Comparison of Carbon Footprint of Spray Polyurethane Foam Building Enclosures with Non-Foam Alternatives

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ABSTRACT
Sustainability has become a core focus in architectural design, driving the construction industry toward more environmentally responsible building practices. As architects seek to minimize the carbon footprint of their projects, understanding material choices is crucial. Three key green building standards—LEED, Passive House, and the Living Building Challenge—offer strategies to reduce environmental impact through comprehensive performance and operational approaches.

With development by the academic community of a simulation with the partnership of SPF system houses there is the ability to detail the total carbon footprint of a building assembly. A series pre-designed of spray foam wall enclosures have been evaluated. The evaluation includes detailing the total carbon footprint of the enclosure, including options for various cladding types, structural systems, and thermal insulation, giving architects an invaluable tool to make informed, sustainable design decisions.

This presentation will highlight how carbon footprint stacks up against traditional insulation options and how its raw materials contribute to its status as a low-carbon solution. Additionally, key terms such as carbon footprint, embodied carbon, LCAs, and EPDs will be clearly explained to ensure the reader leaves with a solid understanding of these critical concepts.

INTRODUCTION
The construction industry is responsible for roughly 40% of the worldwide carbon emissions. This is larger than any other segment. (Figure 1).

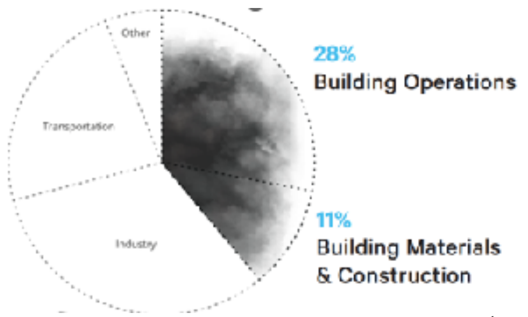


Figure 1. Worldwide Carbon Emissions[1]

When one looks at the carbon impact of a building there are two sources of carbon emissions from a building (Figure 1), one associated with building operation which is estimated to be ~28% of the emissions and the other, embodied carbon, which is associated with the manufacture of the building materials used in the structure which is estimated to be ~11%. The construction and design community have done extensive work on making the buildings more energy efficient, and in the process, reduced the building's operational carbon. So, the focus on the embodied carbon associated with the manufacture of the building products has become more visible to the design and regulatory community.

Embodied carbon can easily be defined as the GHG emissions before a building is ever commissioned or built. It includes items such as emissions from the energy used to extract raw materials (mining, logging, refining), the energy associated with the manufacture of building products (such as kilns, furnaces, laminators, foam reactors), transporting materials to the job site, installations and eventually disposal or recycling at the end of life. Figure 2

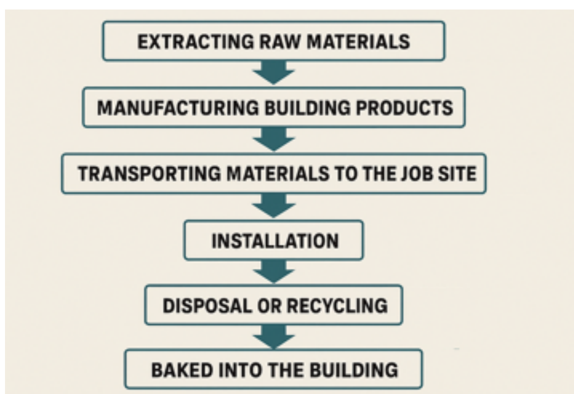


Figure 2. Sources of Embodied Carbon in Building Materials

With the ever-changing regulatory landscape, the focus on carbon emissions has varied. Figure 3 shows the world's carbon emissions by country.

[1] Global ABC- Global Status Report 2018

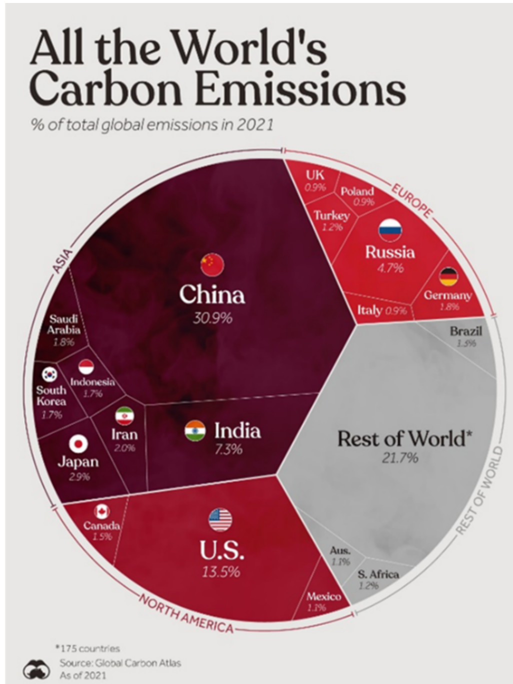


Figure 2. World's Carbon Emissions by Country[2]

Canada represents only 1.5% of the carbon emissions but it has made significant regulatory efforts to reduce all the carbon emissions associated with buildings. The Canadian Board for Harmonized Construction Codes (CBHCC) has approved changes on an objective to address greenhouse gas (GHG) emissions and technical requirements for operations GHG emissions for the 2025 editions of the National Energy Code of Canada for Building (NECB) and the National Building Code of Canada[3]. This focuses on reducing building energy requirements (i.e. the operational carbon footprint). In addition, the CBHCC's work plan for the 2030 code cycle includes the development of technical requirements to minimize excessive embodied GHG emissions. The CBHCC's federal, provincial, and territorial Working Group on Climate Change Mitigation was struck to draft policy direction to inform the planned technical work for the 2030 Codes. These efforts will focus on new homes and commercial buildings.

