

How to build a Passivhaus: Rules of thumb



About the Passivhaus Trust

The Passivhaus Trust is an independent, non-profit organisation that provides leadership in the UK for the adoption of the Passivhaus standard and methodology. Its aim is to promote the principles of Passivhaus as a highly effective way of reducing energy use and carbon emissions from buildings in the UK, as well as providing high standards of comfort and building health.

The Passivhaus Trust aims to:

preserve the integrity of Passivhaus standards and methodology

promote Passivhaus principles to the industry and government

undertake research and development on Passivhaus standards in the UK.

For more information:

www.passivhaustrust.org.uk

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Design approach and system choices

Jonathan Hines

Summary

Passivhaus should inform and influence every aspect of your design approach and choice of construction system. This need not be seen as limiting creativity of design nor as restricting what construction system to adopt. To achieve an economic solution, Passivhaus must be understood and integrated into the design approach and system choice from the outset.

Design approach

There are many factors influencing your approach to designing a building, including: location and site; your client's brief, budget, and programme; funding requirements and regulatory standards; and your own design philosophy.

Passivhaus should be seen as one of the fundamental factors influencing design as it cannot be achieved simply by meeting each separate technical standard such as airtightness or window U-values. Passivhaus should become an integrated part of your design approach, underpinning, and even inspiring, all the other factors influencing your design.

Choosing the design approach

To ensure that Passivhaus is integrated into the design of the very earliest ideas, its principles and standards must be understood by all members of the design team.

Key early decisions that may be difficult or impossible to change later – including siting, orientation, building form, and fenestration – have a major impact on the viability and economy of achieving Passivhaus.

It is recommended that the design is modelled using the Passivhaus Planning Package (PHPP) at the earliest

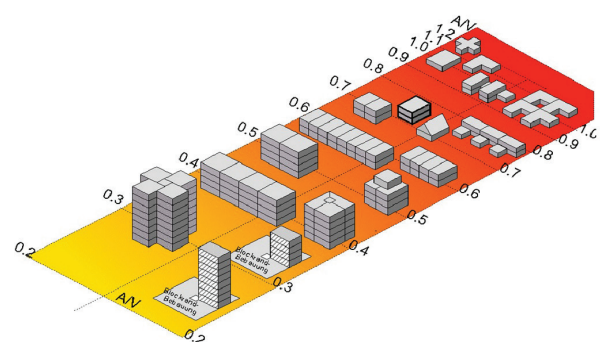
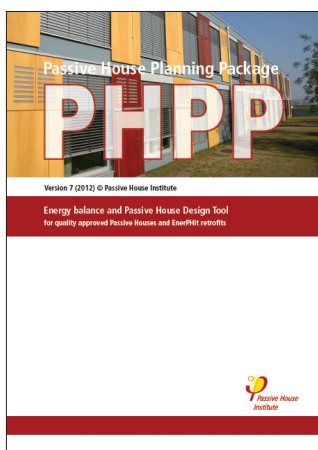
opportunity, in order to test and shape these key early design decisions. PHPP should be seen and used as a powerful design tool, helping you to develop your design approach, rather than as a procedure for proving compliance later, when it might be too late.

Explore the impact of the building's form-factor ratio, the area of external envelope through which heat will escape compared to the area of usable internal building area, and you will quickly discover that whilst almost anything can be made to work, the better this ratio is then the more economic the solution. Aim for a ratio of 0.3 or less.

Test the influence of altering the building's siting and orientation, or the total and relative quantity of glazing on each elevation, and you will be able to understand the way in which simple environmental principles influence the energy efficiency of a building's performance. Achieving good design requires not only the solving of a multitude of design challenges, but in the development of creative synergy between them.

Good Passivhaus design requires a fully integrated design approach, out of which an even greater creative synergy can be developed. This will produce buildings that not only meet the client's brief, and look and feel good, but do actually work with proven energy efficiency and excellent comfort.

Passivhaus Planning Package (PHPP) Manual cover



Form-Factor Ratio



ABOVE: Standard masonry construction. Photo: Architype.
LEFT: Standard concrete frame construction. Photo: Architype.

System choices

Passivhaus does not dictate any particular construction system. Indeed, practically any construction system can be used and adapted to achieve Passivhaus, though each will have its own advantages and challenges for your particular project.

The important issue to consider is which construction system is best suited to achieve the stringent requirements of Passivhaus – such as airtightness, elimination of thermal bridging and appropriate U-values – given the particular building type you are designing, its function and the form you are developing.

As a general rule avoid mixing different systems within one building, as this introduces interfaces that will make achieving Passivhaus challenging and more expensive than it needs to be.

System choices for Passivhaus developments

Construction systems can generally be classified as lightweight with less thermal mass (such as timber or steel frame) or as heavyweight with more thermal mass (such as masonry or concrete frame), although elements of thermal mass can be introduced to timber or steel.

The high levels of fabric performance and carefully controlled solar gain lead to internal environmental conditions remaining very stable. Passivhaus does not generally require either light or heavy thermal mass, and other considerations such as function, occupancy and climate will influence this choice.

An important factor in choice of system, is the likely procurement route, and the availability of an appropriate contractor. Thus if you are working on a domestic project and local builders are experienced in traditional masonry, choose masonry as you are more likely to achieve Passivhaus by working with the available skill base.

On larger projects there may be pressure to use steel frame due to its familiarity to large contractors and consequent cost advantages, so you may need to choose steel frame and adapt it to suit Passivhaus.

Similarly, key aspects of construction detailing should inform system choice. Details and junctions need to be designed with construction and assembly on site under realistic conditions (eg weather!) in mind. This is to avoid site compromises or later changes under pressures such as time, cost and materials availability during construction that can easily compromise design and cost.

Key Passivhaus issues with each of the main construction systems are summarised below.

Steel frame:

- Address potential thermal bridge with connection of columns to foundations.
- Ensure steel structure does not pass through the thermal envelope at floors, roofs or for ancillary elements of the building.
- Achieving airtightness on the inner side of the wall will be challenging, if not impossible, due to the number of structural penetrations. Ideally locate the airtightness line within the wall and on the outside of the structure where it can be continuous and unbroken by the structure.
- Avoid heavy external cladding hung off the structure, or excessive cantilevered structures, as this will create unnecessary thermal bridging.

Timber frame:

- Generally easy to build on a concrete raft 'floating' on EPS insulation, to eliminate thermal bridging.
- Consider the wall build up carefully, to avoid thermal bridging caused by solid studs, and use I-beams or a two layer wall with an inner structure and outer insulation wrap.
- Airtightness can generally be achieved with a membrane or racking board with tape over joints; racking boards are more robust. If a membrane is used on the internal face of the wall it is beneficial to have a service void to protect the membrane.
- Avoid elements of structure crossing the thermal envelope, for example, avoid roof overhangs with projecting joists that act as thermal bridges and make airtightness tricky.
- Avoid heavy cladding that might require a separate foundation.

Traditional masonry:

- Achieving Passivhaus with traditional masonry requires very wide insulated cavities between inner and outer masonry and thermal bridge free ties.
- This can create tricky detailing at window and door openings, and structural instability over large openings.
- It also creates voids under cavity barriers that are difficult to insulate on site.
- Airtightness can generally be achieved with parge or plaster.
- A wide cavity building on a concrete raft floating on insulation can be tricky, as the external skin requires support, so a thermal break will generally be required.

do

- integrate Passivhaus into your design approach from the earliest possible point
- use PHPP as a design tool to understand, influence and improve design
- make the building itself do all the hard work in achieving Passivhaus economically
- ensure that orientation, form and fenestration are optimised
- select a construction system that is appropriate for your building type, form and function, procurement and contractor.

Concrete frame:

- Address potential thermal bridges at the connection of columns to foundations.
- Ensure concrete structure does not pass through the thermal envelope at floors, roofs or for ancillary elements of the building.
- Airtightness can be achieved with parge or plaster where external walls are infilled with masonry, or with membranes or board and tape, where infilled with lightweight construction such as timber or steel stud.
- Avoid heavy external cladding hung off the structure, or excessive cantilevered structures such as balconies, as this will create unnecessary thermal bridging.

don't

- leave Passivhaus until late in the design process or treat PHPP as a compliance check late in the design
- assume that Passivhaus dictates any particular construction system
- combine unnecessarily different construction systems within one building
- create design problems such as thermal bridges or challenging air tightness details by using unnecessary cantilevered structures or structural penetrations.

Case Study Enterprise Centre



The Enterprise Centre, a new development by the Adapt Low Carbon Group at the University of East Anglia (UEA) in Norwich, is aiming to achieve both Passivhaus certification and BREEM outstanding ratings, as well as having one of the lowest embodied carbon footprints of any building of its size in the UK.



The development hopes to be the first to offer both Passivhaus performance alongside natural and bio-renewable materials sourced through local supply chains. The design team hosted a number of workshops with local suppliers to determine which locally sourced products could be used in the construction of the building.

Shading analysis was undertaken to calculate the optimal level of shading for comfortable internal conditions.

Future climate data was generated by the UEA Climate Team, and used to simulate a range of design scenarios in PHPP to identify the most robust solution over an 87-year period. The lifecycle carbon study, including embodied carbon, allowed optimisation of the building mass, glazing ratios, shading and natural ventilation design.



2

Use of PHPP and quality assurance

Sally Godber

Summary

The Passivhaus Planning Package (PHPP) is a very useful and powerful design tool, but it is easy to misinterpret the conventions, giving erroneous results. Avoiding these simple mistakes can reduce the need to find additional energy savings late on in a project. In a worst-case scenario, such mistakes might mean that a project cannot achieve certification.

Be conservative with values, as the thermal performance of elements very rarely gets better during design development. Optimistic inputs will be a problem later!

Introduction

Training in the use of PHPP is strongly recommended, in order to be fully competent with the software. This section is aimed at those who have undertaken training and are embarking on one of their first Passivhaus projects.

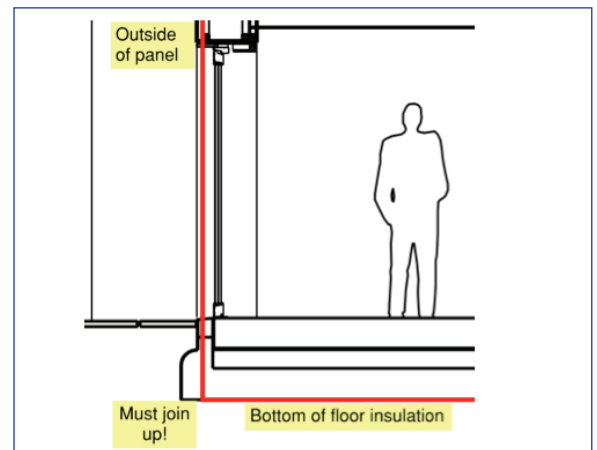
Climate and altitude

Check carefully that you have identified the right weather data set. The map on page 11 is very useful. The 22 data sets follow county boundaries, use additional county maps if you're unsure which set to use.

Entering the altitude of your site is just as important. Most of the data sets are from locations less than 50 metres above sea level, and if your site is significantly higher than the weather station this could easily add 1 kWh or more to the heating demand. Conversely some sets are at quite high altitude – the Severn set for instance uses data from RAF Lynham, which is at 150 metres.

Heat loss areas

Heat loss areas in Passivhaus are measured to the outside of the thermal envelope. This can be less straightforward than the SAP internal measurement methodology, as what constitutes the outside of the thermal envelope may not be immediately clear. Put simply, the thermal envelope ends at the last element used in your U-value calculation. So for a masonry wall with fully filled cavity the last element is the exterior brick or block; for a timber frame wall with a ventilated cavity and rain-screen, the thermal envelope will end on the outside of the timber frame wall, because the thermal performance of the rain-screen and cavity are unpredictable and are therefore ignored. Using dimensions which match the element build-ups you use for U-value calculations will help ensure an accurate PHPP model.



Heat loss areas must join up!

A critical eye

Passivhaus certifiers will be keeping a watchful eye out for things that will affect the building performance in practice, for example:


- manufacturer/supplier claims for material conductivities – if you are unsure use standard values from the PHPP handbook
- correct inclusion of repeating thermal bridges (refer to BS 6946 for guidance)
- can the insulation be easily constructed without air gaps between or behind the material?
- areas that are likely to be damp (eg, in contact with ground), as conductivity of porous elements such as open-cell insulation or lightweight blocks can vary significantly with moisture content
- is there a risk of thermal bypass?

So, be critical about the information you're given. For example, are insulation conductivities stated using the

correct conventions? (Eg, 90/90 values, see www.bbacerts.co.uk for further information)

Window entries

Unlike the UK's National Calculation Methods (NCMs), such as SAP and SBEM, where each rough opening can be considered as one window, PHPP needs accurate window entries, which count each casement separately. Entering two adjacent window casements as one means that the frame losses are underestimated, and the solar gains overestimated. Also, opening windows nearly always have thicker frames than fixed, so it is good practice to assume that all windows are opening ones early on in a design; this should avoid underestimating frame heat losses.



Quantity	Description	Width	Height	
		m	m	
1	Casement 1	1.000	1.200	✓
1	Casement 2	1.000	1.200	
2	Casement 1&2	1.000	1.200	✓
1	Combined casements	2.000	1.200	✗

Input into PHPP of two casement windows

Using an installation psi-value of 0.04W/m²K is a good conservative estimate for early design, and can easily be improved upon. This typically represents a window installed into a standard timber frame.

Primary energy

For most Passivhaus dwellings in the UK the primary energy target is easily met. The exceptions are when providing heating and/or hot water by direct electric or when using a district heating system/central plant. For this reason in most cases the primary energy does not need to be modelled early in design.

Ventilation rates

PHPP generally assumes a ventilation rate of around 0.3 air changes per hour (ACH), which is based on German property sizes and occupancy rates. For most UK homes, which are smaller and more densely occupied, higher ventilation rates are required.

MVHR duct data

The fresh air and exhaust ducts from the MVHR to the outside environment are essentially outdoor spaces within the thermal envelope and can add significantly to the heat loss of your design. Be realistic about the duct lengths, diameters and the amount of insulation which will be fitted. Where the MVHR is located right against an external wall, duct lengths of >1.5m are still likely. 160mm diameter ducts and 25mm insulation are typical values for a domestic installation and closed cell insulation should be used to avoid condensation problems.

Multiple MVHRs

If your design includes more than one ventilation unit, for example, in a terrace of houses or block of flats, you must use the Additional Vent sheet which is included in the more recent versions of PHPP. Although this sheet is challenging to use, it is vital to do so, as without it you will underestimate duct losses significantly.

A test to see if you're using the 'Additional Vent' sheet correctly is to fill in the 'Ventilation' sheet for a single ventilation unit, with associated duct lengths. Change the flowrate to represent the area served by that ventilation unit. The efficiency should be similar to the overall value in the 'Additional Vent' sheet.

Shading

The shading sheet is probably the trickiest within PHPP to get right, and it's worth reading the PHPP manual carefully so you understand the instructions, especially about averaging reveal figures. It's not sensible to be overly conservative and assume more shading than there is, because this can hide overheating problems. Be clear and reasonable in your assumptions and a Certifier is unlikely to disagree with you. If you are at all uncertain, get a Certifier appointed and agree the shading strategy early on.

For very complex shading it is possible to use separate software to calculate the shading such as IES, TAS or Ecotect. See page 94 of the PHPP manual for more information.

Whilst it is possible to get carried away worrying about shading accuracy, a good design should not be too sensitive to exact shading values as this suggests there is probably too much glazing. It is better to be more conservative in your assumptions.

Overheating

The overheating check in PHPP is basic, and as such shouldn't be used for non-residential or complex residential buildings. PHPP considers the building as one zone, distributing the gains evenly and as a result won't identify high solar gains concentrated in one room. Be cautious about using high ventilation rates to solve an overheating issue, as this may not be realistic due to security or noise issues. A useful stress test is:

- Use the IHG sheet to accurately represent the actual internal gains – and consider modelling various scenarios to demonstrate differences in user behaviour. Note this will require several additional sheets to be filled in such as the hot water and electricity sheets. To represent small buildings with high occupancy, a value of $7W/m^2$ is reasonable if no other data is available.
- Input minimum user-operated summer shading. If you are building the house for yourself then you may be willing to open and shut blinds 10 times a day but the next residents may have a different view!
- In our experience the effectiveness of MVHR 'summer bypass' mode is overstated in PHPP so set at half normal vent rate (0.2ACH, for example).
- Assume no natural ventilation during the day.
- Assume half the achievable night time ventilation – again in most cases this is user determined, and be careful about assuming internal doors are open.

