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Embodied Carbon Studies at C&H

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Executive Summary

Reducing our carbon footprint is critical because it lessens the effects of global climate change, improves public health, and maintains biodiversity. Emissions produced by the built environment account for 40% of global emissions, making reduction of building sector emissions an utmost priority for creating a low carbon future. In recent years, there has been a push towards decreasing the operational carbon of buildings, with the goal of “carbon-neutrality”. However, a building cannot be carbon neutral without considering the emissions associated with construction, material production, maintenance, and demolition. This is where embodied carbon comes in. Embodied carbon is “the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials”, as defined by the Carbon Leadership Forum. In order for a building to be carbon neutral or even low-carbon, both operational and embodied carbon must decrease. High embodied carbon has a negative impact on the environment, while the impact of high carbon sequestration is positive.

This project is a carbon study exploring the embodied and operational carbon of Washburn House, an 150-year old dormitory building at Smith College. We calculated the changes over time of the embodied carbon - using the BEAM Tool - as the building went through several renovations, and tracked the operational energy as the college transitioned from coal to oil to methane gas, and soon to a low-temp hot water system powered by electric ground-source heat pumps. Many experts have begun encouraging the renovation of older buildings over demolition, as renovation often releases less total carbon emissions than an entire new build.

Using the CARE Tool, we analyzed two different scenarios, one comparing renovation to a new low-carbon building and another comparing renovation to a typical new building. For the low-carbon building, the renovation produced less emissions for the first 15 years before the new building became slightly lower in emissions due to lower energy consumption. With the typical building comparison, the renovation produced significantly lower emissions for the entire study. Both scenarios supported the notion that renovation is preferable over demolition, as carbon emissions being produced now is of the utmost importance to avoid.

With the ultimate goal of the study being to assess the feasibility of tax credits based on avoided embodied carbon, we then calculated the embodied emissions that would be avoided through renovating instead of demolishing. This included the emissions associated with demolishing Washburn House as well as the embodied carbon of the new build. We chose to complete these calculations for the low-carbon building, meaning the tax credit value would be larger for the typical building.

In order to calculate the value of tax credits, we needed to understand the social cost of carbon, “an estimate of the cost, in dollars, of the damage done by each additional ton of carbon emissions' ', as defined by Brookings Institute. Due to technical challenges, such as environmental tipping points and positive-feedback loops fueled by carbon emissions, as well as

political disagreements about how to quantify environmental damage, there is still much debate about a precise value for carbon. Although this is the case, many experts still believe carbon is currently greatly undervalued, and considering that as more carbon is added to the environment, the Earth creeps closer to these environmental tipping points, the value of carbon should be ever increasing.

Currently the Biden Administration has set the value at $51/ton, while the EPA suggests raising the number to $190/ton. Even at this increased figure, the value of the carbon tax credits is still too low to have a significant impact on the construction industry and decisions around avoiding demolition to decrease carbon emissions. However, higher figures have been proposed. Specifically, some modeling done by the EPA showing values as high as $340/ton and other modeling completed by the BPEA and Resources for the Future that have shown the value as high as $719/ton. Although these values are currently considered to be outliers, these values must be considered for significant change to occur, as the current and proposed values are far too low to have an impact on construction decisions.

Project Background

The objective of this project was to conduct a carbon study of Washburn House, a dormitory at Smith College in Northampton, Massachusetts. Washburn House, constructed in 1878, is a masonry building with wood framing. Over the building's nearly 150-year lifespan, Washburn has undergone several renovations, including a recent 2020 renovation by C&H Architects. This specific renovation included the addition of an energy recovery unit, fan coils, interior renovations, including bathroom and kitchen upgrades, and accessibility improvements, namely the reconfiguration of the front entrance. Additionally, this renovation set up Washburn House to be compatible with the low-temp hot water system that the college plans to transition to in 2028.

Figure 1: Washburn House after 2020 renovation

Building History

Our first objective was to track the embodied and operational carbon throughout the history of Washburn House. Operational carbon is widely understood to be the carbon emissions associated with the energy needed to operate a building, while embodied carbon is defined as "the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials".[1]

[1] As defined by the Carbon Leadership Forum

Figure 2 below depicts the timeline of changes in embodied and operational carbon resulting from both renovations and energy source transitions. Original drawings as well as information from the college's archives informed this timeline. While the timeline was fairly complete, there were some gaps in the history, which is expected considering the building's age. Specifically, there is a small addition to the first floor for which there were no construction documents. While the actual date of construction is unknown, the addition shows up for the first time on construction documents in 2012 as part of the existing conditions. Thus, we accounted for the addition in the previous 2009 renovation.

The embodied carbon timeline includes the original construction in 1878 and seven subsequent renovations. The first renovation, bathroom and kitchen upgrades, took place between 1878 and 1903. The second renovation added electricity to the building in 1916, followed by the addition of a sprinkler system in 1954. Between 1977 and the early 1980's a ramp was added to the front entrance and the building was rewired. The renovation of 2008-2009 upgraded the bathrooms, added a computer lab to the first floor and replaced the roof. As previously mentioned, this renovation also accounts for the first floor addition. In 2012, the bedroom lighting was upgraded and in 2020, the aforementioned C&H renovation was completed.

