

Passivhaus primer: Designer's guide

A guide for the design team and local authorities



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Orientation

Where possible a Passivhaus building should be orientated along an east/west principle axis so that the building faces within 30 degrees of due south (in the Northern hemisphere). This allows the building to derive maximum benefit from useful solar gains, which are predominantly available to south facing facades during the winter months. With good planning a Passivhaus building can also be realised where a south facing orientation is not possible, although the annual heating demand may increase by 30-40% as a result.

Building form

The compactness of a building is indicated by the surface area to volume (A/V) ratio. This ratio, between the external surface area and the internal volume of a building, has a considerable influence on the overall energy demand. Buildings with identical U-values and air change rates, and orientations could have significantly different heating demands simply as a result of their A/V ratio.

The size of a building also influences the A/V ratio. Small buildings with an identical form have higher A/V ratios than their larger counterparts. It is therefore particularly important to design small detached buildings with a very compact form, whilst larger buildings offer the designer greater freedom to explore more complex geometries.

Figure 1 illustrates the influence of form and size on the A/V ratio. A favourable compactness ratio is considered to be one where the A/V ratio $\leq 0.7 \text{ m}^2/\text{m}^3$. In some parts of the UK with poor winter insulation very small detached dwellings may require even lower A/V ratios in order to achieve the Passivhaus specific heating demand.

Form factor

A useful variant of the A/V ratio known as the 'Form Factor' describes the relationship between the external surface area (A) and the internal Treated Floor Area (TFA). This allows useful comparisons of the efficiency of the building form relative to the useful floor area. Achieving a heat loss Form Factors of ≤ 3 is a useful bench mark guide when designing small Passivhaus buildings.

Irregular forms

Figures 2 and 3 illustrate the effects of designing more complex forms which result in an increased surface area for the same useful floor area. This change in the A/V ratio impacts on the amount of additional insulation required to maintain the same heating demand:

In addition to increasing the insulation required to achieve the same overall Heat Loss Parameter (HLP) a building with a more complex form is likely to have a higher proportion of thermal bridges and increased shading- factors that will have an additional impact on the annual energy balance.

All of the forms in Figure 4 are able to achieve the Passivhaus standard but a higher performance specification to the built fabric is likely, instead of the recommended $0.15 \text{ W}/\text{m}^2\text{K}$ the fabric may need to achieve circa $0.08\text{-}0.10 \text{ W}/\text{m}^2\text{K}$.

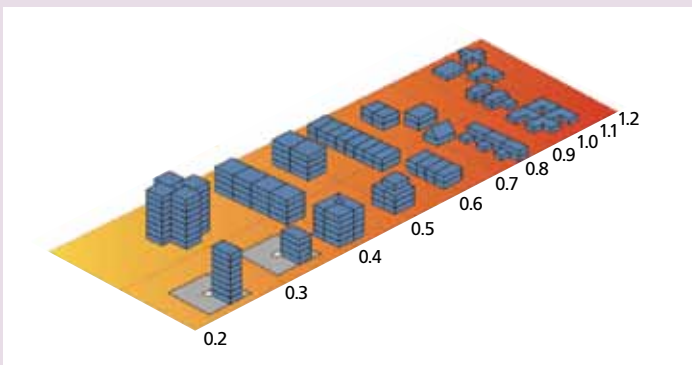


Figure 1 Surface area to volume ratio (A/V)

