Insulation Energy Savings: Key Issues and Performance Factors

Overview: Why Is Energy Performance of Paramount Importance to Building Owners?

As codes tighten and energy costs skyrocket, there is significant and renewed interest in energy performance of buildings. The American Institute of Architects (AIA), The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the United States Green Building Council (USGBC) and Architecture 2030 have joined to support goals that will reduce greenhouse-gas-emitting fossil-fuel energy use by at least 50 percent by 2010, and an additional five percent each year, resulting in carbon-neutral buildings by 2030.

In addition to these voluntary initiatives, building codes enacted in the International Energy Conservation Code (IECC) and in several states – including Wisconsin, Massachusetts, Michigan, California and a number more to follow – are mandating higher energy performance. These new codes and standards will include increased R-value requirements for roofs and walls, air barriers for all new buildings, and improved mechanical-system efficiency.

The ASHRAE/IESN Standard 90.1 is a national consensus standard developed by ASHRAE and the Illuminating Engineering Society of North America (IESNA) that sets minimum requirements to promote the principles of effective, energy-conserving design for buildings and building systems. New revisions to the ASHRAE/IESNA 90.1 standard create a difficult challenge in commercial buildings. At the crux of this challenge is the question of how to consistently and cost effectively meet the standard's thermal, air-barrier and moisture requirements. Proposed changes to the standard will mandate air barriers in new commercial buildings and significantly increase thermal and moisture performance requirements. Particularly, changes in the standard will require buildings to use an air-barrier system that is continuous, durable, able to withstand significant air pressures from wind washing and internal pressurization of the indoor environment. Air-barrier systems, not just materials, shall meet the new ASTM- E-2357-05 in additional to

Table of Contents

ASTM E-2178, ASTM E-1677 in order to confirm performance under both positive and negative pressures.

According to the Environmental Protection Agency (EPA), trends show that the demand for energy will skyrocket in the next 25 years:

- Global demand for all energy sources is forecasted to grow by 57 percent.
- U.S. demand for energy is forecasted to increase by 31 percent.
- Demand for electricity in the U.S. will grow by at least 40 percent.
- New power generation equal to nearly 300 power plants will be needed to meet electricity demand.

This trend, along with the groundswell of the green-building industry, is creating a need for more efficient and cost-effective systems to address energy-performance issues in commercial buildings. In the following pages, we examine the energy considerations involved in the design and construction of commercial building envelopes, along with the business issues that surround the selection and specification of building-envelope systems that improve energy performance.

First, we present an overview of the impact of energy performance in commercial construction; a discussion of the key issues in building-envelope design and construction; a discussion of closed-cell spray polyurethane foam (ccSPF) insulation and waterproofing and its applications to improve energy performance; and a cost analysis of the use of ccSPF insulation and waterproofing systems. We conclude the paper with a set of constructive recommendations—an "Action Plan"—for consideration by building designers, constructors, developers and owners concerned about issues critical to energy and the environment.

California Energy Commission (CEC) to Increase Energy Performance Standards in 2008

"The Energy Commission is in the process of developing the next version of building standards expected to be adopted in 2008. Some of the efficiency features that are expected to be in the final version of the standards include updated lighting and mechanical measures, cool roofs for residential applications, better controls for central hot-water distribution, residential programmable communicating thermostats, nonresidential demand shedding controls for demand response capabilities, a new optional compliance tier for photovoltaic systems, and updated nonresidential outdoor-lighting requirements."

– CEC, Energy Savings from Building Standards, 2007 Integrated Energy Policy Report

Aggressive Goals for Energy Performance in U.S. Federal Buildings

In December of 2007, the House of Representatives passed the Energy Independence and Security Act. Section 433 of the bill requires that all federal buildings meet significantly improved energy standards. The bill states that: **"Buildings shall be designed so that the fossil fuel–generated energy consumption of the buildings is reduced, as compared with such energy consumption by a similar building in fiscal year 2003 (as measured by Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Agency), by the percentage specified in the following table:**

Year	Percent Reduction
2010	55
2015	65
2020	80
2025	90
2030	100

Department of Energy Finalizes Regulations to Increase Energy Efficiency in New Federal Buildings by 30%

In December of 2007, the U.S. Department of Energy (DOE) announced it has established regulations that require new Federal buildings to achieve at least 30 percent greater energy efficiency over prevailing building codes. Mandated by the Energy Policy Act of 2005 (EPAct), these standards apply to new federal commercial and multi-family high-rise residential buildings, as well as new federal low-rise residential buildings designed for construction that began on or after January 3, 2007. These standards are also 40 percent more efficient than the current Code of Federal Regulations (CFR) and carry out portions of President Bush's Executive Order, announced earlier this year, which directed federal agencies to reduce energy intensity and greenhouse-gas emissions; substantially increase use and efficiency of renewable energy technologies; and adopt sustainable design practices.

Over the course of the next 10 years, these standards are estimated to save taxpayers $776 million dollars (in 2004 dollars) and more than 40 trillion British thermal units of energy, while reducing emissions by an estimated 2 million metric tons of carbon dioxide. These new standards are based on the American National Standards Institute (ANSI)/ American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)/ Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004 for commercial and high-rise multi-family residential buildings and the 2004 version of the International Code Council (ICC) International Energy Conservation Code (IECC) for low-rise residential buildings.

Energy Performance in Commercial Buildings

According to the Department of Energy, in 2005, commercial buildings accounted for approximately 18 percent of total energy use in the United States and 35 percent of total electricity consumption. More than 60 percent of commercial-building energy use is attributable to losses through walls, foundations and roofs due to air infiltration or exfiltration. Energy costs account for approximately 30 percent of a building's total operating costs. According to the Environmental Protection Agency (EPA), the savings potential from the proper design and installation of energy-efficient upgrades is more than 35 percent – for example, approximately $25,000 for every 50,000 square feet of office space.

In addition to energy cost savings, the State of California's Efficiency Partnership has found that good energy-management practices serve up several less obvious financial benefits:

- Management teams who are successful at dealing with the process of managing energy and environmental issues in their buildings often have the infrastructure and problem-solving skills to manage a financially healthy company. Good energy management is linked to stock market performance: **"This relationship [between energy management and financial performance] can be seen in the recent pressure by investor groups on businesses to disclose environmental and energy performance as part of their annual reporting."** – *Energy Partnership, 2007*
- Energy efficiency improvements can be used as a high-return investment. Reducing building operating costs can directly increase net operating income (NOI). In addition, energy-efficient buildings help lure tenants and buyers whose buying and leasing decisions are increasingly impacted by operating costs. **"As fuel prices set records, office rents in buildings certified energy efficient by the government are rising two thirds faster than rents in buildings without the ratings, according to CoStar Group, which provides real-estate data."** – *Bloomberg News*

According to independent studies done by Oak Ridge National Laboratory (ORNL) and the National Research Council Canada (NRCC), between 30 and 50 percent of energy loss is attributed to air leakage and heat transfer in the building envelope. Roof, wall and below-grade insulation systems and air-barriers are a critical part of reducing these losses.

Closed-Cell Spray Polyurethane Foam (ccSPF): Products and Applications

Closed-cell spray polyurethane foam (ccSPF) insulation is a self-adhering, two-component product that is spray-applied on site. The material tenaciously bonds to most construction material substrates (i.e. metal, wood, plastic, masonry) and provides a rigid insulation system that adds structural strength to buildings. It has the highest level of thermal performance per inch for commonly used thermal insulation products. Typically, this performance shows a design R-value of 6.2 for 2-lb at 75 degrees F for ccSPF wall insulation, and a design R-value of 6.7 for 3-lb at 75 degrees F ccSPF roof insulation at a mean temperature of 75 degrees F (ASTM C 518 04).

