DESIGNED *to* PERFORM

AN ILLUSTRATED GUIDE TO DELIVERING ENERGY EFFICIENT HOMES

RIBA Publishing

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Tom is Head of Sustainable Design at Pollard Thomas Edwards (PTE). Tom works across the practice to promote a sustainable approach to all projects and to provide project teams with the requisite awareness, training and support. Tom is also directly involved with PTE's projects, especially low-energy schools and housing. He was project architect on some of PTE's most sustainable schemes including Virido Concept House, Highbury Quadrant and Cygnus E-Smart modular housing.

He has a particular interest in practical solutions which ensure that the actual energy performance of buildings measures up to the design intent. His recent work for the Zero Carbon Hub includes writing the Builders' Book and the Services Guide to address the performance gap in the delivery of energy-efficient homes, based on 21 case studies around the UK. Tom hosts regular training days and events in sustainable design for the wider industry as well as for PTE. He is a core trainer for the Green Register of Construction Professionals and a Director of the Good Homes Alliance. He is a certified Passivhaus designer, BREEAM and Code for Sustainable Homes Assessor. Tom leads the design and site review process for the UK Government's 'Building for 2050' project which will set out the required steps to accelerate the uptake of low cost, low carbon homes.

Pollard Thomas Edwards

PTE uses practical experience and research to complement and inform one another. We contribute to best practice and debate through research, post-occupancy evaluation and public speaking. Recent publications have included the Builders' Book, Services Guide, Superdensity, the HAPPI report and research into housing density, overheating, ventilation and the performance gap in homes.

As architects, we continue to create the whole spectrum of residential development and other essential ingredients which make our cities, towns and villages into thriving and sustainable places.

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Foreword

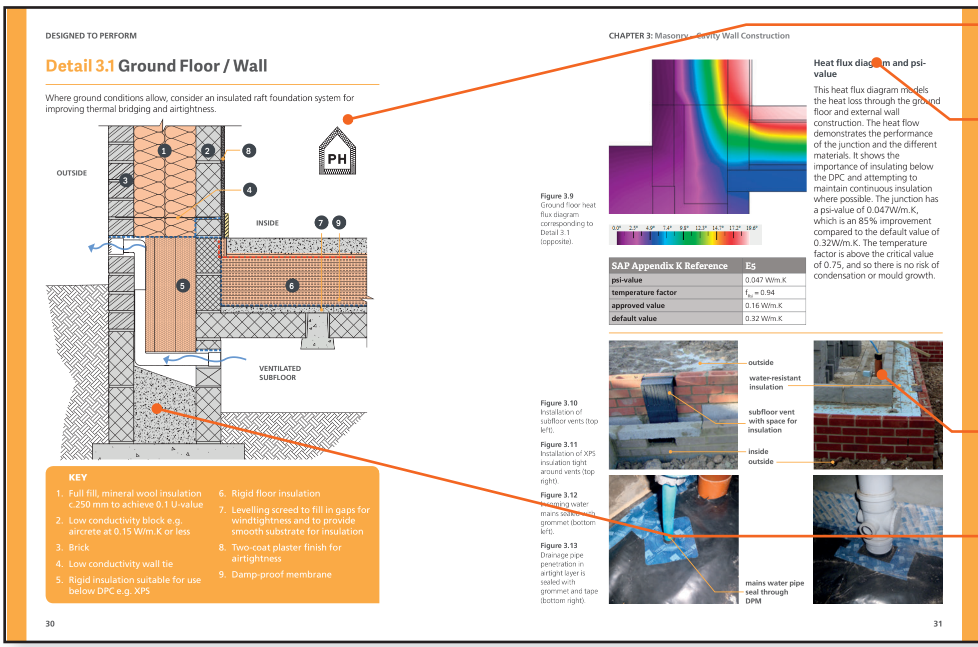
Designing for performance is not new. Built environment professionals have long battled to achieve their designs in reality. The idea of the ‘performance gap’ came on to my radar in 2010, at a Good Homes Alliance event. It was quickly becoming a real issue for an industry that was gearing up to achieve Zero Carbon Homes. It resonated with me at the time because I was working as project architect on a Code for Sustainable Homes level 4 housing scheme that was hailed as ‘industry leading’, yet likely had a significant performance gap that we could do very little about. I felt disillusioned with the status quo of delivering the minimum required performance, for a minimum price which ultimately lead to ‘value engineering’ or more accurately cost cutting. The disaster at Grenfell tower is the result of this cost and quality cutting process, an epidemic across our industry and culture where cost is king. If we are to rectify this situation, a radical re-think of procurement processes, enforcement of the regulations and attention to quality is needed. I hope this book goes a small way to improving the quality of design thinking and helps architects, clients and contractors in the challenge of delivering energy-efficient homes.

Contents

How to use this book

This is an illustrated guide to designing and constructing better homes. The majority of the book consists of good practice diagrams and annotated photos taken on live construction sites. Each chapter covers a different construction type, and examines the key details impacting thermal performance.

The details show good practice and with the appropriate specification can be Passivhaus compliant. Each detail has a double-page spread, similar to the example shown below: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Detail 3.1 Ground Floor / Wall

Where ground conditions allow, consider an insulated raft foundation system for improving thermal bridging and airtightness.

KEY

1. Full fill, mineral wool insulation c.250 mm to achieve 0.1 U-value
2. Low conductivity block e.g. aircrete at 0.15 W/m.K or less
3. Brick
4. Low conductivity wall tie
5. Rigid insulation suitable for use below DPC e.g. XPS
6. Rigid floor insulation
7. Levelling screed to fill in gaps for windtightness and to provide smooth substrate for insulation
8. Two-coat plaster finish for airtightness
9. Damp-proof membrane

30

CHAPTER 3: Masonry – Cavity Wall Construction

Figure 3.9 Ground floor heat flux diagram corresponding to Detail 3.1 (opposite).

SAP Appendix K Reference	E5
psi-value	0.047 W/m.K
temperature factor	f_{Rsi} = 0.94
approved value	0.16 W/m.K
default value	0.32 W/m.K

Heat flux diagram and psi-value

This heat flux diagram models the heat loss through the ground floor and external wall construction. The heat flow demonstrates the performance of the junction and the different materials. It shows the importance of insulating below the DPC and attempting to maintain continuous insulation where possible. The junction has a psi-value of 0.047W/m.K, which is an 85% improvement compared to the default value of 0.32W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth.

Figure 3.10 Installation of subfloor vents (top left).

Figure 3.11 Installation of XPS insulation tight around vents (top right).

Figure 3.12 Incoming water mains sealed with grommet (bottom left).

Figure 3.13 Drainage pipe penetration in airtight layer is sealed with grommet and tape (bottom right).

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Detail is Passivhaus compliant

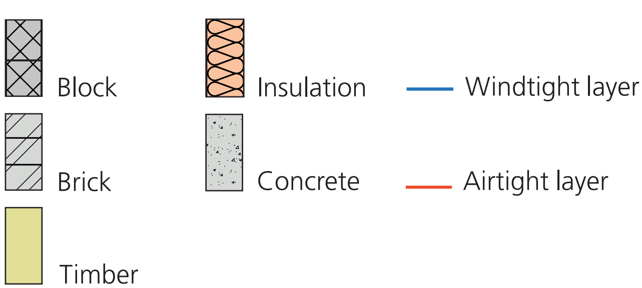
psi-value of this detail calculated for SAP with internal boundaries and heat flux illustration

Default psi-value included as a comparison

Annotated photos during construction

Annotated detail showing key aspects of performance (scale 1:10)

Key illustrating the components used in illustrations throughout the book.



Glossary

AAC
Autoclaved aerated concrete is a lightweight foam concrete building material with improved thermal performance. Commonly known as aircrete blocks.

ASHP
An air-source heat pump extracts and upgrades heat from the outside air to use in the home. CHP (combined heat and power), also referred to as cogeneration, is a form of decentralised energy production. A CHP system burns fuel to produce electricity and uses the waste heat to provide space heating (or cooling) and hot water.

DPC
Damp-proof course.

DPM
Damp-proof membrane.

EPS
Expanded polystyrene is a closed-cell insulation manufactured by expanding a polystyrene polymer into rigid boards or blown beads.

FGHR
Flue gas heat recovery is an additional option for a gas boiler that further increases the efficiency by recovering heat from the boiler flue.

GSHP
A ground-source heat pumps heat from the ground to heat the home.

HIU
Heat interface unit, installed in each dwelling and connected to communal boiler or distribution network. Typically a wall-mounted appliance of similar size and appearance to a domestic combination boiler.

HQM
Home Quality Mark, a national voluntary home labelling scheme by BRE. It provides impartial information on a new home's design, construction quality and running costs.

HWSC
Hot water storage cylinder (commonly known as a hot water tank), which stores hot water for use in wet-rooms.

MCS
Microgeneration Certification Scheme, quality assurance scheme for microgeneration technology like PV panels and heat pumps.

MEV
Mechanical extract ventilation. continuous mechanical extract as a centralised unit or individual fans in wet-rooms.

MVHR
Mechanical ventilation with heat recovery, uses mechanical supply and extract fans with a heat exchanger to provide fresh air to the dwelling while minimising heat loss.

Part L
Approved Document Part L (2016) of the Building Regulations.

Passivhaus / Passive house
A rigorous voluntary standard for energy efficiency in a building using fabric-first principles. It results in high comfort, very low-energy buildings that do not require a traditional heating system.

PSV
Passive stack ventilation, uses a combination of air flowing over the roof and buoyancy of warm moist air to lift air out from wet-rooms through vertical ducting.

PV
Photovoltaic solar panels that convert energy from the sun into electricity.

PU/PIR
Polyurethane (PUR) and polyisocyanurate (PIR) insulation, commonly produced as rigid boards.

SAP
Standard Assessment Procedure (SAP), the UK methodology used to assess and compare the energy performance of dwellings.

SHW or solar thermal
Solar hot water system uses panels that convert energy from the sun into hot water for use in the home.

SIP
Structurally Insulated Panel, commonly an OSB and insulation sandwich.

Temperature Factor (f Rsi)
The ratio of the internal surface temperature over the temperature difference between outside and inside (normally 20 °C is used). An indication of condensation potential on the inside face.

Thermal bridge
Also called a cold bridge, a part of the building that has significantly higher heat transfer than the surrounding materials, resulting in greater heat loss for the entire building.

Thermal bypass
The heat transfer that bypasses the conductive heat transfer between two regions. Air infiltration through gaps in the insulation layer, convection loops or windwashing are common examples.

U-value
A measurement of heat loss through an area of building fabric: wall, floor, roof or window, with units $W/m^2.K$. A lower number is a better insulator.

VCL
Vapour control layer installed on the inside face of the building to reduce the amount of moisture passing through the structure. Mainly performed by membranes (intelligent or standard) but can also be sheet products like OSB.

WWHR
Waste water heat recovery systems use a heat exchanger pipe to extract heat from waste water from a shower and bath.

XPS
Extruded polystyrene foam is a rigid insulation board used commonly in below grade or inverted roofing applications where it is likely to get wet.

Y-value
A global measurement of heat lost through all the junctions in a building. It is the combined average of all the psi-values, and used in a SAP assessment to represent thermal bridging losses for the whole house. The default score is 0.15, and 0.04 or less represents a building with minimal thermal bridges.

Ψ-value or psi-value
This is a measure of linear heat loss with units W/m.K. It is used to measure the heat flow through a specific junction in a building, e.g. window lintel / cill / jamb, or roof eaves. There are normally between 10 and 30 psi-values needed to calculate heat loss through linear junctions of a house.

Introduction

Introduction

It's all in the detail. And attention to detail is key to successful design and delivery of quality homes. Lack of attention to detail leads to critical errors that affect the performance of new homes. This book is an attempt to rectify some of these performance issues to help designers and contractors reduce this performance and quality gap so that we can consistently deliver better homes.

Better homes have low energy use, good thermal comfort and excellent indoor air quality. Studies by the Zero Carbon Hub, Innovate UK and others show that the majority of newly built homes are failing to meet their required performance. The underlying reason for this failure is that energy efficiency, comfort and indoor air quality are difficult to check.

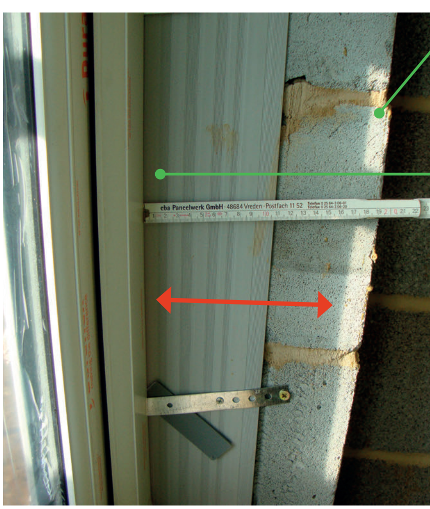
The home buyer cannot see the quality of the inner construction, elements that directly influence their heating bills, indoor air quality and comfort. Thermal performance is unlikely to attract customers and therefore it is not high on the list for housebuilders to engage with. All of the 300 homes in the Zero Carbon Hub inspections (2012–2016) and Innovate UK BPE study (2016) failed to meet their intended performance when tested. The majority were short of Part L and Part F of the Building Regulations by a significant margin (50% or more).

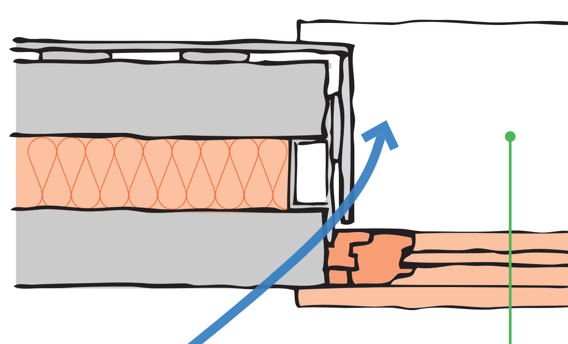
Common failings uncovered in this study are highlighted in the **Builders' Book**, **Services Guide** and the **Thermal Bridging Guide** (Zero Carbon Hub 2016) and include unaccounted thermal bridging, thermal bypass, uncontrolled air leakage and poorly designed, installed and commissioned building services. The evidence showed many minor errors that have a significant impact on performance. An example is shown in Figures 0.1 and 0.2, where the installation of the window differed by 50 mm and reduced the performance of the junction by 140%.[1]

The combined result of these failures is poorly performing homes. This book highlights such common failings and offers solutions for design and construction of homes that do what they should be doing: providing a low-energy, healthy environment to live in.

Figure 0.1
No overlap of window and cavity creates a thermal bridge (below left).

Figure 0.2
Thermal bridge example [2] (below right).





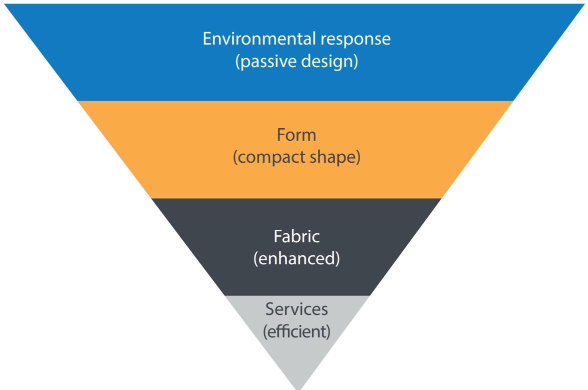


Figure 0.3 Energy performance hierarchy.

The energy performance hierarchy (Figure 0.3) illustrates that orientation and form have the largest impact on the performance of a home and are determined by a range of factors to meet the brief and function. Form responds to environmental context, but this is normally secondary to other planning considerations such as height, density, house type, vernacular style and design constraints such as existing roads, buildings, noise sources and conservation areas. As the form is normally decided according to these site-specific constraints, this book focuses on making improvements to the last two parts of the performance hierarchy – fabric and services, which are common to all new homes. This is where the largest performance gap lies, and where the largest improvements can be made.

Chapter 1 examines the gap between design and as-built performance and highlights common areas that designers and builders need to engage with. It also takes a strategic view on ways industry and government can improve the performance of new-build housing. Chapter 2 describes current performance standards, and the principles of a thermally efficient building envelope. It summarises good practice, detailing principles applicable to all construction methods.

Chapters 3 to 7 highlight different construction types common for new homes and key areas of the thermal envelope that often are problematic. The drawings show potential solutions that will help designers and contractors improve the performance. These chapters look at each construction fabric in turn, starting with the most common in the UK and finishing with the least common yet more innovative methods.

All photos were taken by the author on live construction sites except where noted. The detail drawings of good practice show a fabric-first approach that meets and exceeds Part L 2016 of the Building Regulations and is likely to comply with future versions of Part L and higher standards such as Passivhaus and zero-energy buildings. All details have been built and checked for buildability and compliance on site. Some of the details are compatible with the Passivhaus standard and have been noted as such. The diagrams can directly inform the architect's own detail drawings of the building envelope. The construction principles in this book will be valuable to all those who are seeking to design better performing thermal envelopes. In particular it addresses thermal bridging, thermal bypass, airtightness, buildability and site issues.

Applying the principles of reduced thermal bridging and improved airtightness to all elements of the building will significantly reduce the heat demand, associated heating bills and overall CO_2 emissions. The book highlights the typical construction junctions and

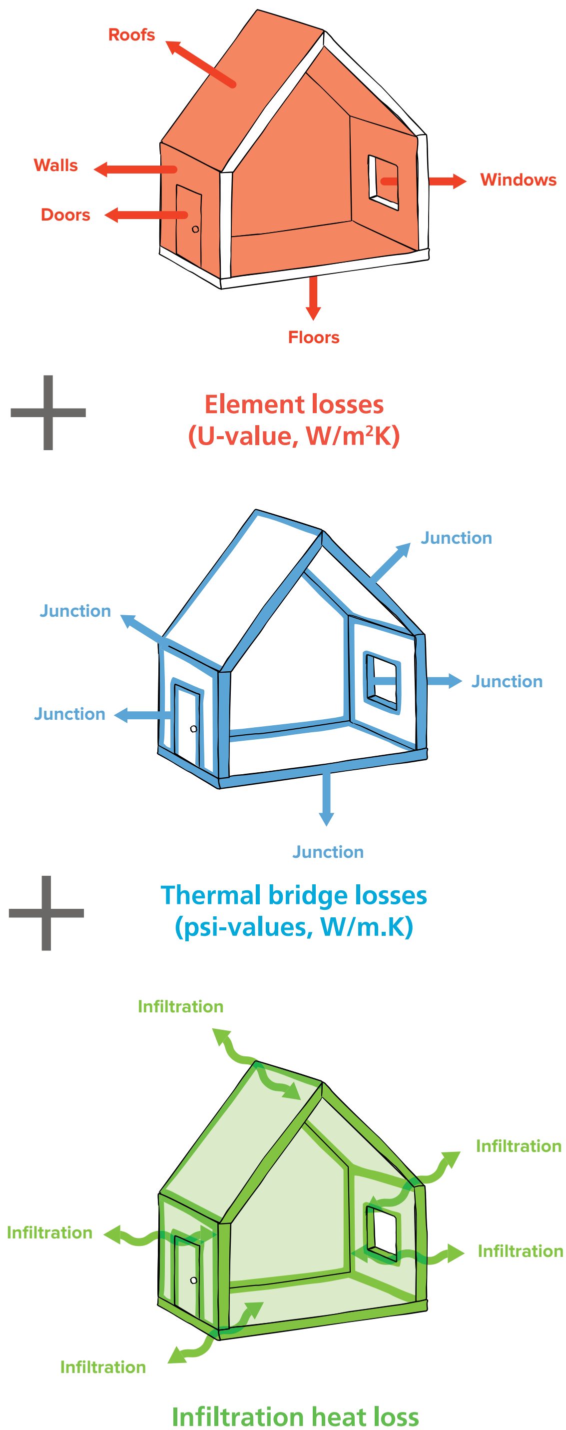


Figure 0.4
U-values, psi-values and infiltration combine to give the total heat loss of a dwelling.

typical performance given in U-values and psi-values. The psi-values have made standard assumptions for the thermal resistance of materials, which are stated in Appendix 3.

Key details have been modelled in thermal bridging software to ensure minimal heat loss at the junctions and to provide a psi-value to aid designers in energy calculations (SAP). For use in SAP calculations, they should be recalculated with project-specific information. The psi-values have been calculated using THERM 7.4.3 for 2D and TRISCO 13.0 software for 3D models in accordance with BR 497. Figure 0.4 shows how U-values, psi-values and infiltration combine to give the total heat loss of a dwelling.

Chapter 8 examines the common mechanical and electrical services in new homes. The diagrams help improve the detailing and specification of new homes at construction stage, and also inform designers of services requirements at early stage design. Heating and ventilation systems that are not installed or commissioned correctly form a significant part of the performance gap.

