AirTight SprayFoam

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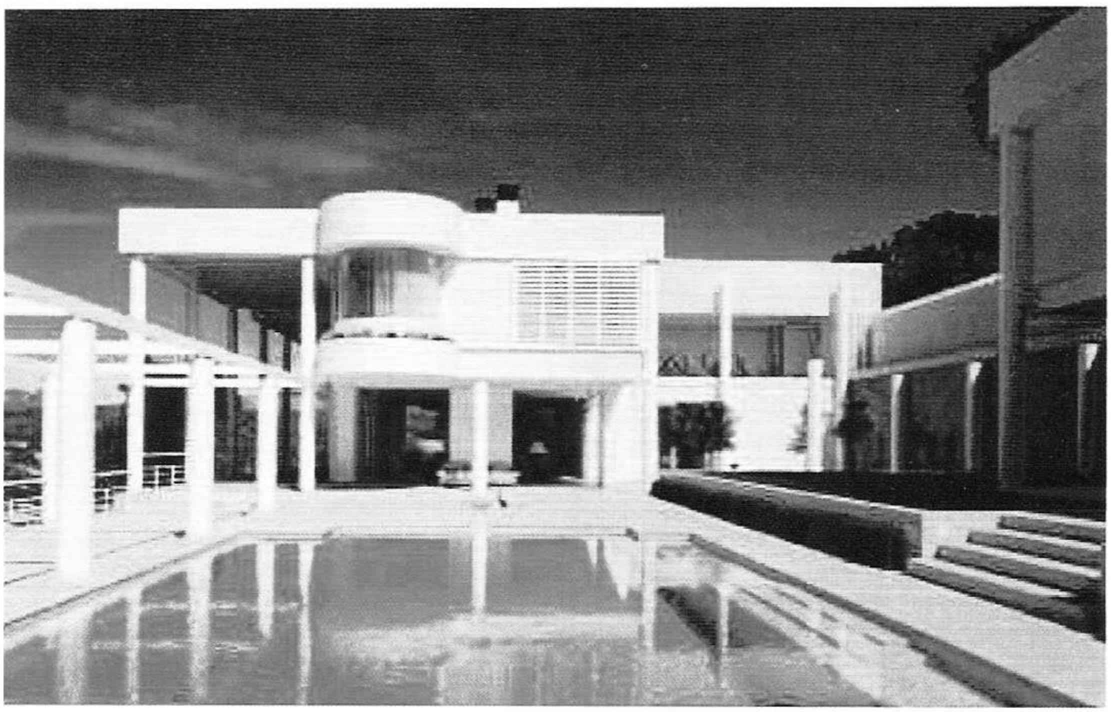
Designing for Occupant Comfort

Providing true occupant comfort at reasonable cost goes far beyond maximizing R-values and controlling thermal losses. It requires careful systems planning, a thorough understanding of building envelope thermal characteristics, and methods of controlling air and moisture flow. Spray polyurethane foams can provide economical, high-performance insulation, air barriers and moisture barriers in new construction and in renovation and restoration projects.



Only by continually balancing interior temperature, air flow volume, velocity and moisture content can the designer ensure occupant comfort under all circumstances.

Naturally, while a pleasant ambience is the result, it is a pragmatic systems approach that provides the means, beginning with a careful analysis of thermal gradients, and potential air, moisture, and vapor flow paths throughout the structure.

With a detailed analysis in hand, the architect can begin to specify the structural elements, construction materials and building techniques that, together, will create total comfort.

It is the intent of this learning module to describe how the use of spray polyurethane foam technologies help to control air, moisture and vapor flow, as well as interior temperature.

In a well-designed interior space, questions of comfort never occur to those who inhabit it. They simply *are* comfortable. For the designer, the goal is to exert such perfect control over the dynamic interior environment that those within remain totally unaware of the array of structural elements and technologies responsible for their comfort.

