The Environmental and Societal Value of Extruded Polystyrene Foam Insulation

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Abstract

In recent years, the building community has taken a more active role in the sustainable design of buildings. The concept of environmentally-conscious building design ("green building") has already been incorporated into tools that measure environmental performance of buildings and building materials. Tools such as LEED™ (Leadership in Energy and Environmental Design) strive to utilize design and construction practices that significantly reduce or eliminate the impact of materials and buildings on the environment and its inhabitants. Optimizing material selection is a key component in building "green". Extruded polystyrene foam insulation (XPS) is an excellent choice as one potential environmentally-responsible alternative to other types of building insulation. XPS ranks well in most of the key attributes of a "green" building material, i.e., recycled and/or recovered content; reusability/recyclability; durability, embodied energy, and air quality.

Due to the thermoplastic nature of XPS, virtually 100% of all in-plant scrap is recycled and reused in the primary extrusion process, thus resulting in very high material utilization. Additionally, the thermoplastic nature of XPS makes it an excellent candidate for using post-consumer and post-industrial recycled and/or recovered polystyrene foam. The increasing costs of material disposal and landfilling make the reusability of XPS a very attractive option. XPS building insulation reduces energy consumption,[1] while increasing the comfort level of occupants compared to under-insulated buildings.[2] The many outstanding attributes of XPS, stable R-value, moisture resistance, and high compressive strength, make it an excellent material choice for insulation. In a variety of harsh and unique applications, XPS is often the only product accepted by building code agencies.

This paper discusses both the environmental and societal aspects of extruded polystyrene foam insulation from its manufacture to beyond end-use.

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[1] *Energy and Environmental Benefits of Extruded Polystyrene Foam and Fiberglass Insulation Products in U.S. Residential and Commercial Buildings*, Merle F. McBride, Owens Corning, Granville, OH, USA 43023; regarding insulated vs. uninsulated buildings.

[2] Department of Energy Insulation Fact Sheet; DOE/CE-0180 2002 states: "To maintain comfort, the heat lost in winter must be replaced by your heating system and the heat gained in summer must be removed by your air conditioner. Insulating ceilings, walls, and floors decreases this heat flow by providing an effective resistance to the flow of heat." Found at http://www.ornl.gov/sci/roofs+walls/insulation/ins_02.html. Publication issued by Assistant Secretary, Energy Efficiency and Renewable Energy.

Introduction

Decisions about insulation usage are among the most important an architect or designer will make relative to the environmental impact of a building. In recent years, the building community has taken a more active role in the utilization of green or sustainable building design. Sustainable building design can be as narrow as choosing to use materials with recycled content or by achieving energy efficiency. It can also be complex by encompassing a systems approach using recyclability, reusability, durability, embodied energy and air quality. The building community has adopted tools such as LEED™ (Leadership in Energy and Environmental Design) to measure the environmental performance of a building. The use of extruded polystyrene foam insulation can play an effective and important role in responsible environmental stewardship in building design and construction.

XPS Manufacturing Process

XPS foam, which is technically referred to as extruded polystyrene, is an ideal thermal insulation because it offers a high strength to weight ratio and an excellent balance between cost and performance. XPS foam is manufactured by expanding a mixture of molten polystyrene and low-conductivity blowing agents into a low density, closed cell foam. The strength of the resulting product can be engineered to achieve a variety of compressive strengths.

In the XPS foam process, a feed system introduces polystyrene resin and other minor components (such as a nucleating agent, colorant, flame retardant, etc.) into an extruder where it is melted and mixed. A pressurized blowing agent in a liquid state is then introduced and the resulting mixture is extruded at an elevated temperature and pressure through a slot-shaped orifice at ambient temperature and atmospheric pressure (or in some cases at a partial vacuum). As the molten mixture passes through the orifice, the blowing agent vaporizes because of the reduced pressure and the molten mixture expands to form a cellular foam. The material is extruded as a continuous board with high-density skin surfaces that are formed as a result of friction when the board moves through mechanical plates used to shape the flat sheets.

As the foam board moves down a conveyor system, it is printed on the top surface with the manufacturer's logo, R-value and other important information. Further downstream, the boards are trimmed to the finished dimensions and profile (e.g. square, tongue and groove, or shiplap) prior to final packaging. Trim material is captured at the cutting stage and conveyed to a grinder that chops it into small pieces of foam (commonly referred to as fluff). The polystyrene fluff is then either stored for future reprocessing or is immediately conveyed to a reclaim system, where it is melted and re-extruded into pellets. The pellets are then conveyed to a storage silo or re-used in the original extrusion process. This reprocessed polystyrene (commonly referred to as industrial scrap resin or post-industrial resin) is combined with virgin polystyrene resin pellets at typical loadings of 0 – 30 wt%, depending on the product type being made.

Key XPS Foam Attributes

Durability

Durability of an insulation material is a very important environmental consideration. An essential attribute for any environmentally-preferred product, especially insulation, is the ability of the product to perform its intended function for its useful life. Good insulation performance is essential for the proper design of a building's heating and air conditioning systems as well as its management of water and water vapor.

