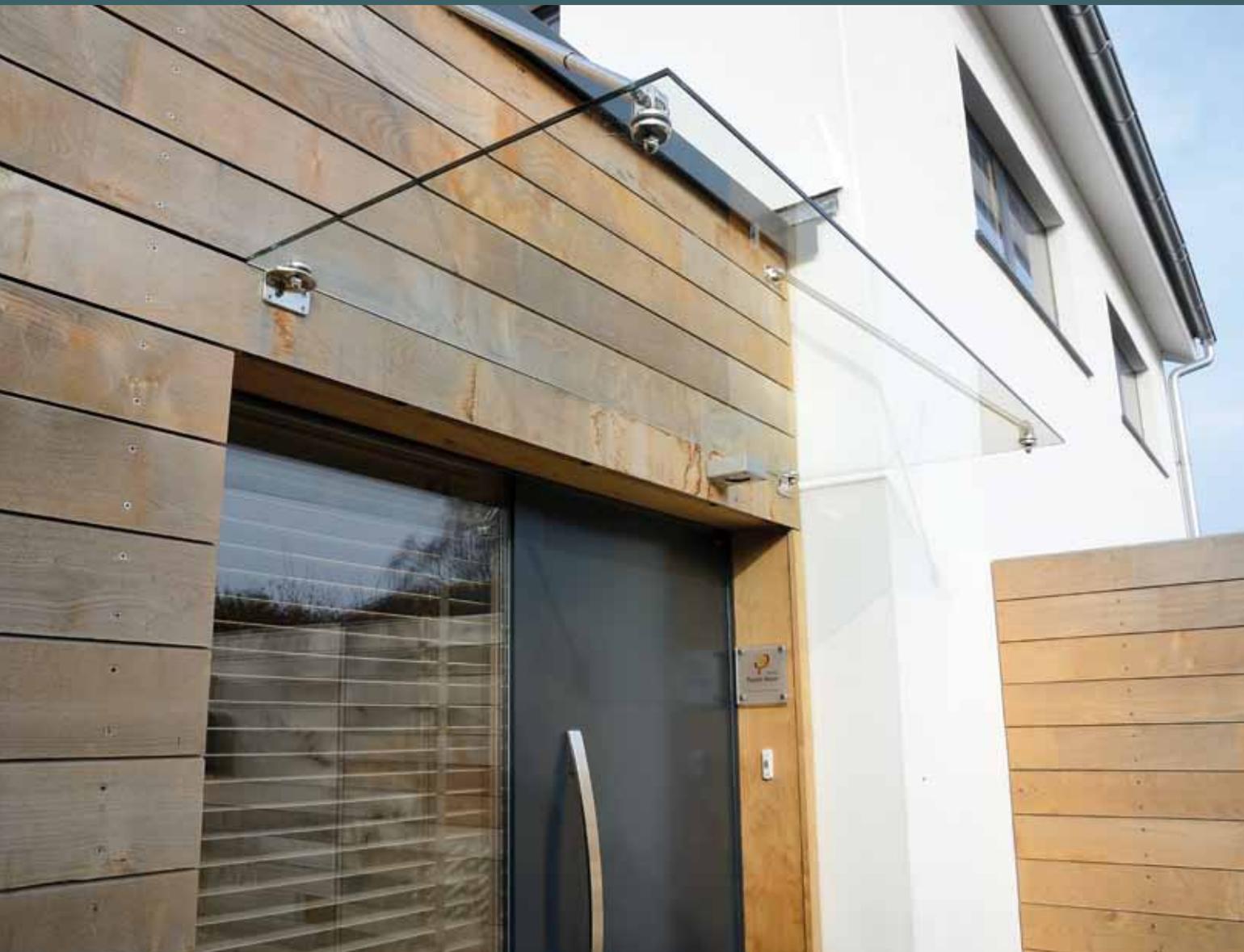


The Passivhaus Handbook

A practical guide to constructing
and retrofitting buildings for ultra-low-energy performance