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AIA/ARCHITECTURAL RECORD CONTINUING EDUCATION

Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD/AIA*Continuing Education article. To receive credit,* *turn to page XXX and follow the instructions.*

LEARNING OBJECTIVES

When you have finished this course, you should:

- *understand how thermal gradients, and the flow of air, moisture, and vapor within the structural envelope affect occupant comfort*
- *identify common air, moisture and vapor flow problems that exacerbate comfort*
- *recognize the benefits of spray polyurethane foam (SPF) in ensuring comfort*
- *distinguish between one-component and two-component SPF applications*

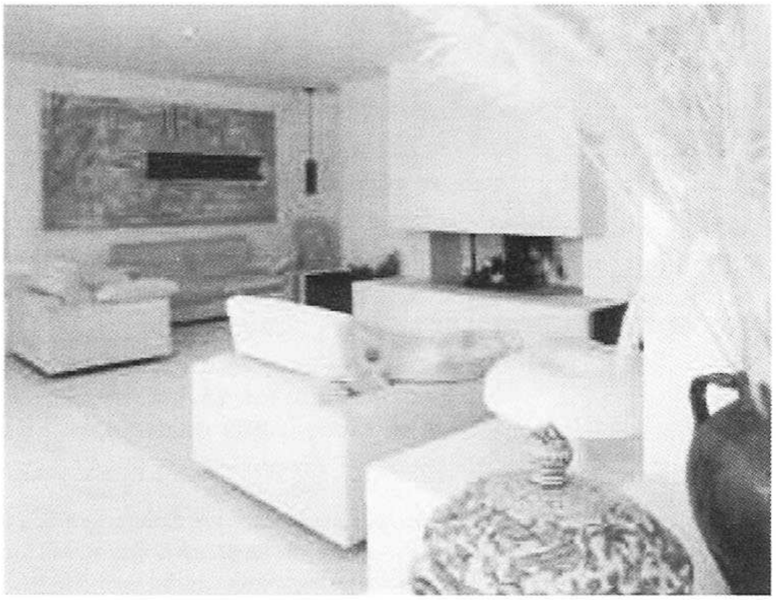
Why spray polyurethane foam?

Spray polyurethane foam (SPF) offers the architect tremendous versatility. It can bond disparate materials, adhere to a plethora of substrates to provide thermal insulation and sound deadening, fill cracks and voids to control air and moisture flow, even as it conforms to virtually any architectural shape or surface configuration that might be used in residential or commercial applications.

SPF products are used for insulating homes, commercial buildings, roofs, storage tanks, cold storage facilities, ducts, pipes and more. Depending on the reactivity of the polymeric mixture and the delivery mechanism, SPF may be supplied as:

- Poured foam — where a liquid stream reaches the substrate
- Spray foam — where a large quantity of small liquid droplets reach the substrate
- Froth foam — where the liquid droplets reaching the substrate contain already-nucleated miniature gas bubbles.

SPF's versatile physical properties make it useful in perhaps unexpected applications. For instance, in restoration or rehabilitation projects, instead of demolishing the outer leaf of a brick wall to install new wall-ties, rigid SPF can be injected to bond the brick veneer to the inner wall. SPF products can also be used to consolidate friable strata to prevent soil erosion in challenging landscaping projects. Specially designed, poured SPF has also been used for repair (leveling) of commercial/industrial building floors where a slab with direct ground contact has settled unevenly.



In construction of the building envelope, SPF products are used mainly to control heat transfer and to provide air and moisture barriers. SPF can provide a complete seamless building envelope, creating a more comfortable indoor environment for the life of the structure. It seals cracks and seams, giving added protection.

SPF can form a seamless bond with building components to create a structurally sound, uniform air-infiltration-barrier system, which retains its superior thermal properties even in the most extreme climates.

All of these roles help SPF to contribute to a comfortable interior environment and extraordinary occupant comfort.

Comfort's thermal component

Economically maintaining desirable indoor temperatures requires a well-insulated building envelope. The higher the R-value of any envelope component (e.g., foundation, wall or roof), the greater the envelope's resistance to heat transfer.

Since the capacity of the heating, ventilating and air-conditioning (HVAC) system must equal the net sum of all heat losses and gains under worst-case weather and building-use conditions, the higher the envelope R-value, the smaller the HVAC system for a given design and envelope configuration.