Closed-cell spray polyurethane foam also has nearly zero air permeability and acts as an integral vapor barrier. Because the product is sprayed onto the substrate and expands to nearly 30 times its original volume when applied, it conforms to many irregular spaces and fills voids that other insulation materials leave open. It requires no fasteners and is typically installed in a single application.

What's the Difference Between Open-Cell (oc) and Closed-Cell (cc) Spray Polyurethane Foams?

Spray Polyurethane Foams (SPF) are created by combining several key components – liquid polyurethane precursors and a blowing agent. The blowing agent "foams" the liquid mixture as it is applied to the surface and then solidifies. Typically, polyurethane foam is composed of 97 percent insulating bubbles (called cells) and is only 3 percent solid by volume. The difference between ocSPF and ccSPF foam insulation systems is primarily in the structure of the cells that form the polyurethane foam. Open-cell spray polyurethane foam (ocSPF) utilizes carbon dioxide as the sole blowing agent. In ocSPF, the cells burst open and are suspended in the finished foam in an open form. Closed-cell spray polyurethane foam insulation utilizes advanced blowing-agent technology, Enovate® 245fa, a hydrofluorocarbon that is a zero-ozone-depleting, non-flammable gas. In ccSPF, the cells are suspended in the final product in a closed form, providing superior thermal insulating performance. In comparison to ocSPF, the foaming technology used to create ccSPF insulation makes a material with higher R-value, superior waterproofing, improved dimensional stability, higher compressive strength, superior adhesion, lower air permeability, superior moisture resistance, increased durability and greatly improved structural strength. Closed-cell spray polyurethane foam (ccSPF) is a waterproof system when properly surfaced, whereas open-cell spray polyurethane foam (ocSPF) can act like a sponge that soaks up water, creating an environment for mold and mildew.

Closed-cell spray polyurethane foam insulation carries a slightly higher cost, but when considering all the factors mentioned above, it is actually a much better value. The choice of blowing-agent technology that creates the cell structure is critical to ccSPF performance and energy-savings capabilities.

Roofs

Closed-cell spray polyurethane foam (ccSPF) insulation is an ideal roofing material because it can be sprayed on a new roof substrate, used for tear-off replacement, or applied over an existing roof as a re-cover. It provides a weather-tight barrier, has excellent thermal performance and can be highly reflective, utilizing a variety of elastomeric coatings (i.e. acrylic, silicone, urethane and polyurea). Gravel-surfaced systems and single-ply membrane technology (i.e. fully adhered fleece-backed membranes, loose-laid ballasted) can also be used with ccSPF roof systems. Because even the densest foam is lightweight (approx. ½-lb. per sq. ft. on average), it adds little weight to the building and is often used in renovations for this reason.

As with any other roof system, effective installation and performance of a ccSPF insulation and waterproofing system requires a thorough inspection of existing conditions, thorough specifications including detail drawings, a quality formulated product, proper roof surface preparation, manufacturer or third-party consultant inspections, good maintenance, and most importantly a manufacturer-authorized and licensed, factory-trained professional contractor. In re-roofing situations, proper remediation of the existing roof is critical. Although ccSPF insulation tolerates moisture extremely well in comparison to other insulation systems, excessive retained water and moisture in an existing conventional roof system can cause problems with the roof system's structural integrity if not addressed or removed. Existing coated ccSPF roof systems will need to be recoated based on the manufacturer's specifications at 10-, 15- or 20-year intervals based on membrane or coating system thickness. Closed-cell spray polyurethane foam (ccSPF) insulation and roofing manufacturers offer extended warranties beyond the original warranty period contingent on re-inspection for damage, repairs and bringing the roof back up to manufacturer's standards for recoating. Like any other roof system, ccSPF insulation must be applied to clean dry substrates, so weather planning is critical for installation. According to the National Roofing Foundation, the service life of a ccSPF roof system is more than 30 years, with proper maintenance and recoating.

The use of ccSPF in roofing applications provides significant energy efficiency benefits because of high R-value, ease of application and renewability, and the elimination of thermal bridging effects that occur with other roof insulation systems. The system provides an additional energy benefit due to its compatibility with high-reflectivity coatings and vegetative green-roof systems.

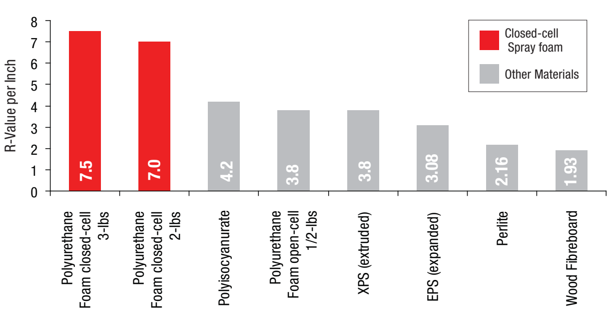
Walls

In walls, ccSPF insulation can be used throughout the interior or exterior of a structure and may be applied to nearly any construction surface (i.e. masonry, gypsum board products, wood, metal), including exposed or new-construction wall framing. Closed-cell spray polyurethane foam wall-insulation systems provide a continuous air barrier, improved building strength and significant thermal performance. The system addresses all key issues associated with insulation and air-barrier systems in commercial insulation performance, because of:

- Superior effective R-value in a complete assembly
- A monolithic, integral vapor and air barrier that requires no additional products to reduce air and moisture infiltration and exfiltration, thereby exceeding building codes and standards and meeting ASTM C1029/SPFA guidelines
- Low water vapor permeability, low liquid water absorption and high thermal performance, which combine to minimize condensation and water intrusion into the building
- Complete coverage of the building envelope (i.e. roof, walls, foundation and slab), which minimizes thermal bridging caused by fasteners, joints, cracks, penetrations and framing

Effective Insulation Performance Per Inch Thickness

Effective R-Values of Insulation Materials at 40° F



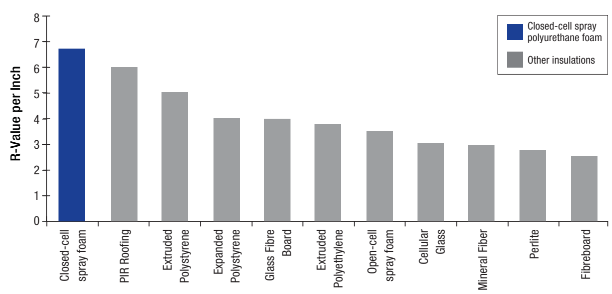
In-place effective R-value studies show joints, gaps and fasteners allow energy to escape, reducing effective R-value performance of board-stock insulations: 23% in the winter heating season and as much as 16% in the summer cooling season. Pentane-based insulating gases decrease R-value by as much as and additional 20% at 40°F vs 75°F

Finally, ccSPF insulation and waterproofing systems employed in the building envelope (i.e. roof, walls, foundation and slab) can substantially improve the structural integrity of the building. In fact, studies show that using ccSPF insulation in walls increases racking strength two to three times compared to assemblies using traditional insulation products.