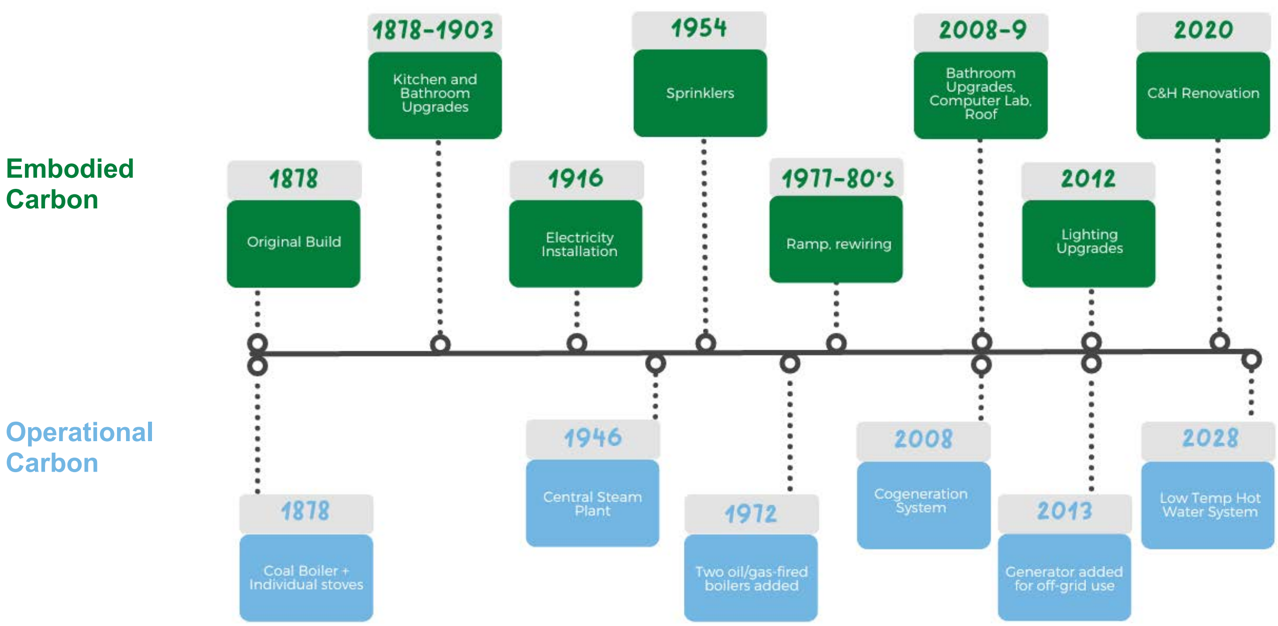


Figure 2

Washburn's operational energy was originally produced by a coal boiler in the basement and potbelly stoves in each student's room. In 1946, as the college expanded and individual boilers became overwhelming to manage, the entire campus was switched to a central steam plant, powered by coal boilers. In 1972, two oil and gas-fired boilers were added to the plant, transitioning the campus and Washburn House away from coal. The next major energy system upgrade came in 2008 when a cogeneration system was added to the steam plant and the old coal boilers were removed. The cogeneration system produces both steam and electricity, increasing the system's efficiency as the cogen engine burns methane gas[2], reducing site emissions. Shortly after, in 2013, a generator was added, allowing the campus to operate off the grid during power outages. The next change in operational carbon will be in 2028 when the campus switches to a low-temp hot water system powered by electric ground-source heat pumps.[3] This system is currently under construction and Washburn House is expected to transition to the system upon completion.

2020 Renovation Overview

Figure 3 displays the existing conditions of Washburn House prior to the most recent renovation. The ramp, added in the 1980's, can be seen in this image. While this ramp did meet accessibility standards, the ramp and the stark white trim did not fit with the building's historical character, which originally had colored trim. In addition to prioritizing sustainability and upgrading the building to be compatible with the college's upcoming low-temp hot water system, the 2020 upgrade prioritized accessibility and historical character. In total, the construction cost of this renovation was $4.2 million.

Figure 3: Washburn House prior to the 2020 renovation

[2] The processed fossil fuel known as "natural gas" is composed of four main gases, methane, butane, propane, and ethane, with nearly 95% being methane. Methane gas is often considered to be a cleaner fossil fuel, because its combustion produces less emissions than other fossil fuels. However, methane itself is an extremely potent greenhouse gas and when methane gas leaks from pipelines and wells, significant emissions are released. While these leaks are often overlooked, we now know that they account for significantly higher emissions than previously believed.

[3] Low-temp hot water systems are often referred to as geothermal energy.

Figure 4: Front of Washburn Hose post-2020 Renovation, including the new porch

Figures 5, 6 and 7 are excerpts from the C&H Washburn House drawing set. The images highlight the work completed during the most recent renovation of the bathrooms and front porch to increase the building's accessibility, as well as the addition of insulation and air sealing on the roof. To justify the modification, studies were done prior to renovation to understand the payback periods of various upgrades. This data informed the decisions made by Smith College and C&H during the most recent renovation of Washburn House. For example, double pane windows were chosen instead of triple pane windows, because of the relatively small reduction in heat loss for a significant increase in price.

