Reducing the footprint of your facade

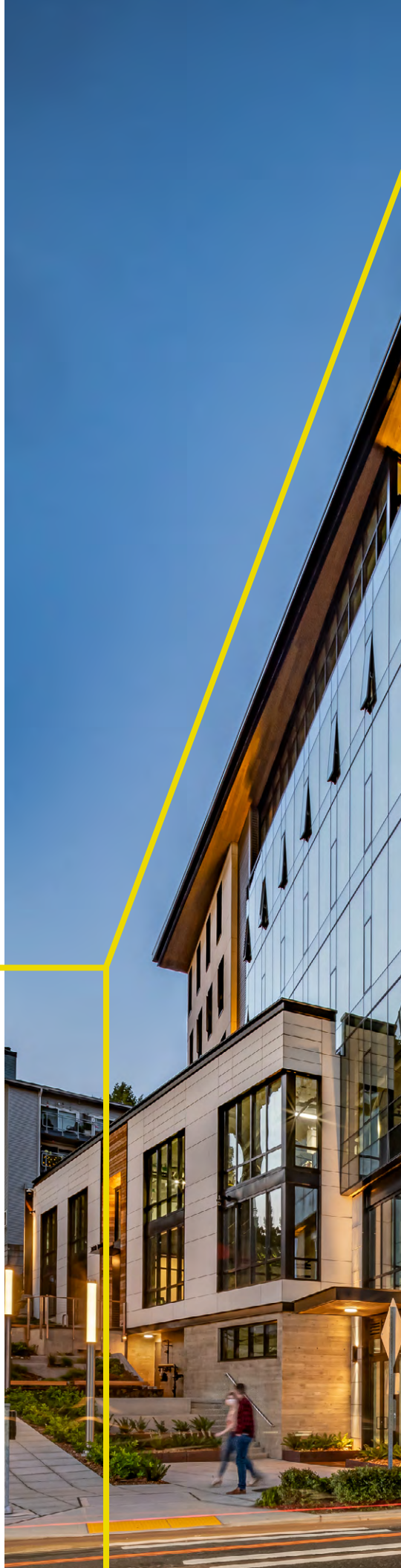
A CLOSER LOOK AT CARBON IN COMMERCIAL FENESTRATION

Oldcastle BuildingEnvelope®

At Oldcastle BuildingEnvelope®...

... our journey to re-invent a better future begins with creating industry leading solutions that have a positive impact on our people, our products, and our planet. We've developed certified environmental product declarations (EPDs) and health product declarations (HPDs) intended to promote transparency as well as provide software tools to help architects and engineers understand embodied carbon and operational carbon and how to reduce it wherever possible.

In this e-book, we take it a step further by providing an analysis of a fenestration system and commercial building in such a way to compare the embodied and operational carbon by looking at some of the key factors driving the total carbon footprint. It's another way our experts are in it with you as we strive to reduce the environmental impact of our products and operations on the built environment.



INTRODUCTION

Operational Carbon In Commercial Fenestration

It is well known that the built environment is responsible for approximately 40% of global greenhouse gas emissions, but the best path forward for reducing its impact is not always obvious. The tradeoff between choosing energy efficient new construction or retrofitting existing building stock can be complicated and involves a balance of operational carbon versus embodied carbon.

Operational carbon refers to all the greenhouse gases emitted because of a building's energy use, including electricity and direct fossil fuel consumption. Reducing operational carbon has been the focus of energy efficiency efforts for decades and includes the development of more efficient HVAC systems, LED lighting, better building envelope insulation, smart building controls, and high-performance fenestration. As the operational carbon of buildings has continued to decrease, the embodied carbon has become a greater concern for carbon reduction efforts.

Embodied carbon refers to the greenhouse gases emitted in the process of building construction that includes raw material extraction, transportation, and manufacturing of building materials. In some cases, the embodied carbon can account for more than half of the total carbon footprint of a commercial building over its lifetime, however, this can vary dramatically depending on a building's energy mix, design, and material sources.

There can also be a large difference in how the building subsystems contribute to operational and embodied carbon. By examining and optimizing the carbon footprint of building subsystems, architects can aim to reduce the whole building carbon footprint and break down the problem to more manageable levels.

In this ebook, we attempt to explain and quantify the carbon footprint specifically due to the fenestration system. We explain and calculate the main contributors to operational and embodied carbon of fenestration products along with practical information that can help lessen the impact of fenestration systems on a new building. We'll also look at how to assess the impact of window retrofitting and calculate the carbon payback of replacement windows.

WHAT DO WE MEAN BY CARBON FOOTPRINT?

The carbon footprint is the **total greenhouse gas emissions** (GHG), quantified as the global warming potential (GWP) which is a standard environmental impact used in life cycle assessments (LCAs). The units are typically kgCO2eq where all GHGs are converted to an equivalent of carbon dioxide emitted based on the global warming potential of the gas.

Operational Carbon Footprint In Fenestration

The operational carbon of a building results from energy consumption of the HVAC system, water heating, lighting, plug loads, and possibly refrigeration and is also affected by passive building elements such as windows, walls, roofs as well as natural ventilation and thermal mass. The specific energy consumption and operational carbon associated with fenestration is less obvious, since it is not a system that directly consumes electricity or fossil fuels. **To understand how the fenestration system contributes to energy consumption, we must isolate and calculate the heat loss and heat gain from the fenestration system and then attribute that portion of the HVAC energy consumption.** This step of energy attribution is critically important because it lets us separate and study the fenestration system and assess how changes to fenestration can affect carbon in a way that is not tied to a particular building design or a specific level of opaque insulation, HVAC system, etc. While there are too many variables to develop any simple rule of thumb, the following case study can provide insights on how general fenestration systems can be optimized for carbon footprint and energy consumption—learnings that can be applied to a range of projects.

Modeling The Energy Consumption Of Fenestration

Quantifying the energy consumption of an air conditioner or light bulb is easy, we can measure or calculate the electricity needed to power it for given periods of time. With a window or curtain wall, there is no electricity or natural gas supplying it that can be quantified. The energy consumption due to a window is attributed to the net change in energy consumption the heating, air conditioning, and ventilation system requires to adjust to heat transfer from the fenestration. **In some cases, this can be unwanted heat transfer that requires additional energy from the HVAC system;** in other cases, the heat transferred through windows can reduce the energy consumption of the HVAC. If for an entire year, the total HVAC energy consumption is less as a result of the fenestration, we would then consider that fenestration system to have a negative operational carbon footprint.