The many outstanding attributes of XPS, stable R-value, moisture resistance, and strength make it the best, if not only, product acceptable in a variety of harsh and unique applications.

Stable (Long-Term) R-Value

Extruded polystyrene foam insulation products (XPS) in North America have a closed-cell structure filled with a blowing agent, HCFC 142b, specifically selected for its low thermal conductivity and low diffusivity to enhance the thermal performance of the foam.

Over a long period of time (*i.e.*, 30 to 50 years), the blowing agent diffuses through the thickness of the foam, and air diffuses into these same closed cellular volumes. Because of this gas movement, the overall thermal resistance (*i.e.*, R-value) of the insulation product changes over time. This phenomenon is typically called "aging". Foam aging is not new and has been discussed in numerous papers over the years. Recent long-term data published by Paquet and Vo [3]confirm the slow diffusion rate of CFC 12, HCFC 142b and HFC 134a through XPS foam which results in a very slow aging process. This data demonstrates the excellent long term thermal performance of XPS foams in the laboratory as well as under field conditions.

Energy Efficiency

The impact of material changes in foam formulations must be analyzed in terms of their resulting thermal performance for a total environmental assessment. To this end, the following information should be considered when evaluating the "energy efficiency" of a product.

According to the website of the United States Environmental Protection Agency (EPA), and also the Energy Star Program[4] "... Carbon dioxide (CO_2) is the key greenhouse gas responsible for global warming concerns. The overwhelming share of U.S. and world CO_2 emissions[5] comes from burning fossil fuels, such as oil, coal and gas – our main sources of energy. Burning fossil fuel causes emissions of other greenhouse gases as well, such as methane (CH_4) and nitrous oxide (NO_2)."

The energy efficiency "payback" from the high levels of long-term R per inch that is used to insulate buildings and residences far exceeds the marginal contribution of ozone depletion potential (ODP) coming from HCFCs and HFCs deployed in XPS use until their Montreal Protocol required phase-out dates.[6]

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[3] Vo, Chau V., Dow Deutschland GmbH; Rheinmuenster, Germany, D-77836; Paquet, Andrew N., The Dow Chemical Company, Midland, MI, USA 48674; *An Evaluation Of The Thermal Conductivity For Extruded Polystyrene Foam Blown With HFC-134a or HCFC-142b*; Journal of Cellular Plastics, 2004

[4] All members of XPSA, The Dow Chemical Company, Owens Corning, Inc., and Pactiv Corporation are allies of the Energy Star Homes Program.

[5] EPA Website at: http://www.epa.gov/globalwarming/emissions/national/co2.html.

[6] *Energy and Environmental Benefits of Extruded Polystyrene Foam and Fiberglass Insulation Products in U.S. Residential and Commercial Buildings*, Merle F. McBride, Owens Corning, Granville, OH, USA 43023; regarding insulated vs. uninsulated buildings.

There is a further environmental aspect that must be considered in assessing the **total** environmental impact of the materials used in the production of foam insulating materials—that of energy efficiency and conservation relative to Global Climate Change. In May of 1999 the technical experts working on both the Montreal and Kyoto Protocols collaborated in Petten, Netherlands at the Joint IPCC/TEAP Expert Meeting on "*Options for the Limitation of Emissions of HFC's and PFC's*". One of its conclusions was that the use of foams enable higher levels of energy efficiency. Specifically, they stated, "Insulating foams account for at least 30% of the overall global insulating market despite their higher cost per unit." They noted that "an average increase in global energy efficiency of 1% in buildings would equate to an annualized reduction of CO_2 emissions of some 50-80,000 tons.

A.D. Little conducted a study, "*Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant and Fire Protection Applications*" which included a Life Cycle Climate Performance (LCCP) and provided an analysis of *Insulating Sheathing for Residential Wood Frame Walls*. It concluded, "These results show that far more energy is saved than consumed by manufacturing the foam and that far more greenhouse gas emissions due to space condition energy consumption are avoided than are emitted in the manufacture of the foam." Thus, the impact of material changes in foam formulation must be analyzed in terms of their resulting thermal performance for a total environmental assessment.

Moisture Resistance

A critical factor affecting long-term thermal performance is the ability of an insulating material to resist the intrusion of moisture. Moisture can come in contact with insulation not only during construction, but throughout the life of the building. If absorbed, its effect is to drastically reduce thermal efficiency (R-value). The closed-cell structure and lack of voids in XPS helps it to resist moisture penetration better than other types of insulating materials without the need for a facer or laminate to achieve this property.[7] The excellent moisture resistance of XPS foam insulation has been confirmed repeatedly and consistently in laboratory tests and under field use conditions.[8] Without the need for a facer or laminate, XPS products only absorb 0.3% by weight [9].

With its closed-cell structure, XPS foam products form a natural "skin" surface which is not conducive to moisture absorbency. Thus, when installed in walls, XPS shifts damaging dew points minimizing the potential for condensation to occur within a wall. This helps to ensure the insulating power remains in the wall and does not degrade due to moisture intrusion.

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[7] ASTM Standard, C 578-03a for molded expanded (EPS) and extruded (XPS) rigid cellular polystyrene thermal insulation, ASTM 1289-02 for faced rigid cellular polyisocyanurate thermal insulation board; and ASTM C 1029 for spray applied rigid cellular polyurethane thermal insulation.

