INFINITE FACADE

# Life Cycle Assessment Report

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# Contents

# Introduction

Clark Pacific engaged Walter P Moore and Associates, Inc. to perform a lifecycle assessment on several typical configurations of their Infinite Façade panel system for the purpose of understanding the global warming potential per square foot of each configuration. This study is a follow-up study to the Clark Pacific Envelope study produced by Glumac that studied energy performance. Glumac's energy analysis studied the impact of different Infinite Facade enclosure system configurations on the operational energy use of prototype buildings. The purpose of the current study is to understand the embodied carbon of the same Infinite Façade configurations studied by Glumac, as well as functionally equivalent baseline wall types for comparison.

The Infinite Facade system consists of a 2-1/4" precast concrete skin reinforced with welded wire mesh supported by a steel HSS frame with spray foam insulation. The interior finish consists of 5/8" type X gypsum board over steel furring channels. For panels with windows, the glazing system is a captured aluminum window system with a thermally broken frame. The aluminum frame is 5" x 2.5" with a weight of 2.41lbs/ft. The window considered in this study is a 1" IGU with a buildup of ¼" annealed glass with low-e coating on the #2 surface + argon-filled airspace + ¼" annealed glass.

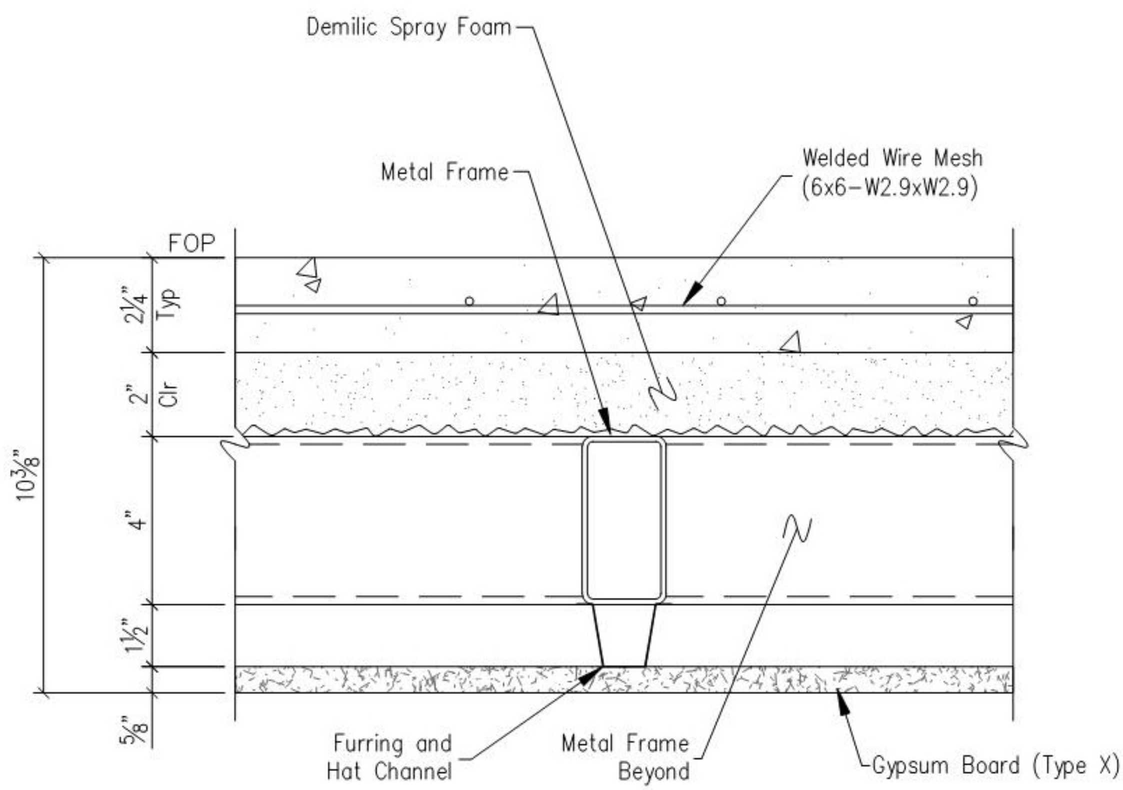



*Figure 1: Plan detail of Infinite Facade system (not to scale)*

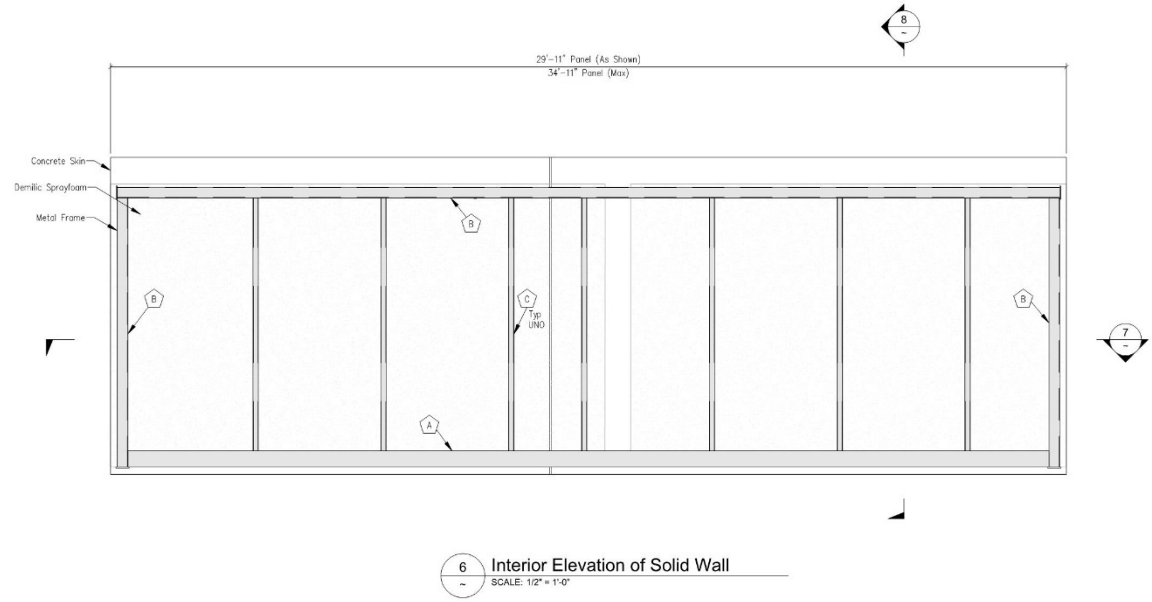



*Figure 2: Infinite Facade solid wall panel interior elevation (not to scale)*

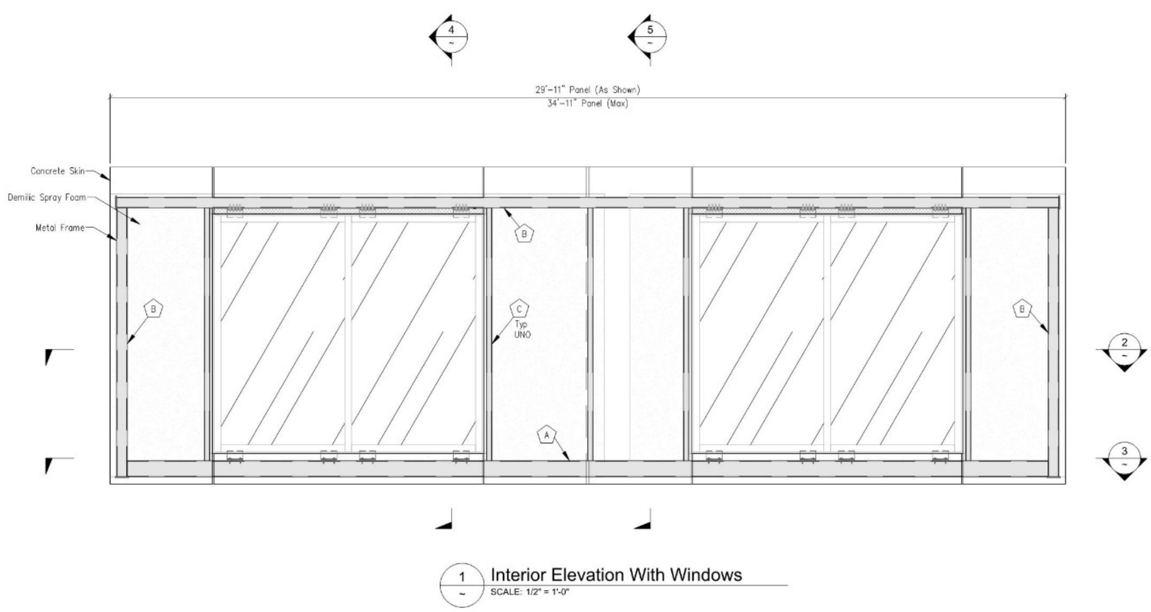



*Figure 3: Infinite Facade wall panel with windows interior elevation (not to scale)*

The following variables have been analyzed in the LCA studies in this report:

**Insulation Type and Thickness**

Two wall types have been considered, W3 and W4. Type W3 has 2" of spray foam insulation for an effective U-value of 0.065 Btu/h-sf-F for the opaque wall assembly and Type W4 has 3" of spray foam insulation for an effective U-value of 0.046 Btu/h-sf-F for the opaque wall assembly. For each wall type, two different blowing agents for the spray foam insulation have been considered: HFC and HFO.

**Concrete Mix**
Two different concrete mixes have been considered, Mix A and Mix B. Concrete mix proportions were provided by Clark Pacific based on common mixes used in the wall panels. See concrete mix tables in the Material Assumptions section of this report for mix design.

**Window to Wall Ratio**
Three different window to wall ratios have been considered as well as one solid opaque panel option. The three window to wall ratios are the same as those studied by Glumac.

| | | Solid panel | | 40% Glazed | | 55% Glazed | | 70% Glazed | |
|---|---|---|---|---|---|---|---|---|---|
| | | Concrete Mix A | Concrete Mix B | Concrete Mix A | Concrete Mix B | Concrete Mix A | Concrete Mix B | Concrete Mix A | Concrete Mix B |
| W3 | 2" Spray Foam Insulation (HFO blowing agent) | * | * | * | | * | | * | |
| | 2" Spray Foam Insulation (HFC blowing agent) | * | | | | | | | |
| W4 | 3" Spray Foam Insulation (HFO blowing agent) | * | | | | | | | |
| | 3" Spray Foam Insulation (HFC blowing agent) | * | | | | | | | |

* indicates option to be studied

**Comparison with Alternative Wall Assemblies**
A selection of other common enclosure buildups has been included for comparison with the Infinite Façade system, including two opaque wall assemblies that are functionally equivalent to the code baseline wall from Glumac's energy study, as well as two glazed curtain wall assemblies.

