

Good Practice Guide to Insulation

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Sponsors



Introduction

Buildings in the UK have been consistently shown to use more energy than predicted during design. A large part of this is due to construction quality, air gaps between and behind insulation are a major factor.

Passivhaus aims to directly address construction issues with a thorough quality assurance process. Nevertheless, testing has shown that there is still room for improvement on some Passivhaus developments. This guide aims to give building professionals an insight into good practice for designing, procuring, storing and installing insulation materials.

Lessons learnt from Passivhaus construction can also contribute to improving construction quality generally. This guide will be useful for any building professional interested in getting the most from the materials they use.

This guide is not a detailed design manual; other technical considerations should be considered when specifying and installing insulation materials. Refer to the manufacturer's product installation guides where available; these highlight particular material properties and give specific advice, which takes precedence over more general advice given here.

Background

Insulation reduces heat loss from a building by limiting heat transfer through external surfaces. Generally, this is by trapping small pockets of air or other gas inside a low conductivity material and minimising convection within the material.



Close-up photographs showing how a variety of common insulation materials trap gas within their structure. L- R: Mineral Wool, PIR Board, EPS, Woodfibre board, XPS.

The performance of insulation is dependent on the material and manufacturing process in the factory, **and** the installation on site.

During manufacture materials are tested regularly and certified independently when they leave the factory. By law they must state a 'declared thermal conductivity' (with the symbol λ_d) as part of their CE mark. This measurement is also called $\lambda_{90/90}$, the thermal conductivity achieved by 90% of the production with 90% confidence, it considers production variance and aging over a projected material life.

How an insulation material is installed on site is not tested (in the way, for example, airtightness is tested) and often not checked. Yet the way insulation is installed has a big impact on the actual performance. If gaps are left that allow air movement through, between or behind the insulation materials, more heat will be lost. For example, an air gap of 10mm behind insulation boards has been shown to double the heat loss through a construction¹. This is known as 'thermal bypass'.

Potential problems when fitting insulation are:

- Gaps between pieces of insulation material; rolls, boards or batts.
- Gaps where the insulation meets the building structure.
- Damaged or damp insulation materials being installed.
- Insulation getting damaged or wet before it is covered.
- Site work-arounds where design is unbuildable or detail is missing.

All these issues occur during installation, but are caused by a combination of the design, the specification of the material, and the workmanship on site.



This cavity has gaps between and behind the insulation boards. The actual heat loss through this wall will be far higher than the design predicts.

¹ [Lecompte 1990] Lecompte J, The Influence of Natural Convection on the thermal quality of insulated cavity construction, Building Research and Practice 6, 349 - 354 (1990)

Design

General

As in any form of manufacture or assembly, construction quality problems often begin at the design stage. This is also the time when it is most cost effective to solve them.

Decisions made early in the design may unintentionally limit the choice of insulation, for example by restricting the wall thickness shown in planning drawings. The likely specification needs to be considered right from the beginning of the project.

The role of the designer is to choose insulation materials that can meet the thermal performance requirements in use and on site. This goes further than materials that can theoretically achieve a given U-value. How the insulation will be installed and the final build quality need to be considered to meet the excellent thermal performance required for Passivhaus.

At the initial design stage specify a wall and roof thickness that can meet the thermal requirements even with an insulation that has a relatively low thermal performance by thickness: for example, with a conductivity of 0.040W/mK. This will leave room for choice in the material and façade connections during construction design.

U-Value Calculations

The designer should carry out U-value calculations based on realistic assumptions for what can be achieved in construction. In early design, a margin should be left to account for unresolved details, and to give flexibility during the development of the construction drawings. Remember to allow for how the insulation will be incorporated in the structure. e.g. will it fit between studs or form a continuous layer, as this makes a significant difference to U-values.

Calculations by manufacturers or suppliers should be rigorously checked by the designer; for more complex constructions a façade specialist should be used. Common errors in U-value calculations are:

- Not including accurate properties for other materials in the construction.
- Under-estimating repeat thermal bridges.
- Overlooking circumstances on site such as masonry supports.
- Using the lowest conductivity possible for masonry or concrete products.
- Missing or using lower densities of fixings.
- Missing correction factors for air gaps when using rigid board insulations².
- Including materials on the cold side of air gaps.

