

The science of insulation explained

How heat flows

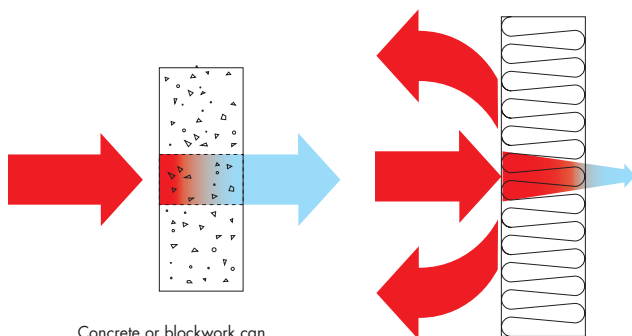
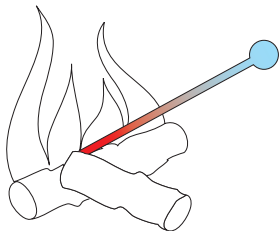
To understand how insulation works, it is first necessary to explain the different ways heat flows through a construction. Physically, heat always moves from areas of high temperature to those at a lower temperature, which is why, in the cold external temperatures of winter, the warmth inside a building will try to escape through walls, windows, roof and floor.

This heat flow takes place by conduction, convection and radiation.

Conduction

Conduction is the transmission of heat through a material, or from one material to another, through direct contact. Conduction can take place in solids, liquids and gases.

Metal conducts heat rapidly



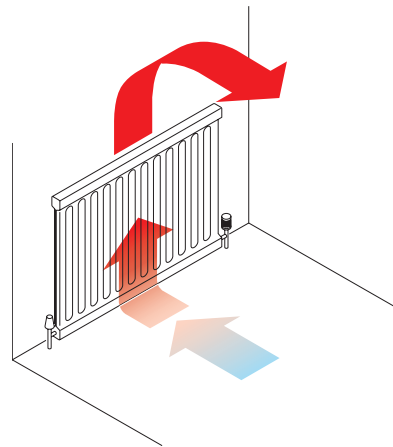
Concrete or blockwork can be efficient conductors of heat

Mineral wool is a poor conductor of heat and therefore a highly efficient insulant

In relation to construction materials, metals are the best conductors of heat, followed by concrete and masonry. In contrast, wood and insulation materials are poor conductors, as are air and other gases.

Convection

Convection occurs in gases and liquids. If a hot surface is in contact with cooler air, heat is conducted to the air. This air then becomes warmer and therefore less dense than the adjacent cooler air. The warmer, lighter air rises upwards and is replaced by cooler air, causing a continuous flow of air by natural convection – gradually removing heat from the hot surface to the air. The process is reversed if warm air comes into contact with a cold surface.

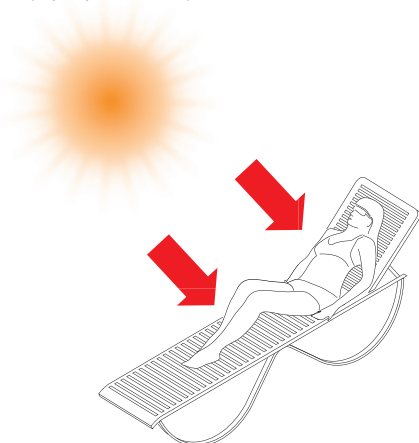


In constructions, the convective heat transfer we are interested in occurs mainly in wall and roof cavities.

Radiation

Radiation is the transmission of infra-red radiant energy from a 'hot' surface to a 'cold' surface through air or a vacuum. Radiant energy moves through space without heating anything in between – the energy is only absorbed when its path is blocked by an object which absorbs the energy and converts it to heat. All materials emit radiant energy to a greater or lesser extent according to their surface characteristics and the temperature of the surface. The higher the temperature of a surface the greater the amount of radiant energy emitted.

The most common example of this is the radiant heat from the sun, which travels millions of miles through space, and only has any effect when it is blocked by an object, e.g. people, buildings or the earth itself.