[8] *Development of Experimental Data on Extruded Polystyrene Roofing Insulation under Simulated Winter Exposure Conditions*, Report #SPI-6443, by Energy Materials Testing Laboratory, Biddeford, ME 04005. U.S. Army Cold Regions Research and Engineering Laboratories Report: Moisture in the Roofs of Cold Storage Buildings, Wayne Tobiasson and Alan Greatorex November 1998. Report found at: http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/SR98_13.pdf ; Various ASTM material standards

[9] ASTM Standard, C 578-03a

Mold, Mildew, Corrosion Resistance
Because XPS foam is a plastic material, it will not corrode or rot or support the growth of mold or mildew. It is resistant to microorganisms found in soil and provides no nutrient value to vermin. These properties make it an outstanding insulating material for below grade applications.

Compressive Strength
The closed-cell structure of XPS imparts excellent long-term compressive strength and durability. It is dimensionally stable and products are available in a wide range of compressive strengths (from 15 psi to 100 psi) to suit a variety of application requirements.

Applications Where XPS Insulation Excels

Exterior Wall Sheathing
With a long-term R-value from 3 [for ½ -in. thick (13 mm) sheathing boards] to 5 [for 1-in.-thick (25 mm) boards], XPS sheathing boards increase the R-value of the entire wall. XPS sheathing boards provide a continuous layer of protection against water moisture infiltration while guarding against thermal bridging. Thermal bridging occurs due to wood studs and other un-insulated parts of the wall, such as framing, ducts, wiring, and plumbing – which typically account for over 25% of the exterior walls in an average home. When properly installed, it also forms a continuous air barrier that minimizes convection currents and air infiltration, the leading cause of energy loss. When moisture gets into a wall assembly it compromises wood components and as a result can reduce the overall R-value of the building envelope.

Unlike many other types of sheathing, XPS does not have to rely on facers or laminates to obtain compressive strength or achieve its ability to resist water moisture intrusion. Therefore, it is an excellent choice for ensuring a building's envelope will be properly sheathed and assure that its subsequent performance will not be compromised during installation of the sheathing due to nails, glue and other materials.

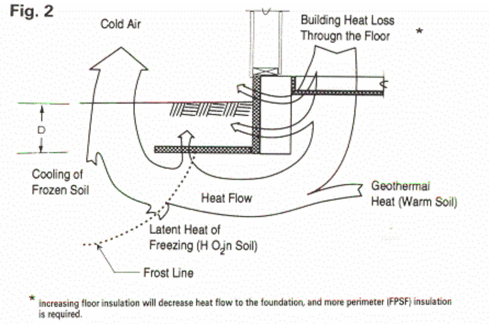
Cold Storage
XPS is the product of choice for cold storage buildings. In 1997, Owens Corning completed a survey of the moisture content in the roofing systems of existing cold storage buildings. Owens Corning engaged the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratories (CRREL) to conduct the building evaluations. In a report issued by CRREL[10], they discussed insulation including: fibrous glass, fiberboard, perlite, wood fiber, expanded polystyrene, extruded polystyrene, polyisocyanurate, and phenolic. Areas of wet insulation were found in 8 of the 10 roofs evaluated. Representatives from CRREL performed daytime indoor and nighttime, on the roof, infrared roof moisture surveys (Tobiasson and Korhonen 1985 and Special Report 98-13) to identify wet sections of the roofs.

[10] Tobiasson, Wayne and Greatorex, Alan; U.S. Army Cold Regions Research and Engineering Laboratories Report: *Moisture in the Roofs of Cold Storage Buildings*, November 1998.

Core sampling of the membranes and insulation were collected for laboratory evaluation. The specimens were evaluated for:

- Dry Density
- Moisture Content
- Thermal Resistance – as sampled
- Thermal Resistance-after drying

Fig. 2

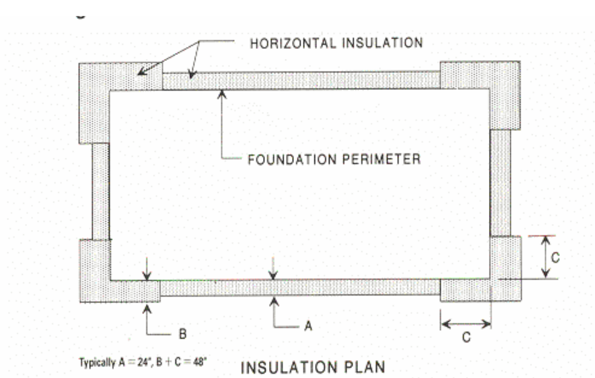


FPSF Heat Flow Diagram for a Heated Building with Optional Floor Insulation.

