# CLOSED CELL FOAM INSULATIONS:

## RESOLVING THE ISSUE OF THERMAL PERFORMANCE

By Peter Kalinger and Michel Drouin

As Yogi Berra once said, "It's *déjà vu* all over again." Reminiscent of the early 1970s, we are once again witnessing sharp increases in the cost of fuels and being warned of impending shortages or even power brownouts. Energy conservation is again a topic of discussion. As the demand for energy increases, prices rise and resources become scarcer.

One of the most effective ways of conserving energy is to make the buildings we occupy more energy efficient. This involves the use of thermal insulations in the building envelope to retard the passage of heat. Heat is transferred across an air space by a combination of conduction, convection, and radiation. Mass insulation consists of solids in the form of fibers, granules, or cells that contain air- or gas-filled pockets and voids arranged to retard the passage of heat. The latter is commonly referred to as cellular foam insulation and can be further categorized into thermoplastic foams (expanded and extruded polystyrene) or thermoset foams (polyurethane, phenolic, polyisocyanurate). These insulations are produced either as rigid boards or, in the case of sprayed polyurethane foams (SPF), are sprayed-in-place on-site. The cell structure of some of these insulations can be either open, allowing the passage of air, or closed.

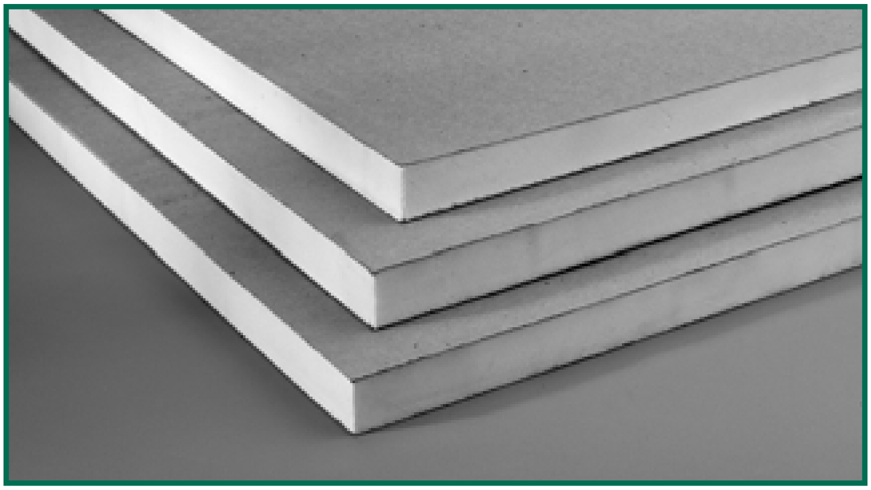
*Extruded polystyrene insulation is used in protected membrane roof assemblies.*

### Captive Blowing Agents

Gases other than air in the cells can increase the thermal resistance of closed cell foam insulations. Referred to as "captive blowing agents," these gases have a lower conductivity than that of air, and consequently the conductivity of the insulation will be lower than air-filled materials. Up until the mid-1980s, the most widely used blowing agents for thermoset and extruded polystyrene foams were CFCs (chlorofluorocarbons) because they had physical properties that made them very useful as blowing agents for insulation materials. They possessed low toxicity, were odorless, non-flammable, and very stable chemically. The publication of the British Antarctic Survey in 1985, however, showed that the chlorine in CFCs was responsible for degrading the ozone layer approximately 25 km above the earth's surface. In 1987, the Montreal Protocol was established to define specific strategies for reducing their consumption.

As manufacturers searched for alternative blowing agent compounds, there appeared to be hope in the form of hydrochlorofluorocarbons (HCFCs) because they behaved similarly to CFCs, and their ozone depleting potential (ODP) was only five to ten percent that of CFCs. Unfortunately, HCFCs were classified as "transitional substances" under the terms of the London Amendment to the Montreal Protocol, while under the Copenhagen Amendment (1992) they became controlled substances with restrictions on their use and production. In accordance with Article 2F.6 of the Montreal Protocol, HCFCs are to be completely phased out by 2030.