The upper limit for certification is to keep the building below $25^{\circ}C$ for <10% of the year, and best practice is <5% of the year. It is likely the latter will become a certification criteria in future.

do

- engage with a building designer at the earliest opportunity
- model your design in PHPP at the early design stages
- make sure you are using the correct climate data within PHPP.

don't

- assume that a building specification from a previous development will suit all future Passivhaus buildings
- be over-reliant on glazing.

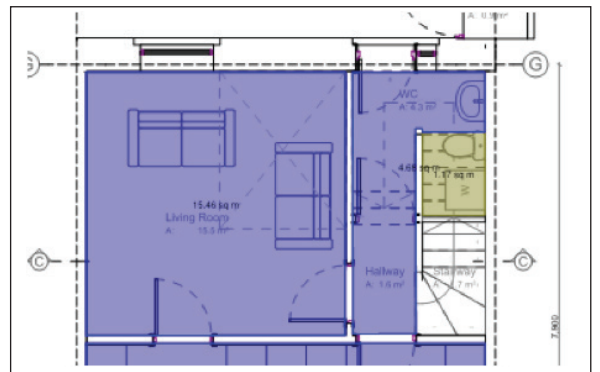
Solar gains

Whilst it is possible to build almost anything to the Passivhaus standard, be cautious about projects with large expanses of glass. These will have a strong reliance on high performance glazing but the structure that surrounds glass is more complex and therefore probably won't perform as well. In addition, the building is highly reliant on the weather for both internal comfort and energy consumption – this does not make it easy to achieve the comfort and energy requirements!

QA process

It is easy to make mistakes with any modelling software, so having a robust QA procedure within your organisation is key. Ideally there will be someone who can look over your PHPP on a regular basis. Clear mark-ups of treated floor area, heat loss areas, windows and shading make for easy checking, as does keeping previous versions of your PHPP.

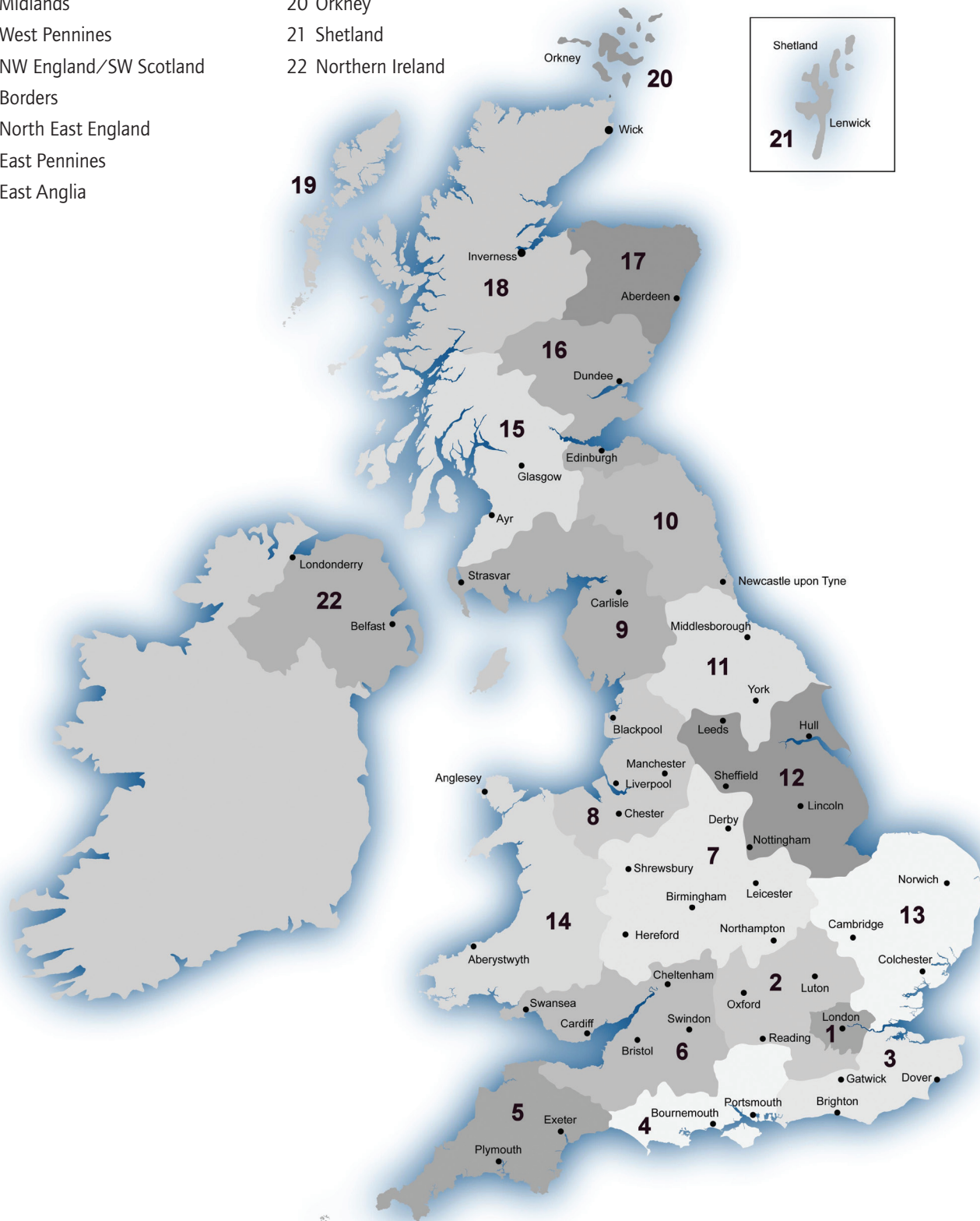
If your experience is limited employ a Certifier early on in a project to check what you're doing, agree any points of contention and provide any hand-holding you may need. Whilst certification usually starts pre-construction, having some experienced input (especially before planning) will ensure you're on the right track.



Typical TFA markup where inclusions/exclusions can easily be identified

UK regional climate data

- | | |
|--------------------------|------------------------|
| 1 Central London | 14 Wales |
| 2 Thames Valley | 15 West Scotland |
| 3 South East England | 16 East Scotland |
| 4 South England | 17 North East Scotland |
| 5 South West England | 18 Highlands |
| 6 Severn | 19 Western Isles |
| 7 Midlands | 20 Orkney |
| 8 West Pennines | 21 Shetland |
| 9 NW England/SW Scotland | 22 Northern Ireland |
| 10 Borders | |
| 11 North East England | |
| 12 East Pennines | |
| 13 East Anglia | |



For more information visit the Passivhaus Trust website: www.passivhaustrust.org.uk

3

Building fabric

Bill Butcher

Summary

The fabric, or envelope, of a Passivhaus needs to achieve high thermal and airtight performance whilst providing structural stability and weather protection. For building durability the design also needs to eliminate the danger of interstitial condensation forming within the structure. This section will look at general principles to consider regarding design and construction of the building fabric.

Introduction

All construction types can achieve the Passivhaus standard. The decision over construction type often comes down to

- building form and planning restrictions
- ease of achieving a good thermal envelope
- cost restraints, buildability, speed, material availability, risk, client preference and local skills.

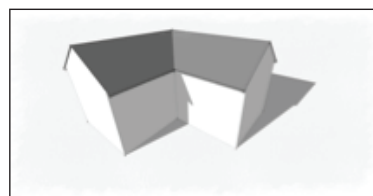
Form factor

Compactness of building form makes it easier to achieve Passivhaus standards, because the heat loss area (envelope) is minimised in relation to the building's volume. In general the larger the building the easier it is to achieve the standard, including airtightness. However, for Passivhaus we are interested in heat loss per m² of Treated Floor Area (TFA) – therefore high ceilings and double height spaces all contribute to the volume but not the habitable floor area. As a rule, terraced housing will need less insulation than detached houses, and a block of flats less still. Integral garages, ornate dormer windows, bay windows, or an intricate building footprint, all worsen the ratio between a building's envelope and its volume, and make it more difficult to achieve Passivhaus.

Essential elements of the thermal envelope

- 1 Rainscreen
- 2 Wind tight vapour open layer
- 3 Super insulation
- 4 Air tight layer
- 5 Structural zone
- 6 Service zone

Please note: The above list does not suggest that the elements will be arranged in this order.



The above building forms are able to achieve the Passivhaus Standard but a higher performance specification to the built fabric is likely. Images by Toby Rollason

Principles of design

To help obtain the high energy standards necessary for Passivhaus, it is crucial that the design of a building allows it to be buildable. The essential principles, both in the design and the build processes, to be considered by the whole team throughout the whole process in delivering a Passivhaus are:

Continuity of super insulation

There has to be a consistency of 'wrapping' the whole building, with particular attention to the junctions of the different fabric elements.

Minimising thermal bridging

The need for structural integrity, and the need to allow light and access into a building leads inevitably to the use of different materials with different thermal properties. Good design of each of these details to minimise the thermal loss is crucial both to keep heating demand down and to avoid cold spots where condensation might form.

Maintaining airtightness

Passivhaus buildings need to achieve 0.6 air changes/hour @ 50 Pascals, approximately 15 times more airtight than the present UK Building Regulation requirements.

The airtightness strategy needs to include a continuous layer joining each of the fabric components, using an appropriate material robust enough to last the lifetime of a building. Not only does an effective airtightness layer stop draughts and

reduces energy consumption (by limiting heat loss), it also protects the fabric of a building by preventing internal warm humid air from passing into the fabric, where it could form interstitial condensation. To minimise this risk, a rule of thumb is for the airtightness layer to be within the first third of the insulation build-up from the warm side. Beyond that third, it is advisable for the detail to be 'modelled' (eg, in WUFI hygrothermal modelling software) to ascertain the risk.

Minimising thermal bypass

A thermal bypass is the wicking of heat from a building by air movement around and through its fabric. A breather membrane layer on the cold side of the building's fabric will help avoid some of the more common examples.

Heavy weight or lightweight construction?

In general terms, the more mass there is within the thermal envelope the easier it is to control the possibility of overheating in summer months. A building with high thermal mass, exposed internally, will tend to have even temperatures and a good internal environment over the changing seasons. This does not mean, however, that we need to build all Passivhaus buildings in masonry: a timber frame construction with a solid ground floor (usually concrete on top of insulation) is often used and is a good way to provide thermal mass. In addition, the Passivhaus Planning Package (PHPP) will, of course, allow the designer to accurately design a shading strategy for any type of construction.

*Lightweight timber frame construction – Oakmeadow Primary School
Photo: Architype*



1 Walls

Introduction

Typically wall, roof and floor elements in Passivhaus buildings should aspire to: a U-value of between 0.10 W/m²K to 0.15 W/m²K, whatever the construction method employed; minimal thermal bridging; and ideally an internal service void so that services do not penetrate the airtight/vapour barrier. The thickness of the wall construction needed to achieve the required thermal performance will vary greatly, possibly from 300mm to 500mm, depending on the chosen insulation and construction type used. This section looks at the advantages and disadvantages of typical UK wall construction techniques.

Timber construction

Timber frame

Can be site fabricated (known as 'stick construction') or prefabricated in a factory situation delivered to site in panels.

Timber stud

The most common timber framing system would typically use 144/44mm timber studs at 600mm centres when filled with insulation. This would not normally achieve a recommended u-value of 0.1 – 0.15W/m²K, particularly when extra studs have to be inserted for structural reasons around window openings. Therefore additional insulation is required, usually applied externally over the whole frame, covering junctions and studs.

TJI joist system

Truss Joist I-joists or TJI joists have a lot of advantages and offer a relatively economic way to attain low U-values. They are available in many sizes and are structurally strong, with minimal thermal bridging due to the slim compressed timber web.

Double timber studs

This is a relatively simple way of achieving the depth of insulation needed, whilst providing the buildings structure or skeleton.

Larsen trusses

Though not offering structural support to a building, Larsen trusses offer a useful method of containing insulation and giving support for a cladding board and rain screen, such as rendering or timber cladding. Larsen trusses can be used in conjunction with timber framing or masonry walls in new build or retrofit projects. They are very simple to use and can be built on site or prefabricated.



ABOVE: Larsen timber trusses
Photo: Eco Arc Architects

BELOW: I beam portal frame
Photo: Conker Conservation



Component materials with timber frame

This section looks at the types of materials used with timber frame construction, to make up the rest of the walls.

In a timber frame wall construction, the windtight layer (also known as the breather membrane) can be a rigid board or membrane, which will need taping to eliminate thermal bypass. Modern 'vapour open' but windtight and water-resistant materials allow any moisture within the fabric to evaporate harmlessly to the outside.

Insulation in timber frame walls can be of any type, either flexible insulation can be used between studs to cope with the thermal movement of the timber, minimising the possibility of air pockets which can lead to thermal

bypass, or if rigid board can be used between timber studs, in which case careful installation is essential to ensure all gaps are fully filled.

The airtightness, or vapour control, layer is often achieved by using OSB board, well taped at the joints. However OSB is not supplied as an airtightness product and can vary in its effectiveness; it is therefore recommended to use at least an 18mm board. Polythene sheeting is a cost-effective barrier, but may be difficult to install into the difficult corners to achieve a good seal. The main problem with polythene is its vulnerability to damage during the build process and also during any subsequent alteration works. Modern reinforced purpose-made membranes, with the appropriate tapes, are the safest route in achieving the desired airtightness.



ABOVE: Airtight membrane fixed internally.
Photo: PYC Insulation



ABOVE: 18mm OSB-3 with joints taped successfully installed as airtight membrane.
Photo: Eco Arc Architects

Advantages and disadvantages of timber frame construction

The key **advantages** of timber framing are the speed of erection and the ability to easily monitor the quality of insulation and membranes. Airtightness testing can be carried out at an early stage of the build process, when any faults can be rectified relatively easily.

Disadvantages of timber frame walls are the need for additional studs to perform a structural role (e.g. around window openings), which create extra thermal bridging. When timber frame is used with a brick or stone rainscreen, there is a danger of moisture build up in the timber frame particularly during the summer months when strong sunshine can drive moisture from a rain soaked masonry façade into the cavity (known as 'solar driven moisture'). This situation can be prevented and controlled by ensuring that there is an adequately ventilated cavity, but research in this area is still in its infancy.

Masonry cavity wall

Cavity wall is still probably the most common form of construction in the UK, so should not concern to most builders, but the approach needs to be adopted to achieve the more rigorous Passivhaus requirements.

For masonry cavity wall to meet Passivhaus standards we need to be able to cope with the natural rough surfaces of masonry walling without leaving air passageways for thermal bypass. One way to do this is to use soft fibrous insulation, such as mineral wool, where mineral wool cavity batts are woven in vertical layers and are designed to be able to get wet in the first 10 – 15mm from any wind driven rain penetration through the naturally porous brick or stone. The use of well-installed cavity trays over window and door openings, and vigilance in keeping insulation batts clean from mortar droppings ensures thermal performance is as designed.



ABOVE: 300mm full-fill cavity with soft fibrous insulation. Photo: Parsons + Whittley Architects

The repeating thermal bridging of stainless steel wall ties within the super insulation would diminish the overall U-value of the wall, and create a danger of cold spots on the internal plaster work, potentially leading to condensation. Thermal bridging from wall ties should therefore be minimised by the use of specialist wall ties made of lower conductivity materials such as basalt and resin or nylon.

Airtightness can be adequately dealt with by traditional two-coat plasters. Where the plaster meets another material, such as timber, OSB, plywood, etc, cracking will occur through differential movement, seriously affecting the airtightness strategy. Specialist airtightness tapes are needed to address and cope with this issue.

Components such as intermediate timber floors, staircases, SVPs, etc that are installed before plastering require a preliminary simple weak sand, cement/lime parge coat applied to the blockwork. The parge coat should give adequate airtightness and blend with the plastering later.