Although the regulatory driver is important in any situation the bigger influence is the adoption of using total carbon (embodied + operation) in the absence of regulations by the building design community. The 2030 Architectural Challenge is a global effort to evaluate embodied carbon in building assemblies. This effort is fully engaged in Canada. To support this effort the industry formed an advisory panel of Building science firms, Universities, Government agencies, Architects, Manufacturers to develop a catalog of various building materials and wall assembly design for architects to use as reference when considering embodied carbon. The initial work was entitled "New Design Resources for Embodied Carbon Targets" and published by RDH Building Science[4]. *"In this guide, we have quantified the embodied carbon intensity of commonly used enclosure systems in the Greater Toronto and Hamilton Area (GTHA) used in office, multi-unit residential and institutional buildings (Ontario Building Code (OBC) Part 3 buildings). Using a standardized life cycle assessment methodology for calculating CO_2 equivalent emissions, embodied carbon metrics were established for 26 different enclosure assemblies."* [4]

[2] Global Carbon Atlas as of 2021
[3] https://cbhcc-cchcc.ca/en/phase-1-embodied-ghg-draft-policy-positions/
[4] RDH-TMU Embodied Carbon Resource Guide and Udisi et al. Embodied Carbon Impacts of Building Envelope Systems, World Sustainable Built Environment (2024).

The transition from HFC to Honeywell's Solstice HFO blowing agents has dramatically reduced the embodied carbon of polyurethane foam. This reduction is highlighted in the product LCA and EPD published by the manufacturers. It is also discussed in a paper published by Honeywell in 2012.[5] This makes the use of Solstice LBA based spray foam an ideal insulation for building assemblies, especially when embodied carbon is a consideration.

Lifecycle Analysis (LCA) VS Environmental Product Declaration (EPD)

Data for this analysis comes from a variety of sources. Often today the terms LCA (Life Cycle Assessment) and EPD (Environmental Product Declaration) are used interchangeably by the casual observer. Both sources are used in this analysis, and it is important to understand the difference. Table 1 below compares the documents and cites their similarities and differences.

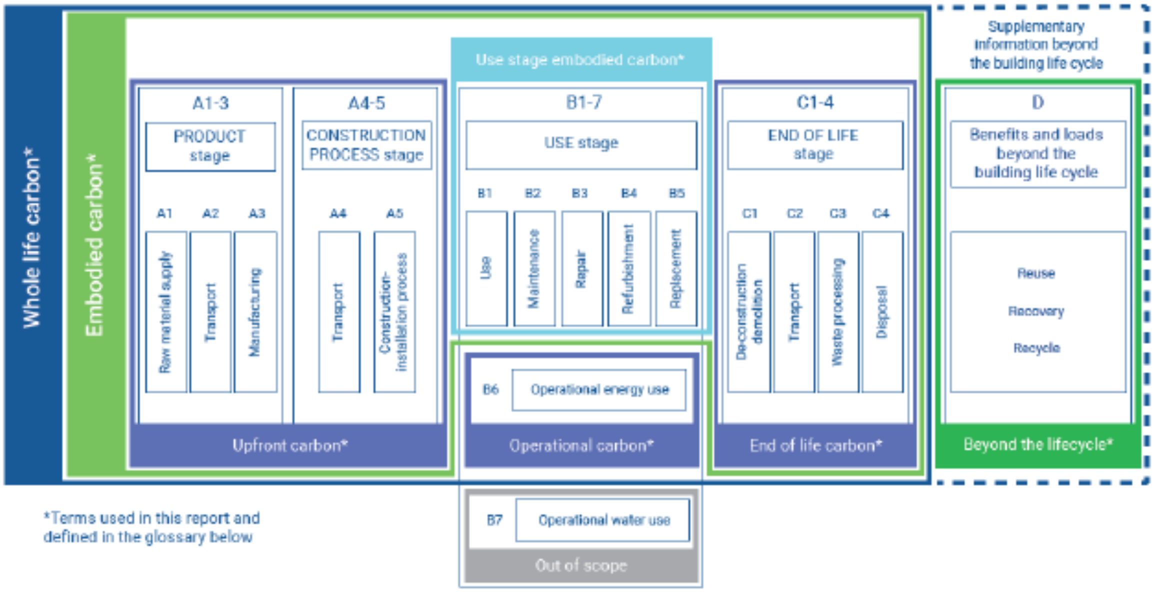
Table 1: Comparison of LCA and EPD

Document:	**LCA** **Life Cycle Assessment**	**EPD** **Environmental Product Declaration**
What is it:	A scientific methodology for assessing the environmental impacts of a product, process or service throughout its entire life cycle (from raw material extraction to disposal)	A standardized 3rd party verified report that provides transparent and comparable information about the environmental impact of a product throughout its life cycle. Created from LCA
Purpose:	To understand and quantify environmental impacts (e.g. carbon footprint, water use, energy use, pollution)	To communicate environmental performance transparently and credibly to external stakeholders (e.g. customers, regulators, building rating systems like LEED)
Scope:	Flexible, can be comparative, exploratory, or support internal decision-making	Follow a specific Product Category Rule (PCR) to ensure comparability between similar products
Audience:	Internal stakeholders, researchers, policy makers	External- architects, engineers, sustainability professionals, procurement officers
Standards:	ISO 14040 ISO 4444	ISO 14025 (Type II Environmental Declarations) EN 158-4 (for construction)

Although both follow ISO standards, the EPD follows a product category rule which makes the data used in the EPD more consistent in units and sources. Therefore, in this analysis the EPD data was more heavily relied upon. Since this work relies on a simulation it is also important to be specific on what components of a product life cycle are included and what is not in this comparison. The graphic in Figure 3 below indicates the areas included in embodied and operational carbon in this analysis.

