Thermal Resistance (R – Value)

An *R-value* indicates an insulation's resistance to heat flow. The higher the R-value, the greater the insulating effectiveness.

The R-value depends on the type of insulation and includes its material, thickness, and density. When calculating the R-value of a multilayered installation, add the R-values of the individual layers. Installing more insulation in your home increases the R-value and the resistance to heat flow.

The effectiveness of an insulation's resistance to heat flow also depends on how and where the insulation is installed. For example, insulation that is compressed will not provide its full rated R-value. The overall R-value of a wall or ceiling will be somewhat different from the R-value of the insulation itself because some heat flows around the insulation through the studs and joists. Therefore, it's important to properly install your insulation to achieve the maximum R-value.

The amount of insulation or R-value you'll need depends on your climate, type of heating and cooling system, and the section of the house you plan to insulate. For more information, see our information on adding insulation to an existing house or insulating a new house.

The R-value is a measure of insulation's heat loss retardation under specified test conditions. The primary mode of heat transfer impeded by insulation is convection but unavoidably it also impedes heat loss by all three heat transfer modes: **conduction, convection, and radiation**

Under uniform conditions it is the ratio of the temperature difference across an insulator and the heat flux (heat flow per unit area, $\dot{Q}_A$) through it or $R = \Delta T/\dot{Q}_A$. The bigger the number, the better the building insulation's effectiveness[2]. R-value is the reciprocal of U-value.

Around most of the world, R-values are given in SI units, typically square-metre kelvins per watt or $m^2 \cdot K/W$ (or equivalently to $m^2 \cdot °C/W$).

Multiple layers

In calculating the R-value of a multi-layered installation, the R-values of the individual layers are added.

R-value$_{\text{(outside air film)}}$ + R-value$_{\text{(brick)}}$ + R-value$_{\text{(sheathing)}}$ + R-value$_{\text{(insulation)}}$ + R-value$_{\text{(plasterboard)}}$ + R-value$_{\text{(inside air film)}}$ = R-value$_{\text{(total)}}$.

To account for other components in a wall such as framing, an area-weighted average R-value of the whole wall may be calculated

Thermal conductivity versus apparent thermal conductivity

Thermal conductivity is conventionally defined as the rate of thermal conduction through a material per unit area per unit thickness per unit temperature differential (delta-T). The inverse of conductivity is resistivity (or R per unit thickness). Thermal conductance is the rate of heat flux through a unit area at the installed thickness and any given delta-T.

Experimentally, thermal conduction is measured by placing the material in contact between two conducting plates and measuring the energy flux required to maintain a certain temperature gradient.

Increasing the thickness of an insulating layer increases the thermal resistance. For example, doubling the thickness of fibreglass batting will double its R-value, perhaps from 2.0 m^2K/W for 110 mm of thickness, up to 4.0 m^2K/W for 220 mm of thickness. Heat transfer through an insulating layer is analogous to adding resistance to a series circuit with a fixed voltage. However, this only holds approximately because the effective thermal conductivity of some insulating materials depends on thickness. The addition of materials to enclose the insulation such as sheetrock and siding provides additional but typically much smaller R-value.

There are many factors that come into play when using R-values to compute heat loss for a particular wall. Manufacturer R values apply only to properly installed insulation. Squashing two layers of batting into the thickness intended for one layer will increase but not double the R-value. Another important factor to consider is that studs and windows provide a parallel heat conduction path that is unaffected by the insulation's R-value. The practical implication of this is that one could double the R value used to insulate a home and realize substantially less than a 50% reduction in heat loss. Even perfect wall insulation only eliminates conduction through the insulation but leaves unaffected the conductive heat loss through such materials as glass windows and studs as well as heat losses from air exchange.

Resistance

When thermal resistances occur in series, they are additive. So when heat flows through two components each with a resistance of 1 °C/W, the total resistance is 2 °C/W.

A common engineering design problem involves the selection of an appropriate sized heat sink for a given heat source. Working in units of thermal resistance greatly simplifies the design calculation. The following formula can be used to estimate the performance:

$$R_{hs} = \frac{\Delta T}{P_{th}} - R_s$$

where:

- R_{hs} is the maximum thermal resistance of the heat sink to ambient, in °C/W
- ΔT is the temperature difference (temperature drop), in °C
- P_{th} is the thermal power (heat flow), in watts
- R_s is the thermal resistance of the heat source, in °C/W

For example, if a component produces 100 W of heat, and has a thermal resistance of 0.5 °C/W, what is the maximum thermal resistance of the heat sink? Suppose the maximum temperature is 125 °C, and the ambient temperature is 25 °C; then the ΔT is 100 °C. The heat sink's thermal resistance to ambient must then be 0.5 °C/W or less.