# Scope and Methodology

To understand the impacts of different variables within the Infinite Façade system and how it compares to other common wall assemblies, we conducted four separate LCA studies using the Tally software plugin for Revit. The five environmental impact measures that Tally calculates are global warming potential, acidification, eutrophication, smog formation, and non-renewable energy. These are the WBLCA metrics used in nationally recognized high-performance green building codes, standards and rating systems (e.g. International Green Construction Code, ASHRAE 189.1 and in LEED v4/4.1). While operational energy for the building can be included in Tally, it was considered outside the scope of this study, and was not analyzed. The primary impact considered in this study is Global Warming Potential (GWP). The scope of this study was limited to the façade system and included lifecycle stages available in Tally: A1-A3 (product), A4 (transportation), B2-B5 (maintenance and replacement), C2-C4 (end of life), and module D. See the Lifespan Assumptions section for more information on stages B2-B5.
For each wall type, the quantity of each material per square foot of wall area was modeled in Revit and analyzed in Tally. See the Material Assumptions section for detailed information on LCI and EPD data used for each material.

## Study 1: Insulation Type and R-Value Comparison

The purpose of the first study is to understand the impacts of insulation type and thickness on the global warming potential of the wall assembly.

| | HFO Blowing Agent | HFC Blowing Agent |
|---|---|---|
| W3 - 2" Spray Foam Insulation | 1.1 | 1.2 |
| W4 - 3" Spray Foam Insulation | 1.3 | 1.4 |

## Study 2: Concrete Mix Design Comparison

The purpose of the second study is to understand the impact of concrete mix design on the global warming potential of the wall assembly by comparing two typical mix designs that Clark Pacific uses frequently, referred to here as Mix A and Mix B. See the Material Assumptions section of this report for more detailed information on each concrete mix. From Study 1, one insulation option was selected as the baseline wall buildup for comparing the two concrete mixes (Wall Type W3 with HFO blowing agent).

| | Concrete Mix A | Concrete Mix B |
|---|---|---|
| W3 - 2" Spray Foam Insulation (HFO) | 2.1 | 2.2 |

## Study 3: Window to Wall Ratio and Curtainwall Comparison

The purpose of the third study is to understand the impact of glazing on the global warming potential of the wall assembly. From Study 2, one wall assembly and concrete mix were selected for further study (Wall Type W3 with HFO blowing agent and Mix B). This study compares a solid wall to walls with 40%, 55%, and 70% window-to-wall ratios. In addition, two curtain wall assemblies were added to the comparison – one based on an EPD for a complete curtain wall system from Kawneer, and the other based on a custom glass buildup (matching the windows used in the Infinite Facade system) with curtain wall mullion system EPD from YKK.

| | Solid | 40% Glazed | 55% Glazed | 70% Glazed | Curtain Wall 1 (YKK) | Curtain Wall 2 (Kawneer) |
|---|---|---|---|---|---|---|
| W3 - 2" Spray Foam Insulation (HFO) - Concrete Mix B | 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 |

## Study 4: Comparison to Alternative Wall Types

The purpose of the fourth study is to understand how the Infinite Façade system compares to other opaque enclosure options. From Study 2, one Infinite Façade wall assembly and concrete mix combination were selected for further study (Wall Type W3 with HFO blowing agent and Mix B). The infinite façade panel is then compared to two different wall buildups, both with ACM rainscreen cladding.

| | Infinite Façade | Backup Wall 1 | Backup Wall 2 |
|---|---|---|---|
| **Infinite Façade**<br>W3 - 2" Spray Foam Insulation (HFO) - Concrete Mix B | 4.1 | n/a | n/a |
| ACM Rainscreen Cladding | n/a | 4.2 | 4.3 |

### Wall Assemblies

For the backup wall assemblies, two options were considered. The first option is a metal stud wall with mineral wool cavity insulation and mineral wool continuous insulation on the exterior of the façade, which is a similar configuration to the code baseline wall from Glumac's report and provides the same U-value. The second backup wall option is a buildup that also meets code and that Walter P Moore considers to be more typical, which is a metal stud wall with all the code-required insulation provided as continuous insulation on the exterior of the wall. See the table above and wall sections in Figure 4 for more information on the backup wall buildups.