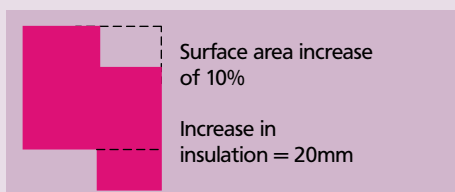


Figure 2 10% greater surface area

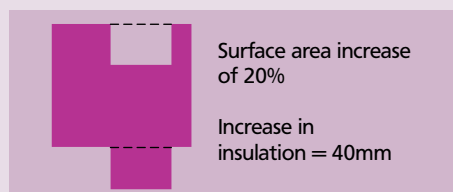


Figure 3 20% greater surface area

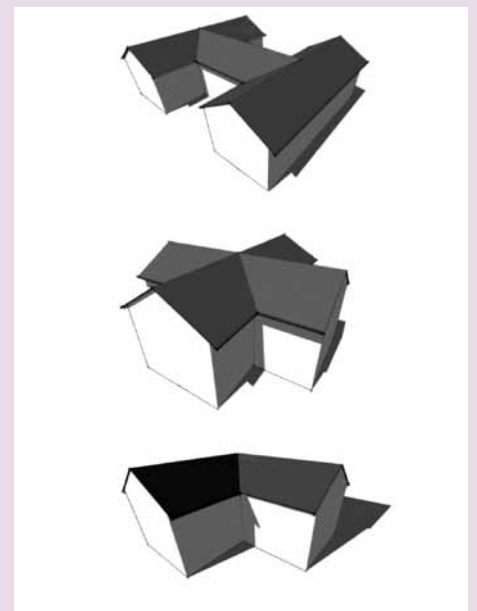
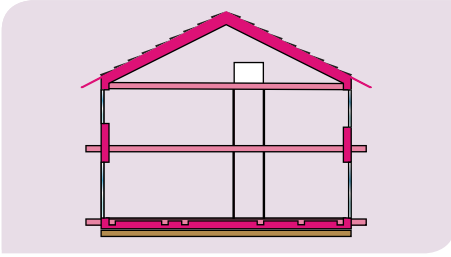


Figure 4 Forms



U values of fabric and opaque elements

The Passivhaus standard requires that all thermal elements have a very good U value. Whilst the absolute value adopted for the opaque elements will vary according to the buildings context (location, form etc), the recommended limits are:

- walls, floors and roofs $\leq 0.15 \text{ W/m}^2\text{K}$
- complete window installation $\leq 0.85 \text{ W/m}^2\text{K}$

In some situations these backstop values will need to be improved upon and should therefore be regarded as the maximum acceptable U-values.

Construction types

Virtually all construction methods can be successfully utilised for Passivhaus design. Masonry (cavity wall and monolithic), timber frame, off-site prefabricated elements, insulated concrete formwork; steel, straw bale and many hybrid constructions have been successfully used in Passivhaus buildings.

External insulation is widely used in Passivhaus' due to the reduction in thermal bridging that occurs when the structural members are wrapped in insulation.

Figure 5 shows a variety of wall constructions capable of achieving a U value of $\leq 0.15 \text{ W/m}^2\text{K}$ with less than a 450mm build-up.

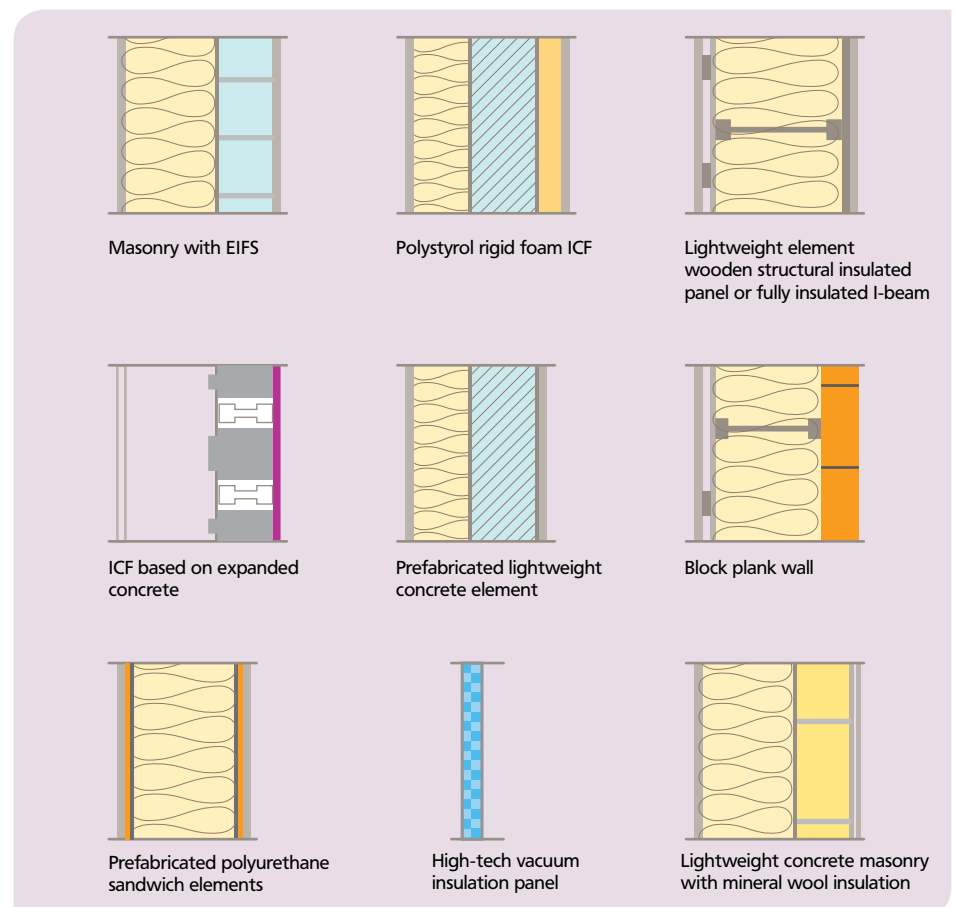
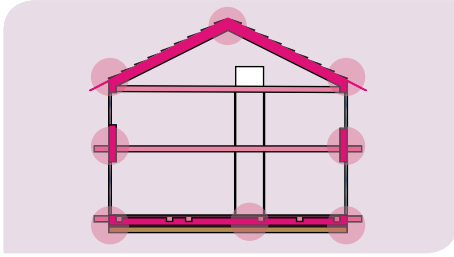