How to reduce heat flow by the use of insulating materials in buildings

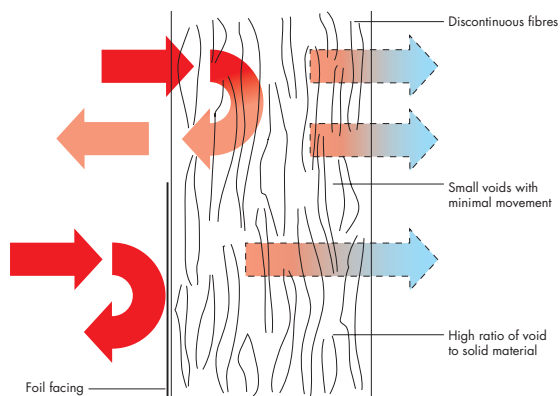
In order to perform effectively, an insulation material must reduce heat flow.

How conduction is reduced

To reduce heat transfer by conduction, an insulating material should have a very small amount of solid material in relation to void. Additionally, the solid material should consist of thin connecting walls, or discontinuous fibres. Conduction across the voids can be further reduced if they are filled by an inert gas rather than air.

How convection is reduced

To reduce heat transfer by convection, an insulating material should contain small voids or air pockets within which air movement is minimised. Similarly, within a construction, convection can be reduced by having small self contained air spaces, rather than large ventilated air spaces.



How radiation is reduced

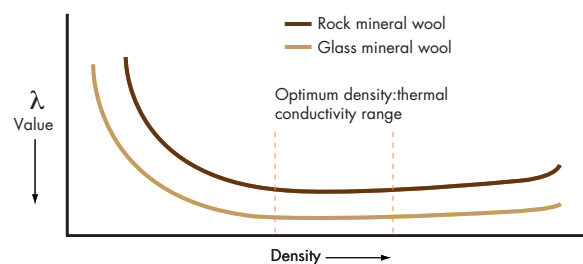
The transmission of heat by radiation is stopped when it is absorbed into the surface of a material, this results in a rise in temperature of the material. However that material will in turn emit radiant energy. The most effective surface is a "low emissivity" surface that emits very little radiant energy and absorbs a very small percentage of the radiant energy falling on it. A "low emissivity" surface is characterised by a shiny metallic finish. In a building the transmission of heat by radiation from one internal surface to another is not regarded as heat loss however the transmission of heat from external elements of the building away from the building is.

Thermal conductivity (K value or λ value)

The measure of a materials ability to transmit heat is known as thermal conductivity (units W/mK) it is also known as lambda value (λ).

Thermal conductivity by material type

The graph below shows the classic curve type associated with the thermal conductivity performance of traditional bulk insulation materials.



Each type of material has its own classic curve
Glass mineral wool is more efficient at normal building temperatures than rock mineral wool

This particular graph shows the curve for glass and rock mineral wool products, as can be seen the thermal conductivity of the product is improved as the density of the product increases, however the rate of change diminishes as density increases and ultimately, at higher densities, the thermal conductivity starts to increase.

The basic trend of this graph holds true for all bulk insulation materials, and its shape is a function of the varying efficiency of the material at restricting the three different methods of heat flow at different densities.

Thermal conductivity also varies with temperature. As temperature rises then the thermal conductivity of materials generally increases. This is not a phenomenon that is of concern in buildings because the variance only becomes significant at temperatures which would not be experienced in normal conditions. It is a consideration when insulating building services and high temperature processes.

Measurement of thermal conductivity

From May 2003, it became a legal requirement that thermal insulation products for buildings are tested to - and comply with - the Construction Products Regulations, as defined in United Kingdom law. One major consequence of this is the change to the way that thermal conductivity (lambda value) of thermal insulation products is measured and declared.

All insulation products have an inherent variability when it comes to thermal conductivity. This is basically dependent on the method by which the insulation is made and actually 'works'. Put simply, the lambda value for building insulation products must be such that 90% of the results obtained are within 90% of the quoted value - hence 'Lambda 90/90'. The aim is to ensure that the values quoted for insulation performance are consistent and give both users and building designers confidence in the products and solutions that are being specified.

Lambda 90/90 effectively means that all thermal insulation products manufactured in accordance with harmonised European Standards have their lambda value tested and declared to the same methodology, establishing a level playing field for all materials. Thermal conductivity is determined by testing in accordance with BS EN 12667: 2001.

