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LCA of SPF insulation for residential and commercial building applications

The life cyle of spray polyurethane foam (SPF) insulation was evaluated for its environmental footprint in residential and commercial building applications. This study is the first comprehensive life cycle assessment (LCA) of SPF insulation conducted in North America, and covers primary energy from non-renewable resources, plus five environmental impacts related to air/water pollution: climate change (carbon footprint), acidification, eutrophication, ozone depletion, and smog creation. This LCA improves understanding of environmental impacts across the life cycle, demonstrates the benefits of SPF insulation using rigorous assessment methodology, and provides publically available industry averages for SPF products. Results show that energy and environmental benefits from the use of SPF in new residential construction and commercial roofing retrofits outweigh the embodied energy and environmental impacts of manufacturing, installation, transportation, and disposal of the insulation at end-of-life compared to the use phase benefits. Variations in the ratios and payback periods for energy savings and environmental impacts result mainly from the type of SPF applied, different climate zones, and type of energy used. When open-cell SPF (ocSPF) is installed on 2,500 ft^2 (240 m^2) residential houses in Houston, TX, (IECC climate zone 2A), Richmond, VA, (IECC climate zone 4A), and Minneapolis, MN, USA, (IECC climate zone 6A), energy savings versus no cavity insulation during a 60 year service life are from 64–194 times greater than the embodied energy in the ocSPF. The results for closed-cell SPF (ccSPF) insulation yield energy saved to energy embodied ratios that are half as much, ranging from 32–98 times greater than the ccSPF embodied energy. Climate change results show, the difference in the reduction of greenhouse gas (GHG) emissions are even greater from ocSPF versus ccSPF. The GHG avoided to embodied ratios for ocSPF in residential houses in these zones range from 92–248, whereas the GHG avoided to GHG embodied ratios for ccSPF range from approximately 8–21. The ccSPF GHG avoided to GHG embodied ratios are about a 12 times less compared to ocSPF, mainly due to the high global warming potential (GWP) of the blowing agent currently used to make ccSPF. Regarding other environmental impacts avoided for residential housing, the impacts avoided to embodied ratios for ocSPF range from 44–134 (Houston) and 40–159 (Minneapolis). For ccSPF the ratios are similar to those observed for energy, i. e. approximately half compared to ocSPF as result of greater embodied impacts associated with the denser ccSPF. Existing commercial buildings were evaluated for roofing retrofits. For roofing SPF installed to obtain an R20 retrofit on a 22,500 ft^2 (~2,100 m^2) strip mall, energy savings in Houston, Richmond, and Minneapolis during the 60 year service insulation life range from 55–66 times greater than the baseline of R4. The results for an R12 baseline to an R20 retrofit yielded energy saved to energy embodied ratios in these cities approximately 30 times greater than the baseline. As expected, the energy savings to energy embodied ratios for the R12 baseline case are half of that compared to the R4 baseline, but nevertheless significant. Climate change results show a similar trend, with ratios of use phase GHG avoided to embodied ranging from 15–17 for an R4 to R20 retrofit, and ratios of use phase GHG avoided to embodied ranging from 7–8 for an R12 to R20 retrofit. Other environmental impacts for the commercial building show similar but more pronounced trends resulting from higher impacts associated with electricity use in climate zone 2 (Houston), as use phase impacts avoided to embodied impacts range from 30–106 (Houston) and 20–71 (Minneapolis) for an R4 to R20 retrofit, and 16–57 (Houston) and 9–31 (Minneapolis) for an R12 to R20 retrofit.

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1. Introduction

This study was conducted in two parts to determine the environmental impacts of all SPF life cycle phases:

- **Embodied phases:** SPF raw materials and blending, transportation, installation and end-of-life. Embodied phases are assessed according to ISO LCA standards [1, 2] methodology, which define the embodied phases goal and scope, inventory analysis, impact assessment, and interpretation.
- **Use phase:** SPF insulation during its service life in new residential houses and commercial building roofing retrofits. The use phase is evaluated with whole building energy simulation tools: Residential Energy Services Network (RESNET)-approved software (EnergyGauge) for residential, and US Department of Energy (DOE) software (EnergyPlus) for commercial.

In order to verify conformance with globally-recognized standards for LCA (ISO 14040/14044) and strengthen the credibility of this study, the Spray Polyurethane Foam Alliance (SPFA) commissioned critical reviews, according to the critical review requirements of ISO 14040/44 by a panel of three independent LCA/insulation industry experts.

Similarly, the reports on SPF residential energy modeling analysis and SPF commercial energy modeling analysis were reviewed by independent building science experts. It should be noted that the other inherent benefits of ccSPF insulation, such as its integrated vapor retarder (required by building codes in colder climates), water resistance, and added structural performance, are not included in this analysis. Also, it is important to note that the SPF products evaluated were used to fill cavities and not applied externally as a continuous insulation in typical residential housing. Continuous insulation further improves insulation performance by eliminating thermal breaks.

2. Embodied phases: LCA goal and scope

2.1 Purpose and audience

The purpose of the embodied phases study is to understand the environmental impact of SPF from cradle to end-of-life on a product level according to ISO 14040/44. The product level means that life cycle impacts from the building use level such as reduction in energy and environmental impacts due to the presence of insulation are not covered. The results of this section are primarily intended for use in North America by the building and construction community and users of publicly available life cycle inventories. These results address all emissions covered in the US EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI 2.0) methodology. The study considers cradle to end-of-life environmental impacts of SPF on a product level in both commercial and residential applications as well as their final end-of-life treatment. The three specific products considered are low density ocSPF and medium density ccSPF for use in wall cavities, plus ccSPF used in exterior low-slope roofing applications. Primary data for embodied phases were collected from six formulation locations, literature provided by chemical suppliers, and six installation contractors to attain an industry average of energy and material usage. Best available data (representative of technology, geographical area, recent information etc.) were used for all upstream raw materials.

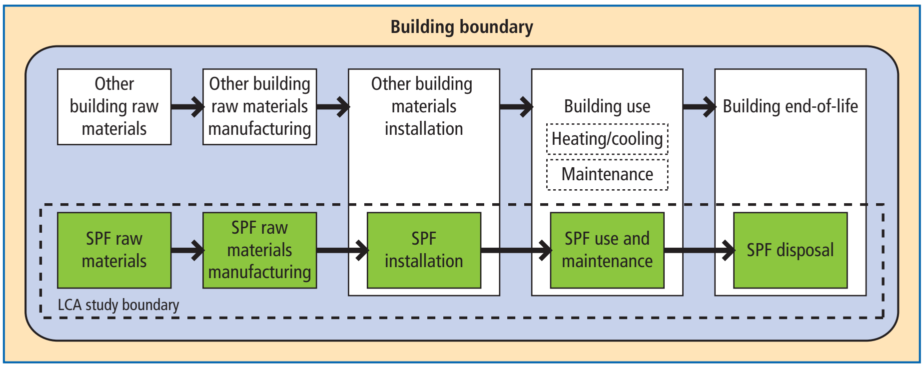
2.2 System boundaries

Figure 1 shows the life cycle stages associated with the embodied phase study, which focuses only on the SPF insulation in a building, excluding all other building materials. As shown in **figure 1**, "SPF use and maintenance" includes only the impacts of blowing agent lost to the environment during SPF installation. The effects of SPF insulation on the thermal resistance of the building envelope are covered in later sections. Included in the embodied phases are upstream processing and production of materials and energies needed for the production of SPF, transport of materials (chemicals and packaging) to SPF installation sites, formulation of SPF, transportation, the installation site, installation, removal and transport of insulation to disposal site, and end-of-life disposal in a landfill. **Table 1** summarizes what is included in and excluded from the embodied phases study.