**Cladding Material**

The finish material for both alternative wall types studied is an ACM rainscreen panel system. ACM was selected due to its low cost and widespread use as a cladding material.

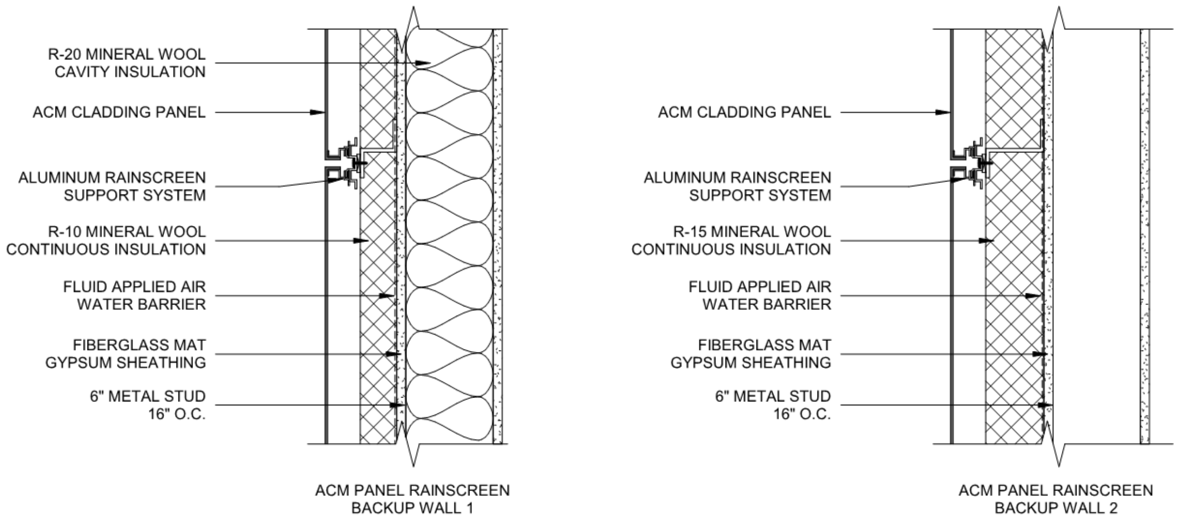



*Figure 4: Section details of alternative wall type buildups for Study 4 (not to scale)*

# Material Assumptions

Tally permits quantities to be entered in a variety of ways. The quantity takeoff method and LCI data source for each material are listed in the text and tables below. Tally uses the mass of each material in the model to calculate the environmental impacts. For components measured by volume (for example, concrete), Tally uses density data from its material database to calculate the mass. For components measured by area (walls), or length (framing members), Tally uses the mass per square foot or mass per linear foot from its material database to calculate the quantity.

## Concrete

Concrete was measured by modeled volume. Materials were assigned to each mix component using the custom concrete mix material in Tally. EPDs for different aggregates, sand, cement, and admixtures are not available in Tally, so both mixes use the same LCI data for these elements. The difference in quantity of each component of the mix is what causes the difference in environmental impact for the two mixes. EPD's for individual admixtures are not available in Tally, so the default admixture material has been assigned to the total weight of admixtures in each mix. The tables below indicate the quantities of each component of the concrete mix and the EPD used for each.

| **Concrete Mix A** | | | | |
|---|---|---|---|---|
| **Product** | **LCI Source** | **Quantity** | **Weight (lb/yd3)** | **Mass (kg/m3)** |
| Cement - 13025 - Lehigh White - Type I - White - Lehigh White | US: Portland cement PCA/ts (2014) | 900lb | 900 | 533.95 |
| Water - H20 - Potable Water - City Water - Water, W.Sac / Total Water (288.0 lb) | US: Tap water from groundwater ts (2017) | 288lb | 283.6 | 168.25 |
| Stone - 13168 - 3/8" X #8 - Crushed stone - Calrock Premium | EU-28: Gravel 2/32 ts (2017) | 1400lb | 1734 | 1028.74 |
| Sand - 13169 - #4 - Manufactured sand - Calrock Premium | US: Silica sand (Excavation and processing) ts (2017) | 1292lb | 1310 | 777.19 |
| Admixture - 13128 - 4R - Viscosity modifier - Sika, Santa Fe Springs | US: Diethanolamine (DEA) ts (2017) | 45.00oz/yd3 | 2.86875 | 1.70 |
| Admixture - 13174 - Perfin 305 - Concrete Surface Enhancing Admixture - Sika, Santa Fe | US: Tensides (alcohol ethoxy sulfate (AES)) ts (2017) | 45.00oz/yd3 | 2.503125 | 1.49 |
| Admixture - 13190 - SIKA TARD 440 - Hydration stabilizer - Sika, Santa Fe Springs | | 18.00oz/yd3 | 1.29375 | 0.77 |
| Admixture - 13181 - ViscoCrete 1000 - High range water reducer - Sika, Santa Fe Springs | | 45.00oz/yd3 | 2.98125 | 1.77 |
| Admixture - 13131.A902 - WHITE - Pigment - Davis / Water Included, Volume Included | | 24.84lb/yd3 | 24.24 | 14.38 |
| Admixture - 13314 - ViscoFlow 2020 - Slump Retention - Sika, Santa Fe Springs | | 45.00oz/cwt | 26.325 | 15.62 |
| Other constituent - 13178 - Sika Fibers HP 1/2" - Fibers - Sika, Santa Fe Springs | | 1lb | 1 | 0.59 |
| **Admixture Total** | | | **61.211875** | **36.32** |
| **TOTAL** | | | **4288** | **2544.45** |
| Reinforcement - Steel, Welded Wire Mesh | GLO: Steel wire rod worldsteel (2014)<br>DE: Copper wire (0.6 mm) ts (2017)<br>US: Electricity grid mix ts (2014)<br>US: Thermal energy from natural gas ts (2014) | 0.42psf | | |

| Concrete Mix B | | | | |
|---|---|---|---|---|
| **Product** | **LCI Source** | **Quantity** | **Weight (lb/yd3)** | **Mass (kg/m3** |
| Cement - 13319 - Cal Portland type III - Type III - Cal Portland | US: Portland cement PCA/ts (2014) | 850 lb | 850 | 504.28 |
| Water - H-20 - Well Water - Well - Well Water | US: Tap water from groundwater ts (2017) | 340.0 lb | 340 | 201.71 |
| Stone - 13193 - 1/2" X 3/8" - Crushed stone - Handley, Gonzales | EU-28: Gravel 2/32 ts (2017) | 1400 lb | 1400 | 830.59 |
| Sand - 13082 - #4 - Manufactured sand - CP08, Lhoist | US: Silica sand (Excavation and processing) ts (2017) | 1292 lb | 1292 | 766.51 |
| Admixture - 13131 - Scofield G30 (Yellow) - Granular Color - Scofield | US: Diethanolamine (DEA) ts (2017) | 25.500 lb/yd³ | 25.5 | 15.13 |
| Admixture - 13131 - Scofield G20 (Light Red) - Granular Color - Scofield | US: Tensides (alcohol ethoxy sulfate (AES)) ts (2017) | 2.500 lb/yd³ | 2.5 | 1.48 |
| Admixture - 13131 - Scofield G10 (Black) - Granular Color - Scofield | | 2.000 lb/yd³ | 2 | 1.19 |
| Admixture - 13181 - ViscoCrete 1000 - High range water reducer - Sika, Santa Fe Springs | | 64.00 oz/yd³ | 4.24 | 2.52 |
| Admixture - 13128 - 4R - Viscosity modifier - Sika, Santa Fe Springs | | 34.00 oz/yd³ | 2.1675 | 1.29 |
| Admixture - 13314 - ViscoFlow 2020 - Slump Retention - Sika, Santa Fe Springs | | 85.00 oz/yd³ | 5.525 | 3.28 |
| Admixture - 13330 - Plastiment XR - Retarder - Sika, Santa Fe Springs | | 25.00 oz/yd³ | 1.6875 | 1.00 |
| Admixture Total | | | 43.62 | 25.88 |
| **TOTAL** | | | **3882** | **2328.98** |
| Reinforcement - Steel, Welded Wire Mesh | GLO: Steel wire rod worldsteel (2014)<br>DE: Copper wire (0.6 mm) ts (2017)<br>US: Electricity grid mix ts (2014)<br>US: Thermal energy from natural gas ts (2014) | 0.42psf | | |