The conclusions reached by CRREL from the roof study state that due to the intense vapor drive and air infiltration and the propensity of the cold storage roofs to exhibit water infiltration, the only roof insulation available that can offer much improved moisture resistance in the roofs of freezers and coolers is XPS.[11]

Frost Protected Shallow Foundations (FPSF)

XPS is the only code approved product for use in horizontal applications in code-compliant FPSF. The concept of FPSF involves the placement of rigid foam insulation in a way that raises the frost penetration depth around a building to permit foundation footing depths as shallow as 16 inches, even in cold climates. According to the FPSF Design Guide issued by the Department of Housing and Urban Development, "The frost-protected shallow foundation technology offers builders an opportunity to excavate less earth, use less material, and build homes more cost effectively.[12] Although relatively new in the United States, FPSF has been extensively used in Scandinavian countries for over 40 years. During this time, in excess of one (1) million homes have been successfully built using this construction method. FPSF is commonly used in monolithic slab on grade; independent slab and stem wall; and permanent wood foundation applications. Moisture resistance is extremely important in FPSF because of the insulation's placement in potentially wet soil and because of the freeze/thaw cycles that may occur.



FPSF design parameters for heated buildings using the simplified design procedure.

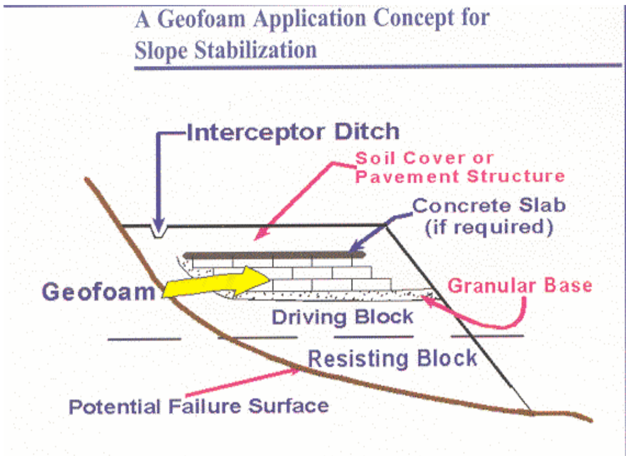
The exceptional moisture resistance along with a stable R-value in the presence of moisture, make XPS the product of choice and the only insulation material approved by U.S. building codes for horizontal applications of below-grade insulation in the FPSF application.

Geofoam

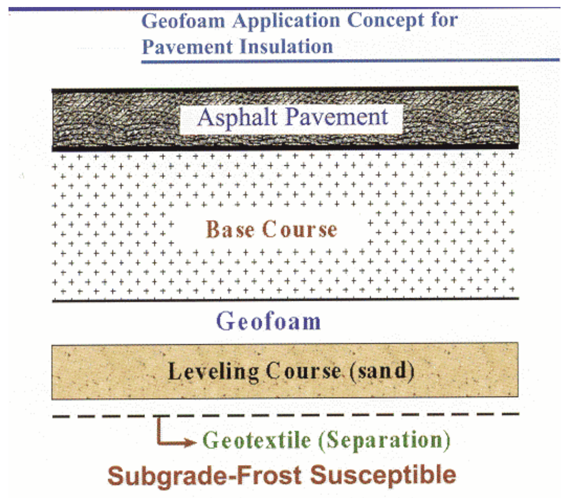
[11] Ibid 9.

[12] Design Guide for Frost-Protected Shallow Foundations, U.S. Department of Housing and Urban Development; Office of Policy Development and Research. HUD-1497-PDR (1); April 1995

Design and construction on soft ground has been a challenge to geotechnical engineers for years. The growing population around the world has demanded innovative and economical solution for site development. XPS has been used as a light weight fill material for slope stabilization, retaining walls, and abutment backfill. Also due to the stable R-value, high resistance to water moisture absorption, and high compressive strength, XPS has been used to minimize frost heave on roadways and airport runways as a subgrade insulation.[13]

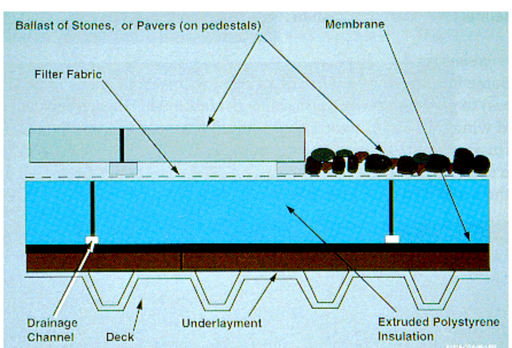


Drawings from "Properties & Applications of GEOFOAM"©, D.Negussey, PhD, P.Eng for Society of the Plastics Industry, Inc. 1997



The depth requirements for pipeline burials below frost penetration could be reduced if geofoam is used.[14]

Roof Recover and PRMA Applications

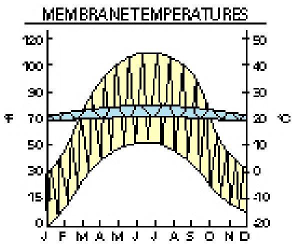


A Protected Roof Membrane Assembly (PMRA) differs from a conventional roof design in that the membrane is placed under the insulation layer, maximizing membrane life by protecting it from temperature extremes, freeze/thaw cycles, UV degradation, and traffic wear. A PMRA begins with the application of the EPDM membrane, followed by the XPS boards, the protective scrim, and finally the ballast. Extruded polystyrene foam is the only type of insulation recommended for use in a PRMA system because it resists moisture and crushing so thoroughly — critical properties in the selection of PRMA insulation.