Figure 5 Passivhaus wall constructions



Thermal bridges

Geometric junctions and connections between elements typically provide a thermally conductive bypass route for heat loss and must be reduced or eliminated wherever possible. The diagram top left shows some common areas which thermal bridges can occur. Careful construction detailing is required to ensure the junctions do not create unnecessary heat loss paths. The use of external insulation provides a major advantage in reducing thermal bridges at geometric junctions. Strategic placement of insulation in and around junction details helps to reduce connection heat loss paths.

To avoid unnecessary heat loss a Passivhaus should be thermally bridge free, in practice this means that any linear (two dimensional) thermal bridges should have a psi (Ψ) value of ≤ 0.01 W/mK. In a Passivhaus the heat loss areas and thermal bridges are calculated relative to the external boundary layer, and with good detailing it is possible to achieve negative psi values in some cases. A negative psi value implies that a junction is so well insulated that the two dimensional heat flow through the junction is less than the respective one dimensional heat flows. Point (three dimensional) thermal bridges can occur at the corners of buildings and whenever a column or point fixing creates a three dimensional heat flow path through a thermal element. In Passivhaus design these

bridges are usually designed out and can be ignored unless they contribute to significant heat losses.

The Passivhaus Planning Package (PHPP) and certification process requires the quantified input of all significant thermal bridges. Where standard Passivhaus details are used a number of reference sources are available for psi value determination. The use of bespoke construction details will necessitate accurate modelling of individual thermal bridges using specialist software. Two and three dimensional thermal bridging calculations can be carried out by BRE to confirm the Psi and Chi values of any junction and expert advice given on ways to improve construction detailing.

Once built thermal bridges may be identified through the use of infra-red thermography, however at this stage it is usually too late to do anything about them! The first strategy in thermal bridge free detailing is to identify all of the possible thermal bridges at the outset and design them out systematically. With experience it is usually possible to tell whether a thermally bridge free design has been achieved before numerical calculations are carried out.