These regulations make it all the more difficult for manufacturers to find alternative blowing agents for insulating foams that meet the detailed list of requirements for their thermal conductivity, toxicity, boiling point, and reaction with other components—not to mention minimal negative impact on the environment. The frontrunners in the race for substitutes seem to be hydrocarbons (pentane-based formulations) and hydroflourocarbons (HFCs). Honeywell recently announced that it will commence large-scale production of HFC-245*fa* as a blowing agent for the foam insulation industry, and many insulation manufacturers have already converted to pentane formulations. Other already



*Closed-cell foam insulation.*

available HFCs and hydrocarbons are also being considered.

## Blowing Agents and Thermal Drift

Unfortunately, the controversy regarding captive blowing agents has not been limited to environmental concerns. A high proportion of the cells in foam insulations that are properly manufactured will contain the captive blowing agent and possess low thermal conductivities. However, their conductivities will increase slowly with time as air permeates into the cells and dilutes or replaces the blowing agents. Known as "thermal drift," this phenomenon applies to all insulations that incorporate captive blowing agents other than air.[1] It takes place over an extended period of time (10 to 50 years) and it generally happens at a much faster rate for expanded-extruded polystyrene (XPS) than polyurethane and polyisocyanurate (PUR/PIR) foam insulations (*see Figure 1*).

The speed at which thermal drift occurs depends on a number of factors such as exposure conditions, material density, manufacturing process, thickness of the insulation, cell geometry and structure, chemical composition, and surface permeability. Clearly, each product will have its own unique thermal aging curve, but until recently, it has been impossible to predict the long-term thermal resistance values with any degree of accuracy. Adding to the confusion are the many different sample conditioning techniques used to calculate thermal values within the product standards. Manufacturer associations in the U.S. representing the foam insulation industry undertook the task of creating a standard conditioning and testing procedure. Intended to create a uniform conditioning procedure to be used by all industrial and commercial plastic foam roof insulation, the Roof Insulation Committee of Thermal Insulation Manufacturers Association (RIC/TIMA) issued *Technical Bulletin 281-1*. Contrary to popular belief, this procedure was never intended to be representative of an "aged" thermal resistance value; neither did it imply that the thermal value of the products were stabilized at the end of the conditioning period. It simply provided a level playing field for comparison of these products.

This procedure was introduced in several ASTM (American Society for Testing and Materials) material standards (C-1289 for PUR/PIR, C-578 for XPS, and C-1029 for SPF) and required conditioning for 180 ± 5 days at 23 ± 2°C at 50 percent RH ±5%, or thermal conditioning for 90 days at 60 ±1°C prior to testing. In Canada, the now obsolete CGSB standards were also using elevated temperatures for conditioning (28 days at 100°C for PUR/PIR, phenolic and SPF, and 70°C for XPS). Unfortunately, accelerating the aging process by exposing the material to elevated temperatures does not yield accurate results because it changes the permeability and solubility co-efficients of the gases to such a degree that the results cannot be precisely correlated with *in-situ* performance.

While endorsed by the design and user community, attempts to standardize sampling and conditioning methods did not resolve the problems of thermal drift. In 1987, the National Roofing Contractors Association (NRCA) and the Midwest Roofing Contractors Association (MRCA) issued a joint Technical Bulletin stating that, in the absence of an accepted method of determining the stabilized R-value of PUR/PIR products (which are much slower to stabilize than XPS and therefore much more difficult to predict), users should select an RSI-value (metric equivalent of a resistivity or R-value) of 0.986 per 25 mm (5.6 per inch) of thickness as a reasonable value for calculating thermal performance over the anticipated life of the roof.

Similarly, in Canada, the Canadian Construction Materials Center (CCMC) states, "The thermal resistance of PUR/PIR product decreases with age, and a maximum RSI value of 1.05 per 25 mm is the recognized long-term thermal resistance," adding that values beyond the 1.05 per 25 mm "may be obtained through the testing of 5-year aged specimens." In the case of XPS insulation, an RSI value of 0.88 (R=5 per inch) was considered by the industry to be its "stabilized" value. In the case of PUR/PIR products, given the recurring changes to raw materials, blowing agents, and material formulations, the option of waiting five years was impractical.