Specific calculations should be carried out, where possible, by a professional registered with a competency scheme such as the BBA/TIMSA U-value calculation competency scheme, or a Certified Passivhaus Designer.

Review the assumptions behind manufacturer U-value calculations, and ask for changes if they do not exactly reflect the construction design.

² Annex D.2 - BS EN ISO 6946:2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.



Materials

There is a wide range of insulation materials offering different properties and installation methods suited to different situations. All can potentially be used in Passivhaus projects. When choosing the right insulation material, the designer needs to consider:

- Thermal performance and the thickness needed.
- Resistance to factors in the environment and exposure to weathering, water and light.
- Structural support or loading through the material.
- Moisture transfer requirements.
- Acoustic requirements
- Fire resistance.
- Ecological considerations, such as embodied carbon or Ozone depletion potential.
- Life cycle and disposal considerations.
- Cost and availability.
- **How and where the material will be installed.**

Balancing these different requirements is difficult, and often a compromise. The practical process of installation can sometimes be neglected and is the focus of this guide. A summary of the main insulation materials available is given in the following table.

Insulation type	Typical thermal conductivity range	Description	Characteristics
PIR/PUR (Polyisocyanurate/Rigid polyurethane)	0.021-0.028W/mK	Foil or fleece faced rigid board	●
Phenolic	0.018-0.023W/mK	Foil or fleece faced rigid board	●
Expanded Polystyrene (EPS)	0.036-0.038W/mK	White rigid board	●
Graphite Expanded Polystyrene (GPS) Neopor™	0.030 – 0.032W/mK	Grey rigid board	●
Extruded polystyrene (XPS)	0.033-0.036W/mK	Rigid board	●
Mineral or glass wool	0.032-0.045W/mK	Roll, rectangular batt or blown loose fibres in range of densities	● ●
Cellulose	0.038-0.040W/mK	Loose fibres	● ●
Woodfibre wool	0.038-0.040W/mK	Rectangular batt	● ●
Woodfibre board	0.037-0.050W/mK	Board in a range of densities	● ●
Vacuum Insulated Panels (VIP)	0.007W/mK	Rigid foil faced boards of fixed size	
Aerogel™	0.015W/mK	Fibre batt or backing to rigid gypsum fibreboard	●
Hemp wool	0.038-0.040W/mK	Rectangular batt	● ●
Sheep's wool	0.042-0.050W/mK	Roll or rectangular batt	● ●
Straw bale	0.055-0.065W/mK	Bale or loose fibres	● ●
Foamglass	0.041-0.050W/mK	Rigid block, board or loose fill	● ●
Cork	0.060W/mK	Board	● ●
Vermiculite	0.058-0.075W/mK	Loose fill	● ● ●
Calcium Silicate board	0.059 W/mK	Board	● ●

Table 1: A summary of readily available insulation materials with their typical conductivities and an indication of other characteristics.

Characteristics Key:

- Degrades and crumbles after extended exposure to light
- Impermeable to moisture / can be used below ground
- Incombustible
- Permeable to water or water vapour
- Hygroscopic and can absorb moisture from the air

Specify the thermal conductivity of the insulation build-up, not just the product or U-value. Check that this is based on the declared thermal conductivity and is achievable at the thickness of insulation that you are using.



Tolerance

Construction is not a precise process: tolerances of greater than +/- 10mm are possible, and locally this can be much higher. The finished construction also moves over time, settling at different rates depending on the material and conditions. These factors must be considered during design.

Insulation is installed against or between parts of the building's structure. It needs to be fitted with no air gaps, and often at speed thanks to pressure from project costs. Making allowance for the interaction between materials is important.

Rigid boards work well covering large flat areas where they are fitted against a single uninterrupted surface. Fitting them between elements such as timber studs, especially in more complex geometry, is not easy to do accurately unless the product is specially designed for that use, or particular and time-consuming care is taken when cutting.

Fitting rigid sheets against an uneven surface such as a masonry wall or cast concrete edge can result in gaps behind the boards. Consider how the board is held against the surface, whether any adhesive will fill the small gaps, or whether a levelling coat will be required.