Case Study

Throughout these articles we use a single concept to model energy consumption and carbon footprint: a generic fixed window product in a medium office building modeled with different thermal performance, aluminum sources, frame size, weather, and electricity mix too examine how the footprint can change with design and geography. We look at the energy consumption and operational carbon per unit fenestration area to minimize the effect of building size and window to wall ratio. Building energy consumption is simulated using EnergyPlus (version 9.6) software with an American Society Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 model Medium Office Building set to the 2019 code standard (Prototype Model Buildings, 2021).

The Effect Of Climate Zone And Fenestration Specifications On Energy Consumption

We first examine how the fenestration thermal properties affect energy consumption in different climates by performing a detailed set of building simulations in the U.S. cities of Buffalo, New York and Tucson, Arizona to mimic a heating and cooling dominated climate, respectively. The details of the building and climate are listed in Table 1.

TABLE 1.

Model building and weather properties for energy use simulation

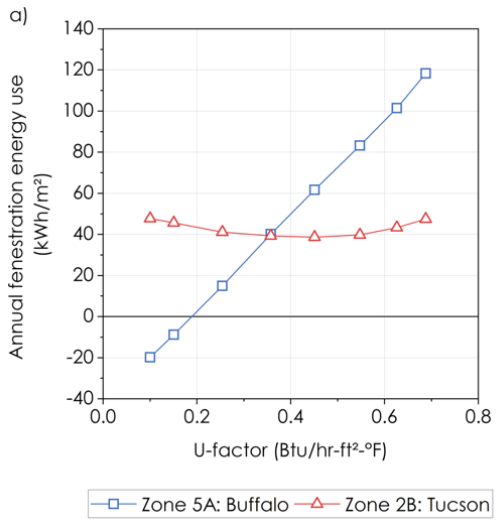
Parameter	Buffalo	Tucson
Building description	Medium office	
Standard	ASHRAE 2019	
Total floor area, m²	4,922	
Floors	3	
Window area, m²	652	
Window to wall ratio	33%	
Grid carbon intensity, kgCO2/MWh	206	323
Window U-factor, Btu/hr-ft²-°F	0.36	0.46
Window U-factor, W/m²-K	2.04	2.61
Solar heat gain coefficient	0.38	0.25
Climate zone	5A	2B
Cooling degree days (18°C)	310	1765
Heating degree days (18°C)	3632	815
Solar Irradiance, kWh/m²	39	71

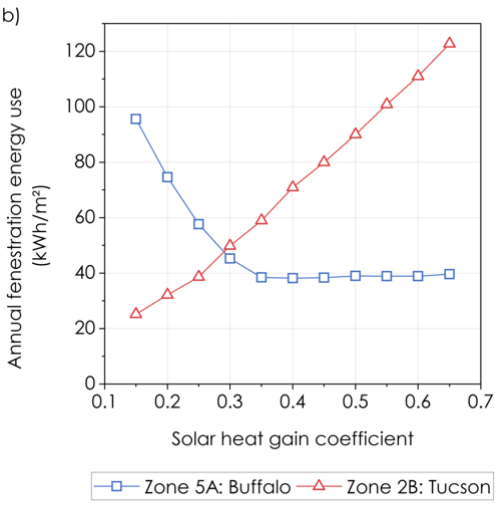
In a cooling dominated climate such as Tucson (Zone 2B) the annual fenestration energy consumption is most impacted by the solar heat gain coefficient (SGHC) **- quantifying the thermal radiation from the sun passing through a window (Figure 1.1a) while in a heating dominated climate such as Buffalo (Zone 5A) the U- factor quantifying the thermal insulation**

Will have the biggest impact on the energy consumption (Figure 1.1b). The medium office building uses natural gas as the primary source of energy for heating and electricity for cooling. It is interesting to note that when using the 2019 model code, the energy consumption of the fenestration in ***Buffalo*** and ***Tucson*** are within ***4%*** of each other indicating that the ASHRAE 90.1 designated ***U-factor and SHGC values are working well in this case to create similar energy consumption in very different climates.***

FIGURE 1.1.

Annual HVAC energy consumption of ASHRAE Medium Office model building versus a) fenestration U-factor and b) SHGC for Buffalo, New York (climate zone 5A) and Tucson, Arizona (climate zone 2B). The energy is normalized by the fenestration area.





The fenestration energy consumption becomes negative as the U-factor drops below ~1 W/m²-K (0.2 Btu/hr-ft²-°F), which is a high insulation value. In this case, the benefits from solar heating in the cold winter outweigh any heat losses through the window or unwanted solar heat gains in the hot summer. **This demonstrates that if the U-factor of the fenestration is low enough in this climate, the fenestration system provides net energy savings to the building resulting in a negative operational carbon footprint.**

This is an important concept for building design – the most energy efficient building is not always created by minimizing fenestration area – in certain regions increasing the area of the right fenestration system can improve a building's energy efficiency.

THE **CARBON INTENSITY** OF THE ELECTRICAL GRID

The carbon intensity of the electric grid in the U.S. varies greatly depending on the source employed by a given utility, hydroelectric power, wind, solar, natural gas, nuclear, and coal. A building's electricity supply plays a large role in its carbon emissions and the operational carbon of the fenestration system.

For example, the state of Washington primarily uses hydroelectric dams for its power and has an average carbon intensity of 103 kgCO2/MWh (Figure 1.2), while Wyoming uses coal to generate most of its electricity and has nine times higher carbon intensity (892 kgCO2/MWh).

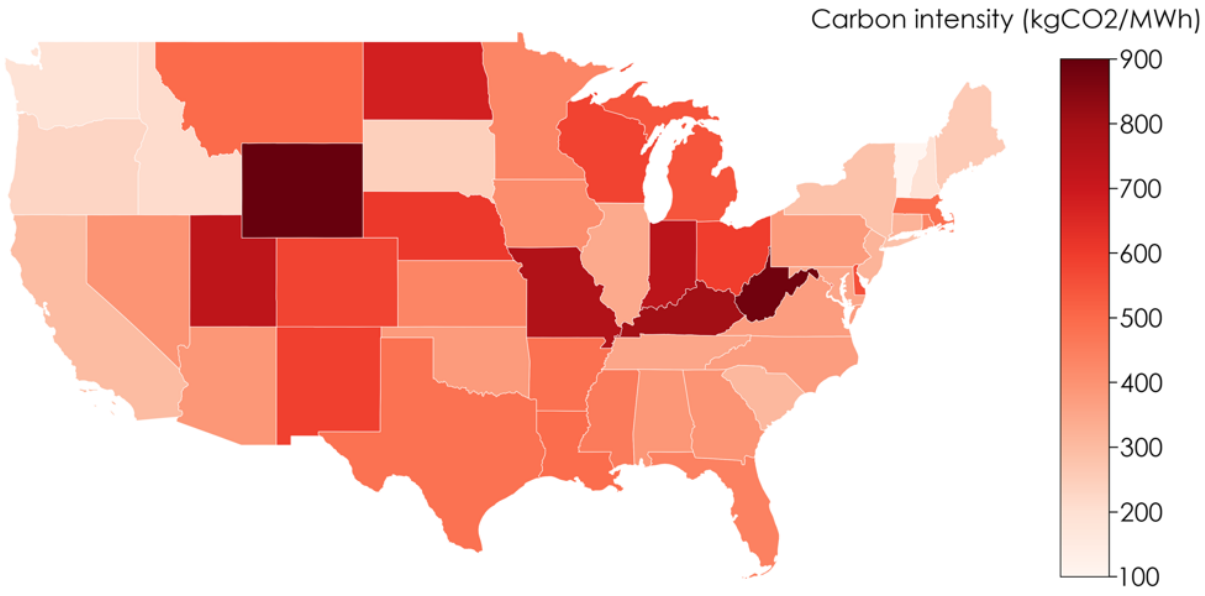
The national average for the U.S. in 2019 was 400 kgCO2/MWh and according to the Energy Information Association (EIA) is projected to decrease to 300 kgCO2/MWh by 2050 (Annual Energy Outlook 2021).