## Steel

Steel was modeled by length & section size in Revit and measured by volume in Tally.

| Steel | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Weight (psf) | | | | | | | |
| | | Wall Type W3 | | | | Wall Type W4 | | | |
| Product | LCI Source | Solid | 40/60 | 55/45 | 70/30 | Solid | 40/60 | 55/45 | 70/30 |
| Steel HSS | RNA: Steel finished cold rolled coil worldsteel (2007)<br>GLO: Steel sheet stamping and bending (5% loss) ts (2017)<br>US: Electricity grid mix ts (2014)<br>US: Lubricants at refinery ts (2014)<br>GLO: Compressed air 7 bar (medium power consumption) ts (2014)<br>GLO: Value of scrap worldsteel (2014) | 4.21 | 3.96 | 3.83 | 3.58 | 4.21 | 3.96 | 3.83 | 3.58 |
| Steel Furring & Hat Channel | RNA: Steel finished cold rolled coil worldsteel (2007)<br>GLO: Steel sheet stamping and bending (5% loss) ts (2017)<br>US: Electricity grid mix ts (2014)<br>US: Lubricants at refinery ts (2014)<br>GLO: Compressed air 7 bar (medium power consumption) ts (2014)<br>GLO: Value of scrap worldsteel (2014) | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |

## Glazing, Insulation, and Finishes

Spray foam insulation was measured by volume using a 2” layer of spray foam for Wall Type W3 and a 3” layer of spray foam for Wall Type W4. The IGU was created using the custom IGU material in Tally and was measured by modeled area. Tally calculates the mass of each component of the IGU based on the area of wall assigned to the Tally IGU material. The aluminum mullion was measured by length and assigned a weight of 2.41psf which was provided by Clark Pacific for their typical mullion.

| Glazing, Insulation, and Finishes | |
|---|---|
| **Product** | **LCI Source** |
| Gypsum Wall Board, Type X | DE: Gypsum plaster board (Fire protection) (EN15804 A1-A3)PE (2017) |
| Spray Polyurethane Foam Insulation (HFO Blowing Agent) | EPD (US), SPFA (2018) - EPD: ASTM-EPD085 |
| Spray Polyurethane Foam Insulation (HFC Blowing Agent) | EPD (US), SPFA (2018) - EPD: ASTM-EPD087 |
| IGU - Glass | DE: Window glass simple (EN15804 A1-A3) ts (2017) |
| IGU - Low-e coating | Low-e coating from DE: Double glazing unit (EN15804 A1-A3) ts (2017) |
| IGU - Argon Gas | US: Argon (gaseous) ts (2017) |
| IGU - Spacer | DE: Polybutadiene rubber ts (2017)<br>DE: Nitrile butadiene rubber, incl. MMA (NBR-speciality) ts (2017) |
| Aluminum Mullion | EPD (US), American Extruders Council (2016) - EPD: 11240237.102.1 |

## Materials for Alternative Wall Types

**Backup Walls**

For each wall model in study 4, a 10'x10' model was created, to enable the stud walls to be measured by modeled area using 16" on center one-way spacing with perimeter members. Output values were then converted to a per-square-foot basis.

Mineral wool cavity insulation was measured by area using R-20 low density mineral wool. Mineral wool continuous insulation was measured by area using R10 high density mineral wool board insulation for Backup Wall 1 and R-15 high density mineral wool board insulation for Backup Wall 2.

**Sheathing, Waterproofing, Rainscreen Cladding Systems**

Sheathing, waterproofing, and rainscreen cladding panels were measured by modeled area. Tally calculates the mass of each component of the cladding system based on the area of wall assigned to the Tally cladding material. The Tally material for the ACM panel system includes both the finish and aluminum extrusions that support the panels.

**Glazed Curtain Wall Systems**

For the YKK curtain wall system, the IGU was created using the custom IGU material in Tally and was measured by modeled area. Tally calculates the mass of each component of the IGU based on the area of wall assigned to the Tally IGU material. The mullion system was also measured by area. The mullion system EPD from YKK provides a fixed mass per square foot of curtain wall area and Tally uses this information to calculate the amount of mullion material.

For the Kawneer curtain wall system, the EPD is for a complete curtain wall system. Tally uses the EPD information to calculate the environmental impacts based on total area of curtain wall.

| Materials in Alternative Wall Types | |
|---|---|
| **Product** | **LCI Source** |
| Aluminum Rainscreen Support - Aluminum extrusion, AEC - EPD | RNA: Aluminum extrusion, mill finish - AEC (A1-A3) ts-EPD (2015)<br>RNA: Primary Aluminum Ingot AA/ts (2010)<br>RNA: Secondary Aluminum Ingot AA/ts (2010) |
| Aluminum-faced composite wall panel (ACM), MCA - EPD | US: Metal composite material (MCM) panel MCA (2010) |
| Metal Studs - Cold formed structural steel | RNA: Steel finished cold rolled coil worldsteel (2007)<br>GLO: Steel sheet stamping and bending (5% loss) ts (2017)<br>US: Electricity grid mix ts (2014)<br>US: Lubricants at refinery ts (2014)<br>GLO: Compressed air 7 bar (medium power consumption) ts (2014)<br>GLO: Value of scrap worldsteel (2014) |
| Curtain Wall Mullion System - YKK | EPD (US), YKK AP America (2015) |
| Curtain Wall System - Kawneer | EPD (US), Kawneer North America (2015) |
| Fiberglass mat gypsum sheathing board | DE: Gypsum plaster board (Moisture resistant) (EN15804 A1-A3) ts (2017)<br>US: Fiberglass Duct Board NAIMA (2007) |