In Figure 6 you can see the cold bridging at the wall and roof junctions and around the windows (image shown is not a Passivhaus)

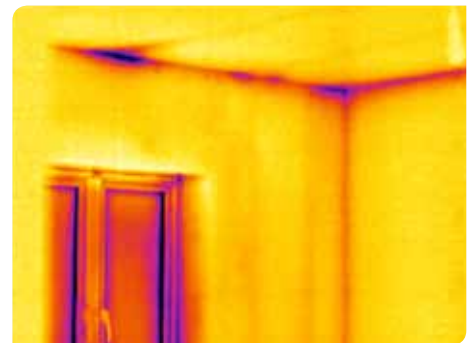
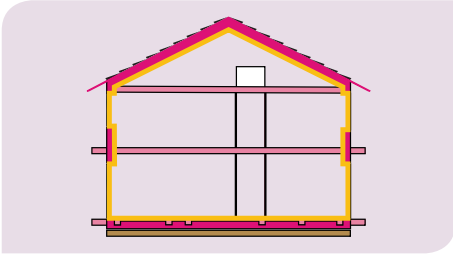


Figure 6 Cold bridging



Airtightness

In order to reduce the heating demand and prevent warm moisture laden air from entering the building must have very good airtightness levels. Good airtightness levels can only be achieved by using an air tight membrane or barrier within each of the building elements. Depending on the type of construction being used the air tight barrier may be formed by either a parging coat (masonry) a vapour barrier membrane or by using OSB-3 board or other timber sheet products of suitable thickness and airtightness. (See Figures 7 and 8.)

Where this layer is interrupted - by a window for example - a suitable proprietary tape is applied to connect the air-tight membrane or barrier layer to the window to ensure continuity of the air tight layer. The airtight layer should be clearly defined and specified at the Detailed Design stage and illustrated on all production drawings.

The air tightness of a Passivhaus building is defined by an n50 test measurement which combines both under and over pressurisation tests. The resultant air leakage at 50 Pascals pressure must be no greater than 0.6 air changes per hour (0.6 ac/h @ 50 Pa). The n50 test differs from the UK q50 test which measures the rate of air infiltration of the exposed building fabric irrespective of the buildings volume ($\text{m}^3/\text{m}^2\text{h}$ @ 50 Pa). Since the testing conventions also differ it is not possible to make direct comparisons between n50 and q50 readings.

Delivering such rigorous standards in practice is facilitated by good design at the outset. Correctly siting the air tight barrier within the construction build up reduces the need for repeated service penetrations (for cabling, pipe work etc). Where such penetrations are unavoidable proprietary gaskets and grommets are available to maintain an air tight seal. The airtightness of the building is greatly affected by the workmanship of the site operatives, so air tightness details must be buildable on site. It is imperative that the contractors are aware of the impacts of their trades on maintaining the airtight barrier and its importance in achieving the overall Passivhaus standard.

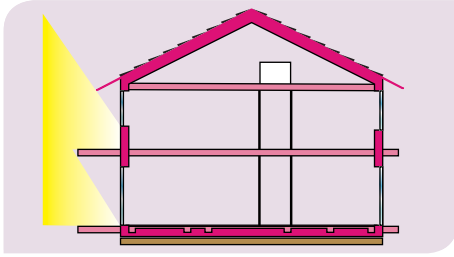
It is strongly recommended that at least two airtightness tests are built in to the construction schedule. The first test should be commissioned whilst the air-barrier is still exposed, ideally at the end of first fix stage when the joinery has been installed. A final test can then be carried out at completion by an ATTMA registered tester for inclusion in the PHI certification dossier.



Figure 7 Airtight membrane



Figure 8 OSB-3 with joints taped



Glazing, solar gains and shading

In order to benefit from the useful solar gains a Passivhaus requires the glazing to be optimised on the south façade with reduced glazing on the North façade. Historically Passivhaus buildings in continental Europe had very large areas of South facing glazing often in excess of 50% of the façade area. With good design and modern glazing systems it is possible to reduce the glazed area of the South façade to approximately 25-35% allowing more conventional glazing ratios to be adopted where this is a planning requirement.

It is desirable to position habitable rooms such as living rooms, dining rooms, children's bedrooms etc. on the south façade as the larger windows will provide a pleasant ambiance with good daylight factors. Conversely, rooms where a view out and good daylight factors are not so important such as WCs, bathrooms, store rooms and building services can be placed on the north façade (Figure 9).

