this thesis is to consider which method of development will best serve the growing population, as well the natural environment.

Historic Preservation

Historic preservation aims to protect and sustain history and culture through site specific structures. As such, the ultimate goal of preservationists is to maintain as many of the existing qualities of a structure as there once was. In some cases, this results in a tension between preservationists and new urbanists. Preservationists may be reluctant to add solar panels to the rooftop of a historic structure, limiting the possibility of greening an old building. However, there are ways in which a historic structure can be modified and improved to ensure energy efficient standards, all while keeping the historic design characteristics in tact. Weatherizing a building is a process by which one takes cost-effective strategies to retrofit the interior and exterior of a historic structure to improve energy.[12] For instance, patching cracks that may appear in the outer shell of a structure can prevent the infiltration of airflow within the building, or updating appliances and windows that mirror an original style can aid in reducing energy consumption. Energy retrofitting can improve a building and bring it up to code without having

[11] Schittich, Christian. Building in Existing Fabric : Refurbishment, Extensions, New Design. Birkhäuser, 2012.
[12] "Energy Efficiency in Historic Buildings-Technical Preservation Services, National Park Service." National Parks Service. Accessed November 15, 2018. https://www.nps.gov/tps/sustainability/energy-efficiency.htm.

to sacrifice the historical or architectural significance of a structure. A building should be both usable and functional for it to carry out its significance within society.

Carl Elefante, the former president of the American Institute of Architects (AIA), once said, “The greenest building is the one that is already built”.[13] Retrofitting historic structures is a great opportunity to reduce waste and reuse resources, while simultaneously revitalizing a community and preserving history.

Historic preservation can serve as a constructive method of increasing density and promoting resiliency and sustainability within the built environment. A study by the National Trust for Historic Preservation showed that areas with a mix of older and newer buildings have a higher population density than areas composed solely of newer buildings.[14] Additionally, historic commercial structures rank among the best in terms of energy consumption, with those built before 1920 using considerably less energy per square foot than those built 50 years later.[15] Buildings created before the 1920s have more energy conserving design features due to the lack of heating and cooling technology present at the time of construction.

Many structures were built for their environment, either to retain heat or provide cooling. In northern regions, houses had thick masonry walls to keep heat in and cool air out, along with smaller openings and compact ceilings. In the south, though, the building was intended to increase cooling, so high ceilings and large openings with porches were a staple for cross

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[13] Carl Elefante. “The Greenest Building Is...One That Is Already Built.” *Forum Journal* 27, no. 1 (2012): 67-72. https://muse.jhu.edu/ (accessed October 23, 2018).

[14] *Older, smaller, better: Measuring how the character of buildings and blocks influences urban vitality.* Washington, DC: National Trust for Historic Preservation. May 2014.

[15] "Energy Efficiency in Historic Buildings-Technical Preservation Services, National Park Service." National Parks Service. Accessed November 15, 2018. https://www.nps.gov/tps/sustainability/energy-efficiency.htm.

ventilation and air flow. The consideration of a building's regional location was a vital step towards the building's resiliency and efficiency.

Sustainable Design

Sustainability has many definitions, however one common attribute is to satisfy the needs of the present without compromising the needs of future generations. Sustainability has seen a resurgence in contemporary architecture with the daunting issue of climate change, however, sustainability can still apply to historic buildings. Historic structures are both resilient and sustainable; by remaining functional and significant throughout history, it was able to uphold the testament of satisfying both the needs of its respective generation and the one that exists today.

In the 1990s, more environmental advocacy groups began to sprout up over the country, including USGBC in 1994.[16] They created standards that emphasized reusable materials and improved energy efficiency. Similar to older structures, "green architecture" values sustainable site design, in which buildings are oriented in a way to maximize energy sources depending on their geographic location.[17] While this is still an objective of sustainable architecture, many contemporary buildings that employ these practices tend to be glass encased structures. With the primary materials of choice tending to be glass and metals, like steel, buildings ultimately end up with far shorter lifespans than the wood and brick buildings of the 19th and 20th centuries. Though they may be sourced from recycled materials and local areas, sustainable buildings must also be resilient in the face of time and climate change. A structure that exists for 50 years only

[16] "Better Buildings Are Our Legacy." About USGBC. Accessed October 16, 2018. https://new.usgbc.org/about.
[17] Wines, James. "Green Architecture." Encyclopædia Britannica. December 13, 2018. Accessed December 14, 2018. https://www.britannica.com/art/green-architecture.

to be demolished is contributing to climate change regardless of its high efficiency operational energy.

Throughout this thesis, when referencing green buildings, it is an indication for LEED certified buildings that were built with the intention of being sustainably designed from construction. These buildings have a sustainable mindset and focus on their interaction with the environment, however they are all newly built and composed of a different set of materials and resources. These buildings are constructed with the intent of minimizing their environmental footprint and being resource-efficient throughout the entirety of their lifespan.

Certification systems have been developed within the late 20th century to encourage architects and developers to be more sustainably minded and continue to push the limits of efficiency and positive impacts on the environment. With LEED certification, a different rubric exists for different types of buildings, ensuring that the measurements are best adapted to the functionality and purpose of the structure. The rubric takes into account issues from water efficiency, to site location, to interior lighting.[18] Certain benchmarks are required, such as reaching the minimum energy performance or minimum indoor air quality performance, while others are additional points like encouraging biking or using green vehicles to get to work.[19] The reference guides continue to update as standards change and technology improves, illustrating how LEED promotes progress. In a similar fashion, ENERGY STAR also encourages improvement by reevaluating building rankings each year with the present building stock. These certification standards promote efficiency and growth by forcing building owners to continually

[18] Checklist: LEED v4 for Building Design and Construction. April 5, 2016. Raw data. Project teams can use these LEED v4 checklists to track their project goals and progress
[19] Ibid.

check up on energy standards and maintain efficient performance levels. These certification standards, while generally optional, promote a market for green infrastructure.

Case Studies

In an attempt to better understand the energy usage of a retrofit historic structure and LEED building, this paper will examine the energy efficiency of the historic Monadnock building and newly built, LEED certified USG Headquarters in downtown Chicago when interpreting the statistical results. Through this contextual analysis, one can see how these sustainable building practices come to fruition and impact the structure's energy usage.

Using the Monadnock building as a case-study will help contextualize the general historic office building stock in Chicago through a deeper analysis and example statistics and figures. The Monadnock building is a representative figure due to its historic significance in Chicago, and its impressive and extensive retrofitting. The building was originally designed in the 19th century, undergoing two different phases of construction, and was ultimately completed in 1893.[20] Currently, it boasts a 99 ENERGY STAR rating, and has a LEED Gold certification.[21] While a great deal of the energy efficiency can be attributed to the retrofitted steam-system, a great amount of energy is also saved simply by the original design features, such as operable windows

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[20] "Monadnock Building." Chicago Architecture Center - CAC. Accessed November 15, 2018. http://www.architecture.org/learn/resources/buildings-of-chicago/building/monadnock-building.

[21] Chicago Data Portal. Chicago Energy Benchmarking - 2016 Data Reported in 2017. February 8, 2018. Raw data. Chicago.

and thick masonry walls.[22] Analyzing the energy savings for the Monadnock building will illustrate the implications of retrofitting historic buildings and improving their energy efficiency.

In addition to the Monadnock building, this paper will be taking a closer look at a new, LEED office building in Chicago. The USG Building in Chicago will represent the newer green buildings in the case-study analysis of energy performance amongst green buildings and historic structures. The new USG Headquarters building was constructed in 2006 and has an 85 ENERGY STAR rating, and sought out a LEED Gold certification.[23,24] Comprised of 18 stories, the USG HQ is made of new steel and glass and has achieved a 30% energy reduction from their former building.[25] USG, a company that prides itself on its sustainability commitment, used some of its own products to achieve their green ratings. Many products are high in recycled content and low in embodied energy, thereby reducing emissions even more.[26] Through an analysis of the new building's total energy consumption, this paper will be able to compare the 2006 green building with the 1890 historic, retrofitted building.

Building Energy

A great deal has to be considered when evaluating a building's net energy consumption. Not only is the lifespan important in terms of calculating the duration of energy usage, but one

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[22] Unger, David J. "Chicago Sees Progress, Challenges in Early Years of Energy Efficiency Benchmarking." Energy News Network. March 23, 2017. Accessed December 15, 2018. https://energynews.us/2017/03/16/midwest/chicago-sees-progress-challenges-in-early-years-of-energy-efficiency-benchmarking/.

[23] Chicago Data Portal. Chicago Energy Benchmarking - 2016 Data Reported in 2017. February 8, 2018. Raw data. Chicago.

[24] "USG Corporate Headquarters Project Profile." USG. Accessed December 15, 2018. https://www.usg.com/content/usgcom/en/inspiration-center/project-gallery/usg-corporate-headquarters.html.