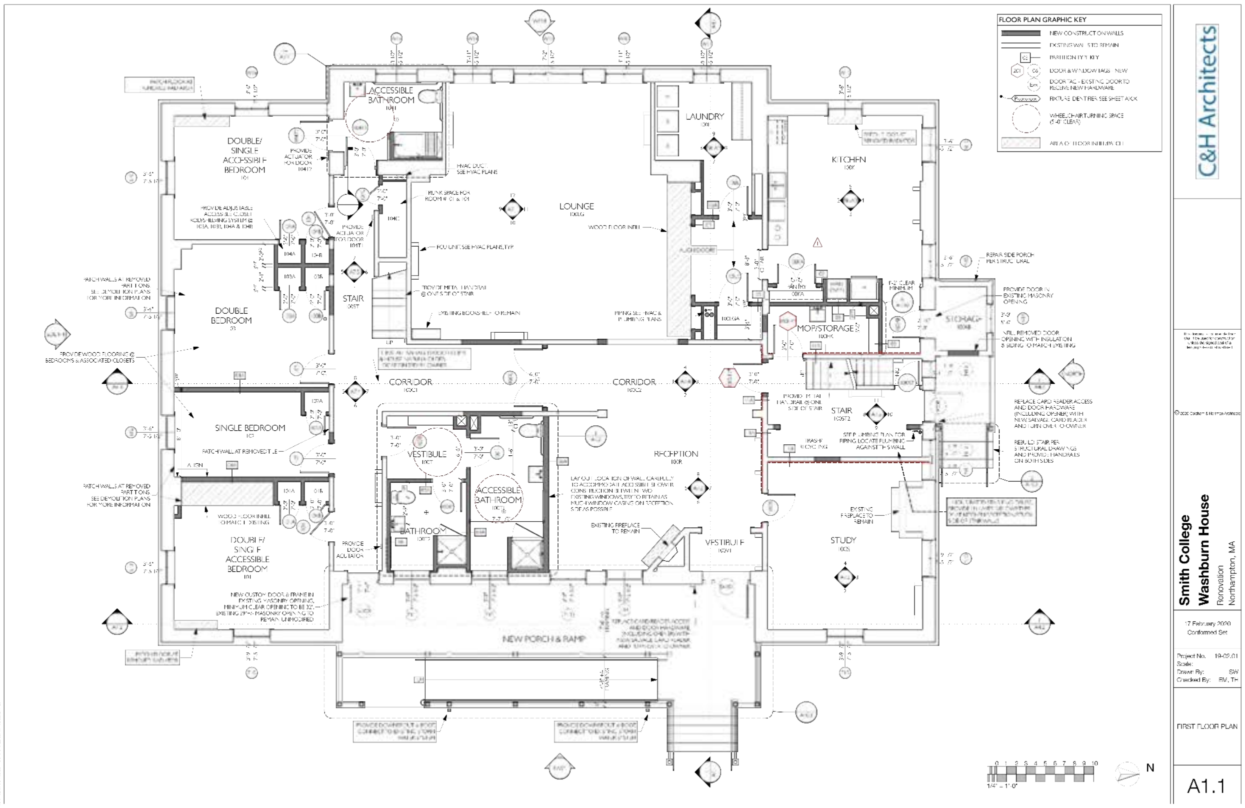


Figure 5: First floor plan highlighting the two new accessible bathrooms

Figure 6: Front Elevation, the new porch prioritizes accessibility and historical character by reconstructing the original porch design with an added ramp

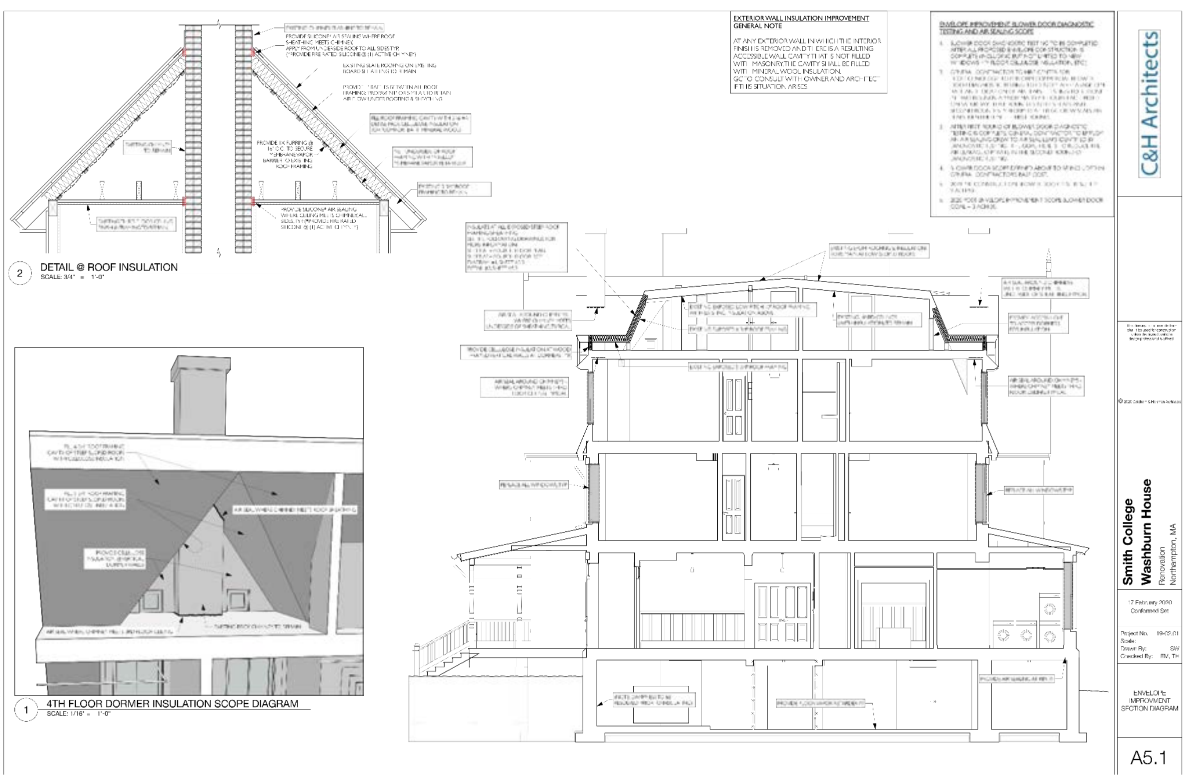


Figure 7: Roof section, depicts the plan for air sealing and insulation to reduce heat loss

Project Goals

1. Embodied Carbon

Calculate the embodied carbon throughout the renovations and lifetime of Washburn House.

2. Operational Carbon

Calculate the operational carbon over time as the energy sources transition throughout the college's history.

3. Comparison to New Build

Compare the embodied carbon associated with renovating Washburn House to the embodied carbon emitted by demolishing the current building and constructing a new building.

4. Monetizing Carbon

Assess the feasibility of tax credits based on embodied carbon and avoided emissions.

Embodied Carbon

As defined by the Carbon Leadership Forum, embodied carbon is “the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials”. Embodied carbon is an important aspect of the carbon neutrality equation. In order for building projects to be truly carbon neutral, both operational and embodied carbon must be considered.

Embodied carbon can be broken down into several stages correlated with the phases of the building’s life cycle. As described in Figure 8, there are four main stages, production, construction, maintenance and use, and end of life, each with sub-stages. There is an additional fifth stage which accounts for recycling and recovery. Figure 8 is from the New Buildings Institute[4].