Triple glazing and doors

In more temperate climates such as parts of Southern Europe it is possible to achieve the Passivhaus standard using good quality double glazing. In the UK however Passivhaus buildings must use triple glazed windows; there are two main reasons for this:

- 1 To reduce unwanted heat losses through the window
- 2 To increase the surface temperature of the inner pane thereby reducing radiant the sensation of cold "draughts" from the glass and the possibility of mould growth.

Glazing suitable for use in a Passivhaus building should have been independently certified by the Passivhaus institute in order to verify that a standard glazing unit (1.24 x 1.48m) has a whole window UW value of $\leq 0.80 \text{ W/m}^2\text{K}$ and can achieve U value $\leq 0.85 \text{ W/m}^2\text{K}$ once installed.

Glazed components of doors must achieve a similar glazing specification and the installed U value of a Passivhaus door should be $\leq 0.80 \text{ W/m}^2\text{K}$.

Airtightness is a critical aspect of all Passivhaus glazing and doors and is often overlooked. It is critical that multiple continuous airtight seals are used in conjunction with a robust gearing system to ensure that air leakage when tested at $Q(100 \text{ Pa}) \leq 2.25 \text{ m}^3/\text{hm}$.

Solar gains and glazing

Solar gains make up a significant component of the free heat gains available to a Passivhaus during the heating season (Figure 10). For this reason Professor Wolfgang Feist stated that "as a side effect these windows themselves become radiators for the room"!

To make optimum use of the useful solar gains in winter in addition to good orientation the glazing must have low installed U values ($\leq 0.85 \text{ W/m}^2\text{K}$) to reduce heat losses and good solar transmittance (g-values ≥ 0.5).

Conversely too much glazing can lead to an overheating risk in summer, so good seasonal shading is important in Passivhaus design. Careful attention should be given to shading from the high summer sun angle particularly on South, West and East facades. The efficacy of seasonal and permanent shading devices can be tested in the Passivhaus Planning Package as part of an overheating reduction strategy. For maximum performance the glazing and shading specification should be fine-tuned on each façade of a Passivhaus building.

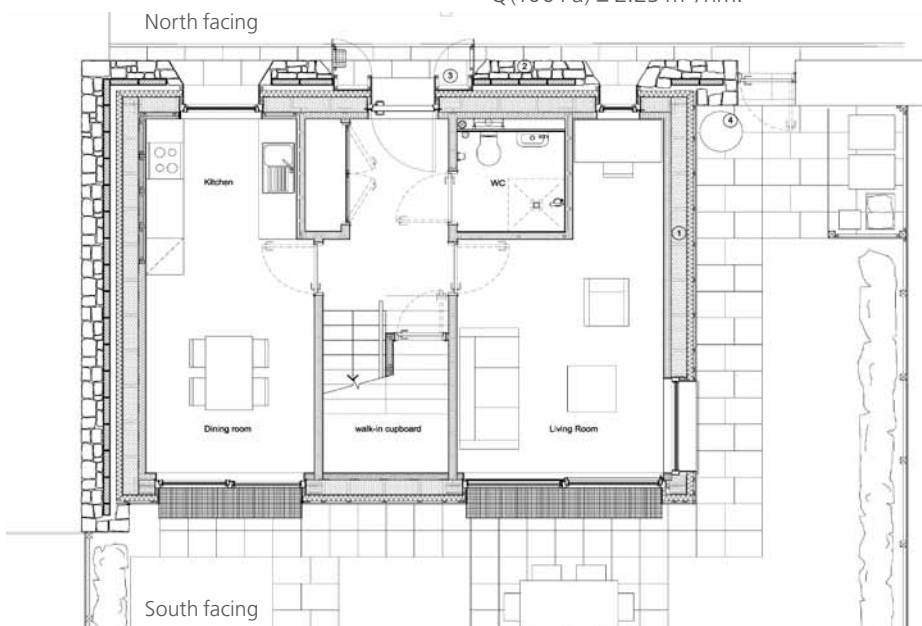


Figure 9

Summer overheating and shading

A central part of the Passivhaus principle is to make use of solar gains in winter to reduce the heating demand. This can mean that there is a potential for overheating in the summer, particularly where south facing glazing has been maximised. Therefore it may be necessary to incorporate some external shading to reduce the amount of direct solar gains in the summer. The diagram on the previous page shows a simple external shading system which utilises extended eaves for the first floor and a thermally broken brise-soleil for the ground floor in order to reduce high angled solar gains in summer. Correct positioning of fixed shading devices will allow maximum use of direct solar gains from the lower angled winter sun when it is most needed.