JANET COTTERELL and ADAM DADEBY

Contents

INTRODUCTION.....	12
HOW TO USE THIS BOOK.....	15
PART ONE	The how and why of Passivhaus
CHAPTER ONE	What is a Passivhaus?..... 18
CHAPTER TWO	The economics of a Passivhaus 32
CHAPTER THREE	Passivhaus Certification..... 40
CHAPTER FOUR	Challenges of meeting the Passivhaus standard..... 46
CHAPTER FIVE	Natural materials, low embodied energy and zero carbon.....58
CHAPTER SIX	Setting up a Passivhaus project..... 70
PART TWO	Passivhaus projects: a practical guide
CHAPTER SEVEN	Using the Passivhaus Planning Package (PHPP)..... 86
CHAPTER EIGHT	Thermal bridges..... 106
CHAPTER NINE	Airtightness and sequencing 116
CHAPTER TEN	Moisture 136
CHAPTER ELEVEN	Ventilation 160
CHAPTER TWELVE	Windows..... 180
CHAPTER THIRTEEN	Living in a Passivhaus..... 198
CHAPTER FOURTEEN	Policy change 206
GLOSSARIES	Glossary of terms 218
	Glossary of units 222
APPENDICES	Appendix A: Thermal conductivity of materials 224
	Appendix B: Metric-US units conversion 225
	Appendix C: Certified Passivhaus projects in the UK..... 226
REFERENCES.....	230
RESOURCES	233
INDEX	235

Introduction

This book is aimed at a broad readership, including builders, self-builders, architects, energy assessors, registered social landlords (RSLs), planners, building control officers, politicians, clients – in fact anyone who is, wants to be or should be involved in future housing provision, whether new or retrofit.

It is intended to give you – architect, builder, client, etc. – knowledge of both the methodology and skills needed to achieve genuinely low-energy buildings, whether new or retrofit, that perform as intended. In the UK especially we have a very poor record when it comes to transferring design intent into real-world building performance. Building sustainably involves a wide variety of considerations, from water use to recycling to low-embodied-energy materials, and so forth. Passivhaus concentrates the attention on the energy consumed in the lifetime of a building. This is where we make (by far) the largest carbon savings – a necessary step if we seriously want to move towards a low-carbon economy and address a less energy-rich future. This is also where we have failed to find success to date in our houses and eco-buildings. We can install solar panels on our roofs, we can reduce water use, we can recycle, we can choose to use materials with lower embodied energy. But can we radically reduce our space-heating needs?

Effectively reducing the energy consumed for space heating (or cooling) requires training and up-skilling, both of which pose significant challenges. In the UK, we are in the process of adopting a broad-based sustainability assessment system, the Code for Sustainable Homes (CSH),

where points are awarded for a range of possible sustainability features – you collect the points and rise up the levels (from Levels 1 to 6, where Levels 5 and 6 are termed zero carbon). While the broad approach has much merit, an unintended side effect can be that fabric performance – the energy demands of the building itself – is perceived as one option among many – and other criteria are often easier and less challenging to meet (and often more exciting!). Energy in use, however, lies at the very heart of a truly sustainable architecture. If you get this right it also brings many associated benefits – health (indoor air quality), material preservation (avoiding moisture damage) and indoor comfort conditions (consistent temperatures with no draughts). By focusing on fabric performance, Passivhaus addresses the fundamentals and ensures that these key benefits are realised.

Passivhaus may currently be seen as a niche approach and as an interest for a small minority of enthusiasts. However, it simply applies the laws of nature to building for low-energy use and human comfort. These are the principles we all need to understand if we are to intelligently engage in constructing buildings. Passivhaus is ‘low-energy design’ and therefore its principles should be an integral part of any sustainability assessment system, even if the targets lie a little outside the Passivhaus-certified standards, as in the CSH. The application of Passivhaus principles to less demanding energy targets, and the link to zero carbon, are discussed in Chapter 5.

Architecture has tended to be driven by aesthetics rather than energy performance. The fact that it

CHAPTER ONE

What is a Passivhaus?

The Passivhaus energy standard, the Passivhaus concept, common misconceptions, retrofitting and the EnerPHit energy standard

A Passivhaus building is designed to be very comfortable and healthy and to use vastly less energy than conventional buildings, irrespective of the climate. This is achieved by careful design informed by building physics, and, crucially, by thoughtful and careful construction by a properly skilled and motivated team.