As with any building mechanical system, the initial capital costs of insulation and other thermal efficiency measures must be balanced against the potential savings in ongoing HVACoperating costs. The final design R-value should be determined by optimizing all cost factors.

Contributions to energy efficiency and perceived occupant comfort are also made by the exterior design and materials selection, building orientation, extent of windows, use of passive solar strategies, and the selection of interior space geometries, materials, surface treatments and even colors.

Here, we will confine the discussion to the control of heat transfer, and to the use of various techniques to control air, moisture and vapor flow through the envelope.

Heat transfer refresher

Heat flows from points of higher temperature to points of lower temperature by three distinct mechanisms:

- *conduction*—heat flow through a solid
- *convection*—heat flow from a solid surface to a fluid (liquid or gas)
- *radiation*—heat flow directly from one body or surface to another via electromagnetic waves (without changing the temperature of the intervening space).

All three of these heat transfer modes occur simultaneously in any real system (though one or two often dominate), and all three can play a role in occupant comfort.

The rate of heat transfer between any two points is determined by the physical characteristics and geometries of the materials and spaces separating them, plus the temperature differential between the two points.

For instance, examine the flow of heat through the exterior wall of a residential project on a cold winter day. Assume the heating system is operating properly and that the interior room air is 70°F, while the outside air is 35°F.

Heat will flow from the room air to the wall surface primarily via convection, then through the interior wall by conduction. At the studs, heat will flow from the wall to the studs, then through the exterior sheathing and exterior cladding, all by conduction. Finally, the heat will flow by convection from the exterior cladding surface to the outside air.

If the wall area between the studs—which represents about 90% of the total wall surface—is filled with insulation, heat will follow the same path and transfer methods as outlined above, except through the insulation instead of the studs.

If, on the other hand, the insulation does not fill the cavity between the interior wall and the exterior sheathing, then heat will not flow through the entire envelope by conduction. Rather, an added convection circuit will carry heat from the interior wall into the air in the gap between the wall and insulation, and then from the air in the gap to the insulation.

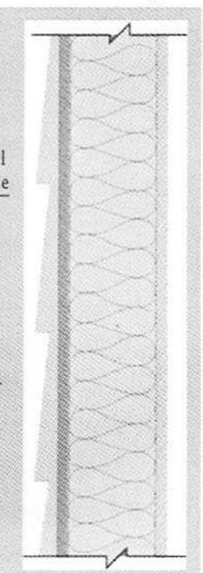
R-value

Every material exhibits its own characteristic resistance to the flow of thermal energy through it. Thermal resistance, R, for a given structural component is the sum of all resistances encountered along the path of heat flow.

Insulation materials are chosen for their high resistance to thermal flow, given in English units as ft^2-hr-F°/BTU-in, often expressed as a value per inch of thickness.

The temperature profile of a wall or roof cross-section can be calculated by apportioning the total temperature difference across the section in the same proportion as the individual structural member's R-value bears to the total R-value.

Component	Typical R-value
Air film outside	0.15
Siding (metal)	0.70
Sheathing (1/2")	0.64
3" insulation — batt	9.60
Gypsum board (3/8")	0.32
Air film inside	0.61
Composite (Total)	12.02



Moisture flow

Moisture migration in residential buildings is a particularly important, and at times complex, topic. Apart from water problems related to the plumbing system, moisture problems in residential structures are typically related to liquid water or water vapor finding its way in or out through the building envelope. There are four mechanisms of moisture migration:

Gravity — Downward flow of liquid water due to gravity (e.g., roof leaks or condensation on windows collecting on the sills).

Capillary Action — The movement of liquid water through very narrow spaces (e.g., up through porous masonry or tightly lapped wood siding).

Air Transport — Water vapor carried by air flow (e.g., warm, humid inside air exfiltrating through unintentional gaps in the envelope).

Vapor Diffusion — Transport of water vapor through permeable building envelope materials, by diffusion (from the warm, humid side to the cooler, dryer side).