Softer mineral wool or fibre insulation products are flexible and can be installed acceptably between structural elements, but the roll or batt may not always hold its shape, meaning gaps are left in the insulation layer. The width and thickness of rolls or batts should be sized to the application to minimise cutting. Generally oversizing the thickness by around 10-30mm ensures a snug fit.

The designer should consider the layers of insulation and the sequence that they will be installed in. This detail on drawings is important and can help the contractor during installation.

Blown insulation products remove the need for cutting and fitting on site and can provide a reliable, high quality and fast installation – even to complex geometries.

PIR, PUR and Phenolic rigid boards are readily available and have a low thermal conductivity meaning a theoretically lower construction thickness for the same performance. This makes them attractive to specify, which can sometimes lead to them being used in inappropriate situations, where a good installation may be difficult. The actual performance is very dependent on the installation and this should be factored in to the design calculation, for example by including the air gap corrections recommended in the calculation standards².



Perimeter insulation against a masonry wall showing that an unacceptable gap behind the boards is possible even when they are fixed against the wall. Image: Will South 2017.

Consider the structure that the insulation material will sit against. Is it flat and straight? Are there regular sized gaps that the insulation must be cut between? What is the substrate that the insulation is to be installed against?

Installation Method

Most insulation materials can be installed on or off site – through cutting and fitting by hand, blown or sprayed application. The options available depends on the construction method.

Cutting and fitting by hand will take considerably more time and quality management on site to ensure the required quality is met. Consider offsite pre-fabrication or blown insulation where there is complex geometry to overcome, or time on site is particularly constrained. These come with a cost premium, but this must be offset against the additional time required on site by skilled trades to achieve the same quality.



Procurement

Contractual obligations

It is crucial that the designer clearly identifies the required performance in formal contract documents. The exact form of this varies between contract types and projects. As a minimum, U-values are always specified, and it is important to note that the contractor is responsible for delivering the quality of installation to achieve the rate of heat loss that this indicates. This will be checked during construction by the designer – arrangements for this should be agreed from the start of the contract.

A separate, skilled task

Insulation requires care with cutting and fitting and should be considered a dedicated process in the construction programme. The contractor should carefully consider whose subcontract package the insulation fits in to, whether they have the required skills and tooling, and when it fits in the sequencing of tasks.

Understand the specification

Each insulation material will have been chosen and specified for a reason. During purchasing the material properties, thickness and thermal conductivity of the insulation products must be checked and maintained by the buyer.

The performance of the same insulation type can vary between manufacturers and even between different thickness of material from the same manufacturer. This has a substantial effect on the U-value and actual performance of the construction.

Case study

The declared thermal conductivity has been compared between different manufacturers and thicknesses for XPS insulation. A decrease in performance of more than 15% is shown across different manufacturers and thickness. All values are from manufacture data sheets.

Change	XPS Product	Declared thermal conductivity
Base case	50mm board from manufacturer W	0.033W/mK
Different manufacturer	50mm board from manufacturer X	0.035W/mK
Different thickness	150mm board from manufacturer X	0.038W/mK

Table 2 – A comparison between the thermal conductivity of the same material provided by different manufacturers and at different thicknesses. This could be similar for other materials.

This means that if the same overall depth and type of insulation was used, the three 50mm boards or one 150mm board would give different performance. Note that in this case the conductivity gets worse for a thicker board, it can be more usual for the conductivity of other materials to improve with thickness.

Substitution

Changes of material may be necessary due to product availability or cost savings between manufacturers, or it may not be possible or practical to install the insulation material where the designer intended. It is important that the contractor manages these changes and alerts the design team so that they can confirm that any different performance or material is acceptable.

Standard thicknesses of material can be cheaper, even if they are thicker, due to availability and the quantities manufactured. For example, 100mm board is generally cheaper to purchase than 90mm. Again, check with the designer that any change is acceptable.



Delivery & Storage

Insulation takes up a lot of space and is vulnerable to damage from the weather or traffic on site. Care when storing and moving the product, to protect it from damage, can make a huge difference to the finished installed result.