[25] Schneider, Jay W. "USG Headquarters Ingrained in Green." Building Design Construction. October 01, 2007. Accessed December 15, 2018. https://www.bdcnetwork.com/usg-headquarters-ingrained-green.

[26] Ibid.

should also consider the embodied and operational energy of a structure. Operational energy is the conventional understanding of how a building consumes energy and releases emissions. Operational energy can be defined as the energy needed to sustain a building and keep it functional.[27] This may result from the lighting fixtures or heating and cooling systems within the structure. Embodied energy, on the other hand, is the energy consumed in the processes of constructing a building.[28] This includes anything from the mining of natural resources, to machinery used to create the building's frame, to the delivery of products used for final touches. Embodied energy is often forgotten when considering how sustainable and energy efficient a building is. Together, embodied and operational energy make up the total energy used throughout a building's life cycle.[29]

Existing Research and Policy

In 2013, Mayor Rahm Emanuel adopted an energy benchmarking ordinance to increase transparency and encourage best practices and saving opportunities for businesses and residents throughout Chicago.[30] Since the ordinance, roughly 88% of Chicago's large buildings have reported their building energy usage, with over 1,000 buildings voluntarily benchmarking.[31] While reporting energy usage has impacts such as cost savings and energy reductions for building operators, the transparency that reporting provides also helps the public analyze best

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[27] Hossain, Adnan, and Monjur Mourshed. "Retrofitting Buildings: Embodied & Operational Energy Use in English Housing Stock." *Proceedings* 2, no. 15 (2018): 1135. doi:10.3390/proceedings2151135.
[28] Ibid.
[29] Ibid.
[30] Chicago Data Portal. Chicago Energy Benchmarking - 2016 Data Reported in 2017. February 8, 2018. Raw data. Chicago.
[31] Mayor's Office. *2018 Chicago Energy Benchmarking Report*. Chicago, IL, 2019.
The City of Chicago released an infographic on their @SustainChicago account in which they noted successful statistics regarding the program.

practices moving forward. Measuring a building's energy output allows a building operator to understand where inefficiencies may lie and where there is room for improvement. Without this knowledge, and an understanding of the general commercial building sector energy performance, there would be a lack of improvements in energy usage and reductions in costs. This paper will test the hypothesis that older, retrofit buildings would perform equally as well as LEED certified buildings with respect to their ENERGY STAR rating. Furthermore, it will hypothesizes that older, historic structures will not be energy efficient unless controlled for retrofits, meanwhile predicting that newer buildings are more likely to be LEED certified.

The retrofit variable is compiled, in part, by the Retrofit Challenge. Originating in 2012, buildings signed on to the challenge agree to reduce their operational energy usage by 20% within 5 years. Despite the Retrofit Chicago Energy Challenge being limited in scope, it still boasts a list of 76 participants, of which have accrued an annual savings of 90 million kWh of electricity and 70,000 metric tonnes of avoided GHG emissions.[32] These buildings exemplify what it means to retrofit a building and not only save energy, but money as well.

The City of Chicago also conducted a Chicago Historic Resource Survey (CHRS) in 1995 to collect and review the historical and architectural importance of buildings constructed prior to 1940. This database identified each of the buildings' architects, date of construction, architectural style and placed them on a color-ranking system. Using data from CHRS, along with information regarding current operational energy usage found on the City of Chicago Data

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[32] C40 Cities. "Urban Efficiency II: Innovative City Programmes for Existing Building Energy Efficiency." *Issuu*, February 16, 2017.

Portal, this paper will evaluate historic building's energy usage compared to new LEED certified buildings over their respective life cycles.

LITERATURE REVIEW

This project sits at the intersection of three significant bodies of thought revolving around historic preservation and sustainable design, types of building energy, and sourcing of building materials, respectively. However, it is unclear as to how historic preservation and sustainable design compare in terms of their overall building energy, given original and recycled materials.

While it is feasible to bring historic buildings up to code in terms of energy efficiency, a tension lies between interior standards for rehabilitation and mandated energy ordinances. Oftentimes states provide exemption forms for historic buildings in the case that adhering to the energy code would have adverse effects on the historic resource.[33] It was only around the late 1970s that a connection was made between preservation and energy savings.[34] Baird Smith from the National Park Service published a report in which he noted that buildings constructed prior to WWII have a tendency to use less energy than newer buildings.[35] Smith identified heat, light and ventilation as the major sources of energy consumption within a building, noting that older structures self-regulated these systems more efficiently than new constructions.[36]

A year later, another study was released by the Advisory Council on Historic Preservation, defining the term "embodied energy," and calculating the amount present within

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[33] United States. State of Vermont. Division for Historic Preservation. *2015 Vermont Energy Code - Historic Buildings Exemption Report*.
[34] Wagner, Richard. "Finding a Seat at the Table: Preservation and Sustainability." In *Sustainability & Historic Preservation: Toward a Holistic View*. University of Delaware, 2011.
[35] Ibid.
[36] Ibid.

existing buildings. Embodied energy is considered to be the "amount of energy required to process and put materials of construction in place. Embodied energy...is not recoverable."[37] As such, preserving a building saves energy by not wasting the embodied energy of a structure and using additional energy to create a new building. The Advisory Council on Historic Preservation devised formulas to calculate the amount of energy (in BTU) needed to restore and rehabilitate existing buildings versus the amount of energy needed to demolish and replace structures with similar ones. Through several case-studies, the Advisory concluded that an existing building would have a net energy advantage over equivalent new structures. For example, the Grand Central Arcade in Seattle, Washington, would take roughly 250 years before the energy investment of a new structure would be equivalent to that of the existing Grand Central Arcade.[38]

Other studies, like Avrami, show however, that embodied energy is only a small portion of the energy used throughout the lifecycle of a building. Though historical buildings may reduce energy consumption as a result of accounting for embodied energy, the operational energy, or energy used to run and maintain a building, far exceeds that of which is used for construction.[39] Buildings tend to have rather long lifespans, meaning that 80% of the energy considered in the life cycle of a structure results from operating it.[40] Avrami finds fault with the Advisory Council's method due to the inaccuracy and variability in quantifying embodied energy data.

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[37] Advisory Council on Historic Preservation. "Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples." *Bulletin of the Association for Preservation Technology* 12, no. 4 (January 1979): 116. doi:10.2307/1493825.
[38] Ibid.
[39] Avrami, Erica. "Making Historic Preservation Sustainable." *Journal of the American Planning Association* 82, no. 2 (January 28, 2016): 104-12. Accessed November 13, 2018. doi:https://doi-org.proxy.uchicago.edu/10.1080/01944363.2015.1126196.
[40] Ibid.

Instead, Avrami suggests placing an emphasis on operational energy, which is a recurring expense that can be accounted for much more simply.

While energy standards have improved significantly to ensure a reduction in operational energy, Avrami argues that historic buildings must also comply with these policies.[41] Creating more inclusive energy standards and encouraging a market for greener buildings can alter the mindset of preservationists and realign their goals with sustainability. A growing number of preservation groups are already beginning to promote greener methods of development and restoration to account for the increased population growth and environmental concerns. Avrami argues for more conclusive and complete data regarding historic preservation's role in sustainability and the benefits it provides to society, the economy and environment at large.[42]

Unlike Avrami, Dixit et al. suggest that energy reduction should focus on embodied energy.[43] While Dixit agrees that operational energy is more clearly defined and calculated, it is already an area that is making great strides in energy efficiency. Embodied energy, on the other hand, is not as consistent of a measure, however it is still considered to be a large, upfront contributor of energy consumption in a building's lifespan. Both Avrami and Dixit et al. point out the need for a standardized approach to calculating and collecting data on embodied energy as an additional step to reducing energy. Without concrete data it is difficult to determine which type of energy has a more significant impact on reducing a building's energy efficiency. Both forms of energy, operational and embodied, are crucial to understanding the impact of a building's existence on the environment from its creation to its demolition.

[41] Ibid.
[42] Ibid.
[43] Dixit, Manish Kumar, José L. Fernández-Solís, Sarel Lavy, and Charles H. Culp. "Identification of Parameters for Embodied Energy Measurement: A Literature Review." *Energy and Buildings* 42, no. 8 (August 2010): 1238-247. Accessed November 13, 2018. doi:10.1016/j.enbuild.2010.02.016.

Avrami's argument for an emphasis on operational energy is substantiated by the fact that more newly constructed buildings are minimizing their carbon footprint when sourcing materials. While a building's embodied energy does play a crucial amount in a structure's overall energy efficiency, it is quite difficult to assess the energy used to source materials from centuries ago. In this present moment, what is most impactful for these buildings is how they operate and use energy today. It should be noted that new LEED certified buildings are becoming more conscious of their material sourcing and extraction. As a result, these new buildings are reducing their overall embodied energy, despite being a new construction on a preexisting site. While demolishing an existing building to replace it with a new LEED certified building may not be the most environmentally-conscious decision, the new structure's emphasis on sourcing construction materials from sustainable and renewable methods can help mitigate the overall impact of the building's embodied energy, while simultaneously being more energy efficient in terms of its operation. Through an analysis of various models, this paper will test which method of design, if any, is most efficient in Chicago's building stock.