When we model the operational carbon of fenestration over 30 years, we apply these changes in electricity.

It is important to note that electricity generation and carbon intensity varies with local providers and utilities and is not constant for an entire state, however this averaged data provides a good representation of geographical variability in the carbon intensity of the U.S. grid.

FIGURE 1.2.

Carbon intensity of electricity supply for various states in the U.S. used in this study (U.S. Energy Information Administration, 2021)



The Regional Variability Of Operational Carbon

To assess the regional variation of operational carbon, we use local weather in each state along with the model fenestration specifications (ASHRAE 90.1 2019) for the local climate zone in conjunction with the average carbon intensity for electricity in each state. The operational carbon of the fenestration varies dramatically with six states over 1,000 kgCO2/m² (North Dakota, West Virginia, Kentucky, Indiana, Missouri, Utah) and eight states at or below zero (Washington, Oregon, Vermont, New Hampshire, Maine, California, New York, South Dakota).

This most commonly occurs in northern regions where solar heat gain in the winter can reduce natural gas consumption, and the electricity grid has low carbon intensity and thus a smaller footprint for summer cooling. It is well understood that under the right conditions and specifications, a fenestration system can provide a net energy benefit;

What is interesting is that the operational negative carbon footprint can be achieved in multiple states using the fenestration specified by the 2019 model code without the need to add a triple pane insulating glass unit (IGU) or any advanced technology.

Realizing a fenestration system with negative operational carbon has become more practical with a cleaner electricity source; the dynamics of this will shift for any building using heat pumps rather than natural gas for heating. As expected, there is a relatively strong correlation between the carbon intensity of the grid (Figure 1.2) and the operational carbon of the fenestration (Figure 1.3).

Operational Carbon Footprint Of Fenestration By State

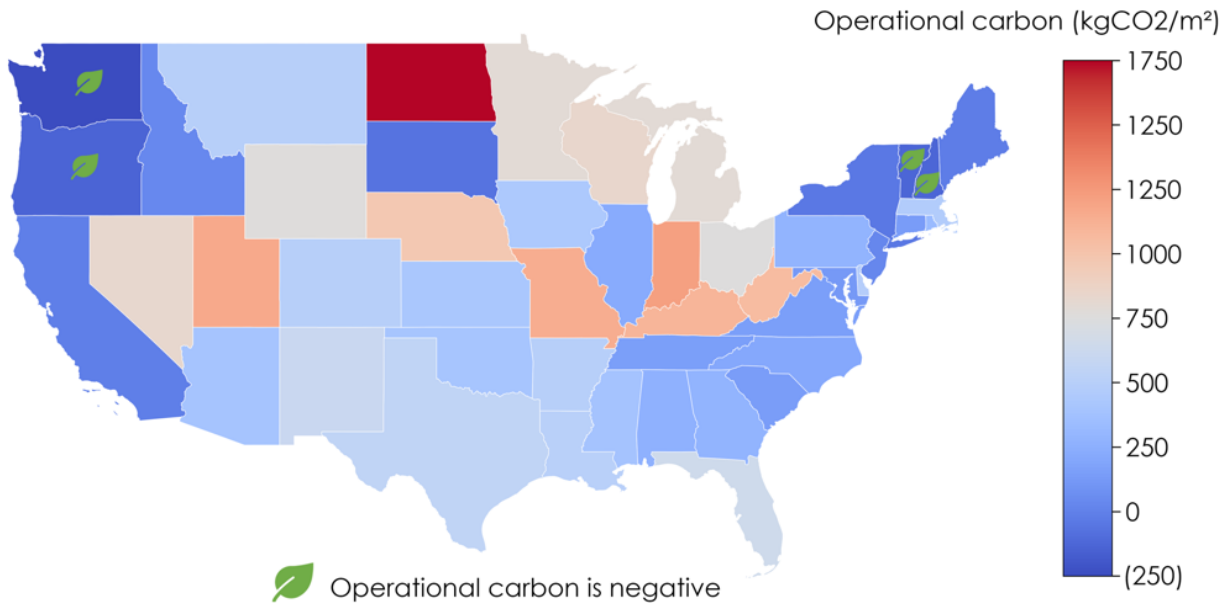


FIGURE 1.3.

For each state, one weather file is used along with the model building for the correct climate zone to calculate the energy usage associated with the fenestration system. State average electricity GWP (Figure 1.2) is used to calculate the cumulative carbon footprint assuming a 30-year lifetime. The GWP is normalized by the total building window area (650 m2).

This reinforces the importance of site-specific modeling and utility-specific carbon intensity information when possible. The regions such as the Midwest, with the highest operational carbon represent an opportunity where specifying higher thermal performance fenestration products can have the biggest impact on greenhouse gas emissions reductions. And, as we'll discuss in the subsequent articles, the U.S. states in the Northeast and West with the lowest operational carbon are regions where embodied carbon can be the main contributor to the carbon footprint of fenestration.

THE BASICS OF EMBODIED CARBON

Embodied Carbon in Fenestration

Embodied carbon is a critical aspect of the total carbon impact of materials in building construction and needs to be carefully considered during the design phase of any new building or retrofit project. While a number of tools are available to quantify whole building embodied carbon, this does not always lead to a better understanding of specific portions of the building such as the fenestration.