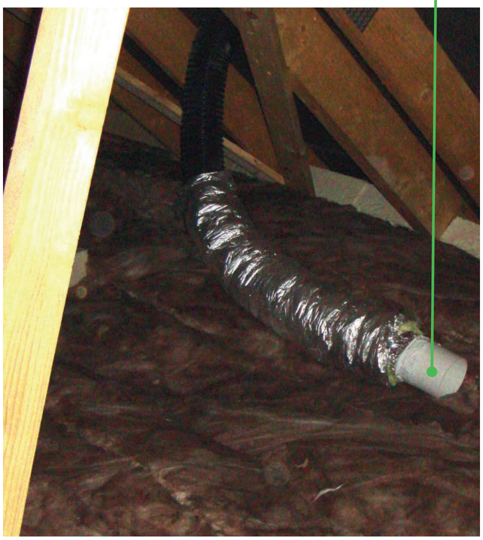
Common examples of this poor design and installation of services are shown in Figures 0.5, 0.6 and 0.7 (see page 6). Chapter 8 highlights basic performance recommendations for key building services to deliver their intended performance.

Chapter 9 concludes the book with a summary of how to deliver improved performance for new homes. Designers, contractors, policy makers and clients all have significant roles to play in improving the quality of new-build homes, and this chapter offers some recommendations for improvement.

Chapter 10 examines the common mechanical and electrical services in new homes. The diagrams help architects to improve their detailing and specification at construction stage, and also inform concept designers of services requirements at early stage design. The building services in new homes commonly fail to meet Building Regulations, in particular the heating and ventilation systems that are being installed incorrectly and not commissioned.[3]

The Appendices include checklists for both designers and contractors based on the RIBA Plan of Work and traditional build sequencing. These checklists are project management tools, and should be adapted to suit individual project requirements and construction methods. It is hoped this book will offer some practical guidance to help professional, client and contractor teams improve the design and construction quality of new homes.

ductwork not connected



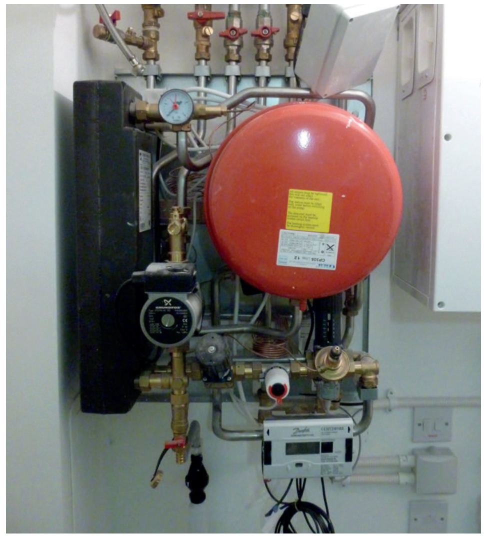


Figure 0.5 Poorly installed ventilation ductwork in loft space (left).

Figure 0.6 Uninsulated, poorly installed heat interface unit (HIU) (right).

flexi-duct too long

Figure 0.7 Flexi-duct too long and not supported means that fans will be noisy and inefficient.

Chapter 1: The performance gap and how to reduce it

Chapter 1: The performance gap and how to reduce it

1

What is the performance gap?

The performance gap is the common term used for the gap between predicted and as-built performance. It has been demonstrated by a wealth of evidence, including a government-funded £8 million research programme by Innovate UK into building performance. In 2012, the Zero Carbon Hub was commissioned by the government to lead a comprehensive review of the performance gap. The report, called 'Closing the Gap Between Design and As-Built Performance' set out the '2020 ambition' for industry to be able to demonstrate that 90% of all new homes meet the designed energy performance. Determining the size and origin of the gap was a key aim for the report, and it also highlights recommendations for industry and government to close the gap. The report included input from 180 organisations and experts and reviewed over 250 new homes on 21 sites during construction to see where the gap occurred in the process of housebuilding. The conclusion from the Innovate UK and the Zero Carbon Hub study, totalling inspections and monitoring of over 350 new homes, is that this gap is endemic across the industry, complex and widespread in origin and is on average 2.6 times worse than design predictions.

Why is it important?

A significant gap in a building's energy performance undermines its vital role in delivering the national carbon reduction plan, which in turn has major consequences for climate change and global resource depletion and major implications for national and international policy. It also presents significant reputational dangers to industry by undermining consumer confidence if energy bills are higher than anticipated.

What can we do about it?

To answer this, the Zero Carbon Hub identified three common themes across all stages of the housebuilding process. They are:

1. Lack of understanding, knowledge and skills
2. Unclear allocation of responsibility
3. Inadequate communication of information

To reduce the performance gap, we need a change in culture across the industry to place greater importance on in-use energy performance. Energy performance needs to be valued as highly as other issues such as acoustics, fire and access. The improvement in acoustic performance of new homes is a good case study in how to improve standards, and was done with cross-industry and government support through Building Regulations mechanisms such as Part E testing and Robust Details. The introduction of acoustic testing of new homes has dramatically improved acoustic performance, because the test drove associated improvement in skills, knowledge and standards. A similar improvement is evident is health and safety standards in the last 20 years. The introduction of the CDM Regulations in a clear format kick-started a whole industry and saw radical improvements in safety performance. To improve energy performance it will require similar investment and support over the next 10 years. Part L needs to be simpler and easier to use, with greater emphasis on compliance and site checks on delivered performance of the buildings. In combination with regulation change, there needs to be greater education and resources for industry professionals and operatives to understand building performance and their role in delivering quality. This lack of 'energy literacy' should be addressed within programmes at CITB, CIBSE, CIOB, FMB, ICE, and RIBA, with greater emphasis on practical education and skills. This book provides information on the design of better homes to reduce the performance gap but a significant improvement will need further action from policy makers, designers and contractors.

What can policy makers do?

Policy makers can reduce the performance gap with the following changes:

1. Streamline, simplify and improve compliance with Approved Document Part L, to include a simple but comprehensive as-built performance check. This will include increased building control presence on site to check energy performance and associated construction quality. Award good practice in this area with incentives such the NHBC Pride in the Job Awards.
2. Make a construction guidance web resource available to all, to share and improve levels of construction. Include helpful tips, user videos and guidance on design and installation. To include standard details and installation sequencing.
3. Improve energy literacy: Training design and site teams in energy efficiency and correct installation of fabric and services to be included in standard training and qualification routes.

These three actions would dramatically improve the quality of new homes, but will not happen in this competitive market unless there is greater enforcement of these regulations. The current energy standards in Building Regulations are overly complicated and rely on expert consultancy and detailed reports, rather than checks on site. The process and regulations need to be radically simplified to allow developers options to demonstrate as-built performance. Building regulations need to be clarified, with greater emphasis on compliance and site checks to improve as-built performance.

What can the designer do?

Designers can draw and specify a thermally efficient home that will reduce the theoretical heat demand to meet the optimum level of the Passivhaus standard, 10 W/m^2. However, this high standard of performance can also be more difficult and expensive to build.

To prevent this, designers must consider buildability, sequencing and supply chain with the contractor at an early stage, and agree a construction type most suited to requirements. Chapters 3 to 7 will aid these discussions and Appendix 2 is a guide for effective project management using the RIBA Plan of Work. A thermally efficient building can be more difficult to build so it is crucial that designers consider buildability and sequencing with the site team at an early stage.

Designers can improve the quality of new homes by designing better performing building envelopes and services, encompassing the following five actions:

1. Design a simple and compact building envelope, with minimal external surface area, reduced complexity of detailing, continuous insulation and airtightness.
2. Reduce thermal bridging by following design guidance and carrying out bespoke modelling.
3. Specify simple building services that perform as intended and are easy to operate and maintain.
4. Ensure drawings and specifications are clear and consider construction sequencing, buildability and as-built performance.
5. Ensure project team has the skills and experience to identify and deliver an efficient solution. Invest in training and seek expert guidance on energy analysis to improve performance.

What can the contractor do?

Whilst the designer can design out many issues like thermal bridging, the responsibility for production lies with the main contractor, who must ensure that the design is made a reality. The contractor must ensure the following:

1. Improve quality assurance on site with finishing foreman role on large sites, extra building control visits and a clerk of works to inspect quality.
2. Increase role and responsibility of designer on site, with better communication between designer and site team. Ensure design continuity by appointing the design team through to construction stage.
3. Nominate one of the project team to be 'energy champion' on site, to be responsible for as-built energy performance. The role encompasses airtightness, windtightness, continuous insulation, correct building services and commissioning check.
4. Install correct products according to specification and SAP.
5. Ensure the building services are thoroughly commissioned, especially ventilation, and provide information and training to residents on use and maintenance.
6. Ensure subcontractors have suitable training and experience for their job, e.g. BPEC in ventilation. Carry out toolbox talks to emphasise airtightness, thermal bridges and building services commissioning.

Contractors should refer to Appendix 1 for more detailed guidance on how to improve quality on site.

It's about quality, not just energy

Poor energy performance is symptomatic of poor design and construction quality. As-built energy performance is directly related to the wider aspects of construction quality. For example, the performance of a cavity wall will depend on a number of quality factors: the mortar joint quality, the cleanliness of the cavity, the tolerance of the insulation, the specification of the block, insulation, and cavity ties. All these items will affect the level of acoustic, thermal, damp, life expectancy, fire and structural performance. Thermal performance is a key indicator for other performance measures such as acoustics, airtightness, moisture movement, damp control, structural strength, life expectancy and fire performance. A development that achieves good thermal performance requires high levels of quality assurance, that delivers good performance in the other criteria.

Quality of construction should not be defined by the expense of finish e.g. gold standard bathroom or kitchen. It means that appropriately specified materials have been installed correctly. For example, a window installation needs the correct window, accurately positioned and fixed to the inner leaf to minimise thermal bridging and air leakage. The performance of the product goes hand in hand with the installation quality. Quality construction provides a building that meets or exceeds the brief by achieving a low energy, comfortable, enjoyable, robust and functional building that will last – a 'sustainable' building in its literal sense.

The quality of new housing is a product of what the customer and regulations demand. Housebuilders will typically not go further than minimum regulations unless the customer demands it, or if there is a competitive advantage for doing so. In terms of energy efficiency, this often means the minimum possible standards with very little compliance checks to ensure this is met. Consequently we produce homes that are performing considerably worse than intended.

Performance of a new home in terms of energy efficiency, comfort and indoor air quality is relatively difficult to see and evaluate. The long term impact of poorly performing homes on our health, wellbeing, the environment and our pockets are considerable. How do we check and improve performance of new homes?

Improved quality inspection on site

The simple answer to improve quality lies in increasing the frequency and quality of inspection and testing. The most effective and economical test is the 'eye-ball' test that is already used by many building surveyors and could be adapted to look for energy performance issues. A recommended 'eye ball checklist' is included as Appendix 1 and can be amended and used by anyone inspecting sites. Improving the regulation and inspection regime will create a level playing field of required performance for developers. Any future regulation should give flexibility in method with an easier process to achieve a higher quality as-built standard. This policy leads to improved training and communication in energy performance, and a virtuous circle of improved construction quality.

Chapter 2:
How to detail a thermally efficient building envelope

Chapter 2:
How to detail a thermally efficient building envelope

2

This chapter focuses on thermal performance of the fabric, but there are many synergies with these other factors. The building fabric and services design are the two key aspects of a building's performance. A successful fabric will be thermally efficient and keep the weather, pollution, fire, noise, damp and other external factors removed from the internal environment. A thermally efficient building envelope will need to be well built, structurally sound, airtight, weatherproof, fire resistant and have good acoustic performance due to the insulation and airtightness. The attention to detail and quality assurance on site needed to deliver a thermally efficient building will also normally lead to increased performance in other areas.

Three layers

A thermally efficient building envelope will have three continuous layers:

1. Windtight and weathertight (outside layer)
2. Continuous insulation with no thermal bridges
3. Airtight layer (normally the inside layer)

Ensuring the continuity and robustness of these three is key to detailing a fabric that performs to expectations. Figure 2.1 below shows an indicative structure and orders the layers of airtightness, insulation and weatherproofing in the typical position. An alternative order is shown in Figure 2.4.

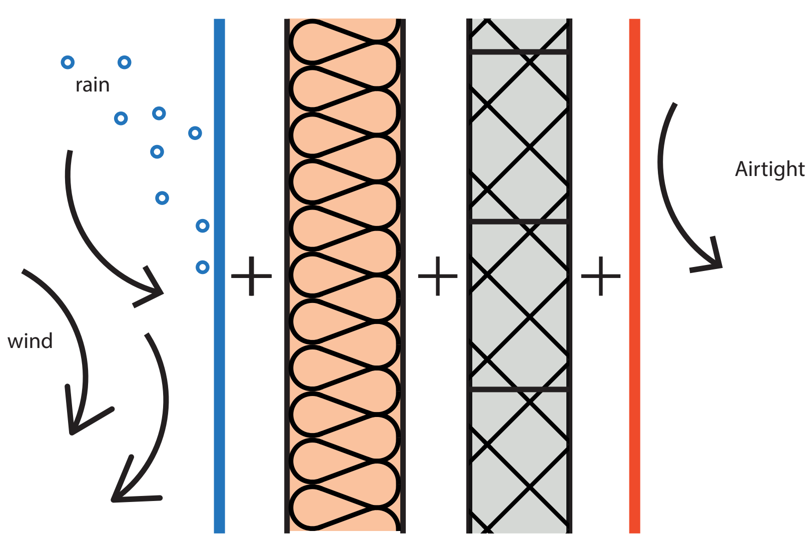


Figure 2.1
Typical construction build-up for thermal performance.

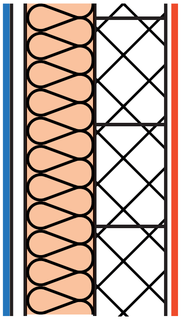


Figure 2.2
Solid masonry construction.

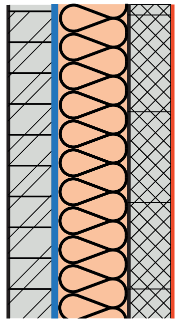


Figure 2.3
Cavity wall.

Continuity of all three layers

The challenge when detailing and delivering a building is to keep the thermal envelope continuous. The majority of buildings in the UK have poor airtightness and significant thermal bridges. The aim of retaining a consistent thermal line with continuous insulation and airtightness is often compromised by architectural design. It can also be compromised by a structural or services design that does not consider thermal integrity.

Continuity of insulation and airtightness is often not prioritised when designing the structure and services penetrations. Certain construction types that require cladding to be supported with steel brackets or ties are more difficult to achieve continuous insulation and airtightness and can contribute towards poor building performance. It is these construction types where project teams need to concentrate on minimising the amount of fixings that conduct heat through the insulation, rather than just increasing insulation thickness.

Insulation layer

Part L of the Building Regulations states that buildings should be constructed to ‘reasonably avoid thermal bridges’. These normally occur in insulation layers that have been bridged by a structural element or an insulation gap at junctions such as roof eaves, windows and floor. An ideal building has a continuous insulation layer around junctions which at no point is below two-thirds of its full thermal performance. The insulation value is consistent around the whole envelope and there are no thermal bridges. Any fixings through the insulation layer should be minimised or thermal breaks need to be introduced. The designer should also consider the practicalities of installing the insulation in certain hard to reach areas like eaves and below ground and door reveals. The insulation needs to be installed tight to the structure with no air gaps.

Windtight layer

The windtight barrier protects the insulation from ‘wind washing’, which produces ‘thermal bypass’ that hugely reduces the performance of the insulation. A common analogy for this diagram is a windproof jacket above your fleece in order to protect it from wind that will blow away the trapped warm air in the fleece. If you unzip the windproof jacket, the wind blows in and reduces the performance of the fleece.

The windtight layer can take the form of a variety of different materials such as brick, render or a membrane over the insulation. If there is a ventilated cavity between cladding and insulation, thermal bypass may also occur with cold air rising up the cavity. In this case, a separate breather membrane may be required to prevent moisture and air ingress into the insulation. The weatherproof layer can be a variety of materials, preferably a robust, long-lasting material with little need of additional structure supports that will penetrate the insulation layer. Examples of this layer include tiles and roofing membrane, or rainscreen cladding and breather membrane. The details in Chapters 3 to7 use a brick cladding as the windproof layer, which requires ties back to the structure and so is a challenge to achieve thermal continuity.

Airtight layer

Airtightness will radically reduce the amount of heat lost through draughts or 'infiltration'.

A REHVA study (2013)[4] concluded that 15% of the space heating use can be saved by going from 11.5 $m^3/(m^2{\cdot}h)$ @50 Pa (average current value) down to 5 $m^3/(m^2{\cdot}h)$ @50 Pa (achievable). An insulated but leaky home will require a large amount of continuous heating, as the heat is lost through unmanaged infiltration. In order to get the best thermal performance a contractor must aim to make the building fabric fully airtight. There is little point in aiming for half way between airtight and leaky and doing so is a waste of material, time and money. Airtightness is often a high priority, and a challenge for the contractor as there is a test required for Building Regulations approval. A typical target for the air test is 5 $m^3/(m^2{\cdot}h)$ @50 Pa, which although an improvement on 2013 figures, still represents a significant amount of uncontrolled air leakage through the building fabric. The optimum target for new-build homes is to aim for less than 1 $m^3/(m^2{\cdot}h)$ @50 Pa. This is the tipping point to achieve the optimum heat demand of less than 10 W/m^2, which is a quarter of the demand of a new-build home. To achieve this level of airtightness, there needs to be a continuous airtightness layer.

The airtight layer should be tight up against the insulation with no air gaps between. Ideally, it should also be on the outside of the services and structure layer to minimise penetrations for services/structure and to protect from future maintenance, as shown in Figure 2.4. The more times the services or structure have to puncture this layer, the more work there is to seal up this hole.

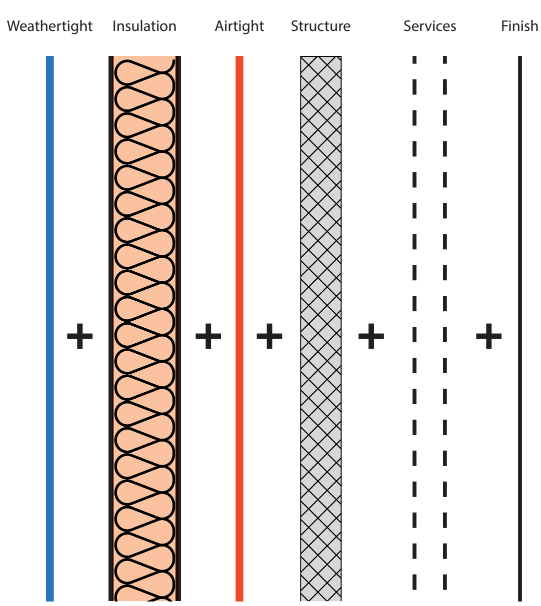


Figure 2.4
Ideal order of construction elements for thermal performance.

Build tight

The optimum airtightness target for the thermal envelope of new-build homes is to aim for less than 1 $m^3/(m^2 \cdot h)$ @50 Pa – as airtight as possible!

The more common, easier to build method is to place this notional airtightness layer on the inside of the structure (Figure 2.1). By doing this, it is easier to inspect any potential failures as an airtightness test can highlight any leaks, and they can be sealed from the inside. A service zone on the inside of the airtightness line also helps achieve a simple airtight layer that will enable the contractor to install services without puncturing the airtightness layer. This services zone will also allow future occupants to drill through the finishing plaster or plasterboard without puncturing the airtightness layer.

In summary all three elements – windtightness, insulation and airtightness – need to be continuous to ensure as-built performance in any new construction. Examples of these principles working in different types of wall construction are illustrated in the summary table on pages 20–21.

Summary of construction types for dwellings

All construction types can achieve high levels of fabric performance with three continuous layers of windtightness, insulation and airtightness. All construction types can also meet the Passivhaus standard, but some are more suited to this higher performance than others. The most economical can achieve both continuous insulation and airtightness with minimal effort. This table 2.2 gives a concise summary of the benefits, constraints and recommendations for the typical construction types used to build new housing in the UK. Each of these construction types is examined in more detail in Chapters 3 to 7.

Passivhaus: the optimum building envelope

Passivhaus is the optimum fabric-first solution, and reduces the heating load to a minimum, less than 10 W/m^2. This is 75% less than the average new home and provides the best comfort and indoor air quality. It also means there is no need for radiators as heat is provided by the sun, internal gains and heat recovery ventilation. In order to achieve this higher energy and comfort standard, greater attention to detail is needed in the design and on site. The quality assurance needed for Passivhaus certification often produces homes with performance that meets the design targets.[5] The five pillars of Passivhaus demonstrate good practice for delivery of energy efficient homes, and are shown in figure 2.5.