Advantages and disadvantages of masonry cavity wall

Advantages Materials are readily available, and the construction method is familiar to local labour, though not necessarily to the stringent Passivhaus standards. Being a heavyweight construction, traditional blockwork gives excellent thermal storage and soundproofing properties. There is no danger of interstitial condensation and holes in the plaster airtightness layer are always repaired as part of redecoration work. Masonry cavity wall can be the cheapest construction method and is still the most common house building construction method in the UK so its use will avoid taking builders outside of their experience and 'comfort zone', and hence avoid over-pricing due to perceptions of risk.

Disadvantages Masonry cavity wall is a slower construction method than timber frame and it is more difficult to check the quality of the continuity of insulation, (eg, the cleanliness from mortar dropping, etc.). Airtightness testing occurs later in the building programme which can make it more difficult to rectify hidden faults. The absence of a service void means that more care is needed in services design and execution. Although electric cabling can be buried in the plaster effectively, badly installed back boxes can create weak points. A longer structural drying out period will affect the first season's heating demand

RIGHT: Partial fill cavity with rigid insulation
Photos: Kingspan Insulation



Case Study The Greenhouses at Sulgrave Gardens



The Greenhouses offer an example of affordable Passivhaus level construction in a tight urban setting. The development includes a row of three-storey terraces (Block A) and two five-storey apartment buildings (Blocks B & C). Both Blocks A and B are Passivhaus certified.

The primary façade material is brick, complementing the surrounding architecture. To minimise the remaining construction thickness whilst achieving the required thermal performance and airtightness, the Kingspan TEK® Building System was specified for Block A. A 90 mm thick layer of Kingspan Kooltherm® K12 Framing Board was fixed outside the panel with an airtight membrane taped to its internal face.

On Block B, Kingspan TEK® Cladding Panels were fixed to the concrete floor slab using angled cleats. The build-up mirrored those in Block A with the airtight membrane sealed to the concrete frame and soffits with airtight tape.

Both build-up's achieved a final external wall U-value of 0.10 W/m².K, and the detailing, in combination with the Kingspan TEK® proprietary jointing system, ensured air loss was below 0.6 air changes per hour @ 50 Pa.

Solid masonry with external insulation

This in theory is the easiest method to attain the Passivhaus goals for walling, and can be achieved with a wide choice of rigid and semi rigid insulation materials. The structure, usually of concrete or blockwork, is inside the thermal envelope providing good thermal mass. The airtightness layer is usually applied to the outside of the structure in the form of a flattening render coat, in preparation for the adhesive layer for the insulation. Thermally broken mechanical fixings are usually required. The rainscreen is commonly a render system, with integral keying membrane.

It is crucial to inhibit air movement between the insulation and the structural walling, as any thermal bypass would seriously diminish the thermal performance. It is important to have a flat surface on which to fix the insulation and to apply adhesive evenly with a notched trowel.

Advantages and disadvantages of solid masonry with external insulation

Advantages Insulation and structure are completely separated, meaning that thermal bridging can be minimised. With this system, quality of workmanship is, on the whole, visible, making quality assurance easier. There is also no need for cavity trays with this method of construction. All trades can proceed within the building without the worry of damaging the airtightness layer.

Disadvantages External rendering can be easily damaged because there is no structure behind it. If heavier cladding (such as brick slips) is used there may be significant thermal bridging problems if supported off the internal structure. Contractors in the UK do not appear to be experienced yet in the care needed to minimise thermal bypass, and external insulation systems to reach Passivhaus standards seem expensive in the UK at the present.

Structural insulated panels

Structural Insulated Panels (SIPs) are an off-site, easy to build wall system commonly made up of insulation sandwiched between 15mm board. This should preferably be installed externally to minimise the thermal bridging of solid timber sole and wall plates, and to compensate for the additional timber commonly used around window and door openings. Some SIP panel systems need additional insulation to achieve the U-values necessary for Passivhaus, particularly the thermal bridging criteria.



SIPs wall being craned into place
Photo: Kingspan Insulation

Advantages and disadvantages of structural insulated panels

Advantages

- Off-site construction provides accurate tolerances, window and door holes etc.
- Ease and speed of erection.

Disadvantages

- Some modification may be needed to reach Passivhaus performance levels, particularly for thermal bridging.

2 Ground floors

Introduction

Ground floors can be either solid or suspended. Solid floors tend to be the easier and cheaper option, whereas suspended floors tend to be used where the thermal envelope is above a basement, or where planning authorities require a floor void because of flooding risk. Suspended timber ground floors are not advisable for Passivhaus buildings, because of the inherent moisture risk and complicated detailing required.

Insulated slab

An insulated slab ground floor system satisfies all the Passivhaus principles of design, including: continuity of insulation, no thermal bridging, airtightness of the concrete slab, and no issues with thermal bypass. In principle, achieving a 'thermal bridge free' junction with the walls is ideal, although the design depends on the walling system that is being used:

- A lightweight construction, such as timber frame, lends itself to being built directly off the slab.
- Heavyweight construction commonly needs direct support from the foundation; cost-effective minimisation of this thermal bridge requires the project's structural engineer to understand the fundamentals of 'thermal bridge free' construction.



ABOVE: Insulation being installed below the floor slab
Photo: DOW Building Solutions

Beam and block

On its own, beam and block floor construction will not satisfy the principles of Passivhaus design mentioned previously. By its very nature, ventilation is created under the system allowing air movement in and around the floor structure. The simplest strategy is to treat the beam and block floor as providing support only. To achieve Passivhaus performance levels, a taped windtightness membrane can be laid over the beam and block and carefully joined in with the wall windtightness layer. Insulation should then be added to the required depth on top, with the top screed over. The screed will also become the floor's airtightness layer but will need taping into the wall airtightness layer, as the screed will shrink back from the internal walls during drying out.



ABOVE: Beam and block floor construction
Photo: Total Concrete Products Ltd

Insulation materials in damp conditions

Care is needed in choosing insulation for ground floor and foundations that are outside the damp-proof membrane, as the thermal performance can be substantially diminished depending on which material is used. Extruded polystyrene is probably the most appropriate insulation material in ground floors and foundations, where installed below the damp proof membrane.

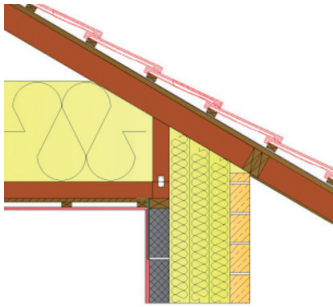
3 Roofs

Introduction

Roofs for residential buildings are predominantly pitched and designed as either a 'cold' roof with insulation at horizontal ceiling level, or a cathedral roof where the insulation follows the line of the pitch of the roof.

Cold roofs

Timber trussed rafters are very familiar to the construction industry and are inexpensive and fast to erect. To create a 'thermal bridge free' junction, 'dropped ceiling' or 'bob tail trusses' allow for the continuity of insulation between the roof void and wall. Airtightness is dealt with at ceiling level with OSB board or other robust membranes. Thermal bridging is minimised with only the timber bracing members of the truss penetrating the insulation layer. There should not be any air movement in the roof void, to avoid thermal bypass. This is achieved by using modern high quality 'vapour open', under-slate membranes taped at laps and carefully detailed at the eaves and verge.



Typical eaves detail for a cold roof



Detail under construction on-site.
Photo: Green Building Store

Cathedral roofs

TJI timber joists can help cathedral roofs meet Passivhaus performance requirements. The joists come in various depths for soft or blown insulation, and thermal bridging is minimised thanks to the slender timber hardboard web. Thermal bridging can further be reduced by using either a vapour open insulation sarking board externally (also acting as the windtightness layer), and/or using insulation board internally, immediately followed by the airtightness membrane and before a service void for lighting and cabling. The roof/wall junction needs careful detailing to provide minimal thermal bridging and to satisfy aesthetic demands.



External view of a 'Cathedral' style roof under construction



Internal view of a 'Cathedral' style roof under construction
Photos: Green Building Store

Flat roofs

The basic principles for flat roof design apply to a Passivhaus in the same way as any other building, and generally fall into two categories: ventilated roofs or warm roofs.

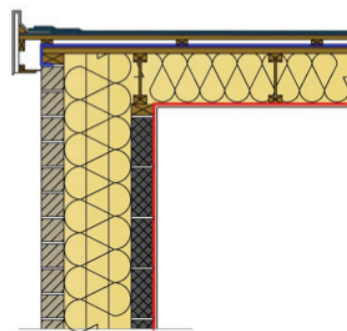
A ventilated flat roof allows any unwanted interstitial moisture to evaporate away. There should, of course, be less danger of this happening with Passivhaus levels of airtightness as long as the vapour control/airtightness layer is positioned correctly on the warm side of the insulation. TJI timber joists are, again, very useful for giving good structural strength with minimal thermal bridging.

Warm roofs tend to cause less potential interstitial moisture problems by separating the roof structure and placing the rigid insulation on top of the decking.

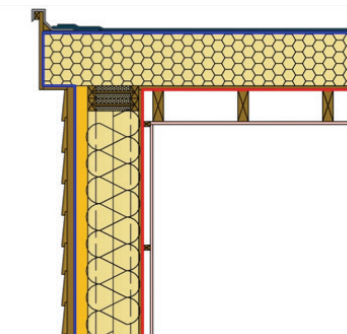
Another version of the warm roof is the inverted roof. This is where the insulation is placed on top of the roofing membrane to give it protection from sunlight and subsequent differential thermal movement. This places the insulation in a wet position which is not ideal for its thermal integrity, as the thermal performance of all insulation materials is affected by moisture, particularly running water.

The designed U-value can be seriously compromised in flat roofs if there is any potential for moisture in or around insulation material, whether interstitial or from precipitation.

Parapet walls are potentially a very bad thermal bridge if not designed very carefully.



Typical Flat roof with cavity wall construction



Typical Flat roof with timber wall construction

Images: Green Building Store

4 Junctions and thermal bridges

Mark Siddall

Introduction

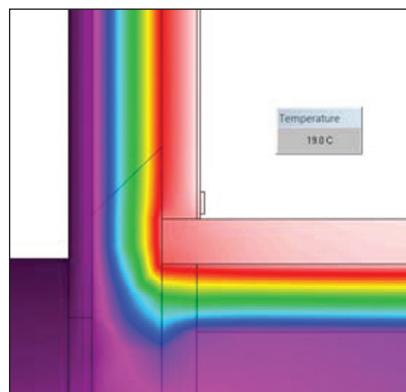
In a building that meets the Passivhaus Standard the junctions and interfaces require specific attention. It is at these points in the building fabric that heat loss can occur through thermal bridges; furthermore low surface temperatures can result in surface condensation and mould growth. Unaddressed thermal bridges can increase fabric heat loss by over 30%. This chapter considers the impact that thermal bridging and reduced surface temperatures can have upon building performance.

Thermal bridges and energy calculations

It is possible to calculate thermal bridges using internal and external dimensions. The use of internal dimensions tends to underestimate heat loss. The use of external dimensions tends to overestimate heat loss. The two methods should not be combined.

The Passivhaus Standard uses external dimensions whilst UK conventions utilise internal dimensions. Calculations based upon UK conventions should not be used when calculating the heat loss from a building that is designed to meet the Passivhaus Standard. Likewise thermal bridging calculations developed for the Passivhaus Standard should not be used in SAP or iSBEM calculations.

Ground Floor wall junction – Heat Flux
Image: Mark Siddall



Types of thermal bridge

There are essentially three types of thermal bridge:

- Repeating thermal bridges
- Linear thermal bridges: The Ψ -value (psi-value)
- Nodal thermal bridges: The X-value (chi-value)

Linear and nodal thermal bridges are determined in accordance with BS EN ISO 10211. Linear thermal bridges occur at the junctions between two building elements. Nodal thermal bridges arise when three building elements intersect (eg, a corner between two walls and a floor) or where a single element (eg, a steel beam) penetrates the insulation.

Zero thermal bridging concepts

The concept of 'zero thermal bridging' can only be used successfully when using external dimensions. Due to geometry it is not possible to achieve zero thermal bridging using internal dimensions. The Passivhaus Standard considers a detail to be 'thermal bridge free' when the psi-value is <0.01 W/mK.

do

- minimise complexity – this reduces the chance of error and can assist buildability
- at junctions between elements, insulating layers should meet without any gaps
- insulating layers should join without interruption or misalignment
- design edges and corners to have as obtuse angles as possible
- during the design process ensure that simple robust details are developed with adequate construction tolerance.

don't

- allow disruptions to the thermal envelope - where an unavoidable disruption is made to an insulating layer, the thermal resistance in the insulation should be as high as possible
- underestimate construction tolerances.

Rules of thumb

The use of external dimensions allows a Passivhaus Certifier to conduct a visual assessment of thermal bridging. If they are satisfied, then thermal bridging calculations may be avoided. A detail may be considered 'thermal bridge free' when the following rules are met:

Prevention: Try to avoid disruptions to the thermal envelope.

Penetration: Where an unavoidable disruption is made to the insulating layer, the thermal resistance in the insulation should be as high as possible.

Junction: At the junction between building elements insulating layers should join without interruption or misalignment.

Complexity: Minimise complexity – this reduces the chance of error and can assist buildability.

Geometry: Design edges and corners to have as obtuse angles as possible. Pay specific attention to corners, ground floor/wall interfaces, eaves, verges, gable ends, structural openings (head, jamb and sill).

Buildability: Ensure that simple robust details are developed with adequate construction tolerance.

Construction tolerance: Think of a reasonable dimension for a construction tolerance, and then double it.

Protection: Protect insulation materials from mechanical damage and the weather.

Workmanship: Avoid gaps and discontinuities and ensure a clean working environment.

Improvisation: Do not improvise, read the drawings and specification or ask the design team if unclear.

Inspection: Inspect details prior to closing any openings, to ensure that there are no gaps and discontinuities.

5 Windows and doors

Sally Godber

Introduction

Manufacturers are not used to providing thermal performance data in a format suitable for inclusion in PHPP, so spend time reviewing the exact frame, glazing and spacer specification they provide for each window. This is usually easier for certified windows but still take care.

Once you have interpreted manufacturer information and put it into PHPP, we would recommend sending a copy back to the manufacturer for them to confirm the values you have taken.

Performance

It is not necessary to use certified windows as long as manufacturers can supply data to EN 10077 to fill in the 'Components' worksheet in PHPP. In particular, ask for separate frame U-values (head, cill and jamb); and glazing U-values need to be given to two decimal places.

If you are planning to use a non-certified window it is important to check the average temperature of the internal surface of the installed window does not drop below 16°C internally, at the lowest external design conditions, otherwise cold down draughts may occur. Certified windows have already been checked against an external temperature of -10°C, but in many parts of England the external design temperature might be much higher, meaning that poorer performing window frames (possibly even non-insulated) might be allowed.

Certificate

Certified Passive House Component
for cool, temperate climates; valid until 31.12.2015

Passive House Institute
Dr. Wolfgang Feist
64283 Darmstadt
GERMANY

Category: **Window Frame**
Manufacturer: **Munster Joinery**
Product name: **Lacka Cross, Ireland**
Passiv Aluclad T&T

This certificate was awarded based on the following criteria:

Given a U_g value of 0.70 W/(m²K) and a window size of 1.23 m by 1.48 m,

$U_w = 0.76$ W/(m²K) ≤ 0.80 W/(m²K)

Taking into account the installation based thermal bridges and provided that the installation is, with regard to the thermal bridges, equal or better than shown in the data sheet, the window meets the following criterion.

$U_{w,installed} \leq 0.85$ W/(m²K)

Thermal data

	U_g -value [W/(m ² K)]	Width [mm]	Ψ_g [W/(mK)]	$f_{RSi=0.25}$ [-]
Spacer			Superspacer TriSeal*	
Bottom	0.72	128	0.020	0.79
Side/top	0.72	128	0.020	

*Spacers of lower thermal quality, especially those made of aluminium, lead to significantly higher thermal losses and lower temperature factors.

For further information, please see the data sheet

www.passivehouse.com 0462wi03

Passive House Efficiency Class

phA advanced component

phB basic component

phC certifiable component

not suitable for Passive Houses

CERTIFIED COMPONENT
Passive House Institute

Certification document for Munster Joinery's Passiv AluClad Tilt and Turn window frame

To achieve the 16°C, non-insulated window frames must be well-wrapped with insulation on site.