It is a requirement for Passivhaus certification that temperatures exceeding 25°C cannot occur in a building for more than 10% of the occupied year. For a dwelling the occupied year is considered to be 365 days a year but for a school this period might be much shorter. In the light of climate change predictions designers are recommended to achieve a figure of 5% overheating frequency or less (using current day data) and to make provision for additional seasonal shading devices to combat future overheating risks.

A number of further strategies are available to reduce overheating risk in Passivhaus design. These include the use of conventional cross ventilation and night purge ventilation. Mechanical options include using the Heat Recovery Ventilation system in by pass mode with or without additional ground or brine loop pre-cooling options. Thermal mass may also be used where appropriate to attenuate some of the diurnal temperature variations induced by unwanted solar gains however attention should be given avoid over reliance on this concept since it may be contra indicated during periods of prolonged overheating.

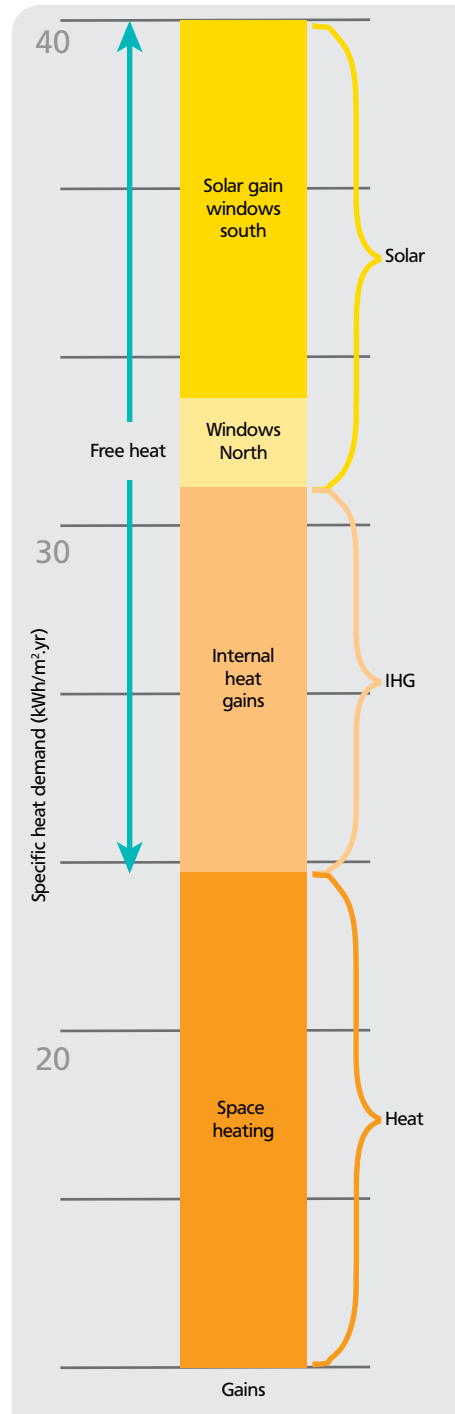
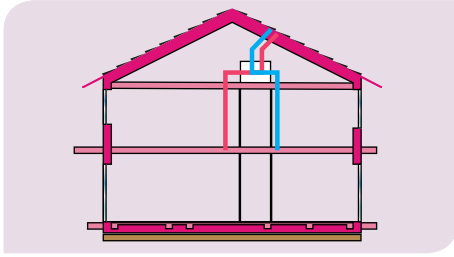


Figure 10 Useful solar gains as a percentage of free heat gains





Mechanical ventilation with heat recovery (MVHR)

Ventilation losses account for a significant component of the total heat losses in a low energy building. The only way to further reduce these losses whilst maintaining indoor air quality is to recover some of the heat lost from the outgoing air. By using natural ventilation through open windows in winter all of the heat from the warm air leaving the building is lost. Furthermore natural ventilation in winter is often undesirable as it can involve cold drafts and in some cases noise and environmental pollution entering the building.

