Chapter 70
The Greening of Foam Insulating Materials Considering Their Life Cycle and Effective Thermal Properties

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Abstract The construction industry has a large environmental impact considering the building material manufacturing, construction, operations, and decommissioning. Not surprisingly, there is an increasing request to reduce this significant environmental impact through the use of materials with low global warming potential (GWP), which could also guarantee efficient building operation. Insulating materials reduce the building energy demand, but they have a negative environmental impact for the raw material extraction, transportation, manufacturing, and end-of-life disposal. This article focuses on closed cell foam materials and present recent advancements in the fourth generation of blowing agents. The article also discusses the importance of considering the effective thermal conductivity to account for the in-field long-term performance of these insulating materials. The aim of this paper is to promote a more holistic thinking about the characteristics of foam insulating materials.

Keywords Global warming potential · GHG · Green foams · Insulating materials

70.1 Introduction

Traditional insulating materials can be divided into two groups: the materials that contain or trap air to obtain high thermal resistance values, such as fibrous insulation and open cell foams, and the materials that trap a blowing agent, i.e. a gas with lower thermal conductivity than air. This last family of materials aim to retain the blowing gas for as long as possible to keep their thermal properties to remain stable.

Blowing agents have a continuous impact throughout the life cycle of a material as often the blowing gas leaves the material through the entire life of the material. Facings or coverings is hence beneficial to lower the GWP of foams (Berardi 2018). However, the effect of facing depends on the type of the finishing (paper face, fibreglass matt, foil, etc.).

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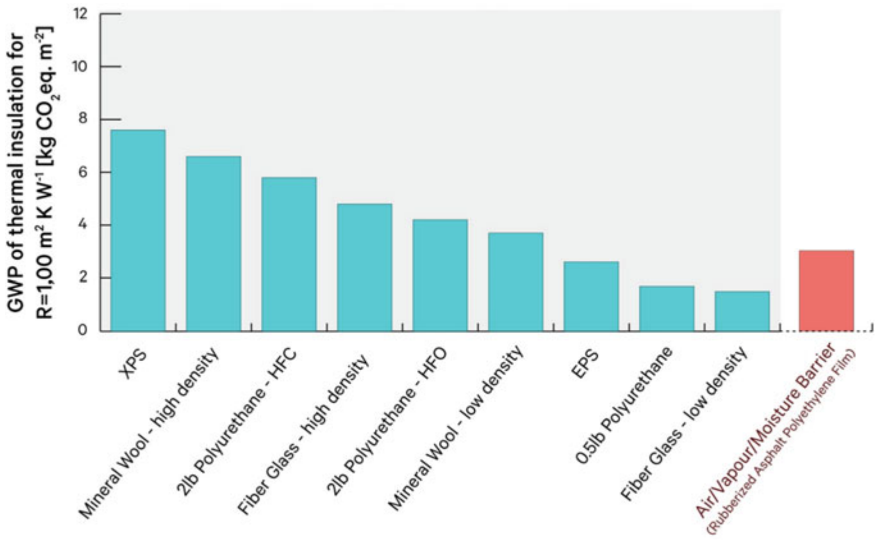

Fig. 70.1 The embodied GWP of different thermal insulation materials

The most common foam products on the market using blowing agents are expanded and extruded polystyrene (EPS and XPS), polyisocyanurate (ISO), and sprayed polyurethane foam (ccSPF). Closed-cell foam insulations, both board stock and spray applied, use various commercially available HFC blowing agents. The chemical composition of the blowing agents impact climate change through their radiative efficiency and by their lifetime. The GWP of blowing agents expressed comparing them to a baseline carbon dioxide (CO_2) gas assigned at GWP 1. Figure 70.1 shows the GWP ratings of some common insulating materials (Berardi and Naldi 2017).

