Building Science Corporation

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Thermal Metric Research Project

In 2007, BSC assembled a consortium of insulation manufacturers to study the thermal performance of building enclosures under realistic conditions.

Objective

The Thermal Metric (TM) consortium has undertaken a series of laboratory research projects to:

- Advance the understanding and quantification of building enclosure thermal performance
- Support the development of a new thermal performance system or metric that credits high-performance assemblies (of all types of construction and insulation materials)
- Support good design and construction practices

Motivation

R-value is an effective, well-established, and widely accepted metric for describing the thermal performance of building materials, but it is an incomplete metric for describing the thermal performance of building enclosure assemblies.

The thermal performance of any building enclosure assembly is highly dependent on the amount of insulation installed (i.e. installed R-value); however it can also be heavily influenced by a number of other factors, including but not limited to:

- Thermal bridging
- Change in insulation R-value with change in temperature
- Airflow in and through the assembly
- Change in insulation R-value over time
- Change in insulation R-value with change in material moisture content

Approach

A new hot-box apparatus and test method were developed to study the thermal performance of full-scale (8 x 12 ft, 2.4 x 3.2 m), representative wall assemblies exposed to realistic outdoor temperatures (-25 to 145°F, -32 to 63°C) and air pressures (up to ±25 Pa for flows up to 32 cfm, 900 lpm).

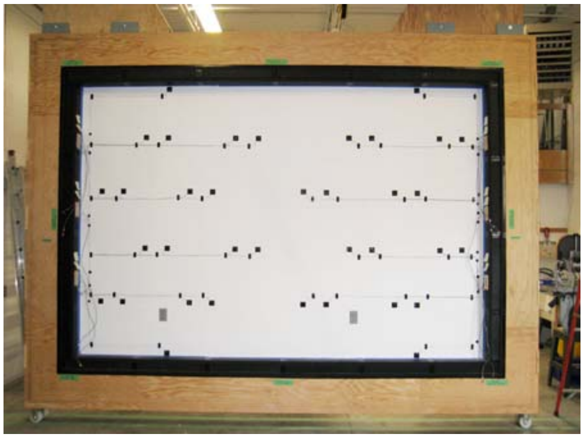
The apparatus and test method account for the effects of thermal bridging, temperature dependency of insulation R-value, and interactions between heat flow and airflow. Moisture dependency and time dependency are specifically excluded (i.e. hot-box RH is maintained at 10-20% and wall specimens are seasoned prior to testing).

Testing

In 2010, the TM consortium completed the first phase of research, which consisted of the development of the hot-box apparatus and a test method that permitted the quantification of combined heat and airflow in wall assemblies.

The TM consortium recently completed the second phase of research, which involved the testing of a series of wood-framed wall assemblies that employed different insulation materials. Five wall assemblies were constructed using 2x4 framing @ 16" OC (13.6% framing factor):

- Damp-sprayed cellulose fiber insulation (CFI)
- Inset-stapled kraft-faced fiberglass (FG) batt
- Face-stapled kraft-faced FG batt
- Open-cell sprayed polyurethane foam (ocSPF)
- Closed-cell sprayed polyurethane foam (ccSPF)




In all cases the insulation materials were installed between the studs to achieve a nominal insulation R-value of 13 (when measured in accordance with FTC Title 16 CFR Part 460).

Two additional assemblies were constructed to examine the impact of adding more insulation:

- 2x4 @ 16" OC with nominal R-13 friction-fit fiberglass batt + 1" XPS exterior insulating sheathing (nominal R5)
- 2x6 @ 16" OC with nominal R-21 friction-fit fiberglass batt

The manufacturer's recommended installation practices were strictly adhered to and, for many of the test wall assemblies, manufacturer's representatives and installers were present to supervise and complete the insulation install.

All of the assemblies tested had a minimum of thermal bridging (i.e. no extra framing beyond regularly spaced studs @ 16" OC (resulting in a 13.6% framing factor) and were more airtight than most real wall assemblies (e.g. 0.05 to 0.20 cfm50/ft^2).

Findings

A number of important and interesting observations have come out of the first two phases of the work:

- When walls are constructed with *the same installed R-value* in the stud space, and are *air sealed* both inside and outside (i.e. there is effectively zero air leakage through the assembly), they exhibit essentially the *same thermal performance regardless of the type of insulation material* used.
- *All* of the tested wall assemblies were subject to thermal bridging regardless of the type of insulation material used in the stud space. Thermal bridging through the framing resulted in a roughly 15% decrease in thermal performance. Commercially available 2D and 3D heat transfer models provided good predictions of the thermal bridging in the assemblies tested as did the parallel path method described in the *ASHRAE Handbook of Fundamentals* and other texts.
- *All* of the insulation materials exhibited temperature-dependent thermal performance (i.e. changes in insulation R-value with changes in mean temperature). The mechanisms that explain this phenomenon are well understood; however there is a lack of relevant material-property information (i.e. measurements of insulation R-value at different temperatures).

- In this study temperature dependency of insulation R-value was accounted for by material-specific thermal conductivity measurements (made at the hot-box test temperatures). The temperature-dependence effect resulted in improved thermal performance at lower mean temperatures (e.g. an outdoor temperature of 0°F, -18°C resulted in roughly a 10% improvement in thermal performance of the insulation) and reduced thermal performance at higher mean temperatures (e.g. an outdoor temperature of 144°F, 62°C resulted in roughly a 15% decrease in thermal performance of the insulation).
- *All* wall assemblies experience *a loss in thermal performance due to air movement* through the assembly. This is true for all of the assemblies tested regardless of the type of insulation material used (e.g. cellulose, fiber glass, ocSPF, ccSPF, XPS).
- The energy impact of airflow depends on the flow path, the *interaction* between the air and the solid materials in the assembly, and the installed R-value of the assembly.
- Conventional energy models (i.e. those that account for air leakage energy using Q=mcdT) may over predict the negative energy impact on walls that have a significant interaction effect (e.g. air moving through insulation).