Insulated Panel Systems
North America

Finding the Meaning in the R-Value and U-Factor of Insulated Metal Panel Building Envelopes

Understanding the values and test methods to compare like products based on performance in the field

Executive Summary

Insulated Metal Panels (IMPs) are a unique panelized building envelope product solution growing both in use and application for the last 50 years. Aside from replacing traditional building insulation with high-performing rigid foam plastic, they offer a ready-made, easily installed, aesthetically pleasing, and long-lasting solution for both roofs and walls.

However, because the metal skins used as the fascia and liner materials for these products are highly conductive and foam plastic properties are unique and esoteric, traditional views of thermal performance do not paint a complete picture of IMP performance. In particular, choosing an IMP solely on the basis of R-value will certainly lead to less than desired results.

This paper provides a complete discussion of IMP thermal performance, while making specific, detailed recommendations for specifiers to follow to ensure their evaluation of materials is complete and accurate, resulting in the desired outcome.

The Basics of Heat Transfer

Heat transfer rates for building envelopes are usually expressed in watts per unit of area, or W/m^2. In imperial units, heat transfer rates are measured in $Btu/(h \cdot ft^2)$. One Btu is the amount of heat needed to raise the temperature of a pound of water by 1 degree Fahrenheit.

A key point about heat transfer: The rate of heat flow is multi-dimensional from warm to cold and follows the path of least resistance. Thus, even a small amount of insulation can make a difference if it is located correctly. Likewise, large amounts of insulation can have little or no positive impact in a poorly designed assembly.

K-factor, R-value and U-factor

When specifying building envelope materials or systems, specifiers turn to U-value and R-value to establish a baseline for efficiency.

- **K-factor** represents the thermal conductivity of a material, measuring its ability to conduct the heat. The lower the K-value, the better the product is at insulating the envelope.
- **R-value** measures a product's thermal resistance to heat flow through a single material, like a single metal panel. Because R-value measures resistance to heat flow, the higher the R-value, the better the material is at insulating the building.
- **U-factor** measures a product's thermal transmittance of heat flow through a building envelope assembly, like an IMP system. Because U-value measures the transmittance of heat, the lower the U-value, the better the total system is at insulating the building.

Building Insulation and Insulated Assemblies

Building envelopes perform many functions including restricting heat exchange with the exterior environment. Most insulation materials cannot adequately perform all the required functions of an envelope and therefore are part of an insulated assembly such as a roof or wall. Therefore, it is not only important to consider R-value of the insulation alone but also how the other materials and cavities in the envelope contribute, both positively and negatively, to the overall U-factor of the total assembly. This is why building codes and referenced standards pay close attention to how R-value and U-factors are determined, not just their values.

Insulated Metal Panels

Insulated metal panels (IMPs) are factory assembled, panelized products consisting of a core of insulating materials bonded to two metal skins — an insulated assembly. The core is generally either foam plastic or inorganic fibers and the skins are most commonly aluminum or corrosion resistant coated steel. The panels are joined along the edges by interlocking tongue-and-grove joints that incorporate mechanical fasteners anchoring the panel to a framing system. The fasteners may be exposed or concealed, and the outer skin (or fascia) may be a simple butt joint, lap joint or in the case of roof panels, a standing seam lap joint. The joints often incorporate factory-applied seals as well. A typical IMP is shown in Figure 1.