Included	*Excluded*
• Extraction of raw materials • Production and manufacturing of raw materials for SPF and packaging • SPF formulation • SPF installation • SPF use phase emissions • End-of-life of insulation and packaging • Transportation between all life cycle stages	*• Construction of capital equipment • Maintenance of support equipment • Human labor and employee commute • Energy savings and environmental impacts avoided from product use*

◄ ***Tab. 1:*** *Embodied phases system boundaries*

▼ ***Fig. 1:*** *Life cycle flow diagram of SPF insulation products*



2.3 Functional unit

The functional unit is based on providing thermal insulation for building envelopes, as defined by the Product Category Rule (PCR) for Building Envelope Thermal Insulation, product category rule No. UL 110116 [3]: 1 m² of insulation material with a thickness that gives a design thermal resistance R_{SI} = 1 m²·K/W (R_{IP} = 5.68 h·ft²·°F/Btu) and with a building service life of 60 years. The standard unit of measurement for SPF insulation is a board foot (bd ft), which is 1 ft² (~ 930 cm²) of insulation that is 1 inch (2.54 cm) thick. To achieve 1 m² with a thickness that provides R_{SI} = 1, the different foam products require unique reference flows. The reference flows are needed as a basis for performing the life cycle calculations, as these defined volumes can be converted to mass values. The thickness required to provide R_{SI} = 1 is calculated by dividing the target R value defined in the functional unit above by the foam's R value. For the purposes of this report and dataset generation, representative R values given by the SPFA are used. Reference flows (i. e. defined area and thickness, to be converted to mass for subsequent calculations) for the three foam products are shown in **table 2.**

It is important to note that the nominal or core density of each product is used to define different SPF product classes. The actual density of SPF is considerably higher because of densification that occurs during application in a building. Since the foam is sprayed on walls/roofs in multiple passes, thin films of more dense foam form between the layers. This densification also occurs at the substrate and at the free surface (skin). **Figure 2** shows the densification of foam that occurs after SPF is applied. For ease of reporting, the nominal density will be used when describing foams throughout this report. The density of the foam is calculated based on the specific gravity of ocSPF and ccSPF, combined with installers' reported volume blown. Based on industry MSDS data for 2.0 lb/ft³ (32 kg/m³) ccSPF and 0.5 lb/ft³ (8 kg/m³) ocSPF systems, the reported specific gravity for the A side, open-cell B side (low density), and closed-cell B side (medium density and roofing), are 1.10, 1.22, and 1.17 respectively. Since 55 gallon (208 l) drums of each A and B side are used, the total weights of foam ingredients typically used are shown below. Based on industry safe practices and input on drum filling, 51 gallons (193 l) is the amount of material typically contained in a drum. **Table 3** shows the material weights, converting the specific gravities using a density of water at 8.33 lb/gal (1 kg/l).

This calculated density is slightly higher than the actual density because losses occur during foaming. Water vapor, as well as some CO_2 and HFC blowing agents are released when the liquid ingredients combine and expand. The mass of HFC escaping is simply calculated by multiplying the HFC content of the foam with the assumed rate of emission at installation. CO_2 is also liberated as a result of the reaction between water and isocyanate. This mass is calculated differently for ccSPF versus ocSPF. In the case of ccSPFs, all the B side water reacts with isocyanate. The molar ratio of CO_2 to water is 44/18 or 2.44, so assuming that the B side formulation contains 1.75 % water, 497 lbs (225 kg) of B side (as calculated in **table 3)** would yield 0.021 lbs (9.5 g) CO_2/lb ingredients or 2.1 % loss.

In the case of ocSPF, only a fraction of water reacts with isocyanate. Typically, half pound or low density SPF is formulated with an excess of water in the B side beyond what is needed for reaction. Generally, about 25 – 35 % of the water is consumed by reaction with isocyanate, and the rest is converted to steam during the exothermic foaming process. Assuming that the B side formulation contains 17.5 % water and 25 % of it reacts, 467 lbs (212 kg) of B side would yield 0.051 lbs (23 g) CO_2/lb ingredients or 5.1 % loss. Both the yield losses calculated above and installation trim scrap increase the raw materials and processing upstream needed to achieve the specified 1 m² with a thickness that provides R_{SI} = 1, so the mass calculation is scaled upward to account for these losses. Average installed volume and scrap losses are based on surveys and input from SPF installers. It is assumed that the thermal resistance increases in a fixed ratio with foam thickness, and thus the mass of foam for each reference flow can be calculated. As noted previously, to achieve 1 m² with a thickness that provides R_{SI} = 1, the different foam products require unique reference flow mass values. **Table 4** shows the reference flows and physical properties.

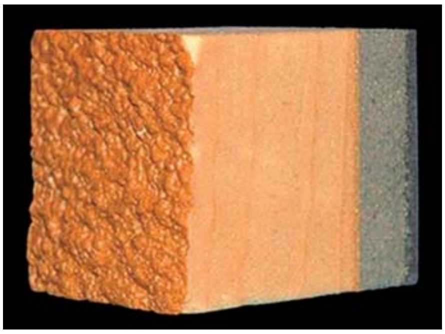
2.4 Data inventory sources

Primary data were collected from six formulation locations and six installation contractors. In addition to primary data, the model utilizes GaBi 5 (Ganzheitliche Bilanzierung, German for holistic balancing) background data.

2.4.1 Fuels and energy – background data

National averages for electricity grid mixes are from the GaBi 5 database. For each of

Fig. 2: Cross-section of ccSPF insulation with layers of various densities (Courtesy: collectspace.com)



Tab. 2: Reference flows – 1 m² with specified thicknesses

Property	Units	Low density ocSPF	Medium density ccSPF	Roofing, ccSPF
Target R value	h·ft²·°F/Btu	5.68	5.68	5.68
Foam R value	h·ft²·°F/Btu per inch	3.6	6.2	6.2
Thickness	inches	1.58	0.92	0.92

Tab. 3: Calculated weights of foam ingredients

	Low density ocSPF	Medium density ccSPF	Roofing, ccSPF
A side	1.22 x 8.33 lb/gal x 51 gal = 518 lb (235 kg)	1.22 x 8.33 lb/gal x 51 gal = 518 lb (235 kg)	1.22 x 8.33 lb/gal x 51 gal = 518 lb (235 kg)
B side	1.1 x 8.33 lb/gal x 51 gal = 467 lb (212 kg)	1.17 x 8.33 lb/gal x 51 gal = 497 lb (225 kg)	1.17 x 8.33 lb/gal x 51 gal = 497 lb (225 kg)
Total drum set	518 + 467 = 985 lb (447 kg)	518 + 497 = 1,015 lb (460 kg)	518 + 497 = 1,015 lb (460 kg)

Tab. 4: Mass values and intermediate calculations of reference flows

Property	Units	Low density ocSPF	Medium density ccSPF	Roofing, ccSPF
Thickness	inches	1.58	0.92	0.92
Nominal density	lbs/ft³	0.5	2	3
Average installed volume	bd ft/drumset	14,000	4,100	2,800
ρ (actual density)	lbs/ft³	0.84	2.97	4.35
Yield loss	wt. fraction 0 – 1	0.05	0.03	0.03
Scrap	wt. fraction 0 – 1	0.08	0.04	0.02
Mass	lbs	1.31	2.55	3.67

the formulation manufacturers and for SPF installation, the most recent US national average energy data from the GaBi 5 database are used.

2.4.2 Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials to formulation facilities, as well as to the construction site and disposal at end-of-life. The GaBi 5 database was used to model all transportation and fuel production. Truck transportation within the USA was modeled using the GaBi US truck transportation datasets. The vehicle types, fuel usage, and emissions for these transportation processes were developed using a GaBi model based on the most recent US Census Bureau Vehicle Inventory and Use Survey (2002) and US EPA emissions standards for heavy trucks in 2007.

2.4.3 Allocation

As most SPF formulators create more than just the chemicals needed for SPF, mass allocation of the facility's total life cycle inventory was performed based on the annual output mass of the products created. Allocation of upstream data (energy and materials) in the GaBi 5 database is as follows:

- For all refinery products, allocation by mass and net calorific value is applied. The manufacturing route of every refinery product is modeled and so the burden for producing these products is calculated specifically. Two allocation rules are applied:
  1. The raw material (crude oil) consumption of the respective stages, which is necessary for the production of a product or an intermediate product, is allocated by total energy based on the calorific value of the product.
  2. The energy consumption (thermal energy, steam, electricity) of a process, e. g. atmospheric distillation, being required by a product or an intermediate product, are charged to the product according to the share of the throughput of the stage (mass allocation).
- Materials and chemicals needed during manufacturing are modeled using the allocation rule most suitable for the respective product. For example, the major raw material used to produce SPF, pMDI, was developed in the American Chemistry Council (ACC) study using mass allocation by assigning environmental burdens (energy, GHGs, etc.) to the product (pMDI) and its co-product (HCl) [4]. Further information on a specific product is available from GaBi documentation [5].