The science of insulation explained

Thermal resistance (R-value)

The measure of a material's ability to resist the transfer of heat, it is specific to a particular thickness of material. Units: $\text{m}^2\text{K}/\text{W}$.

$$\text{R-value} = \frac{\text{Thickness (m)}}{\text{Thermal conductivity (W/mK)}}$$

Thermal Resistance is the most important material characteristic that should be defined when specifying insulation. From the formula for calculating, it is apparent that there are two factors affecting the thermal resistance: the thickness of the insulation and the thermal conductivity of the material. Simply specifying thickness of material is not enough

Example: the designer requires an insulation material with a thermal resistance of $2.25 \text{ m}^2\text{K}/\text{W}$

This can be provided in a number of ways:

$$\text{R-value of 100mm of Loft Roll 44} = \frac{0.100}{0.044}$$

$$= 2.2727 = 2.25 \text{ m}^2\text{K}/\text{W}.*$$

$$\text{R-value of 75mm of Rafter Roll} = \frac{0.075}{0.032}$$

$$= 2.3437 = 2.30 \text{ m}^2\text{K}/\text{W}.*$$

* R-values are required to be rounded down to the nearest 0.05 interval for CE marking purposes.

Earthwool® Loft Roll 44 has a higher thermal conductivity than Earthwool Rafter Roll, but applied in a higher thickness it provides an almost equal level of thermal resistance.

The lower thermal conductivity of the Earthwool Rafter Roll is a function of higher density, therefore it requires a greater amount of material and it would be more economic to satisfy the thermal resistance requirement with the Earthwool Loft Roll, provided the 100mm depth can be accommodated.

To achieve a specific thermal resistance, increased product thickness is more economically efficient than using a product with a lower thermal conductivity.

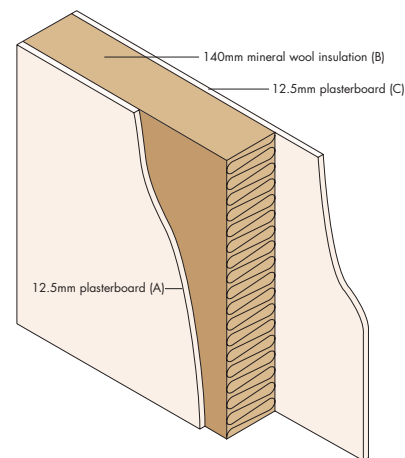
Thermal transmittance (U-value)

Commonly known as the U-value, it is a measure of the rate of conductive heat loss of a building element or component. Units: $\text{W}/\text{m}^2\text{K}$.

The actual thermal transmittance of a building element is a function of the thermal resistance of the materials that are used in the construction and the way they are assembled.

U-values of building elements can be established by laboratory testing, but the process is costly, time consuming and size limited. Furthermore, the result would only hold true for an identical construction or element. Testing is widely used to establish the thermal transmittance of glazing and doors, but for other construction elements it is more normal to use numerical and mathematical models to predict the U-value.

In its simplest form, a U-value is calculated by establishing the thermal resistance of each layer in the construction element and adding them together to provide a total resistance (TR) value. The U-value is calculated from the reciprocal of the combined resistances of the materials in the element, including any airspaces and surface resistance values.



$$\text{TR} = \text{Rsi} + \text{Ra} + \text{Rb} + \text{Rc} + \text{Rso}$$

Rsi is the internal surface resistance

Rso is the outer surface resistance

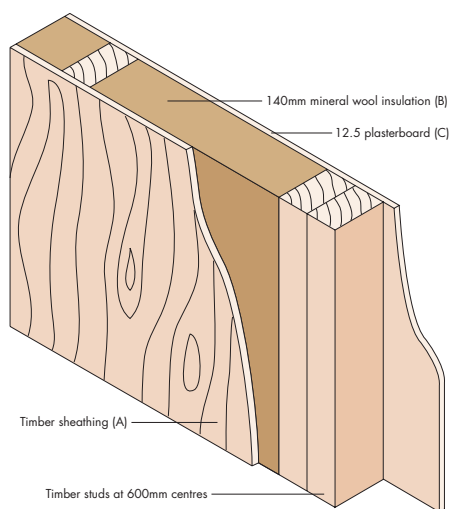
$$\text{Therefore U-value} = \frac{1}{\text{TR}}$$

For instance an external wall with a total thermal resistance of $3.50 \text{ m}^2\text{K}/\text{W}$ would have a U-value of $\frac{1}{3.50}$ or $0.29 \text{ W}/\text{m}^2\text{K}$.