(continued next page)

| Materials in Alternative Wall Types (continued) | |
|---|---|
| **Product** | **LCI Source** |
| Fluid applied elastomeric air barrier | US: Styrene-butadiene rubber (SBR) ts (2017)<br>US: Naphtha at refinery ts (2014)<br>US: Bitumen at refinery ts (2014)<br>US: Silica sand (flour) ts (2017)<br>US: Electricity grid mix ts (2014) |
| Fluoropolymer coating, metal stock | US: Coil coating MCA (2010)<br>US: Electricity grid mix ts (2014)<br>US: Thermal energy from natural gas ts (2014) |
| Gypsum Wall Board, Type X | DE: Gypsum plaster board (Fire protection) (EN15804 A1-A3)PE (2017) |
| IGU - Argon Gas | US: Argon (gaseous) ts (2017) |
| IGU - Glass | DE: Window glass simple (EN15804 A1-A3) ts (2017) |
| IGU - Low-e coating | Low-e coating from DE: Double glazing unit (EN15804 A1-A3) ts (2017) |
| IGU - Spacer | DE: Polybutadiene rubber ts (2017)<br>DE: Nitrile butadiene rubber, incl. MMA (NBR-speciality) ts (2017) |
| Mineral wool, high density, NAIMA - EPD | US: Rock board insulation (heavy density) NAIMA (2007) |
| Mineral wool, low density, NAIMA - EPD | US: Rock board insulation (light density) NAIMA (2007) |

## Transportation Assumptions

Because complete transportation information for the products used in these assemblies is not available, we used Tally's default transportation distances. Tally's default transportation values are based on the three-digit material commodity code in the 2012 Commodity Flow Survey by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation is not available.

| Transportation Distances | | | | |
|---|---|---|---|---|
| **Material (Tally Entry)** | **Truck (km)** | **Rail (km)** | **Barge (km)** | **Container Ship (km)** |
| Admixture | 229 | 7 | 0 | 0 |
| Aluminum curtain wall system, YKK AP – EPD* | 663 | 0 | 0 | 0 |
| Aluminum extrusion, thermally-improved painted, AEC - EPD | 663 | 0 | 0 | 0 |
| Aluminum-faced composite wall panel (ACM), MCA – EPD* | 663 | 0 | 0 | 0 |
| Argon gas for IGU | 940 | 0 | 0 | 0 |
| Coarse aggregate | 37 | 29 | 5 | 12 |
| Cold formed structural steel | 431 | 0 | 0 | 0 |
| Curtain wall system, Kawneer, 1600 Wall System – EPD* | 663 | 0 | 0 | 0 |
| Fiberglass mat gypsum sheathing board* | 172 | 0 | 0 | 0 |
| Fluid applied elastomeric air barrier* | 172 | 0 | 0 | 0 |
| Fluoropolymer coating, metal stock (for ACM panel)* | 0 | 0 | 0 | 0 |
| Glazing, monolithic sheet, generic | 940 | 0 | 0 | 0 |
| IGU spacer | 940 | 0 | 0 | 0 |
| Low-e coating (for glazing) | 0 | 0 | 0 | 0 |
| Mineral wool, high density, NAIMA – EPD* | 172 | 0 | 0 | 0 |
| Mineral wool, low density, NAIMA – EPD* | 172 | 0 | 0 | 0 |
| Portland cement, PCA - EPD | 120 | 72 | 67 | 399 |
| Sand | 37 | 14 | 4 | 24 |
| Spray polyurethane foam, closed cell (HFC blowing agent), SPFA - EPD | 1,683 | 0 | 0 | 0 |
| Spray polyurethane foam, closed cell (HFO blowing agent), SPFA - EPD | 1,683 | 0 | 0 | 0 |
| Steel, welded wire mesh | 431 | 0 | 0 | 0 |
| Wall board, gypsum, fire-resistant (Type X) | 172 | 0 | 0 | 0 |
| Water | 0 | 0 | 0 | 0 |

* these materials are used in the alternative wall types only

## Lifespan Assumptions

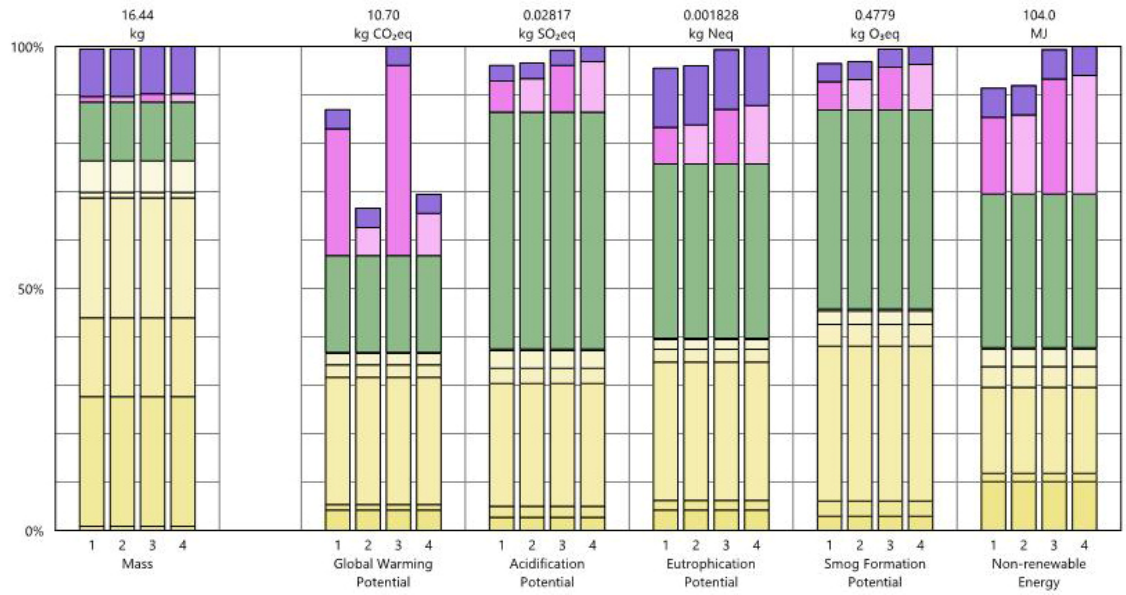
For the purposes of these studies, the lifespan of all materials has been set to the building life to remove material replacement cycles from consideration (lifecycle stages B2-B5). The building life has been set to the default setting of 60 years.

# Results

## Study 1: Insulation Options

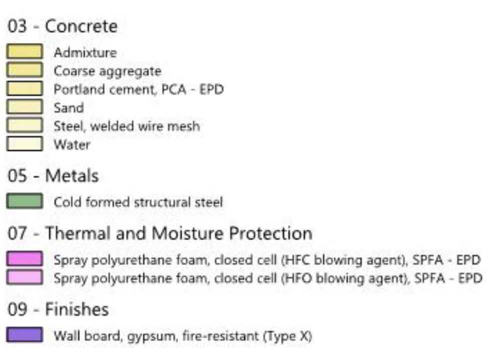
This study compares two insulation thicknesses and two spray foam blowing agent types for a solid wall panel.  All other variables including concrete mix design are kept consistent across all options.  The spray foam options that use HFO blowing agent have a much lower global warming potential than the options that use HFC blowing agent.  Wall type W3 with HFC blowing agent has a global warming potential of 9.30kgCO2eq/sf while the same wall with HFO blowing agent has a global warming potential of 7.12kgCO2eq/sf.  Wall type W4 with HFC blowing agent has a global warming potential of 10.70kgCO2eq/sf and 7.43kgCO2eq/sf with HFO blowing agent.  Changing the blowing agent can have a greater impact than changing the quantity of insulation.

