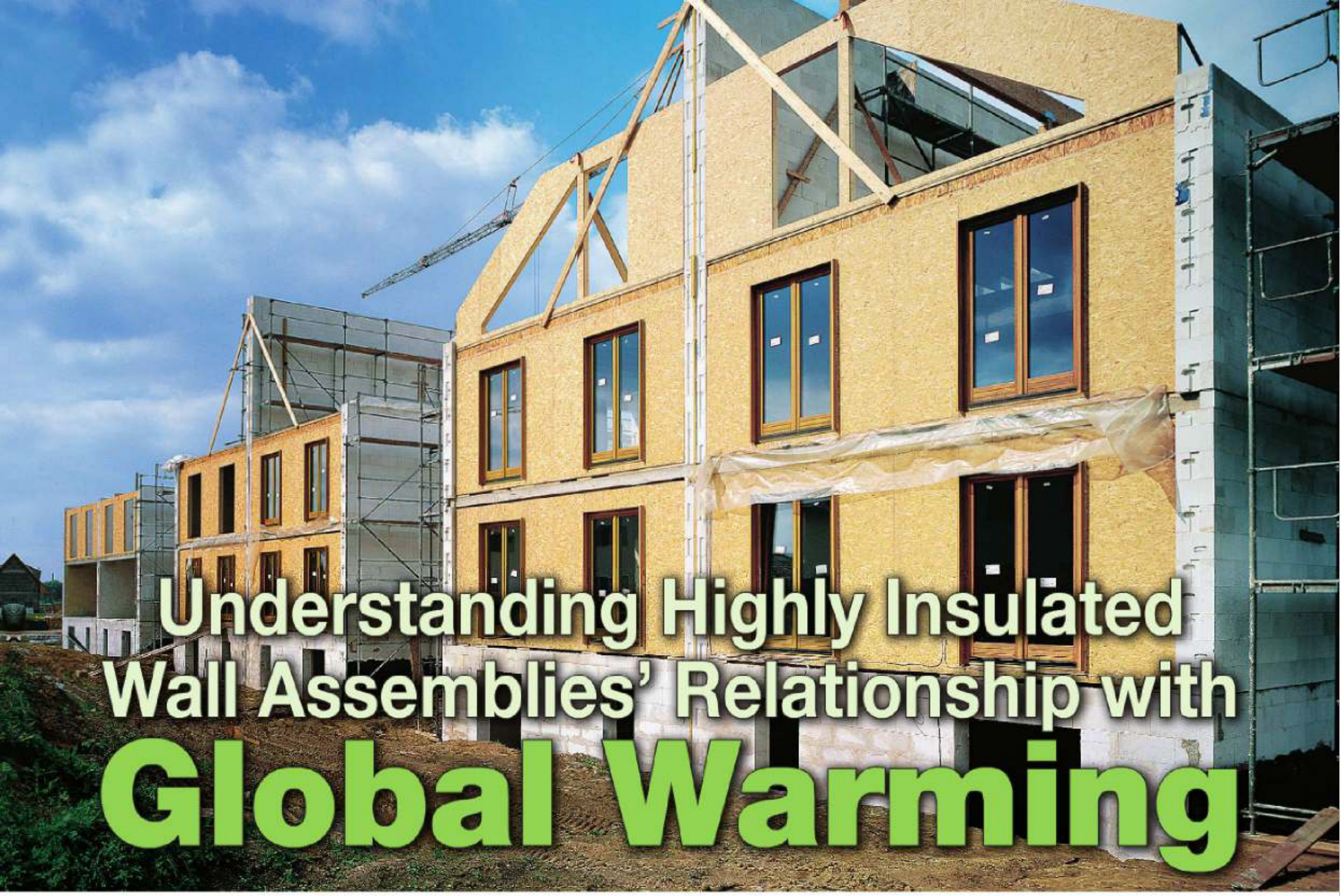


Understanding Highly Insulated Wall Assemblies' Relationship with Global Warming

by Jim Lambach

Images courtesy Covestro LLC

A WELL-INSULATED BUILDING ENVELOPE IS THE STARTING POINT IN ANY ENERGY CONSERVATION STRATEGY. THE EMBODIED GLOBAL WARMING POTENTIAL (GWP) OF THE INSULATING MATERIAL, AS PART OF A COMPLETE WALL ASSEMBLY, MUST BE WEIGHED AGAINST THE USE-PHASE ENERGY EFFICIENCY CONTRIBUTION TO SEE THE COMPLETE ENVIRONMENTAL PICTURE. THIS ARTICLE EXAMINES THE IMPACT OF BOTH HIGH- AND LOW-EMBODIED GWP INSULATION MATERIALS ON THE ULTIMATE BENEFIT OF HIGHLY INSULATED WALL ASSEMBLIES.

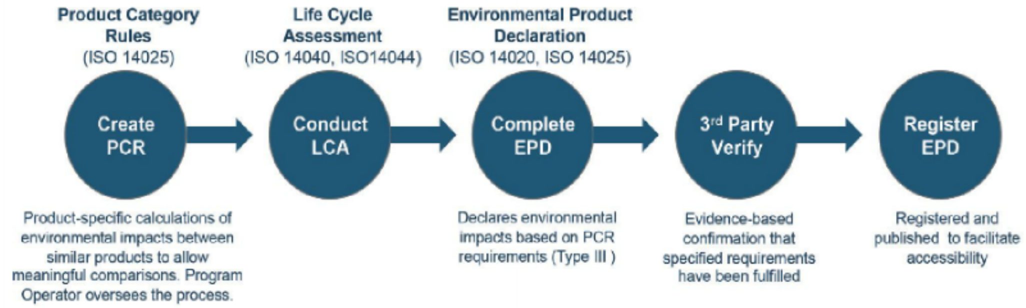
Global warming potential is a data point frequently considered when selecting building materials, including insulation. It is typically expressed only as output—greenhouse gases (GHGs) emitted during the material's manufacturing, installation, use phase, and disposal. What is rarely taken into account is the prevention of GHG emissions due to use-phase energy efficiency. This is especially true when the material is measured in its installed state as part of a complete system.

Understanding the holistic energy savings measurement will be increasingly relevant as the industry continues to embrace long-term resilience when creating new buildings.

This article compares two highly insulated R-38 assemblies—one a low-embodied GWP wall that contains fiberglass insulation between framing, with polyisocyanurate (polyiso) as the continuous insulation (ci) layer, and another higher-embodied one that contains closed-cell sprayed polyurethane foam (ccSPF) between framing, with polyiso again used as the ci layer. By taking a simplified approach for estimating heat transfer across the functional unit (instead of the whole building) in the use-phase, it becomes straightforward to calculate the overall GWP benefit of a highly insulated wall assembly.

As this article demonstrates, even in the case of the higher GWP wall assembly, the payback (*i.e.* time required for in-use GWP conservation to equal the cradle-to-grave embodied GWP of the insulation) is reached in a short time relative to the building's service life. Perhaps surprisingly, the high GWP wall assembly is in GWP conservation mode for 95 to 98 percent of its service life. It is findings like this, when the data is clear and comprehensive, that architects and builders can use to design for resilience.

Figure 1



Schematic of the environmental product declaration (EPD) process.

Understanding EPDs and LCAs for appropriate data input

Environmental product declarations (EPDs) have been published for numerous insulation materials. A required output from the EPD is the list of environmental impacts, which are reported on the basis of a common functional unit, enabling comparison of different types of insulation materials. Insulation EPDs may also include a whole building use-phase analysis of energy savings.

In the big picture, EPDs are a disclosure tool developed by product manufacturers to assist building designers in better understanding a product's environmental impact so they can make more informed product selections. The basic steps to create an EPD are shown in Figure 1.