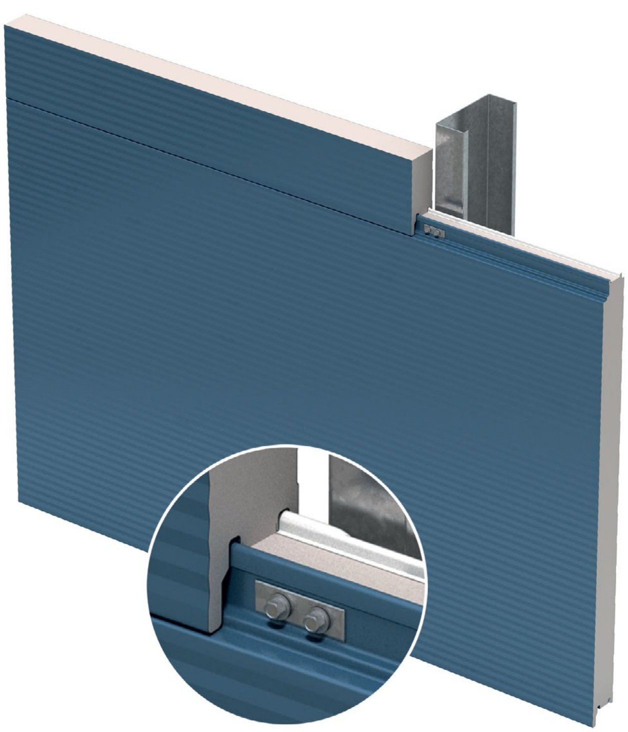

Figure 1. Typical IMP construction

ASHRAE 90.1 and R-value and U-factors

The International Energy Conservation Code (IECC) has its own unique provisions, but it also allows another standard, ASHRAE 90.1, as an alternate compliance path under most conditions. Therefore, the recommendations made by this paper will follow ASHRAE 90.1 2019 provisions as they are largely applicable to Canada as well.

According to ASHRAE, materials intended to act as insulation for compliance purposes must be rated for R-value by their manufacturer. R-values are specific to insulation and singular components of an assembly. When applied to insulation, the R- value must be rated by the manufacturer at a mean temperature of 75°F. U-factors are specific to assemblies of insulation and other building materials installed as a system.

ASHRAE addresses quantification of R-values and U-factors in Sections A9.3.1 and A9.3.2 of Appendix A respectively. When using R-values for compliance, ASHRAE requires the following:

- R-values of building materials must be established by ASTM C177, ASTM C518 or ASTM C1363.

Air films should not be included. For U-factors, ASHRAE requires the following:

- ASTM C1363 is the only acceptable test method to determine U-factors.
- Samples tested must be production line materials assembled using the details intended for installation and shall include the representative joinery and other materials impacting the results.

Being constructed of different materials and subject to lateral heat flows stemming from the joints, IMPs should be evaluated as insulated assemblies, not stand-alone insulation. This implies that U-factors are more appropriate than R-values. Because IMPs are essentially extruded two-dimensional shapes, full-blown three-dimensional analysis is not required.

ASTM Standards and Test Methods

ASTM C177

ASTM C177, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus, is a material test as opposed to an assembly test. It encloses two identical specimens of insulation with known dimensions within an apparatus just big enough to hold the samples. A schematic for the assembly is shown in Figure 2.

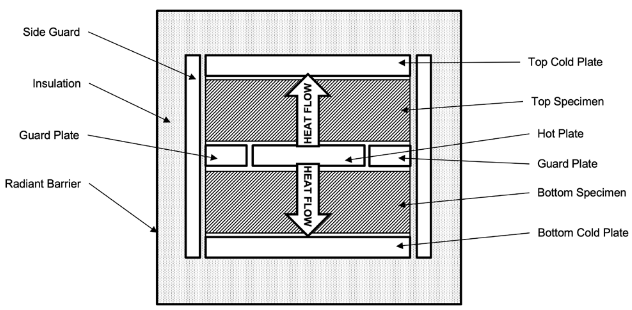

Figure 2.

In this test, the hot plates are heated to a common temperature using electric resistance heat. Electricity is used because the efficiency of an electric heater is 100%; therefore no power loss adjustments are needed. The concentric design of the hot plate relegates lateral heat flow due to unintentional temperature differences with the sides of the apparatus to the area interfacing with the outer plate. The inner plate is instrumented to monitor the power delivered to it. The cold plates are cooled to a common temperature, inducing heat flow from the hot plates outward in two directions, through the thickness of the two specimens, to the cold plates. The R-value can then be deduced from the input power divided by the cross-sectional area times the combined thicknesses of the specimens. This effectively averages the results for the two specimens, eliminating any gravity-induced bias.

ASTM C177 is a highly accurate and easily repeatable test and has been the primary method of determining R-value for most insulating materials for decades. Its primary disadvantage is that the apparatus is very elaborate and expensive, leaving it primarily as a laboratory test.