While any of the four mechanisms can cause major problems in a particular structure, the majority of residential moisture problems in a residence with sound structure are related to interior surface condensation on windows, uninsulated walls, or cold surfaces within the building envelope.

Vapor flow

Again, it's usually the flow of water in its vapor state, rather than in its liquid state, that leads to most moisture damage in residential construction. However, it is not until this water vapor condenses that real problems develop. Such liquid moisture build-up can cause rotting of wooden materials, other structural damage, and soaking of insulation materials, reducing their effectiveness.

By far the major moisture migration mechanism is air leakage outward through the building envelope (exfiltration). The impact of vapor diffusion on moisture migration is relatively small by comparison.

An air/vapor retarder, like plastic film, oil-based or vapor-retarder paints and certain wall finishes, installed on the warm side of the insulation can prevent moisture migration through the wall.

Air flow

Just as heat flows through a material because of a temperature difference, air will flow into or out of a structure due to a difference in air pressure. Air flow, whether infiltration or exfiltration, is influenced by the following factors:

- The number, size and location of holes, gaps and cracks in the envelope
- Pressure differences resulting from:
  - ventilation and exhaust fans
  - chimneys for fuel-fired appliances
  - wind direction and velocity
  - the temperature differential between indoor and outdoor air, which can produce a pressure difference called stack effect.

Air barrier systems

The air barrier system within the building envelope is a critically important element for economically controlling moisture and thermal transfer, and for preserving structural integrity. Inadequate air barrier systems allow leakage of air through holes, cracks and gaps in the thermal envelope. Leaking air can carry humidity to the dew point locations in the building envelope, where resulting condensation can promote black rot and mildew, as well as the deposition of smoke, dust and dirt particles and other contaminants. These unfriendly elements are deposited in building materials through which the air passes on its way into, out of, or through the structure.

For leakage to occur, a difference in air pressure must exist between one side of the air barrier and the other. Such imbalances are common. They can be caused by wind pressure on the exterior; by stack effect, as warm air travels quickly upwards through the building; by exhaust systems purging stale air; and by the mechanical system operator trying (against the odds) to condition the indoor environment for maximum comfort.

Air barrier systems that inadequately control moisture transfer across the envelope adversely affect buildings and occupants in several ways. The most frequent and noticeable include:

- uncomfortable indoor environments
- unnecessarily high heating and air conditioning costs
- accelerated decay of building materials, particularly in walls, cladding systems, windows and roofing
- deteriorating aesthetic appearance of the building's exterior.

All of these problems can in some part be attributed to faulty air barrier system design and/or installation. Performance testing of the air barrier system may be carried out using a variety of means, including blower door, large and small smoke generating devices, infrared thermography, window testers and large scale fan depressurization devices.

In most instances, geographical location and indoor environmental requirements are not the major causes of air leakage. The worst leakage areas are mechanical penthouses, soffits, parapets, punched windows, overhand parapets, links connecting below-grade areas to other buildings; joints between one system and another such as at wall-to-roof joints or doors.

What makes a good air barrier system?

It should be continuously impermeable to air, structurally supported so that it remains in place, durable, and accessible for inspection, maintenance and repair.

Theoretically, the air barrier can be located anywhere in the building envelope, providing it meets all of the above criteria. Traditionally, this means placing it on the warm side of, and in firm contact with, the insulation. It may also be located on the cold side of the insulation, but care should be taken to avoid the possibility of moisture problems inside the assembly if the air barrier system is also acting as a vapor barrier.

Compartmentalization and decoupling

In renovation and restoration applications, where it is impossible to create continuity of the air barrier because not all of the structural components are accessible, the interior corners of the building should be sealed in order to "compartmentalize" each floor area. The effect would be to reduce the pressures caused by the flow of air around the building inside the wall system.

It is also advisable to "decouple" the building vertically in order to reduce stack effects. This can be achieved by a variety of measures, for instance, in hi-rise buildings, creating elevator lobbies on each floor and controlling air leakage through fire doors and all vertical penetrations. Building Code requires floor perimeters to be fire-stopped; they should be sealed, too, to create an air barrier that will also prevent smoke transfer.