EPDs are developed after the product lifecycle assessment (LCA) is conducted, and are based on the applicable product category rules (PCR) that ultimately enable all products within a category to be compared by creating data consistency, regardless of manufacturer. The format of the EPD also provides a simple, consistent summary of environmental impacts.

The EPD process is prescribed by International Organization for Standardization (ISO) standards developed using a consensus process with multiple stakeholders. Groups overseeing development of EPDs and/or offer listing and registration services include ASTM, UL, International Code Council Evaluation Service (ICC-ES), PE International, SCS Global Services, and NSF International.

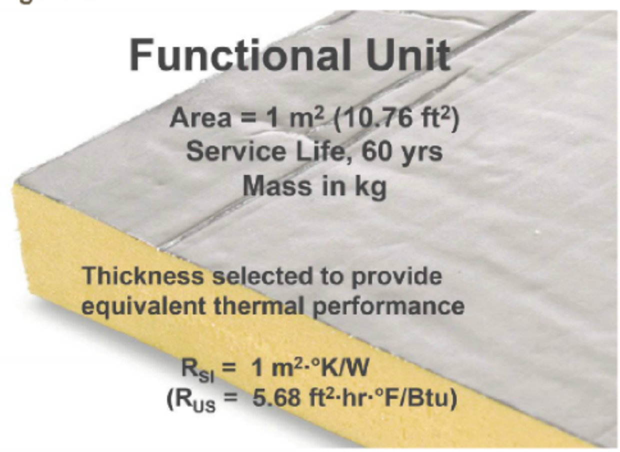
EPDs and/or LCAs are currently available for a variety of insulation materials:

- polyiso foam board;
- ccSPF;
- extruded polystyrene (XPS);
- fiberglass; and
- mineral wool.

PCRs for thermal insulation

Product category rules describe reporting requirements for consumption of material resources and primary energy, as well as cradle-to-grave environmental impacts for a product category such as thermal insulation. The PCR applies to all of the commercially available thermal insulation products, regardless of type.

Figure 2



The insulation 'functional unit.'

The *PCR for Building Envelope Thermal Insulation* is listed on the UL website;[1] it defines the thermal insulation functional unit, as illustrated by Figure 2. The PCR states the following limitation in its "Goal and Scope (v1.2, Section 1.0):"

> This is not intended to be a full building LCA, therefore, the installation phase impacts do not address the energy savings that result from the ongoing building operation due to the installed insulation.

In Section 5.2.4, it then provides the following option (with a section underlined by this author for emphasis):

> During its service life, insulation significantly reduces the energy use in a building, thereby reducing the impact on the environment. The exclusion of the building heating and cooling during the insulation material's use phase severely underestimates the benefits that insulation has on the environment. This section may describe the energy savings and environmental benefits during use of the product in a building and only references operational consideration.