Receipt of delivery

The contractor should identify a designated area for each insulation type before orders are due on site. This could be a marked off compound or a room that has no works underway. Ideally the storage area will be as close to the installation site as possible, to limit the need to move and carry delicate materials. Different products should be separated so that it is clear which products are to be used in which location.

Take delivery of the order as close to the install time as possible. For insulation deliveries, the packaging and label showing the thermal conductivity should be photographed by the contractor. This should be compared to the specification and will be needed as evidence for any building performance assessment.



The label on a pack of insulation showing the thermal conductivity of the product.

Check for any split packs or damage from strapping on delivery and reject damaged materials, or reserve for areas that require cut material. Offsite pre-fabricated parts should also be checked on delivery.

Check insulation deliveries and photograph packaging labels to check the thermal conductivity against the design.

Storing insulation materials

Lay board insulation flat on a smooth clean surface or on regular timber supports clear of the ground. Stacking sheets on their side damages the edges and corners and makes a good installation difficult.

Mineral wool and other soft materials absorb water, so must be protected from the weather and moisture from the ground. If space is available store the material inside. Mineral wool that has become saturated can change mechanical properties and take a long time to dry out fully; it should not be used.

Oil-based insulation materials are typically degraded by long exposure to light (UV), and can also be vulnerable to substances (for example fuel and solvents). Cover and protect packs of insulation, particularly if they are partly open. On an exposed site packs may need to be weighted down to prevent them being blown over and damaged.



An example of good storage on site. The insulation packs are complete and unopened and raised off the ground to prevent water ingress.

Moving materials around site

Keep the insulation in its original packaging for as long as possible - it is designed to protect the insulation and enables correct identification.

Generally large packs should be lifted by machine to the storage area, in their original packaging. If it is not on a pallet it should be well supported by some sacrificial material.

After delivery operatives will generally carry materials by hand. Mineral wool batts and rolls are generally robust and can be carried, passed and stacked with little fear of damage. Rigid boards are more vulnerable, and should be carried in small stacks by two people; although most can easily be handled by one person, the size and bulk mean the edges and facing get damaged easily, particularly when negotiating scaffolding or tight spaces.



Installation

Benchmarking

Installing thick layers of insulation is still relatively unusual in the UK, and operatives may not have come across the required workmanship before. Demonstrating what 'good' looks like and showing relevant examples of best practice is a key part to achieving high quality on site. These sessions are also invaluable for designers.

For specialist construction, it may be necessary to build an example panel to demonstrate how the materials will go together and to highlight key challenges. For most cases photographs of good practice are sufficient. This guide includes a range of good practice photos.

Make sure the installers understand what is required of them and have the correct training, not just the supervisor. Training or 'toolbox talks' may be available from the manufacturer or supplier.

Preparation

Check and clean all surfaces that the insulation will be installed against for dust and obstacles that may form air gaps. This should include:

- Thoroughly sweeping floor surfaces, membranes or concrete slabs.
- Removing any mortar spots or irregularities in the surface.
- Repairing any holes or voids.
- Removing any existing finishes that could degrade or decay behind the insulation.

Cutting insulation

Generally, cutting insulation should be kept to a minimum. Where cuts are necessary, a clear strategy or method statement should be used. Follow manufacturer's recommendations for suitable protective equipment, but generally wearing gloves, safety glasses, long sleeves and a dust mask is recommended.

Fibre based products

Loose and easily compressed fibres are relatively easy to cut, but difficult to cut neatly. Do not rip or tear the material.

Cut the insulation when still compressed in its packaging where possible. This creates a neater edge and is more effective where a large amount of material of the same dimension is needed, for example a narrower batt to fit between timber studs. Use an old carpentry hand saw or serrated blade to cut packs of insulation.

Single pieces of insulation to fit in irregular gaps can be cut by compressing the insulation on a hard surface with a straight edge, for example a piece of timber, and using a sharp blade. The insulation should be cut over size by 5-10% of the width, to ensure there are no air gaps. This type of insulation is generally more forgiving of cut joints as it is compressible.

Rigid boards

Plain insulation boards are soft and easy to cut, but difficult to cut straight and flat for butt joints. This is especially true for thicker boards. The trailing edge of the saw is likely to wander meaning only one corner of the cut edge is straight, which causes air gaps.