Retrofitting existing buildings is also becoming a more popular trend for redevelopment as a result of increased demand for urban living. A greater amount of existing commercial buildings are being repurposed and reused to revitalize communities and accommodate growth.[44] An estimated 26% of U.S. commercial buildings were constructed prior to 1960.[45] Many city landmark policies use a threshold of 50 years old for designation status, indicating that a quarter of the US building stock could be considered eligible as historic structures. Furthermore, the

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[44] Andrews, Clinton J., David Hattis, David Listokin, Jennifer A. Senick, Gabriel B. Sherman, and Jennifer Souder. "Energy-Efficient Reuse of Existing Commercial Buildings." *Journal of the American Planning Association*, 2nd ser., 82 (February 11, 2016): 113-33. Accessed November 13, 2018. doi:https://doi-org.proxy.uchicago.edu/10.1080/01944363.2015.1134275.
[45] Ibid.

American Institute of Architects estimates that nearly 75% of the existing public building stock will need renovations by 2030.[46] Enforcing policies that promote reuse and redevelopment can make significant impacts on the overall energy consumption within the United States by simply improving the energy efficiency of these structures.

The United Nations conducted a case-study analysis of their headquarters in New York to evaluate whether it was better to retrofit the structure or demolish it and create a new building in its place. The study concluded that there was a 35-70 year "break-even" point at which the carbon reduction will be realized.[47] Using a life cycle assessment software, the UN was able to estimate the embodied energy contained within their headquarters and resulting carbon emissions.[48] Through a simple ratio of operational energy to embodied energy, the report determined it would take 1.37 years for embodied energy to equal operational energy.[49] However, when taking into account the avoided impacts of demolishing a structure, based on CO2e, a 10% improvement in efficiency for a new structure was estimated to take 35 years for the CO2e emissions to be recouped.[50] The report ultimately suggests that mid-to-high-rise commercial structures made of concrete and steel emit between 40-45 pounds of CO2e/GSF for every 3-5 years of building operations.[51] Thus, the UN proposed to renovate their headquarters

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[46] Pfaehler, Gretchen K. "Demolish or Renovate? Embodied Energy Measurements Can Help You Decide." Buildings. October 01, 2008. Accessed April 11, 2019. https://www.buildings.com/article-details/articleid/6585/title/demolish-or-renovate-embodied-energy-measurements-can-help-you-decide.

[47] United States. United Nations. The United Nations Capital Master Plan. By Michael Adlerstein. United Nations, 2007-2015. December 6, 2016. http://www.vidaris.com/uploads/files/assessing-the-carbon-saving-value-of-retrofitting-versus-demolition-and-new-construction-at-the-united-nations-headquarters-199.pdf.

[48] Ibid.

[49] Ibid.

[50] Ibid.

[51] Ibid.

over constructing a new building, given that the proposed operational energy was nearly the same, and embodied energy was ultimately saved.

While this study provided key insight about the amount of time needed to recoup the carbon emissions via building operations, the scope of the project was limited to one building. Each structure should undergo a careful analysis of carbon emissions before reaching a decision on retrofitting versus new construction. The embodied energy is contingent upon the sourcing of materials, and in some cases a building may have originally been poorly designed. For instance, the UN headquarters was built in 1952 and didn't undergo renovations until 2007, whereas the Aon Center in downtown Chicago was constructed in 1973 and required significant exterior renovations in 1992.[52,53] The original material for the Aon Center could not withstand Chicago's natural environment, resulting in cracks and an $80 million exterior renovation. The embodied energy for the, at the time, 20-year-old structure was quite high, and generally unsustainable. The original facade was covered in Carrara marble, from the Carrara Mountains in Italy, resulting in high embodied energy given the extraction and shipping of the materials.[54] In such a scenario, a more efficient structure may have been more suitable as a replacement rather than sourcing a new facade of granite from North Carolina.[55] The building is expected to undergo yet another renovation project in the coming years with glass enclosed elevators and observatory decks.[56] As

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[52] Ibid
[53] "Aon Center." Chicago Architecture Center - CAC. Accessed April 11, 2019. http://www.architecture.org/learn/resources/buildings-of-chicago/building/aon-center/.
[54] Arndt, Michael. "AMOCO CHUCKS ALL THE MARBLE ON ITS TOWER." Chicagotribune.com. September 03, 2018. Accessed April 12, 2019. https://www.chicagotribune.com/news/ct-xpm-1989-03-07-8903240963-story.html.
[55] Ibid.
[56] Ori, Ryan. "Aon Center Observatory, Redevelopments at Uptown and Congress Theaters Win Plan Commission Approval." Chicagotribune.com. December 21, 2018. Accessed April 12, 2019. https://www.chicagotribune.com/business/columnists/ori/ct-biz-plan-commission-entertainment-venues-ryan-ori-20181220-story.html.

the building continues to undergo renovations and additions, the structure continues to increase embodied energy, which ultimately could have been avoided if carefully planned and designed with the original intention of being sustainable.

Material sourcing is a vital factor in considering a building's total energy usage, regardless of whether it is a renovation or new construction. In a Swiss pilot program, the Swiss Federal Office of Energy (SFOE) evaluated the performance and capability of installing a highly efficient insulation material into older buildings. Through in-situ measurements, like hot plate tests and infrared technology, the SFOE was able to test and determine that thin layers of insulation materials that don't change the overall appearance of a structure can still improve a building's energy performance.[57] While this method is both efficient and beneficial to the structure, the difference in material cost of conventional insulation materials compared to the type used for the retrofit is 1:7.[58] This is a distinctive difference in upfront costs that developers must consider when making their decisions about materials. However, costs can be reduced by applying thinner layers of insulation that are still at a high performance level.

In another study conducted by Hossain in England, researchers evaluated both the embodied and operational energy used for seven common insulating materials within the British housing stock.[59] Ultimately it was decided that EPS, sheep wool and mineral wool were the optimal insulants for a variety of walls and pitch roofs.[60] A variety of sustainable materials exist

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[57] Wakili, K. Ghazi, B. Binder, M. Zimmermann, and Ch. Tanner. "Efficiency Verification of a Combination of High Performance and Conventional Insulation Layers in Retrofitting a 130-year Old Building." *Energy and Buildings* 82 (October 2014): 237-42. Accessed November 13, 2018. doi:10.1016/j.enbuild.2014.06.050.
[58] Ibid.
[59] Hossain, Adnan, and Monjur Mourshed. "Retrofitting Buildings: Embodied & Operational Energy Use in English Housing Stock." *Proceedings* 2, no. 15 (August 23, 2018): 1135. Accessed November 13, 2018. doi:10.3390/proceedings2151135.
[60] Ibid.

for a developer to choose from, allowing flexibility while still promoting reduced embodied energy.

While these methods are proven to increase building efficiency and reduce overall carbon emissions, a cost-benefit analysis must still be considered to evaluate whether or not retrofitting existing buildings is worth the cost of renovations. Almeida et al. conducted six case studies in Europe to see whether embodied energy and carbon emissions are relevant when considering the cost effectiveness of a building renovation.[61] Their study found that embodied energy and embodied carbon emissions don't affect the cost-effectiveness of solutions. However, when the target is a high cost, the embodied aspects are more influential and relevant to the findings.

A great deal of debate exists with regard to evaluating the energy usage of a building and whether or not a retrofit is cost-effective. This paper aims to uncover how different architectural practices, such as retrofitting or sustainable design, impact the structure's overall energy efficiency. This paper will examine the relationship of an older building and its energy efficiency, while controlling for whether or not it has been retrofit, and compare the outcome with the relationship of a new LEED certified building and its energy performance. In these models, historical buildings are used to indicate an emphasis on embodied energy, whereas LEED certified buildings, and those that have been retrofit, may suggest a more efficient operational energy usage. Depending on which type of building has a higher ENERGY STAR rating, one can attempt to deduce whether focusing on embodied or operational energy is most efficient for an office building. By better understanding the areas of overall energy consumption, one can strategically focus reductions on high impact areas and lower total building emissions.

[61] Almeida, Manuela, Marco Ferreira, and Ricardo Barbosa. "Relevance of Embodied Energy and Carbon Emissions on Assessing Cost Effectiveness in Building Renovation—Contribution from the Analysis of Case Studies in Six European Countries." *Buildings* 8, no. 8 (2018): 103. doi:10.3390/buildings8080103.

DATA & METHODOLOGY

This project is an analysis of Chicago's building energy efficiency between older, retrofit buildings and newly designed green buildings. The building energy data is taken from the publically available City of Chicago Data Portal. The energy benchmarking data includes information like the building address, square footage, energy performance score, energy use intensity (EUI), and annual greenhouse gas emissions.[62] The following sections provide an overview of the data sets assessed and models put forth to understand the relationship of building age, style and energy performance.