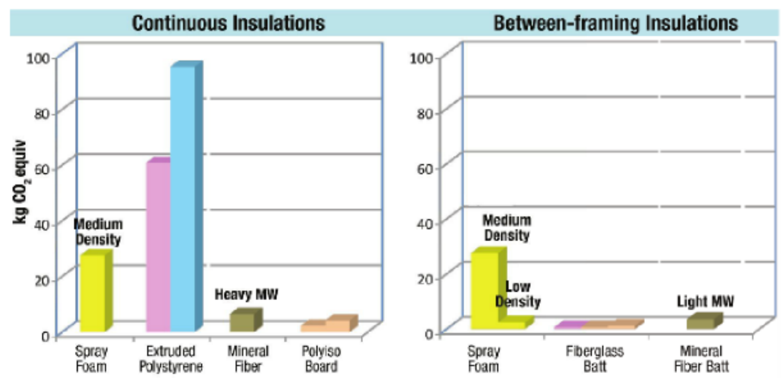
Figure 3

ATMOSPHERE			WATER	
Global Warming Potential refers to long-term changes in global weather patterns – including temperature and precipitation – that are caused by increased concentrations of greenhouse gases in the atmosphere.	**Ozone Depletion Potential** is the destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation that's harmful to life, caused by human-made air pollution.	**Photochemical Ozone Creation Potential** happens when sunlight reacts with hydrocarbons, nitrogen oxides, and volatile organic compounds, to produce a type of air pollution known as smog.	**Acidification Potential** is the result of human-made emissions and refers to the decrease in pH and increase in acidity of oceans, lakes, rivers, and streams – a phenomenon that pollutes groundwater and harms aquatic life.	**Eutrophication Potential** occurs when excessive nutrients cause increased algae growth in lakes, blocking the underwater penetration of sunlight needed to produce oxygen and resulting in the loss of aquatic life.
kg CO_2 equiv	kg CFC-11 equiv	kg O_3 equiv	mole H+ equiv	kg N equiv

Environmental impacts reported in UL's EPD, *Building Envelope Thermal Insulation*, for Spray Polyurethane Foam Alliance (SPFA), Declaration No. 13CA29310.101.1

Image courtesy UL

Figure 4



Global warming potential (GWP) comparison from EPDs for thermal envelope insulation materials.

Images courtesy Covestro LLC

Environmental impact reporting in thermal insulation EPDs

As environmental impacts are reported on the basis of the functional unit (rather than on a whole building), it is not a straightforward exercise to create comparisons between the environmental impacts and the use-phase energy savings from one insulation material to another. Figure 3 describes the five environmental impacts reported in the insulation EPD, and the units used to report their impact (per functional unit). The first one is the focus of this article—GWP—which is the environmental attribute creating the most dialogue in today's environmental building conversation.

Other impacts like 'ozone depletion potential' (ODP) were a huge issue in the 1980s and 1990s. First-generation blowing agents for ccSPF and polyiso had high ODP values, and the industry solved the problem by converting to second-generation agents in the early to mid-90s.

'Photochemical ozone potential' refers to smog, which is not the clamoring issue it once was since the nation converted to cleaner burning fuels.

'Acidification potential' is a product's tendency to contribute to acid rain, while 'eutrophication potential' is its tendency to contribute to algae growth (thus harming aquatic life).

Global warming potential

GWP provides a relative measure of greenhouse gases emitted to the atmosphere during the manufacturing, installation, service life, and end-of-life of the insulation material. A lower GWP value indicates a lesser environmental impact.

The two bar charts in Figure 4 compare GWP values from published EPDs for various insulation materials.[2] Materials typically used as continuous insulation on the exterior walls are listed on the left chart. Insulation materials used between framing, or as loose fill in the attic, are listed on the right.

The ci group includes ccSPF, polyiso, mineral wool, and XPS. The GWP values for this group ranged from 3 to 95 kg (7 to 209 lb) of carbon dioxide (CO_2) equivalents per functional unit. The between-framing and attic insulations group, on the other hand, includes fiberglass (from multiple sources), mineral wool (loose fill and light density), and open- and closed-cell SPF, with GWP values ranging from 1 to 28 kg (2 to 62 lb) of CO_2 equivalents per functional unit.

Mineral fiber and ccSPF have utility both as ci and between framing, so they were listed on both bar charts. It should be noted mineral fiber used as ci is significantly higher in density than mineral fiber installed between framing members as batt. Two other common insulations, cellulose and expanded polystyrene (EPS), do not have published EPDs, so they are not represented in this graph.

It is clear from the graph there are essentially two GWP populations among these insulation materials: the high GWP group (consisting of XPS and ccSPF) and the low GWP group, consisting of all other insulation materials. Both ccSPF and extruded polystyrene contain a high GWP blowing agent that is primarily responsible for the overall GWP rating of the insulation.