[5] CPI Conference 2012 *"Life Cycle Analysis of Spray Foam Prepared with Solstice® Liquid Blowing Agent*" by Mary Bogdan, Xuaco Pascual

Figure 3 Building life cycle stages contributing to upfront (embodied) and operational carbon emissions[6]



ASSUMPTIONS

To have a building that is energy efficient and optimized for low embodied carbon there is a balance to be made. To do this effectively one needs to look at all options considering both the LCA and EPD of the materials and the structure. It is important to note that the generation of this information is being continually upgraded. Many documents are created for generic industry product vs manufacturer specific products. There is currently a transition to the product and manufacturer specific LCA's and EPDs from a generic product one.

In the analysis conducted by RDH[7] there were several assumptions made and conditions set. They are described in the following paragraphs.

"The embodied carbon emissions analysis was carried out by calculating the volume or mass of material in each layer of the assembly and then using emissions data from appropriate Environmental Product Declarations (EPDs). The calculations were made for a functional unit of 9 m^2 of enclosure assembly. This was to account for all assembly components that might be missing in a smaller area, such as studs, insulations pins, and anchorage systems. However, the data is reported both for 9m^2 and normalized for 1m^2 carbon intensity (kg CO_2e/m^2) to simplify early design stage calculations from enclosure area take-offs. The LCA calculations assumed a building life span of 60 years. If components had a shorter lifespan, the emissions associated with replacement were included.

The outputs for each enclosure include calculations for embodied carbon (kgCO_2e/m^2) for each layer of the system. Life cycle stages A1 to A3 are highlighted, indicating the layers with most impact. Life stages A4 and A5 are also included although these are a small proportion of the total. It should be noted that A5 emissions are attracting considerable attention at present but mostly these are attributed to general site activities and not to individual components or materials. To give some indication of total environmental impact including stages A, B and C, these are also reported based on various TRACI environmental impact categories but with less confidence of their accuracy. Biogenic carbon, which refers to carbon that is taken out of the atmosphere and stored in biological materials such as trees or plants through the process of photosynthesis, is also reported where appropriate. Materials that originate

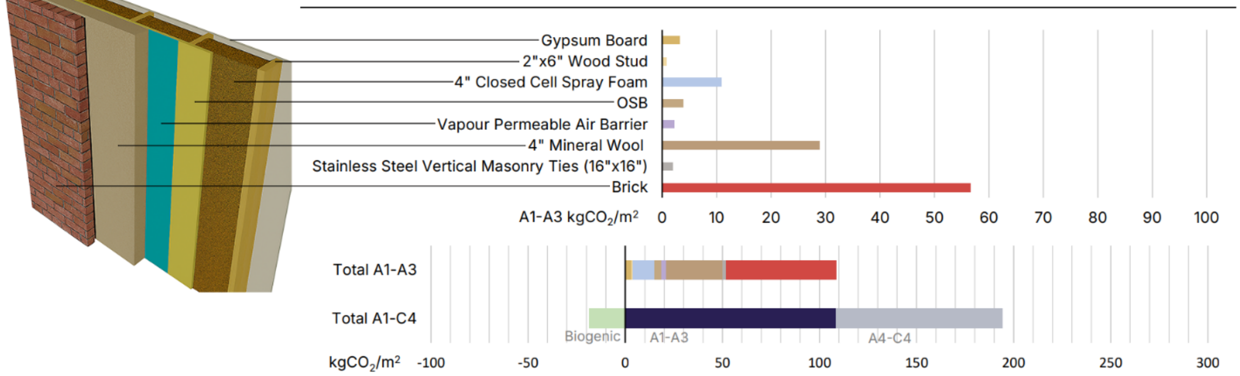
[6] RDH Building Science | Embodied Carbon- Elastochem and Honeywell | July 31, 2025 , Page 2
[7] RDH-TMU Embodied Carbon Resource Guide and Udisi et al. Embodied Carbon Impacts of Building Envelope Systems, World Sustainable Built Environment (2024).page 6-8

from biological sources may sequester carbon while in use as part of the enclosure system. In this respect biogenic carbon stored in timber and other plant-based materials can be viewed as a negative emission. Timber used in construction is considered to lock in the biogenic carbon for the lifetime of the building. When a component using such materials reaches the end of its life it is assumed to be incinerated with the stored carbon released back into the atmosphere."[8]

In Figure 4 below you can see that the A1 to A4 are graphically represented. The data for A4 and A5 are estimated from One Click database. As data generation increases for the building components the accuracy and regional focus of this data will increase and become more accurate.