There was widespread confusion among users and designers as to what thermal resistance values should be used for design of building systems and the selection of products. The entire industry recognized that the thermal drift and long-term thermal resistance issue had to be resolved, and in 1993, representatives from the design community, end users, researchers, and the manufacturing industry formed the Thermal Insulation Systems: Standards and Quality (TISSQ) Consortium Steering Committee to improve the quality and efficiency of Canadian standards for

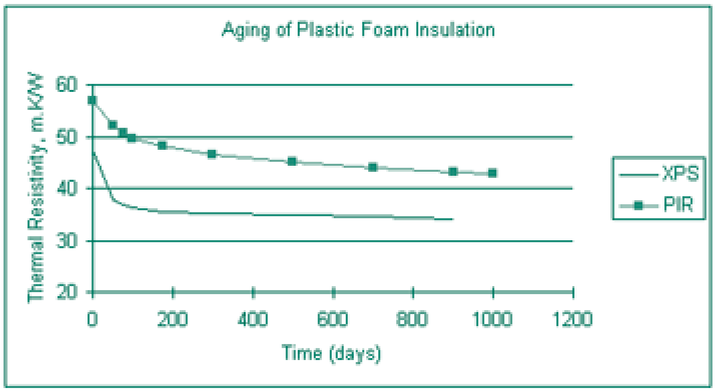


*Figure 1 (Thermal Resistivity as a Function of Time)*[2]

thermal insulations. One of its first tasks was to address the issue of the long-term thermal resistance of cellular plastic foam insulations incorporating captive blowing agents. Based on the best technical information available, it concluded that the thermal performance aging model developed by the National Research Council of Canada (NRC) could be used as the basis to validate a new test procedure to accurately predict their long-term thermal performance[3].

In 1998, a task group under the auspices of the ULC Standards Development Committee on Thermal Insulation and comprising representatives from NRC and all sectors of the plastic foam industry, developed a new standard based on the work done to date.[4] Referred to as CAN/ULC-S770, "Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Thermal Insulating Foams" was published as a National Standard of Canada in December 2000. It will be referenced in all relevant plastic foam material standards, where it stipulates that LTTR (Long-Term Thermal Resistance) values shall be used as the design thermal resistance value for energy calculations.

## Long-Term Thermal Resistance

The thermal resistance of plastic foam products containing captive blowing agents other than air changes during their service life because of aging. Because aging may be a very slow process occurring over many years in some products, the aging process must be accelerated to evaluate the aged or design R-value (henceforth referred to as LTTR). We already know that heat aging via elevated temperatures does not produce reliable results, so what do we do? A more reliable technique is based on the principle that the rate of gas diffusion is inversely proportional to the square of the thickness of the product. Known as thin slicing and scaling, this technique involves cutting and measuring the thermal resistance of very thin slices of foam. For example, if the thickness is halved, the aging is four times as fast. Thus, a 10mm thick slice will be in the same state of aging after 73 days as a 50mm thick board will be after 1,825 days (five years).

The CPIA/NRCC project (Bomberg and Kumaran, 1994) verified that the thermal transmission properties of insulating foam products aged in the field for 2-1/2 years were not significantly different from those for the same products aged in the laboratory. From this and similar information it was concluded that LTTR could be determined by laboratory testing.

Left: *Figure 5: Polyisocyanurate insulation is used in protected membrane roof assemblies. (Photo courtesy CRRC).*

Consensus on design thermal resistance was established in two steps. First, the Canadian Plastics Industry Association (CPIA) and manufacturers agreed that LTTR would be defined as the time weighted average of thermal resistance over 15 years at a given thickness. Secondly, it was demonstrated that the average resistance over a given period of time was equal to the value measured at a reference time obtained by dividing the specified period by a number (approximately 3). Thus, the selected reference time becomes five years (15/3).

The LTTR of a thermal insulating foam product is defined as its thermal resistance measured under standard laboratory conditions (23 ± 2°C and 50 ± 10% RH) after 5-year storage in a room (24 ± 4°C and 45± 20% RH). The LTTR is a design property that can be used for the comparison of different foam products, and the CPIA/NRC project (Bomberg and Kumaran, 1994) later confirmed that the thermal transmission properties of insulating foam products aged in the field for 2.5 years were similar to those aged in the laboratory.