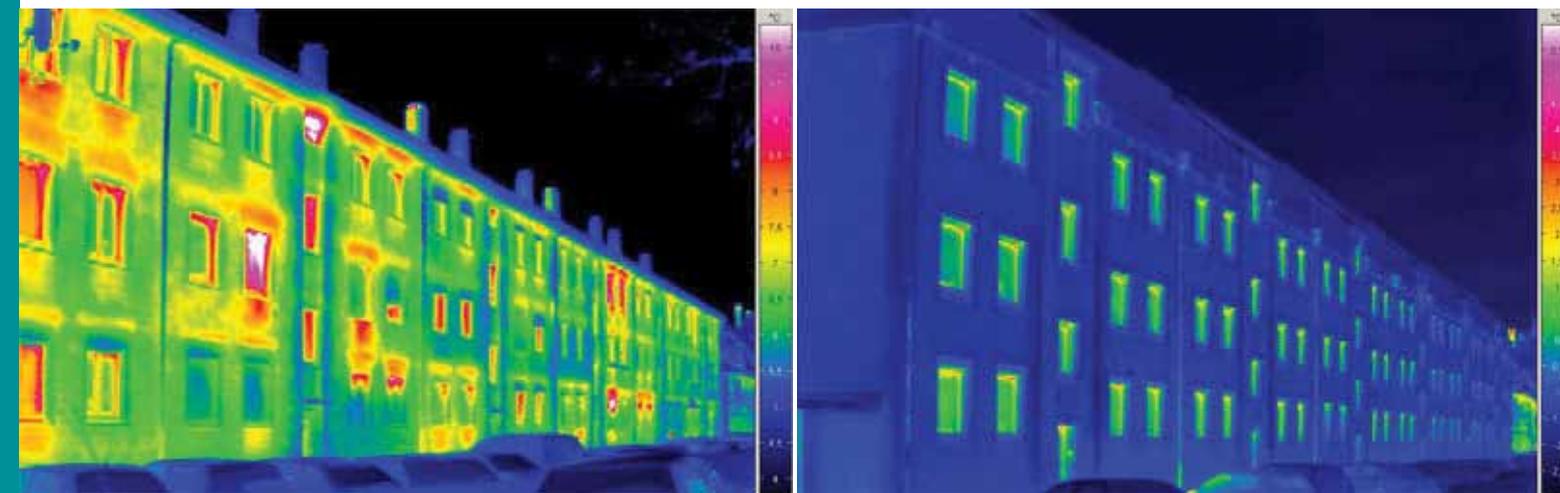
Passivhaus originates in Germany: the German word *Passivhaus* literally translates as ‘passive house or building’, since *Haus* refers to a building as well as a house. The word is being incorporated into English, although the concept is still often referred to as ‘passive house’, particularly in the United States. When people hear the term ‘passive’, they sometimes assume that this means no heating system or that the design relies on ‘passive solar design’, i.e. utilising heat from the sun. There is some truth in these assumptions. A Passivhaus does require a trickle of heat to maintain 20°C, although not nearly enough to justify a central heating system. It relies on high levels of uninterrupted, all-round insulation, airtight design and on heat

gained from the winter sun through the windows; however, solar gain is not in itself sufficient to heat a Passivhaus. A Passivhaus is also more comfortable than a standard build, as there are no draughts or cold spots, and it is healthier, as the air is fresher than in a conventional building. We will see later in the book how and why this is the case.

The thermographic images below show how high levels of insulation that enclose a building without gaps transform its energy performance. A well insulated building in winter has cold external surface temperatures (shown in blue). Thermographic imaging also highlights any ‘thermal bridges’ caused by gaps in insulation.

The Passivhaus energy standard

A building is a Passivhaus if it meets a voluntary, technical standard that, being international, has to be met irrespective of the local climate. It was developed by the Passivhaus Institut (PHI), an



Tevesstrasse project, Germany: before (left) and after (right) its Passivhaus retrofit. Images: Passivhaus Institut



Princesdale Road in London: the UK's first retrofit project to achieve full Passivhaus Certification. Image: Philip Proffit (Princesdale EcoHaus Ltd.)



Wooden Passivhaus-certified windows by ENERGATE® in a period building in Germany. Image: ENERGATE®

Finding a suitable 'conservation-friendly' window product that will perform adequately (see Chapter 12) for an ultra-low-energy building is difficult; until recently there were few, if any, such products on the market. In the Princesdale Road retrofit project (pictured top left; highlighted in pink), a bespoke window solution had to be designed and developed in order to meet the requirements of both the local conservation officer and the Passivhaus standard, as no suitable products had been brought on to the market at that time. A wider range of styles of Passivhaus-certified windows is now available, an example of which is pictured below left.