Currently the only way to recover ventilation heat losses and provide consistently good air quality in a sufficiently energy efficient manner is by using Mechanical Ventilation with Heat Recovery (MVHR). An MVHR system works by extracting air from certain rooms and supplying fresh air to others. The air that is extracted is warm indoor air from wet rooms such as kitchens and bathrooms - this air then passes through a heat exchanger which gives up the warmth from that air to the incoming fresh outdoor air. The incoming and exhaust air masses remain separate throughout and the "pre-warmed" fresh outdoor air is then supplied to bedrooms, living rooms, dining rooms etc.

This is a very efficient and controlled means of providing fresh air to the habitable spaces. In most situations a small heater coil or frost protection unit is used in the MVHR unit to prevent frost occurring within the unit itself during critical winter conditions.

Only ventilation units which have been certified by the Passivhaus Institute and have a heat recovery efficiency of $\geq 75\%$ (calculated according to the Passivhaus Institut methodology) and a specific fan power of $\leq 0.45 \text{ Wh/m}^3$ should be specified. Detailed installation criteria are in place to strictly limit any unwanted noise transfer from the MVHR unit and sound transfer between rooms.

Heating

As the heating demand is so low a conventional heating system consisting of a centralised boiler feeding a series of radiators or under-floor heating coils in each room becomes unnecessary. In all but the coldest temperatures a Passivhaus building will be capable of maintaining an internal temperature of 20°C solely by relying on the heat given off by appliances, occupants and solar gain. During the very coldest weeks of the year a small amount of supplementary heating may be required and this can be provided in the form of a post-air heating unit in the MVHR ventilation system and/or small towel radiators or under floor heating in the bathrooms. Care should be taken when specifying the type and controls used for any back up heating as a poorly designed system could result in unwanted over-heating.



Primary energy appliances

The primary energy demand for heating, ventilation, hot water and domestic electricity is limited to 120 kWh/(m²a). Primary Energy is defined as "Energy as found in the natural environment prior to any conversion process i.e. the energy content of raw unprocessed fuels at the point of extraction and renewable energy resources". Primary energy takes in to account the losses incurred during raw fuel extraction and processing losses, as well as the generation, transmission/transportation losses. Producing and delivering one kWh of electricity requires approximately 2.5 times more energy than delivering one kWh of natural gas. Primary energy is strictly limited in Passivhaus buildings to ensure that there is not a considerable primary energy penalty (and associated carbon emissions) if electric resistance heating is specified throughout. In order to achieve the overall Primary Energy target highly energy efficient appliances (A++ rated washing machines, dishwashers etc.) and equipment (fans, pumps, lighting etc.) must be specified.

It is worth noting that energy generated by Photovoltaic (PV) systems may not be counted against the Primary Energy target in the PHPP methodology. This is deliberately implemented to prevent poor standards of energy efficiency being offset by the use of renewable energy.

Specification and contract

When undertaking a Passivhaus project it is prudent to ensure that all of the key Passivhaus requirements are written into the appropriate contract documentation. This will help ensure that all parties are aware of the requirements and design targets set for the project. Specific contractual clauses should be written to cover performance targets, the quality of materials and any substitution clauses as well as the workmanship required to meet the Passivhaus standard. An example of this would be the airtightness target which is highly dependent upon the quality of construction site workmanship.

Passivhaus Certification requirements

In order to have a building certified as a Passivhaus it needs to meet the following performance criteria:

Building energy performance	
Specific heating demand	≤ 15kWh/m ² .yr
or Specific Peak load	≤ 10 W/m ²
Specific cooling demand	≤ 15kWh/m ² .yr
Primary energy demand	≤ 120kWh/m ² .yr
Elemental performance requirements	
Airtightness	≤ 0.6 ac/h (n50)
Window U value	≤ 0.80 W/m ² K
Window installed U value	≤ 0.85 W/m ² K
Services performance	
MVHR heat recovery efficiency	≥ 75%*
MVHR electrical efficiency	≤ 0.45 Wh/m ³
Thermal and acoustic comfort criteria	
Overheating frequency	> 25°C ≤ 10% of year
Maximum sound from MVHR unit	35 dB(A)
Maximum transfer sound in occupied rooms	25 dB(A)
* Note MVHR efficiency must be calculated according to Passivhaus standards not manufacturer's rating	



Warm climates

The Passivhaus standard was initially developed for mid and northern European climates but the concept has been proven to work extremely well in hot climates as well. High levels of airtightness and insulation work equally well in protecting buildings from overheating provided there is adequate solar shading in place.