Using ccSPF as a wall-insulation system provides significant energy-related benefits. In addition to significantly higher R-value than other insulation materials, ccSPF eliminates moisture and air infiltration and exfiltration concerns associated with other materials.

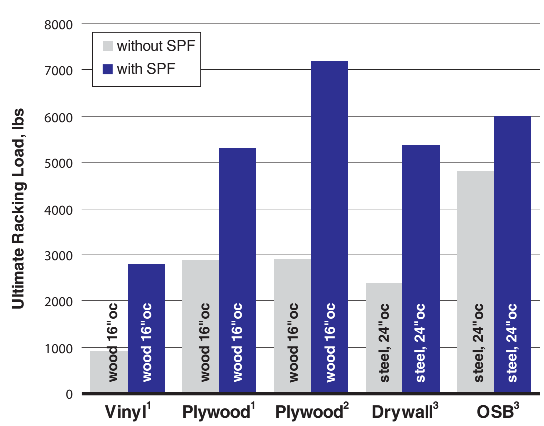
Typical Insulation R-Value per Inch

R-Values of Insulation Materials at 75º F



"Closed-cell Spray Polyurethan Foam" Best Insulator & Air-barrier per Inch

Increased Safety



Slabs and Foundations

Foundations are a significant source of heat loss and require appropriate insulation to ensure proper thermal performance of the building envelope. Exterior below-grade insulation is a unique challenge and opportunity for performance improvement, because it performs many functions. It not only provides insulation between the soil and the building assembly, but also protects the structure from environmental challenges, such as compression and expansion due to frost action, and moisture and water from wet soils. This makes selecting an effective insulation and water-barrier system critical to the overall performance of the building and to obtaining maximum energy savings associated with heating and cooling costs.

A ccSPF insulation and waterproofing system can be used to insulate commercial building slabs using a "sandwich" strategy. After excavation and preparation, a preliminary or "rough" concrete slab is poured, covered with a sprayed layer of ccSPF, then covered with an additional concrete floor slab. In addition, below-grade walls can be insulated on the interior and/or exterior with ccSPF insulation. This process provides excellent thermal performance and has the additional benefit of providing moisture and bulk water resistance to the below-grade building-envelope construction.

A joint research project was undertaken in 1995 by the Canadian Urethane Foam Contractors Association (CUFCA) and the NRCC's Institute for Research in Construction to assess the thermal and moisture performance of a number of insulation products used as exterior below-grade insulation. The study found that although water was detected at the outer surface of the ccSPF insulation and waterproofing below-grade wall system during heavy freeze and thaw periods, the surface on the interior remained dry. Additionally, the study found that thermal performance of the ccSPF insulation and waterproofing material remained stable and was not affected by the exterior water movement. According to Building Science Corporation's white paper on understanding below-grade construction, SPF insulation provides "the least risky interior insulation assemblies from the perspective of installation simplicity, water insensitivity and ease of drying."

Closed-cell spray polyurethane foam is a unique foundation and slab insulation material, because of its moisture resistant and waterproof characteristics, coupled with high thermal performance. Particular attention should be paid to foam density and thickness when specifying any below-grade system.

Energy Performance – Significant Factors

Energy performance in buildings is a complex topic that involves the interplay of environmental factors, mechanical systems and building-envelope system performance. By far the most significant contributor to energy losses, and therefore the most significant opportunity for energy-efficiency improvements, is the building envelope.

Closed-cell spray polyurethane foam provides building designers, owners and builders with a unique system that meets or exceeds performance standards associated with the key issues in building-envelope energy performance. It provides contiguous building-envelope insulation and an air-barrier and moisture-management system that outperforms all of its competitors.

Fundamentally, building-envelope performance can be segregated into three primary areas: roof, walls and foundations. According to Mark Bomberg, a building scientist at Syracuse University who has conducted a significant body of research on building-envelope performance, a number of factors critically affect the overall performance of roof assemblies, which can be extrapolated as general issues in building-envelope energy performance. These include: thermal drift, thermal bridging, air movement, and moisture. The following sections discuss these issues and show how ccSPF insulation and waterproofing systems provide a significant advantage.

Thermal Drift

Thermal drift (aging) is the phenomenon by which R-value decreases as insulation material ages and wind wash occurs with or without thermal variance. The phenomenon occurs in all types of thermal insulation systems. Most thermal drift has been found to occur within the first 30 days of the life of foam plastic insulations, after which R-value reaches a steady state with minimal aging occurring, unless the foam is damaged. Wind-washing occurs as unconditioned air is allowed to move within air-permeable cavity insulations, such as fiberglass, cellulose and board-stock insulations. Wind-washing, a form of forced convection, creates loss of thermal insulating properties because many insulation systems are not seamless and monolithic. In foam board stock insulations that use pentane blowing agents, when the external temperature decreases, the pentane-based blowing agents used in polyisocyanurate board stock insulations change from a gaseous state to a liquid and condense due to the pentane boiling temperature. This can dramatically lower thermal performance. For this reason, insulations should be tested and evaluated at mean temperatures of 0 degrees F, 40 degrees F, and 110 degrees F – not only at 75 degrees F, a mean temperature at which insulation may not be necessary.

According to M.T. Bomberg and M.K. Kumaran (Use of Field-Applied Polyurethane Foams in Buildings, Construction Technology Update no. 32, Dec. 1999), thermal drift creates a problem whereby designers cannot simply rely on published initial R-value performance of the material to calculate energy performance, because thermal resistance changes over time and with temperature variables and wind-washing effects.

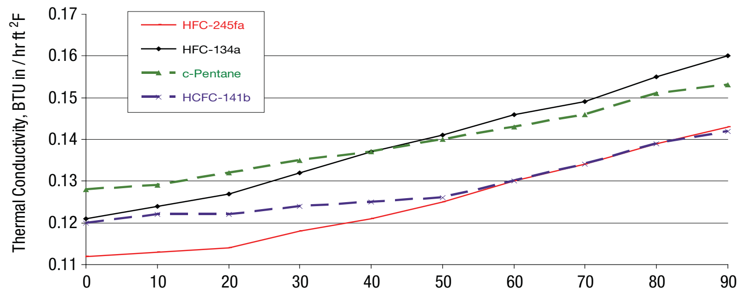
Thermal drift can be resolved in part by increasing thickness above minimum R-value requirements to compensate for thermal drift factors, according to Bomberg. Designing with appropriate values and considering all factors that influence the performance of insulation are critical design considerations when striving to improve energy performance in buildings.