Even if your proposed purchase is not listed and is outside a conservation area or national park, if it is part of an estate or a row of relatively homogeneous properties that has a group value (in terms of architectural merit), it will probably be subject to more constraints than a building that is not. There may also be other circumstances that affect the degree of planning scrutiny for a given location.

It is worth noting that many planning applications make claims about their sustainability credentials to help the application gain planning permission; this is particularly true if 'sustainability' is being used to argue a case to build in a location where planning permission would not otherwise be granted. Planners are aware of this tactic, so be sure to explain (briefly) what Passivhaus means and its wider significance. If your project is going to be certified, mention this and its significance.

Seeking planning advice

There are many other factors that the planners will take into account, which are not Passivhaus-specific but affect all developments. Further reading is recommended (see Resources), to allow you to assess potential

plots through the planners' eyes. If the project size and budget warrant it, or if planning is likely to be particularly challenging because of factors specific to your chosen location, it may be helpful to hire the services of a planning consultant. Planning is discussed in more detail in Chapter 14.

Retrofit considerations

In the case of a retrofit project, there are further issues to consider. Even if the building or plot addresses all of the planning requirements adequately, some buildings lend themselves better to retrofitting than others. There are many factors to take into account, as follows.

- **Original brick or stone facades** These can be externally insulated, but there are two issues. Firstly, board-based insulation will require that the original facade be rendered before application of the insulation, adding to the cost. Secondly, while it is possible to buy external insulation products with a false brick facade, they really do tend to look false(!), and your building is likely to look better if you chose not to attempt to recreate what was there before.
 - **Cavity walls** These create two problems. They are often thicker than their solid (single-skin) wall equivalents, so the addition of sufficient insulation to achieve the Passivhaus performance results in overly thick walls (Passivhaus discourages wall depths beyond 500mm). On many sites, such thick walls are not practical because of space constraints, nor desirable for aesthetic reasons. Also, the cavity itself is a problem if left unfilled, because air movement within the cavity causes heat transfer by convection (known as thermal bypass). Of course, many cavities are already filled and, in some of these, the
- existing insulation performs poorly and may be poorly installed (this is explored further in Chapter 8).
- **Concrete slab floor combined with low ground-floor ceiling heights** If your building sits on a concrete slab, it will probably not make economic sense to remove it, so floor insulation will need to go on top of it. If there is already limited ceiling height and the finished floor level cannot be raised, then unless the first floor is to be removed (a huge intervention by any standards!), there will be very limited space for floor insulation. While this problem might be addressed by using specialist ultra-low-thermal-conductivity insulation, such as vacuum-insulated panels (VIPs), aerogels or similar, this is particularly expensive.
 - **Suspended wooden floors** Many homes have suspended wooden floors in all parts of the ground floor except the kitchen, where there is often a concrete slab. In this case it can be fairly straightforward to remove the slab, as it is probably not a structural element supporting the building. Insulating suspended floors is relatively straightforward if there is enough space to access them from below. This is particularly helpful if you want to retain the existing finished floor – a parquet, for example. However, the majority of suspended floors have only a 350-500mm void, making insulating from below either very difficult or impossible, in which case insulation would need to be done from above. But removing the existing floorboards also has its benefits, as it makes it much easier to properly address airtightness requirements and deal with joist ends. The insulation of suspended wooden floors has to be detailed carefully to ensure that moisture will not form and collect around the joist ends. Some would favour removing the suspended floor completely and



CHAPTER SEVEN
**Using the Passivhaus
Planning Package (PHPP)**

86

CHAPTER EIGHT
Thermal bridges

106

CHAPTER NINE
**Airtightness
and sequencing**

116

CHAPTER TEN
Moisture

136

CHAPTER ELEVEN
Ventilation

160

CHAPTER TWELVE
Windows

180

PART TWO

Passivhaus projects: a practical guide

Retrofit: externally applied insulation

In terms of managing moisture, improving the thermal performance of existing buildings is best done externally. An external insulation system that will protect the existing structure from rainwater penetration can be easily designed. The existing structure then sits on the warm side of the construction and will be at much-reduced risk of water vapour condensing on to any of its surfaces. Thus the risk of condensation on the ends of timber joists penetrating the walls is virtually eliminated.