ASTM Standards and Test Methods

ASTM C518

The most common test method used to determine the R-value of insulation is ASTM C518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. This apparatus is similar in concept to ASTM C177, however, it is usually run with a singular specimen. Instead of directly measuring power input to the hot plate, this test utilizes one or two heat flux transducers to measure the heat flow through the specimen and typically does not utilize side guards. The transducers must be calibrated periodically against a specimen of known R-value or k-factor, usually as determined by ASTM C177. A schematic of the assembly is shown in Figure 3:

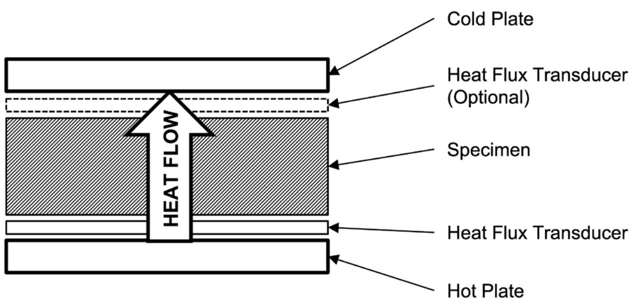

Figure 3.

The ASTM C518 apparatus is well known for delivering reasonably accurate and repeatable results, provided the apparatus is periodically calibrated. Remember that the apparatus directly measures heat flow, not R-value or k-factor, requiring conversion, possibly introducing additional uncertainty.

The advantages of C518 are ease of application, accuracy and repeatability and many insulation manufacturers run it as part of a quality control program. The main shortcomings are that it cannot be used to test assemblies and thicker insulations may have to be cut down to fit in the machine. This requires that the results scaled up using the k-factor relationship sometimes lead to inaccuracy.

ASTM Standards and Test Methods

ASTM C1363

ASTM C1363, Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus, depicted in Figure 4 is a very different test from ASTM C518. It can be used to test individual materials like ASTM C518, but it is designed to test entire assemblies at full scale and as such requires a very large apparatus. Specimens are usually between 5' and 12' on each side. To accommodate this wide variability, most deploy the guarded design to minimize inaccuracies introduced by heat passing through the interface between the specimen perimeter and the edge of the chamber, called flanking loss. By measuring the difference between the surface temperature and the air, the air film R-values on both sides can be determined and subtracted from the result.

Once initiated, the test continues until constant temperatures are achieved on both sides under constant heat input. This may take hours and for very low U-factor specimens, days. The U-factors of the chamber walls and slight flanking heat loss is also pre-determined by calibration against a specimen of known R-value, such that the only variable left is the U-factor of the specimen itself.

ASTM C1363 is widely used for envelope assemblies. The prime advantage is that a large array of materials and assemblies can be facilitated by the apparatus and all active heat transfer modes are captured. The biggest disadvantages are long set up, test and take-down times and lower accuracy and precision versus that of material tests like C518.

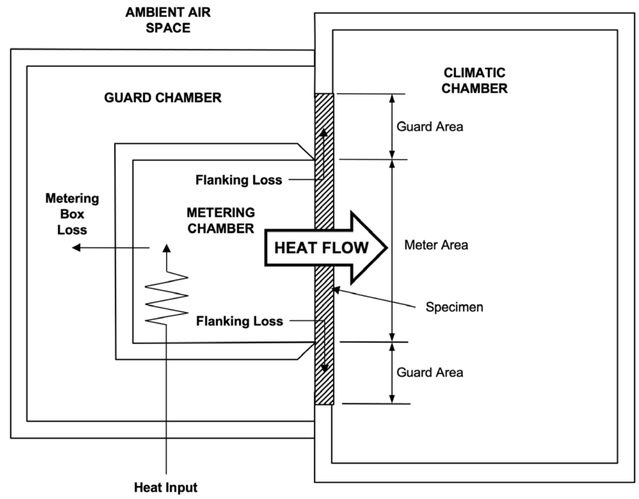

Figure 4.

ASTM Standards and Test Methods

ASTM C1058

As previously mentioned, R-values of insulations that incorporate multiple modes of heat transfer, as most do, are impacted by the temperature difference across the specimen and the mean temperature of the test in a non-linear way. Therefore, it is important to know what these parameters are when comparing different types of insulation. To standardize selection of these parameters, ASTM has published Standard C1058, Standard Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation.