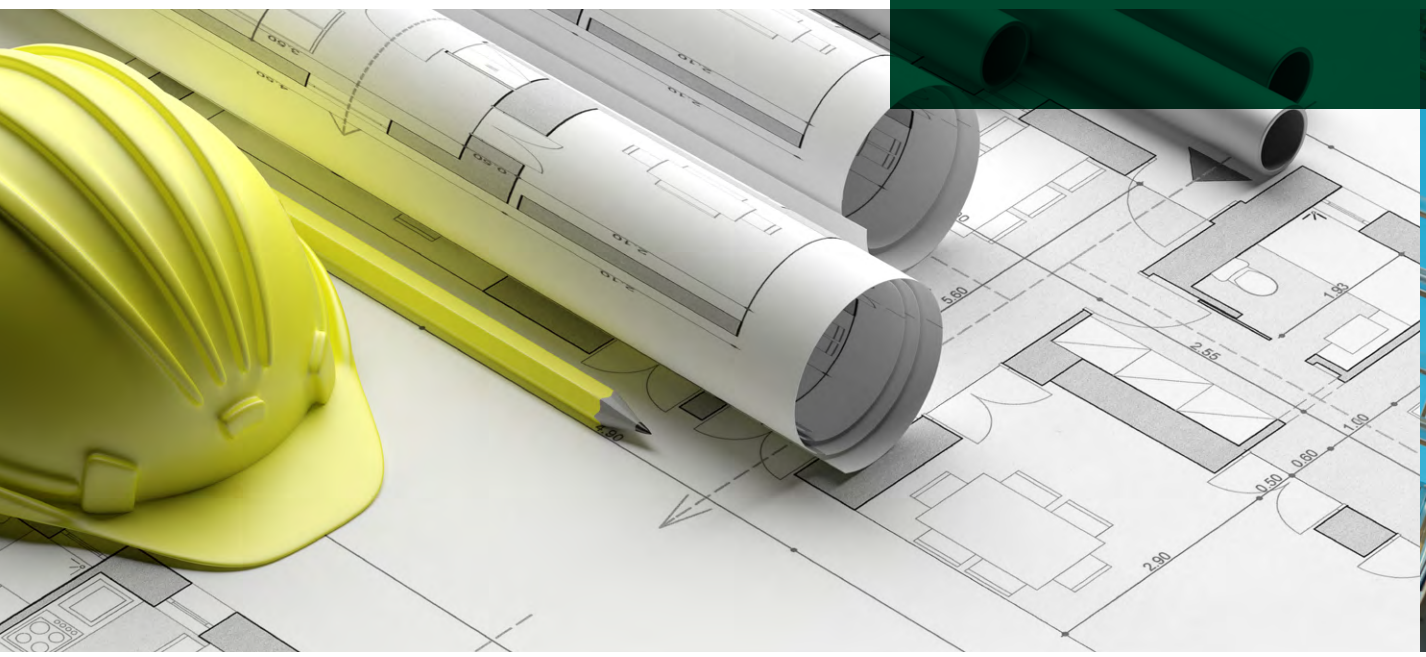
In this article, we review the basics of embodied carbon and dive deeper into the drivers of embodied carbon in aluminum fenestration systems.

HERE ARE A FEW QUICK FACTS ABOUT EMBODIED CARBON

It refers to all the GHG emissions released during the manufacturing and construction of a building, including raw material extraction, transportation, and fabrication as well as maintenance, replacement, and disposal (Figure 2.1).

It is responsible for 28% of building sector greenhouse gas (GHG) emissions and 11% of all GHG worldwide.[1]

It is typically evaluated using a Life Cycle Assessment (LCA), which is a rigorous methodology that quantifies a variety of environmental impacts including global warming potential (GWP).



Whole building LCAs can be used to assess the embodied and operational carbon impacts of an entire building and all materials used therein, these are complex and time consuming to perform, but provide important data to understand the environmental impact of a building.

Environmental product declarations (EPDs) use LCA methodology applied to a specific material or product over the initial stages of raw material extraction, material processing, transportation, and manufacturing. This EPD scope is known as cradle-to-gate, and for fenestration products made of aluminum and glass, this will capture the most energy intensive activities associated with embodied carbon.

A benchmark study found of 291 office buildings found that the median embodied carbon is 396 kgCO2eq/m² with half of all buildings falling between 266 and 515 kgCO2eq/m².[2]

[1] Embodied Carbon, International Codes Council: https://www.iccsafe.org/advocacy/embodied-carbon/Accessed March 9, 2022

[2] Simonen, K., Rodriguez, B., Barrera, S., Huang, M., (2017) CLF Embodied Carbon Benchmark Database, database. Available at http://hdl.handle.net/1773/38017.

The Impact Of Aluminum Cradle-To-Grave

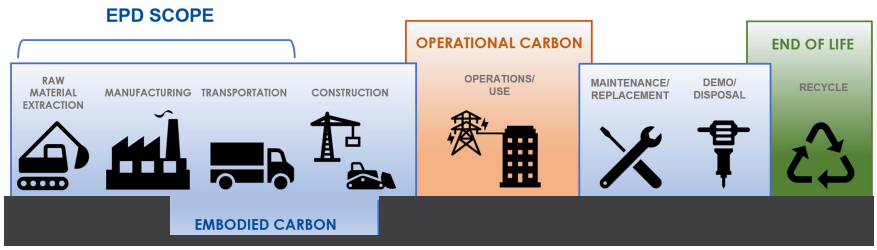
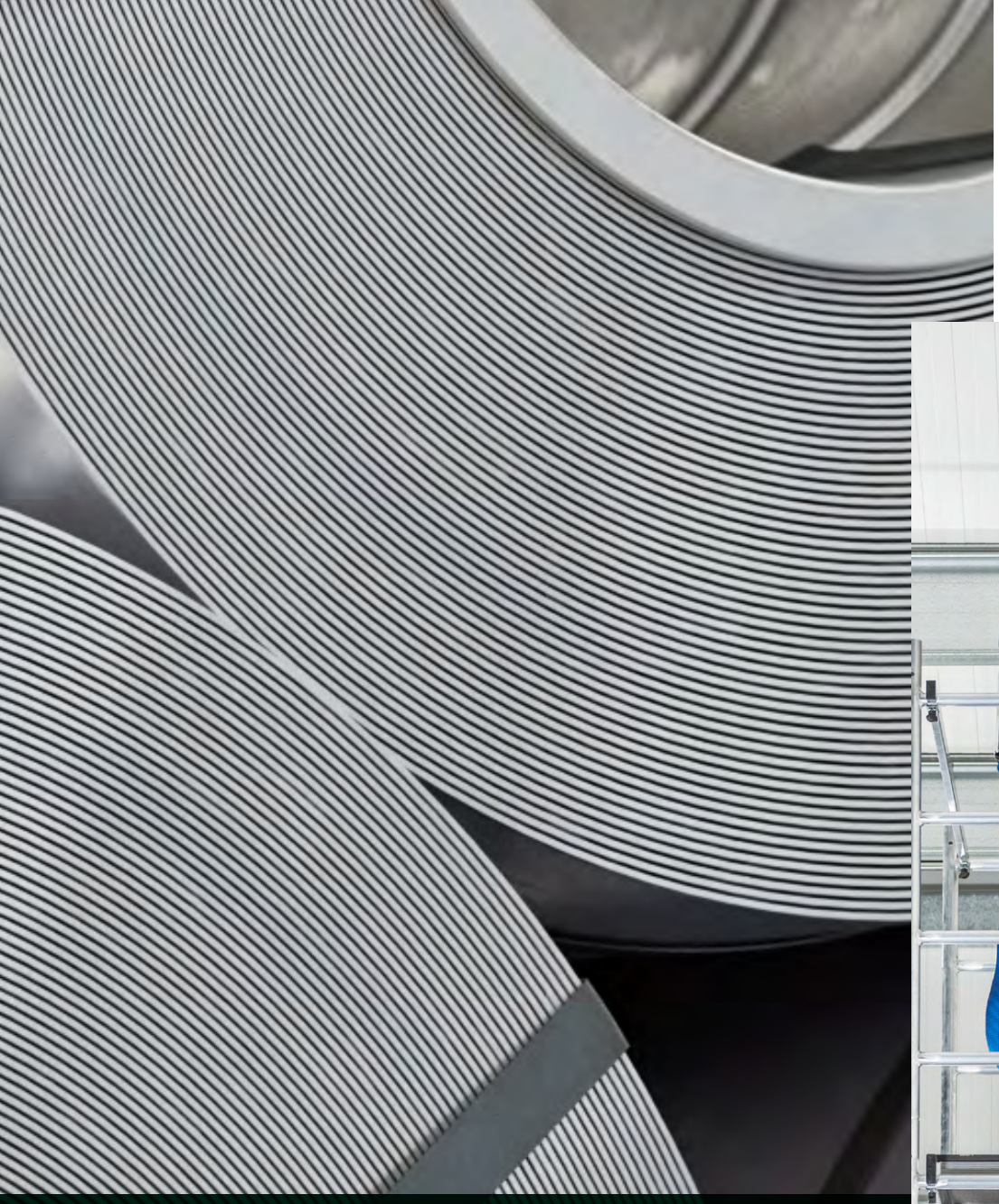