These types of insulation are generally referred to as either external thermal insulation composite systems (ETICS) or external insulation systems (EIS). The insulation is applied to the outside of the masonry construction, whether solid masonry or cavity wall, and finished with a render that protects the insulation from rain penetration, acting as a drainage plain (Figure 10.4 opposite illustrates a section through such a wall). If externally insulating a cavity construction, you should fully fill the cavity to avoid thermal bypass (see Chapter 8). Try to ensure it is fully filled without air gaps – expanded polystyrene-graphite beads (Instabead) are good in this respect, as they flow well. External insulation will normally mean having to adjust your roof and wall junction to suit the new wall depth, unless there are already deep roof overhangs.

Fixings or small cracks in the finishes will introduce potential weak points through which driven rainwater might enter. Any moisture drawn in at these points by a capillary-active material behind may struggle to get out again if the drainage plain is vapour-closed. Similarly, if a vapour-impermeable final finish (some paints and varnishes) is applied, this may also inhibit drying. You should generally assume that some moisture will get in behind the

rendered surface; thus a level of vapour permeability in the drainage plain is advisable. (It might be helpful to reiterate that a material can be watertight but still retain some vapour permeability.) Generally, thin render systems are used, either polymer cement or silicone- or mineral-based renders, all of which allow for some transmission of water vapour. When the sun warms such a rendered wall, some drying out can then take place.

External thermal insulation composite systems (ETICS) usually use high-performance insulations such as rigid phenolic foam boards, which have no capillarity, hygroscopic or vapour-permeable characteristics. When this type of system is applied to a rendered masonry wall, the possibility of any serious moisture damage is limited. There are no 'organic' materials to rot and the insulation is moisture-resistant (no capillarity). An appropriately specified cement-based render, which can still provide some vapour permeability, is therefore suitable for use with such insulations. The key is to maintain the render surface and to detail well around windows and doors to avoid undue water ingress – wind can blow rain some distance up cracks and gaps. The detrimental effect of water lying temporarily against such insulations will be minimal. Far more problematic in this scenario would be if air could enter and then circulate behind your insulation, compromising its performance (see Chapters 8 and 9).

Alternatively, a more 'natural' ETICS solution would be to use wood fibreboards as the insulation material and then protect this with a lime render, which has a much higher permeability than cement render – again, joining materials with similar characteristics. Any moisture that gains access will get absorbed by the wood fibreboards, which are relatively hygroscopic. With a good vapour-permeable lime-based render (which may have some