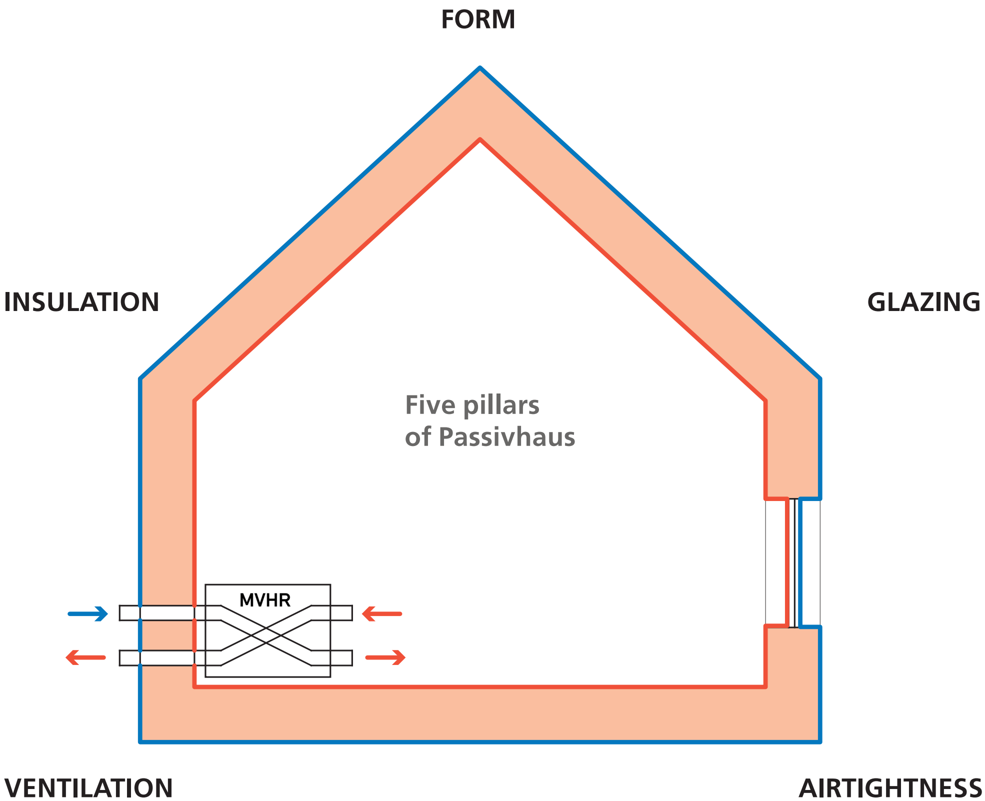


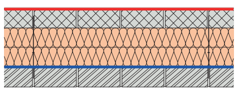
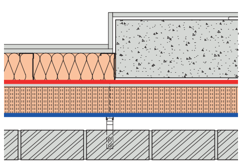
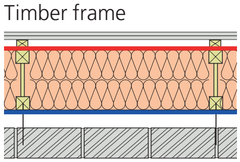
Figure 2.5
The five pillars of Passivhaus

Element	SAP (notional values)	PHPP (guidance values)
External walls	0.18 W/(m².K)	0.1 – 0.15 W/(m².K)
Party walls	0.00 W/(m².K)	0.00 W/(m².K)
Floor	0.13 W/(m².K)	0.1 – 0.15 W/(m².K)
Roof	0.13 W/(m².K)	0.1 – 0.15 W/(m².K)
Glazing	1.4 W/(m².K) (whole window)	≤0.85 W/(m².K) (installed value)
Opaque doors	1.0 W/(m².K)	≤0.85 W/(m².K) (installed value)
Airtightness	≤5.0 m³/(h.m²)	≤0.6 ac/h (mandatory)
Thermal bridging	y=0.15 W/(m².K) (internal calculation)	psi-value (external): ≤0.01W/m.k
Ventilation	System 1 (extract fans)	System 4 (MVHR)
Air conditioning	None	None
Space heating or cooling demand	46 kWh/m².yr for houses (Part L Fabric Energy Efficiency)	≤ 15 kWh/m².yr (mandatory)
Primary energy	Not defined	≤ 120 kWh/m².yr (mandatory)
Opening areas	Max. 25% of internal floor area	N/A (design for good daylight)

Table 2.1 Comparison of SAP notional values and Passivhaus guidance values.

Construction types for dwellings

All construction types can achieve high levels of fabric performance with three continuous layers of windtightness, insulation and airtightness. This table gives a concise summary of the benefits, constraints and recommendations for the typical construction

Chapter	Construction method	Benefits	Risks/Limits	Recommendations
3	Cavity masonry wall 	» Common around the UK » Useful thermal mass* » Good soundproofing and airtightness if plaster is used	» Construction quality is difficult to check » Thermal bypass » Difficult to install rigid boards without gaps » Not airtight if plasterboard is used » Slow construction/ weather dependent	» Closely control quality » Specify full fill cavity with flexible insulation » Ensure continuous insulation with no gaps » Specify aircrete blocks » Specify composite wall ties » Specify two-coat plastic finish for airtightness
4	Concrete frame 	» Common around the UK for apartments above four storeys » Good structural properties » Airtight » Useful thermal mass* » Can be used with steel, timber or masonry infill	» Quality difficult to achieve and check » Partial fill insulation often has gaps » Light steel frame creates repeating thermal bridges » Potential thermal bridge at columns, foundations and balconies » Heavy cladding like brick creates unncessary thermal bridging	» Quality needs to be closely controlled » Insist on continuous insulation, with no gaps between boards » Minimise number of fixings through insulation layer » Racking board taped for airtightness » Ensure concrete or steel does not go through thermal envelope
5	Timber frame 	» Speed of construction » Off-site panels possible » Good thermal performance	» Construction quality can be variable on site » Airtightness difficult » Requires high percentage of timber	» Build off site to control quality » Use I-beams or twin stud panels to minimise thermal bridging » Ply tape at joints for airtightness

* Thermal mass is only useful where the mass is exposed internally and combined with effective night time ventilation.

types used to build new housing in the UK. Each of these construction types is examined in more detail in chapters 3 to 7.

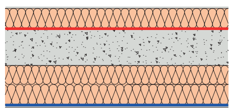
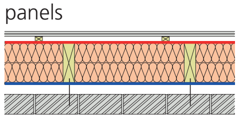
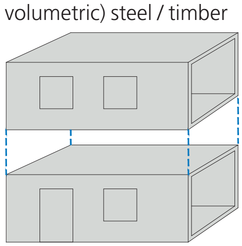
Chapter	Construction method	Benefits	Risks/Limits	Recommendations
6	Insulated concrete formwork (ICF) / masonry 	» Speed of construction » Simple construction » Excellent airtightness with poured concrete » Lightweight blocks » Minimal thermal bridges	» Requires specialist advice and tools to remodel house » Not commonly used in the UK	» Check the system aligns with brick courses » Early collaboration with manufacturer » Airtightness is integral with poured concrete but openings / services need to be taped
7	Structurally insulated panels (SIPs) or CLT panels 	» Airtightness easy » Off-site construction leads to better quality control and tolerances around opening » Good thermal performance per construction thickness » Ease and speed of construction	» Structural limitations mean that structural steel often required » Thermal bridges at floor level and ground » No thermal mass capacity » Late modifications can be pricey » Additional timber commonly used around openings	» Take into account structural limitations to minimise steelwork » Include extra insulation layer on outside to minimise thermal bridging » Early collaboration with manufacturer » Airtightness membrane on outside of panel or inside with a service zone
7	Modular (off-site volumetric) steel / timber 	» Better working conditions: weather, access, stability, safety, waste » Excellent airtightness » Better supervision and quality control » Easier to reuse offcuts and minimise packaging » Easier assembly and deconstruction	» Structural design must address progressive collapse » Lightweight components have little or no thermal mass capacity » Prefabricated components mismatch on-site work » Excessive steelwork can cause thermal bridging	» Requires greater investment and coordination up front » Early collaboration with manufacturer to identify constraints and opportunities » Specify pre-commissioned M&E services » Consider logistics of delivery to site

Table 2.2 Summary of construction types for dwellings.

Chapter 3: Masonry – cavity wall construction

Chapter 3:
Masonry – cavity wall construction

3

This chapter details cavity wall construction and gives both good and bad examples of how it is handled on site. Cavity wall masonry construction accounts for the majority of new-build housing in the UK, and was designed primarily to keep water away from the internal wall. Modern cavity wall construction has adapted to include insulation into the cavity to increase thermal performance to mixed success. This type of construction creates a number of challenges for principles of continuous insulation and airtightness.

Cavity wall construction is insulated in three main ways, depending on various factors, including its level of exposure to rain. A partial filled cavity will generally be more effective at keeping the inner leaf dry in areas subject to wind-driven rain. A full fill cavity wall should use insulation and detailing that reduces any chance of water tracking back across the cavity to the inner leaf.

1. Partial fill: rigid insulation, for example, phenolic foam board.
2. Full fill: generally this is mineral wool (glass or stone).
3. Blown insulation: different types, and popular with larger sites and housebuilders; classified as full fill.

This chapter examines the advantages and disadvantages with cavity wall construction. Examples of common problems and good practice details are illustrated. Rigid insulation boards have the majority of performance issues, and so these good practice details use a full fill wool insulation which is considered easier to install continuously around the envelope, leading to better asbuilt performance. Coverage and quality of the installation of blown insulation is difficult to check, and so it is not recommended.

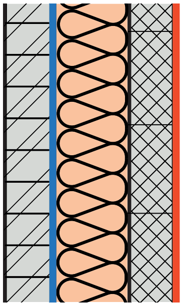


Figure 3.1
Cavity wall full fill.

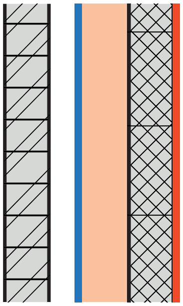


Figure 3.2
Cavity wall partial fill.

Table 3.0.1
Cavity wall insulation methods

Insulation method	Partial rigid board	Full fill	Full fill blown
Ease of construction	Difficult	Moderate	Easy
Performance as-built	Poor	Good	Poor
Ease of quality check	Moderate	Easy	Difficult

Summary

Advantages

- Common around the UK, so materials and labour are normally readily available.
- Useful thermal mass if internal concrete block is exposed.
- Good soundproofing properties.
- If plaster is used as internal finish, then airtightness is easy and long-lasting.
- Brick cladding is robust and long-lasting.
- It is economical as it is perceived by builders as being low risk.
- It can be adapted to meet stringent performance standards like Passivhaus.

Disadvantages

- Depends on construction quality for good performance.
- Quality of installation is often difficult to check.
- Partial fill rigid insulation commonly has gaps and ‘thermal bypass’, rendering insulation useless.
- Thermal bridges are common.
- Steel wall ties conduct heat across the insulation layer; it is difficult to install insulation around the ties.
- Wide cavity needed for thermal performance.
- Airtightness is difficult with plasterboard finish and further heat loss can occur with thermal bypass as air flows in gap between block and plasterboard.
- Slower construction times than timber frame or off-site manufacture.

Recommendations

- Quality needs to be closely monitored.
- Specify full fill cavity with a compressible insulation such as mineral wool.
- Insist on continuous insulation where possible, with no gaps between boards or insulation.
- Consider aircrete (AAC) or clay blockwork for improved thermal performance of inner leaf, but check for reduced acoustic or structural performance.
- Specify low conducting wall ties (basalt fibre or similar) to improve performance.
- A wet plaster internal finish is best for airtightness and thermal mass.
- Penetrations in the plaster layer are made airtight with membranes, tape and grommets as shown in figure 3.7 a & b.

Common Problems

» Gaps in rigid insulation cause thermal bridging and thermal bypass leading to increased heat loss through wall and floor, as shown below.

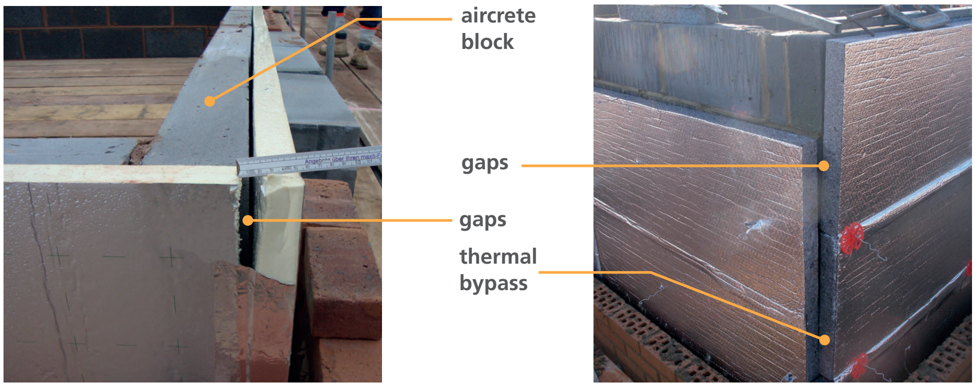


Figure 3.3 a & b
Partial fill cavity wall gaps in rigid insulation within cavity wall construction.

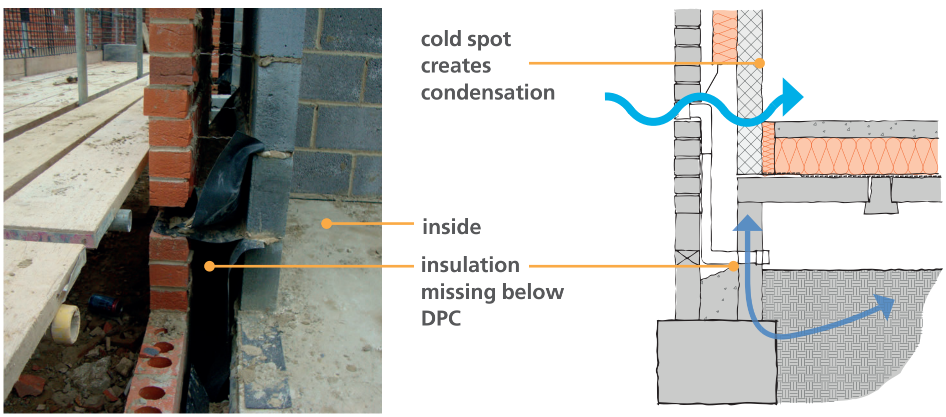


Figure 3.4 a & b
Missing insulation below DPC.

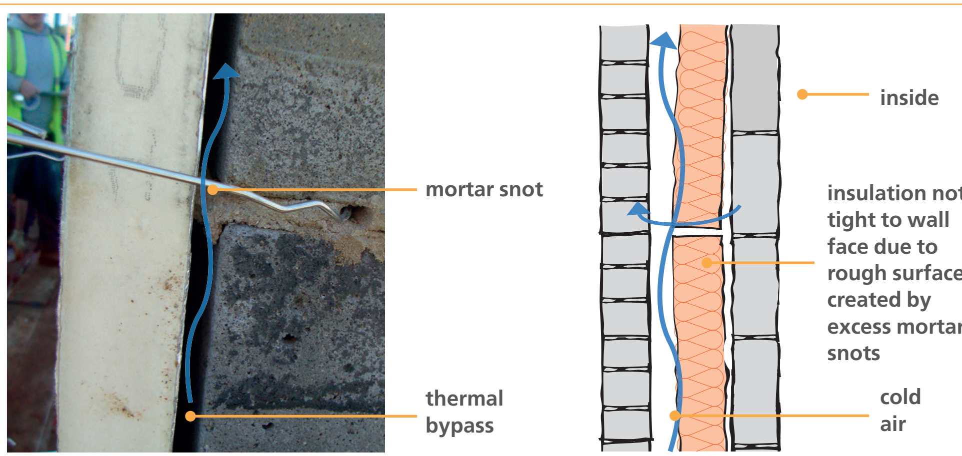


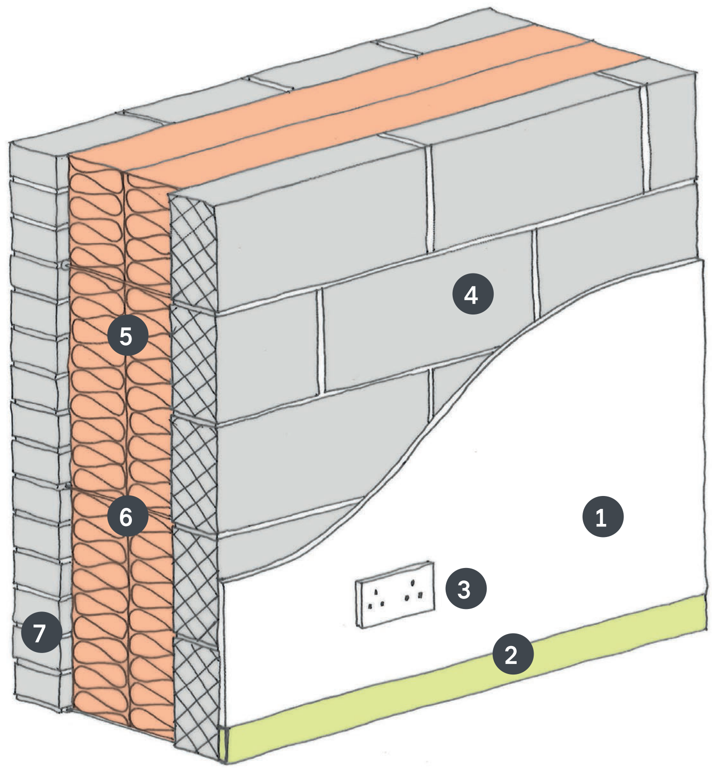
Figure 3.5 a & b
Gap between insulation and block allows cold air to circulate causing thermal bypass and increased heat loss.

Good Practice

Despite the difficulties illustrated in the previous page, cavity wall construction can achieve sufficient thermal performance with good practice detailing and installation. This page and the rest of this chapter offers guidance on how to deliver energy efficient homes using cavity wall construction.

KEY

1. Two-coat plaster internal finish for a robust airtightness layer. Plasterboard is not airtight and can aid thermal bypass.
2. Temporary 13 mm timber batten assures sufficient thickness of plaster for airtight seal.
3. Back boxes to sockets and other services to be sealed with airtight membrane and tape.
4. Inner layer of aircrete, clay block or concrete block to be fully pointed airtight.
5. Two layers (batts) of wool insulation laid continuous with no gaps.
6. Thermally broken wall ties.
7. Brick outer leaf.



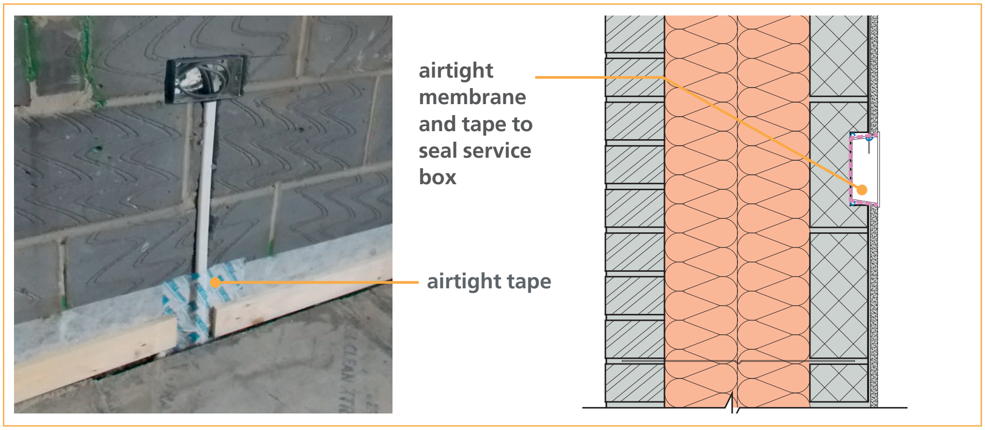


Figure 3.6
Masonry cavity wall construction (above).

Figures 3.7 a & b
Electric sockets chased into block. Airtight membrane and tape used at junction. Two-coat plaster finish will seal the wall (left).

Details

This section through a typical house shows the most significant details affecting thermal performance that are illustrated in more detail in the rest of this chapter.