2.4.4 Cut-off criteria

The cut-off criteria used for including or excluding materials, energy and emissions data of the study are as follows:

- **Mass:** If a flow is less than 1 % of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- **Energy:** If a flow is less than 1 % of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- **Environmental relevance:** If a flow meets the above criteria for exclusion, yet was identified by LCA experts as a potentially relevant contributor, a proxy life cycle inventory (LCI) with conservative environmental burdens was chosen (high burden per unit compared to typical ingredients). If the proxy datasets exceed the 1 % individual cut-offs, additional research or justification is necessary.

The sum of the excluded material flows did not exceed 5 % of mass, energy or environmental relevance.

2.5 Data quality

2.5.1 Representativeness

Efforts were made to use representative data for the embodied phases associated with SPF manufacturing, formulation, transportation, installation and end-of-life in North America, as follows:

- **Technology:** In the study, representative formulas based on SPFA and production technologies for US manufacturing/formulation of the SPFs are used. Profiles from the GaBi 5 software database are utilized for other ancillary or process materials

Fig. 3: *PED by embodied life cycle phase (1 m², R_{SI} = 1)*

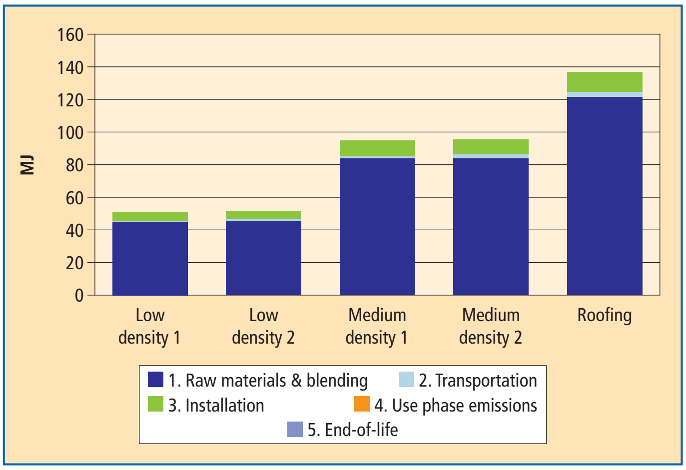
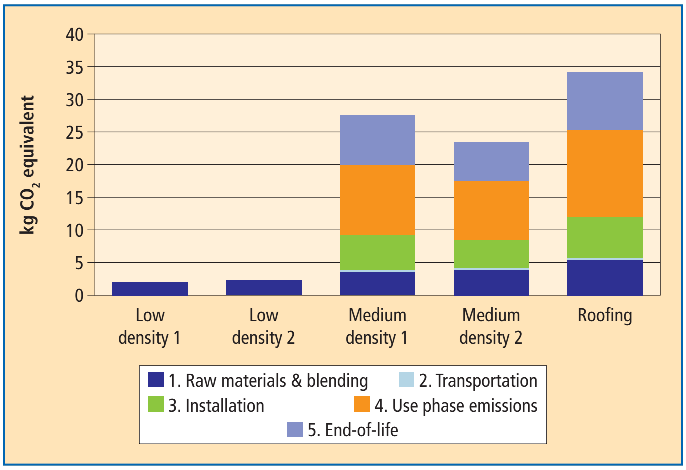


Fig. 4: *GWP by embodied life cycle phase (1 m², R_{SI} = 1)*



such as the production of chemical stock, fuels, power, and regional grid mixes. Access to the most recent US datasets for polyester polyol was granted through permission of the manufacturers or associations which have recently completed LCAs of their products [6].

- **Time Period:** Installation and formulation data were collected from 2010 yearly totals. Secondary data for most primary material components is from 2006 or more recent.
- **Geography:** The geographical coverage of this study is SPF insulation manufacturing and installation in North America. Due to data availability and quality, US-based datasets are used in the model where appropriate.

2.6 Embodied phases life cycle impact assessment results

Table 5 shows an overview of the impacts. The results are displayed for 1 m^2 of insulation material with a thickness that yields R_{SI} = 1. The "low density 1", "medium density 1" and "roofing" are generic or aggregate formulation data developed by SPFA supplier members by a consensus process. The "low density 2" and "medium density 2" are based on generic formulations from the Center for the Polyurethanes Industry (CPI), which are the same formulations used in the current CPI emissions and exposure studies. The CPI formulations are not used in subsequent use phase energy savings and impacts avoided calculations in section 5 of this report, but are provided here for comparison.

Since energy and GWP aspects are typically of greatest interest to most stakeholders, **figures 3** and **4** show the primary energy demand (PED) and GWP by embodied phases of the life cycle. For medium density and roofing foams, the release of the blowing agent HFC-245fa contributes approximately 85 % of the GWP in the embodied phases. Because this emission has such a large effect on GWP and because blowing agent emissions are fairly uncertain, sensitivity analysis was used to evaluate the effects of different blowing agent loss rates on the product footprint related to the embodied phases. For the low density foams, and for the other impact categories considered for medium density and roofing foams (non-GWP), about 90 % of the embodied phase impacts are related to upstream raw materials. **Figure 3** shows the primary energy demand impacts of all foams. Results look very similar for other impact categories, except climate change indicated by GWP in **figure 4,** which highlights the blowing agent effect on the embodied phases GWP. **Figure 4** also shows results based on the assumption that 50 % of the total blowing agent (HFC-245fa used in medium density and roofing foams) is emitted eventually, with 10 % emitted during installation, 24 % emitted during lifetime in building, 16 % emitted during end-of-life and thus 50 % remaining in the product.

Since HFC-245fa has a GWP factor of 1,030 kg CO_2 equivalent/kg, the emissions dominate the climate change results of the embodied phases. Based on research of foam insulation and HFC-245fa, assumptions of the emission rates varied from 25–75 %. This study assumes an emission rate of 50 %, which is in line with the value used in the Polyisocyanurate Insulation Manufacturers Association (PIMA) study [6]. Since this value is an assumption, a sensitivity analysis was performed.

Figure 5 shows how the climate change results for embodied phases are affected by the emission rate of this blowing agent. As discussed in section 6.4, new generation blowing agents for ccSPF (medium density and roofing foam) have been developed and are in the process of being commercialized. The GWP for some new generation blowing agents is reported to be over 100 times less than conventional blowing agents [8]. Referring to **figure 4,** the climate change impact of medium density and roofing foams using these new low GWP blowing agents would be similar to the low density foams. The embodied phases report (PE International, 2012) provides similar details on the other impact categories (acidification, eutrophication, ozone depletion, and smog creation), as well as detailed breakdowns of the life cycle impact contributions of specific chemicals to the raw materials phase. As expected, the embodied life cycle impact contributions of the key raw material that makes up 50 % of the SPF, pMDI, has the most significant effect on the raw material phase life cycle impacts. The impacts contributed by the raw materials and other embodied phases are relatively insignificant when the entire use phase is considered. The embodied phases contribute only a small fraction of the impacts compared to the more significant energy savings and GHG/other impacts avoided in the use phase.

Finally, it is recognized that variation in the R value and density of SPF influences the environmental impacts. SPF formulators report a range of R values and densities achieved which are specific to individual products. To determine the effect of this variability on the LCA results, a sensitivity analysis was performed on the primary energy demand to calculate the impacts based on the minimum and maximum reported R values and densities. Also, the SPFA compiled a range of published density and R value information for SPF

▼ ***Tab. 5:*** *Overview of life cycle impact per reference flow (1 m^2, R_{SI} = 1), embodied phases*

	Low density 1	Low density 2	Medium density 1	Medium density 2	Roofing
Reference flows					
Mass / lbs	1.31	1.31	2.55	2.55	3.67
Thickness / inches	1.58	1.58	0.92	0.92	0.92
Life cycle impacts per reference flow					
Primary energy from resources / MJ	50.5	51.3	94.8	95.5	136.7
Climate change / kg CO_2 equivalent	2.4	2.4	27.6	23.7	34.3
Acidification / kg H^+ moles equivalent	0.396	0.399	0.78	0.755	1.073
Eutrophication / kg N equivalent	4.33E-04	4.39E-04	8.99E-04	9.11E-04	1.33E-03
Ozone depletion / kg CFC11 equivalent	6.59E-08	6.70E-08	1.15E-07	1.18E-07	1.67E-07
Smog creation / kg O_3 equivalent	0.094	0.095	0.18	0.185	0.267

from ICC Evaluation Service (ICC-ES) reports [9]. The values used for calculating best and worst case scenarios come from that research [10]. **Table 6** shows the values used to calculate the results.