Designers must carefully research the characteristics of insulation products and their specific installed assemblies to understand the actual thermal performance of insulation products. Relying on published R-values when considering the placement or need for a vapor barrier could cause a fatal design error. This potential for error is greatly reduced with a

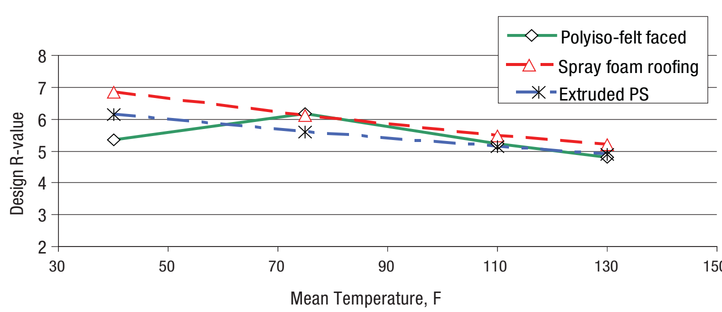
Current Thermal Testing Standards

Insulation	ASTM Standard	Mean Test Temperature, °F	Temperature Differential, °F
R-13 Fiberglass batt with paper facing	ASTM C 653	75	40 or 50
Extruded polystyrene	ASTM C 578	25, 40, 75, 110	Min 40
Polyisocyanurate	ASTM C 1289	40, 75, 110	Min 40
Closed-cell spray foam insulation	ASTM C 1029	40, 75, 110	Min 40
Open-cell spray foam insulation	None	75	Min 40

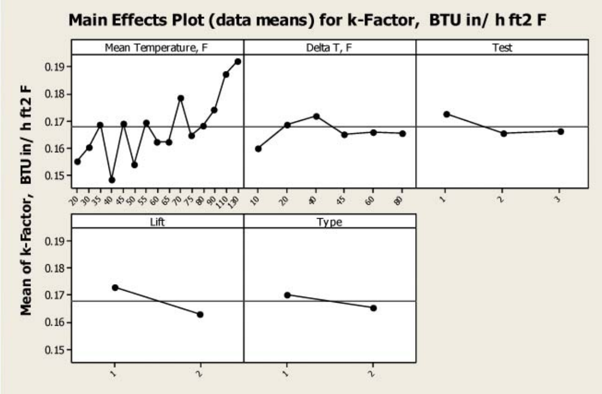
Blowing Agent Temperature Curve



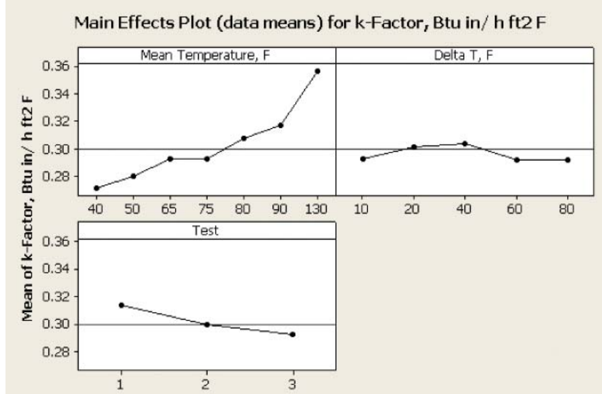
Design R-value Temperature Curve



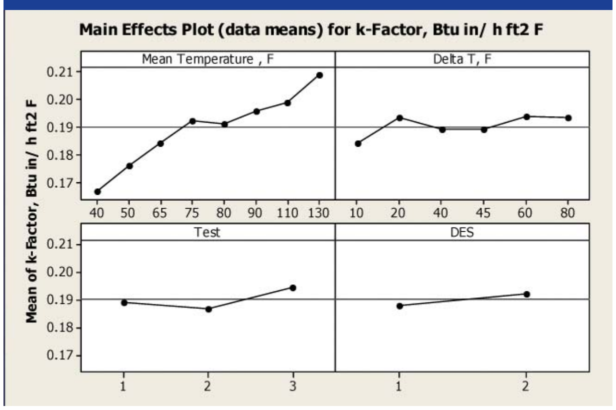
Main Effects Plot Closed-Cell Polyurethane Spray Foam



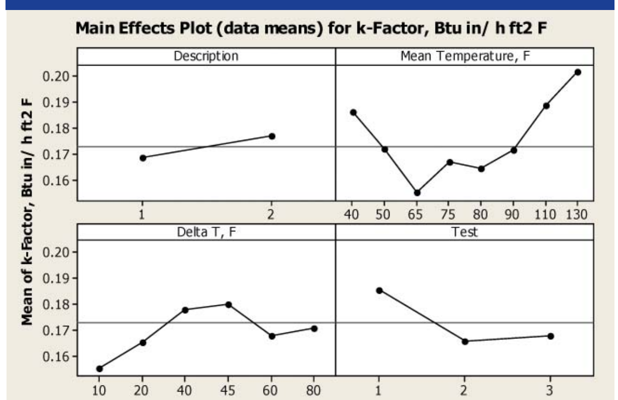
Main Effects Plot Open-Cell Polyurethane Spray Foam



Main Effects Plot Extruded Polystyrene



Main Effects Plot Felt-Faced Polyisocyanurate



ccSPF system, which serves as a vapor, air, moisture and thermal barrier all in a single product and application. The ccSPF system fares very well in tests evaluating long-term aging performance over time, showing a tolerance within 3 percent of published R-values. Such a system experiences no wind-washing effects, acts as a vapor and air barrier, and actually increases in R-value at lower temperatures when a proper blowing-agent technology is used. These are very important reasons why ccSPF outperforms traditional insulation systems such as the ones mentioned above, which can experience a significantly higher rate of thermal drift due to settling, aging, temperature ranges, thermal bridging and air infiltration or wind-washing.

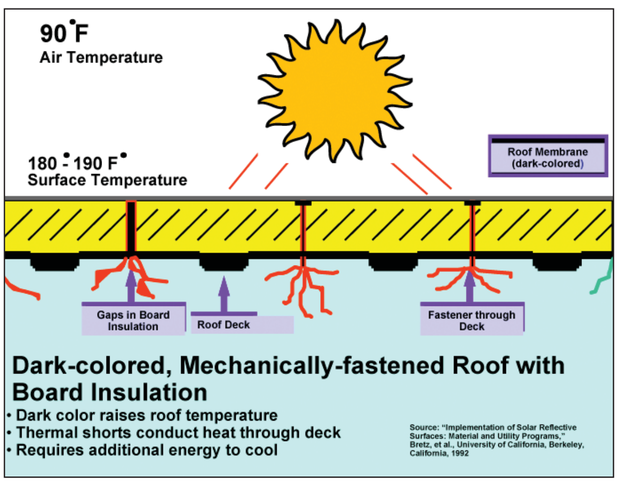
Thermal Bridging

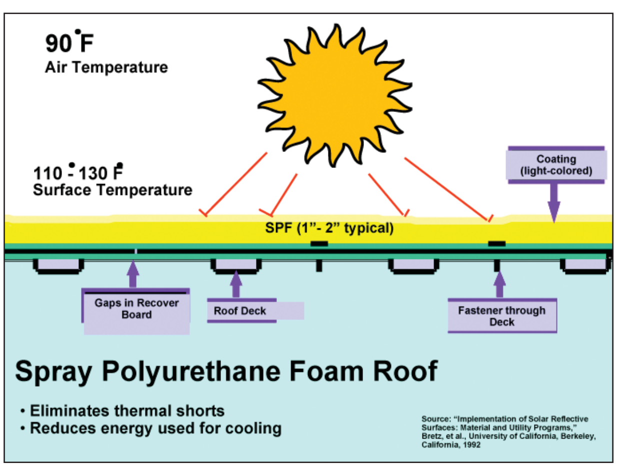
A thermal bridge is an assembly or component in the building envelope that transfers heat at a significantly higher rate than the surrounding insulated area. Thermal bridging can also be created by board-stock insulation fasteners, joints and gaps. Thermal bridging can be a significant cause of heat loss and underperformance of insulation assemblies in commercial buildings, particularly in metal-framed buildings. The Department of Energy's (DOE) building codes and standards group addresses this specific issue in its recommendations because of its significance to energy performance (see sidebar, p.9). According to the Denver American Association of Architects, Committee on the Environment, thermal bridging in steel-framed buildings can reduce the effectiveness of insulation systems by 30 to 50 percent. The reduced insulation effectiveness can lead to lower wall-cavity temperatures, which can lead to condensation and building-envelope moisture problems.