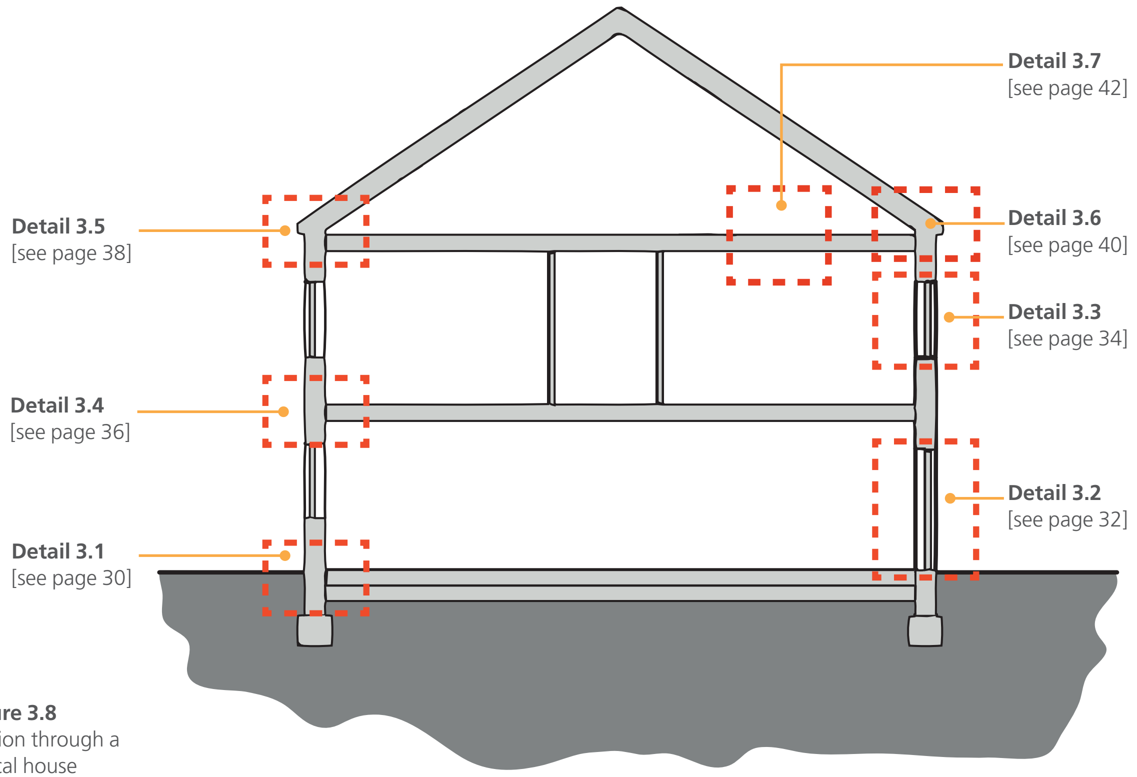
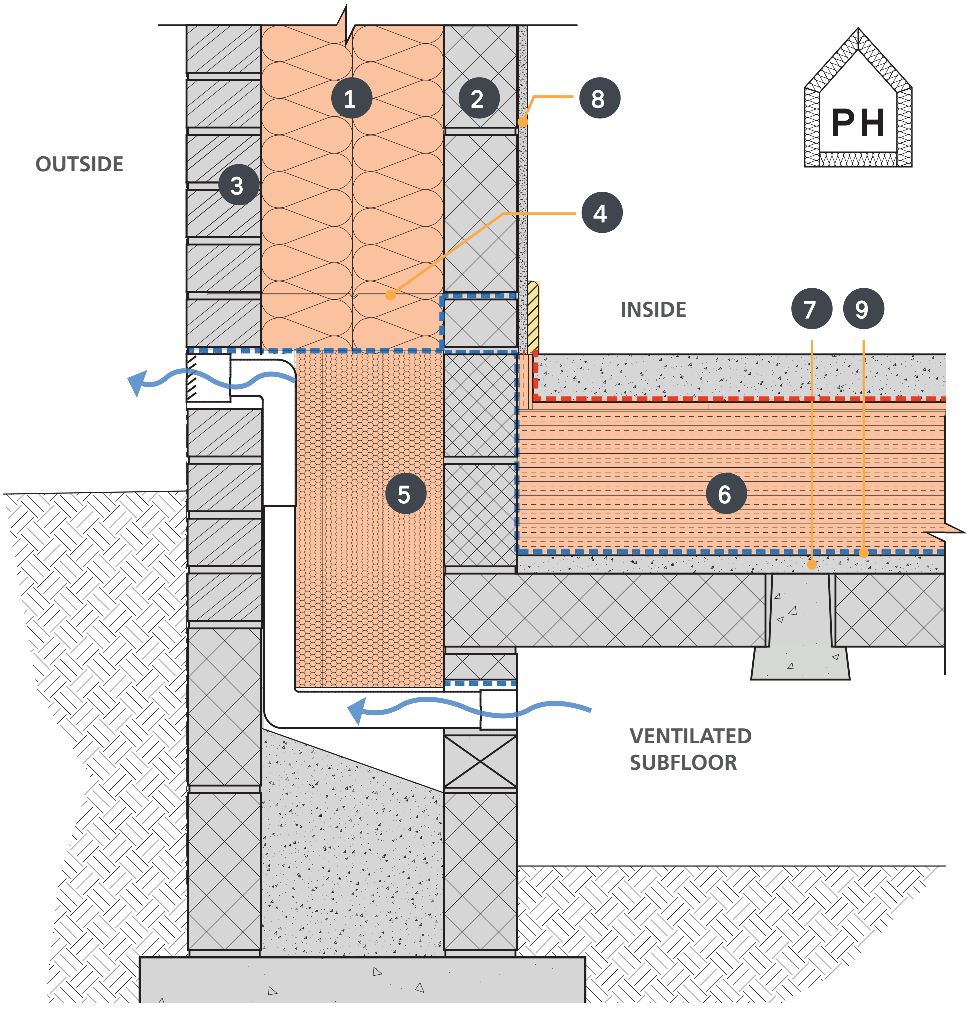


Figure 3.8
Section through a typical house

Detail 3.1 Ground Floor / Wall

As an alternative and where ground conditions allow, consider an insulated raft foundation system to improve thermal bridging and airtightness.



KEY

1. Full fill, mineral wool insulation c.250 mm to achieve 0.1 U-value
2. Low conductivity block e.g. aircrete at 0.15 W/m.K or less
3. Brick
4. Low conductivity wall tie
5. Rigid insulation suitable for use below DPC e.g. XPS
6. Rigid floor insulation
7. Levelling screed to fill in gaps for windtightness and to provide smooth substrate for insulation
8. Two-coat plaster finish for airtightness
9. Damp-proof membrane

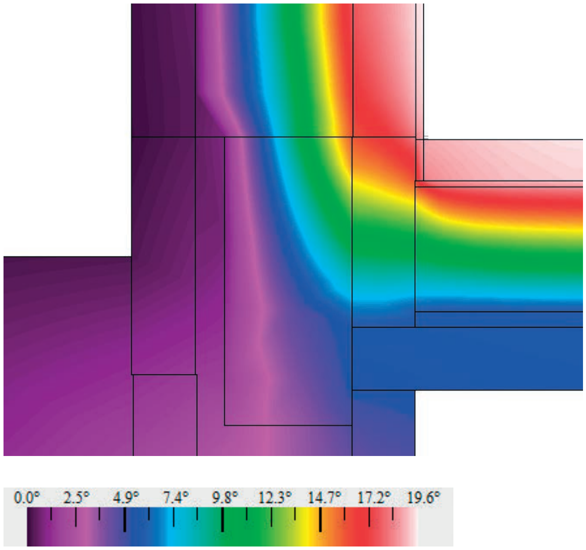


Figure 3.9 Ground floor heat flux diagram corresponding to Detail 3.1 (opposite).

SAP Appendix K Reference	E5
psi-value	0.047 W/m.K
temperature factor	f_{Rsi} = 0.94
approved value	0.16 W/m.K
default value	0.32 W/m.K

Heat flux diagram and psi-value

This heat flux diagram models the heat loss through the ground floor and external wall construction. The heat flow demonstrates the performance of the junction and the different materials. It shows the importance of insulating below the DPC and attempting to maintain continuous insulation where possible. The junction has a psi-value of 0.047W/m.K, which is an 85% improvement compared to the default value of 0.32 W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth.

Figure 3.10 Installation of subfloor vents (top left).

Figure 3.11 Installation of XPS insulation tight around vents (top right).

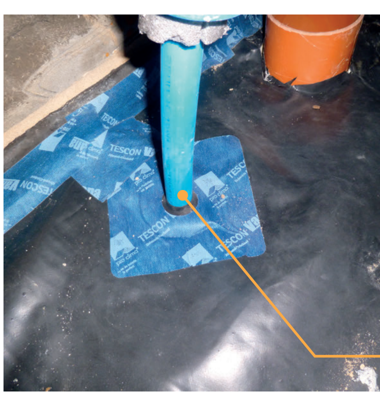
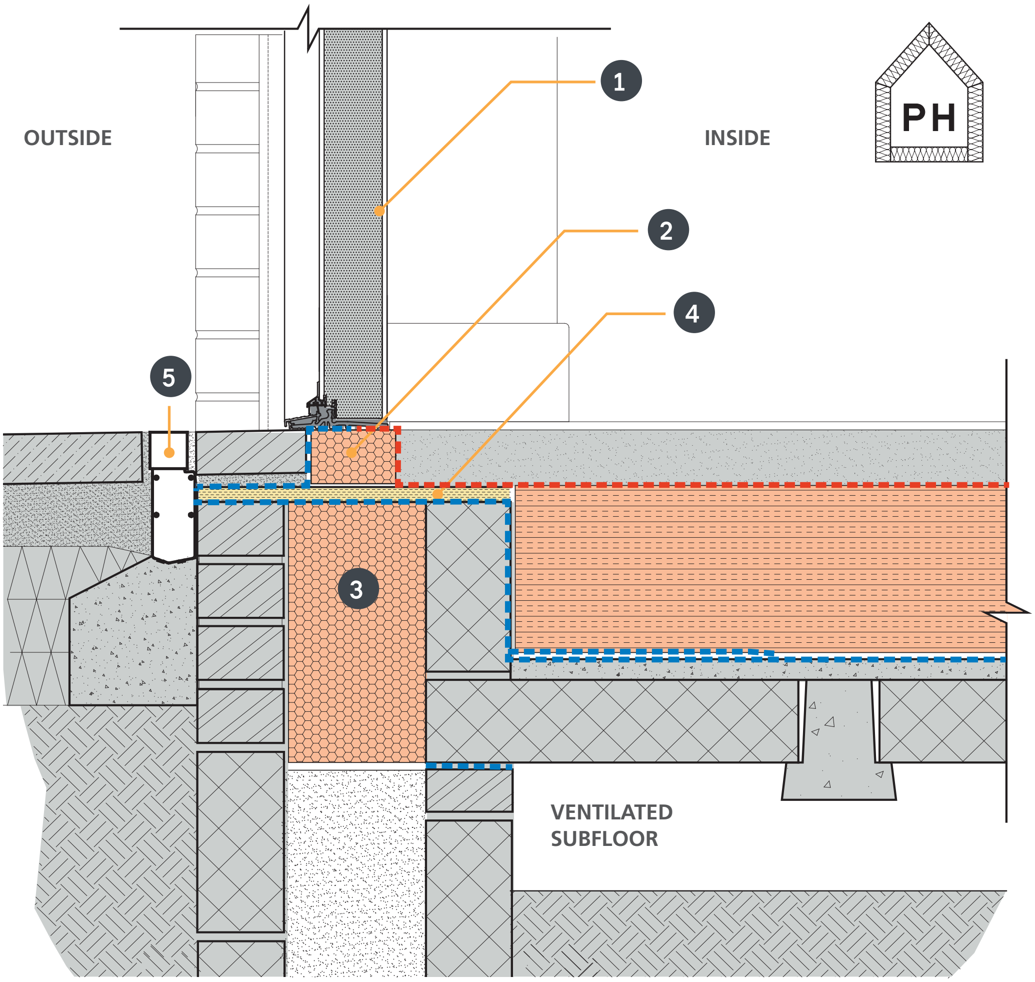


Figure 3.12 Incoming water mains sealed with grommet (bottom left).

Figure 3.13 Drainage pipe penetration in airtight layer is sealed with grommet and tape (bottom right).

Detail 3.2 Level Threshold

This external door threshold is a common area of heat loss through thermal bridging and infiltration. The construction surrounding the door must be thermally broken and made airtight to the door frame.



KEY

1. Door positioned with at least 50 mm overlap on insulation
2. Rigid insulation as thermal break, e.g. FOAMGLAS Perinsul
3. Rigid insulation below DPC, e.g. XPS or similar water-resistant insulation
4. Ply or inert board wrapped with DPC + DPM
5. Drainage channel

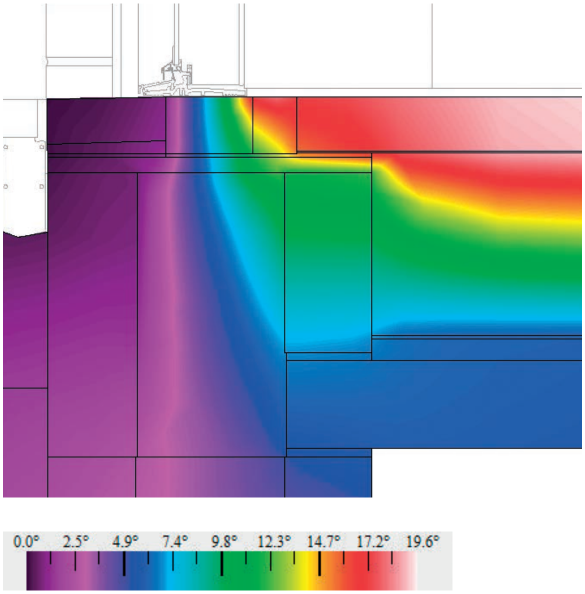


Figure 3.14
Ground floor heat flux diagram corresponding to Detail 3.2 (opposite).

SAP Appendix K Reference	E5
psi-value	0.158 W/m.K
temperature factor	f_{Rsi} = 0.78
approved value	0.16 W/m.K
default value	0.32 W/m.K

Heat flux diagram and psi-value

This heat flux diagram models the heat loss through the level threshold of the external wall construction, which is a common area of heat loss. The junction has a psi-value of 0.158 W/m.K which is a 51% improvement compared to the default value of 0.32 W/m.K.

The temperature factor indicates the internal surface temperature and condensation potential. It should be as high as possible (above 0.75) to minimise risk of mould growth. In this case it is 0.78, which is only just above the minimum.

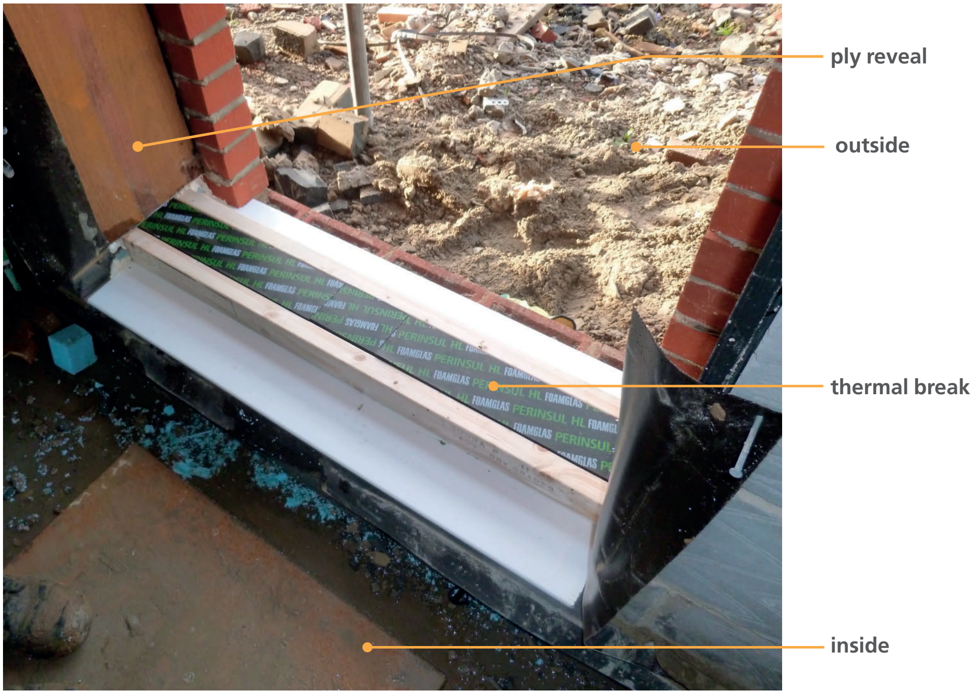
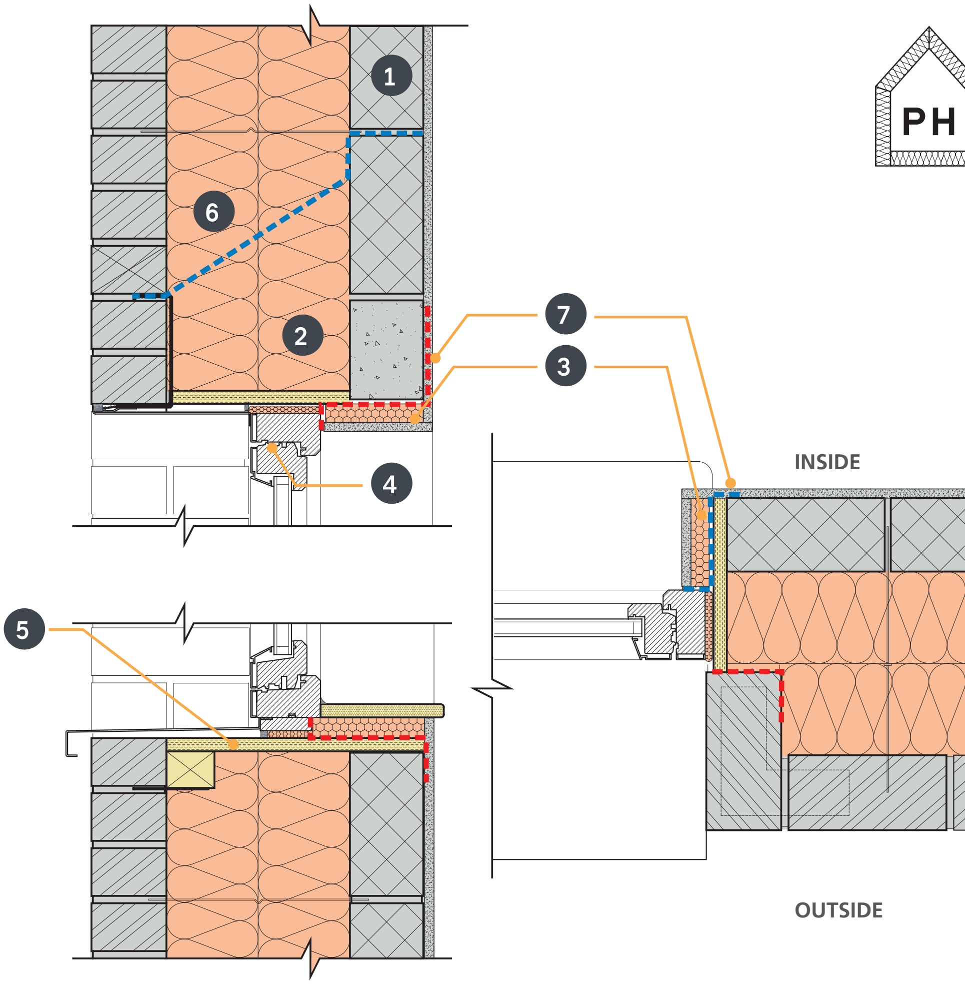


Figure 3.15
Level threshold detail showing thermal break and temporary timber batten as protection.

Detail 3.3 Window

This detail shows good practice with a window set out in line with the insulation layer, and additional insulation in the internal reveals that further improves thermal performance. An alternative to the plywood (5) is to specify a fully insulated cavity closer.



KEY

1. Low conductivity block 0.15 W/m.K or less
2. Full fill insulation packed continuously around cavity tray
3. Rigid insulation to window reveal 0.022 W/m.K conductivity
4. Window positioned in line with cavity insulation
5. Ply box installed to support window and minimise thermal bridging of metal straps
6. DPC cavity tray
7. Opening made airtight with breather membrane taped to window and lapped back into internal plaster layer using stainless steel lath and airtightness tape

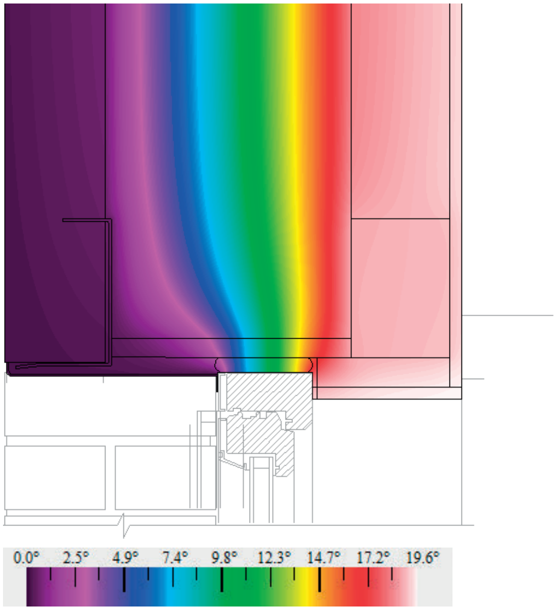


Figure 3.16
Ground floor heat flux diagram corresponding to Detail 3.3 window head (opposite)

Heat flux diagram and psi-value

This heat flux diagram models the heat loss through a window lintel. This junction has a psi-value of 0.025 W/m.K, which is a 97% improvement compared to the default value of 1 W/m.K.

The temperature factor indicates the internal surface temperature and condensation potential and should be as high as possible (above 0.75) to minimise risk of mould growth.

SAP Appendix K Reference	E2 lintel	E3 sill	E4 jamb
psi-value	0.025 W/m.K	0.028 W/m.K	0.024 W/m.K
temperature factor	$f_{Rsi} = 0.98$	$f_{Rsi} = 0.94$	$f_{Rsi} = 0.96$

Figure 3.17
Window construction with cill insulation (top left).

Figure 3.18
Window from outside showing ply and membrane (top right).