The data set used for this paper consists solely of office buildings in Chicago, in an attempt to control for different building functions and operational settings. In order to compare buildings fairly across Chicago, the data needs to account for confounding variables and discrepancies between building types. The data consists of 320 buildings across a time period of over 100 years (Figure 1). Office buildings were chosen for this research due to the fact that they are the second most prevalent building type in the data set, and they are often operated around similar hours. Whereas, multifamily residential units may have far more discrepancies in terms of energy usage and operation throughout the day.

[62] United States. City of Chicago. City Clerk. Amendment of Municipal Code Chapter 18-14 regarding Energy Benchmarking and Implementation of Energy Performance Rating System.

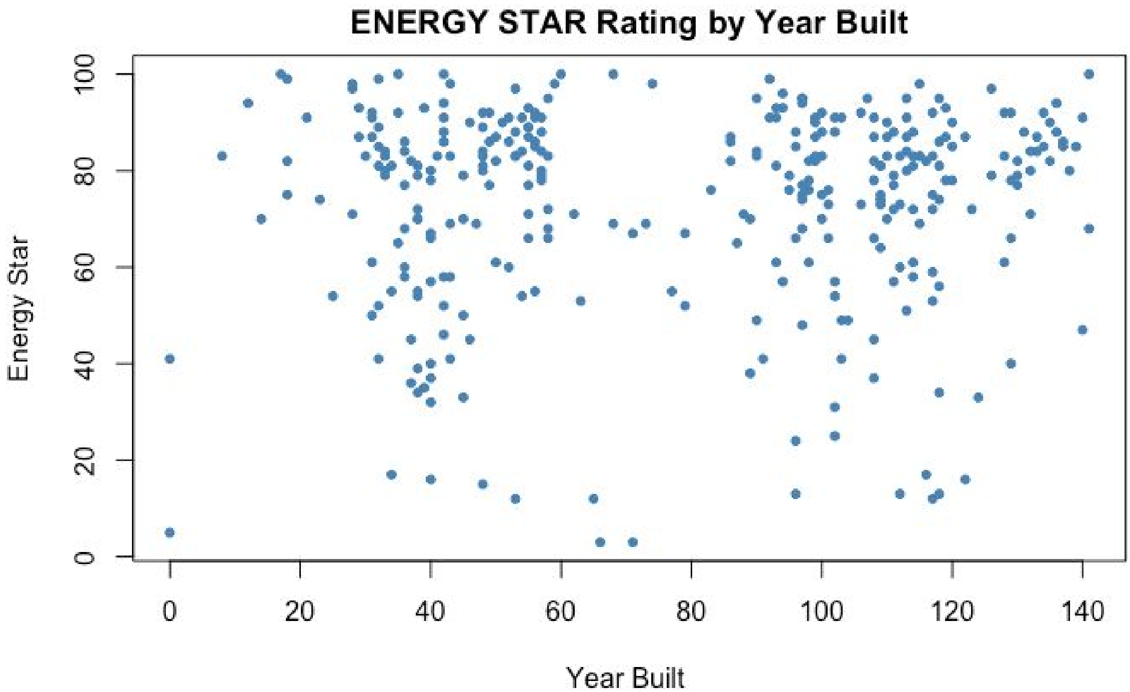

Figure 1. The scatterplot above depicts all 320 buildings based on their year of construction and ENERGY STAR rating in 2016. There appear to be two clusters of buildings with high ratings, with a gap in building construction during the late 1930s to the 1960s, likely as a result of World War II.

In addition to the provided variables from the Chicago Data Portal, factors such as LEED certification and historic status have been added to the overall data set. This paper uses the Chicago Historic Resources Survey (CHRS) from 1995, to cross-list office buildings from the original data set with those deemed as historic by the CHRS. The CHRS assessed all Chicago buildings and encoded them on a color ranking system with "Red" being most historically significant, to "Blue" being buildings built post-1940 and too new to be deemed historical.[63] This survey identified 17,371 buildings as having some historical or architectural significance, though only 50 buildings were cross-listed with the initial data set, all of which were built prior to 1940 (Figure 2).[64] It is recognized that this provides a limited scope due to the outdated CHRS,

[63] "Chicago Historic Resources Survey." Chicago Landmarks - Historic Resources. Accessed March 20, 2019. https://webapps.cityofchicago.org/landmarksweb/web/historicsurvey.htm

[64] Ibid.

however, for the purpose of this analysis, this project will proceed with the 50 designated structures.

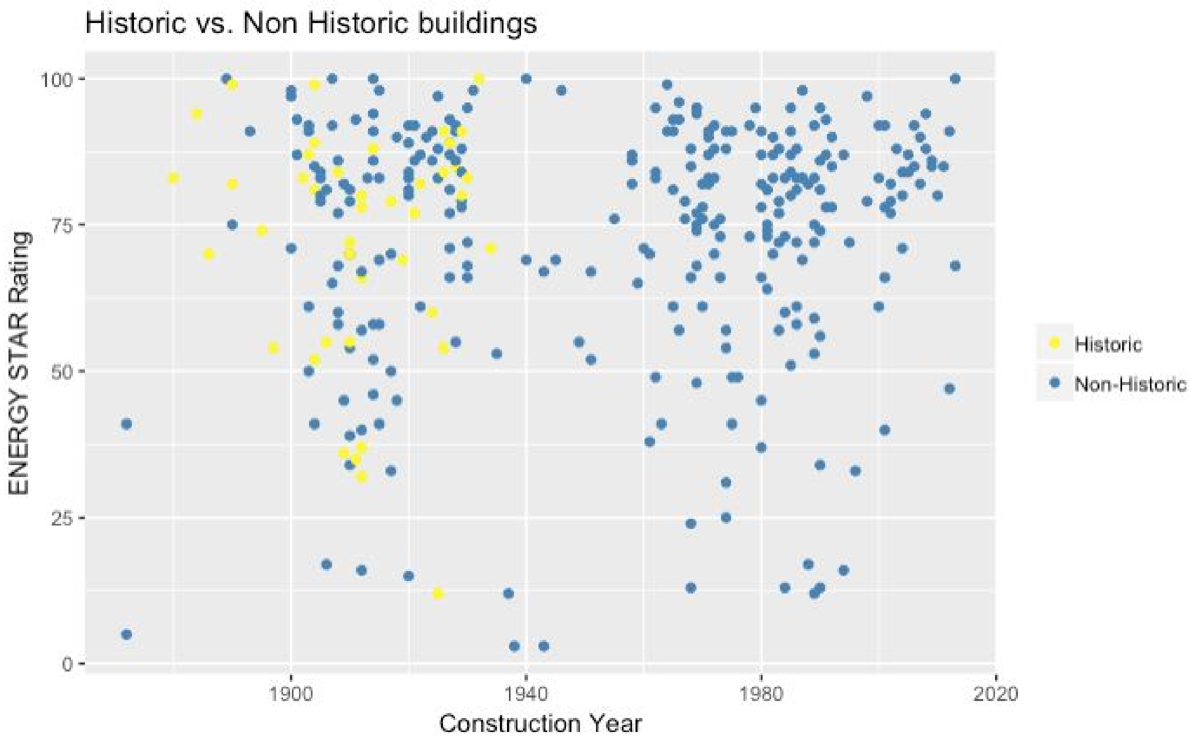

Figure 2. The scatterplot above depicts all the buildings in the data set by the year of construction and their ENERGY STAR rating, however it indicates which buildings are recognized as historic from the CHRS. The yellow indicates a historic structure, all of which appear before 1940.

In addition to the CHRS, data has also been collected from the USGBC site, which lists nearly 100,000 LEED certified buildings on their database. Each of the 320 buildings are coded as either having a LEED certification or not (Figure 3). Furthermore, buildings are identified as being retrofit if they have been recognized as undergoing renovations, or are one of the 76 structures signed on to the Chicago Retrofit Challenge. To be considered recognized for renovations, the building website has to note building updates or has to be documented on the Chicago Building Permit and Inspection Record for significant changes. Ultimately 87.8% of the office buildings have underwent some form of renovation or retrofit since its completion.