The DOE recommends using thermal blocks to eliminate issues with thermal bridging, which can be done by utilizing ccSPF as an insulation system, as it continuously covers existing thermal bridges. In addition, because ccSPF systems require no fasteners, thermal bridging is naturally reduced.

The *2007 Energy Performance of SPF Roofs: Documentation and Literature Review*, produced by Mark T. Bomberg, D. Sc. (Eng), Techn. D., P.E.; Marcin K. Pazera, M. Sc., Ph. D. candidate TI Research (Ottawa, Ontario, and Syracuse, N.Y.); and John P. Nolan (Central Coating Co Inc., Madera, Calif.), examines the effects of thermal bridging in board-stock insulation compared to ccSPF systems. The report states that the thermal bridging effects at insulation joints, fasteners and cracks can reduce the published R-value of board-stock insulation roof assemblies by as much as 16 percent on average during the cooling season and as much as 23 percent during the heating season. Therefore, for example, during the winter a specified insulation system assembly with a published R-value of 20 could be functioning at an R-value of 16, if joints and fasteners create thermal bridging. Closed-cell spray polyurethane foam, on the other hand, is monolithic and seamless and requires no mechanical fasteners (such as metal plates and screws), so it actually performs at its published R-value.

Steel, light-gauge metal, and wood framing systems can also create thermal bridging. Saskatchewan's high-performance building program, R-2000, notes the extent of wood in typical exterior wall construction. With a stud occurring every 16 to 24 inches, at the top and bottom wall plates, and additional framing over windows and doors, R-2000 states that "up to 20 percent of the area of an exterior wall can be solid wood. Since a 2x6 stud has a thermal value of about R-5, the wood areas of the wall have the effect of reducing the advertised R-20 wall to an overall performance of anywhere between R-14 to R-16." Closed-cell spray polyurethane foam properly installed on the exterior can resolve this issue by providing significantly higher R-value per square inch compared to traditional systems, and by creating a thermal block that prevents further thermal bridging due to a high framing factor.

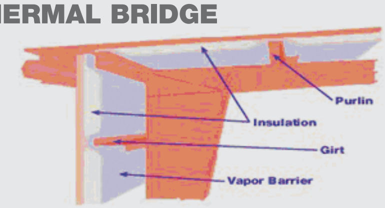




Why might a metal building with R-19 insulation not meet the energy code?

Most energy codes with prescriptive compliance options state that each building component must meet the minimum values specified and that the insulation cannot be compressed. Metal buildings are typically insulated by draping batt-type insulation over the structural supports, then attaching metal panels, compressing the insulation at the supports (see illustration). The fasteners or connectors provide a "thermal short circuit" (known as thermal bridging) through the compressed insulation, significantly reducing the overall thermal performance and thus the full R-value of the insulation. For example, R-19 insulation installed using this technique yields an effective R-value of approximately R-11.

THERMAL BRIDGE



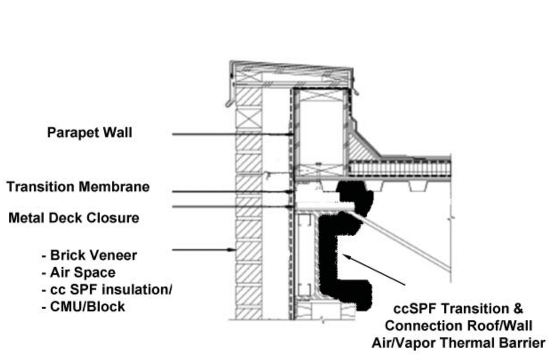
DOE, Building Codes and Standards, Setting the Standard, Fall 2001, Volume 10, Issue 2

Air Infiltration and Exfiltration

Air infiltration and exfiltration account for a significant amount of energy loss in commercial buildings. According to a 2005 National Institute of Science and Technology (NIST) study, an energy savings of up to 62 percent can be realized by undertaking specific airtightness measures. In addition to energy loss, infiltration reduces occupant comfort, interferes with efficient operation of mechanical systems, reduces indoor air quality and contributes to condensation and moisture damage in the building envelope system. The NIST study, entitled "Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use," sought to measure building-envelope airtightness before and after specific air-sealing measures were completed and to calculate related improvements in energy performance. Before the NIST study, measured data on the performance of air barriers in commercial buildings was primarily focused on non-energy impacts.

One of the simplest, quickest and least expensive energy improvements to a commercial building can be achieved by air-sealing the area between a roof deck (such as metal decking) and the exterior walls with ccSPF insulation. In addition, air-sealing with ccSPF around all penetrations (i.e pipes, drains, curbs, HVAC equipment doors, and windows) eliminates the heating and cooling energy that is lost through the stack-effect of unconditioned air flow in and out of the building. The material used to seal must have proper fire-resistance properties outlined in the specifications and meet code. This process can be performed on new buildings, existing facilities and during a re-roofing application.

Wall/Roof ccSPF Air/Vapor Thermal Barrier

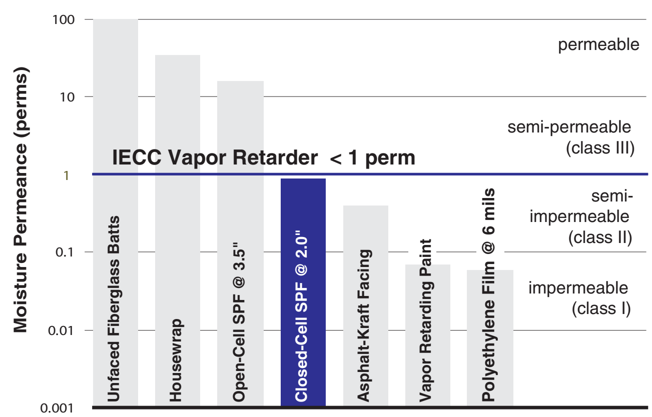


Influenced by NIST's findings and by calls for more sustainable types of construction, ASHRAE has been considering new and more restrictive language in ASHRAE 90.1 that includes use of a continuous air barrier as a requirement. According to ASHRAE's Advanced Energy Design Guide, air-barrier systems should be:

- Continuous, with all joints made airtight.
- Capable of withstanding positive and negative combined design wind, fan and stack pressures on the envelope without damage or displacement. (The system should transfer the load to the structure. It should not displace adjacent materials under full load.)
- Durable or maintainable.
- Joined in an airtight and flexible manner to the air-barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection.
- Materials used should have an air permeability not to exceed 0.004 cfm/ft2 under a pressure differential of 0.3 in. water (1.57 psf) (0.02 L/s*m2 at 75 Pa) when tested in accordance with ASTM E 2178.
- Connections should be made between:
  - Foundation and walls
  - Walls and windows or doors
  - Different wall systems
  - Wall and roof
  - Wall and roof over unconditioned space
  - Walls, floor and roof across construction, control and expansion joints
  - Walls, floors and roof to utility, pipe and duct penetrations