Note that windows smaller than the standard test window size are unlikely to achieve the performance target due to the higher ratio of (poorer performing) frame relative to (high efficiency) glazing. However, their small size means they will not usually cause discomfort.

Whatever door and window options you choose, it must fit the overall energy balance in PHPP. PHPP is a fantastic tool for assessing different frame and glazing options and comparing costs, but be careful to ensure other factors are taken into account.

Support

Some manufacturers are willing to provide support, for example, help with airtightness detailing, installation psi-value calculations and site visits.

Another reason to get manufacturers involved early is to ensure that proposed window sizes are achievable; typically opening windows that are wider than 1.2m can cause problems.

Airtightness

Passivhaus certification of windows requires no airtightness testing to be undertaken, so tread with care. Whilst most certified windows have got a precedent of meeting the airtightness standard, it is recommended to ensure the manufacturer confirms their windows are suitable.

Spacer widths

The performance of sealed glazing units varies with thickness of the frame. A good frame should have a rebate >48mm to allow sufficient glazing options. For triple glazing, 18-20mm cavities are optimum for Argon – 16mm or less gives inferior performance. Krypton is generally unsuitable except for special purposes where narrow cavities are required.

Frames and energy balance

Generally frames perform worse than glazing so small windows, or those with lots of mullions and transoms should be minimised.

When picking a window frame, the dimensions should always be considered as well as frame U-value. While it can be tempting to choose the frame with the best U-value, there is often a trade-off between performance and thickness. A slimmer yet worse performing frame can sometimes prove the better option, as the amount of glazing (which has a better U-value) is optimised and solar gains are increased.

The new Passivhaus window Certificates from the Passivhaus Institut include an A to C rating which gives an indication of the balance between frames and glazing, because gains are considered as well as losses. However, the best approach is to model the various options in PHPP as the 'best' option can vary between projects.

Inward and outward opening windows can perform equally well, although outward opening windows are more common in the UK market. Inward opening windows allow external shutters, blinds or insect mesh to be fitted, and are usually easier to wrap in insulation, thus helping achieve better thermal performance.

Glazing

Triple glazing gives the best energy balance, even in the UK climate, and is needed to meet comfort requirements and to avoid condensation and mould at the edges.

The glazing g-value (Solar Factor) refers to the fraction of solar heat that transmits through the glass and is just as important as the glazing U-value in this optimisation process, so ask for both to two decimal places. Note that Building Regulations only considers losses, so a manufacturer's 'high performance' glazing will often have a low U-value but also very low g-value which is likely to give a poor energy balance in PHPP. Manufacturers will have a range of glass they can supply, with varying costs so ask for alternatives.

Take care to look at the light transmittance of the glass as well; usually the light transmittance percentage is roughly in line with the g-value.

Other standards such as Secured by Design or Building Regulations, may dictate that security glass is used. Generally toughened glass does not impact on performance but laminated glass almost certainly will.

Rooflights

When installing horizontal glass (rooflights) the glazing performance changes; this must be taken into account in the U-value. For example, glazing with a stated U-value of 0.60 W/m²K should be entered as 0.90 W/m²K in PHPP when it is installed horizontally to take account of this. EN673 has a calculator to determine this accurately.

Note that rooflights are very difficult to shade from overheating in summer.

It is very hard to achieve good installation details with a rooflight, although manufacturers have developed installation kits that improve performance.

Glazed doors

Whilst a number of sites have met the airtightness criteria whilst using sliding doors, their use needs careful consideration as the airtightness often degrades faster than a standard door due to wear and tear. This is particularly important if the door is directly next to a living space where a draft could be felt. Tilt and slide doors are inherently more airtight, and may be cheaper than parallel slide versions.

Bi-fold or folding-sliding doors are generally expensive at the level of airtightness needed for a Passivhaus. In addition, it is very difficult to get as good installation psi-values as a normal window/door because of the frame configuration.

Consider using glazed doors as these have a better energy balance than solid doors.

Case Study Coventry Eco House

Munster Joinery supplied windows for a social housing development on behalf of Orbit Heart of England Housing Association. The Coventry Eco House development consisted of two units built to the Passivhaus standard using the Beattie Passive system.

Munster Joinery were able to supply their Passiv uPVC Tilt and Turn window within two weeks from order from their Warwickshire factory.

The window is certified as a Passivhaus suitable component by the Passive House Institute in Germany.

Thermal Data

	U _f -value [W/(m ² K)]	Width [mm]	Ψ _g [W/(mK)]	f _{Rsi=0.25} [-]
Spacer			SuperSpacer Tri Seal*	
Bottom	0.66	125	0.025	
Side/top	0.66	125	0.025	0.76



Installation

For best thermal performance, position frames near the centre of the insulation line. Optimisation of such details in thermal bridging software is worthwhile. However, deep external reveals increase the solar shading which may or may not be advantageous.

The frame dimensions and the way it opens (inward/outward) will determine how much insulation can be wrapped around the frame. For inward opening windows generally insulate externally; for outward opening windows insulate internally.

Thresholds also need careful consideration as they are a difficult area for achieving good thermal performance.

In addition, airtightness needs to be considered when detailing window installations.

Note that there is little or no benefit to wrapping aluminium-clad frames with insulation externally.

Non-conforming components

Some components will not achieve the 0.85 W/m²K target and this may be acceptable as long as they are not adjacent to habitable areas where people are likely to spend significant time.

do

- minimise transoms and mullions in glass
- check window sizes are achievable with the manufacturer
- use PHPP to assess whole component performance, don't just rely on whole window U-values
- look at what glazing options the manufacturer can offer
- consider certified and non-certified windows.

don't

- assume the frame u-value is the same for the window sill, head and jam. Check the PHI Component certificate or manufacturers 3rd party test certificate for performance
- forget to adjust the performance of any rooflights within the PHPP calculation.

4

Airtightness

Paul Jennings

Summary

In this chapter we discuss the Passivhaus requirement for an excellent level of airtightness and explain the principles of airtightness testing, highlighting where dwellings leak and how to go about meeting the airtightness target for a project.

Introduction

Airtightness often appears to be the most difficult element to achieve in Passivhaus projects, yet once a robust airtight design is in place, delivery is primarily about rigor and attention to detail.

Passivhaus airtightness targets

The Passivhaus airtightness target is $< 0.6 \text{ ACH-1 @ } 50 \text{ Pa}$ for newbuild projects and $< 1.0 \text{ ACH-1 @ } 50 \text{ Pa}$ for EnerPHit refurbishment projects. This compares with UK Building Regulations, where a maximum air permeability of $10 \text{ m}^3/\text{hr}/\text{m}^2 @ 50 \text{ Pa}$ is commonly permitted. Hence the Passivhaus airtightness requirements for newbuild are some 15 times more onerous than UK Building Regulations, while insulation requirements will typically only be 3 to 4 times more demanding than Building Regulations. Therefore it is not surprising that UK contractors often find the stringent Passivhaus airtightness requirements particularly difficult to meet.

The quoted targets are the final acceptance value; it is sensible to leave a margin to allow for the leakage often found around services that are installed after the first airtightness test. This should be at least 25%, which means aiming for preliminary test results of:

- $< 0.45 \text{ ACH-1 @ } 50 \text{ Pa}$ for newbuild projects and
- $< 0.75 \text{ ACH-1 @ } 50 \text{ Pa}$ for refurbishment projects.

Airtightness testing procedures

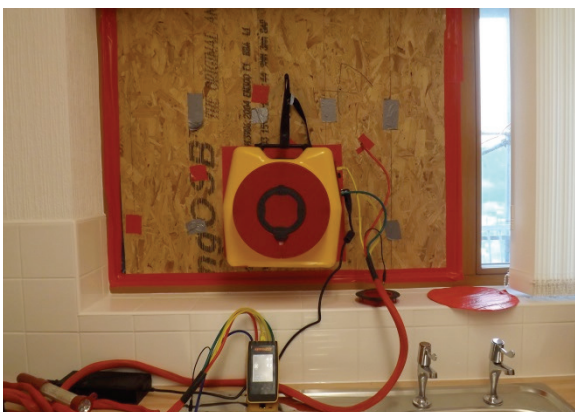
When carrying out an airtightness test, a steady-state condition is established, when the air blown out of the building by the fan is balanced by the air re-entering the building through various cracks, gaps and openings. Typically this is at a pressure of 50 Pascals (Pa), about the same as a 20 mile-an-hour wind acting upon the volume under test, not forgetting that wind speed rises with distance above ground if testing in high-rise blocks.

Testing is carried out in the UK in conformance with the ATTMA (Air Tightness Testing & Measurement Association) 2010 editions of the standards TSL1 (dwellings) and TSL2 (non-dwellings). These are available as a free download from www.attma.org. A new scheme for quality control of testers was established on 1st January 2015.

Requirements for a multi-point test

- a minimum of 7 readings, typically 10 to 12 readings, at $\approx 5 \text{ Pa}$ intervals, 15 or more readings recommended in windy conditions
- at least 1 reading at a pressure differential of magnitude $> 50 \text{ Pa}$
- no readings at pressure differentials of magnitude $> 100 \text{ Pa}$
- the zero-flow pressure differential (e.g. wind-induced) shall have a magnitude of no more than 5 Pa
- the correlation coefficient, r^2 , must be > 0.980
- the airflow exponent, n , (a measure of the turbulence of the airflow through the various leaks) must be: $0.5 < n < 1.0$.

A small calibrated fan mounted in a window board fitted in an open kitchen window during testing



Locating leaks

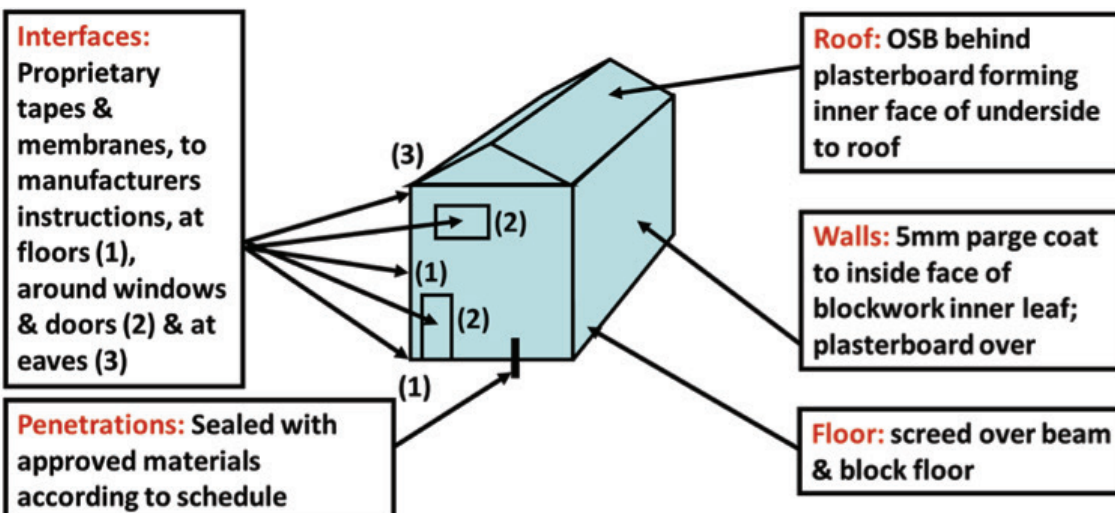
As well as the calibrated test equipment used in measuring the airflow through the building, there is a range of ancillary equipment that a testing organisation will probably use when testing a building, and particularly when investigating leakage after an unsatisfactory initial test. Although the back of one's hand is often completely adequate for tracking down leakage sites in more leaky buildings, leakage rates can be so low in Passivhaus projects that it becomes unreliable. Even the more sensitive human eyeball cannot always be relied upon, hence we use chemical smoke, thermographic cameras and extending vane anemometers when searching for leakage. Another common tactic is to fix a square metre section of polythene or similar membrane over the surface of a wall that we suspect is leaking. Under depressurisation, if the membrane bulges into the property, there is clearly a leak through that wall construction. A common gross leak that we routinely find is through door locks, even in very expensive Passivhaus-certified doors.

Air barrier strategy

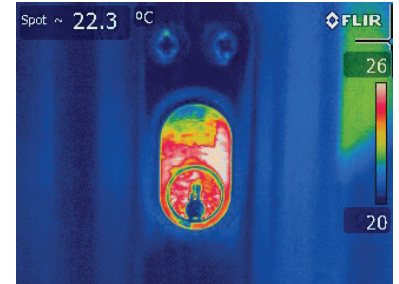
Deciding what sealing products and processes are required to deliver the target airtightness leads to the development of a formal air barrier strategy. For clarity and ease of communication, we suggest that this is summarised in the manner shown below, tailored for an individual project:

The figure below summarises the air barrier strategy to deliver Passivhaus airtightness in a newbuild warm-roof dwelling. For a specific project the manufacturer of sealing tapes and airtightness membranes should be detailed, and a list of penetrations and how they are to be sealed would also be needed. Your project would be individual and almost certainly different, but summarising it in this way is an essential step in communicating how the Passivhaus target is to be achieved. The next step should be to prepare a set of airtightness drawings, detailing the line of the airtightness barrier on plans and sections.

Example of an Air Barrier Strategy, simplified for clarity



Using chemical smoke to check for leakage between upper floorboards



Thermographic image of a leaky door lock, where the blue key hole is much cooler than the adjacent metal lock.

Photos: Paul Jennings



Extending vane anemometer showing a high air velocity of 2.1m/s through a gap at the head of a balcony window

Specifications for airtightness

When specifying airtightness for a building where the target is to achieve Passivhaus or EnerPHit certification, it is essential to specify the airtightness process as well as the airtightness target and the sealing materials and process to be used.

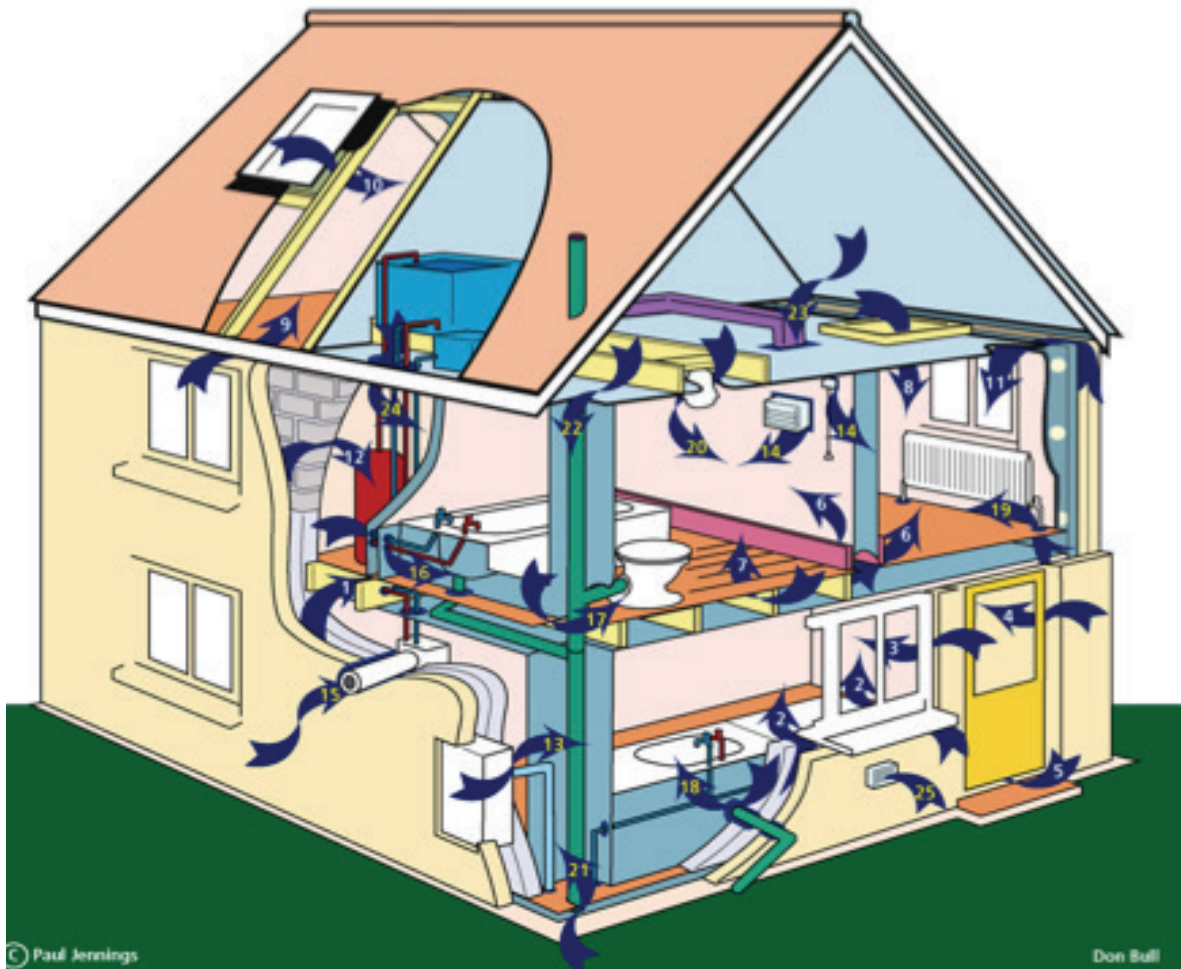
Quality assurance and airtightness champions

This is the key role in ensuring an airtight design and quality assurance is satisfactorily delivered on site. Sealing failures can lead to costly additional works and delays.