Figure 4 Summary of Embodied Carbon for Assembly

Metrics	Results
Description	**Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud**
Effective R-value	RSI 6.1 m²K/W R 35 ft²·°F·h/BTU
Embodied Carbon per m² of Enclosure (A1-A3)	112.4 $kgCO_2/m^2$
Biogenic Carbon per m² of Enclosure	-18.6 $kgCO_2/m^2$



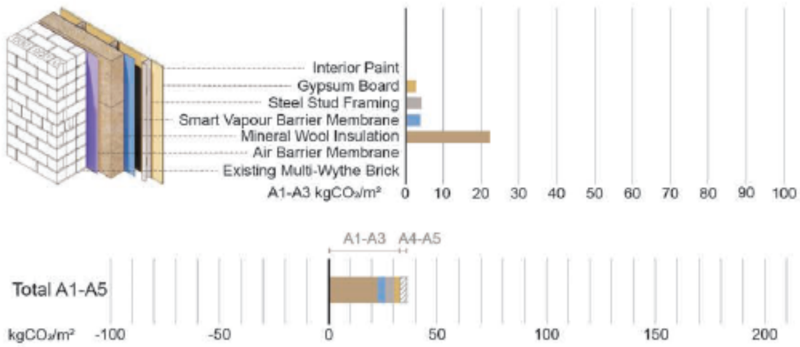
Analysis of Building Assemblies:
The use of this simulation allows the designer to compare two different assemblies or build an assembly with the focus on minimizing embodied carbon. This paper discusses the comparison of a commercial wall assembly one insulated with mineral wool and the other with Solstice LBA spray foam. These assemblies were prepared for the Toronto Ontario market. The paper also presents information on a brick and aluminum panel based commercial assembly that includes multiple types of insulation. These assemblies are for the US market. An option that may be found in high rise structures.

Comparison of Retrofit Assemblies in Toronto
Initially let's begin by comparing the same commercial assembly that utilizes two different insulations. This is an exterior masonry wall assembly. It is a retrofit application. These assemblies were modeled to meet the Toronto Green Standard. The baseline targets effective R-value the roof wall, exposed floor and vision glazing. The thermal performance target was set at R-25 for walls, R-30 for roofs and R-25 for floors. [9] It is important before we compare the assemblies that the details of each assembly are considered separately. The first assembly we are considering is Assembly 14 from the RDH report[9]. It represents an existing masonry with interior mineral wool insulation assembly. A summary of the values for the assembly are represented in Figure 5 below.

Figure 5 Summary of Values for Existing Masonry with Interior Mineral Wool Insulation Assembly[9].

[8] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 3
[9] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46

Summary for W14	
Description	**Existing Masonry with Interior Mineral Wool Insulation**
R-Value	Rsi 4.2 m²K/W R 24.0 ft2·°F·h/BTU
Embodied Carbon per m² of Enclosure (A1-A3)	33.7 $KgCO_2/m^2$
Biogenic Carbon per m² of Enclosure	0 $KgCO_2/m^2$



The mineral wool contributes the most to the assembly embodied carbon of all the components

Table 2 R- Value Calculations for Existing Masonry with Interior Mineral Wool Insulation Assembly. [9]

W14 R-Value Calculations:

Assembly Description	t_{si} [mm]	t_{ip} [in]	k [W/mK]	C (USI) [W/m²K]	RSI Effective [m²K/W]	R-effective (ft²·°F·h/BTU)	R-nominal (ft²·°F·h/BTU)
Interior Air Film					0.12	0.68	
Interior Gypsum Board	12.7	0.5	-	-	0.05	0.3	
Steel Stud-Framed Wall	63.50	2.5	0.49	7.75	0.13	0.73	
Smart Vapour Retarder	-	-	-	-	-	-	
Rigid or Semi-Rigid Mineral Fiber Board Insulation (Continuous)	127	5	-	-	3.75	21.29	21.5
Fluid-Applied Air Barrier and WRB Membrane (Vapour Membrane)	-	-	-	-	-	-	
Existing Multi-Wythe Brick Masonry	203.2	8	1.31	6.45	0.16	0.88	
Exterior Air Film					0.03	0.17	
Total	**406.4**	**16**			**4.2**	**24**	**21.5**

The major contributor to R-value in the assembly is mineral wool.

Table 3 Embodied Carbon Emissions (A1-A3 Life Stages) for $9m^2$ for Existing Masonry with Interior Mineral Wool Insulation Assembly. [10]

Category	Material (RDH Specification)	Description (from EPD)	Thickness [mm]	Volume of Material (m^3)	Carbon Emissions (A1-A3) ($KgCO_2E$)	% of Total
Finish	Interior Paint	Eggshell acrylic paint, 1294.29 kg/m³ (Generic)	0.16 (0.0063")	0.0014	0.56	0.20%
Finish	Gypsum board	Gypsum plaster board, regular, generic, 6.5-25 mm, 10.725 kg/m², (for 12.5 mm), 858 kg/m³	12.7 (0.5")	0.1143	26	8.60%
Back-Up Structure	Steel stud framing, no insulation	Steel stud framing for drywall/gypsum plasterboard per sq. meter of wall area (incl. air gaps per m³), C-profile: 63.5 x 30.48 mm, gauge 25, 3 m height x 406.4 mm (400 mm) spacing (Generic)	-	*	39	12.80%
Exterior Membrane	Smart vapour barrier membrane	Vapor barrier (Generic)	-	*	33	10.90%
Insulation External	Mineral wool insulation board	Heavy density mineral wool board, 1 m²K/W, 34 mm (1.34 in), 4.2 kg/m² (0.86 lb/ft2), 123.52 kg/m3 (7.71 lb/ft3), Industry average US (NAIMA)	127 (5")	1.143	200	66.0%
Air Barrier	Liquid applied air barrier membrane	Air and water barrier system, fluid applied, 0.9 kg/m² (0.184 lbs/ ft2), Tyvek (DuPont) (Product specific)	-	*	5.1	1.70%
Existing Structure	Existing Multi-Wythe Brick	Existing- Not included in calculations				
	Total				303.7	100.20%