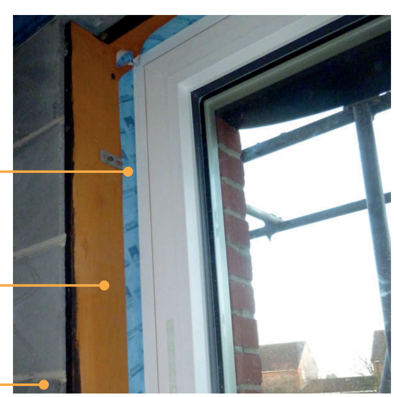
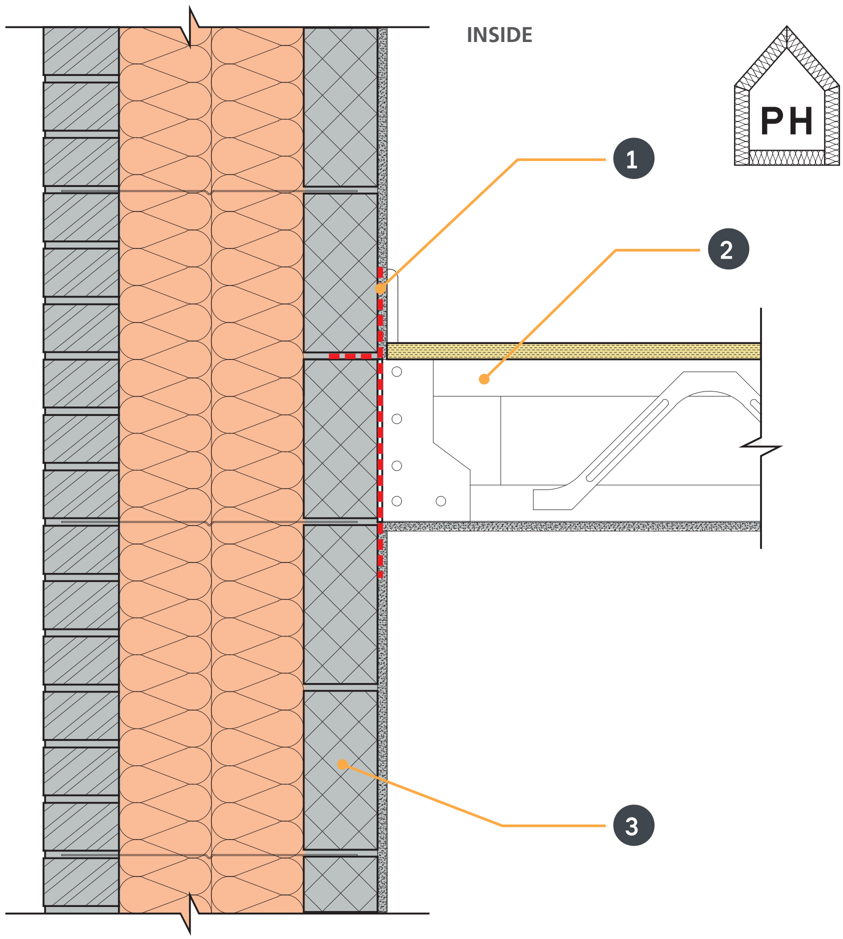


Figure 3.19
Opening sealed with airtight breather membrane (bottom left).

Figure 3.20
Window construction with ply box (bottom right).

Detail 3.4 Intermediate Floor

Floor joists on hangers allow for improved thermal performance and airtightness.



KEY

1. Airtight membrane sealed around floor joists
2. Floor joist on hangers
3. Low conductivity block 0.15 W/m.K or less

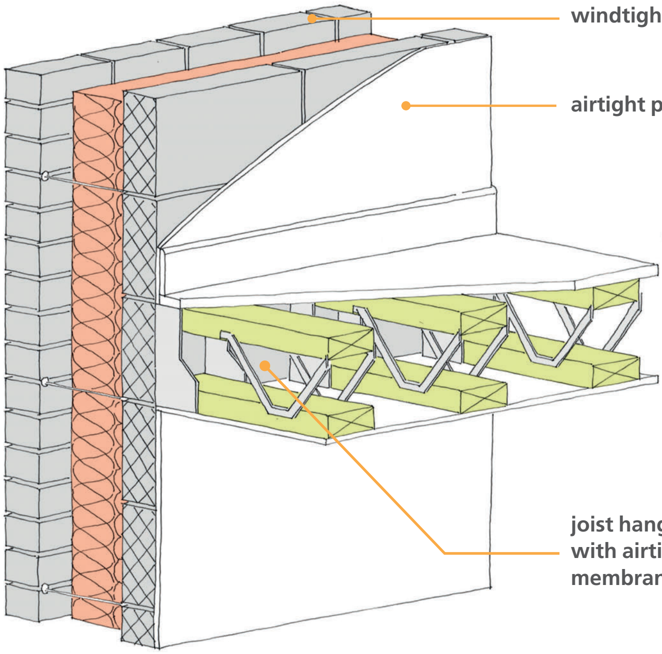


Figure 3.21
3D illustration of intermediate floor construction demonstrating importance of airtightness around joist hangers.

SAP Appendix K Reference	E7
psi-value	0.021 W/m.K
temperature factor	f_{Rsi} = 0.99
approved value	0.07 W/m.K
default value	0.14 W/m.K

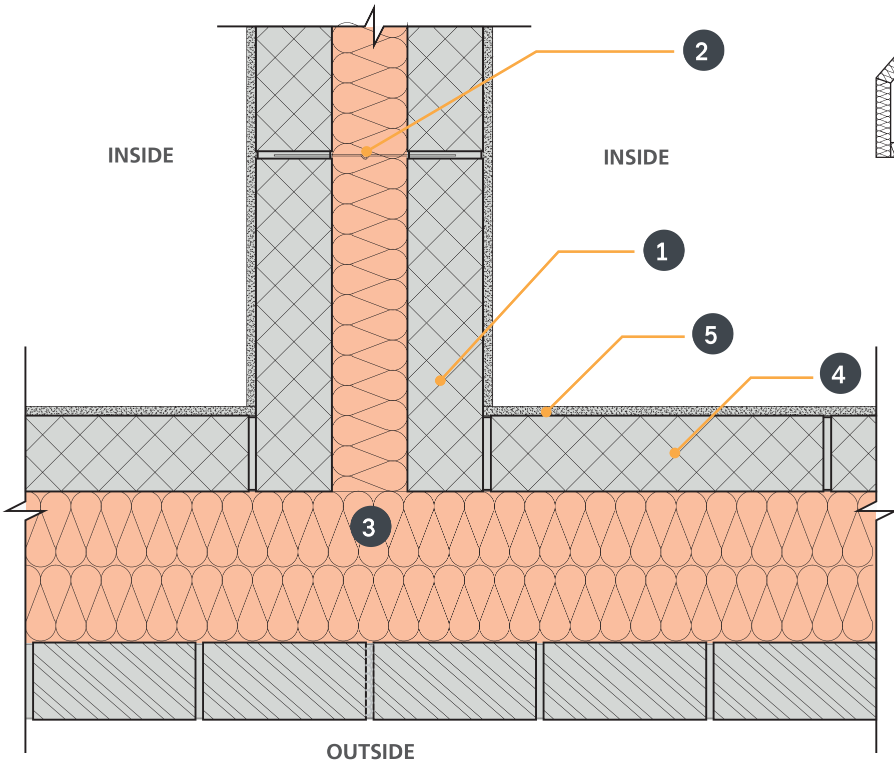
Psi-value

This psi-value is of the intermediate floor and external wall junction, which has relatively little heat loss, but is significant as it has a long length round the whole perimeter. This junction has a psi-value of 0.021W/m.K, which is an 85% improvement compared to the default value, 0.14 W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth.

Figure 3.22
Floor joists sealed with airtight membrane and tape.

Detail 3.5 Party Walls

Mineral wool insulation is easiest to install and does not require a complex party wall junction, as shown in the images opposite.



KEY

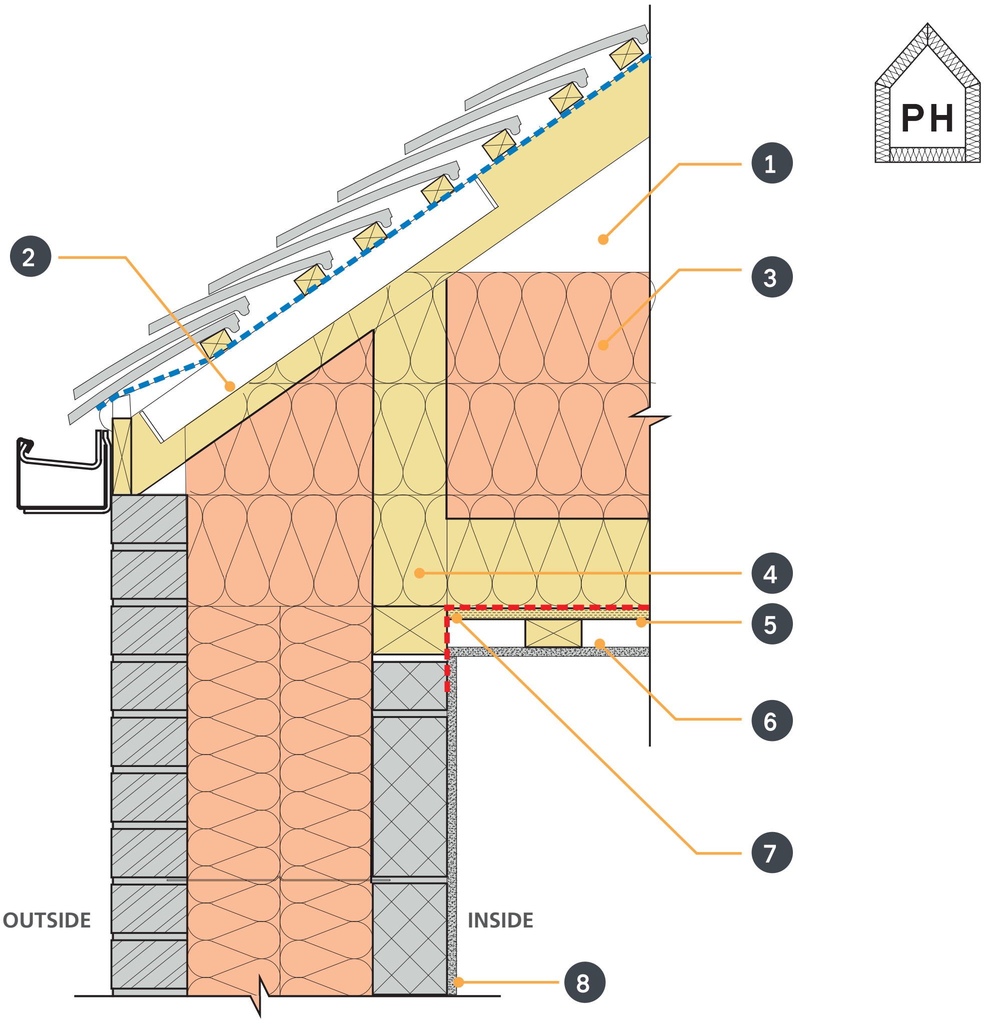
1. Dense concrete block for party wall to meet acoustic requirements
2. Acoustic 'Type A' wall ties
3. Full fill mineral wool insulation means there is no need for fire cavity barrier
4. Low conductivity blocks for improved thermal performance
5. Two-coat plaster finish for airtightness and acoustic performance

Figure 3.23
Party wall between two houses with entrance door tight either side can be tricky to build.

Figure 3.24
Party wall and external wall junction from above – rigid insulation on external wall requires a separate fire barrier / edge seal.

Detail 3.6 Eaves

This design of the roof truss should allow enough height for easy access to install sufficient thickness of insulation into the eaves area.



KEY

1. Cold ventilated loft
2. Eaves ventilator
3. 500 mm of mineral wool insulation cross-lapped
4. Roof truss designed to accommodate full depth of insulation at eaves
5. Airtight OSB or ply taped at joints as robust airtight layer
6. Service zone
7. Airtight membrane taped to block and ply
8. Plaster finish for improved airtightness

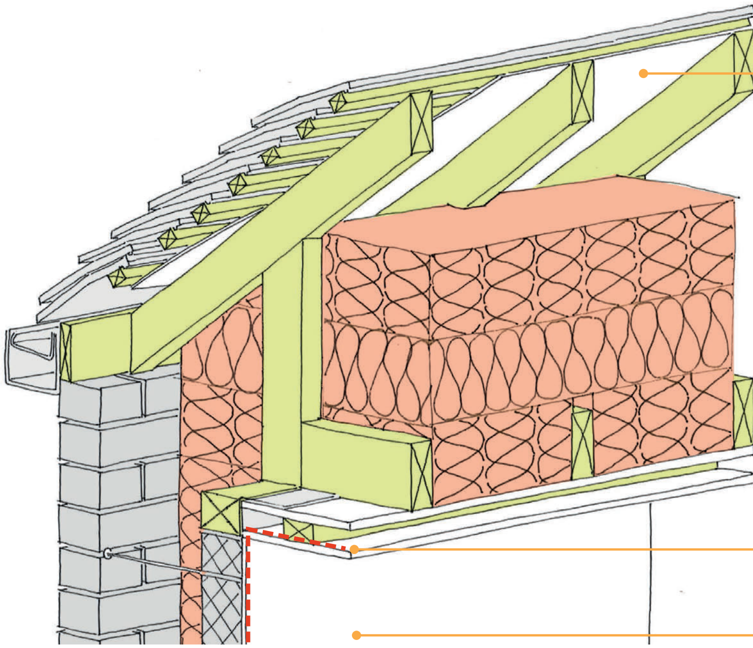


Figure 3.25
3D illustration of eaves construction demonstrating a roof truss design that ensures continuity of insulation and airtightness.

SAP Appendix K Reference	E7
psi-value	0.034 W/m.K
temperature factor	f_{Rsi} = 0.96
approved value	0.04 W/m.K
default value	0.08 W/m.K

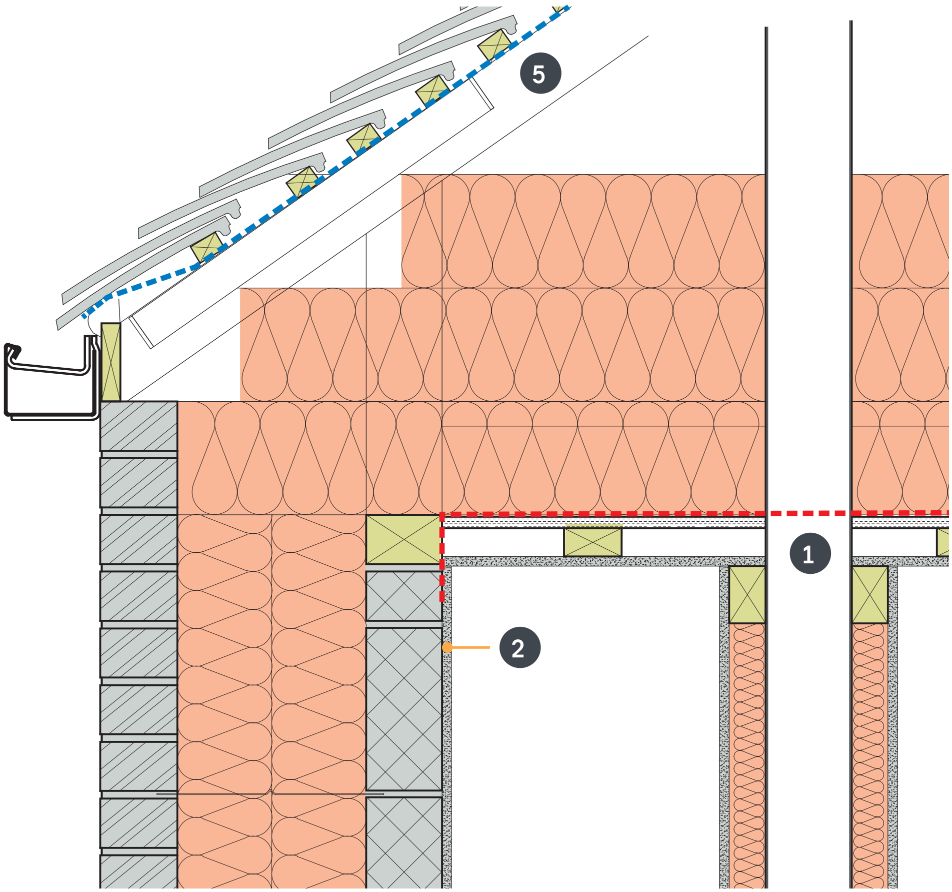
Psi-value

The psi value of this eaves junction is 57% better than the default. There is very little risk of mould with a temperature factor of 0.96.

Figure 3.26
Insulation installed before roof finish.

Detail 3.7 Airtightness Details – Roofs

A 13 mm thick internal plaster finish is an effective airtight seal for walls, but the ceiling is harder to keep airtight. Better airtightness is achieved by specifying a ply ceiling instead of a VCL.



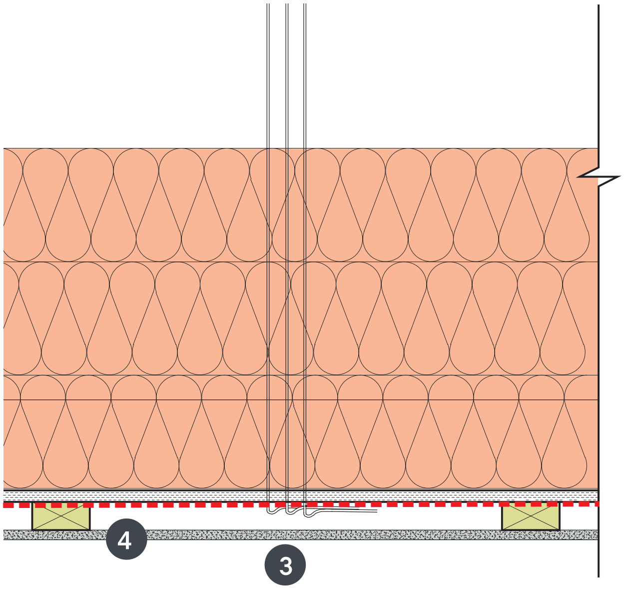
PH

KEY

1. Airtight grommet taped around service pipe
2. Wet plaster finish for airtightness
3. Cable grommet sealing service penetration through membrane
4. Service zone to allow easy and airtight installation of services
5. Windtight roof membrane

Service Zone

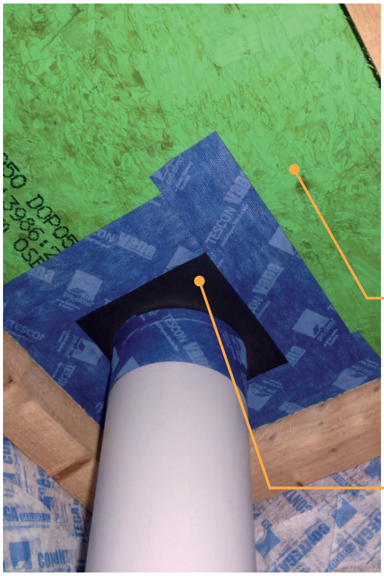
Ply is a robust airtightness barrier in the ceiling where a normal VCL is likely to fail. Check the airtightness of the ply itself and specify smart ply to guarantee performance. The penetrations through the ply can be effectively sealed with grommets and tape or foam. A service zone on the inside face of the ply helps reduce the amount of holes, and provides a clear zone for services to be easily installed. The service zone and plasterboard act as effective long term protection to the airtightness layer.



Services penetrations in the ply, acting as the roof airtight layer.

Figure 3.27 Soil vent pipe penetration in airtight ply layer is sealed with grommet and tape (left).

Figure 3.28 Electrical penetrations in airtight layer of ply are sealed with grommet and foam (right).



Chapter 4: Concrete frame construction

Chapter 4:
Concrete frame construction

4

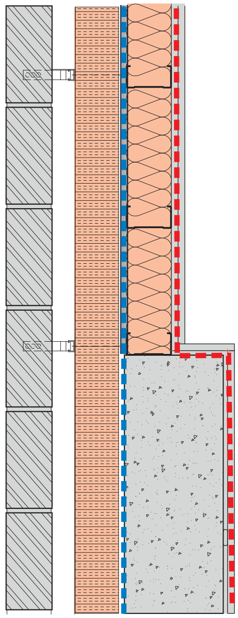
Concrete frame construction accounts for the majority of high-rise residential construction in the UK, and is the normal method for buildings above four storeys, as load bearing masonry approaches it's structural limit.

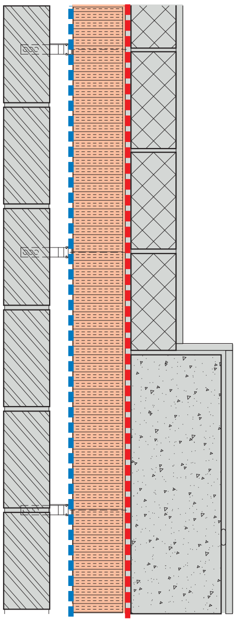
Steel frame is also suitable for high-rise and is often used for commercial buildings. However, it is rarely used in residential settings because of perceived higher material costs and difficulties in achieving acoustic and fire separation. Concrete frame normally combines with light gauge steel infill for the external walls, but can also be specified with a variety of other infill materials including: concrete or clay blocks, precast concrete walls, CLT panels and other prefabricated timber panels or SIPS.