Above: *Figure 4: Workers lay membrane over foam insulation at Brett Favre's Steakhouse, Green Bay, WI. (Photo courtesy Johns Manville).*

## Testing Methodology

The procedure for the determination of LTTR of closed cell plastic foams is based on ASTM standard C-1303, "Standard Test Method for Estimating the Long-Term Change in the Thermal Resistance of Unfaced Rigid Closed Cell Plastic Foams by Slicing and Scaling Under Controlled Laboratory Conditions." The development of this standard was a joint effort between NRC and Oak Ridge National Laboratories in Oak Ridge, Tennessee. The essential part of this standardized technique is "slicing and scaling," based on the principle that the rate of gas diffusion is inversely proportional to the thickness of the material.

The methodology described in CAN/ULC S-770 is very prescriptive compared to C 1303 is and divided into three basic steps:

- The mean initial thermal resistance of the product is determined.
- Thin slices of foam are prepared and aging factors are determined as the ratio between the thermal resistivity at the specified time of aging to its initial value (testing periods vary according to the product's thickness).
- LTTR is calculated as the product of the initial thermal resistance and the aging factor.

Although the scope of the Standard states that this procedure is applicable to products with either permeable or semi-permeable facers, it is widely accepted that impermeably faced products may have significantly lower rates of aging. This issue is currently being studied in a joint industry/NRCC research project, which aims to develop that this can be incorporated into CAN/ULC-S770 for measuring the effect of gas-barrier facers on the rate of aging.

## Conclusion

Closed cell plastic foam insulations are used extensively in construction applications because of their impact on energy conservation and other desirable physical properties, and it is expected that their use will continue to grow. It may be adequate in non-critical designs to compare and select insulation on the basis of its "as manufactured" thermal resistance, but designs that are intended to minimize the amount of insulation required or optimize the efficiency of heating and cooling equipment over the service life of the building or building systems should take into account all the factors that affect thermal resistance, including thermal drift.

The development and promulgation of the CAN/ULC S770 has resolved many of the uncertainties previously associated with thermal performance, including recurring changes to formulations and manufacturing processes. The test method for all cellular plastic foam insulations incorporating captive blowing agents (other than air) provides a means for comparing the thermal performance of these products—essential to their selection and purchase. Even as products change or new materials are developed, the method as described in CAN/ULC S770 can be used to predict LTTR. Although some work is still required to resolve the issue of impermeable facers, the test method has been proven a valid means of reliably determining the effects of aging on the LTTR of closed cell foam insulations. The incorporation of this test procedure in the relevant material standards attests to the industry's commitment to address the issue of "thermal drift" for the benefit of consumers and end-users. Copies of CAN/ULC-S770 can be obtained from Underwriters' Laboratories of Canada, 7 Crouse Road, Toronto, Ontario. M1R 3A9. ■

## Notes

1. Expanded Polystyrene does not suffer from the phenomenon of thermal drift. Although volatile hydrocarbons (pentane) are used as blowing agents in the production process, they diffuse out of the foam soon after manufacture and are replaced with air. Expanded polystyrene is known for its stable thermal resistance.
2. This diagram has been derived from NRC-CNRC Internal Report No. 694, "Procedures to Predict Long-term Thermal Performance of Boardstock Foam Insulations," June, 1995.
3. Known as "The Distributed Parameter Continuum (DIPAC)," it was developed at the National Research Council of Canada (NRC) by Drs. Mark Bomberg and Mavinkal Kumaran.
4. The task group consisted of Dr. M.K. Kumaran, IRC/NRC, Chairman; Martin Hofton, Owens Corning Inc.; Dr. Michel Drouin, Johns Manville Canada Inc.; Gary Chu, Dow North America Inc.; André St-Michel, BASF; Ron Waters, CCMC/NRC; and Dr. Mark Bomberg, ex-officio, as Chairman of the ULC Standards Development Committee.

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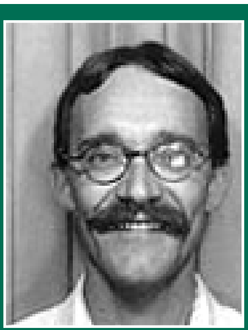

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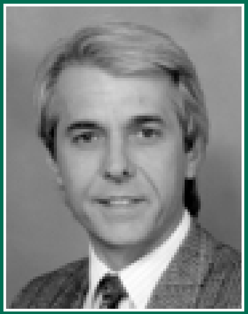

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