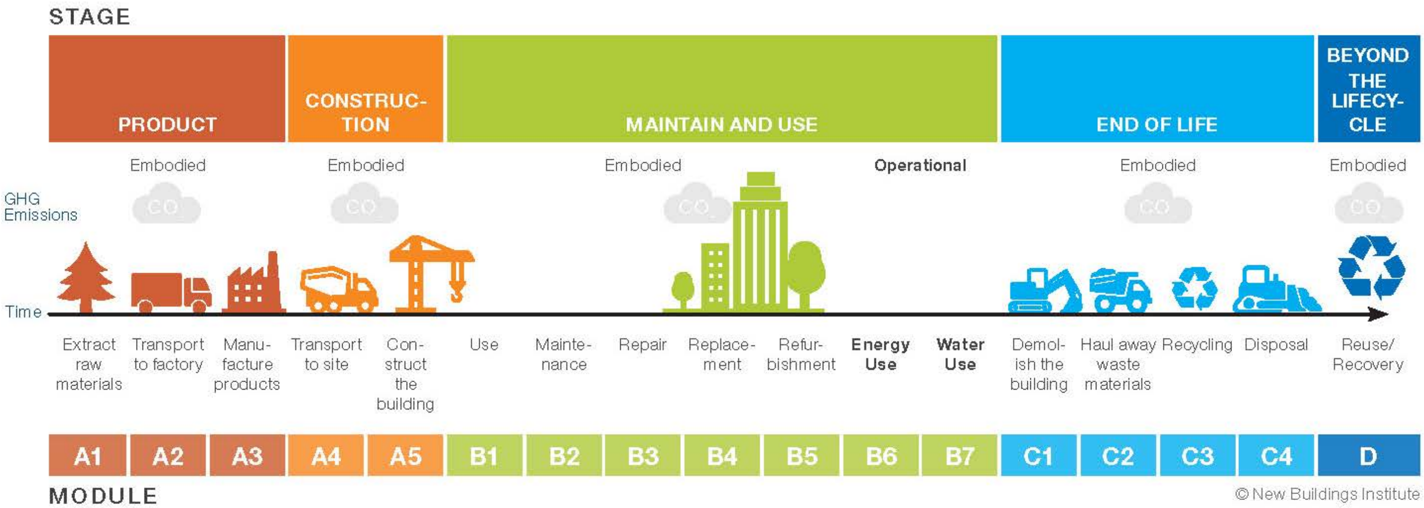


Figure 8

The embodied carbon of Washburn House was calculated using the BEAM Tool created by Builders for Climate Action. The BEAM Tool includes A1-A3 emissions and does not include all materials within the building, most notably excluding MEP systems and finishes. The creators of BEAM estimate that a building’s actual embodied carbon value is 40-50% higher than the calculated value.[5] We scaled the calculated emissions following this guidance. Another factor to consider is that BEAM does not include the carbon sequestered in forest materials due to the controversy surrounding the carbon released in harvesting lumber. The tool does account for sequestration in products sourced from recycled or residue materials, such as cellulose

[4] The New Buildings Institute is a nonprofit aiming to help transition the United State’s energy systems away from fossil fuels with the ultimate goal of zero emission buildings.

[5] These estimates are provided within the User’s Guide for BEAM.

insulation which is made of recycled newspapers. This sequestered carbon is considered to be a negative value of embodied carbon, as it stores carbon within the building's structure, which can help offset the embodied carbon produced during the building's lifetime.

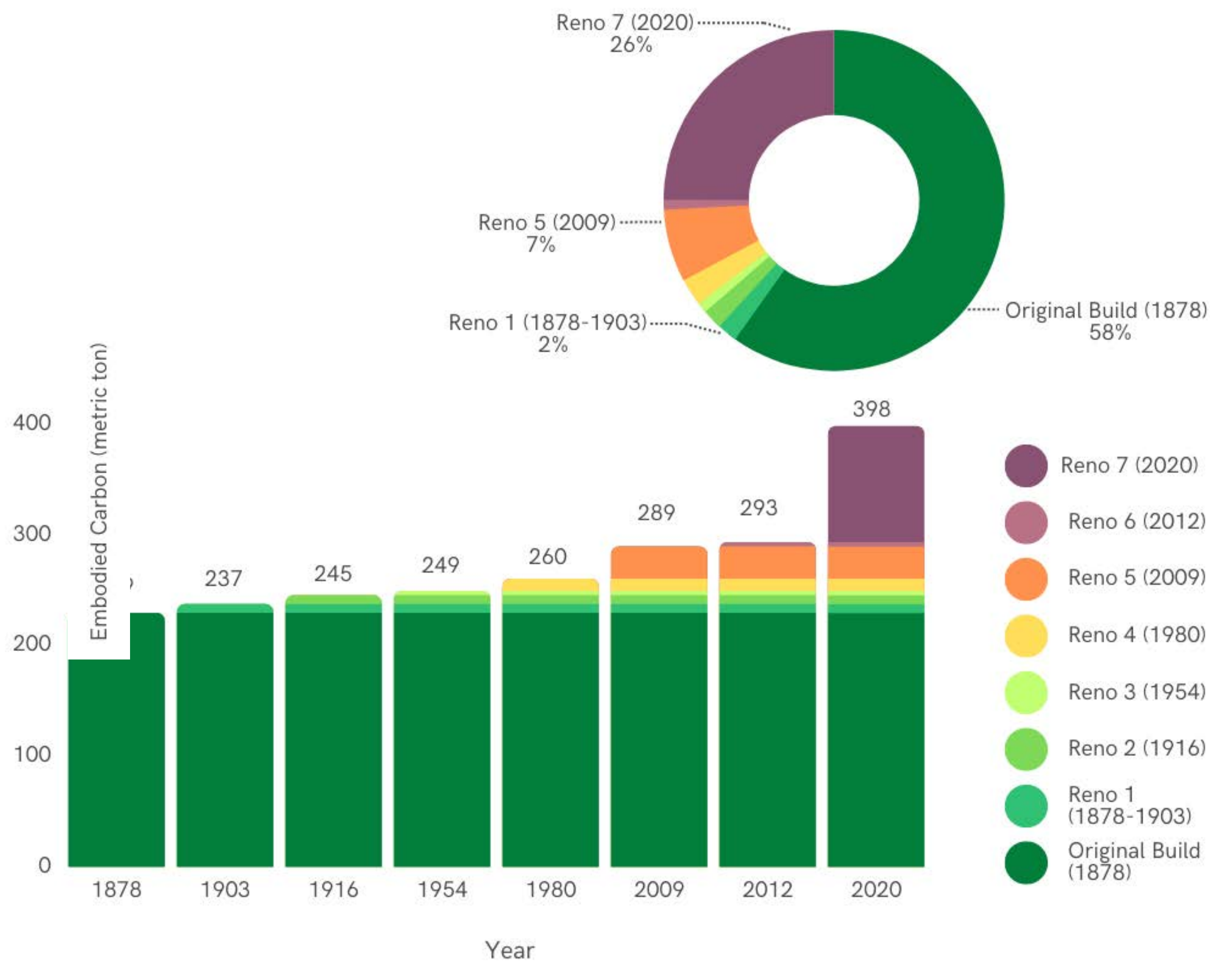
Challenges that we encountered when completing these calculations included the uncertainty of the embodied carbon of historic materials and the uncertainty of the scope and specific materials used in previous renovations. To address these unknowns, we made several assumptions. Specifically, we assumed that the embodied carbon of the historic materials was the same as that of equivalent modern-day materials. Considering that the A1-A3 emissions of these materials have already been released, as long as the values were within the same order of magnitude, the assumptions made about historic materials would not greatly affect the final results.