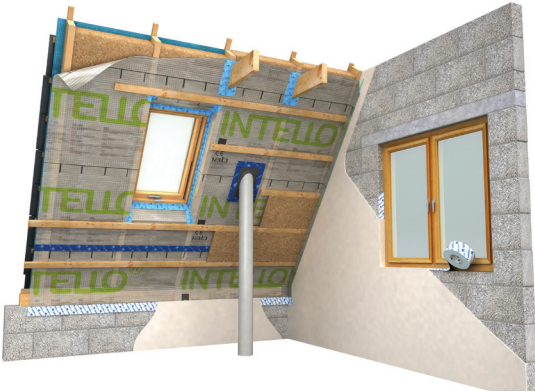
Where dwellings leak

This diagram illustrates many of the leakage sites that have been found in new and existing housing. One key point to remember is that wherever there are voids, there is the potential for complex connecting air paths to form, allowing leakage to occur in some very surprising locations.

- 1 Around floor joists
- 2 Beneath windows sills
- 3 Around windows
- 4 Around doors
- 5 Beneath door threshold
- 6 At edges of suspended floors
- 7 Between floorboards
- 8 Loft hatches
- 9 At eaves
- 10 Around rooflights
- 11 Behind drylining
- 12 Through poor masonry
- 13 Via meter boxes
- 14 Around and through electrical sockets, etc.
- 15 Around boiler flue
- 16 Plumbing to bath
- 17 Around waste from WC
- 18 Kitchen waste
- 19 Around radiator pipes
- 20 Around spotlights
- 21 At base of soil vent pipe
- 22 At top of soil vent pipe
- 23 Around duct connections through ceiling
- 24 Around pipe connections to tanks in unheated loft
- 25 Around tumble drier vent



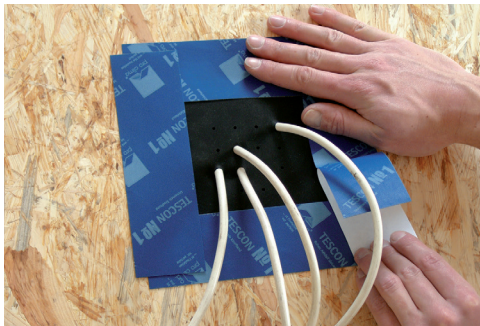
Air barrier applications



LEFT AND RIGHT: Fully sealed vapour and airtight layers
Images: Ecological Building Systems



LEFT AND RIGHT: Sealing around windows
Images: Ecological Building Systems



LEFT AND RIGHT: Sealing pipes and cables.
Images: Ecological Building Systems

do

- develop a formal air barrier strategy
- appoint or nominate a quality assurance and airtightness champion
- the airtightness testing organisation must be acceptable to the certifying body
- pressurisation and depressurisation testing must be carried out and the results averaged
- for a Passivhaus or EnerPHit acceptance test, the building must be finished, no temporary sealing, other than to exclude the ventilation system, is permitted.

don't

- assume that something is sealed – always check
- calculate air changes using the ATTMA volume; the PHI institute has much more detailed calculation requirements and the resulting volume can be 20% smaller, making it harder to pass the airtightness test
- allow the construction program to override quality requirements – remedying airtightness defects at the end of a build can be disruptive, costly and significantly delay completion.

5

Building services

Alan Clarke

Summary

Whilst building fabric is the key to Passivhaus performance, it is important to pay attention to building services. Mechanical ventilation with heat recovery (MVHR) poses the most challenges but it is also important to design heating systems appropriate to the level of heat demand so they run smoothly and economically. This section looks at the principles of building services design.

Introduction

There can be a temptation to think of a Passivhaus as an opportunity to deploy the latest renewable heating systems. However, having put the effort into a high performing fabric, there is little need to spend a lot on heating systems, and the heating demand is so small that extra investment in expensive heat sources may not be worthwhile. The challenge is to deliver systems that don't cost a lot, respond well to small and erratic heat demands, and are still efficient in terms of primary energy and carbon emissions.

On the other hand inexpensive ventilation systems do not usually meet the performance requirements needed for Passivhaus. The importance of heat recovery efficiency in the PHPP energy model means that high quality Passivhaus certified components are justified, and the expense can be offset against additional fabric insulation costs that a poorer MVHR would require.

Ventilation

The performance of the ventilation system is considered an integral element of the primary Passivhaus heating demand calculation, though the rest of the services are not. You can think of this as being because the main intake and exhaust ducts, carrying cold air, actually form part of the building's external envelope. So in keeping with the emphasis on compact form, the designer needs to be aware of these ducts and how to make them as short as possible at an early stage in design.

The impetus for using MVHR may have come from the opportunity for heat recovery but now we recognise that the main benefit of these ventilation systems is basically good ventilation. The Passivhaus standard sets detailed criteria for airflow rates, noise levels and commissioning which, if followed, will lead to ventilation that works well. The ventilation section of this guide provides specific details about designing ventilation to the Passivhaus standard.

Heating and hot water

A Passivhaus does need some heating – this is implicit in the standard, which is in terms of annual heating demand or peak heat load, after taking account of solar and internal heat gains. However, the amount of heating is very small – much less than a standard new building, and far less than the 20th Century buildings our heating systems have developed in.

It should be possible to heat a Passivhaus by heating the ventilation supply air, but this doesn't mean you should do it. There is often a mismatch between where you want air and where you need to supply heat, so it can be easier to separate them. Also neither boilers nor heat pumps are well suited to supplying the steady low level of heating power required by air heating.

In fact the heating system is one area where you can reduce costs compared with a conventional building and still retain conventional suppliers and technologies – simply use a gas boiler but with fewer and smaller radiators.



An unfinished plant room. Photo: Nick Grant



Larch House, Ebbw Vale, using both PV and Solar thermal
Photo: bere:architects

Heat pumps are also well suited to Passivhaus – radiators ‘oversized’ to work at heat pump temperatures (around 45C) are not large or expensive thanks to the low heat load, and there is no risk of the heat pump being unable to meet the demand in cold weather. Thanks to the minimal heating requirements of Passivhaus it makes sense to favour air source heat pumps + radiators over the ground source + under floor heating combinations, which are a little more efficient but at high capital cost.

Biomass heating with pellet boilers is not so well suited to Passivhaus – basically the heating demand is just too small, and the boilers aren’t good at operating continuously at such low output. This could be managed with a large thermal store – but again the expense isn’t justified by the minimal heating demand.

do

- think about MVHR location at an early stage
- make sure the MVHR is easy to access for filter changes
- get a full ductwork design done in time to integrate with the architectural design
- have the system commissioned on completion – you need to do this for certification
- allow for some sort of heating system, but make it cheap and simple.

Renewables

Traditionally solar thermal has been a popular choice for Passivhaus designers. The PHPP energy model allows solar thermal input to reduce the total primary energy demand, which can allow simpler direct electric input as the back-up heat source. However big drops in the cost of solar photovoltaic (PV) generation has changed the landscape and solar thermal is becoming a rare option.

Managing power from solar PV is a fast developing field – the starting point is controllers which use ‘surplus’ power to directly heat hot water, but newer systems are able to manage domestic appliances and heat pumps, running these preferentially when there is a high level of PV generation.

The Passivhaus Institut is moving towards including PV generation in Passivhaus certification. This will be in the form of new classes Passivhaus Plus and Passivhaus Premium. These standards require the same fabric standard as any other Passivhaus plus reductions in the primary energy demand compared with the existing Passivhaus standard, in order to address the problem with ‘net zero energy’ buildings, which generate a surplus of solar power in the summer and claim it back in the winter.

don't

- think you have to heat via the air supply
- get carried away with expensive heating systems – they won’t be used enough to be worth it
- expect to just use direct electric for space and water heating and stay within the Passivhaus primary energy limit
- expect that the MVHR will distribute heat from a heated room to an unheated room – it won’t.

1 Mechanical ventilation heat recovery (MVHR)

Alan Clarke

Introduction

An MVHR system has a ventilation unit with two fans: one draws outside air in and supplies it to bedrooms and living rooms; the other extracts air from kitchens and bathrooms to exhaust to outside. Inside the unit there is a heat exchanger which transfers the heat from the outgoing air to the incoming air without any recirculation of the air itself.

MVHR

The fans run all the time, but can be switched to different speeds – usually low, normal and boost – and these rates are adjusted at commissioning to suit the individual house. The unit includes filters which remove dirt (and insects) from the air supply.

A system of ducts is needed to distribute the air from the ventilation unit to and from the rooms in the dwelling, and there are also ducts between the unit and outside to bring in fresh air and exhaust stale air.



Large Paul MVHR unit. Photo: Conker Conservation



Paul MVHR Unit with optimised duct lengths (pre-insulation). Photo: Alan Clarke

System sizing and flow rates

There are set criteria for working out how much air to supply in a Passivhaus; these are provided in the manual for the Ventilation Final Protocol Worksheet, which is supplied with PHPP. Supply air and extract air are worked out differently, but when the system is running they must be equal, ie, in balance.

Supply air is set at $30\text{m}^3/\text{h}/\text{person}$ – this should be calculated using the actual number of people expected to live in the house, rather than the default figure calculated by PHPP at $35\text{m}^2/\text{person}$. For under-occupied houses ($>40\text{m}^2$ per person) the backstop rate is 0.3 ACH. This gives the standard airflow rate, which is usually set as the middle fan speed.

Extract rates are normally based on individual wet rooms: $60\text{m}^3/\text{h}$ for a kitchen, $40\text{m}^3/\text{h}$ for bathrooms and utility rooms, and $20\text{m}^3/\text{h}$ for a WC.

The total extract rate is usually higher than the supply rate – the difference is dealt with by running both fans at the higher rate when cooking or bathing requires extract. The design 'boost' rate is either the 'standard' rate + 30% or the total extract rate, whichever is larger.

Confusingly, the PHPP calculations of the nominal rate are different: PHPP first sets the maximum flow as the larger of the supply and extract rates, as calculated above, and then sets the standard rate at 77% of this figure. The implications are that for more densely occupied houses the per-person rate will be lower than 30m³/hr/person and for houses with large numbers of bathrooms the per-person rate will be higher.

It's advisable to default to the manual and the 30m³/h/person standard rate and adjust extract rates up or down to give a boost of +30%-40%, provided that the building regulations Part F boost extract rates are still maintained.

When it comes to deciding air flow to each room the basic rules are bedroom supply of at least 15m³/h/person, so 30 m³/h for a double bedroom, and the remainder is available for living spaces. Dining rooms can often rely on air passing through to the kitchen and so don't need their own supply, but this depends on the layout of a particular house. Extract rates are set according to room type but need to be reduced proportionally from the boost rate to the standard rate, so that the supply and extract rates are in balance.

The two settings for normal supply and boost extract are comparable to the Part F approach, though the backstop figure for Part F works out at 0.4 A air changes per hour (ACH) rather than 0.3. We think the Passivhaus level is adequate since MVHR actually provides a significantly higher fresh air rate in bedrooms and living rooms, and the research basis for Part F was in window-ventilated houses which don't benefit from fresh air being supplied just to these rooms. The lower figure for Passivhaus also helps avoid over-drying of internal air in winter.

Passivhaus design also allows for a 'low' fan speed, normally 30% lower than the standard rate, which can be used when the house is unoccupied.

Ventilation unit and ductwork

Ventilation unit location is very important to both the efficiency and also the long term usability of the system. Ducts connecting to outside contain air at the outside temperature, so are effectively outside walls – we use insulated ducts but can't possibly insulate them to the standard of the wall. The ducts therefore need to be as

short as possible, basically the unit needs to be located adjoining an external wall, or failing that, within 2m of one. It is possible to install the unit in a frost free location outside the thermal envelope, eg, a garage, but the connecting ducts still need to be as short as possible and of course the external terminals have to be outside the garage.

Access is needed to change filters (every 3–6 months, depending on how dirty the outside air is), so you should be able to walk up to the unit and reach it without needing a ladder. Some units are too noisy to have in a living room or bedroom, so the ideal is a utility room or WC/cloakroom. Allow space for ducts and ancillary equipment when allocating space – look at previous installations for guidance.

Condensate drainage is needed from the ventilation unit – this should be to the internal soil pipe system via a trap and not just straight to outside, otherwise it could freeze and the unit would flood.

External terminals can be close together – often vertically one above the other with exhaust 600mm below intake is a good solution to minimise wall use on a narrow frontage house. The position of the intake terminal is important for air quality – avoid locating near smells or pollution, eg, bins or car park, and avoid intake through the roof in order to avoid bringing in hot air in summer – even north roofs can get hot. Put the intake 2m or more above ground level to minimise intake of particulates. It is better to have the exhaust on the same wall as the intake, to minimise impact of wind pressure difference. Using a roof exhaust causes problems of condensate from the damp exhaust air collecting in the duct and needs special drainage.

Ductwork can either be rigid – normally steel – in a branched configuration, or newer 'semi-rigid' systems which use plastic ducts that can be bent round corners, but still have a smooth inner bore. For the latter, the ducts are arranged radially running one or two to each room from supply and extract distribution manifolds. 'Flexible' ductwork, like old tumble drier hoses, is not acceptable – it gets squashed and has a high resistance to airflow. All distribution ductwork has to be within the airtight thermal envelope – no exceptions.

Ductwork size is determined initially on air velocity to avoid regenerating noise, and the requirement is <2m/s generally, and up to 3m/s for the main ducts at the MVHR and connections to outside. With these velocities the ductwork system will have low pressure loss, though for larger houses and non-domestic projects, full design is advised (with specialist ductwork design software – the system supplier should be able to do this) to ensure the system remains balanced despite longer duct runs. Higher pressure loss increases fan

*LEFT:
Well-designed duct runs underneath the OSB air barrier.
Photo: Alan Clarke*



energy consumption and the test figures for PHI certified MVHR units only apply up to a maximum system pressure of 100Pa. This should only be exceeded in large non-domestic projects when additional calculation is needed to determine the fan energy usage in PHPP in accordance with actual system pressure loss.

Noise control is needed to make the system unobtrusive – noisy systems get turned down or off. Include proper silencers on supply and exhaust – these are big (900mm long and 100mm larger diameter than the ductwork) so if possible fit them between ceiling joists. Branched systems may also require cross-talk attenuators on the supply to prevent noise transmission between rooms via the duct.



*Spiral wound galvanized steel – Efficient, robust, cleanable
Photo: Alan Clarke*

The Passivhaus ventilation protocol worksheet gives design figures of 25 dB(A) in living and bedrooms and 35 dB(A) in the room containing the MVHR fan unit. These figures are used to calculate attenuation required – they are too low to accurately measure, at least during the day on a busy building site. Once the system is running you shouldn't be able to hear the ventilation in bedrooms or living rooms.