*Software calculates the impact based on the area provided

Since this is a retrofit assembly, the brick does not contribute to the A1-A3 embodied carbon. If this was new construction the contribution for the brick would be significant. Based upon the data for the building materials the internal insulation- mineral wool, represents 66% of the embodied carbon. The final table for the assembly Table 4 is a summary of the environmental emissions (A1 to C4 life stages) for $9m^2$.

Table 4 Environmental Emissions (A1-A3 Life Stages) for $9m^2$ for Existing Masonry with Interior Mineral Wool Insulation Assembly. [11]

		A1 to C4	A1-A3	A4-A5	B1-B5	C1-C4	A1-A3
Result Category	Units	Total	Construction Materials	Transportation to Site & Construction	Material Replacement & Refurbishment	Deconstruction	A1-A3 % of Total
Global Warming	kg CO_2e	805.356	304.58	3.288	94.81	402.678	37.82%
Ozone Depletion	kg CFC11e	7.61E-06	1.31E-06	8.67E-07	1.63E-06	3.81E-06	17.21%
Acidification	kg SO_2e	1.68252	0.6532	0.01806	0.17	0.84126	38.82%
Eutrophication	kg Ne	0.219704	0.095394	0.002558	0.0119	0.109852	43.42%
Formation of Tropospheric Ozone	kg O3e	30.102	10.299	0.502	4.25	15.051	34.21%
Depletion of Nonrenewable Energy	MJ	8004.48	1725.22	92.85	2184.17	4002.24	21.55%
Biogenic Carbon Storage	kg CO_2e bio	0	0				

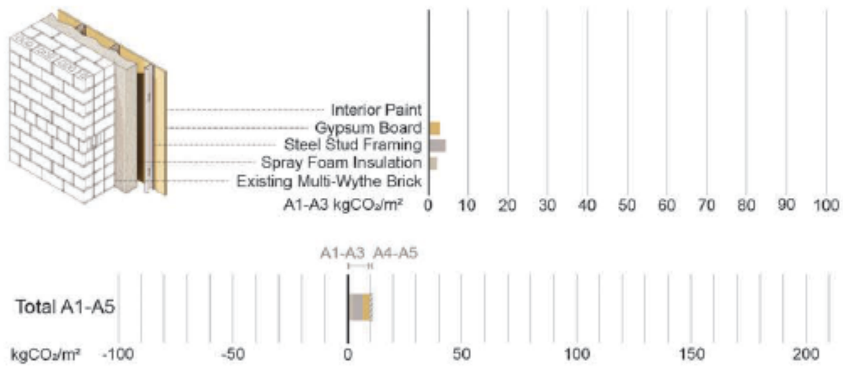
Although significant the GWP impact is not the largest of the categories. The eutrophication is the largest. Eutrophication is the process in which a water body becomes overly enriched with nutrients, leading to the plentiful growth of simple plant life.

The second assembly we are considering is Assembly 15 from the RDH report[12]. It represents an existing masonry with interior HFO spray foam insulation assembly. A summary of the values for the assembly are represented in Figure 6 below.

[10] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45
[11] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45

Figure 6 Summary of Values for Existing Masonry with Interior HFO Spray Foam Insulation Assembly[12].

Summary for W15	
Description	**Existing Masonry with Interior Spray Foam Insulation**
R-Value	Rsi 4.7 m²K/W R 26.8 ft2·°F·h/BTU
Embodied Carbon per m² of Enclosure (A1-A3)	9.8 $KgCO_2/m^2$
Biogenic Carbon per m² of Enclosure	0 $KgCO_2/m^2$



The impact of the embodied carbon for this assembly is minimal.

Table 5 R- Value Calculations for Existing Masonry with Interior HFO Spray Foam Insulation Assembly.[13]

Assembly Description	t_{st} [mm]	t_{ir} [in]	k [W/=mK]	C (USI) [W/m²K]	RSI Effective [m²K/W]	R-effective (ft²·°F·h/BTU)	R-nominal (ft²·°F·h/BTU)
Interior Air Film					0.12	0.68	
Interior Gypsum Board	12.7	0.5	0.16	27.04	0.04	0.21	
Steel Stud-Framed Wall	63.5	2.5	0.49	7.75	0.13	0.73	
Closed-Cell Spray Foam Insulation	101.6	4	-	-	4.26	24.16	24.16
Existing Multi-Wythe Brick Masonry	203.2	8	1.31	6.45	0.16	0.88	
Exterior Air Film					0.03	0.17	
Total	**381**	**15**			**4.7**	**26.8**	**24.2**

The major contributor to R-value in the assembly is HFO closed cell spray foam.