Option 1.1:  2" Spray Foam / HFC Blowing Agent / Concrete Mix B
Option 1.2:  2" Spray Foam / HFO Blowing Agent / Concrete Mix B
Option 1.3:  3" Spray Foam / HFC Blowing Agent / Concrete Mix B
Option 1.4:  3" Spray Foam / HFO Blowing Agent / Concrete Mix B




**Legend**

1. Option 1.1:  2" Spray Foam / HFC Blowing Agent / Concrete Mix B
2. Option 1.2:  2" Spray Foam / HFO Blowing Agent / Concrete Mix B
3. Option 1.3:  3" Spray Foam / HFC Blowing Agent / Concrete Mix B
4. Option 1.4:  3" Spray Foam / HFO Blowing Agent / Concrete Mix B

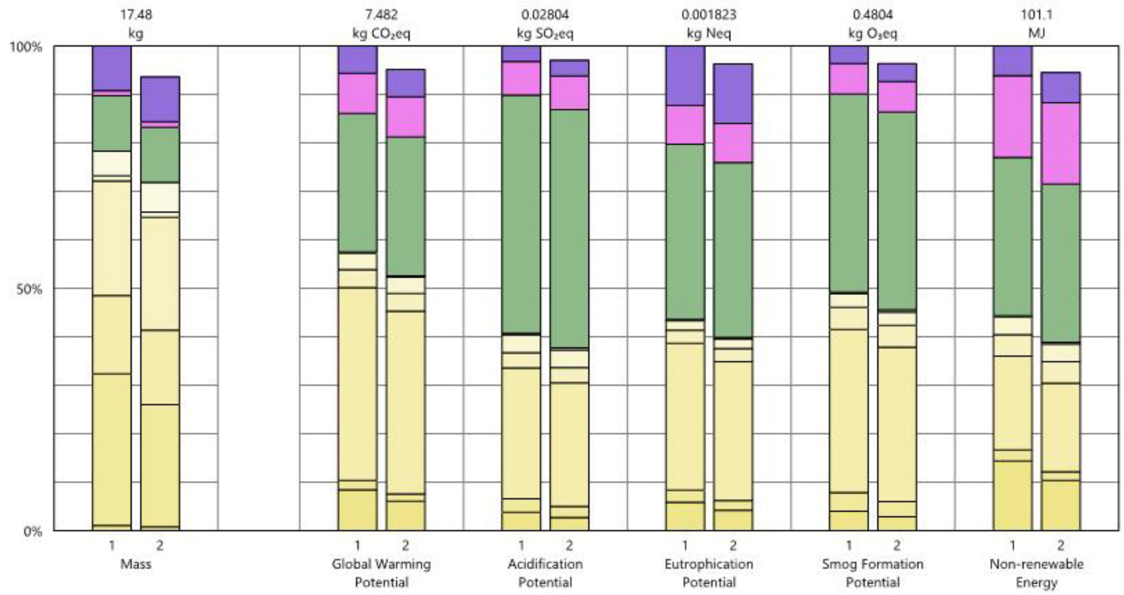


| Study 1: Insulation Options | | | |
|---|---|---|---|
| **Row Labels** | | **Sum of Global Warming Potential Total (kgCO2eq)** | **Sum of Mass Total (kg)** |
| **W3 - HFC** | | **9.30** | **16.35** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam, closed cell (HFC blowing agent) | | 2.80 | 0.19 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |
| **W3 - HFO** | | **7.12** | **16.35** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.62 | 0.19 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |
| **W4 - HFC** | | **10.70** | **16.44** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam, closed cell (HFC blowing agent) | | 4.20 | 0.28 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |
| **W4 - HFO** | | **7.43** | **16.44** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam, closed cell (HFC blowing agent) | | 0.93 | 0.28 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |

## Study 2: Concrete Mix Design

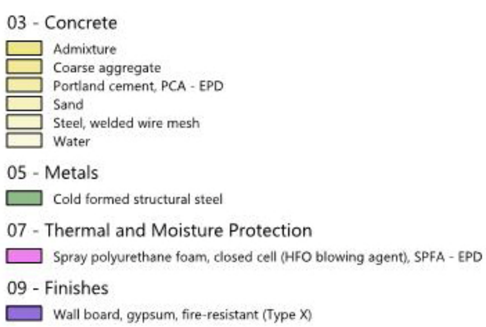
This study compares two concrete mix designs on a solid panel while keeping all other variables in the wall assembly the same. The complete wall assembly with Mix A has a global warming potential of 7.48kgCO2eq/sf while the assembly with Mix B has a global warming potential of 7.12kgCO2eq/sf.

Option 2.1: Mix A / Solid Wall / 2” Spray Foam Insulation (HFO)
Option 2.2: Mix B / Solid Wall / 2” Spray Foam Insulation (HFO)




**Legend**

1. Option 2.1 / Mix A / Solid Wall / 2” Spray Foam Insulation (HFO)
2. Option 2.2 / Mix B / Solid Wall / 2” Spray Foam Insulation (HFO)

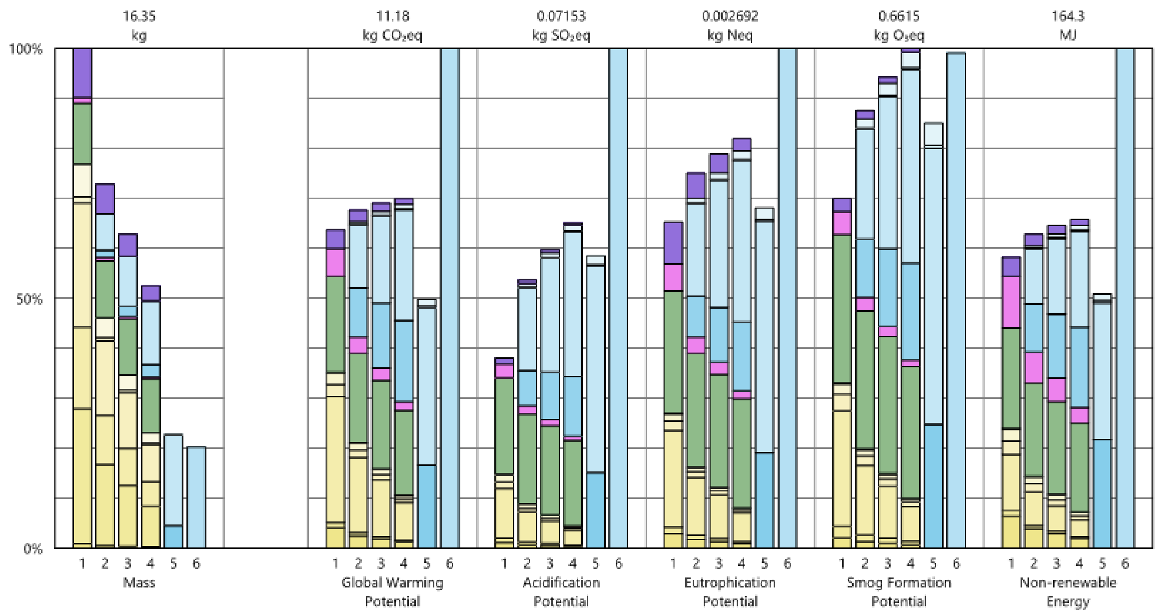


| Study 2: Concrete Mix Design | | | |
|---|---|---|---|
| | | Sum of Global Warming Potential Total (kgCO2eq) | Sum of Mass Total (kg) |
| **Mix A** | | **7.48** | **17.48** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.63 | 0.19 |
| | Coarse aggregate | 0.14 | 5.46 |
| | Portland cement | 2.98 | 2.83 |
| | Sand | 0.28 | 4.13 |
| | Water | 0.02 | 0.89 |
| | Welded wire mesh | 0.25 | 0.19 |
| Spray Polyurethane foam (HFO Blowing Agent) | | 0.62 | 0.19 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |
| **Mix B** | | **7.12** | **16.35** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam | | 0.62 | 0.19 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |

## Study 3: Window to Wall Ratio and Curtain Wall Comparison

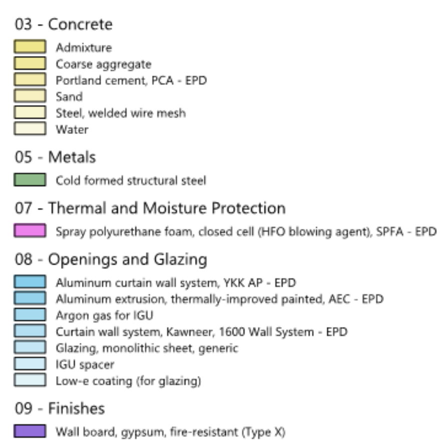
This study compares a solid panel of the Infinite Façade system with three different window to wall ratios while keeping all other variables in the assembly the same. It also includes two curtain wall systems for reference. Of the Infinite Facade variations studied, the 70/30 window to wall ratio has the highest global warming potential at 7.82kgCO2eq/sf while the solid wall has the lowest at 7.12gCO2eq/sf. There is a significant difference in global warming potential between the two curtain wall systems, with Curtain Wall 1 at 5.56kgCO2eq/sf, lower than all four of the Infinite Façade configurations studied here, and Curtain Wall 2 at 11.18kgCO2eq/sf, higher than all four of the Infinite Façade configurations.

Option 3.1: Solid Wall / 2" Spray Foam Insulation (HFO) / Concrete Mix B
Option 3.2: 40/60 Window to Wall / 2" Spray Foam Insulation (HFO) / Concrete Mix B
Option 3.3: 55/45 Window to Wall / 2" Spray Foam Insulation (HFO) / Concrete Mix B
Option 3.4: 70/30 Window to Wall / 2" Spray Foam Insulation (HFO) / Concrete Mix B
Option 3.5: Curtain Wall 1 / Custom IGU Buildup / YKK Mullion System EPD
Option 3.6: Curtain Wall 2 / Kawneer Complete Curtainwall System EPD




**Legend**

1. Option 3.1: Solid Wall
2. Option 3.2: 40/60 Window to Wall
3. Option 3.3: 55/45 Window to Wall
4. Option 3.4: 70/30 Window to Wall
5. Option 3.5: Curtain Wall 1 - YKK
6. Option 3.6: Curtain Wall 2 - Kawneer



| Study 3: Window to Wall Ratio and Curtain Wall Comparison | | Sum of Global Warming Potential Total (kgCO2eq) | Sum of Mass Total (kg) |
|---|---|---|---|
| **0% Glazed** | | **7.12** | **16.35** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| Concrete | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.62 | 0.19 |
| Steel furring channel | | 0.07 | 0.07 |
| Type X Gypsum Board | | 0.42 | 1.61 |
| **40% Glazed** | | **7.55** | **11.90** |
| Steel - HSS Tube | | 1.95 | 1.81 |
| Concrete | Admixture | 0.27 | 0.08 |
| | Coarse aggregate | 0.07 | 2.65 |
| | Portland cement | 1.69 | 1.61 |
| | Sand | 0.16 | 2.44 |
| | Water | 0.01 | 0.64 |
| | Steel, welded wire mesh | 0.15 | 0.11 |
| Glazing | Aluminum extrusion, thermally-improved painted | 1.09 | 0.24 |
| | Argon gas for IGU | <0.01 | <0.01 |
| | Glazing, monolithic sheet, generic | 1.41 | 1.18 |
| | IGU spacer | 0.02 | 0.00 |
| | Low-e coating (for glazing) | 0.06 | 0.01 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.37 | 0.11 |
| Steel furring channel | | 0.04 | 0.04 |
| Type X Gypsum Board | | 0.25 | 0.97 |

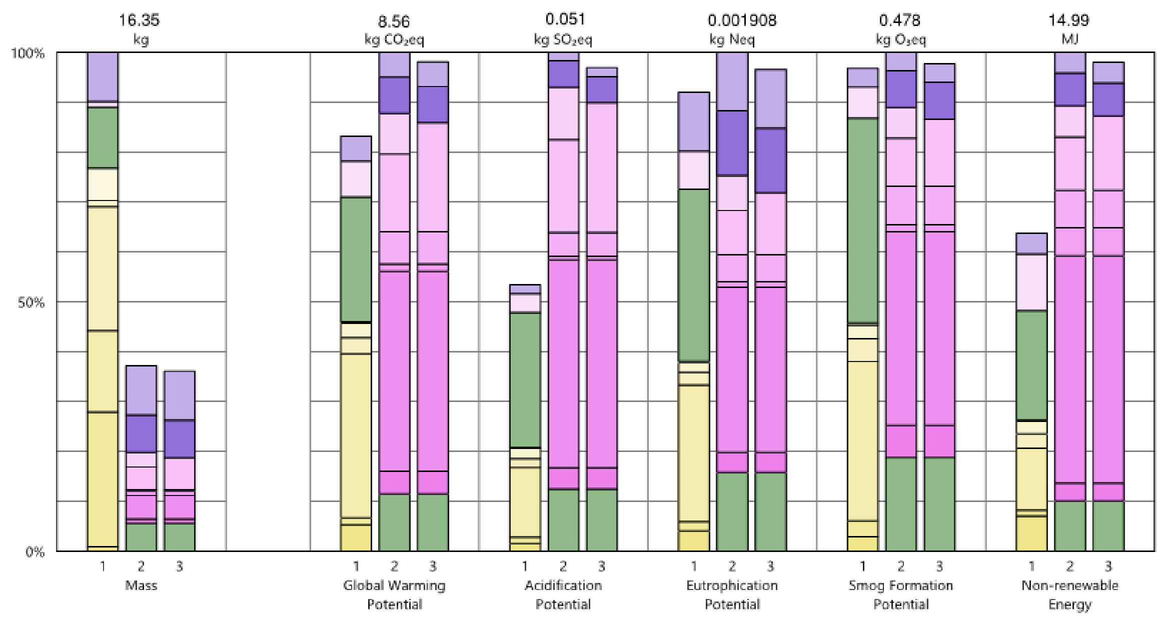
(continued next page)