[13] Negussey, D. PhD, P. Eng.,1997. *Properties & Applications of Geofoam*, Society of the Plastics Industry, Inc.

[14] Ibid.

Due to its compressive strength, stable long-term thermal performance and moisture resistance, XPS offers exceptional performance in plaza, protected membrane roof assemblies (PMRA) and garden roof applications.



PMR roof (blue line) – the membrane temperature remains relatively constant.

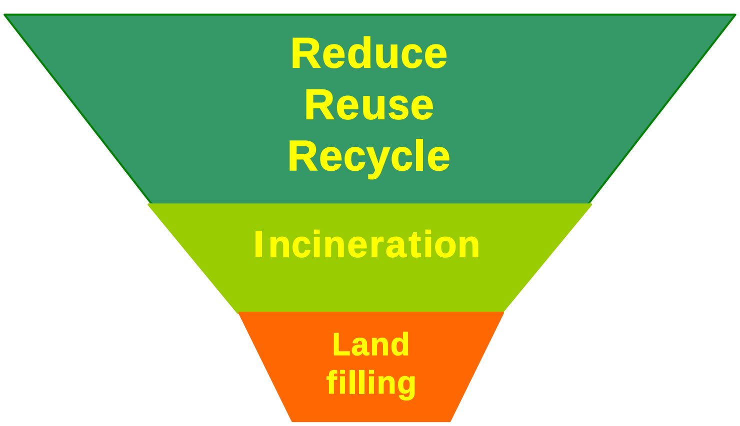
Conventional roof (yellow line) – membrane temperature fluctuates widely

The important properties are:

- Extends plaza deck or roof life, providing protection from ultraviolet deterioration;[15]
- Protects roof membranes against weathering, physical abuse and damage;
- Maintains the membrane at a relatively constant temperature, minimizing effects of freeze-thaw cycling and excessive heat (see diagram Membrane Temperatures above);
- Reduces installation, material and repair expenditures;
- Provides for easy removal and re-installation of ballast and insulation if re-roofing becomes necessary, and
- Provides high moisture resistance and strength to allow vegetation growth

Green Building Principles

The hierarchy of waste management for green building design is as follows:



[15] ASTM D6630 standard, Method P is used to evaluate and is intended to establish minimum performance levels for insulated roof membrane assemblies and lists pertinent design guidelines.

Ideally, during the design stage, one would like to minimize waste generated from a project. Once the end-of-life of the original application is reached, there are several options to consider. If a material or system can be reused, the life of the materials can be extended which in turn, minimizes energy spent and the impact on the environment. Recycling has traditionally been seen as the most effective way to protect and preserve the environment. Recycling has been viewed by much of the public as primarily a social issue. In reality, recycling is a very complex issue which we will discuss below. Incineration is seen as less desirable but even it can have some benefits when XPS is involved. Landfilling is usually viewed as the last viable option to be considered for waste management.

Reuse

The ability to reuse rather than discard a building's insulation can provide important cost and environmental benefits. Some materials reach the end of their life because they simply wear out and are not capable of performing their intended function. This is not true of extruded polystyrene insulation. Consider the example of commercial roofing . In commercial roofing applications, roofing replacements can occur every 10 to 15 years due to the failure of the roof membrane. XPS typically will outlast the roofing membrane under which it was installed. Due to its outstanding water resistance, XPS maintains excellent thermal and compressive strength properties over the life cycle of the building. In 1995, Single Ply Roofing Institute (SPRI) conducted an insulation reuse survey of members from SPRI, National Roofing Contractors Association (NRCA), and Roof Consultants Institute (RCI). The survey was designed to look at the factors important for insulation reuse.[16] The critical factor cited by 80% of the respondents was the issue of moisture. The U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) uses the criteria of the ratio of an insulations wet thermal resistivity to its dry thermal resistivity, expressed as a percentage to determine the materials thermal resistance ratio (TRR).[17]

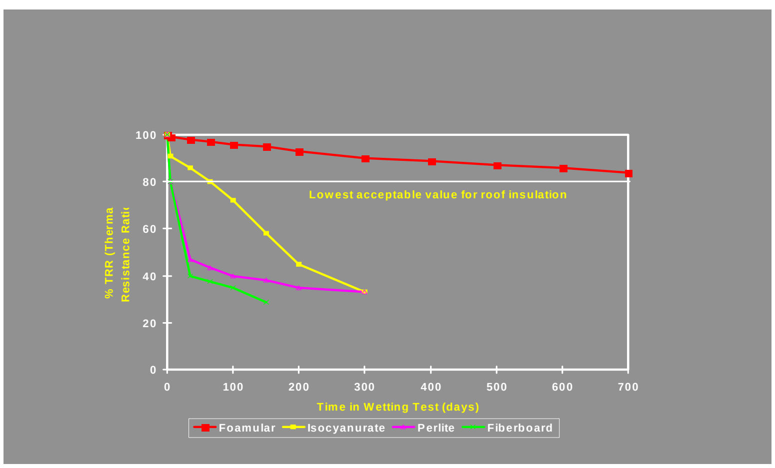


Figure 1. Data from "New wetting curves for common roof insulations" Wayne Tobiasson, Alan Greatorex and Doris Van Pelt, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Hanover, New Hampshire

CRREL considers an insulation wet and unacceptable if the TRR is less than 80 %. The TRR curves (to the left) exhibit that XPS is extremely resistant to moisture and maintains a TRR above 80% out to at least 1000 days in the CRREL wetting tests.