Potential Air Barrier Locations

A typical residential structure contains a large number of paths by which air can leak into, out of, or through the building shell. These can be sealed with single-component or two-component SPF, as noted:

Location	*One-component*	*Two-component*
In Basements and Crawl Spaces		
• Headers	✔	✔
• Sill plate	✔	✔
• Duct penetrations and shafts	✔	✔
• Conduit, wire penetrations	✔	
• Hose bib	✔	
• Windows and surrounds	✔	
• Doors—cold room and exterior	✔	
• Wall cracks	✔	
• Floor–wall junctions	✔	
• Crawl space insulation and seal		✔
In Attics		
• Attic access hatch	✔	
• Ducting and plumbing stacks	✔	✔
• Headers	✔	✔
• Recessed ceilings		✔
• Behind light fixtures		✔
• Wiring and piping penetrations	✔	
• Recessed lights boxed with gypsum	✔	
In Living Areas		
• Baseboards—interior & exterior walls	✔	
• Electrical receptacles and switches	✔	
• Windows and trim	✔	
• Doors and framing—exterior, patio, pocket	✔	
• Dampers and outdoor vents	✔	
• Recessed light fixtures		
• Fireplace damper seal/loose brickwork	✔	
• Recessed cabinets		
• Plumbing penetrations	✔	
• Exhaust fan and heating vent perimeters	✔	
• Electrical wiring penetrations	✔	
• Cold air return ducting		✔
• Range hoods	✔	

SPF as an air barrier

Field experience shows that spray polyurethane foam can significantly improve the energy efficiency of buildings when it is used as an air leakage control material or component of an air barrier system. Moreover, recent evidence shows that a better-performing envelope contributes to the health, safety and comfort of the building occupants. Envelope performance, in large measure, depends on a well-designed air barrier, which should:

- be applied with continuity throughout the building envelope
- adhere to supporting structures (be self-adhesive)
- resist peak wind loads, sustained stack effect, and pressurization from ventilation equipment
- provide virtual air impermeability
- offer durability and long service life

Spray polyurethane foams meet all of these criteria. Add to that R-values as high as 6.0 per inch, and their value as a building envelope component becomes clear.

SPF selection

Spray polyurethane foams are available in several formulations, each offering advantages that make that type particularly suitable for certain applications.

One-component SPF

Single-component polyurethane foam is an insulating sealant consisting of a single mix of chemicals in one pressurized can or tank, formulated to cure when exposed to moisture in the air. Single-component SPF, which takes approximately 45 minutes to an hour to cure at 50% relative humidity, finds its primary use as an economical and practical sealant for cracks, small holes, gaps and joints.

Because it needs moisture to cure, care must be taken to avoid problem areas such as confined, nonporous cavities, which may inhibit cure. Also, if the ambient air is too dry, curing can be slowed or nullified, unless the application area can be spritzed with water to enhance cure rate.

Typically dispensed through a straw, a copper wand or a gun-type tool, one-component SPF is applied in a bead or, if filling a small hole, simply dispensed until the hole is full.

While primarily used as an air sealant, one-component SPF can also yield R-values (aged) in the 3.6 to 3.9 per inch range.

Two-component SPF

Fast chemical curing results in a higher expansion ratio for the two-component polyurethane foams, which makes them suitable for spray-on applications and for filling larger holes and cavities. They have an R-value (aged) of approximately 6.0 per inch.

Dispensing systems provide a fast and uniform flow of polyurethane foam that can be applied to flat or irregular surfaces and into cavities. (Polyurethane foams from portable kits generally cure in 30 to 45 seconds and expand approximately 30 times.)

Because of SPF's superior adhesion properties, it can seal and insulate structural materials, shapes and geometries used in unconventional architectural designs, where more common batts or rigid foam panels would not install or function properly.

Two-component portable kits can also be used to effectively apply SPF in attic spaces where restricted movement and awkward access make some locations difficult to seal or insulate.