Room terminals are different for supply and extract, and there are different terminals for wall supply, directional ceiling supply, and all-round ceiling supply. The position in the room depends on the terminal type: directional terminals are often used to throw air in from the doorway; standard terminals need to be near the middle of the room (but avoid locating over beds) – in front of windows is usually good as the terminals are then unlikely to be obstructed by high furniture. Extract terminals can be put on a wall or ceiling; always put these on the far side of the room from the door.

In housing, door undercuts are the normal way to allow air to flow out of supply rooms and into extract rooms. The minimum undercut is 10mm above final floor finish.

Installation, commissioning and maintenance

Always use a fully designed ductwork system – for domestic ventilation this would usually be done by the system supplier, however they may charge for this. Use the ductwork and fittings specified and don't allow shortcuts with flexible or shallow plastic ductwork.

Cleanliness needs to be maintained during construction. Any dirt in the ductwork system will be blown into the house later. Keep ductwork covered before use and cover open ends of ductwork during construction. Do not run the fans at all until after the final clean of the house to avoid drawing dust etc into the ductwork.

Commissioning is the job of setting the system up with the correct flowrates. This can only be done once the house is clean. Traditional branched systems need to have the flowrate for each room adjusted at the terminal, though good ductwork system design will give required settings (in mm). Semi-rigid systems may come designed with specific flow regulating inserts for the duct to each room. It is still necessary to check the flow at each terminal.

Hand over the system with a description of the system, demonstration of how to operate the controls and how to change filters. Also provide information on where to get replacement filters and written and illustrated instructions on how to change the filters when the time comes 3 or 6 months later.

The primary maintenance requirement is changing filters. Some ventilation units maintain a constant air flow rate when filters get clogged, but in so doing the fans get noisier. Older or cheaper systems just supply less air. So regular filter changes are important. Write the date of install on the filter. Most control units have a filter-change indicator but this is based on number of days.

It is an advantage if occupants can periodically check the system: some systems are so quiet that occupants may not notice if the fans stop running. Over a few years dust builds up on extract valves. These can be removed and cleaned, being careful not to change airflow settings or mix valves between rooms. Terminals should be removed for redecoration, but must be labelled by room if more than one is removed.

BELOW: Filters before and after use
Photos: Andrew Farr



do

- make space for the ventilation unit at the start of the design process
- provide routes for ducts – think of octopus tentacles not just typical section drawings
- fill in the Ventilation worksheet before completing the PHPP
- use a PHI certified ventilation unit
- get a complete ductwork design before starting installation
- use a commissioning specialist familiar with Passivhaus systems.

don't

- just stick the ventilation unit in the loft
- omit silencers
- accept shoddy ductwork installation.

Case Study Knight's Place

Knight's Place is a certified, social housing development of 18 one and two-bedroom apartments, designed by Gale & Snowden Architects for Exeter City Council.

With MVHR an integral feature of all Passivhaus developments, Zehnder's ComfoAir 200 whole house heat recovery system was specified for each apartment.

As the heat loss in each flat is so minimal the heating requirement is met during winter extremes via a small air heater in the supply air duct just after the heat exchanger.

Another key benefit of the CA200 is its filtered bypass, which circumvents the heat recovery mode during warmer months. Ventilation is provided continuously without warm and humid air entering unnecessarily which can assist in reducing summertime overheating.

When tested at the end of a two year monitoring study, Knight's Place apartments maintained a comfortable temperature of 21°C year round for residents, with minimal heating required and low running costs.



2 Heating and hot water

Alan Clarke

Introduction

A Passivhaus building can in theory be heated via the fresh air supply – that is after it is heated to around 50°C. This idea of doing away with a conventional heat distribution system helped define the Passivhaus standard, but isn't necessarily the best choice. Any heating system can be used – radiators, underfloor heating, split system air conditioning, wood burning stove and you can use a gas boiler, a heat pump or district heating. Direct electricity for both heating and hot water is not normally possible because electricity's high primary energy factor means this usually exceeds the Passivhaus primary energy limit of 120kWh/(m².a).

Heating

It makes sense to think of the heating system as primarily providing hot water, plus heating as and when needed. The efficiency of the hot water system, ie, minimising losses from storage and distribution, is significant both in terms of energy use and summer overheating. In PHPP losses that contribute to heating are considered to be part of the heating demand and not the hot water demand – so in fact the heating system itself can be providing significantly less than the calculated 15kWh/(m².a).

Heating loads

PHPP works out an overall heat load, in terms of watts and W/m². This gives a continuous heat load – ie, assuming the heating is on 24/7, and is aimed at seeing if heating via the air is possible. The numbers are finely balanced, which may be lovely in theory but doesn't always make for a robust and easy to live with heating system. For other heat distribution methods, such as radiators, you have the option to turn heating off at night, and warm up relatively quickly when cold. An allowance for extra capacity should be included – as a rule of thumb size Passivhaus heat emitters at 20W/m² (or in other words at 200% of design heat loss).

For radiator systems you can use a simple room by room steady state heat loss model. You can read off the effective ventilation and infiltration rate from the PHPP sheet – a ventilation rate of 0.5 ACH and 90% heat recovery is effectively $0.5 \times (1-0.9) = 0.05$ ACH.



*Radiators can be an excellent match for Passivhaus if sized correctly.
Photo: Alan Clarke*

Heating systems

Air heating is the defining method for Passivhaus, in theory minimising costs. In practice there are a lot of reasons for not using air heating:

- A particular room's demand for heat and fresh air are rarely in balance – bedrooms need plenty of fresh air but little heat, bathrooms get no fresh air but need heat.
- Warm air rises to higher floors – this is not normally a problem but if the heat input to lower floors is strictly limited (by rate of ventilation) then it can be an issue, especially with more than two storeys.
- The air can only absorb a very limited amount of power – several times less than the minimum output of a gas boiler, so some form of buffering is needed if a boiler is used.

Radiators make for a cheap heating system, but are also an excellent match for a Passivhaus. Thanks to triple glazed windows you can put them where you like in a room as there are no draught comfort issues. Individual room control with Thermostatic Radiator Valves (TRVs) allows the system to respond to solar and internal heat gains, which provide a far greater fraction of the heating than in a conventional building.

Radiators can also provide buffering for the minimum output of a gas boiler or heat pump: the thermal mass of the radiators allows the boiler flow temperature to rise gradually even though the boiler may be generating 4 or 5 times the amount of heat the building needs. Then when the boiler stops firing the radiators continue to release heat to the rooms.

Warm radiators generate convective air movement, which helps move heat around a house. This and the high levels of insulation mean you don't need radiators in every room.

Underfloor heating certainly works in a Passivhaus, but is an expensive option since it is a radiant source and you need to install it in every room you want to be warm. This then means that the system can be far too powerful for the heat load – and needs careful control to avoid overheating. If you can keep the floor temperature down to a degree or two above room temperature however, the heat output will be self limiting – once the room is warmer than the floor it will stop heating the room.

Heating sources

Gas boilers are the default heat source in the UK and can easily be used in a Passivhaus. Combi boilers provide hot water on demand, and as such have high kW output so tend to need additional radiator capacity to buffer this. System boilers work with a hot water cylinder, so the boiler will generally be the smallest size available.

To use deliberately oversized radiators (see image, left) and yet avoid overheating, the boiler controls need to be able to run the heating system at a lower temperature than traditional, and yet still provide hot water. Combi boilers do this by default, but system boilers usually require some sort of add on diverter valve arrangement, along with the manufacturer's 'intelligent' controls – all wired quite differently than conventional mid position valves.

In areas with no mains gas there is the alternative of LPG stored in tanks or large bottles. LPG boilers are essentially the same as those used with mains gas, the only downside is higher fuel cost and the space requirements for gas storage.

*MVHR with heat pump in small services room
Photo: Kirsty Maguire Architects*



Air source heat pumps are a practical option for a Passivhaus. Modern pumps are able to heat hot water without needing direct electric boost (immersion heater), which is important considering that hot water forms the majority of their annual usage. This does mean that the performance may be lower than advertised, and remember that some of the heating demand is also met by hot water losses too.

PHPP now has a detailed section for heat pumps which uses the test data normally quoted by manufacturers for a range of operating temperatures, plus the heating and hot water loads of the building to more accurately estimate the electricity consumption and performance (COP) of the heat pump.

Underfloor heating is normally recommended for heat pumps but, remembering that only 25%-40% of the heat pump output is going to the heating, this may not be worthwhile. Radiators oversized to run at 45°C will be nearly as efficient, plus easier to control and cheaper.

Ground source heat pumps are also possible, though the advantage of using the ground as a low grade heat source in winter is reduced since heating is a small proportion of the total demand, and summer hot water efficiency will be lower than an equivalent air source heat pump. So the high cost of installing ground collectors is not normally justified.

Wood burning stoves can be used, but require careful selection to ensure safe operation with an airtight mechanically ventilated house. There are certified 'room air independent stoves' available from Germany and Austria, but they are expensive and hard to find. Alternatively a stove with an external air supply can be used in conjunction with a differential pressure switch to stop the ventilation in the event that it is depressurising the house (due to either supply fan failure or duct blockage).

A cheap, and sensible, approach is to use a stove purely as a room heater, downstairs in a small open plan cottage – that way it can heat the whole house. A hot stove distributes heat via convection very well. The cost of installing a boiler stove with thermal store, associated controls and heating distribution will never pay for itself in a typical Passivhaus, where a wood burning stove is used as a room heater, hot water is normally provided by electricity and solar energy, or a gas boiler.

Hot water systems

Hot water often uses more energy than heating in a Passivhaus so it pays to concentrate on designing an efficient system. Use the DHW sheet in PHPP at an early stage in design, since the losses here are included in the summer overheating calculation

Hot water heat losses fall into three categories: cylinder; continuous (secondary) circulation; and draw-off dead leg. In addition there is the primary heat loss between the boiler or heat pump and the cylinder. To convert the manufacturer's hot water cylinder heat loss data in kWh/24hrs into Watts, multiply by 1000 and divide by 24.

Circulation loss only applies if you have a pumped hot water loop – not normally necessary in houses. If you do have one, then insulation levels and pipe length are the important factors to optimise.

Draw-off losses represent the cooling down of the hot water pipe and its contents after each period of use. Here insulation is not significant – the pipe will cool down anyway: the important factors are pipe diameter and length. Shorter pipes have the advantage of lower pressure loss, which means it may be possible to use smaller diameter pipework. See AECB water standards guidance for details.

Cylinder location is the key to efficient hot water distribution. It needs to be as central to the various hot taps as possible in order to minimise the total draw-off pipe length and avoid the need for secondary circulation. A house layout which groups kitchen, utility and bathrooms in one area is also very beneficial. To minimise the primary pipework heat loss the boiler or heat pump also needs to be as near to the cylinder as practical.

Combi boilers are an alternative in smaller dwellings. Hot water output rate is limited so only use these in single bathroom dwellings. The advantage is that you get rid of the bulky hot water cylinder, connecting pipework and associated heat losses. The only combi boilers which completely avoid hot water storage are gas (or LPG) powered. Oil combi and heat pump combi boilers actually have a hot water tank built in.

BELOW: Passivhaus reduces the need for services!
Photo: Nick Grant



don't

- spend a lot of money on a biomass boiler or bore hole heat pump system
- expect that a 100% electric heating and hot water system will comply with the primary energy limit for Passivhaus certification.

Thermal stores are an alternative approach to hot water storage where hot water is generated on demand via a heat exchanger. Don't use these unless you have to – say for a wood burning boiler. The store has to be kept at a significantly higher temperature than a normal hot water tank, leading to increased heat loss and reduced boiler efficiency (never use with a heat pump). And in the end the hot water performance in terms of flow rate and temperature is generally worse than the standard hot water cylinder.



ABOVE: Water tank located in a cupboard. Photo: Alan Clarke

do

- use a cheap and simple heating system – the investment belongs in the building fabric
- consider radiators as your first option
- arrange the layout to keep hot water outlets in a reasonably compact form
- put the hot water storage (or combi) in the same area
- chose heat pumps that provide good hot water performance rather than heating
- fill in the PHPP DHW section before looking at overheating.

3 Solar thermal and photovoltaics (PV)

Alan Clarke

Solar thermal

Solar thermal has traditionally been the cheaper and lower technology way to harvest solar energy. The heat can only be used in the house where it is installed and PHPP recognises this as contributing to reduced primary energy consumption because less fuel is needed for water heating. Systems need to be carefully designed to provide as much useful hot water as possible whilst avoiding over heating in summer.

Photovoltaics

In the past photovoltaic generation was very expensive thanks to the cost of the high tech semiconductor factories needed to make the collectors. Now mass production has brought costs down to a level where PV makes economic sense.

In PHPP solar PV is now modelled but does not show as a contribution to primary energy – the rationale is that PV systems are connected to the grid, and electricity not used in the house is exported for use elsewhere and there is no direct relationship with the energy used in the dwelling. Also historically the generous subsidies for PV and resultant trend for PV to be installed by third parties as a financial investment has led to the view that PV is not tied to a particular building in the same way as solar thermal.



The new Passivhaus plus energy standard includes PV generation, but retains the same Passivhaus building efficiency levels as the standard Passivhaus.

Standard domestic tariffs don't meter export of electricity so it is in the householder's interest to use as much as possible of their PV generation. Immersion heater controllers are available which divert any surplus power to an immersion heater, providing effectively a cheap solar hot water system. This isn't accounted for in PHPP or Passivhaus certification and the view is that this electricity could be exported and used elsewhere, so it isn't really free.

do

- use MCS products and installers
- ensure solar thermal has regular inspection and maintenance.

don't

- specify an over-sized solar thermal system
- expect PV systems to help you meet the primary energy demand in a standard Passivhaus.

Renewables on Denby Dale Passivhaus
Photo: Green Building Store

4 Fenestration and shading

Nick Grant

Introduction

Good fenestration design requires effort, knowledge and experience but following some basic rules of thumb can help avoid the most common pitfalls.

Orientation

Even Passivhaus windows have about eight times the heat loss of a wall but this is partly offset by solar gains. Graph 1 shows the annual energy balance per m² of large un-shaded Passivhaus quality windows facing the four cardinal points (building located in the UK Midlands). In practice, east and west glazing has much more solar gain than typical south glazing during summer but is difficult to shade. Conversely, simple overhangs from roof and reveals provide shading of the south from the high summer sun.

Because of the net winter gain and relative ease in controlling summer gains, domestic Passivhaus buildings are best designed with as much of the living areas located on the south as possible. This allows the building to be day-lit and ventilated with mostly south glazing.

If we follow this pattern, the south windows would tend to be larger and the others smaller. This further alters the balance in favour of south glazing, as the amount of frame is less in proportion to glass for larger panes. See Graph 2 for a real Passivhaus design in the same climate zone.

Passivhaus is not passive solar

When we calculate the net energy gain and amortise the cost of glazing over an assumed life of say 20 years, we find the cost of free solar heat through south glazing is about 50p/kWh. If the window area is required for daylight, ventilation, views and other functions then the heat really is free. If not, then extra glazing is an expensive way of providing heat!

Glazing ratios

It is possible to design a Passivhaus with lots of glazing. PHPP allows us to balance the high losses with extra gains and additional insulation. We can then design out the resultant summer over heating by adding shading in the form of overhangs and blinds. This might work in a model but in reality it is a very expensive way to meet the Passivhaus standard and it will be very difficult to regulate summer temperatures.

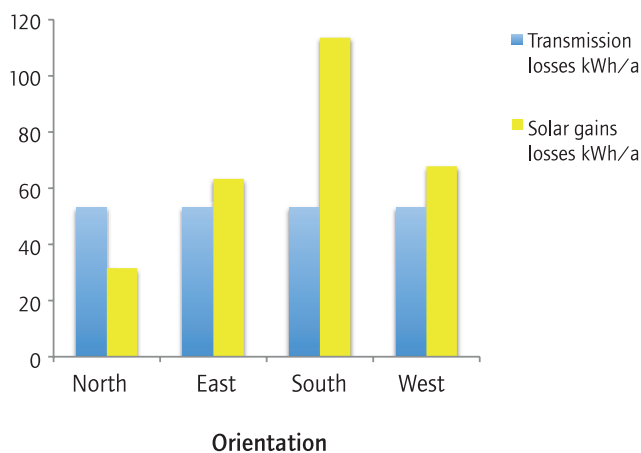
A far better approach is to design for good, but not excessive daylight, with a maximum of about 25% of the internal south facade as glazing. All other orientations should ideally have only as much glazing as is needed for views, daylight and ventilation.