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[16] Sheahan, J.P. and Desjarlais, Andre O.,1997, *Insulation Reuse in Low Slope Roofing in the USA: An Industry Survey*, Proceedings of the Fourth International Symposium on Roofing Technology, National Roofing Contractors Association, Rosemont, IL

[17] Tobiasson, Wayne; Greatorex, Alan, and Van Pelt, Doris, 1991, *New wetting curves for common roof insulations*, Third International Symposium on Roofing Technology, Montreal, Quebec, Canada

A tremendous example of the reusability of XPS was evident during the 2003 re-roofing of the Dallas Fort Worth International Airport. Because the airport roof manager chose a PMRA design, almost 90% of the existing XPS material on the roof was able to be reused. The XPS material on the roof was over 17 years old. Samples of the 17-year material were submitted to the Owens Corning R&D Laboratory for thermal and physical property testing. The testing showed that the in-situ material had lost little of its original R-value, maintained its original compressive strength, and absorbed virtually no moisture.

In this particular application, the benefits of recycling the insulation included:

- Minimal business interruption. New insulation did not have to be loaded on to the airport roof, curtailing airport operations
- Economically attractive (saved $100,000 in labor costs and $180,000 in new material purchases)
- Much lower environmental impact. Fewer trips to the landfill ($15,000 saved in hauling and landfill fees) and less waste disposal (avoided landfilling of 3,036 squares of material)
- Less fossil fuel use in raw materials, manufacturing, and transportation of the new and waste insulation
- Greenhouse gas emissions avoided by minimizing resource processing
- Continual energy savings provided by the insulation

Figure 4. Dallas/Fort Worth reroofing project with Owens Corning Foamular XPS insulation.

Recyclability

Because XPS foam insulation is a thermoplastic, it can be easily "reworked" (see below) and can also include many types of recycled polystyrene streams.

Types of Polystyrene Resins

In September 1990, the American Society for Testing and Materials (ASTM) published a standard that contains definitions for various types of plastics (ASTM D 5033-90, "Standard Guide for The Development of Standards Relating to the Proper Use of Recycled Plastics"). The XPS manufacturing process offers a unique opportunity to use several of these types:

Reworked plastic – a plastic from a processor's own production that has been reground, palletized, or solvated after having been previously processed by molding, extrusion, and so forth.

Post-industrial scrap – The XPS manufacturing process is capable of consuming its own scrap. This is usually in the form of trimmings as the boards are cut to finished dimensions, but also includes boards that are damaged in storage or shipment or otherwise do not meet specifications. The amount of trim scrap varies depending on product thickness and width, surface treatment (skinned versus planed), and edge and end treatments (square versus shiplap versus tongue and groove). In general, geographic regions such as the European Union (EU) or the Pacific that produce mainly 24-inch (600 mm) wide products have a higher fraction of planed material which will have trimmings on the order of 20 – 30%. In North America, where most products are made 48-inch (1200 mm) wide, are somewhat thinner, and where integral skins are kept intact, the range is more typically 10 – 25%.

Post-industrial scrap can also be obtained from other extrusion processes within the same manufacturing plant (e.g., from food service XPS foam sheet trimmings) or from outside sources. For example, some manufacturers of polystyrene products are not able to consume all of the internally-generated scrap and, as a result, will sell the material that they are unable to use through a polystyrene resin broker.

Post-consumer plastic material – a plastic material or finished product that has served its intended use and has been diverted or recovered from waste destined for disposal, having completed its life as a consumer item.

Recovered material – a plastic material and by-products that have been diverted from or recovered from solid waste, but not including those materials and by-products generated from, and commonly reused within, an original manufacturing process.

The History of Polystyrene Recycling

Since 1985, when the plastics industry founded the Plastics Recycling Foundation, millions of dollars have been spent on developing better technology for recycling plastics products and new uses for post-consumer plastics. In 1988, the plastics industry formed and funded the Council for Solid Waste Solutions, an industry group offering programs to educate consumers and communities that wish to participate in recycling programs. In June 1989, The National

Polystyrene Recycling Company (NPRC), a multi-million dollar joint venture of eight polystyrene manufacturers, launched the first U.S. network of polystyrene recycling centers with the ability to collect, and recycle post-consumer polystyrene and market the recycled resin. In 1991, the Canadian Polystyrene Recycling Association (CPRA) opened their polystyrene recycling plant outside Toronto; they recycle up to 3,500 tons of polystyrene per year[18].

Recycled polystyrene can be used to make a variety of products such as office and school supplies, audio and video cassettes, thermal insulation, playground equipment, reusable cafeteria trays, traffic signs, and toys.