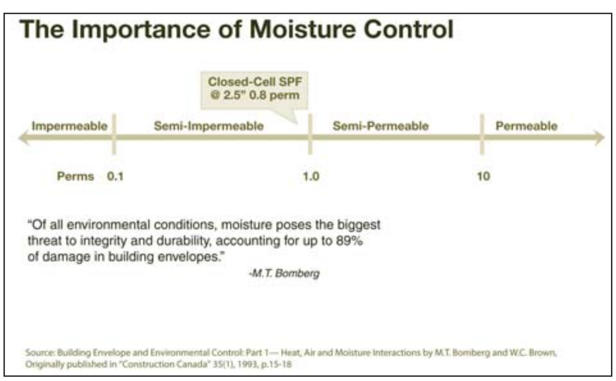
According to many experts, practitioners and enclosure specialists, one of the leading materials that meets (and, in most cases, exceeds) new air-barrier code requirements and standards is ccSPF. "I believe there is a consensus among building-enclosure experts that ccSPF insulation is one of the most effective methods of installing a continuous, high-performance, simultaneous insulation and air barrier," says Judd Peterson, AIA, of the Judd Allen Group. "It is really a very multi-faceted, effective solution in creating air barriers." While many people are familiar with ccSPF being used effectively as an ENERGY-STAR®-rated, environmentally friendly roof system that provides superior thermal insulation and enhanced wind-uplift properties, it's not generally known that ccSPF can be used to insulate and serve as a water, vapor and air barrier in roofs, walls, foundations and floors in commercial buildings. Yet research shows that a ccSPF insulation and waterproofing system offers good performance in resisting moisture transmission and condensation because of its low vapor permeability and air-sealing capabilities. Because air infiltration is such a significant factor in energy efficiency, ccSPF is an ideal insulation system choice.

Integral Vapor Retarder



Moisture Considerations

Moisture considerations go hand in hand with improving energy performance in buildings because systems that improve energy performance in the building envelope can prevent bulk water and water vapor from entering and damaging building assemblies. Insulation and a moisture and air-barrier system are critical parts of a high-performance building envelope. These systems are instrumental to energy performance, but also in helping to prevent water vapor from entering the envelope assembly, where it can condense and turn into liquid water – a key ingredient in corrosion and mold growth. Closed-cell spray polyurethane foam addresses the functions of all of these systems, combined.



Closed-cell spray polyurethane foam provides an excellent form of defense against moisture and water damage to building-envelope assemblies because of its low water and moisture permeability and its ability to assist the building assembly in shedding bulk water. According to Dr. Joseph Lstiburek, P.E., a principal of Building Science Corporation (BSC), air barriers are "of critical importance" at connections between the roof and walls, walls and foundation, and at all building-envelope connections and penetrations, such as parapets, roof edges, equipment curbs, drains, pipes, windows and doors. The greatest source of air and energy leakage from a building is at these critical building envelope connections, which require an effective air seal. In March 2006, Building Science Corporation (BSC) assembled and evaluated available information regarding the use of ccSPF insulation and waterproofing systems. The study focused on building-enclosure design, including foundation, wall, cladding and roof construction as well as interior finishes. According to BSC, the unique characteristics of ccSPF set it apart from all other insulation and waterproofing materials, delivering high R-value per inch at a variety of temperatures, airtightness, low permeability, good material strength and good "liquid water holdout," or rain control. These unique characteristics create a significant competitive advantage when specifying ccSPF, as moisture management is a critical concern in energy-efficient building design and construction.

Cost and Return on Investment (ROI) with ccSPF Insulation and Waterproofing Systems

When reviewed in light of increased performance (which reduces the cost of building maintenance and operation over time) and rising energy costs, ccSPF insulation as a roof system provides a quick return on investment. Texas A&M University studied the energy savings associated with the use of ccSPF roof systems in buildings on its central campus and determined that the energy savings realized from the system paid back the initial investment within 4.5 years. Texas A&M is widely reported as using nothing but ccSPF roofing materials for new and existing buildings on its central campus due to these ROI evaluations.

A report produced by Michelsen Technologies evaluating the lifecycle for ccSPF roof systems found that the system costs between 10 and 50 percent less (installation and maintenance, assuming costs based on a 6-, 10- and

Case Study

Project & Location: Texas A&M University, College Station, Texas

Description: Texas A&M is widely reported as having more than 7 million square feet of ccSPF roofing installed on buildings in its campus, with ccSPF being specified for every new and existing roof project. An analysis completed by an engineer at the Texas A&M Physical Plant concluded that the university covered the cost of the installed roof systems after 4.5 years.

Oak Ridge Labs Case Study

BASE CASE W MAINT SAVINGS

	Payback Period (years)			
	Energy Savings	Maint Savings	Combined	ES Payback Reduction
Knoxville	32	5.5	4.7	0.8
Bismark	19	5.5	4.3	1.2
Chicago	26	5.5	4.6	1.0
Miami	34	5.5	4.7	0.8
Seattle	43	5.5	4.9	0.6

CASE 2: W MAINT SAVINGS

	Payback Period (years)			
	Energy Savings	Maint Savings	Combined	ES Payback Reduction
Knoxville	32	11.1	8.3	2.9
Bismark	19	11.1	7.0	4.1
Chicago	26	11.1	7.6	3.3
Miami	34	11.1	8.4	2.8
Seattle	43	11.1	8.8	2.3

CASE 3: W MAINT SAVINGS

	Payback Period (years)			
	Energy Savings	Maint Savings	Combined	ES Payback Reduction
Knoxville	32	28.4	15.1	13.2
Bismark	19	28.4	11.4	17.0
Chicago	26	28.4	13.6	14.7
Miami	34	28.4	15.4	13.0
Seattle	43	28.4	17.1	11.3

15-year re-cover schedule) than standard built-up-roof, modified-bitumen and single-ply membrane roof systems over a 30-year time frame. The report attributed these savings to:

- Low cost to remove and dispose of existing roof materials
- Energy savings from superior thermal performance and highly reflective ccSPF roof surfacings
- No damage to be repaired from leaking or moisture
- Minimal comparative maintenance and recoating costs

07 57 Coated Foamed Roofing

07 57 13 - Sprayed Polyurethane Foam Roofing

						2008 Bare Costs				Total
0010	SPRAY POLYURETHANE FOAM ROOFING	Crew	Daily Output	Labor-Hours	Unit	Material	Labor	Equipment	Total	Incl. O & P
	Primer for metal substrate, when required	ROFC	3000		S.F.	0.38	0.08		0.46	0.56
	Primer for non-metal substrate, when required	ROFC	3000		S.F.	0.15	0.08		0.23	0.31
	Closed cell spray polyurethane foam, 3 lbs. per cubic foot density, 1", R6.7	G-2A	15000	0.002	S.F.	0.68	0.05	0.04	0.77	0.87
	2", R13.4	G-2A	13125	0.002	S.F.	1.36	0.05	0.05	1.46	1.63
	3", R20.1	G-2A	11485	0.002	S.F.	2.04	0.06	0.05	2.15	2.40
	Spray-on acrylic coating (add an additional $.20/sq.ft. for silicone coating)	G-2A	2500	0.010	S.F.	0.41	0.28	0.24	0.93	1.18
	Warranty, 5 - 20 year manufacturers				S.F.					0.06
	20 year, no dollar limit				S.F.					0.15

07 21 Thermal Insulation

07 21 29.10 - Sprayed Insulation

						2008 Bare Costs				Total
0010	SPRAYED WALL INSULATION	Crew	Daily Output	Labor-Hours	Unit	Material	Labor	Equipment	Total	Incl. O & P
0030	Closed cell, spray polyurethane foam, 2 pounds per cubic foot density									
	1" thick, R6.2	G-2A	6000	0.004	S.F.	0.43	0.12	0.10	0.65	0.78
	2" thick, R12.4	G-2A	3000	0.008	S.F.	0.86	0.23	0.20	1.30	1.55
	3" thick, R18.6	G-2A	2000	0.012	S.F.	1.29	0.35	0.30	1.94	2.33
	3-1/2" thick, R21.7	G-2A	1715	0.014	B.F.	1.50	0.41	0.35	2.26	2.71
	4" thick, R24.8	G-2A	1500	0.016	S.F.	1.72	0.47	0.40	2.59	3.11
	5" thick, R31	G-2A	1200	0.020	S.F.	2.15	0.59	0.50	3.24	3.88
	5-1/2" thick, R34.1	G-2A	1090	0.022	S.F.	2.36	0.64	0.55	3.56	4.27
	6" thick, R37.2	G-2A	1000	0.024	S.F.	2.58	0.70	0.60	3.89	4.66

RSMeans is providing costs based upon the typical assembly information available at present.