As a rule of thumb total glazing area (excluding frame) of around 15-20% of treated floor area (TFA) is a good starting point for design.

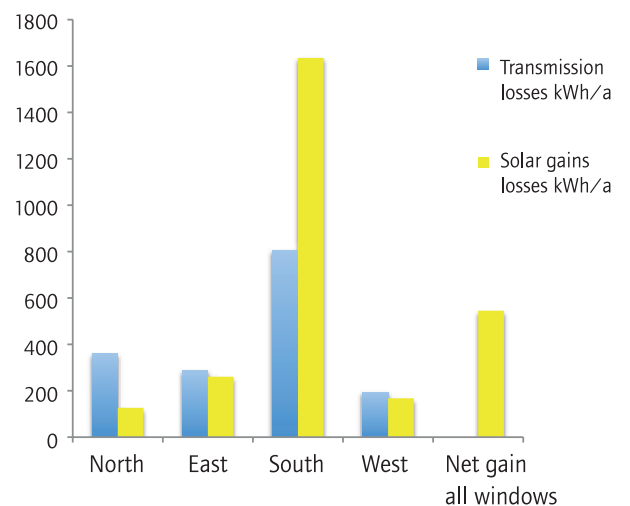
Shading

With modest glazing designed for daylight rather than maximum solar gain, it is often possible to achieve sufficient summer shading of south glazing via the existing roof overhang or window reveals.

Graph 1 Annual energy balance for larger windows



Graph 2 Annual energy balance for an actual design with larger South windows





ABOVE: Wilkinson Primary School Classroom. Photo: Architype

LEFT: River Studio Shading Photo: Marco da Cruz

To fully shade south glazing at summer solstice we need a 60° shading angle in the UK. Low sun in autumn and spring may still cause some overheating but we can open the window for cool air. On hot days in summer the outside air will be warmer than indoors so throwing open the large glass doors doesn't really help.

For hotter climates or where the glazing has been overdone, it is necessary to include external moveable shading. However, blinds and shutters are expensive, require maintenance and obscure the daylight and view that the window was installed to provide.

Internal blinds have much less impact on overheating as the heat is already in the room but have a slight benefit in that they can control glare and provide privacy.

Either inward or outward opening windows are possible but inward opening windows allow external shutters or blinds and fly screens. Note that it is very difficult to effectively shade rooflights, so large skylights can pose an overheating risk.

Rules of thumb

- Maximum south glass area about 25% of internal wall area
- Total glazing about 15-20% of TFA
- Limit skylights to about 10% of floor area for that room
- Glazing below about 850mm from the floor does little to improve daylight
- Window heads close to ceiling maximise daylight penetration (but leave room for curtain rails, blinds, and ventilation opening for tilting windows)
- 2% daylight factor is a good target; higher than 4% might indicate overheating risk for that room

do

- have at least one opening window in every habitable room
- design for daylight and views
- design for daylight quality and usefulness over brute quantity
- for the UK climate do try and design without the need for external blinds
- consider glazed doors rather than solid, for extra light and solar gains
- consider fly screens and security for summer ventilation
- use light wall colours to improve daylight without increasing overheating.

don't

- rely on deciduous trees to provide summer shading
- try and heat the building with the sun
- over-glaze
- make opening window lights too large to open safely.



Whole-building systems

Kym Mead

Summary

A 'Whole-building system' addresses the Passivhaus criteria and performance requirements by providing all parts of the system needed to create high levels of thermal comfort and good air quality. This can ensure that the building specification has been thought about at an early stage ensuring that design and performance backstops are integral to the building conceptual design.

Introduction

Passivhaus encourages designers to address all aspects of the design at an early design stage, including the types of materials/systems that will be used. A whole-building system approach i.e. one where the materials have been pre-selected and developed into a holistic system, can help designers make their design decisions with confidence that the final outcome will meet the Passivhaus requirements. This chapter highlights the key areas that should be addressed when adopting a whole-building system approach.

Holistic design

Passivhaus encourages an approach to design which considers the building as an interconnected whole. Holistic concepts should be applied to the orientation and form of the building, as well as the design of mechanical services and fabric performance.

Designers can address all these interconnected principles/requirements through their own work, for example, through their PHPP calculations. Alternatively, there are now multiple companies that offer a 'Whole-building system' approach to achieving the Passivhaus standard. This may offer a simpler approach, especially for inexperienced designers or clients, as the system providers will have undertaken much of the work to ensure compliance with the Passivhaus standard. In addition, the systems are built in state-of-the-art factories by highly skilled technicians, which allows for closely monitored quality control without the need for multiple on-site visits during varying weather conditions. However, they may not be suitable for all sites, designs or situations!

All whole-building systems should deliver on Passivhaus requirements, including the following principles:

Fabric U-value 0.08 – 0.15W/m²K

The building fabric will probably have 200–300mm of insulation, depending on the lambda value of the insulation, but still needs carefully considered design, which will reduce heating and cooling energy requirements significantly. The design should also avoid thermal bridges, which could compromise the thermal performance of the building, although the system should help as these potential bridges should already have been considered, identified and minimised.

Airtightness

The system should achieve the target of very airtight construction, which has four advantages:

- no draughts, and thermal comfort at lower temperatures
- fabric preservation through preventing moisture ingress into walls from inside
- energy saving
- sound attenuation from external noise.

Again, off-site fabrication should help in achieving the required airtightness level for Passivhaus.

Window U-value less than 0.8W/m²K

The triple glazed windows reduce unwanted cold down draughts by maintaining a minimum internal surface temperature of 17°C, which is standard for Passivhaus and should be included as standard within the system. However, design decisions, such as concentrating window openings on the south facing elevation, and using appropriate shading, will help to reduce heat losses and manage solar gain.

Fresh air ventilation 30m³/person/hour

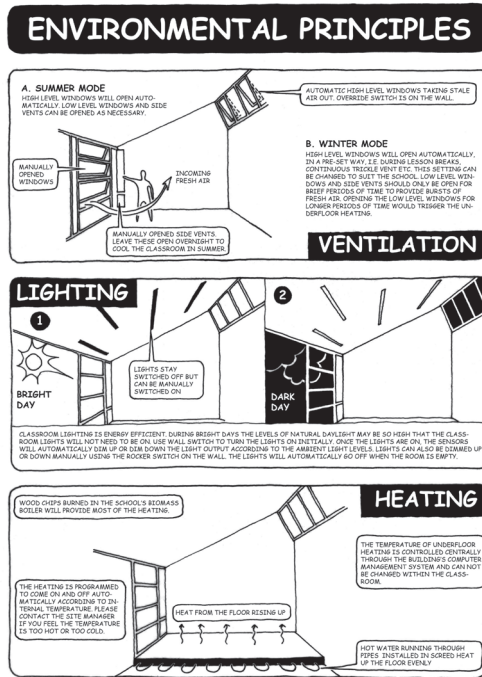
The system should also include an efficient controlled ventilation and heat recovery system to ensure optimum fresh air while managing heat recovery from outgoing air. This should maintain the optimum internal temperature with minimal heating and cooling equipment. However,

the location of the unit and the design/ layout of the ducting will still affect the efficiency of the system.

The whole-building system approach

Overall, a whole-building system approach can assist with meeting Passivhaus requirements, particularly as the pre-fabricated components should have good performance characteristics and their use can reduce construction time, resulting in lower labour costs, and minimise on-site delays due to adverse weather conditions.

However, whole-building systems do not remove the need for effective design input, as outlined above. Orientation, services, design and other factors will all have a significant effect on the cost, efficiency and successful delivery of a project using a whole-building system.



LEFT: User guide cartoon sheet. Photo: Architype

Advantages

- A whole-building system can remove some of the complexities of ensuring that different materials and components can be combined to achieve Passivhaus requirements.
- Prefabricated components can speed up construction time, resulting in lower labour costs.
- Construction programme is less affected by bad weather.
- The mechanisation used in construction increases conformity to the Passivhaus standard.
- Materials are protected from exposure to the elements during construction.
- Quality control and factory airtight sealing ensures better quality control.

Disadvantages

- The system(s) may not work for all projects and design choices.
- Effective design decisions are still required.
- Space is required to transport manufactured modules or components to their site.
- Affordability may be an issue, particularly for smaller projects; increased production volumes on larger projects should offer greater affordability.

do

- consider the orientation of the building early in the design as this will affect the fabric performance
- keep the form of the house as simple as possible which will reduce cost.

don't

- design the house without using PHPP to model the energy flows
- over glaze the house so requiring expensive external mechanical shading devices
- always check if there are transport and access issues for delivering manufactured homes or modules to their intended site.



Construction and quality assurance

Mark Siddall

Summary

Training of site operatives, undertaking detailed site inspections, provision of robust feedback and the inclusion of a dedicated, on site quality assurance champion are all constituent parts of a successful delivery process. This chapter outlines those areas that require specific attention.

Introduction

With a sound design already in place, exemplary standards of on-site quality assurance are required in order for buildings to perform appropriately. This means diligence and excellent standards of craftsmanship must be employed at all times. For a project to be completed successfully, with minimised costly rework and remediation, experience suggests that there is a learning curve that needs to be addressed. This learning curve is not confined to the site office; it affects all trades on site.

Key stage design reviews

Structured reviews that interrogate a design are hugely beneficial, particularly for less experienced project teams. These reviews analyse each and every aspect of the design and the construction. Key characteristics:

- They are not simply 'compliance reviews' – they dig into the details and examine the buildability, sequencing and construction programme.
- Their purpose is to identify and expose risks that could impact upon project delivery.
- They allow the project team the opportunity to formulate strategies that resolve the risks in an open and collaborative fashion.

Training of site operatives (tool box talks)

On some building sites, traditional attitudes can be entrenched and effort must be made to bring all site operatives on board. Each trade, from foundations to roof, has a part to play in the successful completion of a project. One of the best techniques is to hold a series of tool box talks that all site personnel are required to attend. New or replacement personnel should also receive an induction. Typically these tool box talks examine each detail, the sequence in which it will be constructed, the technologies that will be used when forming the



An Airtightness Team, comprising two Airtightness Champions, two Sealing Operatives also including the Site Manager, on the Erneley Close project. Photo: Paul Jennings

Good practice example

PHPP calculations suggested that the design had the potential to satisfy the Passivhaus Standard. The challenge lay in the actual implementation of the delivery process.

A series of Key Stage Design Reviews, training of the dedicated, on site Quality Assurance Champion, tool box talks and site inspections and Feedback underpinned the successful completion of the Certified Passivhaus homes at St. Mary's, Oldham. The result of these processes resulted in buildable details and simplified construction processes.

Site manager Anthony Kavanagh says:

'Compared to the Code 6 homes that are also on site I would prefer to build to the Passivhaus standard. The construction details that we have developed with Mark are proving to be far more practical and easier to build.'

A dedicated, on-site Quality Assurance Champion

The role of a dedicated, on-site Quality Assurance Champion is to make sure that the building satisfies its airtightness target. The role is to also help ensure that the correct insulation system is installed properly. This means ensuring that:

- the interface between insulation products has a good butt joint
- the insulation is encapsulated between the air barrier and the wind barrier
- the wind barrier system is completed in accordance with the design intent.

Their role is also to:

- organise and arrange pressure tests
- arrange for timely tool box talks for all trades
- review the buildability of the air barrier, wind barrier and insulation systems – this means reviewing the sequencing of the build process and considering where challenges may arise before they become an obstacle
- undertake day to day site inspections of the work and instruct remediation as required
- ensure that only the specified materials are used in the construction i.e. avoid ad hoc substitutes, without prior consultation and agreement with the designer.

detail, and trades that will impact upon the successful completion of the detail. An atmosphere of collaboration helps these talks to work best and allows any sceptics to voice their concerns. Inviting sceptics to speak up is vital because:

- they may have a valid point and the sessions create an opportunity to address relevant concerns
- there is an opportunity to address their concerns and to bring them on board
- in the most extreme cases there is the opportunity to identify people that will obstruct the success of the project. They can then be replaced by more appropriate trades people.

Site inspections and feedback

Detailed site reports that support a useful, practical and fully functional feedback loop are invaluable. Discussing the contents of the reports with site managers, rather than simply handing over the document, is critical to establishing this feedback loop. The key thing here is the fact that, compared to standard practice, a closer working relationship is required for Passivhaus projects.

Site inspections may be made by the design team on a periodic basis. For this reason the site reports that they produce are only a snapshot in time. The best site reports also record the lessons learned from the site visit so that they may be fed forward to subsequent phases of the project and for future projects.

don't

- hope for the best
- fail to plan for success
- rely upon standard industry practice when planning construction programmes
- forget to undertake site inspections and feedback.

SITE REVIEW REPORT Inspection undertaken by Mark Siddall

Project number: 117 Project name: Date: 31.08.12
 Weather: Clear Sky Site: Review: 004

Introduction:
 The purpose of this report is to:

- Identify risks that may influence whether the building will achieve the required standards of performance
- Identify risks that may impair the successful formation of the air barrier
- Provide a photographic record of the typical and atypical faults that may impede the delivery of a successful air barrier

Within the scope of the work, time constraints and availability of access it was not possible to physically inspect all aspects of the building envelope. As site inspections are intermittent, with periods of time between visits, it is recognised that the formation of the air barrier may be incomplete and that there may be defects that have been concealed during the construction process.

Progress:

- Scaffold lift up to second floor.
- Second floor structure installed

Risk Status:

HIGH	MEDIUM	LOW
------	--------	-----

Observations:

Figure	Observation	Recommendations	Owner
1	Party wall insulation was found not to be filling the cavity. Concerns regarding party wall bypass.	Remove and reinstall	Bramall
2	The party wall insulation was found not to conform with the specification.	Remove and reinstall with appropriate material	Bramall
3	Horizontal gaps in the insulation are apparent.	Assess cause of gaps and remediate	
4	Insulation is not installed tightly installed against the warm side of the cavity. Thermal bypass risks incurred.	Ensure that insulation is tightly installed against the warm side of the cavity.	
5	Corners are being formed in a neat fashion but are not being interlaced as they turn the corner.	Consider improving practice: greater interlacing of the batts as they turn the corner would reduce the risk of gaps being formed.	
6	Insulation generally appears to be installed tightly installed against the warm side of the cavity. Insulation at external face sometimes compressed by 10mm due to mortar snots.		
7	Insulation to window/door openings has been installed in sloppy manner. Insulation to window/door openings has sagged.	Rework will be required to allow install of windows/doors. Care will need to be taken to avoid gaps between insulation and frames.	

Distribution: Site Manager (Construction) Project Managers (Construction) Contract Manager (Construction) Mech. Eng. Struct. Eng. CDM Advisor Architect File Page 1 of 6

Example of Site Report used by Mark Sidall for a Passivhaus development.

do

- allow time for planning (it will pay back in the future)
- undertake key stage design reviews
- train site operatives
- ensure that there is a dedicated, on-site Quality Assurance Champion
- remediate mistakes ASAP (when you still have the chance).

Case Study Wilkinson Primary School

Wilkinson Primary School in Wolverhampton is the third collaborative Passivhaus school project by contractors Thomas Vale and architects Architype.

Building on the lessons learnt during the design and construction of Bushbury Hill and Oakmeadow Primary Schools, the project team sought to deliver their third Passivhaus school on an even tighter budget.

The project team attended regular design review meetings to check progress and structured reviews that interrogate a design are hugely beneficial, particularly for less experienced project teams. These reviews analyse each and every aspect of the design and the construction.



ABOVE: Having learnt the ropes on two earlier schools, most passivhaus related snagging was carried out by the Architects (Lee Fordham pictured) with minimal input from the Passivhaus consultants Elemental Solutions. Photo: Nick Grant

LEFT: Checking for air leaks with a thermal imaging camera. Photo: Nick Grant

BELOW: Wilkinson Primary School. Image: Architype



Core components of a Passivhaus Project Management checklist

By failing to recognise the boundary between a certification process and the design and construction process individual projects are at risk and may encounter difficulties. In part this may be because the industry has become used to certification systems that are less rigorous and have permitted this gap to go unobserved.