While the BEAM Tool does not account for the emissions released during demolition, the guide book for the tool estimates that 65-85% of emissions are accounted for during the A1-A3 phases. To address this, we categorized the remaining 15-35% as B1-C4 emissions, which includes the emissions produced during the building's use and demolition. We assumed a median value of 75% for A1-A3, and 25% for the remaining stages. This 3 to 1 ratio of A1-A3 to B1-C4 emissions was used to estimate the demolition emissions of each renovation.

The method that we used counted the B and C stage emissions as one entity. As a result, the B stage emissions, which account for the emissions during the building's use, including general maintenance, were only included for materials that were demolished during renovations. Since we did not attempt to quantify the embodied emissions associated with the general maintenance of materials still within the building, this study has likely underestimated the emissions associated with the B stage.

Figure 9 shows the embodied carbon over the building's lifetime, including the embodied carbon of the building's renovations. The majority of Washburn's embodied carbon is from the original building, with the original construction making up 58% of the building's cumulative embodied carbon. This suggests that even with extensive renovations, an existing building retains much of its original materials and carbon value. If materials are retained within an existing building, the demolition emissions of these materials are avoided and production emissions of other materials are reduced as there is a lesser need for new materials with renovations, than a new construction.

Figure 9 - Embodied Carbon Over Time



Operational Carbon

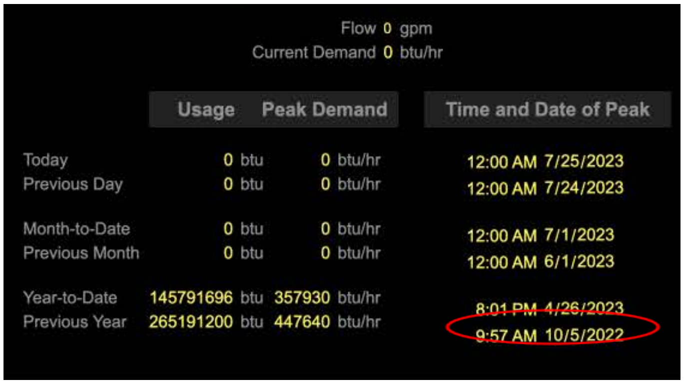
It is not uncommon for energy consumption data to be skewed by computational errors, and thus a general approach can prove to be more accurate. In this case, when calculating the operational carbon, we looked both at the modeled data from the 2020 renovation and the measured data from the building's meters. The modeled data, for comparative analysis between options, produced values that were far too large, providing an EUI[6] of nearly 100 when the expected EUI was approximately 40. Therefore, we could not rely on this modeled data. Further, previous analysis would have overpredicted energy savings on triple pane windows, meaning that all decisions based on payback periods still stand.

We examined the measured data as well, but we found this data to also be inaccurate. The main discrepancy we noticed with this data was illogical cooling and heating peak dates. The

[6] EUI stands for energy use intensity. It is a metric used to quantify the amount of energy used per square foot per year.

peak heating date was in October and the peak cooling date was during April, neither of which was logical considering Massachusetts' climate.

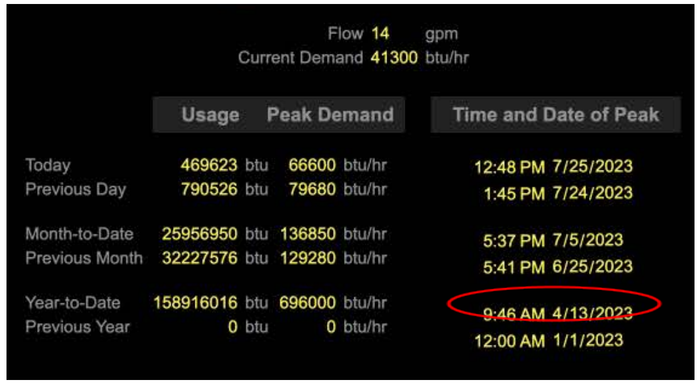
Dual Temp HW Flow



Flow 0 gpm
Current Demand 0 btu/hr

	Usage	Peak Demand	Time and Date of Peak
Today	0 btu	0 btu/hr	12:00 AM 7/25/2023
Previous Day	0 btu	0 btu/hr	12:00 AM 7/24/2023
Month-to-Date	0 btu	0 btu/hr	12:00 AM 7/1/2023
Previous Month	0 btu	0 btu/hr	12:00 AM 6/1/2023
Year-to-Date	145791696 btu	357930 btu/hr	8:01 PM 4/26/2023
Previous Year	265191200 btu	447640 btu/hr	9:57 AM 10/5/2022