Introduced in the mid-1950's, XPS foam is a relatively new insulation in the building industry. Demolition of entire buildings built after the mid-1950's and containing XPS foam has been minimal in the U.S. Other than roofing, there has not been much opportunity to reuse or recycle XPS from other building sections such as walls and foundations.

To reuse or recycle is not always an option depending upon the installation techniques used to secure the material for its intended application. Many conventional roofing systems fully adhere the insulation making it virtually impossible to remove as a separate material. In such cases, landfilling or incineration are the only options. The loose attachment methodology of PRMA roofing provides an excellent opportunity for material reuse. Perhaps by working with and educating the construction industry, new construction techniques could be developed which would allow the reuse or recyclability of a greater percentage of XPS as it becomes available.

In many circumstances, the economic realities of recycling are often overlooked in favor of the perceived societal value of recycling. Collection and transportation costs for XPS insulation are not favorable. Due to the light weight of the material, XPS must be densified or baled to get a sufficiently high density to make transportation over long distances cost effective. Recycling does not end with collection. Recycling is only complete when the recycled XPS has been manufactured into new products and there is a consumer demand for the product. Even though the building community is becoming more and more environmentally aware, building materials are still very cost sensitive. At present, the marketplace is not willing to pay more for "green materials" Unfortunately, a pound of recycled polystyrene can cost as much if not more than a pound of virgin polystyrene resulting in a higher finished good price.

XPS Insulation with Recycle Content

The recycling of polystyrene is an involved process which can encompass washing, drying, grinding and re-processing the polystyrene into pellet form. The finished recycle polystyrene pellets are typically of lower quality than virgin, un-used polystyrene pellets. The recycle pellets are blended with virgin and reworked pellets and converted into items such as fence posts, park benches, boat docks, insulation, etc.

In 1989, Amoco Foam Products Company, a wholly-owned subsidiary of Amoco Corporation (now Pactiv Building Products, a Pactiv Corporation company), opened the first polystyrene post-consumer recycling facility in Brooklyn, New York. The facility was used to process post-

[18] Canadian Polystyrene Recycling Association (CPRA) website, www.cpra-canada.com

consumer polystyrene foam products such as foam packaging products and lunch trays collected from restaurants and schools where collection programs were implemented.

In 1990, Amoco Foam Products Company introduced the first extruded polystyrene insulation board made with recycled polystyrene resin. AMOFOAM®-RCY, was made with a minimum of 50% recycled polystyrene, consisting of a blend of post-consumer and recovered polystyrene resins. The AMOFOAM-RCY met the foam plastic requirements of the National, Standard and Uniform Building Codes. In addition, the product was certified for recycled content by Scientific Certification Systems®.

Amoco Foam Products Company eventually discontinued AMOFOAM-RCY due to difficulties encountered with respect to inclusion in federal government procurement programs and the resulting lack of acceptance and inclusion in job specifications. Although President Bush released an executive order on October 31, 1991 that instructed all federal agencies to implement procurement programs that required the purchase of materials with recycled content, the order conflicted with the long-standing competitive bidding policies that require bids from three potential suppliers. During the period when AMOFOAM-RCY was available, there were no other commercially-available extruded polystyrene insulation products containing post-consumer recycled-content. Furthermore, attempts to work with the U.S. Environmental Protection Agency to include AMOFOAM-RCY in the EPA Procurement Guidelines were futile.

Incineration

When XPS can not be reused or recycled, landfilling or incineration are possible alternatives. When properly incinerated, polystyrene is no more toxic than burning wood. Polystyrene consists solely of carbon and hydrogen. When it is completely combusted, it gives off water, carbon dioxide and ash, the same by-products as paper or wood. In some cases, polystyrene can actually help the incineration process. Polystyrene can produce energy which compares favorably with coal and oil. The energy value of polystyrene is18,400 Btu's per pound while the energy value of coal is approximately 13,000 Btu's per pound and oil at 19,000 Btu per pound.[19] Because of its high fuel value, polystyrene in properly designed incinerators, can help to burn wet garbage efficiently and maintain the high burning temperatures necessary for safe combustion. The incineration of plastics can generate energy. This energy source is already being harnessed by some overseas countries in Western Europe and Japan as well as in the U.S.[20].

Mark and Vehlow, et al, conducted a study in which the co-combustion of pretreated plastic waste from the packaging, automobile, electronic, and building construction industry incinerators was investigated[21]. The XPS foams evaluated in the study contained

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19 West Virginia National AFV Day Odyssey website hosted by West Virginia University National Research Center for Coal and Energy, www.wvodyseey.nrcce.wvu/edu.

20 Polystyrene Australia Pty Ltd. (PSA) website, www.psa.com.au.

21 Mark, F. E.. and Vehlow, J. 2000 *Co-combustion of Plastic Waste in Waste Combustion Systems,* VGB Technische Vereinigung der Frosskraftwerksbetreiber and Vehlow, Jurgen; Bergfeldt, Britta; Hunsinger, Hans; Jay, Klaus; Seifert, Helmut; Mark, Frank E., 2003; *Effects of Various Plastic Wastes on Municipal Waste Incineration,* Friedrich Vieweg & Sohn Verlagsgesellschaft mbH.

fluorochlorohydrocarbons as the foaming agent and bromine containing flame retardants. The study showed that more than 99 % of the organic matter in the incinerators decomposed and there was a decrease in the total organic carbon content (TOC) by approximately 50 %. The increase of the thermal value by the plastics improved the completeness of combustion. Additionally, incineration provides an escape from the foam "end of life" issues due to the total consumption of the polystyrene as well as the blowing agent.