This method of calculating U-values, however, does not allow for non-uniformities that exist in real constructions and therefore will not enable a realistic model to be calculated. The non-uniformities require factors to include allowance for the effect of repeating thermal bridges, (e.g. timber studs in timber frame construction, mortar joints in lightweight and aircrete masonry or metal rails and clips in twin metal skin constructions), fasteners that penetrate the construction and the possibility of the imperfection of fit of layers that might allow air movement around insulation layers. These factors are included in more sophisticated numerical and mathematical models. These methods are defined by international standards such as BS EN ISO 6946 'Building components and building elements – Thermal resistance and thermal transmittance – calculation method' and guidance is given regarding the suitability of each method for the proposed construction. Additionally, reference should also be made to BR443:2006 Conventions for U-value calculations 2006 edition which sets conventions for and gives guidance on the calculation of U-values. This document is referenced directly by the Approved Documents for England and Wales, the Technical Standards in Scotland and Technical Booklets in Northern Ireland.

The calculation methodology detailed in BS EN 6946 is commonly known as the "combined method" and is generally suitable for most elements of construction except where there are metal repeating thermal bridges in the insulation layer.

If the example below is taken to be a timber frame panel, then it becomes apparent that the insulation is bridged by the timber studs. In these circumstances, the combined method is appropriate.



When the combined U-value method is applied to the calculation of the U-value of this construction, it becomes $0.32\text{W/m}^2\text{K}$ as opposed to $0.26\text{W/m}^2\text{K}$ if the effect of the timber studs is ignored.

In this calculation, the proportion of insulation replaced by timber is 15%. This proportion is identified as the default timber fraction in BR443, and a level 0 correction for air gaps in the insulation layer has been applied because mineral wool is deemed to be cut with a positive tolerance so that it has to be compressed between the timber studs to be fitted and all joints in the insulation layer are closed. If a rigid foam board has been used, it might be considered necessary to apply a level 1 air gap correction because the board has to be cut with a negative tolerance to enable fitting and there may well be air gaps greater than 5mm in width.

Clearly the accurate calculation of U-values requires detailed knowledge of product characteristics, calculation methodologies and standards, and construction techniques. The accurate calculation of U-values is a fundamental building block in the development of whole building energy models and Building Regulations submissions.

Whole building approach

The U-values of building elements are critical factors in the overall heat loss from buildings, but there are two other heat loss mechanisms that need to be included to establish the total heat loss from the building fabric, these are: heat losses through non repeating thermal bridges such as window reveals, sills and lintels, and ventilation heat loss, whether intended or unintended (air leakage). All three heat loss mechanisms need to be included in any model of the energy performance of a building.

Calculation methods exist to predict the energy consumption of buildings and these are used both for modelling for building regulations compliance. For dwellings the methodology used is SAP (Standard Assessment Procedure 2009) and for non dwellings it is SBEM (Simplified Building Energy Model 2010).

SAP is the Government's standard for assessing the energy performance of dwellings. SAP ratings are actually energy costs ratings with the energy use for space heating, water heating, ventilation and lighting, minus any cost savings from energy generation technologies incorporated into the dwelling. However, it is also used to generate carbon emission ratings used in the Building Regulation compliance process and to generate the Energy Performance Certificate.

SBEM in simple terms is a SAP program for non dwellings, however it carries with it a far greater degree of complexity in use, and its purpose is to calculate energy use and carbon emission ratings. Generally, non dwellings are far larger than dwellings and there are often many differing types (i.e. offices, shops, warehouses (and even accommodation) etc) within a single building. The fabric of the building has to be carefully defined including internal building elements and the use type of each internal space also defined so the lighting, heating and cooling and hot water requirements can be calculated. The services within the building are defined and then the CO₂ emissions rating is calculated for Building Regulation compliance. The SBEM calculation is also used to generate the Energy Performance Certificate for the building.

Such is the importance of U-value calculations an industry leading U-value and Condensation Calculation Competency Scheme has been created by the British Board of Agrément in conjunction with the Thermal Insulation Manufacturers and Suppliers Association (TIMSA). The primary purpose of the scheme is to promote and assist accurate, objective and consistent calculation of U-values and condensation calculations within the UK construction industry, the scheme was launched on the 1st April 2010.