The most common types are shown in the diagrams below:

1. Concrete frame and light gauge steel
2. Concrete frame with concrete block infill & external airtight parge coat
3. Precast concrete panels.

This chapter examines the detailing of concrete frame construction with light gauge steel infill. This is the most popular type of infill for concrete frame construction and so has been examined more closely in the details and illustrations.





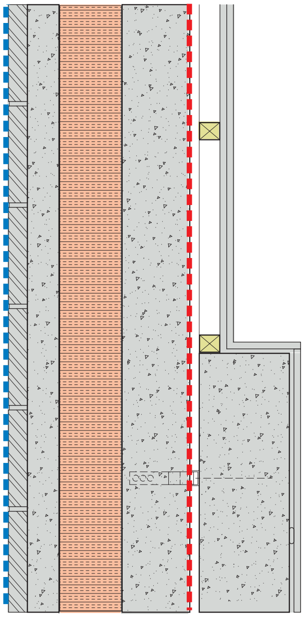


Figure 4.1
Concrete frame and light gauge steel (left).

Figure 4.2
Concrete frame with concrete block infill (centre).

Figure 4.3
Precast concrete panels (right).

Summary

Advantages

- Excellent structural properties.
- Common around the UK for residential use over four storeys.
- Concrete is airtight.
- High mass if exposed internally.

Disadvantages

- Quality is difficult to achieve and check.
- Partial fill insulation commonly has gaps and ‘thermal bypass’ rendering insulation useless.
- Thermal bridges common.
- Airtightness is difficult with plasterboard finish.
- Rigid boards are difficult to install without gaps.
- Light steel frame infill creates thermal bridges.

Recommendations

- Quality needs to be closely monitored.
- Specify continuous insulation where possible, with no gaps between boards / insulation.
- Minimise amount of steel fixings and brackets that penetrate the insulation layer.
- For improved thermal performance and airtightness, consider alternatives to light steel gauge infill like blockwork with a pargecoat (Figure 4.2) or pre-cast concrete panels (Figure 4.3).

Common Problems

- Insulation is missing – commonly at the separating floor, or where shelf angles are used to support bricks at high levels and create additional thermal bridging (Figure 4.8).
- Rigid insulation boards are cut short at junctions, cavity closers, lintels, cavity trays and services (Figure 4.5).
- Some instances of unaccounted bridges, by beams, e.g.canopies.
- Steel stud (LGS) content is greater than SAP assumptions. The percentage of steel content in walls is underestimated, so the heat loss in higher than expected (Figure 4.6).
- Insulation between steel studs is loose and with gaps (Figure 4.7).
- U-values are optimistic and not achievable around columns or slab edges.

Figure 4.4
Rigid insulation is difficult to install without gaps.

Figure 4.5
Rigid board insulation installed with air gaps.

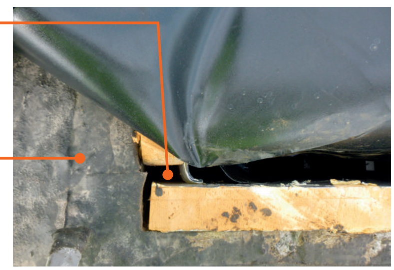


Figure 4.6
Steel content is higher than in U-value calculations.

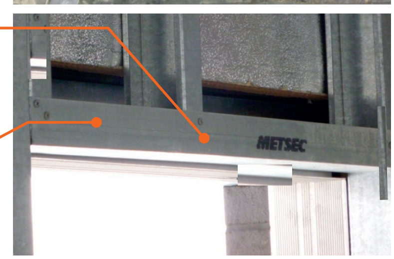


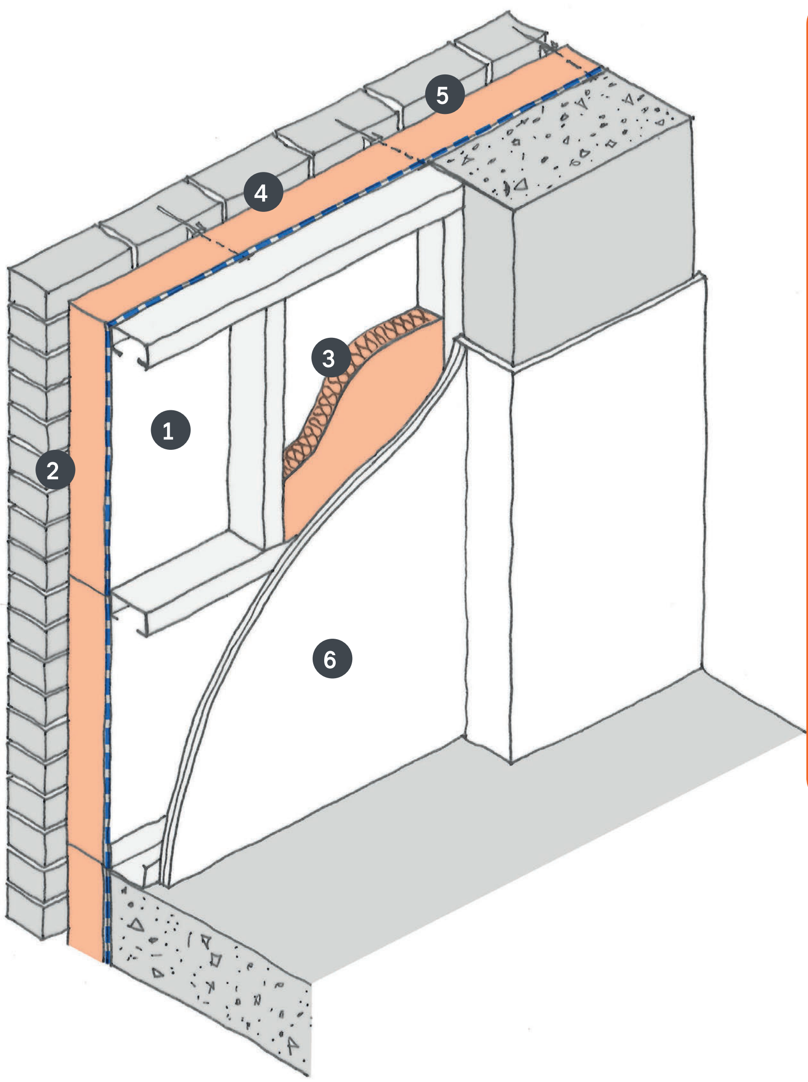
Figure 4.7
Insulation is punctured by steel wall ties.

Figure 4.8
Shelf angles used to support brick.

Good Practice

The rest of this chapter highlights good practice detailing for concrete frame with an emphasis on thermal performance. The locations of these junctions are shown in this section drawing through a typical apartment block. The most significant external envelope details affecting heat demand are drawn with good practice airtightness and continuous insulation where practical. Heat loss is calcuated and psi-value provided where useful for SAP calculations.

Normal construction practice with light gauge steel is to have the airtightness layer as the plasterboard and VCL. This means airtightness is difficult to achieve and is vulnerable to surface penetrations. For better airtightness, consider moving the airtightness layer towards the outside of the construction with an airtight breather membrane.



KEY

1. Inner leaf secondary structure can be metal or timber studwork, blockwork or solid timber panels (CLT)
2. Breather membrane taped over cement particle board
3. Insulation layer between steel studs
4. Continuous insulation (minimum 100 mm)
5. Wall ties on stainless steel vertical channel with thermally broken fixings through insulation back to structure
6. Plasterboard and VCL

Figure 4.9 3d drawing showing good practice for concrete frame and steel infill construction.

Details

This section through a typical apartment block shows the most significant details affecting thermal performance that are illustrated in more detail in the rest of this chapter.

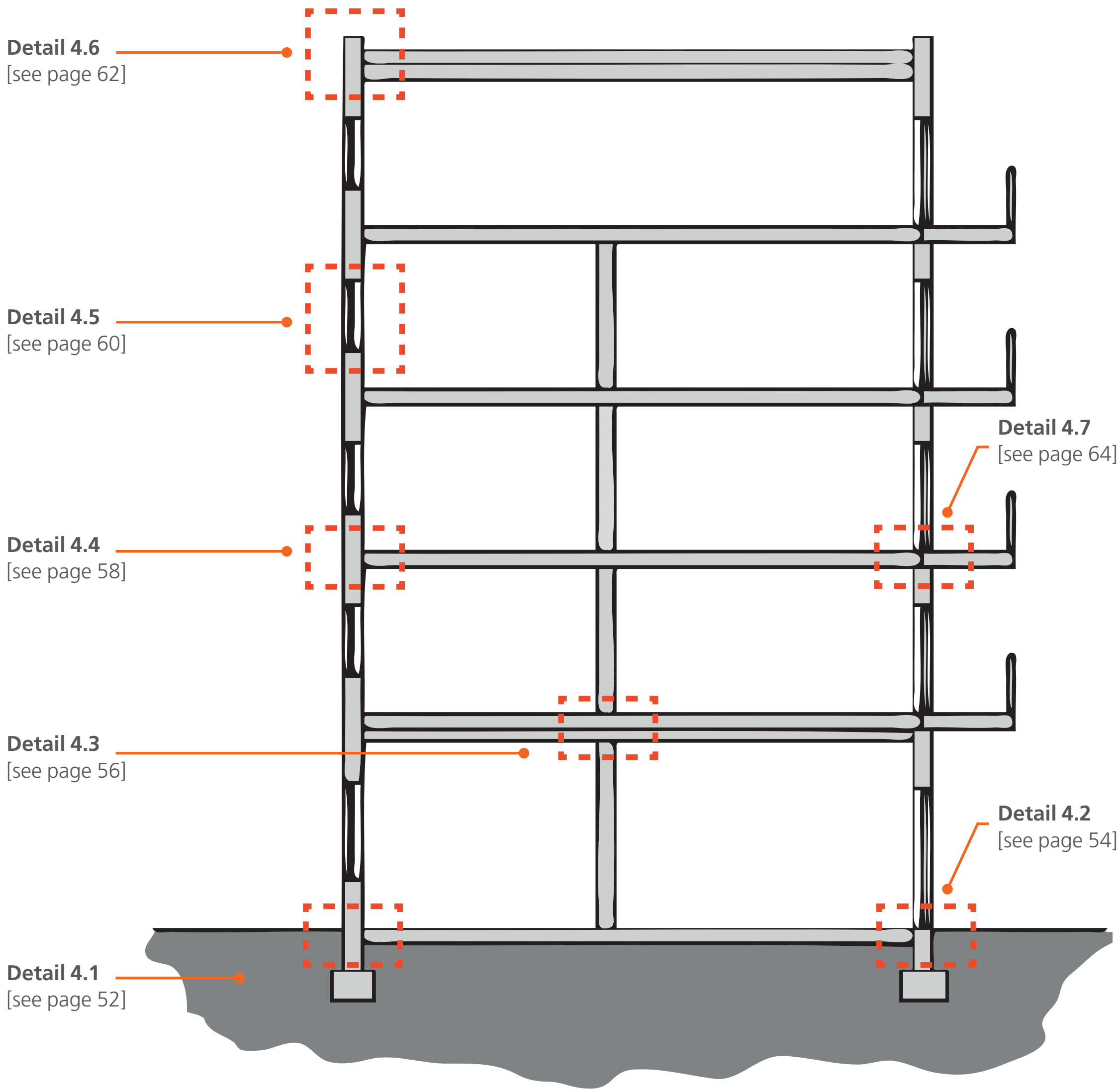
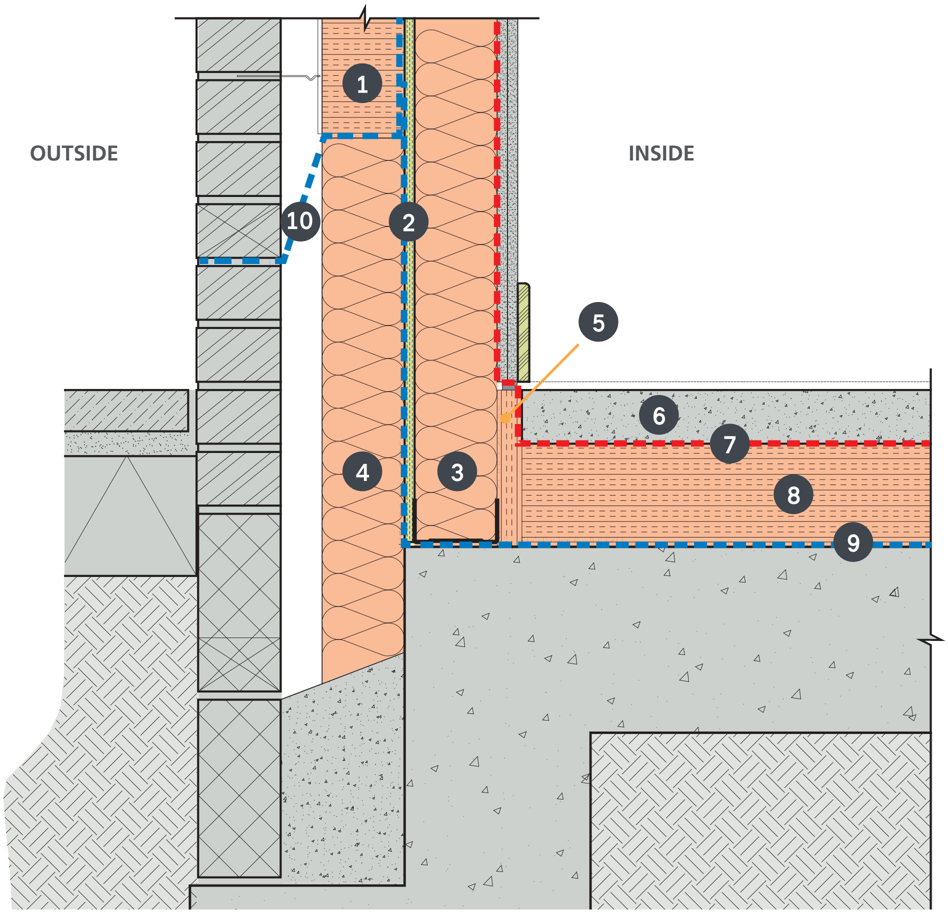


Figure 4.10
Section drawing through apartment block showing the most significant details for energy efficiency covered in this chapter.

Detail 4.1 Ground Floor / Wall

Light gauge steel acts as infill walls for the concrete frame, and must be insulated externally with a rigid board or wool insulation. Airtightness is provided by the VCL, which is vulnerable to be damage. For improved airtightness, use the breather membrane on the outside of the frame.



KEY

1. 100 mm insulation (type and thickness subject to fire, moisture and thermal requirements)
2. Sheathing board and breather membrane as airtight layer
3. Light gauge steel stud and mineral wool
4. Water-resistant insulation
5. Perimeter insulation (minimum 30 mm)
6. Screed and finish
7. Separating layer
8. c.150 mm rigid floor insulation
9. Damp-proof membrane
10. Cavity tray (DPC)

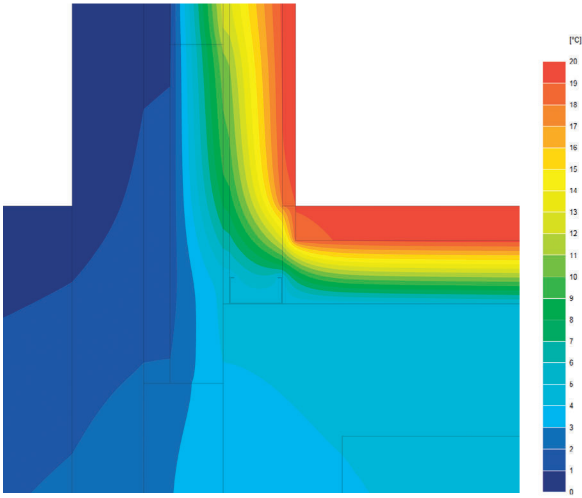


Figure 4.11
Ground floor heat flux diagram corresponding to Detail 4.1 (opposite).

Heat flux diagram and psi-value

This heat flux diagram models the heat loss through the ground floor and external wall construction. The junction has a psi-value of 0.101 W/m.K, which is a 68% improvement compared to the default value of 0.32W/m.K. The temperature factor is above the critical value of 0.75 and so there is no risk of condensation or mould growth.

SAP Appendix K Reference	E5
psi-value	0.101 W/m.K
temperature factor	f_{Rsi} = 0.83
approved value	0.16 W/m.K
default value	0.32 W/m.K

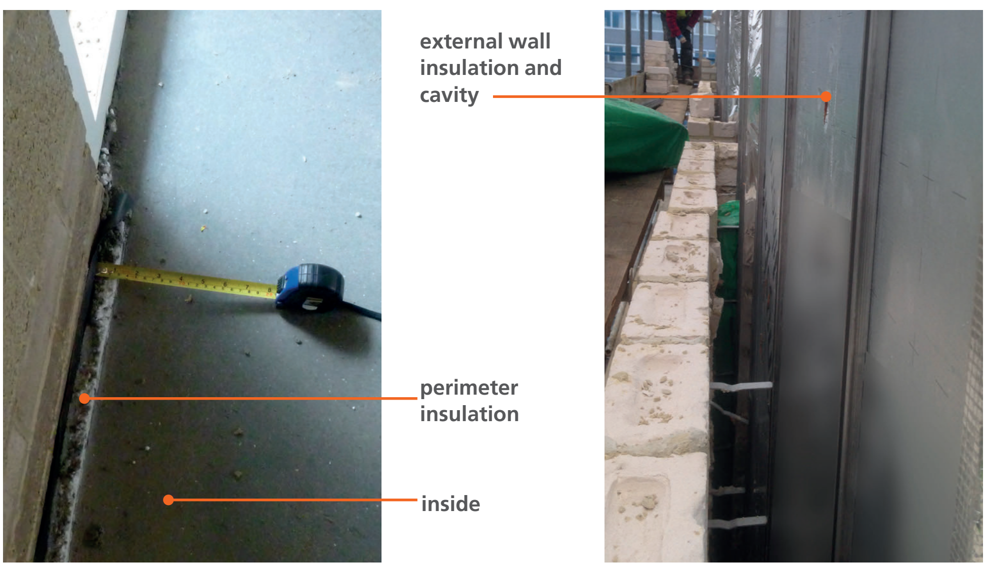
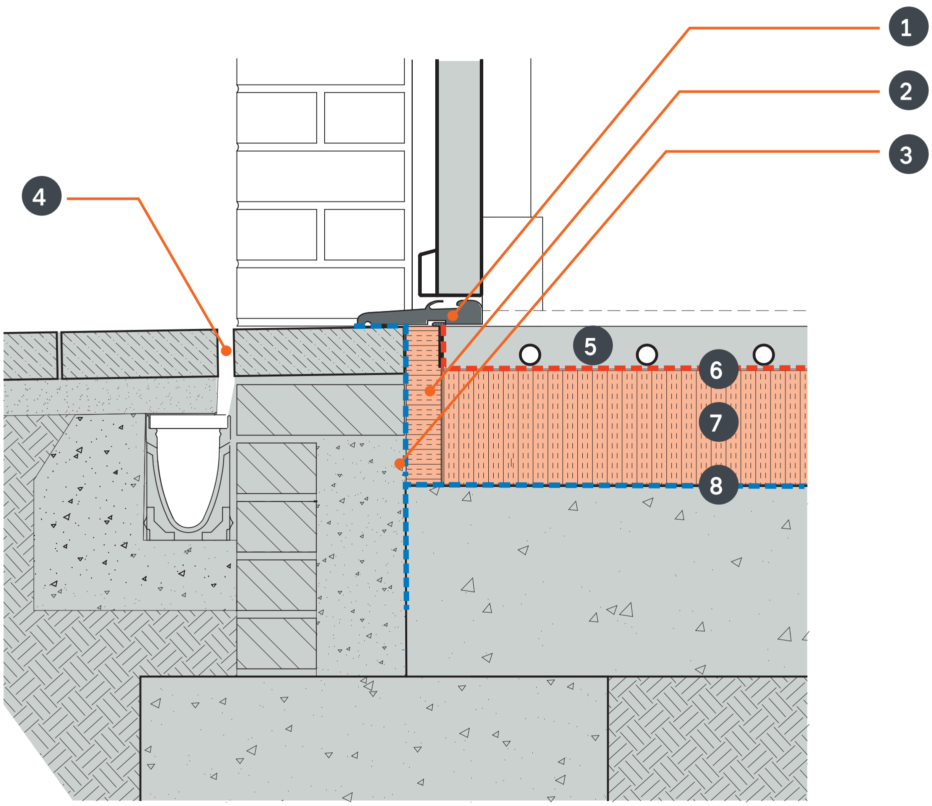


Figure 4.12
Perimeter insulation should be sufficient thickness and not be bridged by screed (left).

Figure 4.13
Cavities minimum 50 mm clear of debris. Wall tie track system to minimuse thermal bridging (right).

Detail 4.2 Level Threshold

The external door threshold is a difficult area to insulate and so thermal bridging occurs. Prevent this with a thermal break on all sides of the door construction as shown below.