FIGURE 2.1.

Simplified summary of a lifecycle separating embodied carbon and operational carbon phases. The EPD scope is commonly referred to as cradle-to-gate, whereas the entire lifecycle is cradle-to-grave.

Aluminum framing used in commercial fenestration is a perfect example of a product in which the vast majority of embodied carbon is emitted during the cradle-to-gate stage of the lifecycle. New primary aluminum starts with bauxite mining which is then refined to produce aluminum oxide (alumina). The alumina is then smelted to create aluminum. Approximately 4 to 5 kg of bauxite creates about 2 kg of alumina, producing 1 kg of aluminum.

The smelting process requires large amounts of electricity to create pure aluminum and the environmental impact of that process is driven in large part by the electricity source used for smelting. An aluminum ingot smelted using hydroelectricity may have a carbon footprint that is more than four times lower than a process using a coal-fired power plant.[3]



In contrast to the smelting process, remelting aluminum only requires about 8% of the energy needed to create a primary ingot.[4] This makes the use of recycled aluminum an effective way to lessen the environmental impact of aluminum framing systems. The Aluminum Extruders Council reports that more than 90% of aluminum used in construction is reused, and unlike plastics can be repeatedly recycled with the same properties as primary aluminum.

Conventional wisdom has always dictated using high-recycled content to reduce the environmental impact of aluminum, but the details of any primary aluminum used in the extrusion is very important as well. This information may be captured in a third- party certified EPD from a building products manufacturer.

[3] (Aluminum Extruders Council (AEC), (2016a). Environmental Product Declaration - Aluminum Extrusions. UL Environment. Retrieved from https://cdn.ymaws.com/www.aec.org/resource/resmgr/Sustainability/101.1_AEC_EPD_Aluminum_Extru.pdf

4 "How Does the Aluminum Extrusion Industry Impact the Environment?" (2022) Aluminum Extruders Council, https://www.aec.org/page/aluminum-extrusion-sustainability

Calculating Embodied Carbon For Fenestration Systems

To calculate the embodied carbon of a fenestration system we examine a fixed window of 1.48 x 1.23 m, an aluminum frame weight of 16 kg and a dual pane insulating glass unit (IGU) with two lites of 6 mm thick glass weighing 49 kg. For the aluminum frame we use an LCA to calculate the GWP of individual processes contributing to the aluminum framing system and we use representative industry EPDs for the IGU, thermal strut, and gaskets.

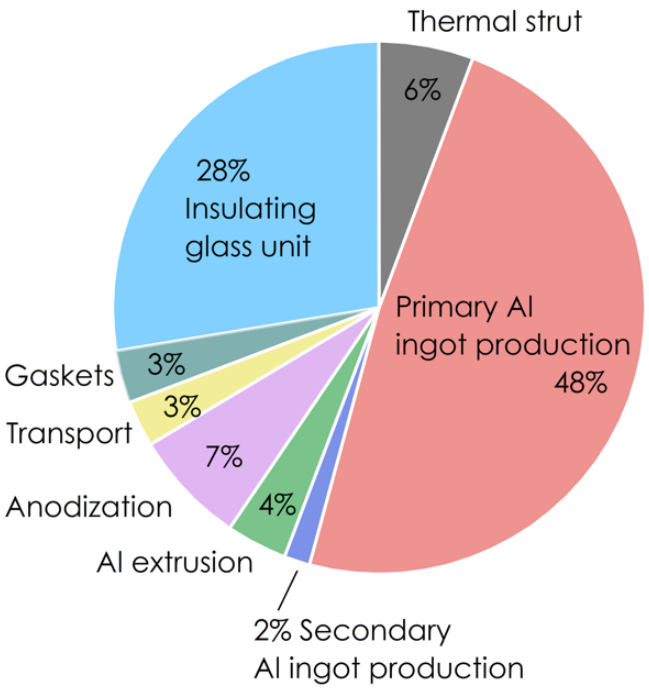


Figure 2.2.

Breakdown of contribution to the GWP of model aluminum fixed window product used in this study. Aluminum billet uses the average U.S. GWP of 8.9 kgCO2eq/kg which includes 54% recycled content.[5]

[5] (Aluminum Extruders Council (AEC), (2016a). Environmental Product Declaration - Aluminum Extrusions. UL Environment. Retrieved from https://cdn.ymaws.com/www.aec.org/resource/resmgr/Sustainability/101.1_AEC_EPD_Aluminum_Extru.pdf

Using these specifications, Figure 2.2 shows the relative contribution to GWP from the various components and processes in the final fenestration system product. In this GWP calculation, the primary ingot is transported 9,000 km by container ship and over 2,000 km by truck, and yet transportation still only accounts for 3% of the carbon in the system. Even when including U.S. average 54% recycled content, the aluminum production and finishing account for 62% of the carbon from the system. The aluminum components of the fenestration system represent the biggest carbon footprint and the biggest opportunity for improvement when considering both recycled content and the source of the primary ingot.