Masonry block party walls, which form chimneys because of their porosity and open cores, can only be sealed effectively with two-component SPF. Two-component SPF also facilitates sealing between stud spaces at the perimeters of drop-ceilings, around plumbing stacks,andaround heating and air-conditioning duct penetrations.

Polyurethane foam is combustible, and model building codes require that a thermal barrier be installed on the habitable side of any SPF used on the interior of the structure. Additional study information about thermal barriers is included in the online portion of this educational module (see box below).

SUMMARY

- Spray polyurethane foam sealants provide continuity to the air barrier system.
- One-component SPF is moisture cured, while two-component SPF is chemically cured.
- One-component SPF is dispensed as a bead for gap and crack filling, while two-component SPF is used to fill larger holes and voids.
- One-component SPF insulation has become the most economical and practical way to effectively stop air infiltration and exfiltration.
- The air barrier system within the building envelope is the most important single element in controlling moisture, energy losses and gains, and structural integrity.
- Proper use of SPF can make a crucial difference in occupant comfort, in both new construction and renovations.

Click for Additional Required Reading

As part of this CES Learning Activity, you are required to read additional material online. To access the material on thermal barriers, visit *www.architecturalrecord.com/CONTEDUC/ConteducC.asp*, or *www.plastics.org/*____________. To obtain a faxed copy of the supplemental material, please call the American Plastics Council at 1-800-XXX-XXXX. The test below includes questions based on the online material.

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AIA/ARCHITECTURAL RECORD CONTINUING EDUCATION

INSTRUCTIONS

- Read the article, "Designing for Occupant Comfort."
- Read the additional web-based materials, which can be found at *http://www.plastics.org/thermalpropertiespage.htm*
- Read and answer the test questions below.
- Fill out the identification data and transfer your answers to the AIA/CES education reporting form on page XXX and submit via mail, or download the form at *www.architecturalrecord.com*

You will receive one (1) AIA learning unit.

TEST QUESTIONS

1. Occupant comfort is dependent on:
   a. interior air temperature
   b. air flow volume and velocity
   c. moisture and vapor flow
   d. all of the above

2. Spray foam applications are characterized by:
   a. already-nucleated miniature gas bubbles in the liquid droplets reaching the substrate
   b. liquid stream reaching the substrate
   c. no liquid in any form reaching the substrate
   d. a large quantity of small liquid droplets reaching the substrate

3. Faulty air barrier systems' adverse effects can include:
   a. accelerated decay of building materials
   b. uncomfortable indoor environments
   c. both a. and b.
   d. neither a. nor b.

4. Two-component SPF is most commonly used to:
   a. fill tiny cracks and seal joints
   b. fill cavities and large holes
   c. attach drywall to studs
   d. none of the above

5. One-component SPF has an R-value (aged) equal to:
   a. 4.9 to 5.2 per inch
   b. 3.6 to 3.9 per inch
   c. 5.7 to 6.0 per inch
   d. 3.0 to 3.4 per inch

6. Thermal barriers used in conjunction with SPF must:
   a. provide a minimum thermal barrier index of 15
   b. offer protection equivalent to 3/4" gypsum board
   c. comply with time-temperature curves in ASTM B-239
   d. limit SPF to max. 342°F after 10 min. of fire exposure

7. Two-component SPF from kits expands approximately:
   a. 3 to 5 times
   b. 10 times
   c. 30 times
   d. 22 to 25 times

8. A person standing in a warm(70°F) roomnear acold window:
   a. could become chilly due to radiation heat loss
   b. would lose heat to the window only if touching it
   c. would absorb heat from the room air via convection
   d. none of the above

9. One-component SPF would work well as an air barrier:
   a. to fill cracks between baseboards and subfloor
   b. to seal plumbing penetrations in exterior walls
   c. to seal gaps between windows and framing
   d. all of the above

10. Residential moisture problems occur most often when:
    a. water vapor in the air condenses on envelope surfaces
    b. effective air barriers and vapor retarders are in place
    c. rain blows in open windows
    d. vertical decoupling is used to reduce stack effect