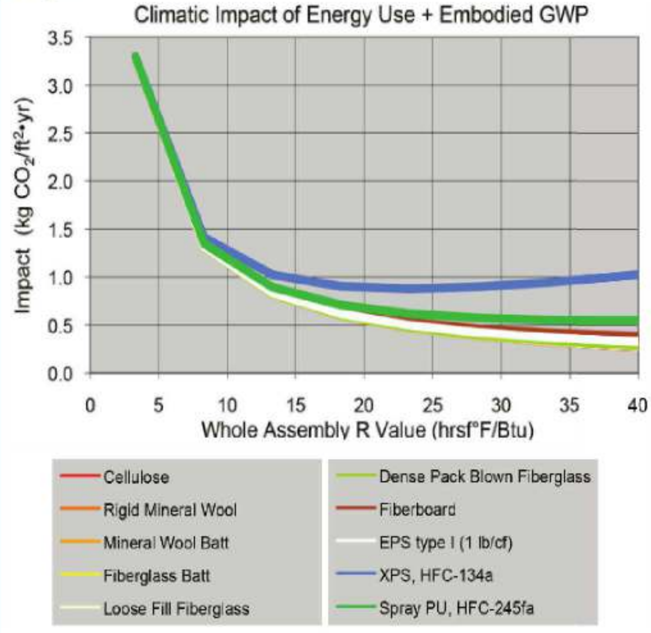
Embodied versus conserved GWP

For insulation materials with high GWP blowing agents, the relevant question is, 'At what insulation level does the overall GWP benefit of the insulation (due to energy savings) offset the embodied GWP?'

The Insulation GWP Calculator attempts to answer this question.[3] Figure 5 contains output from this tool for a variety of thermal insulation materials. To generate this graphic, a starting R-value of 3.3 was selected to represent a typical wood-framed wall with no insulation installed between the framing, and no continuous insulation. Further, the endpoint at R-40 was selected to represent a highly insulated wall assembly.

The resulting graphic generated by the Insulation GWP Calculator makes it possible to visualize the R-value range where GWP benefit begins to transition to an asymptotic region of diminished return. Inspection of the graph shows little difference between insulation materials in terms of GWP impact at lower R-value range—all are beneficial.

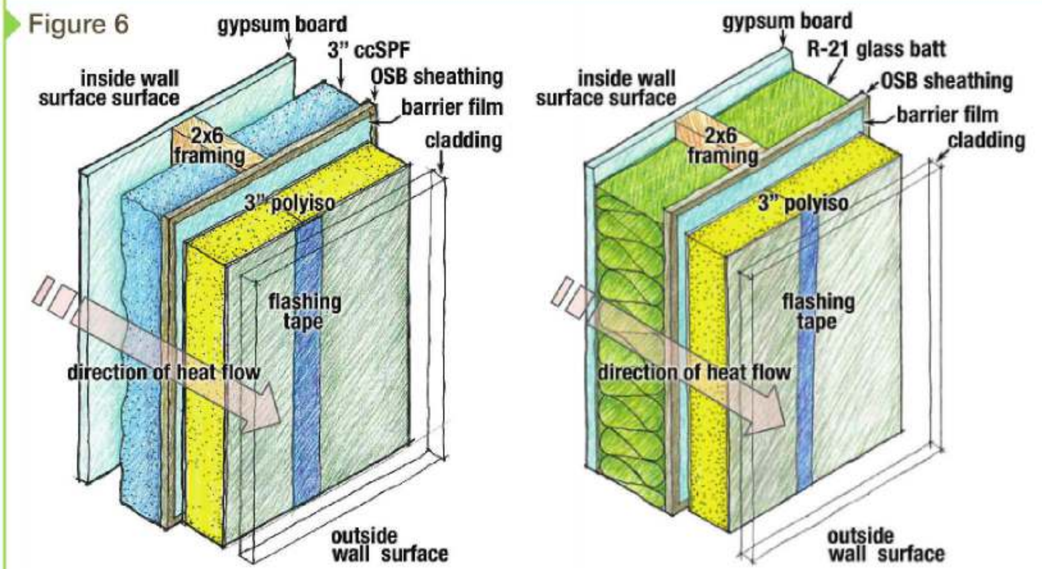
Figure 5



Output from the Insulation GWP Tool v1.2 for insulation materials.