Dual Temp CHW Flow



Flow 14 gpm
Current Demand 41300 btu/hr

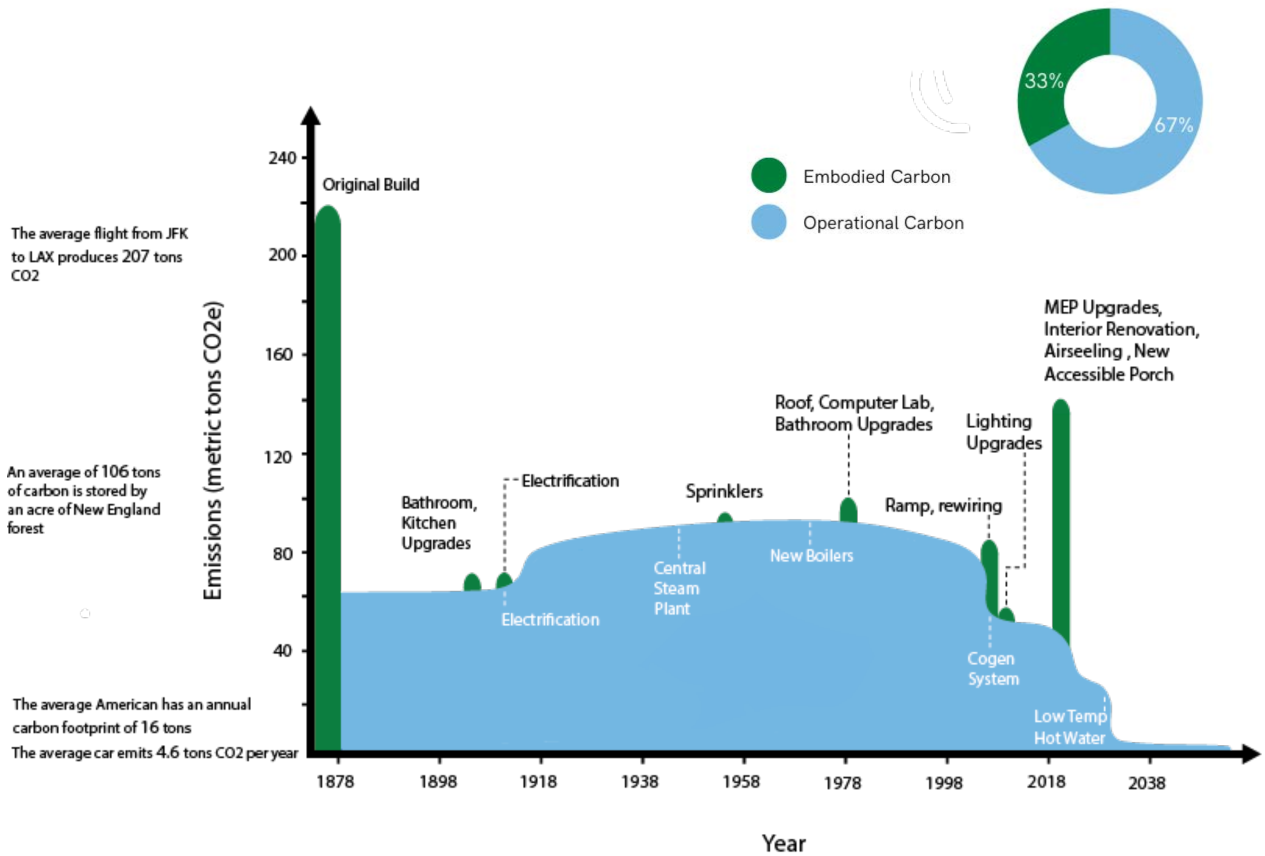
	Usage	Peak Demand	Time and Date of Peak
Today	469623 btu	66600 btu/hr	12:48 PM 7/25/2023
Previous Day	790526 btu	79680 btu/hr	1:45 PM 7/24/2023
Month-to-Date	25956950 btu	136850 btu/hr	5:37 PM 7/5/2023
Previous Month	32227576 btu	129280 btu/hr	5:41 PM 6/25/2023
Year-to-Date	158916016 btu	696000 btu/hr	9:46 AM 4/13/2023
Previous Year	0 btu	0 btu/hr	12:00 AM 1/1/2023

Ultimately, the decision was made to estimate Washburn House's EUI for key dates throughout the building's lifetime, and use these numbers to calculate the building's operational emissions. This method roughly accounts for changes in energy consumption over time while not being dependent on modeled or meter data.

Using historical data for household energy consumption, we adjusted the EUI over time with a starting EUI of 50 in 1878 and slowly increased to a peak EUI of 60 in 2009. With the understanding that energy consumption peaked around 2010, we then decreased the EUI for several years until the 2020 renovation. There was then a sharp decrease in the EUI after the completion of the most recent renovation. The estimated EUI of Washburn is approximately 40 after the renovation, so we used this figure for the remainder of the timeline. Using the EUI and square footage of the building, we calculated the annual energy consumption of the building over its lifespan. Once we had estimated the building's energy consumption over time, we accounted for the changes in the building's energy sources as the fuel source transitioned from coal to oil to methane gas and eventually to the new-low temp hot system.

Emissions were relatively stable until the addition of electricity which accounted for a significant increase in emissions. Emissions then increased gradually before slowly decreasing in the 1980's as Smith transitioned away from coal and towards cleaner fossil fuels. During the last 20 years there have been several sudden decreases in annual operational emissions. The first decrease corresponded to the upgrade to a cogeneration system which uses methane gas and has a high efficiency of approximately 74%. The second decrease occurred after the 2020 renovation which lowered the building's EUI through the addition of insulation in the attic, double-pane windows and air sealing throughout. The third major decrease will be in 2028 when the low-temp hot water system which according to Smith College's estimations will reduce campus emissions by 90%.