| Study 3: Window to Wall Ratio and Curtain Wall Comparison (continued) | | Sum of Global Warming Potential Total (kgCO2eq) | Sum of Mass Total (kg) |
|---|---|---|---|
| **55% Glazed** | | **7.72** | **10.26** |
| Steel - HSS Tube | | 1.95 | 1.81 |
| Concrete | Admixture | 0.20 | 0.06 |
| Concrete | Coarse aggregate | 0.05 | 1.98 |
| Concrete | Portland cement | 1.27 | 1.20 |
| Concrete | Sand | 0.12 | 1.83 |
| Concrete | Water | 0.01 | 0.48 |
| Concrete | Steel, welded wire mesh | 0.11 | 0.09 |
| Glazing | Aluminum extrusion, thermally-improved painted | 1.46 | 0.32 |
| Glazing | Argon gas for IGU | <0.01 | <0.01 |
| Glazing | Glazing, monolithic sheet, generic | 1.94 | 1.62 |
| Glazing | IGU spacer | 0.02 | 0.01 |
| Glazing | Low-e coating (for glazing) | 0.08 | 0.01 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.28 | 0.08 |
| Steel furring channel | | 0.03 | 0.03 |
| Type X Gypsum Board | | 0.19 | 0.72 |
| **70% Glazed** | | **7.82** | **8.57** |
| Steel - HSS Tube | | 1.88 | 1.75 |
| Concrete | Admixture | 0.14 | 0.04 |
| Concrete | Coarse aggregate | 0.04 | 1.32 |
| Concrete | Portland cement | 0.85 | 0.80 |
| Concrete | Sand | 0.08 | 1.22 |
| Concrete | Water | 0.01 | 0.32 |
| Concrete | Steel, welded wire mesh | 0.08 | 0.06 |
| Glazing | Aluminum extrusion, thermally-improved painted | 1.82 | 0.41 |
| Glazing | Argon gas for IGU | <0.01 | <0.01 |
| Glazing | Glazing, monolithic sheet, generic | 2.47 | 2.06 |
| Glazing | IGU spacer | 0.03 | 0.01 |
| Glazing | Low-e coating (for glazing) | 0.10 | 0.01 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.19 | 0.06 |
| Steel furring channel | | 0.02 | 0.02 |
| Type X Gypsum Board | | 0.13 | 0.48 |
| **Curtain Wall 1 - YKK** | | **5.56** | **3.71** |
| Aluminum curtain wall system, YKK AP | | 1.85 | 0.73 |
| Argon gas for IGU | | <0.01 | <0.01 |
| Glazing, monolithic sheet, generic | | 3.53 | 2.95 |
| IGU spacer | | 0.04 | 0.01 |
| Low-e coating (for glazing) | | 0.14 | 0.01 |
| **Curtain Wall 2 - Kawneer** | | **11.18** | **3.31** |
| Curtain wall system, Kawneer, 1600 Wall System | | 11.18 | 3.31 |

## Study 4: Alternative Wall Types Comparison

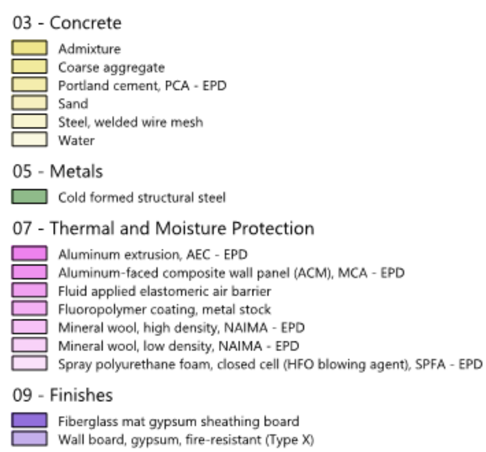
This study compares a solid panel of the Infinite Façade system with two other wall assemblies, both with ACM rainscreen cladding. The Infinite Façade system at 7.12kgCO2eq/sf compares favorably with the other two wall assemblies studied at 8.39kgCO2eq/sf and 8.56kgCO2eq/sf.

Option 4.1 – Infinite Façade / W3 / HFO / Mix B
Option 4.2 – ACM Rainscreen Panel System / Backup Wall 1
6" metal stud at 16" O.C. with R-20 mineral wool cavity insulation + R-10 mineral wool continuous insulation
Option 4.3 – ACM Rainscreen Panel System / Backup Wall 2
6" metal stud at 16" O.C. with R-15 mineral wool continuous insulation




**Legend**

1. Option 4.1 – Infinite Façade
2. Option 4.2 – ACM Panel / Backup Wall 1
3. Option 4.3 – ACM Panel / Backup Wall 2



| Study 4: Alternative Wall Types Comparison | | | |
|---|---|---|---|
| | | **Sum of Global Warming Potential Total (kgCO2eq)** | **Sum of Mass Total (kg)** |
| **Infinite Façade (solid wall)** | | **7.12** | **16.35** |
| Steel - HSS Tube | | 2.07 | 1.93 |
| **Concrete** | Admixture | 0.45 | 0.14 |
| | Coarse aggregate | 0.12 | 4.41 |
| | Portland cement, PCA - EPD | 2.82 | 2.68 |
| | Sand | 0.27 | 4.07 |
| | Water | 0.02 | 1.07 |
| | Steel, welded wire mesh | 0.25 | 0.19 |
| Steel Furring Channel | | 0.07 | 0.07 |
| Spray polyurethane foam, closed cell (HFO blowing agent) | | 0.62 | 0.19 |
| Type X Gypsum Wall Board | | 0.42 | 1.61 |
| **ACM Panel on Backup Wall 1** | | **8.56** | **6.07** |
| **Cladding** | Aluminum Extrusion - Rainscreen Cladding Support | 0.38 | 0.14 |
| | Aluminum-faced composite wall panel (ACM) | 3.43 | 0.77 |
| | Fluoropolymer coating (for ACM Panel) | 0.55 | 0.03 |
| **Backup Wall** | Cold formed structural steel studs | 0.98 | 0.91 |
| | Fiberglass mat gypsum sheathing board | 0.62 | 1.23 |
| | Fluid applied elastomeric air barrier | 0.13 | 0.15 |
| | Mineral Wool, High Density (Continuous Insulation) | 1.34 | 0.76 |
| | Mineral Wool, Low Density (Cavity Insulation) | 0.70 | 0.47 |
| | Type X Gypsum Wall Board | 0.42 | 1.61 |
| **ACM Panel on Backup Wall 2** | | **8.39** | **5.90** |
| **Cladding** | Aluminum Extrusion - Rainscreen Cladding Support | 0.38 | 0.14 |
| | Aluminum-faced composite wall panel (ACM) | 3.43 | 0.77 |
| | Fluoropolymer coating (for ACM Panel) | 0.55 | 0.03 |
| **Backup Wall** | Cold formed structural steel studs | 0.98 | 0.91 |
| | Fiberglass mat gypsum sheathing board | 0.62 | 1.23 |
| | Fluid applied elastomeric air barrier | 0.13 | 0.15 |
| | Mineral Wool, High Density (Continuous Insulation) | 1.87 | 1.06 |
| | Type X Gypsum Wall Board | 0.42 | 1.61 |

# Conclusions

From the insulation option comparison, we can see that using a spray foam product with HFO blowing agent instead of HFC provides a significant reduction in global warming potential, more significant than changing the quantity of insulation used. The concrete mix design comparison shows that cement is the largest contributor to global warming potential of all of the concrete mixes. Changes to the mix design that reduce the amount of cement used can significantly lower the global warming potential of concrete. Glass is also a significant contributor to global warming potential. Reducing the amount of concrete skin while adding glass will increase the global warming potential of the overall assembly, depending on the glass buildup used. The steel HSS members make up nearly 30% of the global warming potential of the solid wall option.

Studies 3 and 4 show that the Infinite Façade system has a lower GWP than several of the other wall options studied, however, it is difficult to make comparisons to a wide variety of enclosure systems at this time because there isn't yet a critical level of data available from throughout the industry.

**Facades Consortium Group**

Facades Consortium Group LLC is a partnership between Wells and Clark Pacific to facilitate and accelerate the R&D efforts surrounding Infinite Facade, a single-source prefabricated building envelope system, simplifying facade design. Both companies are aligned in the vision to evolve the lightweight panel systems that help create a resilient, durable, and sustainable built environment. We are committed to designing, manufacturing, and installing a quality product no matter where the project is located. Infinite Facade is engineered to be flexible to meet regional building and design requirements.