Looking further down the x-axis, extruded polystyrene and, to a lesser extent, ccSPF enter the 'GWP diminishing return range' before the other insulations.

Figure 6



Schematics of two highly insulated wall assemblies used for analysis of heat flow.

Figure 7

INSULATION MATERIAL	FUNCTIONAL UNIT GWP FROM EPD	ASSUMPTIONS	WALL ASSEMBLY 1 HIGH GWP	WALL ASSEMBLY 2 LOW GWP
3 in. Polyiso Foam Board	3.0 kg CO_2/m^2 at R-5.68	R-19.5 as c.i.	10.3 kg CO_2/m^2	10.3 kg CO_2/m^2
R-21 Fiberglass Batt	0.8 kg CO_2/m^2 at R-5.68	R-21 between framing, 25% framing fraction		2.2 kg CO_2/m^2
3 in. ccSPF	27.6 kg CO_2/m^2 at R-5.68	R-21 between framing, 25% framing fraction	76.5 kg CO_2/m^2	
		Total =	**86.8 kg CO_2/m^2**	**12.5 kg CO_2/m^2**

High- and low-embodied GWP wall assemblies.

While this tool is quite useful, it only provides output on wall constructions with a single insulation material. In practice, many wall assemblies contain more than one type of insulation. Additionally, there is now rigorous GWP data available for many insulation materials that were not available when the tool was published.

Approximation of annual heat loss across a highly insulated wall assembly

It is possible to compare the use-phase GWP benefit of the wall assembly over the building life (defined as 60 years in the PCR) with the embodied GWP of the insulation material as represented in the EPD using a simple approximation. The analysis uses the 'functional unit' defined in the PCR as the basis for comparison.

Two highly insulated wall assemblies illustrated in Figure 6, represent both high and low GWP insulation materials. As Figure 7 shows, Wall 1 has an embodied GWP about seven times higher than Wall 2. The simple calculation for approximating annual heat loss is:

Q (annual transmission heat loss) = U x A x HDD65 x 24 hrs/day

While this calculation only recognizes heat loss, that is the predominant mode of heat transfer across much of the United States. Also, this simple calculation does not address energy savings that could be obtained from an energy management program such as nighttime or weekend setback temperatures.[4]

For simplicity, this analysis assumes 6000 heating degree days (HDD65) per year, which is typical for Climate Zone 5. The estimated energy conserved due to the operational function of the insulation can then be calculated by subtracting the annual heat loss across 1 m^2 (10.8 sf) of insulated wall assembly from the heat loss of the same assembly absent insulation. Sample calculations and results are shown in Figure 8.

The energy conservation estimate from Figure 8 can then be converted to an annual estimate of GWP conservation by assuming an energy source for heating the building. Table J2-B of ASHRAE 105-2014, *Standard Methods of Determining, Expressing, and Comparing Building Energy Performance and Greenhouse Gas Emissions*, provides reference values for GHG emissions per MBTU (*i.e.* one million Btus [*i.e.* approximately 5.7M $J/m^2 \cdot C$]) for different heating energy sources.

According to ASHRAE, natural gas emits 64 kg CO_2/MBTU, while electricity emits 203 kg CO_2/MBTU. Multiplying the

Figure 8

WALL ASSEMBLY TYPE	CALCULATION	WALL ASSEMBLY 1 HIGH GWP	WALL ASSEMBLY 2 LOW GWP
Uninsulated, R-3.3	(0.30 BTU/sfx°Fxhr)x(10.8 sf)x(6,000 HDD)x(24 hrs/day)	0.47 MM BTU/m²xyr	
HIGH GWP, R-38	(0.026 BTU/sfx°Fxhr)x(10.8 sf)x(6,000 HDD)x(24 hrs/day)	0.04 MM BTU/m²xyr	
LOW GWP, R-38	(0.027 BTU/sfx°Fxhrx(10.8 sf)x(6,000 HDD)x(24 hrs/day)		0.04 MM BTU/m²xyr
	Energy conserved=	**0.43 MBTU/m²xyr**	**0.42 MBTU/m²xyr**

Annual energy conservation across 1 m² (10.8 sf) of the wall assembly attributed to insulation.