It is not surprising that increasing R value of a foam product decreases the mass required and therefore its burden. Results also show that as the density increases, the impacts increase, therefore, the highest burden scenario for each foam type occurs with maximum density values and minimum R values, while the lowest burden scenarios are those with the minimum density and maximum R value. As shown in **figure 6,** the minimum impacts range from 85–91 % of the impacts found in the study. Conversely, the maximum impacts range from 114–140 % of the impacts found in the study. As the R values and density affect all impacts equally, this sensitivity applies to all impacts. It is important to note that the best case and worst case scenarios are not equidistant from the study results.

3. SPF applications

There are three main types of SPF used in the US construction industry for insulation and roofing systems based on material density and cell structure. Open-cell or low density SPF has a nominal density of 0.4–0.7 lb/ft³ (6–11 kg/m³). These foams use water as the blowing agent. Since this material has an open-cell structure, the cells are filled with air, and the thermal resistivity is in the range of R3.6–R4.0 per inch. OcSPF is permeable to moisture and may need a vapor retarder in cold climate building applications. However, ocSPF is air impermeable and can serve as an air barrier material at certain thicknesses. Closed-cell or medium density SPF has a core or nominal density ranging from 1.7–2.3 lb/ft³. (27–37 kg/m³). 90 % or more of the foam cells are closed. Fluorocarbon blowing agents are used in the B side and convert to a gas from the heat of the reaction to expand the cells. Like a double-pane insulated window, this low thermal conductivity fluorocarbon gas helps yield a thermal resistivity between R5.8–R6.8 per inch. Medium density SPF is resistant to water absorption and effectively impermeable to moisture and air. In addition, medium density foams have measureable stiffness and strength and can provide a moderate increase in the structural performance of certain building assemblies [11–13]. Like medium density foams, the third category of SPF, roofing foam, has a closed-cell structure using the same captive fluorocarbon blowing agents. The major difference between roofing SPF and medium density SPF is the foam density. Roofing foams have nominal densities typically ranging from 2.5–4.0 lb/ft³ (40–66 kg/m³). This increased density provides a higher compressive strength when installed on top surfaces of low slope roofs.

3.1 SPF in residential homes

SPF expands in place providing both insulation and an air barrier. This in-place expansion fills cracks, gaps and penetrations in the building envelope. It can be used in the same envelope applications as fibrous insulations, but due to its adhesive properties, it can be used in several additional locations unsuitable for fibrous insulations, such as under floors and below roof decks to create more energy-efficient unvented attics. In the use-phase analysis, covered in section 5, both low and medium density SPF were considered interchangeably to provide interior insulation for walls, floors and roofs of newly-constructed wood-frame homes. The thick-

Foam	Parameter	Best case	Study results	Worst case
Low density ocSPF	Nominal density	0.42	0.5	0.57
	Actual density	0.73	0.86	0.99
	R value	4.2	3.6	3.2
Medium density ccSPF	Nominal density	1.8	2	2.8
	Actual density	2.81	3.12	4.37
	R value	7	6.2	5.8
Roofing, ccSPF	Nominal density	2.5	3	3.8
	Actual density	4.36	4.58	5.24
	R value	7.1	6.2	5.9

Tab. 6: *Density and R values used in sensitivity analysis*

Fig. 5: *Sensitivity analysis of HFC-245fa emissions, embodied life cycle phase (1 m², R_{SI} = 1)*

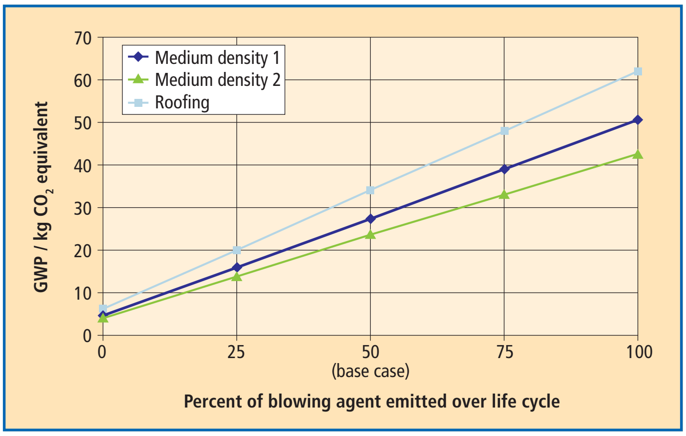
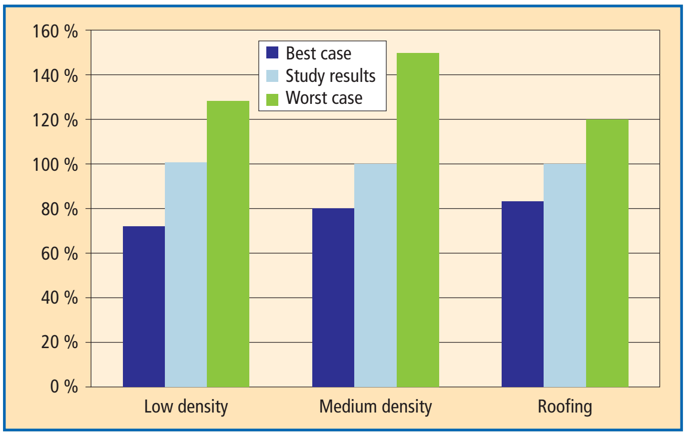


Fig. 6: *Sensitivity of PED from best to worst case density and R values*



ness of the SPF insulation was varied by location to provide minimum R values prescribed by the 2009 International Residential Code (IRC) [9].

3.2 SPF in commercial buildings

While low and medium density SPF can be used as an interior insulation in commercial buildings and medium density SPF exclusively on the exterior, a common commercial building application for SPF is for new and replacement low-slope roof applications. SPF can be used in new buildings or it can be directly applied over existing roof systems. SPF roofing is typically applied at a thickness of 1–2 inches (2.5–5 cm), and tapered to control drainage. After application, it is immediately covered with one of several polymeric coatings to protect it from UV light and surface abrasion. In the use-phase analysis of this study, roofing SPF was used to provide additional insulation to the exterior side of a low-slope roof on a typical 1980's strip mall building in Houston, TX; Richmond, VA; and Minneapolis, MN, USA. The thickness of the SPF insulation was used to increase the continuous R value of the existing roof from R4 to both R12 and R20, to be compliant with the ASHRAE 90.1-2010 energy code [14].

4. Use phase: whole building energy simulation

4.1 Simulation methods

For this study, two different energy simulation programs were employed. These simulations were conducted on typical buildings to evaluate the energy savings using SPF. For residential homes considered in this study, EnergyGauge Software was used; for a typical type of commercial building (strip mall), US DOE EnergyPlus Software was used. All simulations were performed by Sustainable Solutions Corporation of Royersford, PA, USA, under guidance of a registered professional engineer, and independently evaluated by Steven Winter Associates of Norwalk, CT, USA. The details of these simulations are summarized in separate reports [17].

4.2 Simulation basis and results

4.2.1 Residential

For this study, a typical [18] 2,434 ft^2 (~226 m^2) two-storey wood-framed home was modeled using the EnergyGauge program. With the exception of insulation and air infiltration levels, all other aspects of the home remained unchanged. The residential energy modeling documented in the energy simulation reports compared the use phase of a SPF insulated home to two baselines: zero insulation and conventional fibrous insulation. However, since comparable embodied phase life cycle results for fibrous insulation are not available, an evaluation of the entire life cycle (embodied and use phases) for conventional insulation was not conducted. Therefore, this report shows results for a baseline home with no cavity insulation versus SPF insulation. Air infiltration rates for the baseline home and those with SPF insulation are given in **table 7.** For SPF insulation, two cases were modeled. Case 1 and case 2 used SPF insulation to provide the same R value as conventionally insulated homes, but the infiltration rate was lowered to 0.1 ACH_n based on average infiltration rates measured for homes using SPF [19]. As described in **table 7,** case 1 applied insulation to the attic floor, while case 2 applied insulation under the roof deck to create an unvented attic. Case 1 was assumed for all three climates, whereas case 2 was modeled only for the Houston climate (IECC zone 2A).