Depending on the material and site facilities there are a variety of ways to overcome this. In general:

- Set up a cutting table or clear area where the board can be supported flat without damage.
- Run the saw or blade along a straight edge where possible. Otherwise clearly mark a straight line using a string line or marker. For hand saws, a thicker edge or jig perpendicular to the insulation can be used to ensure the blade runs perpendicular to the insulation.



- Be precise! Do not oversize the board too much. This helps to prevent the edge breaking when installing.
- Use a suitable saw or blade for the product. Specialist 'wavy edge' saws and jigsaw blades are available that cut with minimum dust and give a clean edge, but may bind in thicker boards. Toothed hand saws or electric tools cut very easily but leave a rough edge that may bead, and create a lot of waste material. For EPS and XPS boards, specialist hot wire cutters are available.
- Thinner boards can be cut with a blade, but ensure the board is cut from both sides and aim to cut through the material. With boards over 50mm thick cutting with a blade will leave snapped board edges that can cause gaps between material.



A range of hand tool blades designed specifically for cutting insulation. From left to right: an insulation jigsaw blade (Bosch), close-up of a handsaw blade (Bahco), a hot wire cutter for EPS insulation (Hilltop tools)

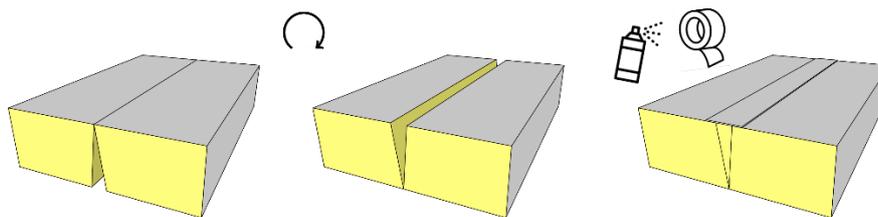
Fitting insulation

The whole of this guide is designed to make the actual installation of insulation as straightforward, fast and simple as possible. There will always be complications in practice though! Fitting insulation well is a skill; the contractor should give a dedicated team with the correct tools the time required on site.

Cutting and fitting insulation

Work from the edges inward. Use whole boards or batts with a straight edge at joints with other materials, and infill the centre of the insulation where it is easily accessible, and at the least vulnerable point for heat loss.

There must be no gaps between pieces of insulation anywhere in the depth. If needed use a suitable fill product, such as site-applied low expansion foam. Turn boards so that the larger gap is exposed and can be easily filled and inspected. Boards with a foil facing must be taped to prevent light getting to the product.



Although the joint between boards appears acceptable from above there is a significant gap between the boards that must be filled.

If there is more than one layer of insulation stagger the joints between layers by a minimum of 100mm, laying in a 'stretcher bond'.

Cut the insulation to fit tightly around any services. Seal gaps around services with a suitable filler such as site applied expanding foam.

Stagger the joints. If small gaps are unavoidable, ensure they are on the visible side and fill them with additional insulation material.



Blown insulation

Blown or sprayed insulation should be installed by a specialist trained in the requirements of the product they are using.

Check with the insulation blowing installer the size of opening needed, and ensure that there are sufficient openings in the right places to reach all cavities and voids in the construction. The installer should carry out density checks for the product as it is installed, and provide a density report for each cavity.

Protecting the insulation

After it has been installed, the contractor must protect the insulation until it can be covered permanently. This is to avoid damage from:

- site operatives and machinery: walking on insulation can damage it
- dirt and debris
- water
- sunlight

Particularly vulnerable locations are:

- Exposed foundation insulation – use a robust membrane or boards on top and do not allow foot traffic.
- Thresholds – cover the insulation with a ramp or walkway bearing on something solid, where access is required.
- Top of a cavity – cover with a membrane or board in bad weather and at the end of each day (ensure this drains away from the cavity, and not into it).
- Perimeter insulation – install after the wall structure where possible, or cover immediately.



Example images of unacceptable masonry cavities that have been left open to debris and water damage.

