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COLUMN

Glows and shadows of thermal insulation

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1. Introduction

The building envelope separates two distinct environments: inside and out. Conditions from both environments continuously impose upon the materials that make up the envelope and affect their performance. Thus it is essential to understand how materials function to be able to make a suitable choice.

There are two challenges involved in selecting thermal insulation materials. One is to characterize the effect of some factors affecting performance of the materials-settlement of loose fills, aging of gas-filled foams, effect of convective air flow on low-density glass-fiber insulations, effect of moisture on thermal performance of all insulations. The second concern is to develop evaluation methods that would produce the results characterizing field performance of these insulations.

None of these two challenges have been met in North America. The main reason—each of the many manufacturers competes with the other on the basis of archaic, comparative rating standards and none has any linkage or direct responsibility for the thermal performance of the completed buildings. The responsibility for thermal performance of a building belongs to the designer, who, unless he/she hires a consultant do it, does not have any technical advice from the scientific community.

2. Arbitrary, comparative tests

As an example we quote a section from the Canadian spray polyurethane foam standard:

5.5.8.5 Dimensional changes of both types of specimens are to be measured after three specimens have been exposed to each of the following exposure conditions:

A 28 d at (−20 ± 3) °C, (50 ± 5) % R.H;
B 28 d at (80 ± 2) °C, (50 ± 5) % R.H; and
C 28 d at (70 ± 3) °C, (97 ± 3) % R.H

The percentage volumetric and linear change obtained shall be reported for each exposure and each specimen. The results are to be expressed as a “plus %” when there has been expansion and as a “minus %” when there has been shrinkage (Table 1).

So for somewhat wet foam and a high level of solar radiation falling on a building one allows 14% of expansion.

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Table 1

Dimensional Stability Without Substrate: % Volume Change at:	Unit	Min	Max	Subsection 5.5.8.5
−20 °C	%	−2	+5	
80 °C		−2	+8	
70 °C, (97 ± 3) % RH		−2	+14	

With other words for a 5 m × 3 m × 4 in. thick insulation (1.5 m^3) foam and uniform expansion of the thickness, and two dimensions, each is allowed to move 60 mm. If this was real case, nobody could use such a material in the construction.

All NA material specifications call for thermal resistance to be tested at 24 °C mean temperature (because it does not involve humidity control in the thermal test) using dry, fresh pieces of a product. But mean temperature of 24 does not represent cold or warm climates.

3. Foam insulations with captive blowing agent

During manufacturing process of several insulations such as polyurethane (PU), extruded polystyrene (XPS), polyisocyanurate (PIR) there is no air inside the cells, only vapors of the blowing agent. The outside air diffuses into the foam and the blowing agent concentration is reduced by the foam walls absorbing the vapors and small but steady diffusion out the cells. As the cell gas composition changes, so changes the thermal performance of the material. In effect of cell gas pressure changes the foam will expand or shrink, depending on the environmental conditions such as temperature and humidity.

Test methodology for long-term thermal performance (LTTP) was developed in the mid 1990. It used thin (5-10 mm) material layers exposed to different environmental conditions to reduce time of testing of all properties related to gas diffusion and solubility of the blowing agent in the foam. Then, based on testing thermal conductivity of thin layers as a function of time and either using scaling of aging time or the computer models for non-homogeneous foams within 3–6 months the 15–20 year field performance could easily be predicted. This methodology was verified against field exposure for different foams yet manufacturers in the NA do not use it. They adhere to the letter of the law and because nobody requires them to address more than laboratory rating of thermal insulation they generally do not continue testing long-term thermal performance but continue to use arbitrary rating tests.

In the United States, for mineral fiber insulations, the national acceptance criteria permit an average of the qualifying test to be 10% below the label value (claimed) making the product average to be 6%–8% lower than it would be if a Canadian or European standard was used.

Air movements can compromise the thermal performance of glass–fiber in wall applications as well. Wind washing, which occurs when wind enters and exits at different locations of the building facade, may also reduce thermal performance. To eliminate these pitfalls, which to a large extent may be caused by the workmanship on the construction site, some NA manufacturers are producing so-called “high-performance batts” (with somewhat higher density i.e., a bit closer to Scandinavian). Applying loose-fill material pneumatically with a water-based adhesive offers another solution. In these blown-in blanket systems the density of the glass–fiber is much higher, approaching 24 kg/m^3. High-performance batts of glass, slag, and rock fibers demonstrate good field performance, provided that they are protected from ingress of air and moisture.

4. Thermal insulations fabricated in situ

Despite the move to high-density insulation, glass–fiber batts and blankets and loose-fill insulations continue to measure about half the density reported for these products 20 years ago. This reduction in density (and increased probability of poor performance) has opened a market niche for other materials made on the construction site (such as sprayed polyurethane foam (SPF) or sprayed fiber insulations) that fill irregular spaces while providing higher thermal resistivity.

This new market, however, is a volatile one, where the main issue is credibility of the installer, rather than agreement between field and laboratory evaluations. Because the materials are manufactured in situ to fit the installation, no part of the structure is un-insulated. However, this arrangement underscores the need for installation standards and contractor certification, particularly since the thermal performance of these materials depends on the quality of the installation. Nevertheless, increased need for thermal upgrading may create a growth industry where insulation, weatherization and drywall application could merge into one trade.