KEY

1. Doorset to include threshold cover plate to form seal with DPC
2. 50 mm rigid phenolic insulation as thermal break at threshold
3. DPC
4. Drainage channel
5. Screed with underfloor heating
6. Separating layer
7. 150 mm PIR floor insulation
8. DPM

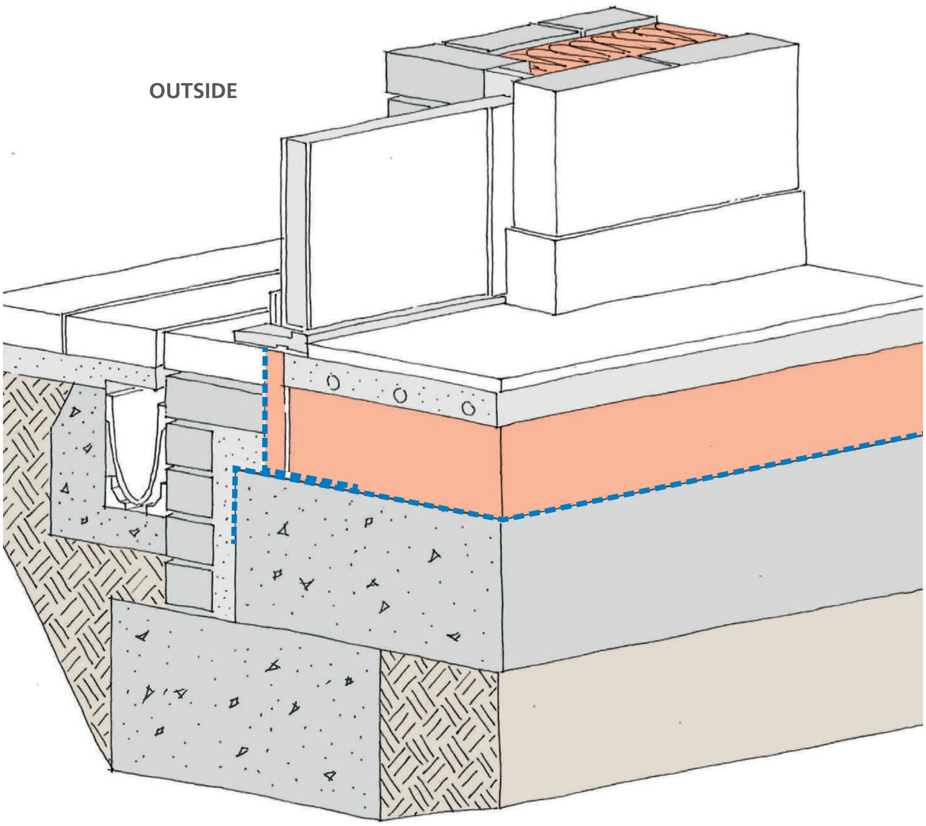


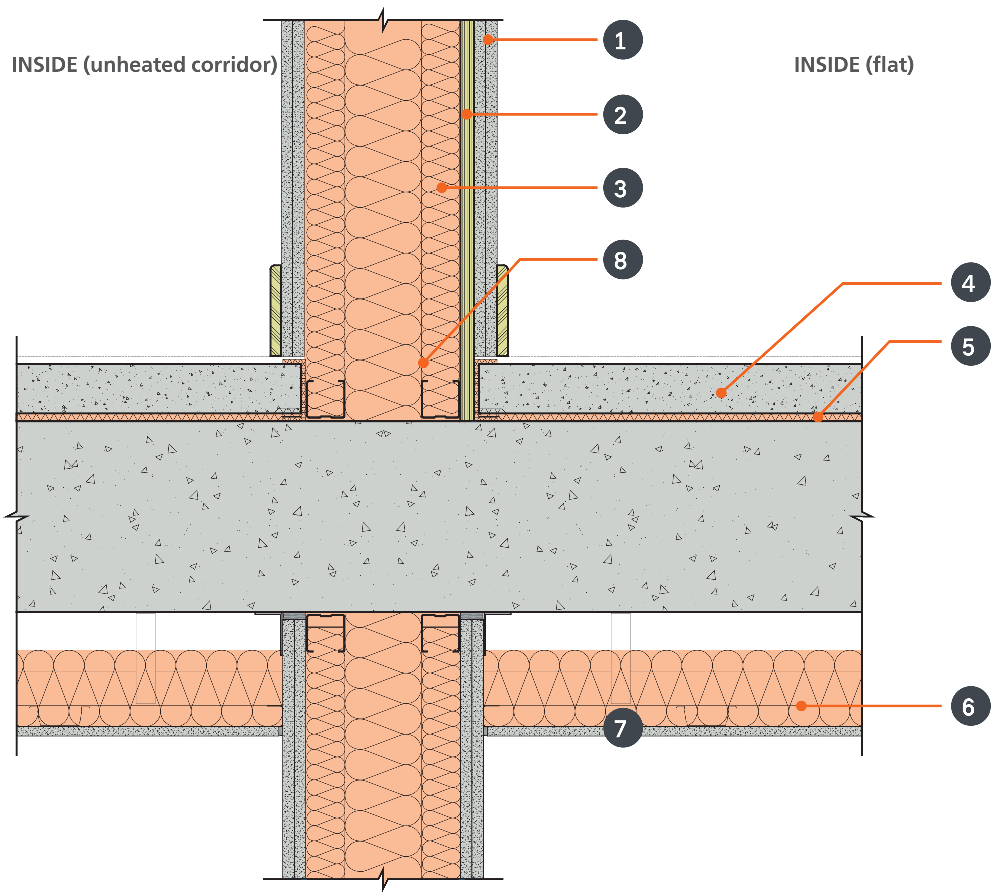
Figure 4.14
3D illustration of level threshold for external door demonstrating the importance of positioning the thermal break in line with the door frame and cavity wall insulation to the side.

Figure 4.15
Door threshold before doorset is fitted (left).

Figure 4.16
Complete door installation and finishes (right).

Detail 4.3 Separating Floor and Wall

This party wall detail has acoustic, fire and thermal performance requirements. Full fill insulation needs to be specified to prevent heat loss through to the corridor.



KEY

1. Two sheets of plasterboard
2. Ply for airtightness and security
3. Twin stud wall filled with mineral wool
4. Screed
5. 10 mm acoustic resilient layer
6. Mineral wool in ceiling zone
7. Acoustic ceiling hanging system
8. Steel stud on concrete with acoustic insulation and screed over to reduce thermal bridge

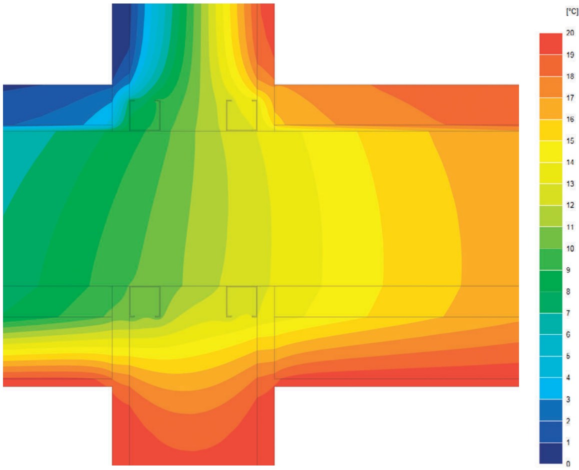


Figure 4.17
Heat flux through separating floor and wall corresponding to Detail 4.3 (opposite).

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through the party wall and separating floor. When the shelter factor is applied, the detail has a psi-value of 0.181 W/m.K, which is a 24% reduction in heat loss compared to the default value of 0.24 W/m.K. The temperature factor is above the critical value of 0.75 so there is no risk of condensation or mould growth.

SAP Appendix K Reference	E24
psi-value	0.181 W/m.K
temperature factor	f_{Rsi} = 0.84
approved value	N/A
default value	0.24 W/m.K

Shelter factor is applied with one corridor and three dwellings.

Total heat loss from junction is 0.542 W/m.K, but a psi-value of 0.181 W/m.K should be applied to each flat.

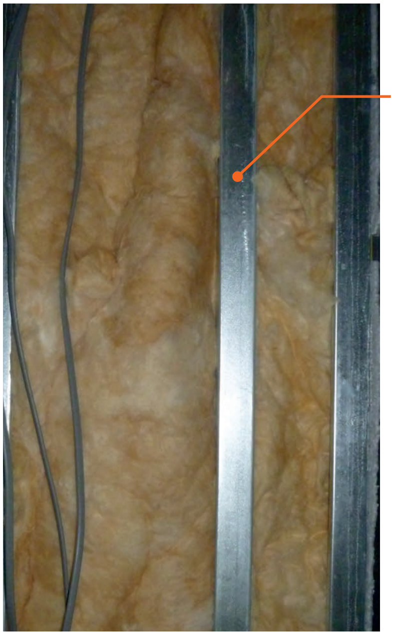
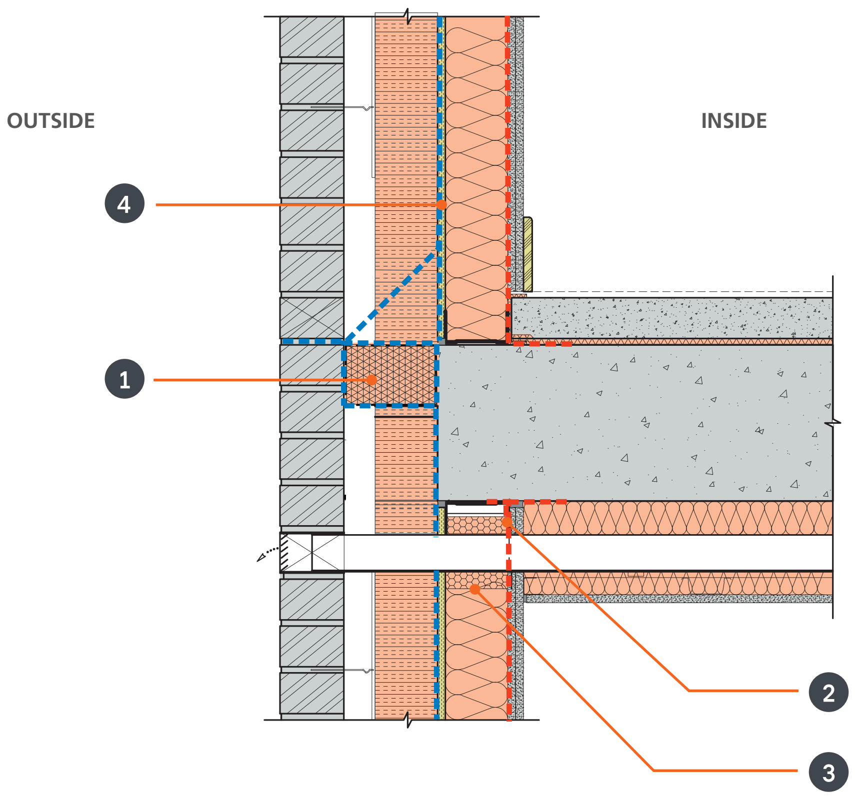


Figure 4.18
Lightweight steel stud party wall must be fully filled with mineral wool.

Figure 4.19
Concrete soffit with suspended ceiling zone for services and layer of mineral wool. A deeper ceiling zone with space for circular duct will improve performance of ventilation system.

Detail 4.4 Separating Floor and External Walls

Ensure the fire barrier, cavity tray and brick supports and co-ordinated with the thermal insulation. Brick shelves should be thermally broken and calculated in the psi value. The cement particle board can alternatively be taken over the concrete and taped airtight.



KEY

1. Fire-rated cavity break (insulation stop sock with DPM, acting as cavity tray)
2. Airtight tape seals concrete to plasterboard
3. Ventilation duct insulated with fire rated sleeve and taped to airtight membrane
4. Breather membrane taped to provide airtight seal between floors

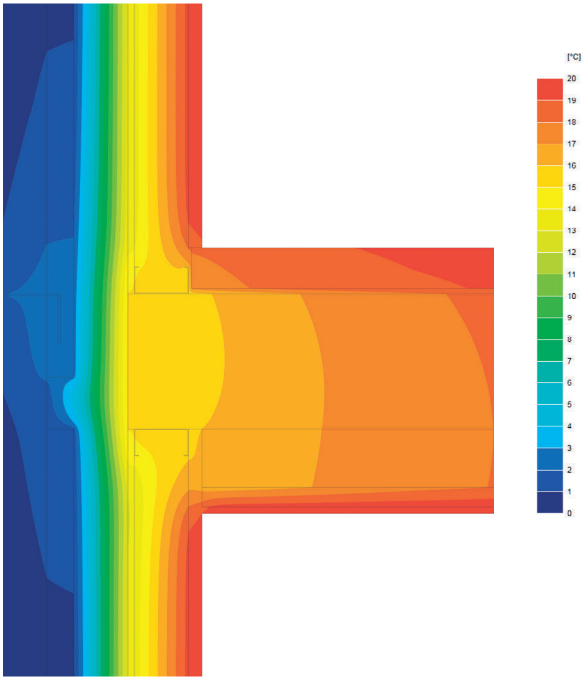


Figure 4.20
Heat flux diagram of separating external wall corresponding to Detail 4.4 (opposite).

SAP Appendix K Reference	E7
psi-value	0.046 W/m.K
temperature factor	$f_{Rsi} = 0.87$
approved value	0.07 W/m.K
default value	0.14 W/m.K

Heat flux diagram and psi-value

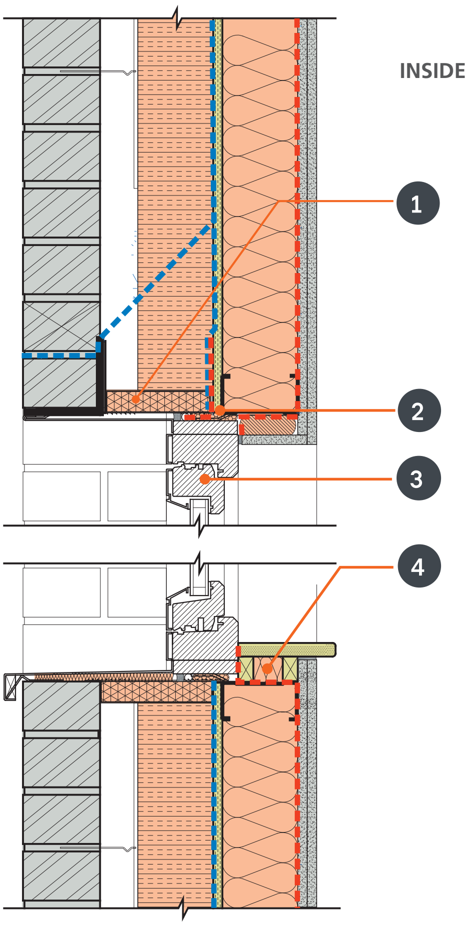
This heat flux diagram shows heat flow through the external wall at intermediate floor level. The detail does not account for brick angles which increase the heat loss. It has a psi-value of 0.046 W/m.K, which is a 67% reduction in heat loss compared to the default value of 0.14 W/m.K. The temperature factor is above the critical value of 0.75 so there is no risk of condensation or mould growth. The psi calculation assumes there is no brick support bracket at floor level. With a steel brick bracket, the psi-value increases to 0.213 W/m.K. The total heat loss is 0.092 W/m.K. As there is a flat either side of the party floor, a shelter factor of 0.5 has been applied.

Figure 4.21
External wall with brick tile cladding above full brick with insulation and cill over cavity tray (left).

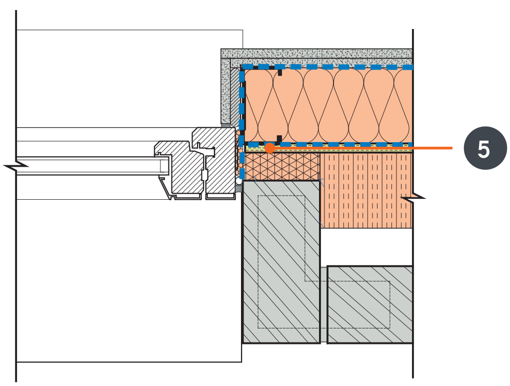
Figure 4.22
Continuous insulation at junctions and up to windows and doors (right).

Detail 4.5 Windows

For improved performance and build-ability, specify a full width cavity closer with half brick reveal instead of a full brick reveal. Consider installing extra insulation on the internal or external reveals for improved psi value.



Section detail



Plan detail

KEY

1. Fire rated cavity closer with insulation conductivity of 0.022 W/mK
2. EPDM sealing window to structure
3. Window positioned in line with insulation layer, with maximum tolerance gap of 10 mm
4. Insulation around window reveal, cill and lintel
5. Check airtight seal and fully insulated cavity closer at reveal

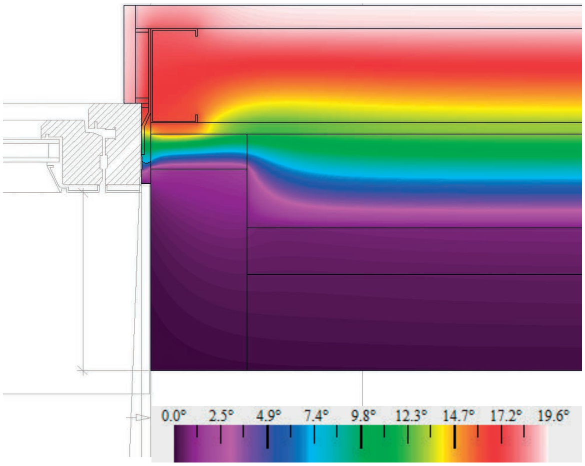


Figure 4.23
Heat flux diagram corresponding to Detail 4.5 window jamb (opposite).

Heat flux diagram and psi-value

There are three psi-values to be calculated for a window: the jamb, cill and lintel. This heat flux diagram shows heat flow through the window jamb (plan detail). This junction has a psi-value of 0.051 W/m.K, which is a 49% improvement compared to the default value of 0.1 W/m.K. The lintel psi-value is 0.038 W/m.K which is a 96% reduction in heat loss compared to the default value of 1 W/m.K.

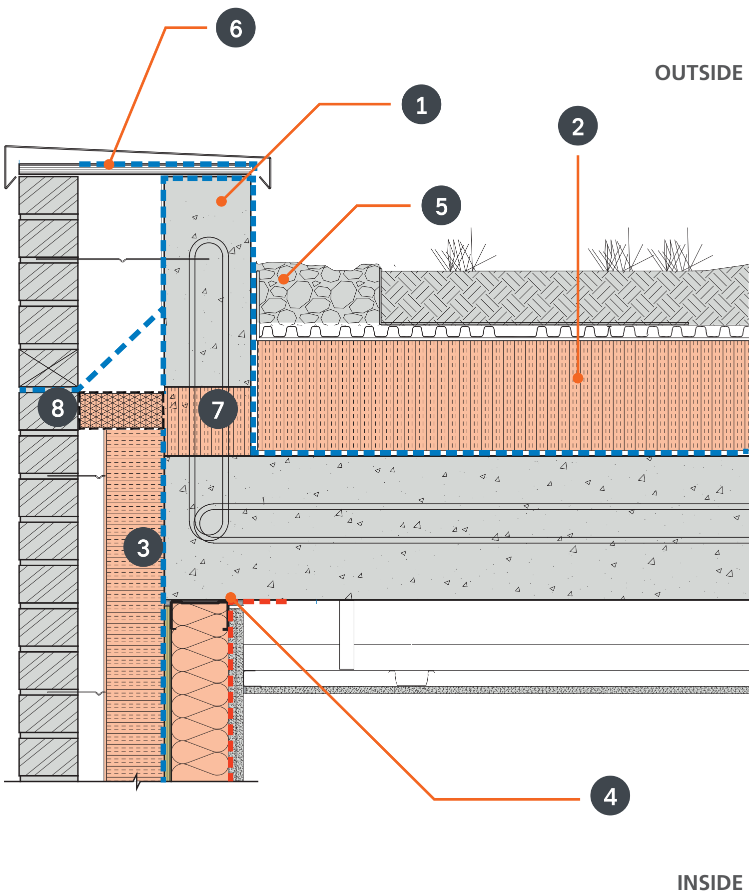
SAP Appendix K Reference	E4 Jamb	E3 Sill	E2 Lintel
psi-value	0.051 W/m.K	0.039 W/m.K	0.038 W/m.K
temperature factor	$f_{Rsi} = 0.95$	$f_{Rsi} = 0.95$	$f_{Rsi} = 0.95$
approved value	0.05 W/m.K	0.04 W/m.K	0.3 W/m.K
default value	0.1 W/m.K	0.08 W/m.K	1 W/m.K

Figure 4.24
Aluminium cill with full brick reveal (left).

Figure 4.25
Window set back to be in line with insulation layer (right).

Detail 4.6 Roof Parapet

The roof parapet can be a significant thermal bridge if it is not thermally broken as shown below. A common alternative is to wrap the concrete upstand with insulation, which increases material, cost and heat loss.