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[12] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 46

[13] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46

Table 6 Embodied Carbon Emissions (A1-A3 Life Stages) for 9m^2 for Existing Masonry with Interior Mineral Wool Insulation Assembly. [14]

Category	Material (RDH Specification)	Description (from EPD)	Thickness [mm]	Volume of Material (m^3)	Carbon Emissions (A1-A3) ($KgCO_2E$)	% of Total
Finish	Interior Paint	Eggshell acrylic paint, 1294.29 kg/m³ (Generic)	0.16 (0.0063")	0.0014	0.56	0.6%
Finish	Gypsum board	Gypsum plaster board, regular (Generic)	12.7 (0.5")	0.1143	26	29.30%
Back-Up Structure	Steel stud framing, no Insulation	Steel stud framing for drywall/gypsum plasterboard per sq. meter of wall area (incl. air gaps per m³), C-profile: 63.5 x 30.48 mm, gauge 25, 3 m height x 406.4 mm (400 mm) spacing (Generic)	-	*	39	43.70%
Exterior Insulation	Spray Foam	Spray polyurethane foam insulation for closed cell, with HFO blowing agent	101.6 (4")	0.9144	23	26.40%
Existing Structure	Existing multi-wythe brick	Existing- Not Included		-	-	-
	Total				88.56	

*Software calculates the impact based on the area provided

Since this is a retrofit the brick does not contribute to the A1-A3 embodied carbon for the assembly. If this was new construction the contribution for the brick would be massive. Based upon the data for the building materials the internal insulation- spray foam only represents 26% of the embodied carbon. The final table for the assembly Table 7 is a summary of the environmental emissions (A1 to C4 life stages) for 9m^2.

Table 7 Environmental Emissions (A1-A3 Life Stages) for 9m^2 for Existing Masonry with Interior HFO Spray Foam Insulation Assembly. [15]

		A1 to C4	A1-A3	A4-A5	B1-B5	C1-C4	A1-A3
Result Category	Units	Total	Construction Materials	Transportation to Site & Construction	Material Replacement & Refurbishment	Deconstruction	A1-A3 % of Total
Global Warming	$kg\ CO_2e$	189.12	89.01	1.72	3.83	94.56	47.07%
Ozone Depletion	kg CFC11e	4.59E-06	1.58E-06	4.55E-07	2.60E-07	2.30E-06	34.42%
Acidification	$kg\ SO_2e$	0.9018	0.4202	9.70E-03	0.021	0.4509	46.60%
Eutrophication	kg Ne	0.194588	0.094944	0.00135	0.001	0.097294	48.79%
Formation of Tropospheric Ozone	kg O3e	13.624	6.049	0.273	0.49	6.812	44.40%
Depletion of Nonrenewable Energy	MJ	1541.3	689.85	48.66	32.14	770.65	44.76%
Biogenic Carbon Storage	$kg\ CO_2e$ bio	0	0				

With the embodied carbon being minimal all the contributions are similar.

[14] 2025 “Embodied Carbon Honeywell Enclosures” by RDH Building Science page 46

[15] 2025 “Embodied Carbon Honeywell Enclosures” by RDH Building Science page 45-46

Since we have now considered each assembly Figure 7 compares the two assemblies.

Figure 7: Summary of Values for Existing Masonry with Interior Insulation Assembly[16].

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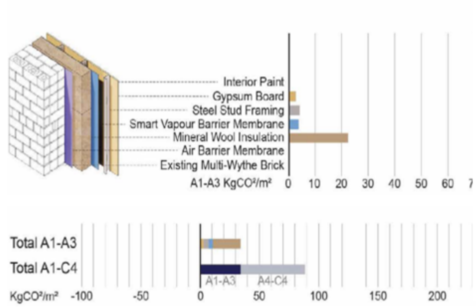
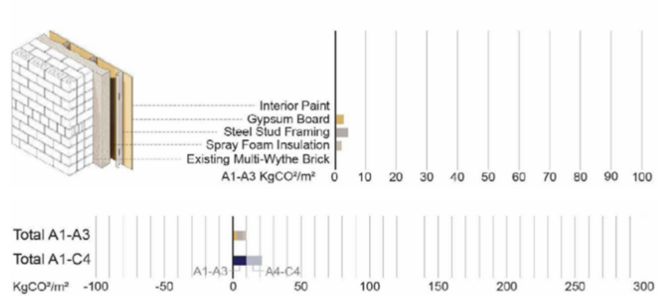
W14: Results Summary

Metrics	Results
Description	**Existing Masonry with Interior Mineral Wool Insulation**
Effective R-value	RSI-4.2 m^2K/W | R-24.0 $ft^2\cdot°F\cdot h/BTU$
Embodied Carbon per m^2 of Enclosure (A1-A3)	33.7 $kgCO_2/m^2$
Biogenic Carbon per m^2 of Enclosure	0 $kgCO_2/m^2$