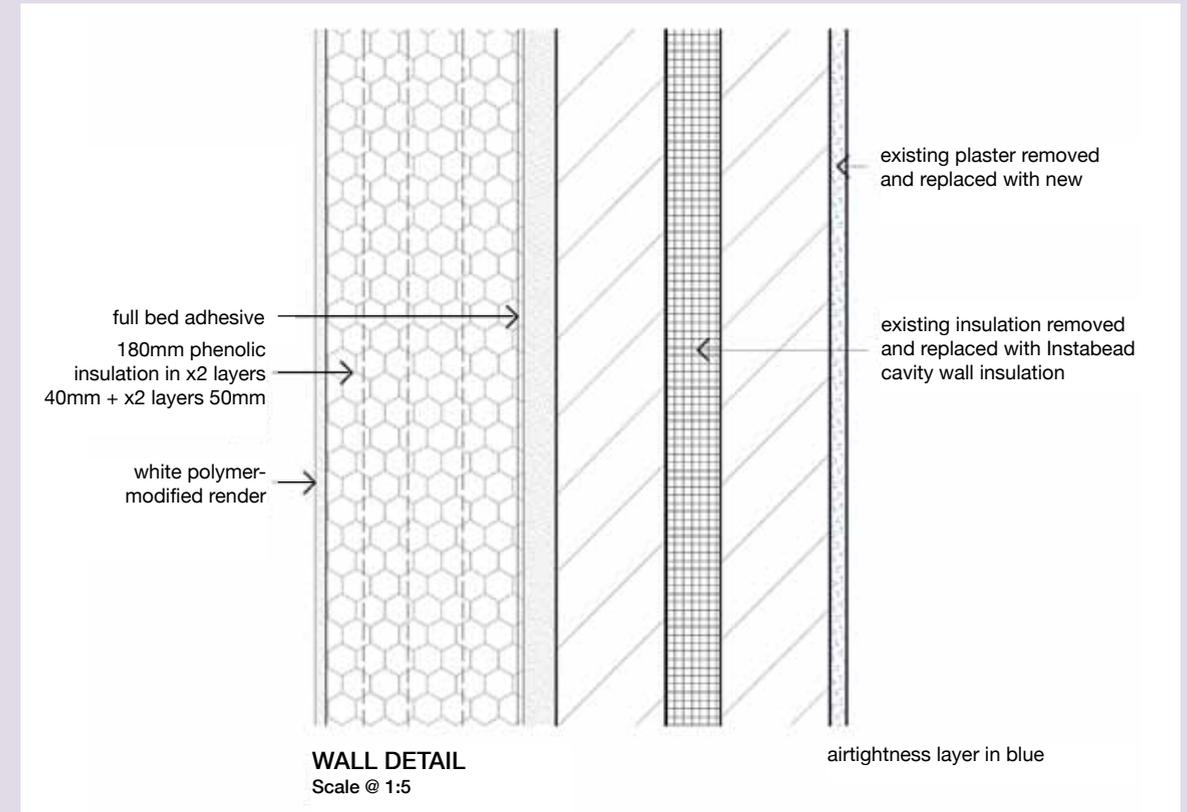
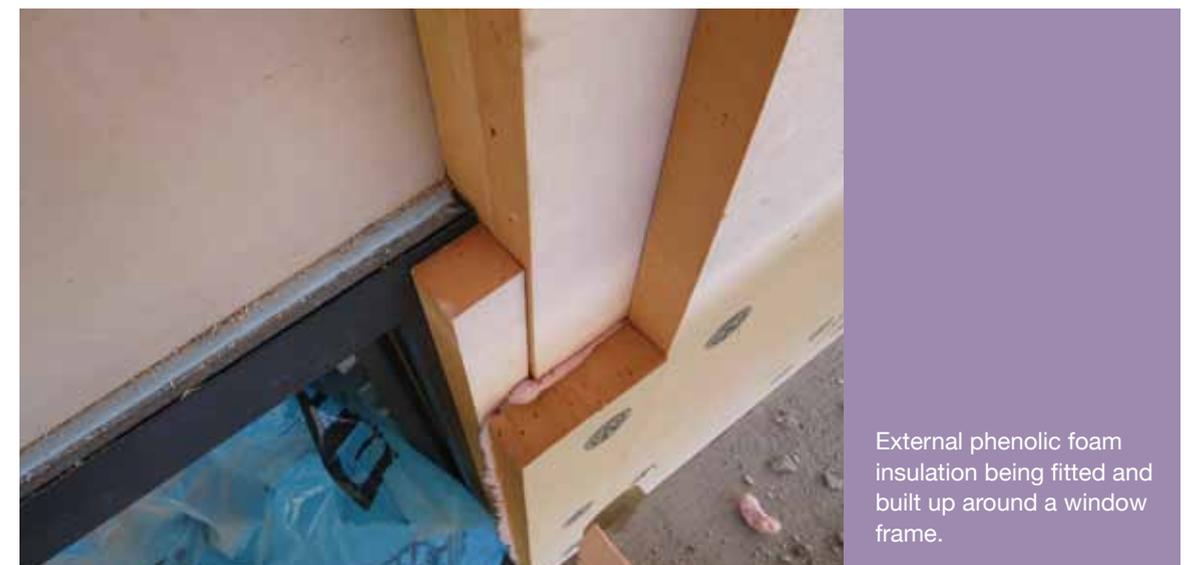


Figure 10.4 Section through externally insulated cavity wall construction.



CHAPTER ELEVEN

Ventilation

Ventilation in UK housing and in Passivhaus, indoor air quality, humidity, mechanical ventilation with heat recovery (MVHR) – heating, airtightness, noise levels, installation

Every new or retrofit building requires a considered ventilation strategy. The basic principle is to ensure that indoor air is being refreshed regularly, although the benefits of achieving a good ventilation strategy are multiple – from avoiding mould growth to limiting airborne pollutants. The quality of the air will also affect how comfortable we feel – too hot, too cold, too dry, etc. Some effects of a poor ventilation strategy, such as cold draughts, overly dry air or noisy extraction fans, will always be noticeable. But it is also important to be aware that we are not always able to assess air quality with our own senses. Bad odours can be very unpleasant, but are often harmless, while more serious health issues relating to ventilation could well go unnoticed.

If you are commissioning or are part of a team delivering an ultra-low-energy building, you must be confident that your ventilation strategy will be effective. The Passivhaus standard adopts a ‘mixed-mode’ ventilation strategy, comprising a mechanical ventilation system (including heat recovery from the exhaust air) and a summer ventilation/cooling system using openable windows. This combined system (which is explained in more detail in the following pages) is an integral and essential part of the Passivhaus low-energy approach and is considered part of the quality standard of a Passivhaus building. It has been adopted not only to address functional needs but is also part of the comfort standard.