Heat Capacity (C)

Heat capacity (usually denoted by a capital *C*, often with subscripts) is the measurable physical quantity that characterizes the amount of heat required to change a body's temperature by a given amount. In the International System of Units, heat capacity is expressed in units of joules per kelvin.

Temperature reflects the average total kinetic energy of particles in matter. Heat is transfer of thermal energy; it flows from regions of high temperature to regions of low temperature. Thermal energy is stored as kinetic energy and, in molecules and solids, also as potential energy in the modes of vibration or phonons.[1] These represent degrees of freedom of movement for atoms. These degrees of freedom, and sometimes others, contribute to the heat capacity of a thermodynamic system. As the temperature approaches absolute zero, the specific heat capacity of a system also approaches zero. Quantum theory can be used to quantitatively predict specific heat capacities in simple systems.

The **heat capacity** indicates how much thermal energy ΔQ a physical body can absorb for a change in temperature ΔT. It refers to a specific body, and gives no indication of the amount of substance or composition of the body.

$$C = \frac{\Delta Q}{\Delta T}$$

C is the heat capacity of the body, and in the International System of Units (SI) has the units $[C] = \frac{\mathrm{J}}{\mathrm{K}}$(joule per kelvin).

If the heat capacity is related to a certain amount of substance, or a volume, we can distinguis

- the **specific heat capacity** c, the heat capacity per unit mass, which has SI units $[c] = \frac{\mathrm{J}}{\mathrm{kg \cdot K}}$

The heat capacity itself is an extensive quantity, meaning one that is a property of the whole body, and is therefore sensitive to the size of the object (for example, a bathtub of water has a greater heat capacity than a cup of water). The three derived quantities are intensive quantities, meaning they are no longer dependent on amount of material, but capture more directly the dependence on the type of material, given the particular physical conditions of heating.

U-value

To put it simply, U-Value is the measure of the rate of heat loss through a material. Thus in all aspects of home design one should strive for the lowest U-Values possible because the lower the U-value – the less heat that is needlessly escaping. So for example single glazed windows have a typical U-value of 5.6 while double glazed windows have a typical U-value of 2.8.
The calculation of U-values can be rather complex - it is measured as the amount of heat lost through a one square meter of the material for every degree difference in temperature either side of the material. It is indicated in units of Watts per Meter Squared per Degree Kelvin or W/m2K. Note that Kelvin is used as the scale of temperature difference, but this is numerically equal to oC. So for example, one square meter of a standard single glazed window will transmit about 5.6 watts of energy for each degree difference either side of the window or a U-Value of 5.6. A double glazed window will be significantly better with a U-value of 2.8 i.e. only transmitting 2.8 watts of energy in similar conditions. The *U-value* (or *U-factor*), more correctly called the overall heat transfer coefficient, describes how well a building element conducts heat. It measures the rate of heat transfer through a building element over a given area, under standardized conditions. The usual standard is at a temperature gradient of 24 °C, at 50% humidity with no wind[4] (a smaller *U-value* is better).

U is the inverse of R with SI units of $W/(m^2K)$ and US units of BTU/(h °F ft^2)

$$U = \frac{1}{R} = \frac{\dot{Q}_A}{\Delta T}$$

Surface temperature in relationship to mode of heat transfer

There are weaknesses to using a single laboratory model to simultaneously assess the properties of a material to resist conducted, radiated or convective heating. Surface temperature varies depending on the mode of heat transfer.

In the absence of radiation or convection, the surface temperature of the insulator should equal the air temperature on each side.

In response to thermal radiation, surface temperature depends on the thermal emissivity of the material. Light, reflective or metallic surfaces exposed to radiation tend to maintain lower temperatures than dark, non-metallic ones

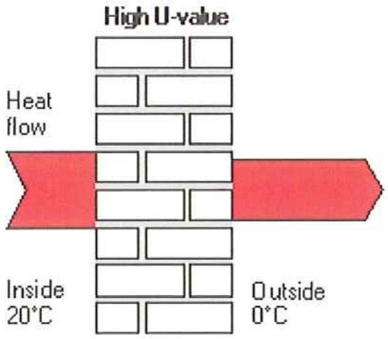
Convection will alter the rate of heat transfer (and surface temperature) of an insulator depending on the flow characteristics of the gas or fluid in contact with it.

With multiple modes of heat transfer, the final surface temperature (and hence observed energy flux and calculated R-value) will be dependent on the relative contributions of radiation, conduction and convection even though the total energy contribution remains the same.