Tab. 7: *Descriptions of residential energy modeling cases*

Case	Description
Baseline	Typical new home construction, no added insulation, using maximum climate-zone dependent infiltration rate from IECC 2009 Section N1102.4.2.1 (0.43, 0.33 or 0.32 ACH_n)
Attic floor	SPF insulation with whole house ventilation, insulation applied to attic floor, using infiltration rate from NAHB study (0.1 ACH_n). Some exposed HVAC ductwork in vented attic.
Unvented attic (UVA)	SPF insulation whole house ventilation, insulation applied to underside of roof deck and over roof rafters to create unvented attic enclosing entire HVAC system inside building envelope, using infiltration rate from NAHB study (0.1 ACH_n)

Tab. 8: *Key results from the residential energy modeling*

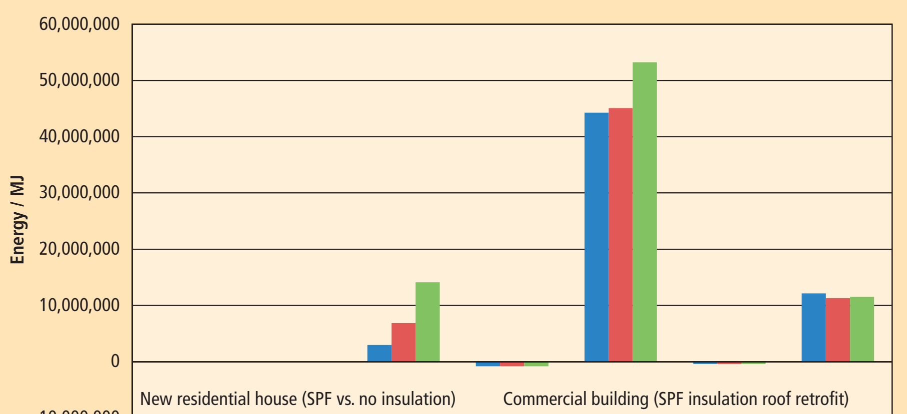
	Houston (zone 2A)			Richmond (zone 4A)		Minneapolis (zone 6A)	
	Baseline	SPF (LD/MD) Attic floor	SPF (LD/MD) UVA	Baseline	SPF (LD/MD)	Baseline	SPF (LD/MD)
Attic floor insulation	0	R30		0		0	
Roof deck insulation			R30	0	R38	0	R49
Wall construction	2x4 16"oc	2x4 16"oc	2x4 16"oc	2x4 16"oc	2x4 16"oc	2x6 16"oc	2x6 16"oc
Wall insulation (cavity)	0	R13	R13	0	R13	0	R19
Ventilation / efficiency/cfm	Exhaust	ERV (78/55)	ERV (78/55)	Exhaust	ERV (78/55)	Exhaust	ERV (78/55)
Air infiltration / ACH_n	0.32	0.1	0.1	0.33	0.1	0.43	0.1
HERS score	129	88	75	122	70	138	66
Annual cooling / kWh	7,087	4,781	3,489	3,665	2,439	1,933	1,062
Annual heating / kWh	2,667	934	782	778	482	1,732	807
Annual heating / thm	0	0	0	994	244	2,217	579

Tab. 9: *Key results from commercial building energy analysis*

	Houston (zone 2A)			Richmond (zone 4A)			Minneapolis (zone 6A)		
	R4 baseline	R12 baseline	R20 with added SPF	R4 baseline	R12 baseline	R20 with added SPF	R4 baseline	R12 baseline	R20 with added SPF
Roof deck insulation	R4	R12	R20	R4	R12	R20	R4	R12	R20
Ventilation fans / kWh	20	16	14	18	14	13	21	18	17
Space cooling / kWh	123	101	92	107	87	78	101	87	81
Annual heating / thm	2,900	2,500	2,300	9,800	8,400	8,000	23,000	20,000	19,100

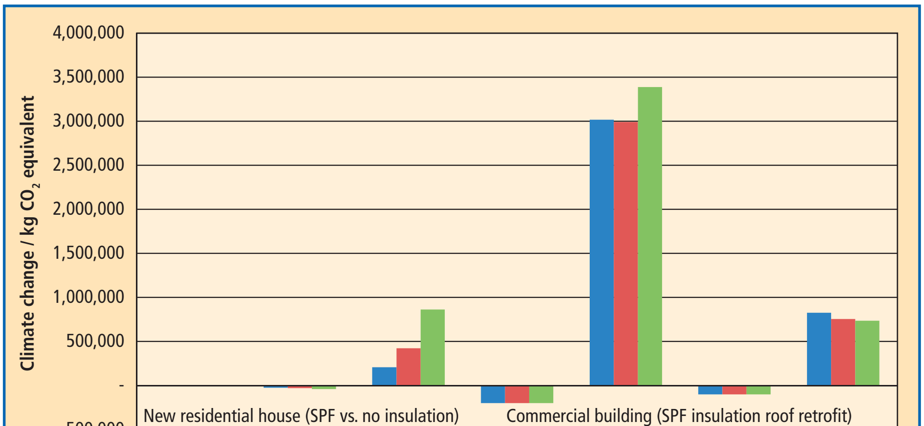
Minimum prescriptive R values are used for SPF insulation per the 2009 IRC, Chapter 11, for each location. The effect of SPF versus no insulation is the R value combined with significantly reduced air infiltration due to the air sealing properties of SPF. Although the comparison is not shown for reasons noted, we believe the air sealing and infiltration rates of SPF would be superior, as SPF will allow less infiltration compared to conventional insulation, based on air permeance data for these materials. When comparing SPF to no insulation, there will be a significant increase in R value for the wall and ceiling assemblies as well as the same improvement regarding infiltration rate. Sustainable Solutions Corporation evaluated multiple studies and data sources to identify an accurate infiltration rate for conventionally insulated new homes and SPF insulated new homes [20, 21]. The model home for each climate zone is a typical construction for the home size and type based on NAHB Builders' Practices Survey and the prescriptive requirements of the 2009 IECC Energy Code. This approach provides a better understanding of the typical energy usage in each region. Extracts of the residential modeling input and results follow below. The key results are provided in **table 8.**

▼ ***Fig. 7:*** *Life cycle primary energy from non-renewable resources (MJ), 60 years*



	ocSPF embodied	ccSPF embodied	Residential saved	R4-R20 embodied	R4-R20 saved	R12-R20 embodied	R12-R20 saved
Houston	-46,634	-92,588	2,971,391	-804,334	44,264,207	-402,167	12,130,480
Richmond	-53,791	-106,799	6,861,794	-804,334	45,092,301	-402,167	11,294,047
Minneapolis	-72,640	-144,223	14,101,602	-804,334	53,231,945	-402,167	11,518,486

▼ ***Fig. 8:*** *Life cycle GHG emissions (kg CO_2 equivalent), 60 years*



	ocSPF embodied	ccSPF embodied	Residential avoided	R4-R20 embodied	R4-R20 avoided	R12-R20 embodied	R12-R20 avoided
Houston	-2,225	-26,956	205,423	-201,967	3,018,338	-100,983	824,689
Richmond	-2,567	-31,093	422,128	-201,967	2,991,984	-100,983	752,929
Minneapolis	-3,467	-41,989	860,775	-201,967	3,387,501	-100,983	733,611

4.2.2 Commercial

For this study, a typical 1980's vintage 22,500 ft^2 strip mall (US DOE Reference Building) was modeled. The commercial energy modeling compared the building using two baselines: existing R4 roof deck insulation (R4 baseline) and existing R12 roof deck insulation (R12 baseline). It is assumed that these baseline roof deck insulation levels are typical for this 30 year old building. A SPF roofing system was applied to increase the total roof deck insulation to R20, as required by ASHRAE 90.1-2010. Since little data exist for air leakage using different roofing systems, the air infiltration values used in the analysis were held constant for all cases. All other aspects of the building, with the exception of roof deck insulation levels, were held constant. Key results are provided in **table 9.**