Figure 9

HIGH GWP (WALL ASSEMBLY 1)

Embodied GWP	87 kg CO_2/m²	
Energy Conserved in use	0.43 MM BTU/m²xyr	
Heating Energy Source	**Electric**	**Natural Gas**
GWP Emissions Factor	203 kg CO_2/MM BTUxm²	64 kg CO_2/MM BTUxm²
GWP Conserved	86 kg CO_2/m²xyr	27 kg CO_2/m²r
Payback Time ($GWP_{Embodied}/GWP_{Conserved}$)	**1.0 yrs**	**3.2 yrs**
% of Service Life that Building is Conserving GWP	**98%**	**95%**

LOW GWP (WALL ASSEMBLY 2)

Embodied GWP	13 kg CO_2/m²	
Energy Conserved in use	0.42 MM BTU/m²xyr	
Heating Energy Source	**Electric**	**Natural Gas**
GWP Emissions Factor	203 kg CO_2/MM BTUxm²	64 kg CO_2/MM BTUxm²
GWP Conserved	86 kg CO2/m²xyr	27 kg CO_2/m²xyr
Payback Time ($GWP_{Embodied}/GWP_{Conserved}$)	**0.15 yrs**	**0.5 yrs**
% of Service Life that Building is Conserving GWP	**>99%**	**>99%**

Significance of embodied GWP of insulation versus GWP conserved during building use-phase.

energy conserved by these emission factors yields the annual GWP conserved, thus allowing a simple calculation of 'payback time.' Subtracting payback time from the building service life of 60 years (as defined per the Insulation Functional Unit in the PCR) provides an estimate of the length (or percentage) of time the building is in GWP conservation mode. Lifetime GWP benefit from use-phase over the assumed service life illustrates that both wall assemblies conserved significant GWP.

For Wall Assembly 1, the payback ranged from one to 3.2 years, depending on the heating source. For Wall Assembly 2, the payback time ranged from 0.15 to 0.5 years, depending on the heating source (Figure 9).

Heating source impact on GWP

Even for the worst case (*i.e.* the high GWP Wall Assembly 1 with natural gas heating), the building was in GWP conservation mode for 95 percent of its service life. As Figure 10 (page 40) shows, the big factor in total GWP conserved over the building life was not insulation choice—it was heating source.

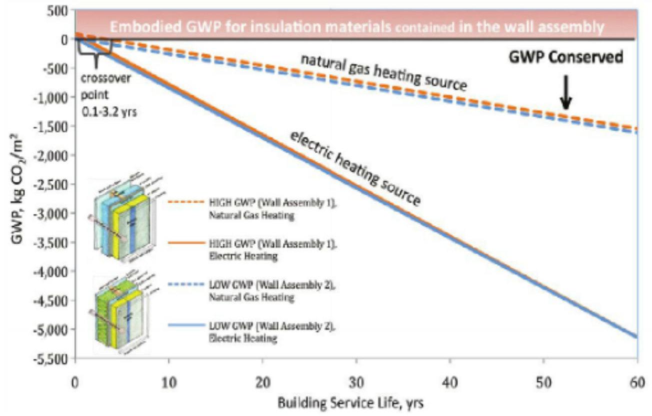
The purpose of this analysis was to provide a frame of reference, or context, when weighing the overall environmental impact of the global warming potential embodied in insulation materials. For the examples selected, it was clearly shown use-phase benefits dominate the big picture. It should be noted both Wall Assemblies 1 and 2 were highly insulated—with more traditional insulation levels, the use-phase would have dominated the embodied GWP to an even greater extent.