Listed below are the major components that are included on a Passivhaus Project Management checklist. Each component, and its constituent sub-components, should be coordinated with relevant BS EN standards. When a building is to be certified it is vital that this checklist is developed and agreed with an approved Passivhaus Certifier.

Photographic evidence of the construction should be gathered at key stages by appropriate members of the design and construction team. The Passivhaus consultant should assist with agreeing the regime for compiling evidence, on a project specific basis.

Training/toolbox talks (pre-start)

- Site storage
- Workmanship
- Activities to be undertaken
- Sequencing of activities

Ductwork protected from site debris during storage.



Insulation installation – materials and workmanship

- Walls, roof, floor, windows
- Junctions
- Services

Check construction tolerances. Insulation is encapsulated tightly between internal and external leaf to avoid thermal bypass.



Windtightness – materials and workmanship

- Primary wind barrier system
- Window installation
- Service penetrations

Wind barrier installed in a manner that allows easy inspection and remediation during construction.



Airtightness – materials and workmanship

- Primary air barrier system
- Window installation
- Service penetrations

Air barrier installed in a manner that allows easy inspection and remediation during construction.



Services – materials and workmanship

- MVHR unit installation
- MVHR ductwork & silencers
- DHW
- Pipes and plumbing
- Heat sources
- Controls

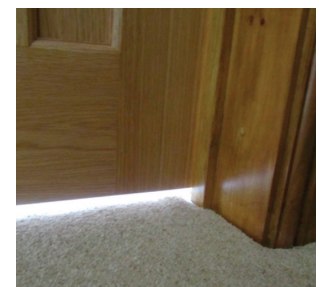
Ductwork protected from site debris during installation.



Builders' work

- Joinery (door over/undercuts etc)

Air transfer provision is checked against design drawings and specification.



Windtightness image: Arden Construction

Other images: Mark Siddall



Certification and quality assurance

Kym Mead

Summary

Passivhaus buildings maintain comfortable indoor temperatures all year round with extremely low energy demands. This is achieved by careful design, robust detailing of the building fabric and services, and effective quality control of the construction process. Certification is essentially the formal assessment and approval of the quality of the project.

Introduction

Essentially Passivhaus certification is a quality control process that ensures that the building will perform as designed. It is advisable that a building certifier or experienced CEPH designer/consultant has early input into the design pre-planning stage as they will be able to advise on the insulation and glazing choices in relation to the orientation and massing of the design. The other crucial stage is a pre-construction check, where confidence can be given that the design will meet the Passivhaus target, ideally before work on site starts.

Passivhaus certification

The Passivhaus Standard is voluntary and based purely on building physics which applies to both domestic and non-domestic buildings. The criteria for Passivhaus certification are performance based, instead of individually specified construction or technical details. Certification requires that overall planning is carried out with a calculated energy assessment within the Passive House Planning Package (PHPP), plus elaboration of the details and supporting documentation on components and services. This ensures that the planned building will actually perform as designed.

Careful planning

Certification is intended to ensure a good quality of work. Airtightness, thermal bridges, the quality of the windows and their installation, the ventilation system and other building services will all be checked as part of the project. The main factor in successfully achieving certification is planning, as only careful and considered planning will ensure you complete all the required factors to achieve the Passivhaus standard.



Quality Assurance Certificate awarded on successful completion of a Passivhaus development

The QA certificate

After the building has successfully achieved the required airtightness level and the commissioning of the building services has been completed, the project is assessed and checked as part of the final quality assurance check, or Certification. Upon successfully achieving all criteria the building certifier will issue the 'Passivhaus Quality Assurance Certificate' to the design team or client.

Checklists

All accredited Passivhaus certifiers use checklists for their quality assurance, which are normally provided on their appointment to the project. These checklists should be referenced during the design stages with information collated as the project develops; this will save time when checks need to be made and signed off by the certifier.

The benefits of certifying a Passivhaus for the designer and building owner

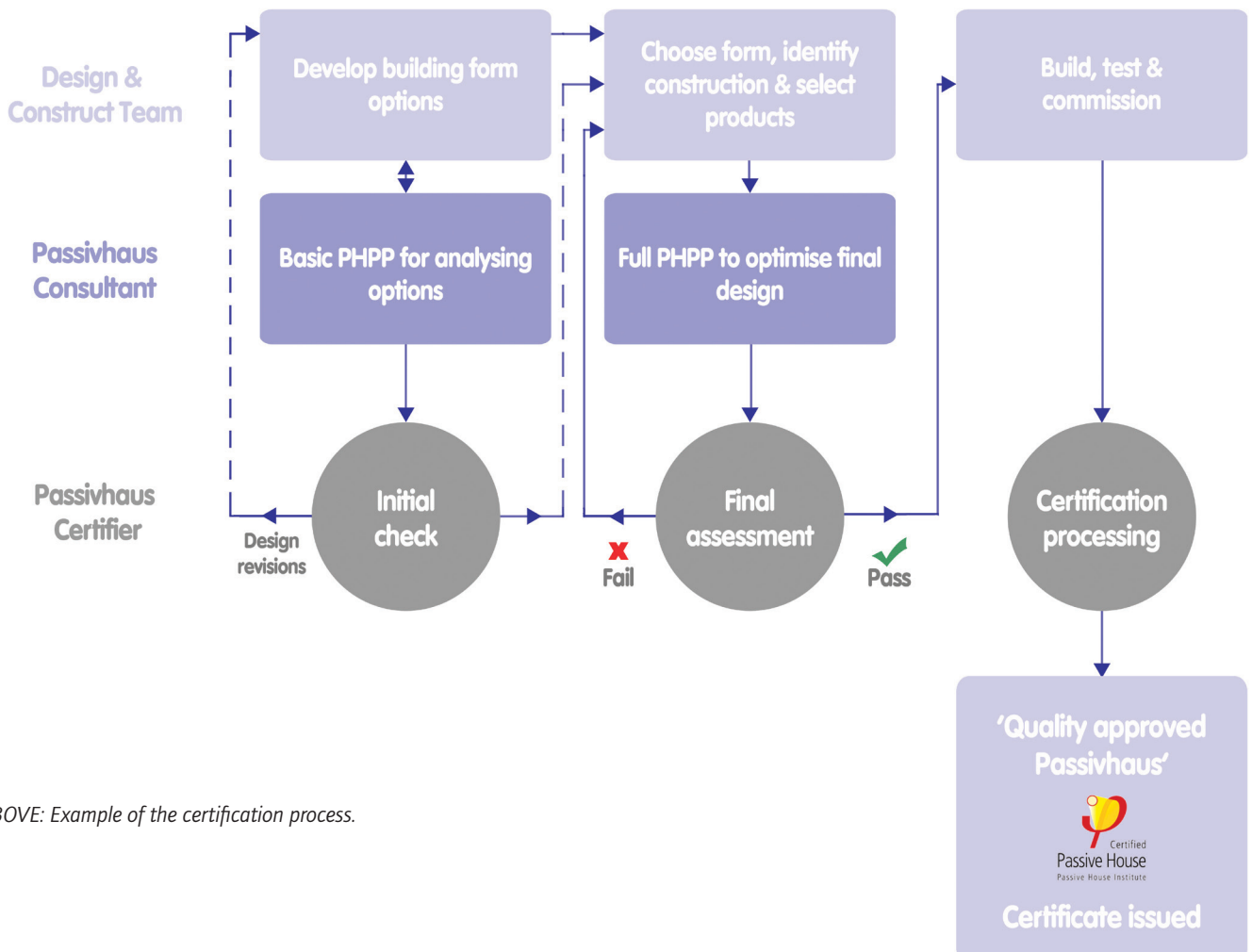
- The certification of a Passivhaus through an accredited building certifier offers quality assurance.
- The experience of building certifiers can benefit designers and architects throughout the design and construction process.
- In the process of certification, the designer receives valuable hints about how quality can be improved, and how solutions can be simplified and implemented in a better and more cost-effective way.
- The support provided by an experienced Passivhaus certifier can result in a more economical building.

do

- engage with a Passivhaus Certifier at the earliest opportunity
- model your design in PHPP at the early design stages
- make sure you are using the correct climate data within PHPP.

don't

- assume that a building specification from a previous development will suit all future Passivhaus buildings
- leave the collation of information to the last minute as this could cause delays in the building being certified.



ABOVE: Example of the certification process.



Handover, maintenance and comfort

Chris Parsons

Summary

It is sometimes thought one drawback of the Passivhaus standard is that it requires occupants to change their behaviour, yet a properly designed Passivhaus should not require any significant behavioural change.

Passivhaus comes in all varieties; not just domestic dwellings, but schools, hotels, hospitals can all be delivered to the standard. The design should only include components and controls that are appropriate for the skills and understanding of the occupants.

Introduction

Each Passivhaus is bespoke in the sense that there is no standard typology, meaning the handover process and the maintenance regime needs to be tailored every time to suit different heating, ventilation and cooling methods, different equipment and component demands, and different occupant types. As always, understanding is the key. For the occupant, a clear understanding of the controls and techniques available to them will ensure they can achieve a comfortable environment with very low energy demands. For those responsible for maintenance, an understanding of the sensitivities and contribution of components to the overall performance will ensure the comfort and energy qualities are delivered.

Advance information

Advance information in the form of a general explanation of the Passivhaus standard and methodology, and how it applies to the specific project can be a helpful start.

'Quick start'

Identify any maintenance items to be carried out by the occupier, and provide clear and simple instructions for doing so. These can be supplemented by stickers or laminated posters affixed to the equipment if helpful.

Provide a very simple 'quick start' guide to the various controls and techniques, checked and proof read by a non-technical person, ideally someone fluent in the occupier's language. It should contain a short simple overview followed by a number of simple headings such as 'what to do if my home is cold', etc. The advice should be limited under each section to no more than a couple of paragraphs. If it needs more than that, your Passivhaus is not passive enough! Including photographs or graphics of the controls being discussed, with simple descriptions of each function, will be helpful.

Also identify who to call when faults or more complex maintenance tasks require action, and if necessary, include a script to use. Complications often arise with inexperienced call centres who may not know what a Passivhaus is or what MVHR stands for.



Wall stickers
at Gento's
Passivhaus
Racecourse Estate.
Photo: Alan Clarke

Other information

Consider the provision of stickers or laminated graphic instructions affixed to plant where maintenance is to be carried out by occupants, or untrained persons. More technical or complex documents should be included as appendices within the overall building manual or log book.

Consider making a short yet specific 'how to' video of each topic for posting on a video sharing website (maybe with a DVD copy for the occupants). These can be accessed on tablets, smart phones and computers and the internet is often the first reference point for today's generations.

don't

- over complicate user guides
- try to familiarise on 'move in' day
- frighten occupants with complicated or technical explanations
- leave the maintenance team in the dark.

do

- provide advance information. The earlier the journey starts, the sooner it finishes
- provide a very simple 'quick start' guide, stickers or posters where appropriate
- consider accessible video guides
- set the building up to function prior to 'move in' day
- familiarise occupants through 'hands on' experiences
- re-familiarise at change of season
- involve maintenance teams in the design
- ensure fault response teams are well informed.



Door hangers
at Gentoo's
Passivhaus
Racecourse Estate
Photo: Alan Clarke

Handover

Set everything up to be working on 'move in' day. This allows occupiers to concentrate on the actual move, without having the added complication of learning new controls and techniques on the day. The 'quick start' guide should form a part of the general documentation which should be handed over on move in day.

Arrange a familiarisation session for a week or two after moving in, with as many occupants as possible. Consider who should lead the session. It is important not to overwhelm or frighten the occupants with hoards of technical experts. In a relaxed atmosphere, work through the 'quick start' guide (perhaps using a checklist) and explain each of the main functions. Involve occupants in hands on experience, and avoid the temptation to demonstrate. Learning by 'doing' is far more effective and confidence building. Questions often occur after the session so provide a further point of contact.

Repeating a similar familiarisation session at the following change to winter/summer provides an opportunity to catch up with how the users have coped so far as well as to go over how users might control for cooling instead of heating, for example.

Case Study Burnham Overy Staithe

Following the delivery of a number of Passivhaus schemes, Hastoe Housing Association have continually reviewed their handover procedure to incorporate a number of revisions, incorporating lessons from each.

Recognising that tenants would have no special knowledge of the Passivhaus methodology, the handover procedure adopted at Burnham Overy Staithe began during design stage with the preparation of a plain English guide for residents. An 8-page A5 size illustrated booklet which answers questions such as 'What should I do if my house is cold?' offers occupiers simple and easy-to-follow instructions for all the major controls.

Tenant familiarisation sessions took place two weeks after occupation with a 'hands on' try out of each control. Occupiers were encouraged to operate the controls themselves rather than have them demonstrated, to ensure they were comfortable in their use. Parsons + Whittle, the architects, produced a checklist to make sure nothing was forgotten and ran through an explanation and discussion of the questions raised in the handbook. Contact details were left should occupants have further questions.



RIGHT: The handover checklist developed for Burnham Overy Staithe by Parsons +Whittle Architects and Hastoe Housing Association.

		Done
1	Welcome and Introduction to Passivhaus	
	Insulation	
	Windows	
	Air tightness – reduced draughts	
	Heat from occupation and solar gain	
2	Heating System	
	Strategy (if house is cold/warm)	
	Windows closed	
	Controls	
3	Domestic Hot Water	
	Controls	
4	Cooling	
	Heating Off	
	Windows – purging strategy	
5	Ventilation	
	MVHR – principles	
	Controls	
	Fan Speeds	
6	Air Leakage	
	Holes!	
7	Fuels	
	LPG – Changeover arrangements	
	Electricity – Smart Meters	
8	Other	

The Passivhaus Trust would like to thank the sponsors of *How to build a Passivhaus: Rules of thumb* for making this publication possible, including the commissioning of independent authors

Publication sponsors



Chapter sponsors

"I read that the construction industry had experimented with adding insulation to new buildings and that energy consumption had failed to reduce. This offended me – it was counter to the basic laws of physics. . . . So I made it my mission to find out what [they were doing wrong] and to establish what was needed to do it right."

Professor Wolfgang Feist, Founder,
Passivhaus Institut, Germany

Useful links

The Passivhaus Trust

www.passivhaustrust.org.uk

The UK Passive House organisation.

The Passivhaus Institut (PHI)

www.passiv.de/07_eng/index_e.html

Founded in 1996 as an independent research institute under the leadership of Dr. Wolfgang Feist. The PHI developed and promoted the Passivhaus concept in Germany and worldwide.

The International Passive House Association (iPHA)

www.passivehouse-international.org

The International network for Passivhaus knowledge, working to promote Passivhaus worldwide.

Passipedia

www.passipedia.passiv.de/passipedia_en

iPHA's wiki-based Passivhaus resource featuring in-depth research and years of accumulated knowledge.

The iPHA forum

www.forum.passivehouse-international.org

A dynamic platform for the direct exchange of ideas on all things Passivhaus amongst iPHA members.

Cepheus

www.cepheus.de

A project within the THERMIE Programme of the European commission. Measurement and evaluation of 250 houses to Passivhaus standards in five European countries.

UK Passivhaus buildings database

www.passivhausbuildings.org.uk

Details of many new and retrofit UK buildings certified to Passivhaus standards.

Passnet

www.pass-net.net

Project to spread knowledge of the Passivhaus standard within Europe, through open days and a buildings database.

For more information on membership, training or events visit The Passivhaus Trust website: www.passivhaustrust.org.uk

How to build a Passivhaus: Rules of thumb

Further information

If you'd like to learn more about the Passivhaus Standard, The Passivhaus Trust offers different level membership packages and runs a series of annual training courses and events.

Passivhaus Trust membership

Helping to promote the Passivhaus standard in the UK, influence policy-makers, developers, clients and other key players; network with leading Passivhaus experts, practitioners and academics; access the latest technical information and experience relating to Passivhaus in the UK.



Training courses

The Trust, through its members, deliver training courses for both entry level and advanced Passivhaus practitioners with in-depth training materials and exercises.



Competitions and events

The aims of the UK Passivhaus Awards, OpenHaus and UK Passivhaus conference are to promote the Passivhaus Standard in the UK, and to encourage and drive enthusiasm for the Passivhaus standard, whilst showcasing the UK's pioneering projects.



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