For the same recycled content (54%), using primary ingot smelted using hydroelectricity in the aluminum would have a GWP of 2 kgCO2eq/kg but using primary ingot smelted using coal fired electricity in would have a GWP of 14 kgCO2eq/kg. If you focus only on the recycled content, the aluminum GWP can vary by a factor of seven. When you are able to reduce the GWP of the finished aluminum to ~4 kgCO2eq/kg it becomes comparable to the GWP of an IGU.

THE EFFECT OF GLASS SIZE ON EMBODIED CARBON

There is an architectural design consideration that can play an important role in determining the embodied carbon of a fenestration system: the size of windows used. For a fixed total window area, the size of each individual opening will alter the embodied carbon of the system, since it changes the amount of framing used per unit area. The equation below calculates the embodied carbon of a window (EC_{win}), where CF is the carbon intensity factor, P is the perimeter, and A is the area.

$$EC_{win} = CF_{frame}\left[\frac{kgCO2}{m}\right] \cdot P_{win}\,[m] + CF_{glass}\left[\frac{kgCO2}{m^2}\right] \cdot A_{win}\,[m^2]$$

In this way, the embodied carbon of the frame is dependent upon the perimeter, and the embodied carbon of the glass is dependent upon the area. Because the frame is typically more carbon intensive than the IGU, specifying larger lites of glass will use less aluminum and thus have an overall lower embodied carbon (in the same total area). Figure 2.3 shows how the embodied carbon of the fenestration system changes as the opening height and width changes.

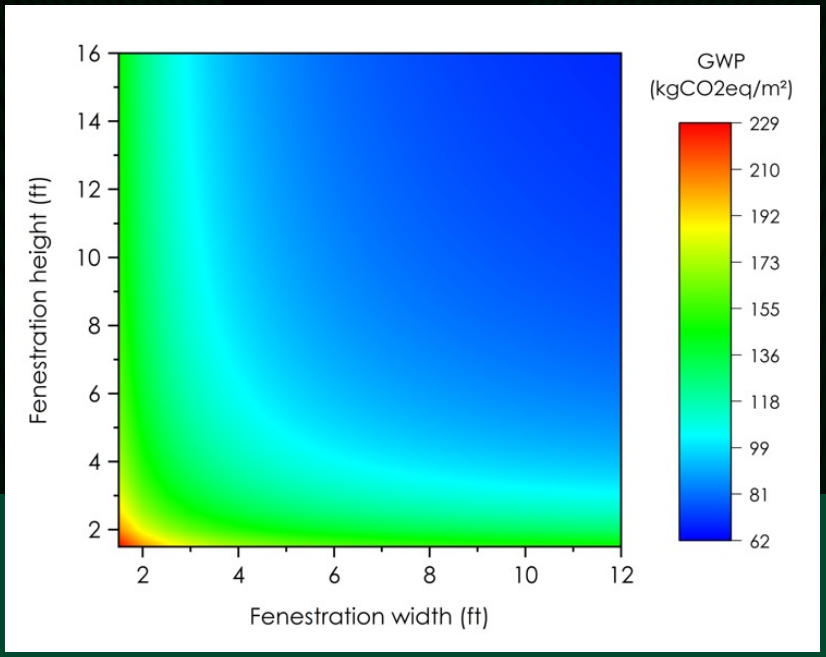


FIGURE 2.3. *Fenestration GWP per unit area as a function of fenestration height and width.*

We'll illustrate a simple example for an area of 4' x 8' (1.2 x 2.4 m). Using two 4' x 4' (1.2 x 1.2 m) windows results in embodied carbon of 117 kgCO2eq/m² but if you instead use a single 4' x 8' window the embodied carbon is reduced to 99 kgCO2eq/m². This simple design decision saves 17% embodied carbon, and the savings can be more pronounced when factoring in even smaller window sizes. Wherever possible minimizing the framing perimeter required for the same fenestration area will reduce the embodied carbon of the system.

An important note is that this relation holds true for a given frame dimension and glass thickness – if increasing the daylight opening dimensions necessitate deeper mullions or thicker glass, this must be taken into account in the comparison. A building products manufacturer should be able to assist in optimizing the fenestration design for given openings. In our analysis we use 1.5 x 1.2 m fixed windows and calculate the embodied carbon to be 130 kgCO2eq/m² per window area (652 m²).

The medium office building considered here has a 33% window to wall ratio and a floor area of 4,982 m², thus the fenestration embodied carbon is 17 kgCO2eq/m² of floor space. This represents 3 to 6% of the total building embodied carbon of the building based on the previously mentioned benchmarking study, however this number can vary significantly as the window to wall ratio or carbon footprint of fenestration changes.

In this article we discussed how the embodied carbon of an aluminum fenestration system can vary dramatically and is primarily driven by the details of the aluminum used. *Choosing a fenestration system that uses aluminum with high recycled content and low carbon primary billet is the biggest step a designer can take to minimize the footprint of the fenestration, although window geometry and glass thickness can also play a role.* Through EPDs, fenestration design, and working with building products manufacturers an architect can calculate the embodied carbon of a building and evaluate options to minimize it.

Total Carbon & Embodied Carbon Percentage

A COMPLETE LOOK AT THE IMPACT OF FENESTRATION SYSTEMS

Through a more detailed understanding of the operational and embodied carbon components of a fenestration system, architects may make better decisions to reduce the total carbon footprint of fenestration and the entire building design. The best strategies will be both comprehensive and detailed. A wholistic approach includes detailed analysis of both embodied carbon and operational carbon through methods like whole building life cycle assessment) and combines tools such as embodied carbon calculators with building energy modeling.

In this article, we combine our calculations of embodied carbon and operational carbon for our model of a medium office building and the aluminum fenestration system to examine the regional variation in carbon footprint makeup to understand the cumulative lifetime carbon emissions of new buildings as well as those with window retrofits.

As discussed in the previous article we are looking at the portion of operational carbon attributed directly to the fenestration system based on heat loss and gain through the window at a state-by-state level using site-specific fenestration specifications, climate, and electricity grids. We also examine geographic variations in the embodied carbon percentage, where embodied carbon percentage is the embodied carbon (cradle-to-gate) divided by the total carbon (embodied plus operational).