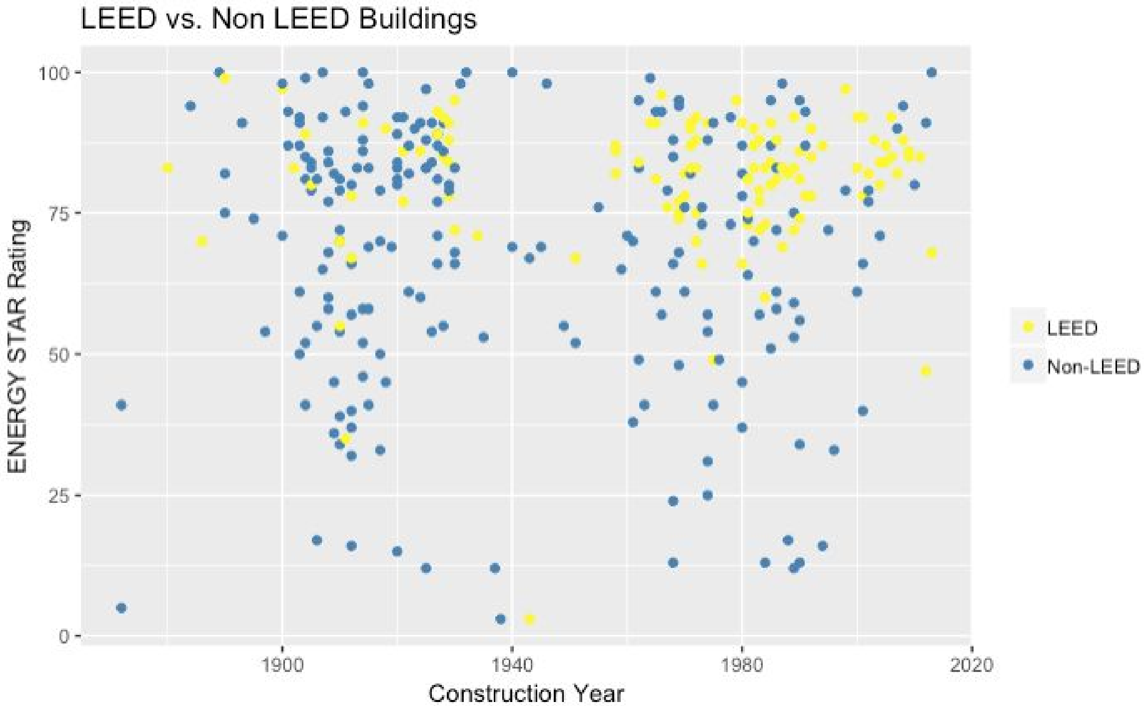

Figure 3. The scatterplot above depicts all the buildings in the data set by the year of construction and their ENERGY STAR rating, however it indicates which buildings are recognized as LEED. The yellow plots indicates a LEED certified structure.

These columns added to the original data set served as a way to compare historic, older buildings with LEED certified buildings when it came to their ENERGY STAR rating and EUI output. ENERGY STAR ratings have already been assigned to the buildings via the Chicago Data Portal and are a standardized way of assessing buildings of comparable function. This assessment takes into account the climate, weather, and business activities related to the building. [65] Given this, ENERGY STAR rating served best as the response variable in the following models. The original data set was ultimately narrowed to 320 after eliminating all buildings for which an ENERGY STAR rating was not provided, of which there were only 26. ENERGY STAR uses a percentile performance ranking between 1-100, with 100 being the best relative to

[65] ENERGY STAR. "ENERGY STAR Score for Offices in the United States." ENERGY STAR Score for Offices. August 2018. Accessed March 20, 2019. ENERGY STAR Score for Offices in the United States.

the national population. The remaining buildings in the data set had a rating spanning from 3 to 100, denoting a wide variety of building performance standards.

ENERGY STAR scores are calculated in a standardized way, using the Department of Energy, Energy Information Administration's 2012 Commercial Building Energy Consumption Survey (CBECS) as reference.[66] The scores are updated periodically as annual energy usage data is collected. ENERGY STAR runs a regression to predict the EUI based on the building's operational characteristics. The ratio of the actual and predicted source EUI results in an energy efficiency ratio that is ordered from lowest to highest to assess the percentile rating.

With the additional variables, similar regressions were ran to better understand the impact of being an older, historically identified building on a building's energy performance, compared to a newly constructed building that has a LEED certification. While a longitudinal study may have resulted in an ongoing trend throughout the buildings, the Data Portal data sets only date back to 2014, and the most recent benchmarking data will still provide an understanding of the existing conditions in Chicago's current building stock. The models below test a relationship between a building's age and energy efficiency.

The programming system R was used to run the following regressions. Below is a table breaking down the variables in the models and their meaning in the context of this analysis.

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[66] Ibid.

Symbol	Name	Description	Descriptive Statistics
Y	ENERGY STAR rating	The response variable is a measure of the building's ENERGY STAR rating, which is a holistic and comparative rating system of building energy efficiency	Min: 3 Mean: 72.96 Max: 100
X_1	Square footage	The square footage of each office building in the data set; controls energy usage per size of structure	Min: 50,000 Mean: 482,325 Max: 4,518,811
X_2	Energy Use Intensity (EUI)	The source EUI of a building, otherwise known as the operational energy of the structure; lower EUI indicates higher energy efficiency	Min: 28.8 Mean: 199.2 Max: 544.5
X_3	Year	The year a structure was built	Min: 1872 Mean: 1951 Max: 2013
X_4	Historic	Indicator variable for whether or not a building is considered historic (Red/Orange/Yellow) via the CHRS	Min: 0 Mean: 0.134 Max: 1
X_5	Retrofit	Indicator variable for whether or not a building has underwent some degree of retrofit or renovation to improve energy efficiency since original construction	Min: 0 Mean: 0.878 Max: 1
X_6	LEED	Indicator variable for whether or not a building has received a LEED certification upon or since building construction	Min: 0 Mean: 0.353 Max: 1

Through forward selecting procedures and model comparisons, buildings were analyzed based on the different effects of the above variables and the overall ENERGY STAR rating. From this data analysis, this project was able to assess the Chicago office building stock and take note of any significant relations found. Each model controlled for the building's square footage and EUI to be sure that each rating justly takes into account each structure's size and energy usage. Age was also included into every model to see if the year a building was constructed had any impact on the response variable.

Historic Building Model

Multiple models assess the significance of being a historic building in relation to the ENERGY STAR rating. The initial model tests the historic nature of a building,

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon \quad (1)$$

where Y is the expected ENERGY STAR rating using the controls listed above, X_1, X_2, X_3, and an indicator variable, X_4, to signify if a building is historic or not. Building off of this model, this thesis evaluates the expected energy performance using the indicator variables retrofit and historic, along with an interaction term between the retrofit and historic variables.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_7 X_4 \cdot X_5 + \varepsilon \quad (2)$$

Model 2 tested if historically retrofit buildings had any significant relationship with the ENERGY STAR rating, while considering any interaction effect between a building being historic and retrofit.

LEED Certified Model

The following models analyze the relation of LEED certified buildings and their ENERGY STAR output. This thesis had hypothesized that the two variables would be positively correlated, with LEED certification being a strong indicator of a high ENERGY STAR score. Similar to the historic building model, multiple models were run in a stepwise fashion to see if controlling for any variables or attaching interaction terms had any influence in the model. As such, the first model ran for this analysis predicted the energy usage based on the same three controlling variables in previous models, X_1, X_2, X_3, with the indicator variable, X_6. Given the assumption that newer buildings would be more likely to participate in the certification process than older constructions, another model was created to test if there were any significant interaction between a building's age and LEED certification,.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_6 X_6 + \beta_8 X_3 \cdot X_6 + \varepsilon \qquad (3)$$

Complete Model

Finally, a full model was tested which included all the variables and reasonable interaction effects. This model included 6 parameters in total, with interaction effects between year and historic status, year and LEED status, retrofit with historic status, and retrofit with LEED status. This was intended to control for retrofitting a structure, and the impact year of construction might have on a building's energy output. This model was created in an attempt to isolate the variables relating to historic nature and LEED certification so a comparison could be made between the two and their relation to their energy performance.

RESULTS AND DISCUSSION

Through these models, one can see the relationship between historic status, LEED certification and retrofitting on the building's overall energy efficiency. In addition to these variables, it should be noted that the square footage and EUI are consistently significant in all the models (Table 1). The estimates are essentially the same in every model, which is expected given that the ENERGY STAR Portfolio Manager states that ratings take into account a building's size and source energy usage. The results indicate that, despite using separate data in these regressions, these variables are in fact vital in calculating the overall ENERGY STAR rating.

Interestingly, the variable year was found to be significant in all models except model 7. A shift occurred when adding the interaction effect between LEED status and year. In this scenario, the variable year was no longer statistically significant, however the interaction effect was. Such a result would suggest that the year alone does not predict a building's ENERGY STAR rating, but rather, the year built has a statistically significant association with ENERGY STAR rating for LEED certified buildings. In the table depicted below, one can see that the LEED and year coefficient are slightly positive and significant, indicating that newer LEED buildings are more likely to have a higher ENERGY STAR rating than non-LEED structures (Table 1). However, this does not occur in the full model despite the interaction term, suggesting that the addition of the other variables lends the relationship between year and ENERGY STAR rating for LEED buildings less significant.