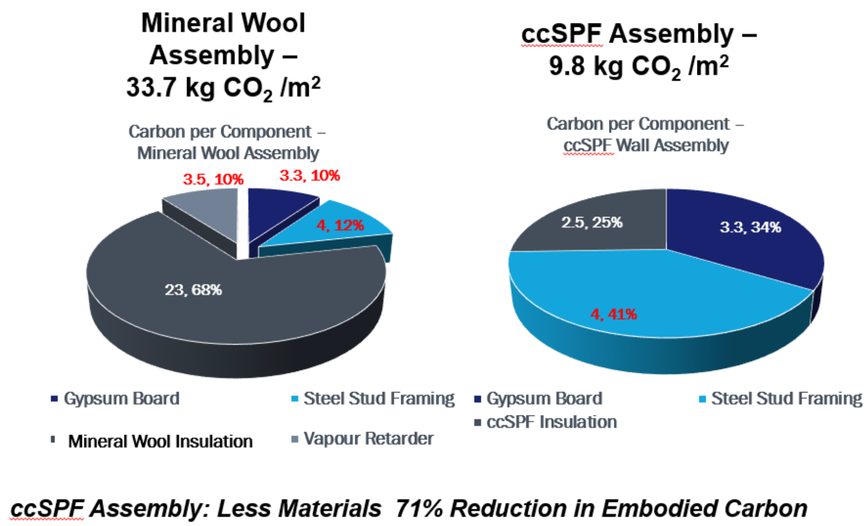
W15: Results Summary

Metrics	Results
Description	**Existing Masonry with Interior Spray Foam Insulation**
Effective R-value	RSI-4.7 m^2K/W | R-26.8 $ft^2\cdot°F\cdot h/BTU$
Embodied Carbon per m^2 of Enclosure (A1-A3)	9.8 $kgCO_2/m^2$
Biogenic Carbon per m^2 of Enclosure	0 $kgCO_2/m^2$



It is apparent from comparing the assemblies that the Embodied carbons for the mineral wool assembly is much higher than the one for the HFO spray foam assembly. The insulation values contribute significantly to the difference. However, the mineral wool assemblies also require more components to meet code. This contributes to the embodied carbon. Figure 8 highlights the differences between assemblies.

Figure 8: Comparison of Values for Existing Masonry with Interior Insulation Assembly[17].



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There is a 71% reduction in embodied carbon when comparing the spray foam assembly with the mineral wool assembly. The biggest impact is the embodied energy of mineral wool. Also, the fact that the mineral wool assembly requires additional materials to meet code adds to the embodied carbon.

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[16] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46

[17] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 46

Comparison of New Assemblies in Boston

We have compared retrofit applications and found significantly lower embodied carbon in the spray foam assembly. However often in an assembly, multiple insulation types are often used. In this analysis we evaluate a new brick clad assembly which uses both mineral wool and HFO spray foam as insulation. Thes assembly was modeled to meet the Boston building code. The baseline targets effective R-value the roof wall, exposed floor and vision glazing. The thermal performance target was set at R-35 for walls. [18] It is important before we compare the assemblies that the details of each assembly are considered separately. The first assembly we are considering is Assembly UR2 from the RDH report[15]. It represents a new masonry assembly with exterior mineral wool insulation and interior HFO spray foam insulation. A summary of the values for the assembly are represented in Figure 8 below.

Figure 8: Summary of Values for Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud[19]

Metrics	Results
Description	**Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud**
Effective R-value	RSI 6.1 m^2K/W R 35 $ft^2 \cdot °F \cdot h/BTU$
Embodied Carbon per m^2 of Enclosure (A1-A3)	112.4 $kgCO_2/m^2$
Biogenic Carbon per m^2 of Enclosure	-18.6 $kgCO_2/m^2$

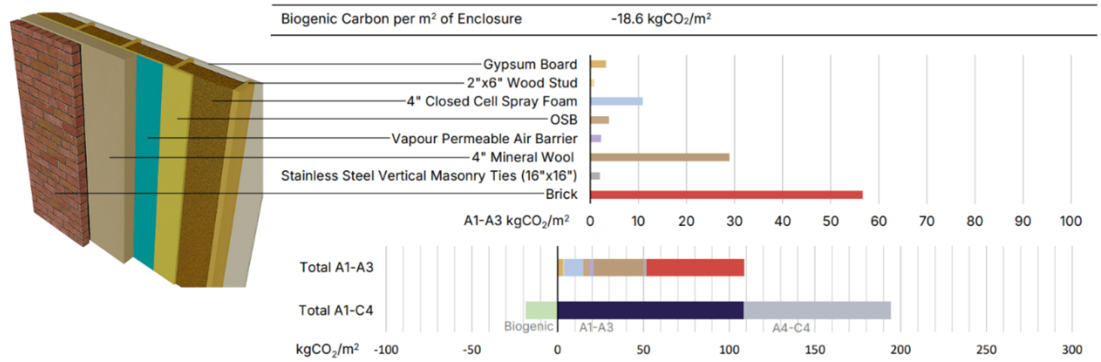

Table 8 R- Value Calculations for Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud. [20]

Description	t_{SI}	t_{IP}	k	C (USI)	$RSI_{effective}$	$R_{effective}$	$R_{nominal}$
Units	mm	in	W/mK	W/m^2K	m^2K/W	$ft^2 \cdot °F \cdot h/BTU$	$ft^2 \cdot °F \cdot h/BTU$
Interior Film	-	-	-	8.30	0.12	0.68	0.68
Interior Gypsum Board	12.70	0.50	-	-	-	-	-
2"x6" Wood Stud with 4" ccSPF	139.70	5.50	-	-	3.13	17.80	24.00
OSB	12.70	0.50	0.16	8.30	0.12	0.68	0.68
Vapour Permeable Air Barrier	-	-	-	-	-	-	-
4" Rockwool with Std. SS Vert. Masonry Ties (16"x16")	101.60	4.00	0.034	0.33	2.71	15.39	16.97
Ventilated Air Space	25.40	1.00	-	-	-	-	-
Brick	-	-	-	-	-	-	-
Exterior Film	-	-	-	34	0.03	0.17	0.17
TOTALS	**292.10**	**11.50**	**-**	**-**	**6.12**	**34.72**	**42.50**

The major contributor to R-value in the assembly is HFO closed cell spray foam.