Cumulative Carbon Emissions

For a deeper look at the total carbon footprint of fenestration systems, we look at two locations: **Buffalo, New York** (climate Zone 5A) where the energy consumption is heating dominated and **Tucson, Arizona** (climate Zone 2B) where the energy consumption is cooling dominated. The model building has 4900 m² of floor space with a window to wall ratio of 33%. The 2019 model code specifies fenestration U-factor = 2.0 W/m²-K (0.35 Btu/hr-ft²-°F) and solar heat gain coefficient (SHGC) = 0.38 for Zone 5A and U-factor = 2.6 W/m²-K (0.46 Btu/hr-ft²-°F) and SHGC = 0.25 for zone 2B.

Building simulations show a similar amount of annual energy usage for the fenestration system in both locations (40 kWh/m² for Buffalo, and 39 kWh/m² for Tucson), however, the carbon intensity of the grid in Arizona is 56% higher compared with New York resulting in an increased operational carbon footprint.

When a building is initially built, its carbon footprint is completely based on the embodied carbon–all the greenhouse gases (GHG) it took to build.

Each year new carbon is emitted from electricity and fossil fuel consumption, increasing the operational carbon, and shifting the embodied carbon percentage lower. **After 30 years of operation, the embodied carbon will account for 37% of the total emissions for Buffalo and 26% for Tucson.** The profile of cumulative total carbon emissions for the Arizona building is shown in Figure 3.1 along with how the percentage of embodied carbon will change throughout a 30-year period. The lifetime of the fenestration system is a critical aspect of the carbon footprint and embodied carbon percentage, but it cannot always be well determined at the time of building design. **As the lifetime of a building product is increased, it is likely that use phase embodied carbon (maintenance, repair, refurbishment) will become more important.**

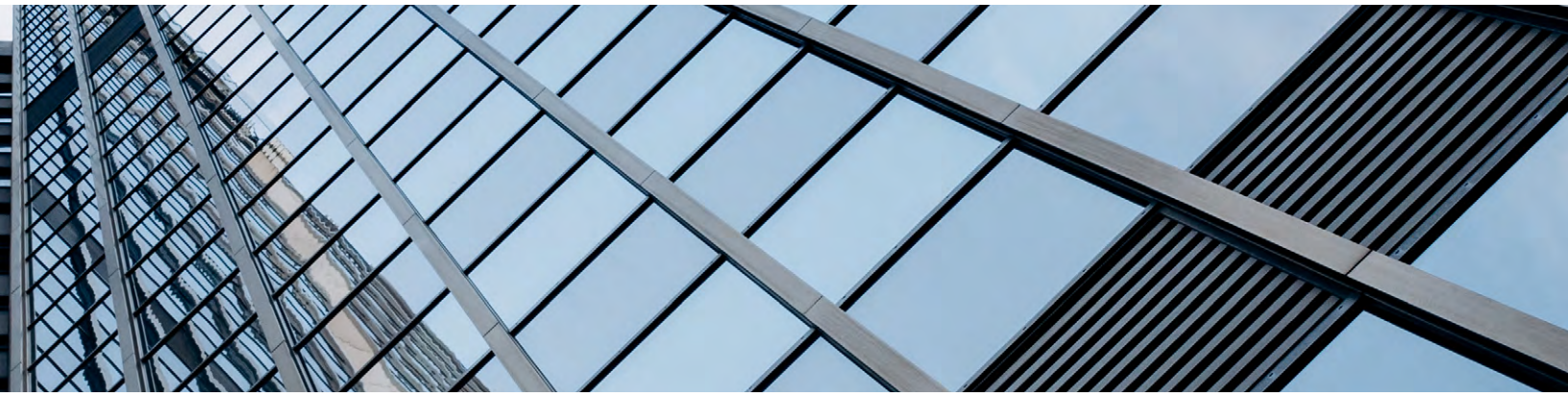
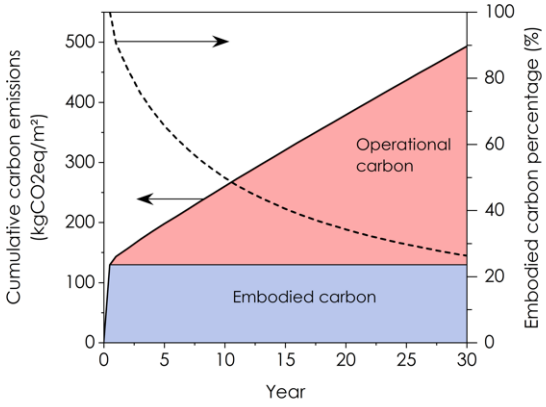


FIGURE 3.1.

Cumulative CO2 emissions from manufacturing ("Embodied") and use ("Operational") phases of fenestration system for the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) medium office building in Tucson, Arizona. The CO2eq emissions are normalized by the total window area (650 m²). Embodied carbon emissions are all attributed to year zero of a building while operational carbon slowly accumulates over the building lifetime.



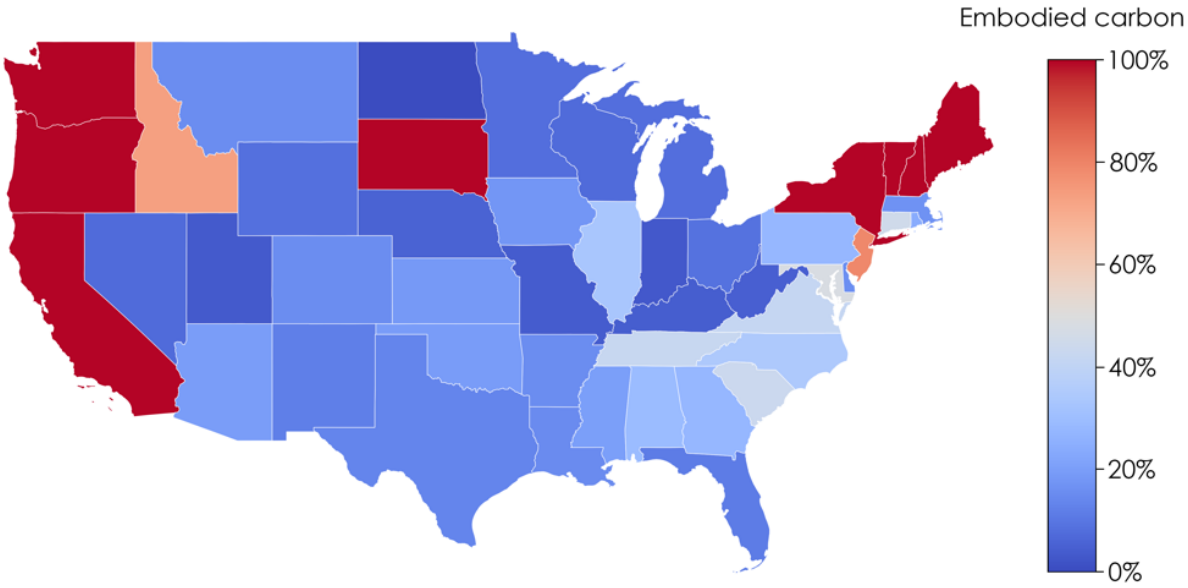
The solid line represents the cumulative carbon emissions while the dashed line represents the embodied carbon percentage.