Use dedicated and clearly marked site traffic routes to avoid damage from walking over the edges of insulation. Remove and replace damaged material.

Fibre based insulation that gets wet on site should be only installed if it has been fully dried; this can be difficult for some materials, as some lose their performance or mechanical structure. Insulation that gets wet after installation usually must be removed and replaced.

Cover insulation at the end of each day and in heavy rain.



Inspection

Inspection is only part of the quality assurance process, and cannot be relied upon alone, but is nonetheless crucial. Structured inspections by the designer and a formal notification process should be used to track defects and remedial work. This establishes the importance of quality at the outset, and can give valuable feedback to the contractor during construction. It also gives feedback to the designer, to inform future projects.

It is impossible for the designer to check every installed location. Instead a careful plan of important or difficult junctions should be prioritised. Key places to include are:

- where the insulation needs to be cut awkwardly;
- insulation that is covered up quickly;
- where the insulation thickness is reduced and so more critical; and
- where a different or specialist product is specified.

Encourage self-inspection by the installation team against the benchmark, or example photographs.

Regular photographs

The contractor should take photographs of all installation, particularly of areas that need to be covered up straightaway such as below cavity trays. This is required as evidence by the building energy assessor. Collect photos regularly to a central storage. The knowledge that work can be seen later can change the quality expectations of the operatives and ultimately the culture towards quality and pride on site.

Spot checks

A surface visual inspection is often not enough: carry out a physical check of areas that are covered, particularly taped joints, underneath membranes, and below cavity trays.



It is important to make spot checks of insulation that has been covered.

Take note of any metalwork, structure or fixings going through the insulation layer to check against the design.

Thermal imaging is rarely useful during the construction programme as it requires specific conditions including at least a 10K temperature difference between inside and out. It can however be used after completion, which means no installation faults are ever completely 'out of sight' – something installers should be aware of!

A visual inspection is often not good enough. Spot check areas that are covered, particularly taped joints, underneath membranes, and below cavity trays.

Completion

Well installed insulation gives the most cost-effective way of reducing energy consumption in a building. Badly installed insulation can be close to worthless. Improving or carrying out remedial work to insulation during the life of a building is very expensive and disruptive, and it is therefore crucial that it is carried out correctly first time. Follow this guide, follow guidance from the manufacturer, do it once, do it properly, and if in doubt ask other members of the team!



Good practice examples



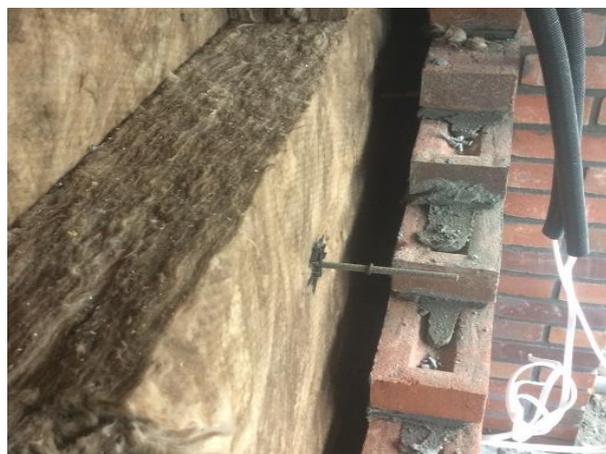
Perimeter insulation held back against the concrete edge using wedges of insulation. The gap will then be grouted to secure the boards. Image: ©Mikhail Riches Architects



Insulation installed beneath a screed with tight joints and clear service openings. The board joints must now all be taped and the vapour control layer laid. Image: ©Mikhail Riches Architects



An example of a foundation insulation product that allows casting of the concrete slab against the insulation to ensure no gaps.



A mineral wool cavity installation with no debris. The insulation is installed well ahead of the brickwork and temporarily covered to ensure no water damage occurs.



Density check of blown insulation.



Low conductivity wall ties & tightly packed soft fibrous cavity insulation clean from debris ©Parsons Whitley

All images in this document, unless otherwise stated, are ©Will South.

References

Specific references are referred to as footnotes within the text. All documents used are listed here. Where used manufacturer data is from the CE mark certificate, Declaration of Performance or BBA Certificate.

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