When in the late 1970s, polyisocyanurate was introduced, the industry used CFC-11 as a blowing agent. Later, stricter environmental regulations gradually limited the use of CFCs, especially after the Montreal Protocol in 1987, when the negative environmental impacts of CFCs and the depletion of the ozone layer pushed their ban. Around the early 1990s, the polyisocyanurate industry moved from chlorofluorocarbon (CFC) to hydrochlorofluorocarbons (HCFC) as blowing agents. In the beginning, the HCFC-141b was considered a significant improvement since it showed a 90% reduction in ozone-depletion potential. However, in more recent years, the manufacturers of polyisocyanurates have converted their plants from HCFC to hydrocarbon based blowing agents and pentane mixtures as blowing agents (Bomberg and Lstiburek 2018). The development of new blowing agents is continuously improving and the exact composition of the blowing agent in current foam material is often an undisclosed proprietary information of each manufacturer.

For most polyurethane foam insulations, HFC (hydrofluorocarbon) gas is used as the blowing agent. While this material does not have the same ozone depleting effects

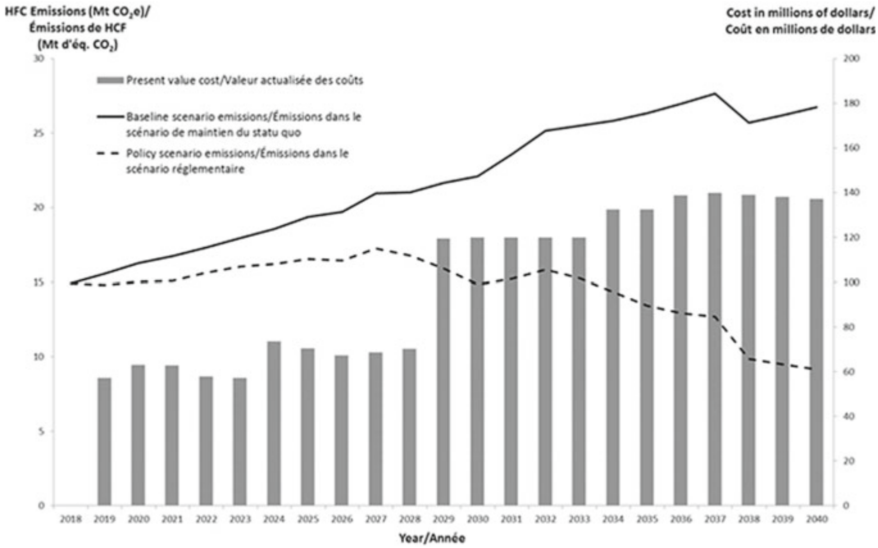

Fig. 70.2 The environmental impact of hydrofluorocarbons (*source* Government of Canada, 2019)

of CFC or HCFC, it still has a high GWP. HFO (hydrofluoroolefin) gas represents the next generation of available blowing agents, as it provides equal or better performance than HFC gasses, while having a much lower global warming potential (Kanaun and Tkachenko 2008). However, other gases are also considered especially in open-cell polyurethanes. With the new blowing agent requirements set out by Environment Canada, the impact of blowing agents is expected to be drastically reduced in the coming years, as shown in Fig. 70.2.

While it is difficult to measure the percentage of blowing agent released over the life of an insulation material, the 2018 Spray Polyurethane Foam Alliance (SPFA) environmental product declaration (EPD) estimates that 10% is released during manufacturing, 24% during the use phase, and 16% during the landfill (CAN ULC S741 2020). Evolution of the refrigerant gas phase out is shown in Fig. 70.3.

The Montréal Protocol regulated CFC gasses as their impact on the ozone and global warming was high. HCFCs were the new, regulated refrigerant gasses due to the reduced impact on the ozone. The Kyoto Protocol aimed to reduce GWP further. The Canadian government has mandated thermal insulations with HFC blowing agents, manufactured and brought into Canada, must have a GWP of 150 or less. This new regulation is now affecting many industries using HFC gases including refrigerators, automotive and building A/C units, HVAC, and building materials. Foam insulation manufacturers in Canada have been forced to change their blowing agents. The ISO board stock insulation industry made these changes approximately 20 years ago, but the negative side-effect was a reduction in RSI values at cold temperatures. ISO companies are currently working on solutions to minimize the impact of cold temperature on their products. Prior to the ISO industry switching to pentane, the GWP of