New Research and Standards – Performance Evaluation Whole-Roof Insulation System Performance

Until recently, there has been a relative lack of good information to show actual in-field performance of whole-roof and roof-insulation systems, since labeled R-value and laboratory studies are often inaccurate in determining whole-roof performance. Additionally, R-value doesn't account for performance reductions caused by humidity, temperature change, air infiltration and thermal bridging. Although methods to evaluate the performance of individual roofing and insulation materials (such as ASTM standards) exist, there are significant challenges in evaluating the performance of whole-system performance. Honeywell researchers recently conducted studies that identified issues with current insulation system performance evaluation. In short, manufacturers only report performance at 75 degrees F temperature in published documents. Designers and consumers should be aware that insulation is subject to a wide range of temperature variables and R-value data should be required, reported and supplied at 40 degrees F, 75 degrees F, and 110 degrees F to show the full range of product performance. Because mean temperature has a critical impact on thermal conductivity, and analysis is performed only at 75 degrees F, this one set of conditions does not accurately reflect product performance. Tested at other mean temperatures, insulation systems perform much differently. Honeywell's research indicates that when tested at cold and hot temperatures, ccSPF roofing systems perform significantly better than other systems. It is suggested that additional evaluation of insulation systems be performed using a broad range of mean temperatures.

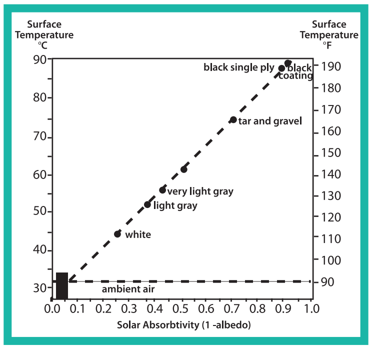
In addition to Honeywell's work, a group called the Council for Performance Criteria for Constructed Roof Systems (PCCRS) has been formed by the National Roofing Contractors Association (NRCA) to create criteria for evaluating complete roof-system performance, rather than performance of individual products. After preliminary review of the suggested criteria – which are still in draft form – it is expected that properly formulated and installed ccSPF roof systems will be one of the few single-system solutions that easily meets or exceeds the standards.

Finally, the work performed by Bomberg at the University of Syracuse proposed new and better strategies for contractors to estimate actual field performance of SPF roof systems. Bomberg's report, "Energy Performance of SPF Roofs," creates a new approach to evaluating the energy performance of roof systems. His findings include the recommendation for a new standard to measure whole-roof performance. According to the report: **"Since the concept of R-value represents dry materials that are not affected by air or moisture flows and does not include other aspects of energy performance, a new terminology is needed. We believe that focus on air and moisture flows requires equivalent consideration as heat transfer through an assembly. We therefore propose to replace R-value with new concepts developed in consultation with the industry and referred hereto as: Energy performance ratio (EPR) and energy performance R-value (Rep)."**

New Research – Cool Roofs and ccSPF Insulation and Waterproofing Systems

Temperatures on a low-slope black surfaced roof can reach 190 degrees F in summer and drop to –20 degrees F in winter. Much of this heat is absorbed into the building interior and can significantly impact cooling and heating loads. During recent decades, highly reflective, low-emissivity roof coatings and membranes for ccSPF insulation and waterproofing systems have been developed and studied. These have resulted in a number of ccSPF insulation elastomeric coatings and ccSPF insulation membrane systems that, combined with proper roof insulation and air barriers, can reduce roof temperatures to a few degrees above ambient temperature on typical roof assemblies, while reducing the energy required to cool a commercial building by as much as half.

Solar Absorbtivity

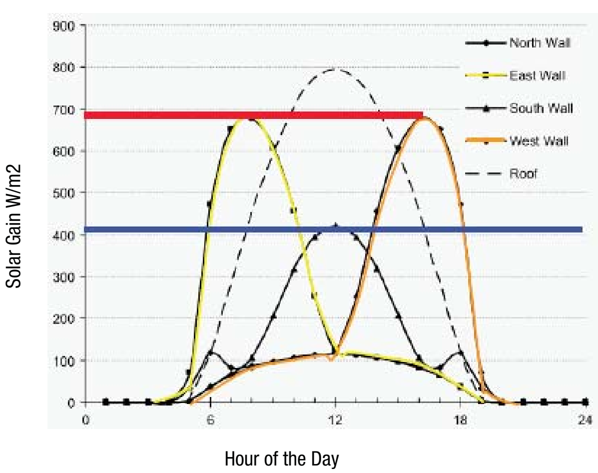


Solar Absorbtivity vs. Surface Temperature of Horizontal Surfaces: *paints, roofing materials, roadways and cities, adjusted to noon on a clear, windless summer day in Austin, TX.*

Source: "Implementation of Solar Reflective Surfaces: Material and Utility Programs," Bretz, et al., University of California, Berkely, California, 1992

In addition to reducing roof temperatures, cool-roof strategies have the benefit of reducing the negative environmental impact of commercial buildings by reducing temperatures in urban heat islands (city areas which are 5 degrees F to 8 degrees F hotter than surrounding areas due to the heat retention of buildings and hardscapes). Hot roofs and building surfaces create hot environments, which lend a great deal to the problem of urban heat islands, which in turn increase energy costs, decrease occupant comfort and increase smog formation. In a study conducted by Lawrence Berkeley National Laboratory's (LBNL) Heat Island Group, potential savings were calculated at about $175 million per year for the 11 cities studied.

Solar Gain — Summer at 45° N. Latitude



Closed-cell spray polyurethane foam roofing systems provide an excellent cool-roof solution in commercial applications because they are sustainable, easily renewable, and can be combined with highly reflective roof coatings or single-ply membranes designed to be used with ccSPF insulation to provide excellent performance. In addition, because ccSPF insulation and waterproofing systems can be used to re-roof over existing roofs, they provide a cost-effective and high-performance re-roofing solution in existing buildings. Closed-cell SPF insulation can be used to incrementally improve the energy performance of a building over time. Additionally, ccSPF insulation greatly reduces the thermal bridging responsible for significant heat losses and gains. It does this by covering existing thermal bridges in the roof deck, which, in turn, reduces heating and cooling costs.

Closed-cell spray polyurethane foam roofs surfaced with a reflective surfacing material can be evaluated through standardized test methods (such as ASTM E 903, ASTM C 1549 and ASTM E 1918) created by ASTM to measure the solar reflectivity of roofing materials. In addition, the EPA's ENERGY STAR Program has created guidelines for the specification of ccSPF roof products to help building designers select products that fit within the program's requirements.

