THERMAL RESISTANCE (R VALUE) TESTING

RESISTANCE TO HEAT FLOW MEASUREMENT

ABSTRACT

R value is a critical metric when assessing how effective a material is as a thermal insulator, and provides significant benefits contributing to green building performance.

Whether you are a manufacturer, designer or construction professional, knowledge of a material's R value is critical to achieve a building's thermal performance requirement and to ensure that standards are met for better thermal protection and energy efficiency.

It helps you to specify your insulation product, or to demonstrate how your product will increase efficiencies in the application.

This article investigates the technique employed to measure the thermal resistance of materials used in buildings. Specifically, we examine ASTM C518, the standard test method covering the measurement of steady-state thermal transmission properties using a heat flow meter apparatus.

The first section of the document provides introductory information on heat flow and R value. This is followed by a detailed explanation of how R value is measured, including a description of the test apparatus. Details on common thermal insulating materials and their R value are also reported.

CONTENTS

BACKGROUND

As sustainability has evolved as a highly important project driver in construction, there exists the need to adopt insulating measures and to adequately assess the ability of insulating materials to resist heat flow throughout the lifetime of a building.

Differences between the indoor and outdoor air temperature result in heat losses or heat surpluses, which in turn have an impact on winter heating or summer air conditioning costs.

With today's increasing energy prices and concerns over environmental impact, incorporating thermal insulating materials into building design has become of paramount importance for both residential homes, commercial and institutional buildings.

Insulation is an effective energy-saving measure which provides resistance to the passage of heat through the building. Designated as R value, thermal resistance indicates how useful a material is as an insulator.

The higher the R value of a material, the greater it's insulating effectiveness. Therefore, having high R value insulating materials installed in the cavities of a building slows the flow of heat through floors, ceilings, and walls. This reduces energy consumption, lowers the carbon footprint of a building, and allows to obtain desirable indoor comfort.

By testing and determining a product's R value, manufacturers can make certain that their product will consistently provide the designed-for resistance to heat flow.

They can demonstrate how their product will increase efficiencies in an application and help construction professionals make informed decisions when incorporating thermal insulating materials in building design.

THERMAL RESISTENCE

HEAT FLOW

Heat moves from warmer to colder areas until there is no longer a difference in the temperatures of the two regions.

This movement is what causes buildings to get colder in winter and hotter in summer. In the winter, heat escapes from the building into the colder environment. The opposite occurs in the summer as heat outside moves into the building.

Heat transfer occurs through conduction, convection or radiation. Therefore, thermal insulation products are designed to resist heat transfer by means of these three mechanisms. As a result, this reduces energy consumption by preventing heat loss or gain by buildings.

R VALUE

The effectiveness of thermal insulation is measured by its ability to restrict heat transfer. This is expressed as its thermal conductivity (K value or λ value) or its thermal resistivity.

Thermal conductivity is the rate at which heat passes through a specified material, expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance.

Thermal resistivity measures the resistance of a specified material to heat flow and is the inverse of thermal conductivity.

Thermal resistance (R value) is the thickness of the insulation material, in meters, multiplied by the thermal resistivity.

Determining the thermal properties of a material allows ascertaining how specific thicknesses of a material affect heat transfer. A lower apparent thermal conductivity or higher thermal resistance is the primary property of a thermal insulation material.

The most frequently used test method to measure the R value is ASTM C518, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus."

The test method involves measuring the R value using a heat flow meter (HFM) apparatus equipped with two parallel plates that are maintained at constant but different temperatures.

The test method applies to the measurement of thermal transmission through a wide range of specimen properties and environmental conditions. It may also be used to characterize material properties, which may or may not be representative of actual terms of use.

R VALUE MEASUREMENT BY THE HEAT FLOW METER

It is assumed in ASTM C518 that the sample is homogeneous and uniform. Heat flow is measured at steady-state condition, one-dimensional conduction in the x-direction with negligible contact resistance. This means that the temperature at each point in the apparatus is independent of time. The output of the heat flow meter is thermal conductivity, λ.

A heat flow meter is based on the one-dimensional Fourier law to measure the thermal conductivity of the speciment:

$$-q = -\lambda(dT/dx)$$

$$\lambda = -q(\Delta x/\Delta T)$$

- Where, q is the heat flux or rate of heat flow rate, Q, through the metering area A (W/m^2)
- and λ is the thermal conductivity (W/m.K)
- dT/dx is the temperature gradient (K/m) across the isothermal plates
- Where Δ x is the distance between the isothermal plates, i.e., thickness of the specimen (m)
- and ΔT is the temperature difference between the isothermal plates in K
- Q is the amount of heat flow across the plates in unit time, i.e., Joules/sec or Watt (W)
- A is the metering area normal to the heat flux direction (m^2) and
- S_{cal} (T_{cal}) is the temperature dependent calibration factor in $W/m^2.mV$

To perform the test, a material is placed in the apparatus between a hot and a cold plate. When the sample is placed between the two plates, the temperature gradient causes the heat to flow from the hot plate to the cold plate and the constant plate temperatures, or isotherms, are disturbed.

The thermal conductivity of a material is determined when the test apparatus has achieved steady-state. This is when the amount of energy (watts) that is required to maintain the hot plate temperature and the temperature difference across the test sample remains constant over a predetermined period of time.