Figure 10 - 150 Years of Carbon



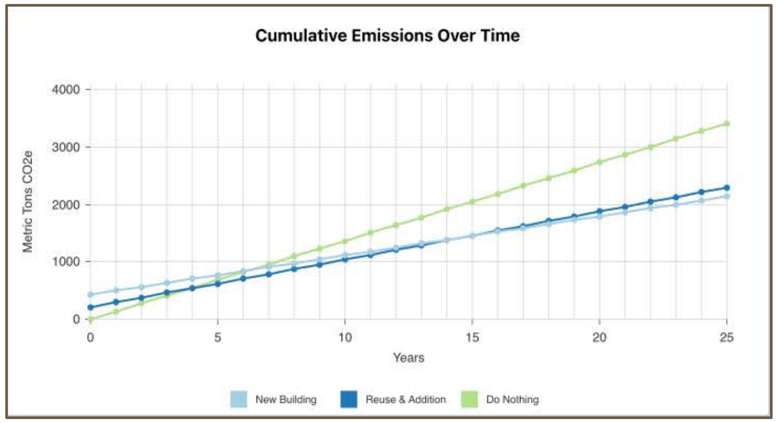
The graph shown in Figure 10 depicts the embodied and operational emissions overtime, with the green representing the embodied carbon of each construction project and the blue representing annual operational emissions.

Over the building's lifetime, a third of the emissions are embodied emissions, while two-thirds are operational. When comparing the building's embodied carbon to common benchmarks, the original build is only slightly more than the emissions of a singular flight[7] from JFK to LAX, and the largest 2020 renovation is approximately the same as the carbon stored by one acre of New England forest.

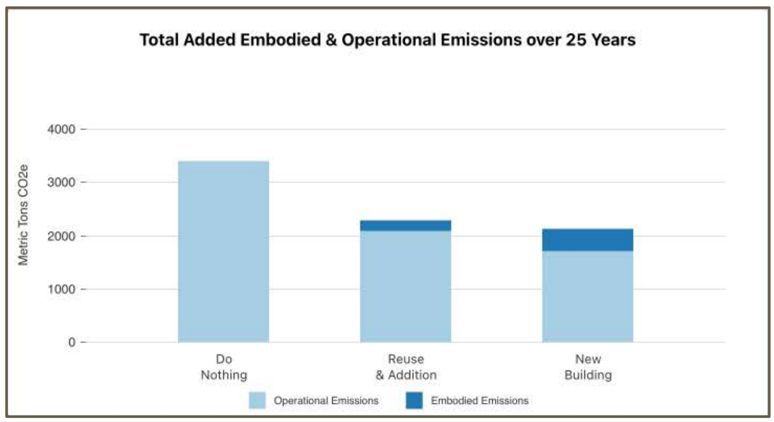
[7] This calculation assumed a full flight on a Boeing 767-400 which is a popular aircraft for this flight. The flight is 6 hours long with an aircraft capacity of 375 passengers and an emissions rate of 92 kg per passenger per hour, for a total value of 207,000 kg or 207 metric tons of CO2 emissions.

Comparison to New Build

The next step was to compare the embodied carbon of Washburn House to that of a new building using the CARE Tool. The CARE Tool is used to inform decisions around renovations. Specifically , the tool compares outcomes associated with doing nothing, renovating, and constructing a new building, helping users decide which option is best in terms of avoiding emissions.



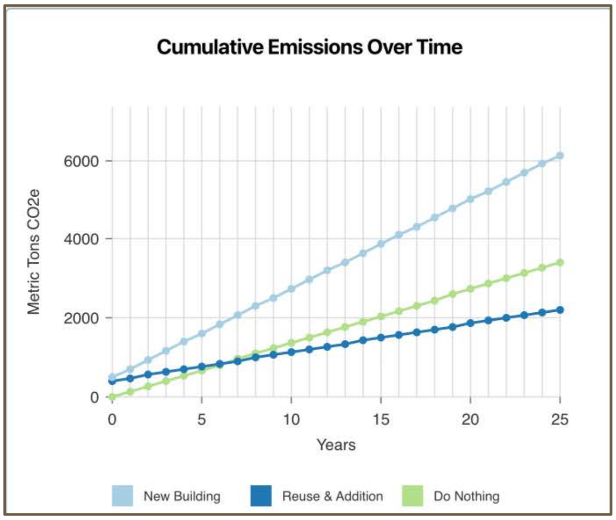
When choosing building attributes, we made conservative estimates and assumed the original building (do nothing) had an EUI of 80, while the renovated building had an EUI of 60 and the new building would have an EUI of 40. We also specified that the new building would be a low carbon, high performance building.

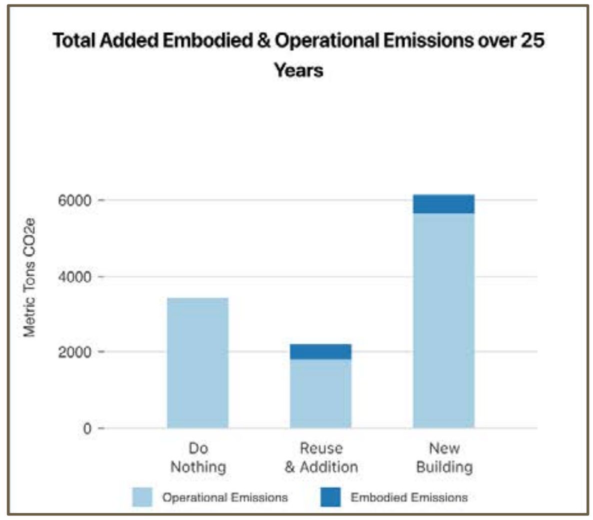


When looking at the embodied emissions, we see that the renovation has less embodied carbon than the new building, which seems reasonable considering the smaller scope of the construction. The new building also has greater emissions overall for the first 15 years before being overtaken slightly by the renovated building. Considering that avoiding carbon emissions now is of the utmost priority, we can see that renovating the building would limit upfront emissions.

We also wanted to calculate the embodied carbon in kilograms of CO_2 per square meter. We found that the lowest measurements were prior to the renovation at 140 $kgCO_2/m^2$. There was only a slight increase after the renovation at 150 $kgCO_2/m^2$, and the new building was the highest at 260 $kgCO_2/m^2$. These numbers are important when comparing projects of different sizes as the total embodied carbon of a building varies greatly depending on the building's size and function.