5. The complete life cycle picture

5.1 The SPF insulation life cycle

The entire SPF insulation life cycle consists of cradle to end-of-life phases for making, processing, transporting, installing, using, and finally disposing of SPF insulation at end-of-life. The SPF insulation life cycle was divided into the following five key phases:

1. Raw materials manufacturing and blending
2. Transportation
3. Installation
4. Use phase
5. End-of-life.

The results in section 2 focus on the embodied phases of a product, i. e. energy and environmental impacts associated with phases 1, 2, 3, and 5. Also, section 2 covers environmental impacts associated with blowing agent emitted during use (phase 4), as well as blowing agent emitted in phases 3 and 5. Standard life cycle inventory and impact assessment methodology described in ISO LCA standards [1, 2] are used for estimating these environmental impacts. As in any comprehensive life cycle assessment, the embodied phases and their associated impacts do not tell the whole story since the energy saved and environmental impacts avoided during insulation use must be considered. Determining energy savings and environmental impacts avoided during insulation use requires a different methodology not covered in ISO 14040/44, sometimes called whole building energy simulation/modeling or analysis. The whole building energy modeling uses the simulation tools described in section 4 of this report. Combining energy and environmental impacts generated in the embodied phases (section 2) with the energy and environmental impacts reduced during SPF insulation use (section 4) provides a complete picture of the SPF insulation life cycle.

5.2 Life cycle impacts and scenarios

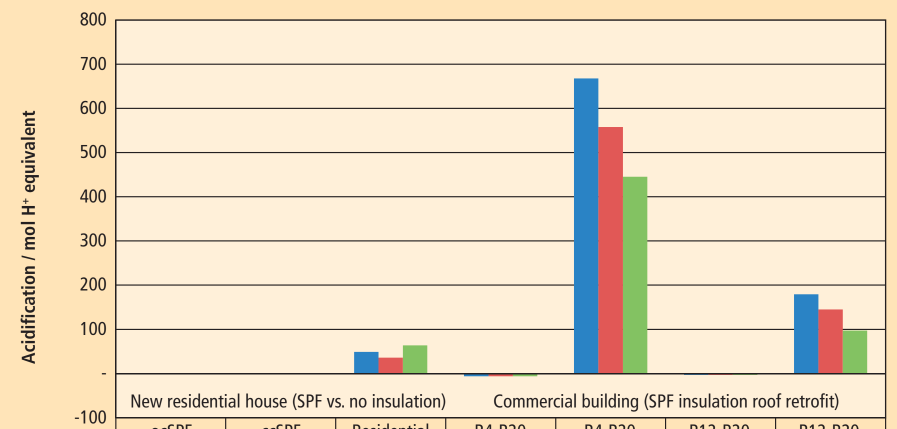
The following sections focus on the total SPF insulation life cycle for each of the following environmental impact categories: PED, climate change, acidification, eutrophication, ozone depletion and smog creation. Typical applications used to demonstrate life cycle results for each of the above six categories in climate zones 2, 4, and 6 were the walls and roof/ceilings of new residential housing and a commercial roof retrofit [3]. Regarding new residential housing applications, results for embodied phase impacts (energy resources, greenhouse gas emissions generated, acidification generated etc.) are combined with the use phase (energy saved, greenhouse gas emissions avoided, acidification avoided etc.) for residential houses in each climate zone. A house with a baseline case of no cavity insulation versus SPF insulation per code is used to demonstrate the value of SPF insulation on a new house. The comparisons for a commercial building [22] roofing retrofit located in each climate zone include a strip mall roof with a base case of R4 roof insulation versus additional SPF roof insulation to bring the total to R20, and a base case of R12 roof insulation versus additional SPF roof insulation to bring the total to R20.

5.3 Life cyle impacts of SPF insulation on residential houses and commercial buildings

Figures 7 through **12** show the total LCI for each impact categories for a new residential house with open-cell (low density) and closed-cell (medium density) SPF insulation compared to no cavity insulation. Also shown for each impact category are results for a commercial building roof insulation retrofit, where SPF is added to existing R4 and R12 baseline insulation levels to bring the total to R20. The magnitude of energy savings, GHGs and other environmental impacts avoided for the commercial building roof retrofit is significantly greater than that for the residential housing.

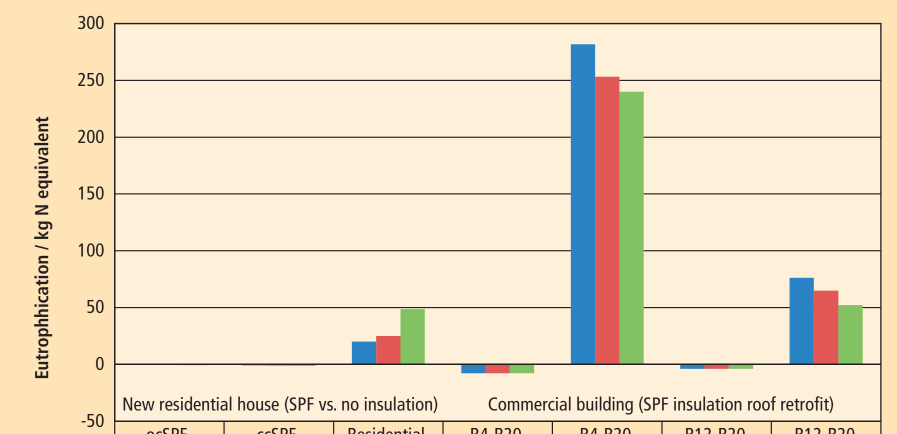
The primary reason causing this significant difference in the magnitude of energy savings results from a commercial roof insulated area that is approximately ten times greater than the insulated area of the residential house modeled. In the case of all impact categories, the embodied energy and environmental impacts are small when compared to the much greater energy savings and environmental impacts avoided during insulation use for 60 years.

Fig. 9: *Life cycle acidification (moles H^+ equivalent), 60 years*



	ocSPF embodied	ccSPF embodied	Residential avoided	R4-R20 embodied	R4-R20 avoided	R12-R20 embodied	R12-R20 Avoided
Houston	-0.366	-0.761	48.969	-6.306	667.754	-3.153	179.337
Richmond	-0.422	-0.878	35.927	-6.306	557.951	-3.153	144.977
Minneapolis	-0.570	-1.185	63.887	-6.306	445.195	-3.153	97.239

Fig. 10: *Life cycle eutrophication (kg N equivalent), 60 years*



	ocSPF embodied	ccSPF embodied	Residential avoided	R4-R20 embodied	R4-R20 avoided	R12-R20 embodied	R12-R20 avoided
Houston	-0.40	-0.88	20.05	-7.83	282	-3.92	76
Richmond	-0.46	-1.01	25.03	-7.83	253	-3.92	65
Minneapolis	-0.62	-1.37	48.69	-7.83	240	-3.92	52

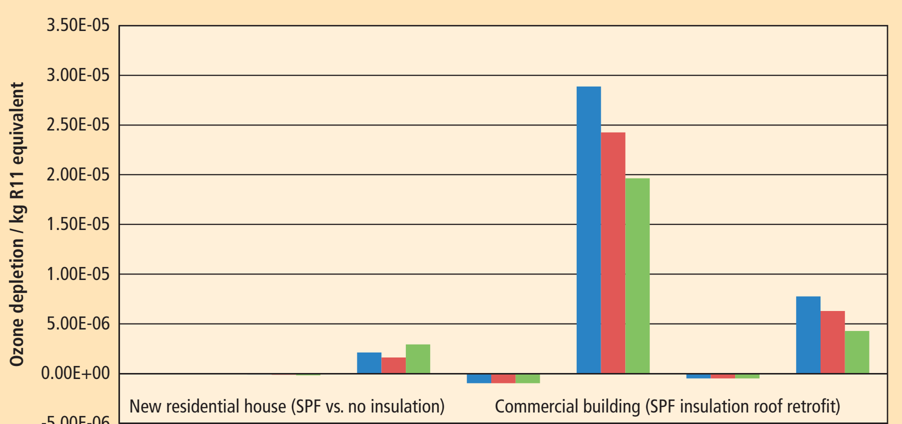
5.4 Life cycle payback analysis

Table 10 shows the energy saved/embodied and GHG avoided/embodied ratios and payback periods in detail for both the residential and commercial scenarios, as energy with its cost implications and climate change are typically of interest to many stakeholders. As seen, when the ratio of energy saved or GHG avoided is higher, the payback is lower. Since the use phase savings or GHG avoided are for a 60 year period, the ratio is the reciprocal of the payback period times 60. For example, in Richmond, the ocSPF saved/embodied energy is 127.6, and the reciprocal or ocSPF embodied/saved ratio is 0.0078, which also indicates the negligible embodied energy compared to the savings. Multiplying by 60 years yields the payback of 0.5 shown in the table. Houston clearly has higher energy payback periods, even though this zone has the lowest embodied energy. The higher embodied energy in the other zones results from higher volumes of insulation required, i. e. 1.3 and 1.6 times the volume of insulation is required in Richmond and Minneapolis, respectively, compared to Houston. However, the energy savings achieved by SPF insulation in the Richmond and Minneapolis houses is 2.3–4.8 times greater than the energy savings in Houston. This is expected since heating energy saved in Richmond/Minneapolis far overwhelms the cooling energy saved in Houston by installing SPF to required code.