The Passivhaus Institute published a detailed study of Passivhaus performance in Southern European climates and found the following:

- Double glazing is acceptable in more temperate climates
- Thermal mass and moisture absorbing (hygrothermal) materials gain in importance
- Movable external shading is essential
- Maybe need for active cooling and/or dehumidifying
- Any additional cooling demand $\leq 15 \text{ kWh}/(\text{m}^2\text{a})$
- The ground can be used as a heat or cold buffer for tempering the supply air

Where the frequency of internal temperatures above 25°C exceeds 10% of the year additional measures are required to protect against summer overheating. Cross ventilation through open windows and night purge ventilation strategies may also be incorporated as part of the Passivhaus cooling concept when appropriate. Where such strategies are not possible Passivhaus permits $15 \text{ kWh}/(\text{m}^2\text{a})$ of additional cooling energy to be used. Such a small cooling load has proven to be sufficient in almost all cases because the Passivhaus concept is highly effective in reducing unwanted heat gains.

Southern hemisphere

The Passivhaus concept has also been proven to work equally well in the Southern hemisphere. The main difference is the need for north facing glazing rather than south facing glazing as is required in the Northern Hemisphere. Additionally, depending on the latitude and climate, it is likely that external shading will be needed on the north and west facing façades to prevent overheating. A mirroring tool is available from Passipedia which allows Southern Hemisphere climate data to be correctly entered in to the PHPP model.



Certified Passivhaus, Santa Fe, California

Our services

Consultancy

All members of BRE's Passivhaus team have completed the Certified Passivhaus Designer training and are able to provide expert advice at all stages of the development, including:

- Design Concept and Strategy
- Low energy design advice
- Construction techniques
- Toolbox talks for on-site inductions and management
- Generating Passivhaus information packs for specific buildings
- Thermal modelling of construction details

Certification

BRE is registered with the Passivhaus Institut as an official Certifier for Passivhaus buildings

- Pre assessments
- Full Building Certification
- Reduced rate certification via BREs Passivhaus Certification Scheme (PCS) for qualified CEPH Designers

Testing

- Airtightness detailing and testing to n50 and q50 testing methods
- Airtightness compliance reports for Passivhaus Certification and UK compliance
- IR Thermography
- Co-heating testing
- Monitoring and testing for 'as built' performance
- Post occupancy surveys

Training

BRE is registered with the Passivhaus Institut as an official training centre for Passivhaus training courses

Certified Passivhaus (CEPH) Designer

A fast track training programme leading to the examination required to become a fully Certified European Passivhaus (CEPH) Designer. This qualification is recognised as the industry standard for those intending to work professionally as a Passivhaus designer in the UK and abroad. BREs CEPH Designer training course has one of the highest pass rates in Europe which has been acknowledged by Dr. Wolfgang Feist.

One-day Passivhaus Introduction and Workshop

An introductory course and workshop is aimed at all those with an interest in low-energy design, construction and the Passivhaus standard. It introduces the delegates to the Passivhaus principles, walking them through best practice construction techniques whilst highlighting the outline specification and certification criteria. The course also introduces the delegates to the Passivhaus Planning Package (PHPP).

For further information

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BRE are registered with the Passivhaus Institut as certifiers and designers for the Passivhaus and EnerPHit Standards.



BRE Trust

The BRE Trust uses profits made by BRE Group to fund new research and education programmes, that will help it meet its goal of 'building a better world'.

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Other Primers in this series:
Passivhaus Primer: Introduction
Passivhaus Primer: Contractor's Guide
Passivhaus Primer: Airtightness Guide

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