Not only is the interaction effect interesting to note, but the fact that the LEED variable is significant in nearly all models is also of importance. This indicates that there is a strong relationship between LEED certified buildings and their ENERGY STAR ratings. In fact, the full model suggests this relationship by noting a LEED certified building ($X_6 = 1$), will have an ENERGY STAR rating 14.34 points higher than non-LEED certified buildings, controlling for all other variables in the model (Table 1). Given that both ENERGY STAR and LEED serve as a classification of green buildings and sustainability, it makes sense that the indicator variable for LEED certification would be a strong predictor of the ENERGY STAR output rating.

Furthermore, it is interesting to note that the variable, retrofit, on its own, is of significance. A building that has undergone restoration and renovation in order to improve their energy efficiency is predicted to have a positive and significant relationship with the building's ENERGY STAR output. In general, this would make sense, given that buildings improving their energy efficiency would score higher on their overall energy ratings. It should also be noted that nearly 90% of the buildings in the data set were considered to be renovated and updated from their original construction, simply as a result of aging and improving technology.

As indicated by Table 1, the full model represents the data best, as seen by the lowest AIC value. LEED classification and retrofitting a building also appear to be the strongest predictors for a building's ENERGY STAR rating. The beanplot below serves as a density plot by indicating buildings concentrated by their ENERGY STAR rating (Figure 4). Buildings classified as LEED were much more predictable and normally distributed by their ENERGY STAR rating, with the average score tending around 80. Non-LEED buildings also had a high average, around 70, however there was a greater spread and overall differentiation of ratings in their distribution.

Table 1: Regression Results

	Dependent variable:							
	energystar							
	mod1	mod2	mod3	mod4	mod5	mod6	mod7	mod8
sqft	0.00001***	0.00001***	0.00001***	0.00001***	0.00000**	0.00000***	0.00000***	0.00000**
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
eui	−0.250***	−0.250***	−0.237***	−0.237***	−0.235***	−0.247***	−0.247***	−0.233***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)
year	0.057***	0.060***	0.074***	0.077***	0.056***	0.039**	0.015	0.041*
	(0.019)	(0.020)	(0.017)	(0.019)	(0.019)	(0.017)	(0.021)	(0.021)
historic	0.450	5.676		0.226	−0.241			6.313
	(1.912)	(5.259)		(6.303)	(1.803)			(7.134)
year:historic		−0.127						−0.138
		(0.119)						(0.112)
retrofit			9.391***	9.362***	8.401***			11.291***
			(1.908)	(2.015)	(1.866)			(2.159)
historic:retrofit				0.555				−0.497
				(6.439)				(6.339)
leed:retrofit								−13.314***
								(4.571)
leed					6.520***	7.226***	0.826	14.340**
					(1.423)	(1.444)	(3.324)	(6.244)
year:leed							0.075**	0.049
							(0.035)	(0.037)
Constant	115.110***	114.876***	103.480***	103.191***	104.344***	114.766***	116.536***	102.447***
	(2.235)	(2.245)	(3.122)	(3.364)	(3.164)	(1.993)	(2.149)	(3.477)
AIC	2416.4	2417.3	2392.8	2396.6	2375.9	2392	2389.4	2368
Observations	319	319	319	319	319	319	319	319
R^2	0.753	0.754	0.771	0.771	0.785	0.771	0.775	0.796
Adjusted R^2	0.750	0.750	0.768	0.767	0.781	0.768	0.771	0.789
F Statistic	239.600***	191.992***	264.090***	175.062***	190.326***	264.889***	215.224***	120.035***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 1. A matrix of the results of all the models and the variables included in them. The value indicates the coefficient value for each variable, with the standard deviation enclosed in the parentheses. At the bottom of the table are general statistics about each model and their fit.

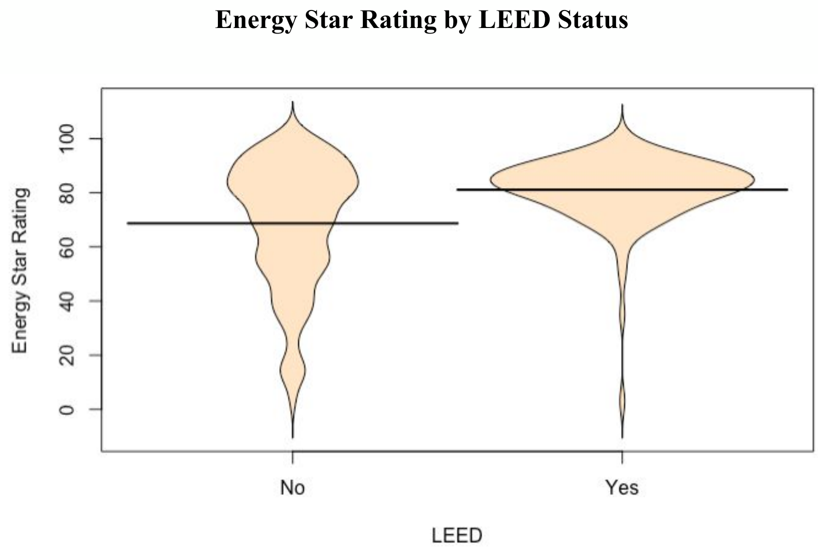

Figure 4. Beanplot indicating the density of buildings by their ENERGY STAR rating, as determined by their LEED or non-LEED classification. Each plot marks the average of their group with non-LEED being around 70, and LEED being around 80.

In a similar comparison, Figure 5 illustrates a density plot for buildings classified as historic or not. As reflected in the beanplot below, the average energy efficiency rating for these types of buildings were nearly identical. Ultimately, the non-historic buildings had a slightly higher ENERGY STAR rating than those considered historic by the CHRS from the 1990s. In this simplified graph, we see that the historic buildings have a much less predictable distribution, with random peaks at 40, 60, and 80. The non-historic buildings likely have a higher average as a result of most LEED buildings being associated with newly constructed buildings. This relationship can be further seen in Figure 6, where buildings are separated by two time periods: before 2000 and 2000s. 2000 serves as the breaking point in this graph, given that the LEED certification program began that year. One can see that the buildings constructed in the 21st century tend to have a higher ENERGY STAR rating, with a fairly even distribution. However, there appears to be a concentration of 2000 buildings that are not performing as efficiently and averaging a score of 40. Meanwhile, a large concentration of buildings constructed before 2000 are also performing well at a score of 70, however due to the wide variety of buildings, and an overall greater number of them, the distribution has a far greater spread, resulting in a lower average.

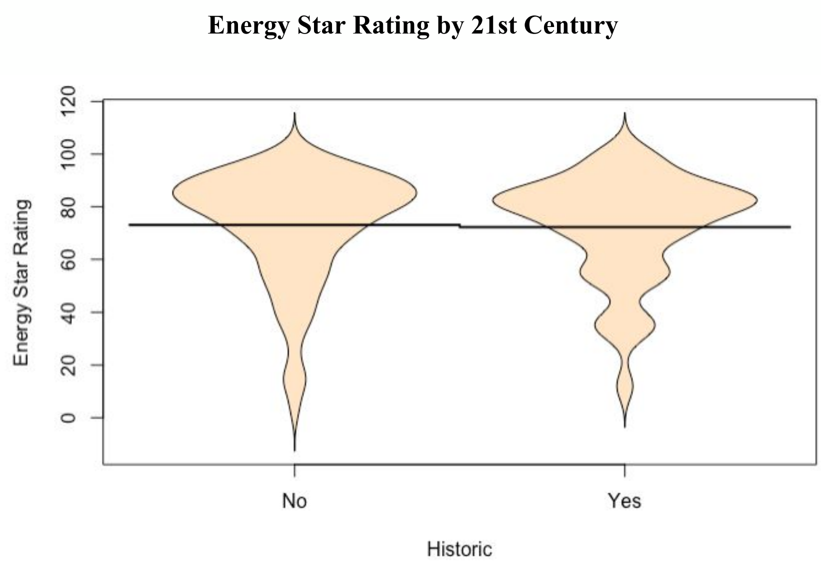

Figure 5. Beanplot indicating the density of buildings by their ENERGY STAR rating, as determined by their historic status. Each plot marks the average of their group, with both being around 70.