The higher ratios of saved/embodied energy (2–3 times higher in Richmond and Minneapolis vs. Houston) is an indication of just how much more energy is saved by air-impermeable insulation in the temperate/cooler climate zones. CcSPF insulation has energy payback periods ranging between 0.6 and 1.9 years, while ocSPF insulation has energy payback periods between 0.3 and 0.9 years. The main reason for the difference is that embodied energy for ccSPF insulation is about twice as high compared to ocSPF insulation installed to the same R value. The higher embodied energy for ccSPF versus ocSPF results from a ccSPF density that is 3.5 times greater than ocSPF, even though ocSPF requires 1.7 times the insulation volume compared to ccSPF insulation.

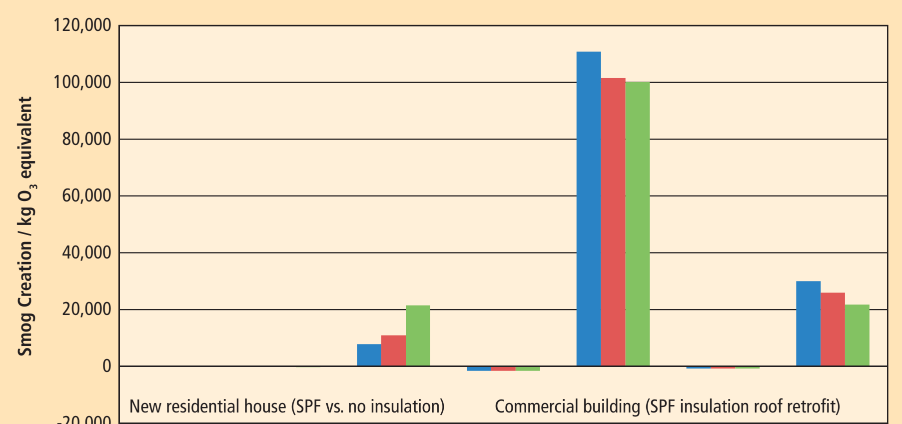
Regarding the residential GHG paybacks, Houston has longer payback periods, and the trends follow those discussed above for energy payback. GHG payback periods for ccSPF range from 7.3–8.3 years, depending on climate zone. GHG payback periods for ocSPF range from 0.2–0.7 years. The disparity between GHG payback periods for ccSPF and ocSPF is primarily due to impact from the fluorocarbon blowing agent used in ccSPF (GWP approximately 1,090 CO_2 equivalents) compared to the CO_2 generated when water is used as the blowing agent in ocSPF (GWP = 1 kg CO_2 equivalents as the 1,090 CO_2 equivalents). When it comes to the amounts of insulation on a commercial roofing retrofit, the embodied energy and GHGs of the ccSPF in going from R4 to R20 (additional R16) are twice that of the R12 to R20 (additional R8) case. However, the energy saved and GHG avoided with twice the amount of insulation are about 3.5–4.5 times greater. As expected, there are diminishing returns when more insulation is added, as retrofitting from R4 to R12 achieves 70–80 % of the total energy savings of an R4 to R20 retrofit. However, the magnitude of additional energy savings achieved from R12 to R20 are still quite significant i. e. 11–12 million MJ (10.4–11.4 billion Btu).

▼ ***Fig. 11:*** *Life cycle ozone depletion (kg CFC11 equivalent), 60 years*



	ocSPF embodied	ccSPF embodied	Residential avoided	R4-R20 embodied	R4-R20 avoided	R12-R20 embodied	R12-R20 avoided
Houston	-4.76E-05	-1.08E-04	2.11E-03	-9.71E-04	2.89E-02	-4.85E-04	7.76E-03
Richmond	-5.49E-05	-1.24E-04	1.63E-03	-9.71E-04	2.43E-02	-4.85E-04	6.30E-03
Minneapolis	-7.41E-05	-1.68E-04	2.93E-03	-9.71E-04	1.96E-02	-4.85E-04	4.29E-03

▼ ***Fig. 12:*** *Life cycle smog creation (kg O_3 equivalent), 60 years*



	ocSPF embodied	ccSPF embodied	Residential avoided	R4-R20 embodied	R4-R20 avoided	R12-R20 embodied	R12-R20 avoided
Houston	-87	-175	7,823	-1,566	110,810	-783	30,028
Richmond	-100	-202	10,911	-1,566	101,544	-783	25,918
Minneapolis	-135	-272	21,501	-1,566	100,080	-783	21,740

In general, the additional R8 and R16 scenarios across climate zones show similar energy and GHG paybacks for all cities, indicating that installing both amounts of ccSPF on a commercial roof yield similar benefits in all zones. As expected due to heating energy, installing ccSPF on the roof results in energy savings and GHG avoided that is increasingly greater going from Houston to Minneapolis. For example, when an additional R16 is installed, this results in an energy savings/embodied ratio of 66.2 and an avoided GHG/embodied ratio of 16.8 in Minneapolis. There is a much greater amount of natural gas heating energy saved for the commercial building in Minneapolis, where 2.4 – 7 times the natural gas energy is required compared to Richmond and Houston, respectively. Thus, energy savings and GHG avoided increase more in the colder climate zones, but the benefits are still significant in all zones.

Table 11 shows the avoided/embodied ratios and payback periods for the other impact categories, where the minimum and maximum values within the other four categories combined are given. For residential applications, ccSPF has a higher payback time of 0.9 – 4.8 years among all three cities, because of ccSPF insulation's higher density despite the lower thicknesses required to meet R value levels. Geographically, Houston generally has a lower payback time for both ocSPF and ccSPF than Minneapolis and Richmond in residential applications, as the embodied aspects for Houston are the lowest (since less insulation is required) and Houston uses the most electricity versus the other zones. Since the other impacts' characterization factors for electricity are 4 – 10 times greater than those for natural gas, the impacts avoided in Houston for saving electricity have a dominant effect in reducing the payback times for that climate zone. Compared to Houston, electricity saved in Richmond is about a third even though more natural gas is used. However, since electricity has more intensive impacts versus natural gas per MJ energy saved in these four categories, less amounts of electricity saved leads to a higher payback period in Richmond. Thus, the environmental impacts reduced by using insulation depend significantly on the type of energy used.

For commercial roofing applications, Houston has the lowest payback times since electricity use is greater than in the other two zones and the impacts avoided by saving electricity are greater than those for natural gas, as discussed above. However, Minneapolis has the highest payback time in commercial roofing applications due to the relative amount of electricity used in the Minneapolis building being lower than the other zones, and thus there are lower impacts avoided from relatively lower electricity use, resulting in higher payback times. Again, just as shown in the residential scenarios, the proportion of electricity and natural gas use combined with the higher impact characterization factors for electricity has a significant effect on environmental impact reduction.