R-value Condition
0.17 All exterior surfaces
0.46 All semiexterior surfaces
0.61 Interior horizontal surfaces, heat flow up 0.92 Interior horizontal surfaces, heat flow down 0.68 Interior vertical surfaces

Table 1. ASHRAE 90.1 Prescribed Air Films

The recommendations for building envelopes are shown in Table 1. Three choices are presented. The standard recommends choosing the one most appropriate for the climate and occupancy of the building. ASHRAE 90.1 requires insulation materials and assemblies to be rated based on testing at 75°F mean temperature to be used for envelope compliance. Test values using other mean temperatures may be useful for specific applications. For example, 40°F is appropriate for cold storage facilities and buildings in extreme northern climates (35°F is sometimes used as well); and 110°F is appropriate for roofing insulation in hot, sunny climates.

Conclusions and Recommendations

Obtaining the proper R-values and U-factors for building envelope components seem complicated. Manufacturers of IMPs generally provide either R-values or U-factors for their products and sometimes both. As this paper has shown, there are many factors that influence these values, and it is not always clear to building specifiers which set of data to use and how to compare products.

An effective evaluation cannot be done simply by comparing R-value or U-factor quantities at surface value, as the user will not know the specific conditions under which the test was run to determine the metric. Many different factors including specific climate, operation, and construction quality are far more likely to determine performance than a variance in R-value of a few percent. Other equally as important performance parameters, such as air infiltration or vapor permeance, are likely to play a role as well.

Users should therefore focus on the completeness and availability of thermal performance data to ensure the quantities they consume are fit for purpose. The user should understand the basic parameters of thermal performance testing and have a thorough understanding of how to apply these parameters to their project. When consuming R-values, the user should ensure:

- The correct test method (ASTM C177, C518 or C1363) was run using appropriate value of mean temperature and temperature differential. Generally, lower mean temperatures will give larger R-values.

- If ASTM C1363 is used, determine if joints were included in the test. Typically, they would not be included in R-values but that is not a given.

When using U-factors, the user should ensure:

- That either ASTM C1363 or finite element models were used. If testing was used, ensure it was run using appropriate value of mean temperature and temperature differential. Generally, lower mean temperatures will give larger R-values. If models were used, the R-value assumed in the analysis should be determined in a manner consistent with the above recommendations.

- Whether or not air film allowances are included in the results and if they are, determine they are consistent with the values from ASHRAE 90.1 shown in Table 1.

Conclusions and Recommendations

Figure 4 summarizes the recommendations of this paper. Each option refers to a specific set of notes presented following the flowchart directing the reader to other sections of the paper if necessary.

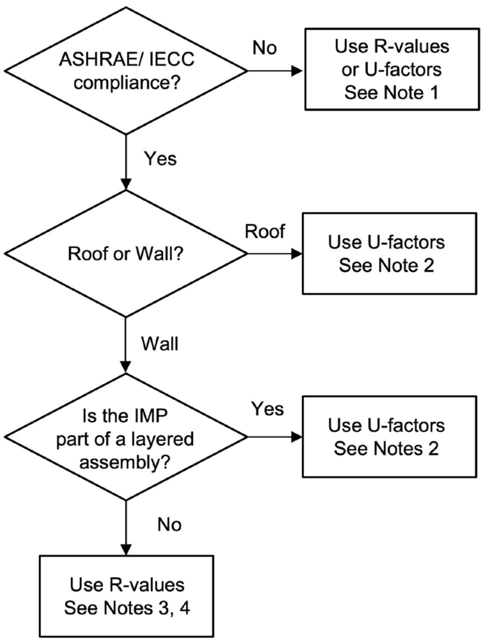

Figure 5.

Flowchart notes:

1. R-values shall come from ASTM C177, ASTM C518 or ASTM C1363 conducted on production foam samples. When converting k-factors to R-values, be consistent with units.
2. U-factors shall come from testing or acceptable 2-dimensional finite element analysis. For testing, use ASTM C1363 at a mean temperature of 75°F and a temperature differential of 50°F. Air film coefficients recorded by ASTM C1363 shall be removed and replaced with the prescribed air film R-values shown in Table 1. Tests or models should include a representative sample of joints.
3. R-values shall come from ASTM C177, ASTM C518 or ASTM C1363 conducted at 75°F with a temperature differential of 50°F. When converting k-factors to R-values, be consistent with units. Air films should not be included.
4. Assembly U-factors shall be calculated using the R-values of the IMPs in conjunction with the other assembly components utilizing the electrical circuit analogy discussed in this paper.

References

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