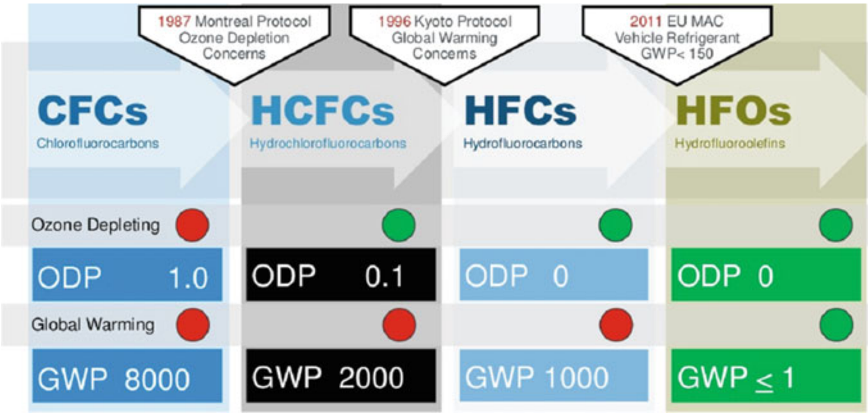

Fig. 70.3 The evolution of refrigerant gases and related embodied GWP

ISO blowing agent was similar to XPS. A ccSPF with hydrofluoroolefin (HFO) blowing agent was launched approximately five years ago. SPF suppliers generally use two ultra-low GWP blowing agents—Honeywell's nonflammable blowing agent Solstice (with a GWP of 1) and Chemours non-flammable blowing agent Opteon 1100 (with a GWP of 2). The EPS industry does not have to change blowing agents as they are within the GWP-150 requirement. XPS manufacturers are still developing low-GWP blowing agent solutions.

70.2 Selection Criteria During Design for Closed Cell Foam Insulation

A high performing and durable building envelope needs to have continuous air, water, vapour and thermal control layers. The combination of continuous control layers in the envelope results in the lowering overall building energy consumption and thus, environmental impact. Closed-cell foam insulations are an attractive construction material in both commercial and residential applications as they can fulfil multiple control layer functions. Closed-cell foam insulations can either be spray applied (ccSPF) or in board form (XPS). Spray foams are available in low 8 kg/m^3 to high 32 kg/m^3 densities but, for the purposes of this article, high density spray foam is to be discussed only.

Both ccSPF and XPS provide excellent thermal control with greater thermal resistance relative to fibrous insulations. ccSPF has a thermal resistance of approximately 1.2 m^2 K/W per 25 mm while XPS is approximately 0.8 m^2 K/W per 25 mm. These thermal resistances are greater compared to fibrous mineral wool which has a thermal resistance of 0.7 m^2 K/W per 25 mm. When the energy efficiency is targeted, the higher thermal resistance of ccSPF and XPS provides a competitive advantage.

Assessing the thermal resistance, it is critical to consider how R value is reported. Typically, a long term thermal resistance (LTTR) is listed for ccSPF while usually a static r value is listed for XPS. In Canada, the foam insulation specification, CAN ULC S701.1, will favour the LTTR measurement for XPS and this is to be adopted by the next National Building Code of Canada.

In terms of providing a continuous air barrier, ccSPF can serve as an air barrier because its cellular structure allows little air to permeate through. In Canada specifically, materials classified as air barriers are tested for air leakage and need to meet an air leakage rate of 0.02 l/sm^2 at a 75 Pa pressure difference (CAN ULC S741 2020). Some of the ccSPF currently available on the market result in air leakage values of around 0.000120 l/sm^2 at a 75 Pa pressure difference which is below the allowable leakage rate Canada uses. In theory, XPS could also behave as an air barrier if it is adequately taped at the joints or seams. The closed cell nature of these two materials inhibit the significant air flow path through the material. From a practical standpoint, it would need to verified if the material is tested and detailed to function as part of the air barrier system. However, XPS does not typically undergo the same testing required to qualify it as an air barrier. Beyond long-term durability issues, air leakage is a cause for approx. 12–25% of increased energy consumption in older buildings (Parekh). While in newer buildings, air leakage is a smaller proportion (3–5%) energy consumption during operation. The use of ccSPF as main component of the air barrier system helps achieves much smaller air leakage rates which in turn reduces energy consumption.