One positive exception in these arbitrary laboratory tests is the cellulose fiber insulation (CFI). Builders are requested to install the CFI product with a 21% correction factor for settlement. Thus, accommodating the differences between a product's initial and long-term performance was incorporated into the cellulose insulation standards.

5. Relation of comparative rating tests to the field performance

Generally there is no relation between laboratory comparative tests and the field performance of different thermal insulations when affected to a varying degree by the environmental conditions.

Mineral fiber and cellulosic materials are affected by the moisture they absorb under service conditions. Air entering into gas-filled cellular plastics dilutes the blowing agent and causes reduction of their thermal resistance with time.

Low-density glass–fiber products are often affected by air flows in the wall cavity. These changes in field performance may vary depending on nature of the material and the manner of its installation.

In Europe, building officials have attempted to resolve the discrepancy between field and laboratory performance of building materials by using two measures of thermal properties: declared and design. The declared value, a statistical estimate, is the expected value of the thermal characteristic of a building material or product assessed through data measured at a reference temperature qand thickness and stated with a given confidence level. The design value is the value of the thermal characteristic of a building material or product in a condition representing typical installation in buildings according to climate and use conditions.

A Swedish example highlights the use of these two concepts. According to the Swedish Building Code (SBN), the design thermal conductivity of pre-formed fiber insulation boards, quality class A varies with aging, moisture content and normal workmanship conditions. Thus, in SBN 1977, Table 33.1 permits a range of design thermal conductivity values: 0.038 W/(m K) for boards attached to airtight sheets and used above ground; 0.040 W/(m K) for other uses of the material in above-ground construction; 0.042 W/(m K) for use of the material in the slab on the ground when surface drainage is ensured; and 0.060 W/(m K) for use of the material outside the basement wall when foundation drainage is ensured.

These European concepts are slowly finding their way into North American market, perhaps too slowly. If designers and specifiers intensified requests for information contained in these concepts, a dramatic improvement would take place in the North American thermal insulation market. In particular, the call for design values would bring assessment of field performance and statistical correlations between field and laboratory data.

Normally, information concerning predictions of long-term field performance is unavailable until after several years of experience and use of the product becomes a tradition. What's more, scientists do not actually predict field performance; they only correlate laboratory estimates with field data.

Finally one may observe the growing popularity of the in-situ applied polyurethane foams despite its high price. These products are known to perform functions of air barrier, thermal insulation and moisture control and in contrast to fibrous insulations the do not need to be protected from weather (except for UV radiation).

6. Closing remarks

Attempts to develop useful strategies for relating laboratory and field performance data remain inconsistent. Indeed, there is a significant lack of performance data for building envelope materials used in environmental control. This situation is caused, in part, to the fact that there has been little demand for such testing. Safety, a primary concern of the building codes, has attracted most of the attention of the individuals who could demand such data and has overshadowed the issues of environmental control.

Using thermal insulation between load bearing elements i.e., discontinuous insulation reduces its efficiency in proportion to how good is its thermal efficiency. It is, therefore, beneficial to use so called thermal efficiency index that is a ratio between the actual, multi-dimensional heat flow through the assembly to the sum of thermal resistances of all layers i.e., one dimensional heat flow through the virtual assembly without any thermal bridges. Below we extract some cases from a table of thermal performance of wood frame wall without and with external thermal insulation (Table 2).

The above table shows that the reduction of thermal transmission coefficient is higher when one use more effective insulation in the wall cavity and that a simple way to improve the thermal efficiency of the assembly is to use external continuous insulation. The level of $Rsi = 1.0$ was

Table 2 Efficiency factor in 2 × 4 wood frame walls without and with external insulation.

Resistivity of insulation material	*k*-factor for insulation material	Thermal resistance of insulation layer	*R*-value of wall, center of cavity	Equivalent *R*-value from 2D code	Reduction from nominal *R*-value, (%)	Thermal Efficiency Index—
BTUI in						
3.15	0.32	11.02	12.85	11.39	11.3	0.89
(21.8)	(0.046)	(1.94)	(2.26)	(2.00)		
4.0	0.25	14.00	15.83	13.38	15.5	0.85
(27.7)	(0.036)	(2.47)	(3.79)	(2.36)		
6.0	0.17	21.00	22.83	17.38	23.9	0.76
(41.6)	(0.024)	(3.70)	(4.02)	(3.06)		
As above	As above	*R*-value of external ins.	As above	As above	As above (%)	As above
3.15		5.6	18.45	17.08	7.4	0.93
(21.8)		(1.0)	(3.25)	(3.01)		
3.15		9.0	21.85	20.49	6.2	0.94
(21.8)		(1.6)	(3.85)	(3.61)		

selected because it corresponds to 1.5 in. of the typical EPS foam. It is evident that requesting continuous exterior insulation for wood frame walls is fully justified.

Concluding this column on thermal insulation we may remind the reader that since the durability of a material depends on both its nature and the environment in which it is installed, performance criteria cannot exist independently of the construction system. So, architects, designers and specifiers should begin to ask questions about documented actual or adequately simulated field performance instead of using arbitrary material rating standards.

Yet, as long as the design of the building envelope is not based on the cost-benefit analysis (e.g., life-cycle cost), the change in approach to environmental control in design will not be initiated by the codes; it must come through a change of attitude of designers and specifiers.

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He emigrated to Canada, worked for 20 years for National Research Council of Canada, leading the field of thermal insulation. After early retirement from NRCC he taught at Condordia U (Montreal, 3 years) and Syracuse U (New York State 8 years) until the current, final choice.

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