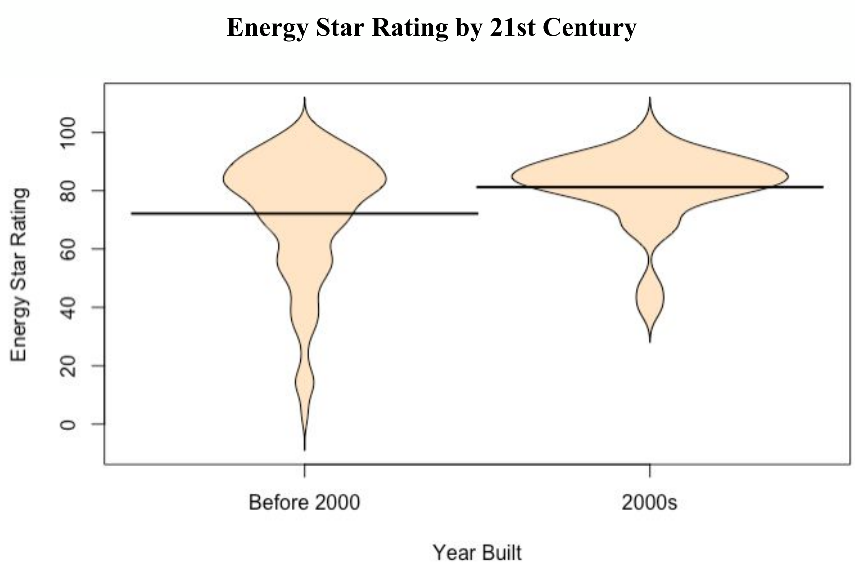

Figure 6. Beanplot indicating the density of buildings by their ENERGY STAR rating, as determined by their year of construction. The groups were divided between the 20th and 21st century. Each plot marks the average of their group with 2000 buildings being around 80, and all other buildings scoring around 70.

The tested models show slight trends in the buildings ENERGY STAR performance. Ultimately, new, LEED buildings resulted in a higher efficiency rating compared to their older, historic buildings. Nevertheless, it was found that retrofitting buildings also improved the structure's energy output, and a building's overall source energy use intensity is significant in determining how efficient it is.

In the literature, a debate existed between whether or not to place an emphasis on the embodied versus operational energy. In these models, the historic variable is intended to represent the emphasis on embodied energy. Isolating these buildings allows us to understand how a building performs, given the fact that it is a pre-existing structure. Meanwhile, operational energy is emphasized in LEED buildings, where there is a minimum energy performance needed as a prerequisite item on the rubric system. Through this research analysis, LEED certified buildings, especially those built new, tended to have a higher ENERGY STAR rating than historic structures, including ones that had been retrofit to LEED status.

Case Studies

Interestingly, the Monadnock building, a historic, retrofit structure built in the 19th century, boasts an ENERGY STAR score of 98, compared to the USG Headquarters, a 21st century LEED construction with an ENERGY STAR rating of 85. While this does not reflect the outcome found in the model, both cases are representative of the type of architectural practices that promote energy efficiency. Understanding the features of these buildings and how they operate can help contextualize the importance of embodied and operational energy of a structure.

The Monadnock building is able to efficiently maintain and regulate its energy usage through its original design, and enhanced retrofit features. The structure has managed to cut down electric and gas consumption by weatherstripping its exterior shell, installing an automated steam-system and installing efficient, sensor-controlled lighting.[67] These new additions further the benefits created by the characteristically thick masonry walls that already serve as a heat sink for the structure. The brick masonry, nearly six-feet thick on the north-half of the building, aids in keeping the building cool during the summer and warm during the winter.[68] In addition to the structure's high thermal mass, the building has operable windows and narrow hallways, allowing for a circulation of air and emphasis on natural lighting. These features reduce the overall electricity and energy needed to warm or cool the structure throughout the year. The low-tech energy saving designs were innate to the structure and exemplify the benefits of thoughtfully designed historic structures.

In a similar fashion, the newly designed USG headquarters showcases the benefits of designing with the intent of being green. As a company committed to sustainability, they made a point to be as efficient as possible. The new construction diverted roughly 70 percent of waste away from landfill, minimizing their embodied energy.[69] In addition to this, they sourced most of their materials from within 500 miles of the building site, reducing energy needed for extraction and transportation.[70] Not only did USG reduce energy in construction, but it also maximized the

[67] Unger, David J. "Chicago Sees Progress, Challenges in Early Years of Energy Efficiency Benchmarking." Energy News Network. March 23, 2017. Accessed April 13, 2019. https://energynews.us/2017/03/16/midwest/chicago-sees-progress-challenges-in-early-years-of-energy-efficiency-benchmarking/.
[68] "The Building." Monadnock. Accessed November 15, 2018. http://www.monadnockbuilding.com/the-building.html.
[69] "USG Corporate Headquarters Project Profile." USG. Accessed April 13, 2019. https://www.usg.com/content/usgcom/en/inspiration-center/project-gallery/usg-corporate-headquarters.html.
[70] Ibid.

natural light, reduced noise, and reduced water usage by 25%.[71] This concentrated effort at reducing the embodied energy of a structure, while simultaneously reducing the operational energy usage by 30%, is indicative of the progress new green design has made.

With both buildings holding a LEED Gold certification, we can better understand how these practices both work at improving the overall efficiency of a building. Chicago continues to serve as a nationwide example of sustainability and progress, through buildings like the Monadnock and USG headquarters. In order to continue its advancement, it must strive towards the best practices for sustainable development and design.

CONCLUSION

This paper examined the impact of retrofit historic buildings and LEED constructions on the overall ENERGY STAR rating of office buildings within the City of Chicago. These building types represent forward thinking practices that strive to improve a structure's energy efficiency. The data set contained of 320 office buildings within Chicago. Using appropriate analytics, the data tracks whole-building energy usage for buildings over 50,000 square feet in 2016. Through running various regression models, it has been found that retrofitting a building and classifying it as LEED certified has a significantly positive effect on a building's ENERGY STAR rating. The original hypotheses presented by this paper predicted a similar outcome for both historic, retrofit buildings and LEED certified structures. In addition to this, it estimated a positive relationship

[71] "USG Corporation Registers New Headquarters Office as LEED for Commercial Interiors Space." USG Corporation Registers New Headquarters Office as LEED for Commercial Interiors Space | Business Wire. May 23, 2007. Accessed April 13, 2019. https://www.businesswire.com/news/home/20070523005684/en/USG-Corporation-Registers-New-Headquarters-Office-LEED.

between year of construction and LEED certification, as well as retrofitting structures improving the energy efficiency of historic structures. Upon running multiple regression analyses, it can be concluded that LEED certified buildings actually outperform historic, retrofit structures within this data set. Nevertheless, older, historic buildings still have a positive relationship with their ENERGY STAR output. Though not significant, buildings encoded as historic and retrofit are predicted to have a higher energy rating than if they were not coded as retrofit.

Before discussing broader implications of the findings, several limitations must be noted. First, the historic variable is intended to represent older buildings with high embodied energy, however this is a rough estimate given that not all older buildings are encoded as historic and it is difficult to assess if particular buildings sourced their materials locally or not. Second, the variable retrofit was not clearly identified in any existing data set, resulting in hand coding for 320 buildings. As such, some discrepancies may exist with buildings not being encoded as retrofit, despite having been, simply by nature of lack of online publication. However, given that nearly 90% of buildings were designated as retrofit, the possibility of buildings not being coded as such would be negligible. Another issue arises from the fact that 90% of buildings in this data set are considered retrofit, though. This designation was given if a structure stated it had: (1) been renovated on their website; (2) signed on to the Retrofit Chicago Challenge by 2013; or (3) shown significant permits for renovations and energy saving procedures via the Building Permit and Inspection Records. This ultimately results in a wide scope of definitions for retrofit, which includes any building that has made improvements or modifications to their building for energy saving purposes. This leaves the possibility of some buildings doing far more than others to improve their operations.

Another limitation pertains to the fact that LEED certification can be acquired after original building construction. In some cases, a building was newly constructed with LEED certification, but then it underwent renovations at a later date to further its level even more, while in others a 19th century building could also receive LEED certification. Since LEED has been strongly correlated with year, the variable still reflects newer buildings and constructions.

More broadly, this study builds a theoretical and empirical bridge between theories of energy systems and architectural building practices by considering the existing Chicago office building stock. This paper shows that retrofitting a historic building has positive impacts on its energy efficiency, and is just shy of a LEED performing building. Meanwhile, retrofitting a building or designating it as LEED has significant, positive impacts on the energy efficiency of a structure. This study offers an examination of building performance, while exploring distinct architectural practices of historic preservation, renovation, and green building certification, in the nation's third largest city.

Looking forward, this research could benefit from further analysis of energy usage per building materials. This data set is limited in information regarding specific details of buildings, however it provides an extensive breakdown of energy usage by type, such as natural gas, steam and electricity. A stronger case for embodied energy could be made from additional information regarding structural materials, rather than simply using building age and historic status. Such an analysis can have large scale impacts on policy and building regulations.

Understanding which methods for making buildings energy efficient can change the current state of urban development. With so much of the carbon and energy usage being attributed to buildings alone, a knowledge of best practices is vital to mitigating climate change.

An important amount of research remains to be done with regard to building energy efficiency. Fortunately, more building owners and operators are consciously deciding to share energy usage data and reduce their footprint. This is a great step in the right direction, and there is always more to be done in terms of optimizing efficiency and current practices.

Works Cited

Advisory Council on Historic Preservation. "Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples." *Bulletin of the Association for Preservation Technology* 12, no. 4 (January 1979): 116. doi:10.2307/1493825.