6. Observations and conclusions

6.1 Use phase dominates energy and environmental performance

Although reductions in life cycle impacts vary by class of SPF, building type, climate zone/code requirements, type of building operating energy used etc., the use phase is by far the largest life cycle contributor for all impacts studied. Embodied impacts are a small fraction of the impacts reduced in the use phase, and the payback periods are relatively short, typically ranging from several months to several years. Embodied impacts from transportation, for example, are even more negligible, as transportation typically accounts for only 2 – 5 % of the total embodied phases for most impact categories. Thus, from an environmental improvement perspective, we believe this study shows that it makes sense to promote and further expand the use of SPF insulation based on its performance, which results from superior thermal resistance and air sealing capabilities. Reducing impacts in the embodied phases may be desirable from a theoretical viewpoint, but it will have relatively little environmental impact compared to benefits of using SPF in residential housing and commercial buildings.

6.2 Energy type for operating buildings affects environmental impacts avoided in the use phase

Based on the US average electric power mix and thermal energy from natural gas, life cycle impacts from electricity use are noticeably greater (from several to nearly ten times) than those associated with natural gas. Thus, insulation will achieve relatively greater energy and environmental impact reductions in buildings using primarily electricity versus natural gas.

6.3 Increasing energy savings and GHGs avoided from climate zone 2 to 4 and 6

Although energy saved and GHGs avoided are impressive in all climate zones studied, energy and GHG benefits are greater in the more temperate climate zones. This is expected due to outside versus inside temperature differences (more heating degree

Tab. 10: *Energy and GHG payback analysis: residential house and strip mall roof, 60 years*

Application	SPF type	Ratio and payback	Houston		Richmond		Minneapolis	
			Energy	GHG	Energy	GHG	Energy	GHG
Residential insulation	Low density ocSPF	Avoided/embodied	64	92	128	164	194	248
		Payback / years	0.9	0.7	0.5	0.4	0.3	0.2
	Medium density ccSPF	Avoided/embodied	32	7.6	64	13.6	98	21
		Payback / years	1.9	7.9	0.9	4.4	0.6	2.9
Commercial roofing	Roofing, R4 -> R20	Avoided/embodied	55	15	56	15	66	17
		Payback / years	1.1	4	1.1	4.1	0.9	3.6
	Roofing, R12 -> R20	Avoided/embodied	30	8.2	28	7.5	29	7.3
		Payback / years	2	7.3	2.1	8.0	2.1	8.3

days) in the colder, more temperate zones. In fact, air infiltration limits are more stringent in building codes governing colder climates as a result of such temperature differences. Thus, SPF insulation with its high thermal resistivity and sealing properties generally has greater energy and associated GHG benefits in colder climate zones.

6.4 Opportunities for reducing the environmental impact of SPF

6.4.1 Primary energy from resources

Regarding embodied phases, across all types of foam, raw materials make up about 90 % of the energy use in the embodied phases, followed by energy used for installation. Of the raw materials used, pMDI contributes about 40–45 %, followed by polyols (30–40 %) and flame retardants (5–20 %). When the use phase energy savings are considered, the raw materials contribution is even less than the embodied contribution, with the contributions of individual materials even lower. Since the entire embodied energy contribution of insulation in the life cycle for a house with ccSPF ranges from 3 % in Houston to 1 % in Minneapolis, reducing the energy contributed by the raw materials would have no appreciable impact on the SPF life cycle energy.

6.4.2 Climate change

In the embodied phases, the GHGs contributed by ocSPF foam are negligible, as water is used as the blowing agent for ocSPF foam. Assuming a 50 % emission loss for ccSPF used as roofing foam, the blowing agent HFC-245fa contributes about 85 % of the GHGs in the embodied phases. The 50 % emissions rate loss of HFC-245fa is based on 10 % of the blowing agent lost during installation. Of the remaining 40 %, it is assumed that 60 % is lost over the lifetime of the product and 40 % at end of life [7]. When the use phase GHG avoided is taken into account, the contribution of HFC-245fa to the total life cycle GHG for a house ranges from 11 % in Houston to 4 % in Minneapolis for ccSPF. Replacement of this blowing agent in ccSPF with one having a negligible GWP would result in GHG embodied/avoided ratios ranging from 2 % in Houston to 0.7 % in Minneapolis. This would be more in line with the GHG avoided when using ocSPF. Low GWP blowing agents have been developed and are in the process of being commercialized for SPF.

6.4.3 Acidification, eutrophication, ozone depletion, and smog creation

The trends for environmental impacts such as acidification, eutrophication, ozone depletion, and smog creation are similar to those for energy and climate change. Regarding embodied phases, for all types of foam, raw materials make up about 91–92 % of the acidification, eutrophication and smog creation, and over 99 % of the ozone depletion in the embodied phases. Of the raw materials used, pMDI contributes most to the impacts, followed by polyols and flame retardants. When the magnitude of the use phase impacts avoided are considered, the raw materials contribution is even less than the embodied contribution, with the contributions of individual materials even correspondingly lower. Considering the raw materials contribution and for a house with ccSPF, for example, the embodied to avoided impacts range from a maximum of 8 % (Richmond) to a minimum of 1.3 % (Minneapolis). Thus, reducing the impacts contributed by the raw materials would have no appreciable effect on the overall SPF life cycle impact results.

Tab. 11: *Other impact categories (acidification, eutrophication, ozone depletion, smog creation) payback analysis: residential house and strip mall roof, 60 years*

Application	SPF type	Ratio and payback	Houston	Richmond	Minneapolis
Residential insulation	Low density ocSPF	Avoided/embodied	35–134	23–109	31–159
		Payback / years	0.4–1.7	0.6–2.6	0.4–1.9
	Medium density ccSPF	Avoided/embodied	19–65	13–54	17–79
		Payback / years	0.9–3.2	1.1–4.8	0.8–3.6
Commercial roofing	Roofing, R4 -> R20	Avoided/embodied	29–106	25–89	20–71
		Payback / years	0.6–2.0	0.7–2.4	0.8–3.0
	Roofing, R12 -> R20	Avoided/embodied	16–57	13–46	8.7–31
		Payback / years	1.1–3.8	1.3–4.7	1.9–6.9

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Piedmont launches 100 % renewable polyester polyols

Piedmont Chemical announced a new offering of renewable, sustainable polyester polyols. The company combines **Susterra** propanediol from **DuPont Tate & Lyle Bio Products (DTL)** with bio-succinic acid from **Myriant Corporation** to produce 100 % bio-based polyols that are said to be functionally equal and cost-competitive with petroleum-derived polyols. The new polyol formulations, which are made from renewable resources, enable the production of eco-friendly, sustainable PU products in industrial applications, including paints and coatings, adhesives and sealants, and microcellular elastomers.

Piedmont, DTL and Myriant have agreed to an "open innovation" concept by which the polyol formulations will be made available to polyol producers and the polyurethanes industry at large. This means that customers will be able to purchase polyols from Piedmont as well as from other polyol producers. Piedmont will manufacture the initial polyol product samples and will offer commercial supply of the polyol products to the market. The technical specification and polyol samples will be available by year-end, says the company.

DTL commercially produces Susterra propanediol from corn sugar in Loudon, TN, USA, with a capacity of 140 million lbs (~ 63,500 t) per year. The plant has been operational since November 2006. The company is a joint venture between **DuPont** and **Tate & Lyle,** a renewable food and industrial ingredients company.

Myriant utilises its proprietary technology platform to develop renewable chemicals based on low-cost sugars. In December 2010, the company broke ground on its flagship 30 million lbs (~ 13,600 t) per year commercial bio-succinic acid facility in Lake Providence, LA, USA, and anticipates beginning commercial production in the first quarter of 2013. The company has agreements with **ThyssenKrupp Uhde GmbH** for engineering, **Davy Process Technology** for the integration of Myriant's bio-succinic acid process with the Davy butanediol process for the production of bio-based butanediol, and **PTT Chemical** for the commercialisation of Myriant's technology in Southeast Asia. The company is headquartered in Quincy, MA, USA.

Piedmont Chemical is a privately owned chemical manufacturer headquartered in High Point, NC, USA. Founded in 1938 to support the local textile industry, the corporation has since evolved into five different production sites in North and South Carolina as well as Tennessee with additional satellite facilities in the Caribbean, Central America and Asia.

According to a 2012 report by **Global Industry Analysts, Inc.** entitled, "Polyols: A Global Strategic Business Report," the world market for polyols is forecast to reach 4.33 billion lbs (~ 2 million t) by 2017.