The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System for New Construction & Major Renovations also provides points for reducing heat-island effects by installing a roof system such as a ccSPF cool-roof or ccSPF vegetative-roof option (up to 50 percent of the roof area), with the following options and criteria:

- Option 1: Use roofing materials having a Solar Reflectance Index (SRI) equal to or greater than the values in the table below (p.16) for a minimum of 75 percent of the roof surface.
- Option 2: Install a vegetated roof for at least 50 percent of the roof area.
- Option 3: Install high-albedo and vegetated roof surfaces that, in combination, meet the following criteria: (Area of SRI Roof / 0.75) + (Area of vegetated roof / 0.5)>=Total Roof Area.

Roof Type	Slope	SRI
Low-Sloped Roof	≤ 2:12	78
Steep-Sloped Roof	> 2:12	29

Source: LEED for New Construction Version 2.2, October 2005

The most common ccSPF insulation roof-surfacing materials used are acrylic, silicone, urethanes, polyurea, fully adhered fleece-backed single-ply or loose-laid single-ply membranes over ccSPF insulation, as well as white aggregate/gravel surfaced ccSPF insulation. These surfaces provide the solar reflectivity needed in a cool-roof system and reduce wear to the system. Another cool option is adding a vegetated roof system – a roof garden. Because ccSPF insulation has low absorption, vegetated roof systems can help insulate and provide additional energy and environmental benefits.

Lawrence Berkeley National Laboratory (LBNL) maintains an extensive database of cool-roofing products at http://eetd.lbl.gov/coolroofs. In addition, the Cool Roof Rating Council (CRRC) provides a database of products at http://www.coolroofs.org, and the ENERGY STAR program maintains a list of cool-roof product manufacturers at http://www.energystar.gov.

Cool-roof systems have been studied extensively by Oak Ridge National Laboratory (ORNL), which has developed the "Cool Roof Calculator" to assist building designers in selecting the proper system. The calculator, created for the Department of Energy, allows building designers to analyze heat losses and gains and associated space-conditioning requirements, which helps them to make decisions about appropriate roofing materials specific to the building type and location. To access this calculator, visit Oak Ridge's website at http://www.ornl.gov and search for "cool roof calculator.

Emissivity and Reflectivity

Cool-roof products are discussed in terms of their emissivity and reflectivity. Emissivity refers to the ability of a material to release heat it has absorbed, while reflectivity refers to the ability of a material to reflect solar radiation. Emissivity is defined as the ratio of radiant heat flux emitted by a material to that of a blackbody radiator at the same temperature. Emissivity values range between 0 and 1, or 0 percent and 100 percent. Higher numbers indicate faster heat transfer, thus reducing the heating load placed on the building. Highly emissive roof products reduce the cooling load on buildings in hot climates by releasing heat absorbed from the sun. However, low-emissivity materials may be beneficial to buildings in colder climates because they retain more heat, thus reducing the heating load. Reflectivity is defined as the ratio of the reflected solar radiation flux to the incident flux. Reflectivity values range between 0 and 1, or 0 percent and 100 percent, with the higher number indicating higher reflectivity. The following chart provided by LBNL highlights the solar reflectivity of various types of cool-roofing products:

Achieving Energy and Green-Building Program Performance Standards Using ccSPF Insulation and Waterproofing

A variety of energy-efficiency and green-building programs exist that specify standards for commercial buildings. These standards inevitably mandate specific levels of energy performance. A ccSPF insulation and waterproofing system helps building designers and owners achieve the standards of programs such as the USGBC LEED for New Construction (NC) and LEED for Existing Buildings (EB) criteria, the EPA's ENERGY STAR for Commercial Buildings, and standards set out by ASHRAE. Closed-cell spray polyurethane foam insulation systems are an excellent part of any building design strategy that seeks to meet or exceed these standards. For example, ccSPF insulation and waterproofing:

- Is an ENERGY STAR-rated product that can be used to improve thermal, moisture and air-barrier performance to the required performance level in new and existing buildings
- Can be used to achieve significant supplemental load reductions as called for in ENERGY STAR's Building Upgrade Manual
- Helps to meet minimum energy-performance standards under the LEED program and to earn additional LEED credits, including:

- SS 7.2, Heat Island Effect
- EA 1, Optimizing Energy Performance
- MR 1.1 – 1.3, Building Reuse, in renovation situations where existing roof systems are being recovered
- Meets or exceeds ASHRAE standards for design of an airtight building envelope

Action Plan for Commercial Buildings

Quite simply, energy costs and building codes are creating a critical demand for the adoption of systems that effectively and consistently insulate and seal commercial buildings, while maintaining reasonable costs, low environmental impact and systems engineering implications. For that reason, we recommend the following actions by commercial building designers and builders:

1. Understand the energy performance of your buildings and how it can be improved – now and with future energy cost in mind. Audit the performance of your building-envelope systems and look for opportunities to improve. Take action within your organization to adopt a culture of continuous improvement in your buildings' energy use.
2. Evaluate the use of ccSPF insulation and waterproofing systems for new construction projects. Design your buildings for the future, and seek to understand the performance and cost trade-offs of various moisture, air-barrier and insulation systems compared to the multi-purpose ccSPF insulation and waterproofing system.
3. Increase the awareness of ccSPF insulation for energy performance applications. Become familiar with ccSPF insulation and waterproofing system characteristics and applications to address performance issues and challenges.
4. Promote the improvement of energy performance in commercial buildings, and set a bar for minimum energy performance for all new and existing buildings. Commitment to improve the performance of buildings increases national energy security, reduces our dependence on foreign oil, decreases the impact of buildings on our environment and improves our bottom line.

Sources Used for this White Paper

- Alliance for the Polyurethanes Industry
- Alliance to Save Energy
- American Plastics Council
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- California Efficiency Partnership
- Honeywell
- Lawrence Berkeley National Laboratory
- Mason Knowles
- National Institute of Building Sciences
- National Institute of Standards and Technology
- National Research Council Canada – Institute for Residential Construction
- National Roofing Contractors Association
- Oak Ridge National Laboratory
- R.S. Means
- Spray Polyurethane Foam Alliance
- U.S. Department of Commerce
- U.S. Department of Energy
- U.S. Environmental Protection Agency

For additional information on closed-cell spray polyurethane foam visit: www.ccFoam.com

Corporate Sponsor Honeywell

Honeywell International is a $36 billion diversified technology and manufacturing leader, serving customers worldwide with aerospace products and services; control technologies for buildings, homes and industry; automotive products; turbochargers; and specialty materials. Based in Morris Township, N.J., Honeywell's shares are traded on the New York, London and Chicago Stock Exchanges.

Specifically, Honeywell is a leading innovator in high-performance foam insulation blowing-agent technology. Honeywell Enovate® blowing agent, a hydrofluorocarbon (HFC), is a non-flammable zero-ozone-depleting liquid that allows insulating foam to expand. Moreover, it helps provide many of the foam's key performance characteristics. Honeywell Enovate has been used for years to help appliances achieve ENERGY STAR® ratings and is rapidly being adopted to insulate commercial buildings, especially in roofing systems, walls, slabs and foundations. This energy-efficient technology also is now being used for novel applications, such as solar water heaters in China and hurricane-resistant roofing for commercial buildings such as the Louisiana Superdome.

For additional information, please visit www.honeywell.com/enovate

Honeywell