The higher the thermal conductivity of the sample, the bigger the amount of energy that will be required to maintain the temperature difference across the sample.

Commonly used test conditions are 35°C for a hot plate and 13°C for the cold plate as per ASTM C518. In the two-transducer HFM apparatus, temperature differences between hot (35°C) and ambient temperature (24°C) or cold (13°C) and ambient (24°C) temperature separately generate potential differences in millivolts (mV).

In the heat flow meter, the potential difference (i.e., temperature difference) is always maintained. The power (in millivolts) required is measured and later compared with the potential variations of standard reference material using a calibration factor ($W/m^2.mV$) that converts the output of the HFM (mV) to the heat flux (W/m^2).

The physical sense of the calibration factor S ($W/m^2.mV$) is the heat flux necessary to create a one microvolt output signal from the heat flow meter's transducer.

Finally, the energy requirements of both hot and cold plates are averaged. To reduce the uncertainty in the calculated thermal conductivity, the average heat flux (q) is used to calculate the thermal conductivity.

Since thermal conductivity is the reciprocal of thermal resistivity, once the thermal conductivity is known, the value can be inverted to obtain the thermal resistivity. The thermal resistivity is then multiplied by the thickness of the product to get the thermal resistance or R value.

The R value is expressed as degrees Fahrenheit x square feet x hour/BTU. Outside the United States, thermal resistance is usually measured with metric units rather than with imperial units. The resulting value is called RSI, which stands for the International System of Units (Système International d' Unités).

R Value **Imperial units**	**RSI Value** **Metric units**
$°F.ft^2.h/BTU.in$	$K.m^2/W$

Conversion: 1 $K.m^2/W$ = 5.678 $°F.ft^2.h/BTU.in$

	UNITS		SPECIMEN 1	
	SI	IMPERIAL	SI	IMPERIAL
Length	mm	in	300.00	11.811
Width	mm	in	300.00	11.811
Test Thickness	mm	in	27.520	1.083
Mass	g	lb	13.94	0.031
Density	kg/m^3	lb/ft^3	5.63	0.351
Upper Surface Temperature	°C	°F	13.02	55.44
Lower Surface Temperature	°C	°F	35.02	95.04
Temperature Differential	°C	°F	22.00	39.60
Avg. Temperature Gradient	K/m	°F/in	799.42	36.55
Mean Temperature	°C	°F	24.02	75.24
Rate of Heat Flux	W/m^2	$BTU/h·ft^2$	30.67	9.72
Thermal Conductance	$W/m^2·K$	$BTU/h·ft^2·°F$	1.39	0.25
Thermal Resistance	$m^2·K/W$	$h·ft^2·°F/BTU$	0.72	4.07
Thermal Conductivity (λ)	W/m·K	$BTU·in/h·ft^2·°F$	0.03836	0.266
Thermal Resistivity	m·K/W	$h·ft^2·°F/BTU·in$	26.07	3.760

Table 1: Example of calculation spreadsheet.
Measurement of the R value from a heat flow meter apparatus according to ASTM C518.

MATERIALS FOR THERMAL RESISTANCE TESTING

Various layers of thermal insulating materials are used in construction to reduce heat transfer. As different types of materials have different R values; they also have varying construction and insulation applications.

Still, the air is an excellent insulator (λ= 0.02-0.025 W/m·K), and reducing the air conduction is the key to increased R value. Rigid gas-filled closed-cell foam insulations rely on a blowing agent or gas (except air) that has a lower thermal conductivity (λ) value for increased thermal resistance.

INSULATING MATERIAL	R VALUE (AT 1 INCH THICKNESS) (°Fλft^{2}λh/BTU-in)
Mineral Fiber Batt	3.1 - 4.0
Expanded polystyrene (EPS)	4.0
Extruded polystyrene (XPS)	5.0

Table 2: R value of some common thermal insulating materials.

CONCLUSION

Using the right materials required to meet the design criteria of a building provides significant benefits to improving a building's thermal comfort while limiting the waste of energy resources.

Testing building materials with respect to their thermal resistance is vital in determining how effective a material is as an insulator. Knowing a material's R value helps assess a product's insulating performance and predict energy efficiency.

Thermal resistance testing is required by insulation manufacturers to label their products or to demonstrate the superiority of a product in the marketplace. Testing can differentiate your product from your competitors' and help you gain the market access you desire.

We provide testing to ASTM C518 Standard Test Method for Steady-State Thermal Transmission Properties by using the Heat Flow Meter Apparatus as well as to ISO 8301 Thermal Insulation – Determination of steady-state thermal resistance and related properties – Heat flow meter apparatus at the same location.

We use LTTR (long-term thermal resistance) testing according to CAN/ULC S770 or ASTM C1303 test methods utilizing ASTM C518.

Additionally, Element is a member of the National Fenestration Rating Council (NFRC), International Code Council – Evaluation Services (ICC-ES), Underwriters Laboratories of Canada (ULC) and the Polyisocyanurate Insulation Manufacturers Association (PIMA).

Element is a global provider of testing, inspection, and certification services for a diverse range of materials and products in sectors where failure in service is not an option. Everything we do is designed to deliver one thing for our customers – certainty that the materials and products we test, inspect, and certify are safe, quality, compliant, and fit for purpose.

REFERENCE

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