Next-generation blowing agents

The foam plastic industry is on the cusp of transition from third- to fourth-generation blowing agents that essentially eliminate the issue (Figure 11, page 40). The first-generation blowing agent, CFC-11, was invented in the 1920s as a refrigerant—it was high in both GWP and ODP. Second- and third-generation agents were introduced in the 1990s and 2000s that addressed ozone depletion potential. They were also improved in terms of GWP, but still about 1000 times above that of CO_2, the reference molecule.

Currently, at least three companies are in various stages of commercializing fourth-generation blowing agents that effectively address both ODP and GWP issues. As commercial quantities become available, the various insulation companies are working to incorporate these new molecules into their formulations.

Figure 10



Heating energy conserved due to wall insulation, shown as GWP.

Figure 11

	INVENTED IN 1920s	EARLY-MID 1990s	2006	2016 MARKET IN TRANSITION
Blowing Agent	Chloro-fluorocarbon CFC-11	Hydrochloro-fluorocarbon HCFC-141	Hydro-fluorocarbon HFC-245fa	Hydro-fluoroolefin
GWP	4,600	794	1,030	0–5
ODP	1.0	0.11	0	0

Evolution of blowing agents used in closed-cell sprayfoam.

Conclusion

Many thermal insulation materials now have LCAs and EPDs to disclose complete and consistent details regarding embodied GWP. When selecting insulation materials for the building envelope, one should consider the following points:

1. EPDs have become available for many thermal insulation materials in the last few years, allowing them to be compared based on environmental impacts from cradle to grave.
2. The embodied (cradle-to-grave) GWP of an insulation material should be considered in combination with the use-phase GWP benefit due to the energy saving function of insulation.
3. Foam plastic insulations offer an excellent choice as insulation materials. They offer additional control layer functionality beyond thermal performance. They can provide weather resistance, along with an air barrier and vapor retarder. The redundancy they provide in these attributes can be used to create a highly robust wall assembly.

As design and construction evolves beyond sustainability toward resilience, the global warming potential of a material should not be considered in isolation. Incorporating the resiliency design principles of passive and redundant systems, durability and scalability when considering the building envelope can help architects and builders achieve a more lasting result. Understanding all the data and how to use it is an important first step. **CS**

Notes

[1] Visit the site ul.com/global/documents/offerings/businesses/environment/PCRs/ULE_PCR_EnvelopeThermalInsulation.pdf.

[2] Visit productguide.ulenvironment.com.

[3] Created by David White, the online tool is available at www2.buildinggreen.com/blogs/global-warming-potential-insulation-materials-new-calculator.

[4] This equation is taken from *Residential Energy: Cost Savings and Comfort for Existing Buildings* by John Krigger and Chris Dorsi (Saturn Resource Management, 2009). If a more quantitative and comprehensive energy analysis is desired, the U.S. Department of Energy (DOE) maintains an up-to-date list of energy estimating programs at apps1.eere.gov/building/tools_directory. Further, in its *ASHRAE Fundamentals Handbook*, the American Society of Heating, Refrigerating, and Air-conditioning Engineers provides a section titled, "Selecting Energy Analysis Computer Programs" in Chapter 19.

ADDITIONAL **INFORMATION**

Author

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Abstract

This article compares two conceptual wall assemblies constructed with different insulation materials—one with relatively low embodied global warming potential (GWP), and one significantly higher—to create a holistic view that contrasts embodied GWP of the insulation materials with the GWP conservation (or avoidance) attributed to the energy-saving benefit of the insulation.

MasterFormat No.

07 21 00–Thermal Insulation

UniFormat No.

B2010–Exterior Walls

Key words

Division 07
Environmental product declaration
Global warming
Greenhouse gas
Insulation
Lifecycle assessment