This is an important consideration in building construction because heat energy arrives in different forms and proportions. The contribution of radiative and conductive heat sources also varies throughout the year and both are important contributors to thermal comfort

In the hot season, solar radiation predominates as the source of heat gain. As radiative heat transfer is related to the cube power of the absolute temperature, such transfer is then at its most significant when the objective is to cool (i.e. when solar radiation has produced very warm surfaces). On the other hand, the conductive and convective heat loss modes play a more significant role during the cooler months. At such lower ambient temperatures the traditional fibrous, plastic and cellulose insulations play by far the major role: the radiative heat transfer component is of far less importance and the main contribution of the radiation barrier is in its superior air-tightness contribution. In summary - claims for radiant barrier insulation are justifiable at high temperatures such as minimizing summer heat transfer, but are not in traditional winter keeping warm conditions.

The U-value measures how well a building component, e.g. a wall, roof or a window, keeps heat inside a building. For those living in a warm climate the U-value is also relevant as it is an indicator of how long the inside of the building can be kept cold.

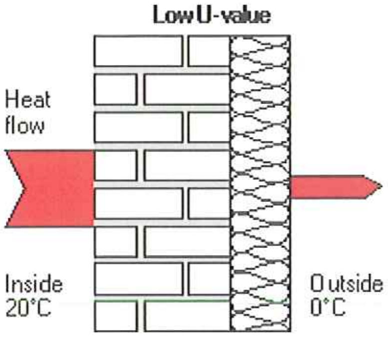


Comfortable indoor climate with good U-values

In both cold and warm climates good U-values are important measures for understanding the amount of energy that is needed to keep a comfortable inside temperature. Learn more about why u-values matter.

What is the U-value?

The U-value is a measure of the heat flow through a building element as illustrated in the figures to the right. The higher the U-value the more heat flows through so a good U-value is a low one as you want to keep heat inside the building or outside depending on the climate you live in. See u-values in action.



The technical explanation of the U-value

Getting a little technical the U-value physically describes how much thermal energy in Watts [W] is transported through a building component with the size of 1 square meter [m²] at a temperature difference of 1 Kelvin [K] (=1°C). Thus the unit for U-values is W/(m²K).

So what is a good U-value? For external walls, roofs, etc. a U-value of less than 0.2 W/(m²K) can be called good. This value can be reached by using thermal insulation with a thickness of about 20 cm or more. For windows the U-value should be less than 1.0 W/(m²K).

Watt (W)

The unit measures the rate of energy conversion. It is defined as one joule per second.

- In terms of Classical mechanics, one watt is the rate at which work is done when an object's velocity is held constant at one meter per second against constant opposing force of one newton.

$$W = \frac{J}{s} = \frac{N \cdot m}{s} = \frac{kg \cdot m^2}{s^3}$$

K - Value

In physics, **thermal conductivity**, *k*, is the property of a material that indicates its ability to conduct heat.

k – Value = power lost through the material for every degree Kelvin difference across the material.

In summary, for a plate of thermal conductivity *k* the *k value* [4]), area *A* and thickness *t*:

- *thermal conductance* = k/t, measured in $W{\cdot}K^{-1}{\cdot}m^{-2}$;
- *thermal resistance* (*R-value*) = t/k, measured in $K{\cdot}m^2{\cdot}W^{-1}$;
- *thermal transmittance* (*U-value*) = $1/(\Sigma(t/k))$ + convection + radiation, measured in $W{\cdot}K^{-1}{\cdot}m^{-2}$.
- *K-value* refers in Europe to the total insulation value of a building. K-value is obtained by multiplying the form factor of the building (= the total inward surface of the outward walls of the building divided by the total volume of the building) with the average U-value of the outward walls of the building. K value is therefore expressed as $(m^2{\cdot}m^{-3}){\cdot}(W{\cdot}K^{-1}{\cdot}m^{-2}) = W{\cdot}K^{-1}{\cdot}m^{-3}$. A house with a volume of 400 m^3 and a K-value of 0.45 (the new European norm. It is commonly referred to as K45) will therefore theoretically require 180 W to maintain its interior temperature 1 K above exterior temperature. So, to maintain the house at 20 °C when it is freezing outside (0 °C), 3600 W of continuous heating is required.

In physics, **thermal conductivity**, k, is the property of a material that indicates its ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Thermal conductivity is measured in watts per kelvin per metre ($W{\cdot}K^{-1}{\cdot}m^{-1}$). Multiplied by a temperature difference (in kelvins, K) and an area (in square metres, m^2), and divided by a thickness (in metres, m) the thermal conductivity predicts the energy loss (in watts, W) through a piece of material.