[18] Embodied Carbon Honeywell Enclosures, RDH Building Science, pg 17
[19] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46
[20] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46

Table 9 Embodied Carbon Emissions (A1-A3 Life Stages) for 9m^2 for Brick Clad with Split Exterior Mineral Wool Insulation and Interior Closed Cell Spray Foam Insulation in Wood Stud. [21]

Category	Material	Description from EPD	Thickness	Other Quantity[1]	Carbon Emissions (A1-A3)	% of total
Units			mm		kgCO$_2$e	%
Finish	Gypsum Board	Gypsum plaster board, regular, generic, 6.5-25 mm (0.25-0.98 in), 10.725 kg/m^2 (2.20 lbs/ft^2) (for 12.5 mm/0.49 in), 858 kg/m^3 (53.6 lbs/ft^3), 0% recycled gypsum	12.7		29	3.0%
Back-up Structure	2"x6" Wood Stud	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m^3, 15% moisture content	139.7	0.84 m^3	7.4	0.8%
Interior Insulation	4" Closed Cell Spray Foam	Spray polyurethane foam insulation closed cell with HFO blowing agent, 1 m^{2}K/W, 20 mm, 0.65 kg/m^2	92.1		98	10.0%
Sheathing	OSB	Oriented strand board (OSB), 11 mm, 3.58 kg/m^2, 325 kg/m^3	12.7		35	3.6%
Exterior Membrane	Vapour Permeable Air Barrier	Self-adhesive air/vapour barrier membrane, tri-laminated polyethylene faced, 40 mil (1 mm), 0.2 lb/ft^2 (0.975 kg/m^2)	*		20	2.0%
Exterior Insulation	4" Mineral Wool	Mineral wool insulation, high density, R = 1 m^{2}K/W, 33.8 mm, 3.49 kg/m^2, 103 kg/m^3	101.6		260	26.6%
Cladding Anchorage	Stainless Steel Vertical Masonry Ties (16"x16")	Cold-formed steel framing products, 7850 kg/m^3		0.001 m^3	18	1.8%
Cladding	Brick	Clay brick, 2120 kg/m^3; Mortar Type N	90.0		510	52.2%
				TOTAL	977.4	100.0%

* Thickness determined by EPD default.

[1]Volume/mass/area only shown if calculated differently than 9 m^2 area and thickness.

The brick is over 50% of the embodied carbon structure followed by mineral wool. The final table for the assembly Table 10 is a summary of the environmental emissions (A1 to C4 life stages) for 9m^2.

Table10 Environmental Emissions (A1-A3 Life Stages) for 9m^2 for Existing Masonry with Interior HFO Spray Foam Insulation Assembly. [22]

Lifecycle Stage		A1 to C4	A1-A3	A4-A5*	B1-B5	C1-C4	A1-A3 Contribution to total
Category	Units	Total	Construction Materials	Transport to Site & Construction	Material Replacement & Refurbishment	Deconstruction	%
Global Warming	kg CO$_2$e	**1,744.9**	974.6	119.2	565.63	85.57	56%
Acidification	kg SO	**15.7**	8.4	0.10	6.52	0.72	53%
Eutrophication	kg Ne	**2.4**	1.5	0.014	0.76	0.07	65%
Ozone Depletion	kg CFC11e	**0.00032**	0.00025	0.00000	0.00006	0.00000	79%
Formation of Tropospheric Ozone	kg O$_3$e	**92.0**	57.6	2.9	30.25	1.23	63%
Fossil Fuel Primary Energy	MJ	**22,260.0**	12,215.7	507.9	9,500.69	35.71	55%
Biogenic Carbon Storage	kg CO$_2$e	**-167.6**	167.6	0.0	0.00	0.00	-17%

*The software does not provide estimates for stage A5 environmental impacts except for GWP, so these results only show stage A4.

This analysis shows the impact of the biogenic carbon storage for wood used in the assembly. The impact of the categories are similar.

Conclusion

The construction industry is responsible for roughly 40% of the worldwide carbon emissions. As we have optimized energy usage in buildings (operational carbon), the efforts are now looking at embodied carbon. Embodied carbon is becoming a key consideration in decision making by the design community. This paper has looked at the embodied carbon in 3 assemblies. Two are retrofit assemblies. One utilizes mineral wool the other utilizes HFO spray foam. The embodied carbon is 71% lower for the spray foam assembly. The third assembly is one that is a new build which

[21] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 46

[22] 2025 "Embodied Carbon Honeywell Enclosures" by RDH Building Science page 45-46

used both mineral wool and HFO spray foam. This assembly highlights the significant increase in embodied carbon in a new build vs retrofit application and the importance that external cladding plays in embodied carbon.
Finally, the analysis of the assemblies presented in this paper point out that to minimize embodied carbon in an assembly one needs to not only consider individual components but also what is used in an assembly. From this analysis it is apparent the HFO blown spray foam has minimal impact to the embodied carbon of the assemblies tested.

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