Closed cell foam insulations also provide a level of vapour control which is essential in minimizing interstitial condensation. ccSPF at a thickness of 2 inches, provides a vapour permeance of 0.9 perm. ccSPF is *semi impermeable or* classified as a Class II vapour control material according to the International Building Code for cold climate zones. XPS at a thickness of 2 inches can be classified as a Class II vapour control. XPS is also available with additional facings which could increase the vapour resistance where the material can serve as a Class I vapour barrier.

The vapour controlling ability of foam insulations avoids the need to add an additional material to an assembly. This saves on installed embodied carbon and also saves on construction schedule.

A potential drawback of ccSPF and XPS is drying ability. Drying ability can be defined as the ability for a material to redistribute or buffer any incidental moisture. In a rain-screen designed envelope assembly, water will be inevitable introduced during a rain or snow event. A ventilation strategy behind the cladding would be necessary to ensure any incidental moisture can dry out of the assembly.

ccSPF can be used in vertical wall assemblies as both on the exterior (behind a cladding system) and on the interior (at the back of precast concrete panels or between stud framing). In these applications, no additional membranes are required for air, vapour or water control purposes. However, transition membranes are necessary around glazing rough openings or other penetrations. The spray applied nature of ccSPF also makes it versatile in sealing areas that are difficult to access for heel trusses where access by other means is difficult. Buildings will require many penetrations through the envelope that are not always easily tracked during the design process.

ccSPF is used as a “spot treatment” for air barrier discontinuities due to a number of penetrations such as structural elements, pipes, mechanical ductwork and electrical conduits.

XPS is also versatile and has applications in exterior wall, roofing and below grade assemblies. Beyond the thermal and vapour controlling properties, XPS has a high compressive strength which may be required in below-grade assemblies if significant structural loads are anticipated. Since XPS is in board form, it requires attachment to the structure for vertical applications which should be considered when analysing the overall thermal performance of an envelope system. Attachment through vertical/horizontal metal girts will result in significant thermal bridges that would reduce the overall thermal resistance of an assembly. Engineered, thermally broken clips, should always be considered with the use XPS in high performing envelope systems (Berardi and Ákos 2019).

70.3 Long Term Resiliency

During the design of a building, long-term resiliency is crucial. Resiliency can be a challenge due to issues such as quality, accelerated speed of construction and cost. With lower quality construction, lighter weight building materials, unknown site conditions and the increasing amount of unpredicted weather events, built in resiliency is crucial for occupant/building survivability.

Three of the most damaging climatic and weather-related events which impact our buildings and communities are wind, flooding and fire. Spray polyurethane foam cannot assist in reducing forest fires events, however SPF can significantly increase the resistance to wind and flooding events. SPF also known in the industry as “house glue” can increase the resiliency of the building structure by increasing the racking strength of the wall enclosure. Typically, during a weather event (hurricane or tornado) the house is damaged by the roof being ripped off and then the remaining walls leveled. Using SPF to connect the walls to the roof assemblies has been shown to increase the resistance wind up lift by 200%. FEMA (Federal Emergency Management Agency) in the United States has been managing and assisting communities after devastating weather events since 1979. To assist in making buildings/communities resilient to flooding, FEMA has developed a Technical Bulletin #2—Flood Damage—Resistant Material Requirements. This document states that the only acceptable material in flood prone regions is closed cell foam, the reason for this claim is due to the fact that the water during the flooding does not get absorbed by the closed cell foam.