Landfilling

The least desirable waste management option for XPS foam is landfilling. Polystyrene degrades very slowly in typical landfills compared to other organic waste materials and therefore continues to represent an increasing percentage of the landfill volume over time. Plastics account for 7% by weight and 20% by volume of our municipal landfills. Of the total plastic content, 15.9% are polystyrenes, yielding 1.1% by weight and 3.2% by volume of polystyrene in the landfills[22]. The good news is that polystyrene is inert and remains unaffected in the landfill. If applied properly, the addition of XPS foam to a landfill can help stabilize an otherwise unstable site. See the discussion on "Geofoam" above.

Green and Sustainable Building Programs

In the U.S., the most viable green building tool is U.S. Green Building Council's LEED™ (Leadership in Energy & Environmental Design) program. Some have recognized shortfalls in the LEED approach, however LEED has gained prominence within the building and architectural community.

Currently, the LEED rating tool is the foremost system being specified and used in the building industry. LEED is a voluntary, consensus-based, market driven building rating system that is based on accepted energy and environmental principles and strikes a balance between established practices and emerging concepts. It evaluates environmental performance from a whole-building perspective, providing a definitive standard for what constitutes a "green building". As mentioned above, some believe a shortfall with the LEED approach is that it is too all-encompassing and does not consider performance of whole building systems like walls or roofs.

Within LEED, there are five (5) major categories where various points can be attained for "green" aspects of the building project. Points are earned for satisfying performance criteria established in the rating system. XPS fits well into many of the LEED performance categories such as:

- Category 1: Sustainable Sites - XPS is one of the few insulation materials that work well in garden roof designs as well as under highly-reflective roofing membranes such as thermoplastic polyolefin (TPOs). XPS used as highway insulation and light-weight fill help the site lower the highway or bridge abutment maintenance costs.
- Category 3: Energy & Atmosphere – As a prerequisite, each project must comply with ASHRAE 90.1 or the local energy code. XPS insulation plays a vital role in this energy compliance. Additionally, credit is given for reducing the design energy cost of a building established in ASHRAE 90.1

22 Hewlett-Packard Development Company, L.P., *Guidelines for Environmentally Responsible Packaging*, www.packaging.hp.com

Category 4: Materials & Resources – XPS can get credit for being reused, helps gain the recycle content credit and local/regionally manufactured product credit.

There are several misconceptions concerning the LEED™ system:

- LEED does not certify individual products
- LEED does not require product certification information as product or material submittal verification
- It is not necessary to accumulate points in every item under each category in order to amass sufficient total points to meet one of the ranking levels of LEED certification
- Individual products have little influence on a category's points (i.e., Materials & Resources) because total points are weighted by the cost of all products used.

XPS and Indoor Air Quality

Both the Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA) recently cited indoor air quality as a critical environmental problem in the U.S. Only low-emitting products that do not compromise indoor air quality should be used in a green-design building. The GREENGUARD Environmental Institute™ is a third party testing facility that certifies the indoor air quality of products which have been subjected to a set of rigorous tests and found to produce low emissions of formaldehyde, volatile organic compounds (VOCs), respirable particles and other pollutants. XPS has been tested and received GREENGUARD Certification demonstrating that the product contributes minimal emissions to the indoor environment.

Conclusions:

XPS thermal insulation has value in a variety of building and insulating applications especially in harsh and unique environments. In many of these applications such as cold storage, frost protected shallow foundation or protected roof membrane assemblies, XPS is the only recommended or approved material as a result of its durable qualities.

The ability to reuse over 90 % of the roofing insulation from the Dallas/Fort Worth International Airport shows that it is feasible to reuse or recycle XPS. There is both an environmental as well as an economic benefit to be gained from its reuse. XPS manufacturers are working with the construction industry towards a mutual goal of minimizing the landfilling of XPS. However, there are still tremendous challenges with the reuse or recyclability of XPS:

- Current building practices do not facilitate the easy removal or collection of XPS
- The conservative nature of the construction industry inhibits new construction practices which would allow more reuse or recycling
- Other than from roofing, there is not a great deal of XPS being removed from existing buildings at the present time due to the life span of buildings built after the mid-1950's.

The XPS industry has demonstrated the ability to recycle and reuse post-industrial as well as post-consumer polystyrene in its products. One manufacturer provided an XPS foam which contained 50% recycled polystyrene yet could not get the support from the building community, government, or the consumer. The material was subsequently removed from the market.

The U.S. consumer is not willing to pay more for a material based on its environmental performance. Programs like LEED are bringing environmental awareness to the building community and are constantly evolving.

Despite the current initiative towards "green building", the U.S. has not embraced the environmental challenges as have the European Union countries. Many of the benefits of XPS will not be practical until the U.S. is forced to be more environmentally conscious in terms of energy efficiency, recyclability and reuse.

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