Ventilation strategies in UK housing

Historically, buildings have been so leaky that there is more than sufficient ventilation for occupants by default. Resultant draughts have been exacerbated by the common use of open fires, which further draw in cold external air in

order to feed the combustion process. The traditional design of the high-backed ‘wing’ chair was adopted to provide shelter from this draught while seated facing the open fire. Up until the 1970s, people were content to live at much lower temperatures and would dress accordingly: in winter you simply wore lots of layers.

Typical housing in the UK, from the 1920s onwards, would be built using a cavity wall construction, consisting of two separate leaves of brickwork (later the inner leaf was changed to concrete blocks). About 80 per cent of existing housing stock is estimated to be of cavity construction. Cavity insulation started from around the 1970s, and, with the introduction of insulation standards, recent new housing stock does provide some improved thermal performance. However, this is still far below what a low-carbon economy would require. Only in 2006 was a statutory value for maximum air leakage set. This figure – a maximum air permeability of $10\text{m}^3/\text{hr}/\text{m}^2$ at 50Pa (see Chapter 9) – is not demanding and we doubt many new houses would fail this requirement. Currently, the typical airtightness level achieved might be an air permeability of around $7\text{m}^3/\text{hr}/\text{m}^2$ at 50Pa. Conventional methods for ensuring adequate ventilation generally take the form of trickle ventilators in windows (often left in the closed position because people are not aware of what they are) combined with localised mechanical extraction from bathrooms (usually on timers, often noisy and sometimes disabled by the disgruntled) and the kitchen (generally via a kitchen cooker hood extracting to the outside). Such mechanical extraction clearly helps to remove smells and moisture at source, and to reduce condensation risks. However, it does not generally involve any heat recovery from the exhausting warm, moist air.

Low-energy design necessarily moves us towards designing less leaky buildings. This minimises

U-values

The thermal performance of a typical double-glazed window is often given by a single 'U'-value. For new windows you can ask your supplier for this value, even if it does not appear on the 'advertising' packaging. In the UK it is still common to appreciate only the performance difference between single-, double- or triple-glazed windows. However, double- or triple-glazed units can perform very differently, with a wide range of U-values. The U-value is a function of the thermal conductivities of the different materials making up a particular component (or construction) and their thicknesses – for example, a wall, floor or window. The lower the U-value, the better the thermal performance.

Typical window performance U-value:
 $>1.5W/m^2K$

The worst U-value you can achieve with a construction is approximately $5.0W/m^2K$ (watts per square metre per degree kelvin). This is for a single-glazed window – which is why changing from single- to double-glazing makes such a huge difference to energy performance and comfort levels! The poor performance of windows means that the internal surface temperature of the glass will normally be the lowest in the house (older readers will probably have memories of scraping ice off the inside of window panes on

cold winter days). The lower the internal surface temperature of the glass becomes, the more uncomfortable it is for the building's occupants, because it creates an asymmetry with other, warmer wall surfaces. We feel the contrasting radiant temperatures from these different surfaces and don't like it! This is one reason why radiators are commonly placed under windows – to compensate for this effect. If surface temperature variations are greater than $4^{\circ}C$, we will feel the difference and choose not to sit next to windows during cold periods, effectively reducing the usable floor area of our homes. Furthermore, the cold surface of the glass cools the air adjacent to it and the air then sinks down, spreading out across the floor and setting up air rotation within the room. This can have the further effect of reducing temperatures at lower levels (around your feet) and increasing temperatures higher up (at the ceiling and around your head). If this temperature stratification becomes greater than $2^{\circ}C$, again it starts to feel uncomfortable. The current Building Regulations in England and Wales (2010) stipulate a maximum U-value of $2.0W/m^2K$ for windows in new dwellings.

Passivhaus window performance U-value: $<0.80W/m^2K$

A Passivhaus window must achieve a 'whole' window U-value (see opposite) of $0.80W/m^2K$.