Almeida, Manuela, Marco Ferreira, and Ricardo Barbosa. "Relevance of Embodied Energy and Carbon Emissions on Assessing Cost Effectiveness in Building Renovation—Contribution from the Analysis of Case Studies in Six European Countries." *Buildings* 8, no. 8 (2018): 103. doi:10.3390/buildings8080103.

Andrews, Clinton J., David Hattis, David Listokin, Jennifer A. Senick, Gabriel B. Sherman, and Jennifer Souder. "Energy-Efficient Reuse of Existing Commercial Buildings." *Journal of the American Planning Association*, 2nd ser., 82 (February 11, 2016): 113-33. Accessed November 13, 2018. doi:https://doi-org.proxy.uchicago.edu/10.1080/01944363.2015.1134275.

"Aon Center." Chicago Architecture Center - CAC. Accessed April 11, 2019. http://www.architecture.org/learn/resources/buildings-of-chicago/building/aon-center/.

Arndt, Michael. "AMOCO CHUCKS ALL THE MARBLE ON ITS TOWER." Chicagotribune.com. September 03, 2018. Accessed April 12, 2019. https://www.chicagotribune.com/news/ct-xpm-1989-03-07-8903240963-story.html.

Avrami, Erica. "Making Historic Preservation Sustainable." *Journal of the American Planning Association* 82, no. 2 (January 28, 2016): 104-12. Accessed November 13, 2018. doi:https://doi-org.proxy.uchicago.edu/10.1080/01944363.2015.1126196.

"Better Buildings Are Our Legacy." About USGBC. Accessed October 16, 2018. https://new.usgbc.org/about.

"Buildings and Climate Change." U.S. Green Building Council. Accessed October 16, 2018. https://www.eesi.org/files/climate.pdf.

Carl Elefante. "The Greenest Building Is...One That Is Already Built." *Forum Journal* 27, no. 1 (2012): 67-72. https://muse.jhu.edu/ (accessed October 23, 2018).

Census Bureau. "American Housing Survey (AHS) Table Creator." US Census Bureau. Accessed October 16, 2018. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html#?s_areas=a16980&s_year=m2017&s_tableName=Table0&s_byGroup1=a4&s_byGroup2=a1&s_filterGroup1=t1&s_filterGroup2=g1&s_show=S.

Checklist: LEED v4 for Building Design and Construction. April 5, 2016. Raw data. *Project teams can use these LEED v4 checklists to track their project goals and progress.*

Chicago Data Portal. Chicago Energy Benchmarking - 2016 Data Reported in 2017. February 8, 2018. Raw data. Chicago.

"Chicago Historic Resources Survey." Chicago Landmarks - Historic Resources. Accessed March 20, 2019. https://webapps.cityofchicago.org/landmarksweb/web/historicsurvey.htm.

C40 Cities. "Urban Efficiency II: Innovative City Programmes for Existing Building Energy Efficiency." *Issuu*, February 16, 2017.

Dixit, Manish Kumar, José L. Fernández-Solís, Sarel Lavy, and Charles H. Culp. "Identification of Parameters for Embodied Energy Measurement: A Literature Review." *Energy and Buildings* 42, no. 8 (August 2010): 1238-247. Accessed November 13, 2018. doi:10.1016/j.enbuild.2010.02.016.

"Energy Efficiency in Historic Buildings-Technical Preservation Services, National Park Service." National Parks Service. Accessed November 15, 2018. https://www.nps.gov/tps/sustainability/energy-efficiency.htm.

"Energy Efficient Buildings." Energy Efficient Buildings. Accessed October 16, 2018. http://www.chicagoclimateaction.org/pages/buildings/12.php.

ENERGY STAR. "ENERGY STAR Score for Offices in the United States." ENERGY STAR Score for Offices. August 2018. Accessed March 20, 2019. ENERGY STAR Score for Offices in the United States.

“About ENERGY STAR.” ENERGY STAR OVERVIEW. Accessed April 10, 2019. https://www.energystar.gov/about?s=footer.com

"Executive Branch | (20 ILCS 3130/) Green Buildings Act." Illinois Compiled Statutes. July 24, 2009. Accessed October 16, 2018. http://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=3109&ChapterID=5.

Hossain, Adnan, and Monjur Mourshed. "Retrofitting Buildings: Embodied & Operational Energy Use in English Housing Stock." *Proceedings* 2, no. 15 (2018): 1135. doi:10.3390/proceedings2151135.

Mayor's Office. *2018 Chicago Energy Benchmarking Report*. Chicago, IL, 2019. *The City of Chicago released an infographic on their @SustainChicago account in which they noted successful statistics regarding the program.*

"Monadnock Building." Chicago Architecture Center - CAC. Accessed November 15, 2018. http://www.architecture.org/learn/resources/buildings-of-chicago/building/monadnock-building.

O'Connor, Jennifer. *Survey on Actual Service Lives for North American Buildings*. Canadian Wood Council. October 2004. Accessed October 16, 2018. http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf. Presented at Woodframe Housing Durability and Disaster Issues conference, Las Vegas, October 2004

Older, smaller, better: Measuring how the character of buildings and blocks influences urban vitality. Washington, DC: National Trust for Historic Preservation. May 2014.

Ori, Ryan. "Aon Center Observatory, Redevelopments at Uptown and Congress Theaters Win Plan Commission Approval." Chicagotribune.com. December 21, 2018. Accessed April 12, 2019. https://www.chicagotribune.com/business/columnists/ori/ct-biz-plan-commission-entertainment-venues-ryan-ori-20181220-story.html.

Pfaehler, Gretchen K. "Demolish or Renovate? Embodied Energy Measurements Can Help You Decide." Buildings. October 01, 2008. Accessed April 11, 2019. https://www.buildings.com/article-details/articleid/6585/title/demolish-or-renovate-embodied-energy-measurements-can-help-you-decide.

Schittich, Christian. Building in Existing Fabric : Refurbishment, Extensions, New Design. Birkhäuser, 2012.

Schneider, Jay W. "USG Headquarters Ingrained in Green." Building Design Construction. October 01, 2007. Accessed December 15, 2018. https://www.bdcnetwork.com/usg-headquarters-ingrained-green.

"The Building." Monadnock. Accessed November 15, 2018. http://www.monadnockbuilding.com/the-building.html.

Unger, David J. "Chicago Sees Progress, Challenges in Early Years of Energy Efficiency Benchmarking." Energy News Network. March 23, 2017. Accessed December 15, 2018. https://energynews.us/2017/03/16/midwest/chicago-sees-progress-challenges-in-early-years-of-energy-efficiency-benchmarking/.

United States. City of Chicago. City Clerk. *Amendment of Municipal Code Chapter 18-14 regarding Energy Benchmarking and Implementation of Energy Performance Rating System*.

United States. State of Vermont. Division for Historic Preservation. *2015 Vermont Energy Code - Historic Buildings Exemption Report*.

United States. United Nations. *The United Nations Capital Master Plan*. By Michael Adlerstein. United Nations, 2007-2015. December 6, 2016. http://www.vidaris.com/uploads/files/assessing-the-carbon-saving-value-of-retrofitting-versus-demolition-and-new-construction-at-the-united-nations-headquarters-199.pdf.

"USG Corporate Headquarters Project Profile." USG. Accessed December 15, 2018. https://www.usg.com/content/usgcom/en/inspiration-center/project-gallery/usg-corporate-headquarters.html.

"USG Corporation Registers New Headquarters Office as LEED for Commercial Interiors Space." USG Corporation Registers New Headquarters Office as LEED for Commercial Interiors Space | Business Wire. May 23, 2007. Accessed April 13, 2019. https://www.businesswire.com/news/home/20070523005684/en/USG-Corporation-Registers-New-Headquarters-Office-LEED.

Wagner, Richard. "Finding a Seat at the Table: Preservation and Sustainability." In *Sustainability & Historic Preservation: Toward a Holistic View*. University of Delaware, 2011.

Wakili, K. Ghazi, B. Binder, M. Zimmermann, and Ch. Tanner. "Efficiency Verification of a Combination of High Performance and Conventional Insulation Layers in Retrofitting a 130-year Old Building." *Energy and Buildings* 82 (October 2014): 237-42. Accessed November 13, 2018. doi:10.1016/j.enbuild.2014.06.050.

Wines, James. "Green Architecture." Encyclopædia Britannica. December 13, 2018. Accessed December 14, 2018. https://www.britannica.com/art/green-architecture.

"World's Population Increasingly Urban with More than Half Living in Urban Areas | UN DESA Department of Economic and Social Affairs." United Nations. July 10, 2014. Accessed October 16, 2018. http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html.

Yim, Stephen, S. Ng, M. Hossain, and James Wong. "Comprehensive Evaluation of Carbon Emissions for the Development of High-Rise Residential Building." *Buildings* 8, no. 11 (2018): 147. doi:10.3390/buildings8110147.