70.4 Construction and Installation

As previously stated, reducing layers, or using SPF as a material other than just for insulation (i.e. water, air and vapor control) can assist in reducing the over carbon impact from the building enclosure. With SPF being manufactured in the field, the potential for only using material that is required is far more achievable, compared to other materials that are purchased in lots (specific amounts) and which require possible site modification in the field. The application of materials that mold to specific shapes, sizes and voids such as SPF reduces the amount of cut offs and surplus of materials, but can also increase the efficiency of the building enclosure (thermal, air, moisture and vapor). Remaining SPF is typically stored in airtight recyclable steel drums for future use. Reducing surplus materials, off-cuts and plastic packaging will not only reduce the carbon foot bring of the building enclosure being built but will minimize the transportation and volume needed in the landfill. As a part of prequalification of a ccSPF installer/subcontractor, the level of experience in working with sprayfoam should be considered. The changeover of blowing agent will result in a learning curve for the installers of spray foam when working with a new blowing agent gas. Given that SPF is manufactured in the field, to ensure optimized use and minimal wasted material, an experienced installer is of utmost importance.

Shipping large quantities of thermal insulation (i.e. air/gas) long distances can have a significant impact on the environment in the form of burning fossil fuels, increasing traffic, added wear and tear on the vehicle and etc. A shipping efficiency plan should be determined from the manufacturing facility to the site as it will assist in determining the best solution for reducing carbon due to transportation. Since insulation manufacturing facilities are located sporadically across North America, identifying the distance, weight and number of transports required, is ideal for reducing the carbon created from excessive transportation. Since SPF is manufactured onsite, the shipping efficiency is very high when compared to board stock thermal insulation. Traditional building SPF transported in liquid form expands a minimum of 30 times its liquid size. To visualize/calculate shipping efficiency a standard calculation was developed by European Chemical Transportation Association that states there is a carbon impact of 101.25 g CO_2 for every ton per km of material shipped. When comparing exterior grade vapour permeable mineral fibre insulation to a vapour permeable ocSPF insulation, the carbon impact can be compared.

70.5 Conclusions

It is crucial to take a holistic view when choosing building materials and to assess the environmental impact of a wall enclosure is often useful to calculate the total system GWP. Some insulation products can be installed individually to meet the intent of all the control layers or several products could be systematically arranged in an assembly to meet the intent of the control layer requirement. When specifying thermal insulation, it is important to make decisions based on many performance and sustainable characteristics rather than deciding solely on the product's thermal performance. Reducing layers (i.e. moisture barrier, air barrier and vapour retarder) can reduce the overall carbon footprint of the enclosure and can eliminate the need for added manufacturing and transportation for these extra materials. One of the most environmentally friendly changes to SPF is transitioning from a high GWP blowing agent (HFC) to an ultra-low GWP blowing agent (HFO). Meanwhile, shipping efficiency maps and calculations should be a requirement for understanding the impact from material shipping and recycling. Removing or reducing trucks on the road for building material transportation will have secondary effects on not just the building industry but on the automotive industry as well. Applying materials in a fashion that reduces material surplus and off cuts will reduce the environmental impacts from shipping to landfill and recycling sites. Building with resiliency and durability should be the top priority for designers and using effective strategies to shape future design will not only reduce the environmental life cycle of these buildings but will also allow for occupation and survivability during catastrophic events. There is perception in the industry that SPF is a huge contributor of carbon, however when factoring some of the most important environmental factors, SPF could be one of the greenest insulations currently on the market. All insulation materials, when used effectively, can reduce the impact buildings have on climate change by reducing heating and cooling loads. The payback of embodied carbon from thermal insulations vary based on thickness, energy use, climate, etc. However, when installed, most thermal insulation will have a greater lifetime carbon savings than the amount of embodied GWP for these insulations during manufacturing. The Canadian government and Environment Canada are taking a strong stance by recognizing the harmful effects of high-GWP materials, and implementing a HFC phase-down plan. Some low-GWP alternatives are already available in the market. Although much work remains to be done, industries currently using low-GWP have proven they can move quickly to protect the environment.

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