Typical domestic window U-values in the UK

Window	U-value (W/m^2K)
Single-glazed	4.0-5.0
Typical UK double-glazed (2010 building stock)	approx. 2.0-3.0
New-build double-glazed, compliant with latest Building Regulations (England and Wales)	<2.0
Passivhaus (triple-glazed)	<0.80

Part of the reason for this particular performance level is to ensure that the internal surface temperature of the window is high enough to keep variations of surface temperature within any room below $4^{\circ}C$. This removes the need for a heat source adjacent to the window, and also means you can remain comfortable wherever you choose to sit, effectively maximising usable floor area. This surface temperature of the internal glass will be high enough to ensure that you don't get temperature stratification in the room, which again is likely to boost comfort levels.

Calculation of the window U-value

In the UK, you will currently often be quoted a single U-value (normally measured through the centre of the pane) for a given window, but this does not take into account the variety of factors that affect the actual thermal performance of a window. Passivhaus requires that a more complex 'whole' window U-value is calculated. The three factors taken into account for this are as follows.

1. Differences between the window frame and the window pane

In reality, every window is made up of two very different 'constructions': the window pane and the window frame. The single U-value calculation can therefore be very misleading, especially if it is based on the window pane only, since this will perform much better than the frame. The window frame will generally be the weakest point in the performance of a building's thermal envelope. The construction and design of the frame is thus a key focus point for manufacturers of high-performance, triple-glazed windows – commonly it will be made of multi-layered bonded wood, with some insulation. This could be hard or soft polyurethane such as purenit® (hard), extruded polystyrene, cork or cellulose. The whole-window calculation takes into account the following:

- The U-value as calculated through the centre of the window pane
- The U-value as calculated through the window frame (the above two values are adjusted to take into account the proportion of glass to frame)
- The window spacer psi-value (explained overleaf).

The whole-window U-value will therefore change according to the proportion of frame to glass. Since the frame is the weaker component, a larger window will perform more efficiently than a small window. Additionally, a window frame designed to be openable will perform worse than a fixed, i.e. non-openable, window



Section through a typical Passivhaus-suitable triple-glazed window, in this case with an aluminum finish externally and wood internally.



The Passivhaus Handbook is an essential guide for everyone wanting to realise a supremely comfortable, healthy and durable home with exceptionally low energy costs. Whether you are building an extension, retrofitting your house or starting from scratch, are new to low-energy design or already have some experience, this book will help you navigate around the potential pitfalls and misconceptions. It brings together current thinking and best practice.

Passivhaus design focuses on getting the building fabric right, to achieve ultra-low energy consumption in the most cost-effective manner. The approach is relevant to a wide range of building types and climates, not just to special structures. Passivhaus methodology can be combined with elements of other building standards, such as the UK's Code for Sustainable Homes (CSH), or with other goals, such as a commitment to using low-impact and natural building materials.

The book includes:

- A clear explanation of the underlying building physics.
- Detailed information on key elements of Passivhaus: avoiding air leakiness, designing out thermal (cold) bridges, moisture management and ventilation strategy.
- Tips for developing a cooperative, motivated project team.
- Photographs and diagrams throughout.

With steeply rising energy prices, uncertain climatic changes and straitened economic times, the Passivhaus approach, proven over 20 years, offers a timely and practical response.



The authors: Janet Cotterell and Adam Dadeby are directors of Passivhaus Homes Ltd (www.passivhaushomes.co.uk).

Janet is a chartered architect with over 20 years' experience, whose work focuses on the implementation of low-energy design principles and on collaborative teamworking. She is also a Certified Passivhaus Designer, and is familiar with working with traditional and natural materials and in sensitive settings such as conservation areas.



Adam is a Certified Passivhaus Consultant and holds a postgraduate diploma in Architecture: Advanced Environmental & Energy Studies. In 2011 Passivhaus Homes Ltd completed a retrofit of Adam's home: one of the very few fully certified Passivhaus retrofits in the UK, which also achieved one of the best airtightness results in the UK.

Image credits: Part Two contents: Canolfan Hyddgen, John Williamson (JPW Construction). Back cover: Left: Camden House, Bere Architects. Middle: Crossway, Hawkes Architecture and consultants SPHC. Right: Denby Dale Passivhaus, Green Building Store



green books

www.greenbooks.co.uk

Publication: October 2012 • £35.00 paperback
255mm x 205mm • 240pp full colour • ISBN 978 0 85784 019 6

Publicity contact: Stacey Hedge, Green Books
Tel: 01803 863260 stacey@greenbooks.co.uk

Sales contact: Signature Book Representation (UK) Ltd
Tel: 0845 862 1730 sales@signaturebooksuk.com