Embodied Carbon Percentage

Historically, operational carbon has far outweighed the embodied carbon of typical buildings due to the poor energy efficiency and the carbon-intensive electric grid in the U.S. **Now with more efficient HVAC, higher performing windows, and LED lighting along with a cleaner grid, the embodied carbon can comprise a significant portion of the total building carbon footprint.** However, the percentage can still vary widely based on the local climate, specific building performance, electric grid, along with the building materials used. To examine how this can change regionally, we can combine state-by-state operational carbon information with the averaged embodied carbon (Figure 3.2).

FIGURE 3.2.

Estimated embodied carbon percentage by state where Embodied carbon percentage = Embodied carbon / (Embodied carbon + Operational carbon). Embodied carbon remains constant and operational carbon is calculated as shown in Figure 1.2. Operating carbon is cumulative over 30 years.



There is a clear geographical concentration of areas with high embodied carbon percentage in the West and Northeast U.S., which coincides with the regions with the lowest carbon electrical grids (Figure 1.2). An important note is that this analysis uses the ASHRAE 90.1 2019 model codes, so it will not include the influence of enacted state code levels. Many of the states with the least stringent enacted codes are those that already show low embodied carbon as a percentage. An analysis using enacted codes would show higher operational carbon in those states driving the embodied carbon percentage lower. In all, there are eight states where the fenestration embodied carbon percentage is 95% or higher, but otherwise the vast majority (70%) have an embodied carbon percentage below 40%.

This study uses a dual pane IGU; introducing advanced glazing products such as triple pane IGUs, vacuum insulating glass (VIG), or electrochromic glass will increase the embodied carbon percentage of the system. Often times these advanced glazing systems will pay pack the higher initial investment in embodied carbon through the reduction in operational carbon over its lifetime.

While any building design should strive to reduce both embodied carbon and operational carbon, understanding the relative amount of each can be useful for a designer to know where to primarily focus efforts. For example, a project in the state of Washington (electricity carbon intensity 103 kgCO2/MWh) is better served to specify an aluminum framing system with a high-recycled content or certified hydro smelting. In contrast, in portions of the Midwest U.S., the biggest carbon reductions will be achieved through high thermal performance fenestration systems. This is not to suggest that embodied carbon and operational carbon cannot be reduced simultaneously, but accurate data regarding the relative contributions can improve design and decisions.

Carbon Payback For Retrofits

One of the most effective ways to reduce the environmental impact of the built environment is to reuse and renovate buildings rather than building new where possible. An analysis of the whole building carbon comparison for new versus renovated is beyond the scope of this article, but we will demonstrate how this can be viewed specifically for a fenestration system. We turn back to our medium office building in Buffalo and Tucson. Let's suppose we are examining a 30-year-old building and want to know the impact of retrofitting the fenestration. If the original windows conform to the ASHRAE 90.1 1989 code and the new windows comply with the 2019 version of the code, we can look at the energy consumption savings with the new windows and translate that into carbon savings to determine how quickly we can offset the embodied carbon of a new fenestration system and what type of lifetime savings can be achieved. We look at a range of embodied carbon with a low carbon (90 kgCO2/m^2) and a high carbon (270 kgCO2/m^2) fenestration system retrofitted in both Buffalo and Tucson.

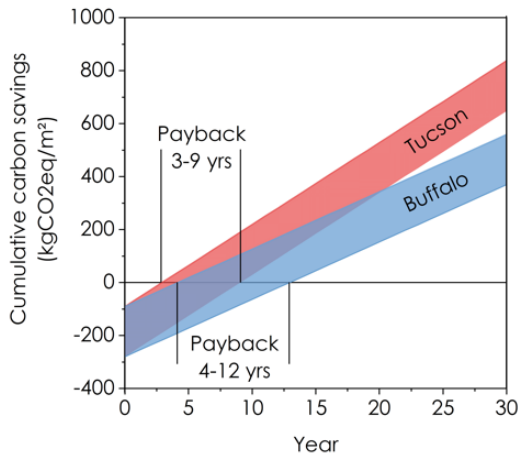


FIGURE 3.3.

Cumulative carbon savings from replacement of 30-year-old windows in Tucson, Arizona (climate Zone 2B) and Buffalo, New York (climate Zone 5A). Carbon payback period is 3-9 years in Tucson and 4-12 years in Buffalo, when operational carbon savings has offset the embodied carbon from the new window system. ***The shaded region represents a range of paybacks based on different starting embodied carbon values****. The CO2eq emissions are normalized by the total window area (650 m^2).*

Figure 3.3 shows the range of cumulative carbon per year starting with a large negative carbon investment in the embodied carbon of a new fenestration system. The annual energy savings in both locations is approximately 100 kWh/m^2 (per unit fenestration area), but the carbon savings is slightly higher in Tucson due to the higher carbon intensity of the grid in that location. In the case of the low embodied carbon fenestration system, the payback can be as little as 3 years in Tucson and 4 years in Buffalo with the upper range of 9 and 12 years, respectively depending upon the specific embodied carbon of the retrofit system.

The total lifetime savings over 30 years would be 600 tonnes CO2eq in Tucson and 420 tonnes CO2eq in Buffalo; with an 85 tonne CO2eq initial spend in embodied carbon this comes out to a **return on investment** of **700%** and **500%**, respectively.

This demonstrates that significant benefits in GHG reductions can be achieved despite upfront embodied carbon emissions for fenestration retrofits. Each retrofit should be analyzed carefully with site specific information to determine the anticipated carbon savings for the project.

Conclusion

It is important for architects and engineers to understand that there is not a general rule of thumb that applies when considering the embodied carbon content of a commercial aluminum fenestration system. It is critical that any building designer motivated to reduce carbon emissions understands the specific situation related to the building and fenestration specified in question to make informed decisions. Understanding the predicted building energy consumption and carbon intensity of the heating and cooling systems is vital, along with the embodied carbon of the aluminum framing system.

The operational carbon is driven by the performance specifications of the fenestration, carbon intensity of the heating and cooling systems, and local weather. The embodied carbon is driven by the aluminum recycled content and source of primary billet along with the ratio of framing to glass. When a holistic view of the manufacturing and use phase of an aluminum fenestration system is considered it is possible to minimize both operational and embodied carbon in a way that provides the best environmental benefit.

To learn more about reducing the footprint of your façade, contact us at carbon@obe.com.