The above study with the CARE Tool assumes that the new building will be a low carbon, high efficiency building, which is not necessarily the case depending on the priorities of the developer and client. Therefore, it is important to compare the emissions of a renovation to a base case, an average new building, instead of a low carbon building. For our analysis, we used a base case that is the same building type and size as Washburn House, had an EUI of 132 (average according to CARE) and a high efficiency MEP system. So that this building would be representative of a typical new building, no other modifications were specified. Looking at the base case, there is an even stronger correlation between avoided emissions and choosing renovation over demolition and rebuilding.



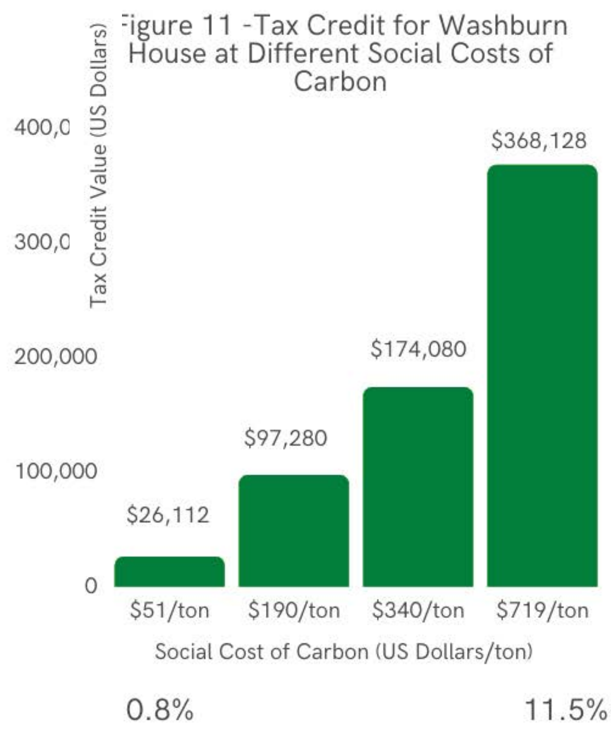


As seen in the emissions graphics, the emissions of an average new build are far greater than both a renovation and doing nothing. The discrepancy is so great because Washburn House pre-renovation already had a lower than average EUI, meaning that constructing a new building with an average EUI would lead to a large amount of operational and embodied emissions which could be avoided.

Monetizing Carbon

With the ultimate goal of this case study being to evaluate the feasibility of tax credits based on avoided embodied carbon emissions, understanding the cost of carbon, specifically the *social* cost of carbon, was an important objective. As defined by the Brookings Institution, the social cost of carbon is “an estimate of the cost, in dollars, of the damage done by each additional ton of carbon emissions”.

While this is a valuable metric and can be influential in terms of impacting decision making related to construction, it is important to acknowledge the challenges associated with assigning a monetary value for carbon. Damage to the environment is not linear and certain harms can not be undone. It is especially challenging to reverse damage in cases where environmental tipping points and positive-feedback loops influenced by carbon emissions make environmental restoration difficult. Additionally, as more carbon is emitted into the environment, the Earth moves closer to these environmental tipping points, suggesting that the cost of carbon is not a static number but instead one that increases over time.



In addition to the technical challenges associated with assigning a monetary value to carbon, there are also complications stemming from differing political viewpoints. For example, the Obama administration calculated the value of carbon based on global environmental damages caused by each ton of carbon for a value of $43/ton, whereas the Trump administration only considered the damage caused within the US by each ton of carbon for a value of $5. The Biden administration mirrored the approach taken by the Obama administration, setting the value at $51/ton. Among most industry experts, there is a popular belief that this valuation is far too low. Newer, more comprehensive modeling accounts for differing discount rates and various trends in population, economic growth and emissions rates. Such models have resulted in a suggested valuation by the EPA of $190/ton, with some EPA values as high as $340/ton and the BPEA and Resources for the Future modeling values as high as $719/ton. While these latter two valuations may appear excessive in comparison to those currently in use, considering the aforementioned environmental tipping points and positive-feedback loops, these higher values should be considered as plausible.

When estimating the value of embodied carbon tax credits, we took into account the reduction in carbon emissions achieved through renovation rather than demolition. Specifically, we considered the tonnage of carbon that would be emitted during the demolition as well as new construction. Utilizing this approach, Figure 11 above shows the possible values of a tax credit for Washburn House for different valuations of the social cost of carbon.

Considering that the budget of most commercial projects is in the range of millions of dollars, it is necessary for tax credits to be in the order of magnitude of hundreds of thousands of dollars or more, in order to be impactful. Looking specifically at Washburn House, with a project cost of $4.2 million, at $51/ton a tax credit is only 0.8% of the project budget, while at $719/ton, the tax credit is 11.5% of the cost. In order to get the attention of owners, the available tax credits would need to be at least 10% of the project cost. In comparison, solar panel tax credits are even higher percentage-wise, having just been raised to 30%. Thus, with the current social cost of carbon, tax credits are not a significant enough incentive to persuade developers to choose to renovate instead of demolish and rebuild. Ultimately, the social cost of carbon must greatly increase in order for such tax credits to be a significant player in the decision making around construction and demolition.

Resources and Tools

BEAM Tool by Builder's for Climate Action

Architecture 2030's CARE Tool

BSA Embodied Carbon 101

Carbon Leadership Forum

New Buildings Institute Lifecycle Stages

EPA's Report on the Social Cost of Carbon

Social Cost of Carbon Presentation at BPEA Fall 2021 Conference

BPEA's Report on the Social Cost of Carbon

Notable Case Studies

United Nations Renovation

University of Washington Housing

Houston Advanced Research Center

About the Author

Molly Neu interned with C&H Architects during the summer of 2023 while a student at Smith College. She is pursuing a double major in architecture and computer science, and a concentration in sustainable design.

C&H Architects is an Amherst, MA based architecture firm working throughout New England and New York. C&H was founded on green design and has continued to be a leader in sustainable building practices for the past 30 years.

At C&H, we design for the next hundred years.

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