KEY

1. Concrete upstand
2. Extensive green roof with inverted warm concrete roof
3. Airtight membrane taped over concrete and sheathing board
4. VCL sealed to underside of concrete
5. 100 mm wide pebble perimeter
6. DPM lapped over 18 mm ply
7. Insulation block as thermal break
8. Fire rated cavity barrier

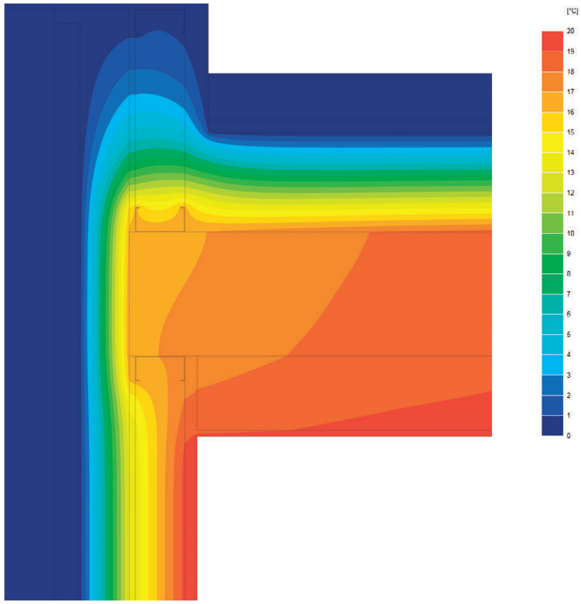


Figure 4.26
Heat flux diagram corresponding to Detail 4.6 (opposite).

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through the roof parapet. A thermal break has been specified to reduce heat flow through the concrete parapet and to remove the need for insulation wrapping the parapet.

This psi-value is 0.075 W/m.K, which is an 87% reduction in heat loss compared to the default value of 0.56 W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth.

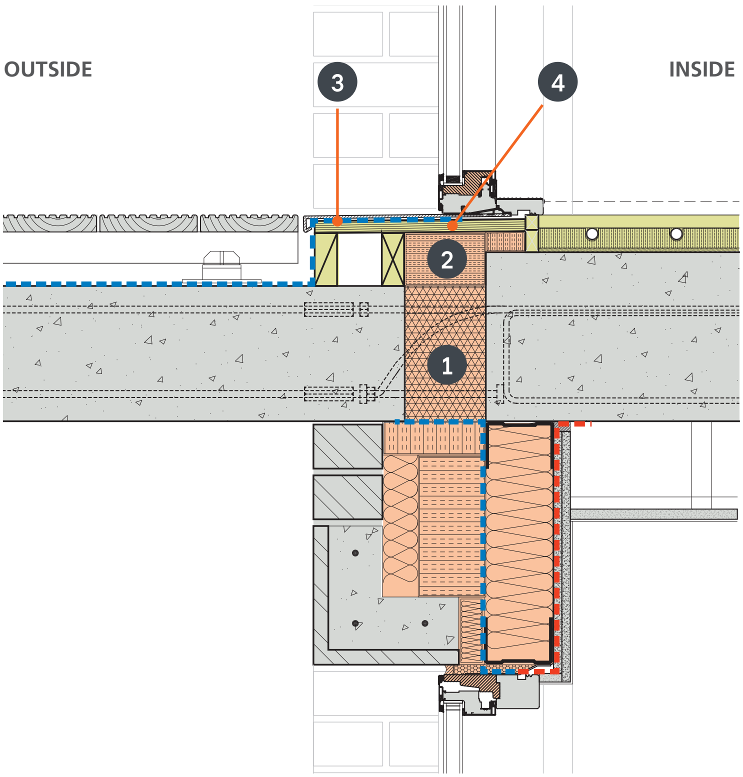
SAP Appendix K Reference	E15
psi-value	0.075 W/m.K
temperature factor	f_{Rsi} = 0.94
approved value	N/A
default value	0.56 W/m.K

Figure 4.27
DPC on plywood before parapet coping is installed (left).

Figure 4.28 a & b
Parapet thermal break installed (right).

Detail 4.7 Cantilevered Balcony

Cantilevered balconies must be thermally broken to reduce thermal bridging. For improved performance, specify independently supported balconies.



KEY

1. 80 mm or 120 mm thick insulation as strucutural thermal break
2. Rigid insulation to threshold
3. Steel plate forming robust threshold
4. EPDM membrane lapped under threshold and bonded to form watertight and airtight seal

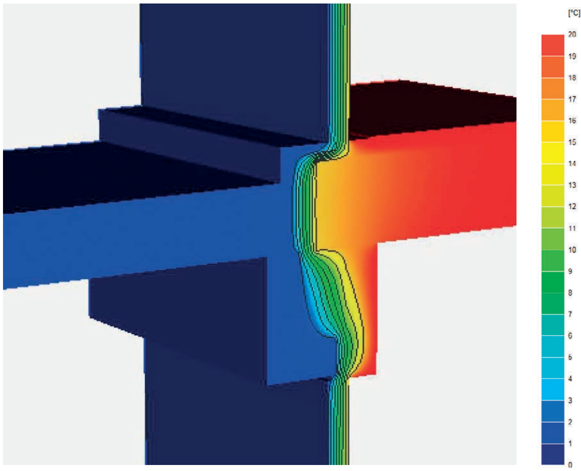


Figure 4.29
Heat flux diagram corresponding to Detail 4.7 (opposite).

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through the concrete balcony. A thermal break reduces heat flow through the concrete cantilevered balcony. This psi-value is 0.326 W/m.K, which is a 67% reduction in heat loss compared to the default value of 1 W/m.K. The psi-value based on 3D calculation of 80 mm concrete to concrete thermal break.

SAP Appendix K Reference	E23
psi-value	0.326 W/m.K
temperature factor	f_{Rsi} = 0.79
approved value	N/A
default value	1.00 W/m.K

Figure 4.30
Thermal break being installed to separate cantilevered balcony.

Chapter 5: Timber frame construction

Chapter 5:
Timber frame construction

5

Timber frame is the second most popular construction method for homes in England and Wales, with 15% of UK housing output. It is the most popular in Scotland with 75% of market share.[6] There are different types but they all use a timber frame as structural support, timber sheathing and insulation between or outside timber studs. Timber frame is best suited to low-rise development of one to four storeys, but solid timber panels and engineered timber can be used to build apartments up to 10 storeys. A vapour barrier is required to prevent moisture entering the wall structure from the inside. A breather membrane is required to protect against external moisture and an outer leaf of cladding protects from weather and solar radiation.

The timber frame is usually manufactured off-site to different levels of completion – either as an open or closed panel. The panels are taken to site and erected by the supplier or sub-contractor. Some contractors and sites will favour 'stick construction' over prefabricated panels, but off-site manufacture of panels or modules can enable better performance.

There are a wide range of types of timber frame, with different types of insulation, moisture barrier, airtightness and erection methods.

The typical methods are shown in Figure 5.1, below.

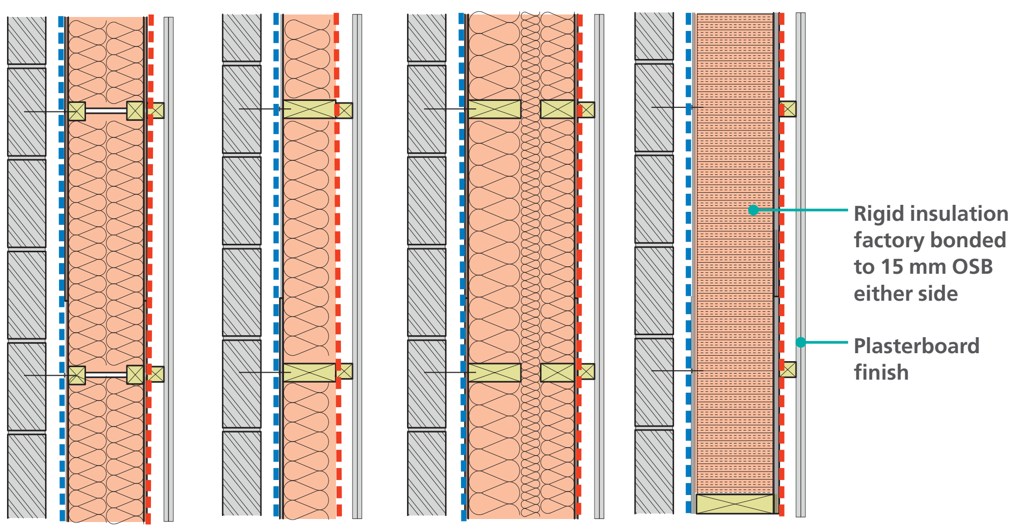


Figure 5.1
Different types of timber frame construction.

Summary

Advantages

- Fast speed of construction, typically 20–30% quicker than masonry.
- Ability to easily monitor insulation and airtightness membranes.
- Flexible aesthetics with different external claddings possible.
- Good airtightness achievable with membrane or ply board.
- Good thermal performance as timber has lower conductivity than masonry.
- Timber is a renewable material and can be reused following demolition.

Disadvantages

- Thermal performance and timber fraction is often estimated at design stage and timber and steel content is often higher in reality.
- Lightweight construction means it is hard to integrate exposed thermal mass, so it is vulnerable to overheating.
- Timber easily absorbs water and deforms, so must be kept dry during construction.
- Differential movement between timber and masonry / windows can lead to poor construction accuracy.

Recommendations

- Consider prefabricated panels that minimise site work.
- Timber frame must be at least 150 mm above ground level (NHBC).
- Select insulation that will not allow air gaps.
- Design so timber does not bridge the whole of the insulation zone.
- Specify steel web floors to allow service zone.
- Consider I-beam or twin stud wall to minimise thermal bridging of solid timber.

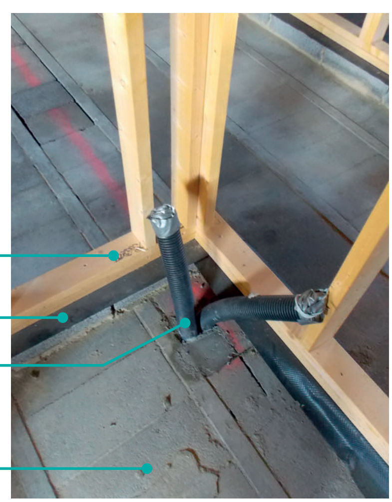


Figure 5.2 Steel web timber joist floor creates service zone (left).

Figure 5.3 Masonry floor and upstand commonly used in timber frame construction (right).

Common Problems

- » Timber and steel content of construction is often not known at design stage, so thermal performance is often worse.
- » Without a service zone, the VCL is vulnerable to damage, causing poor airtightness and condensation issues.
- » Rigid insulation in between timber studs is difficult to fit accurately without gaps.

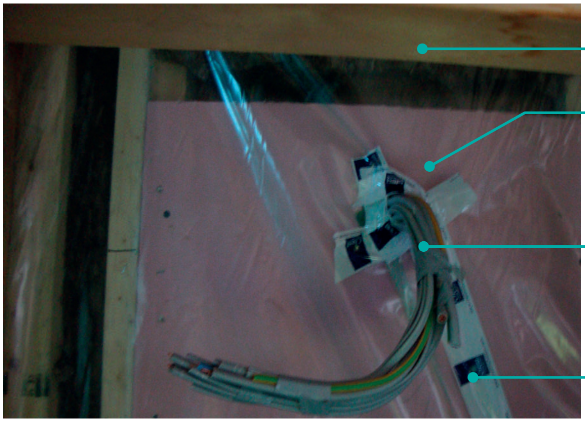


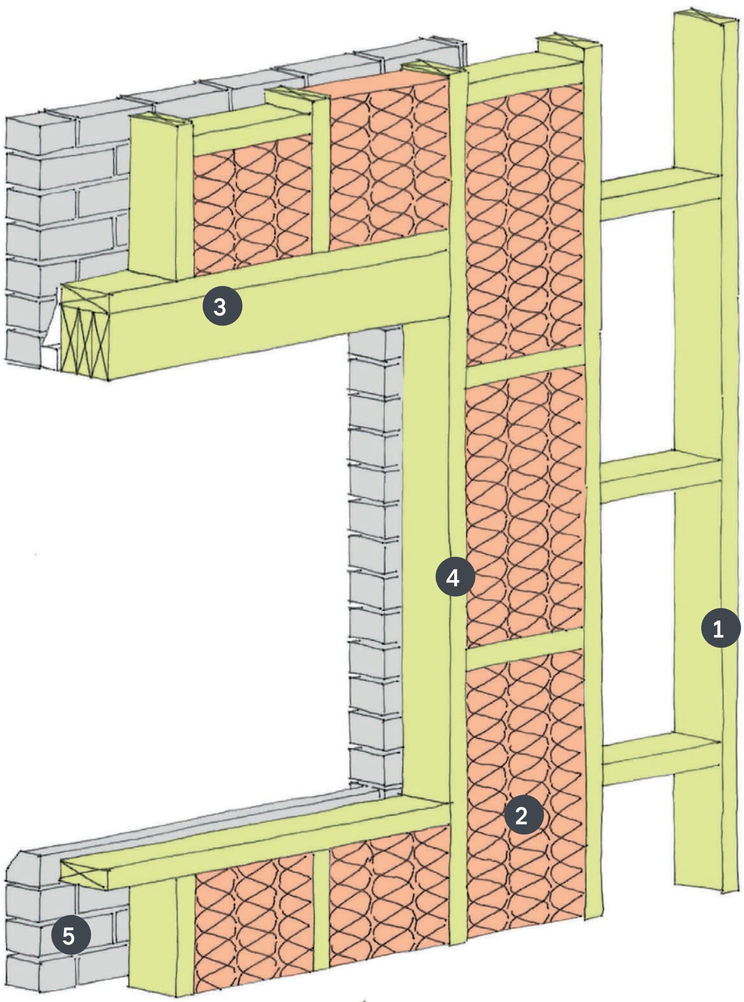
Figure 5.4 Excessive timber and steel content compromises thermal performance.

Figure 5.5 VCL is penetrated by incoming services.

Figure 5.6 Rigid insulation in between timber studs is difficult to fit accurately without gaps.

Good Practice

Timber is approximately five times more conductive than insulation, so more timber results in poor thermal performance. Figure 5.7 demonstrates how an extra layer of insulation should be installed inside or outside the frame to minimise thermal bridging.



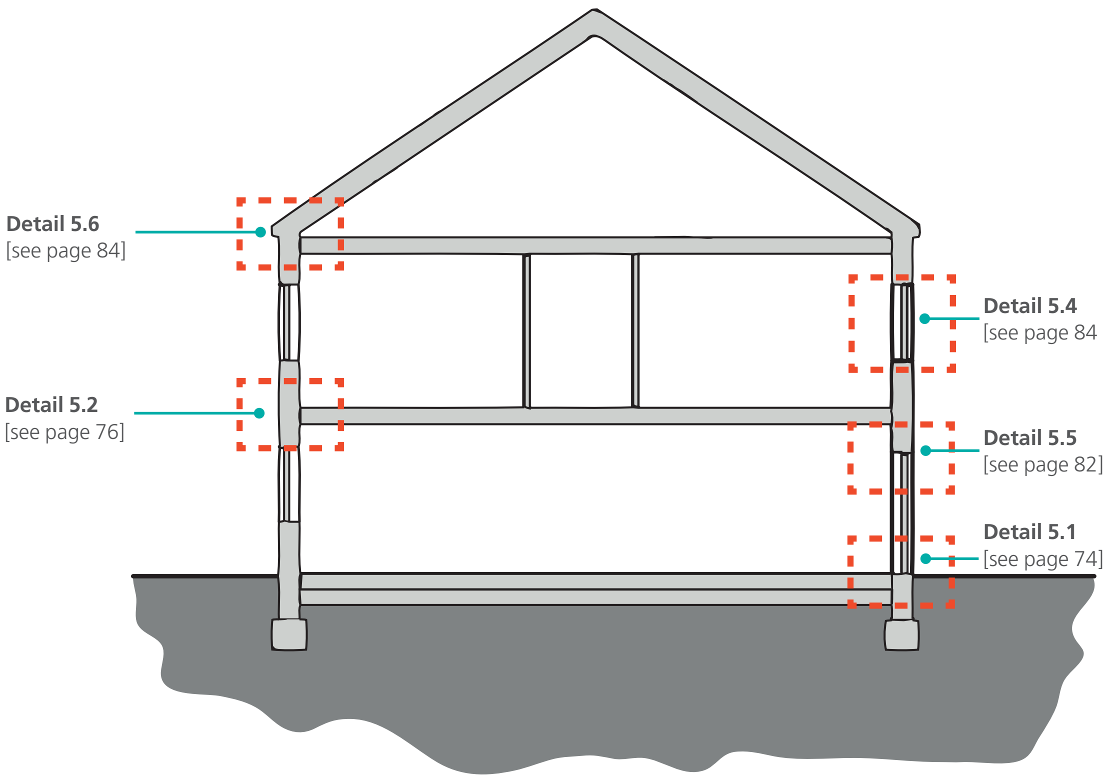
KEY

1. Timber frame = 0.13 W/m.K
2. Insulation fitted accurately between studs with no gaps = 0.030 to 0.045 W/m.K
3. Minimise amount of timber around openings, consider extra insulation inside or outside timber
4. Airtightness is either a taped membrane or sheathing board (airtight OSB or ply)
5. Wall ties can be stainless steel as they do not penetrate the insulation layer

Figure 5.7
3d drawing showing typical timber frame construction and the need to install extra insulation layer in order to minimise thermal bridging.

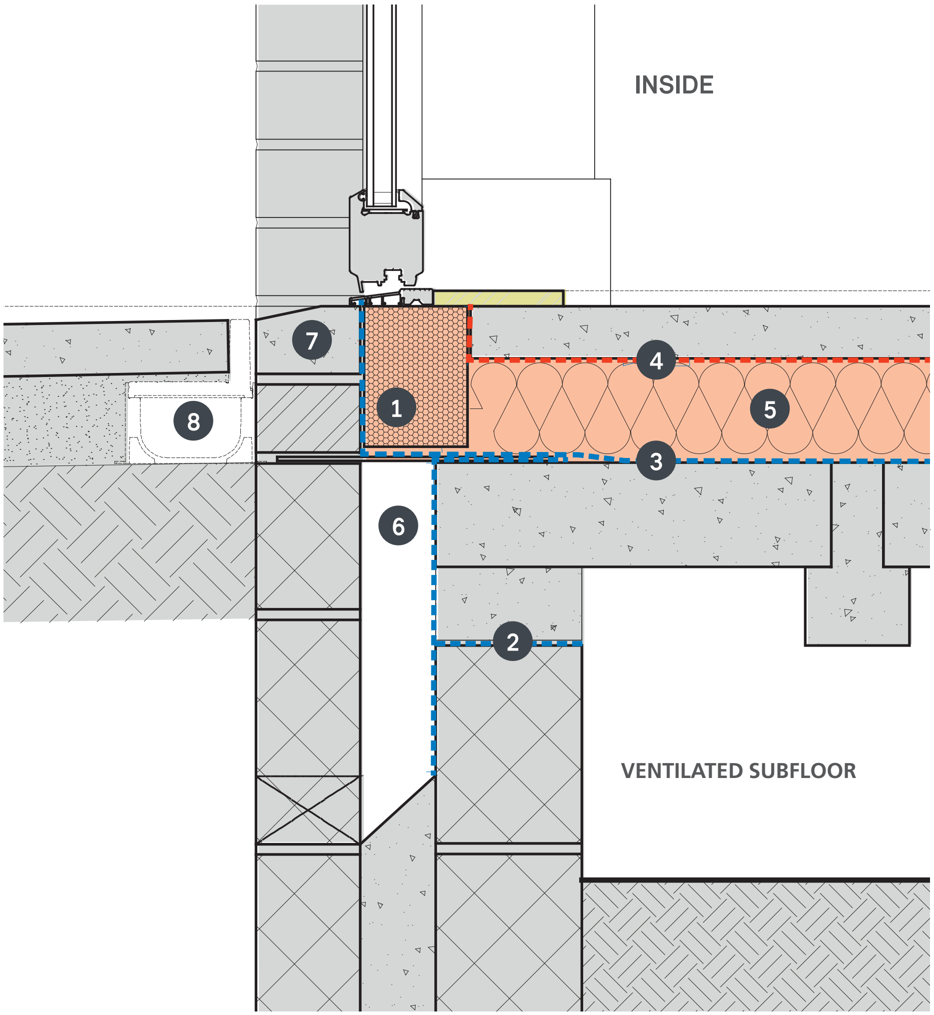
Details

The rest of this chapter highlights good practice detailing for timber frame with emphasis on thermal performance. The location of these junctions are shown in this section drawing through a typical house. The most significant external envelope details affecting heat demand are drawn with good practice airtightness and continuous insulation where practical. Heat loss is calculated and psi-values provided where useful for SAP calculations.



Detail 5.1 Level Threshold

The door must line up with the insulation underneath and timber frame insulation in the adjoining wall. The screed acts as the airtightness in the floor which is taped to the door frame.



KEY

1. 140 x 100 mm structural insulation
2. DPC
3. 1200 gauge polythene DPM
4. Separating layer
5. 150 mm floor insulation
6. Heavy-duty wall ties at threshold
7. Pre-cast concrete cill
8. Slot drain

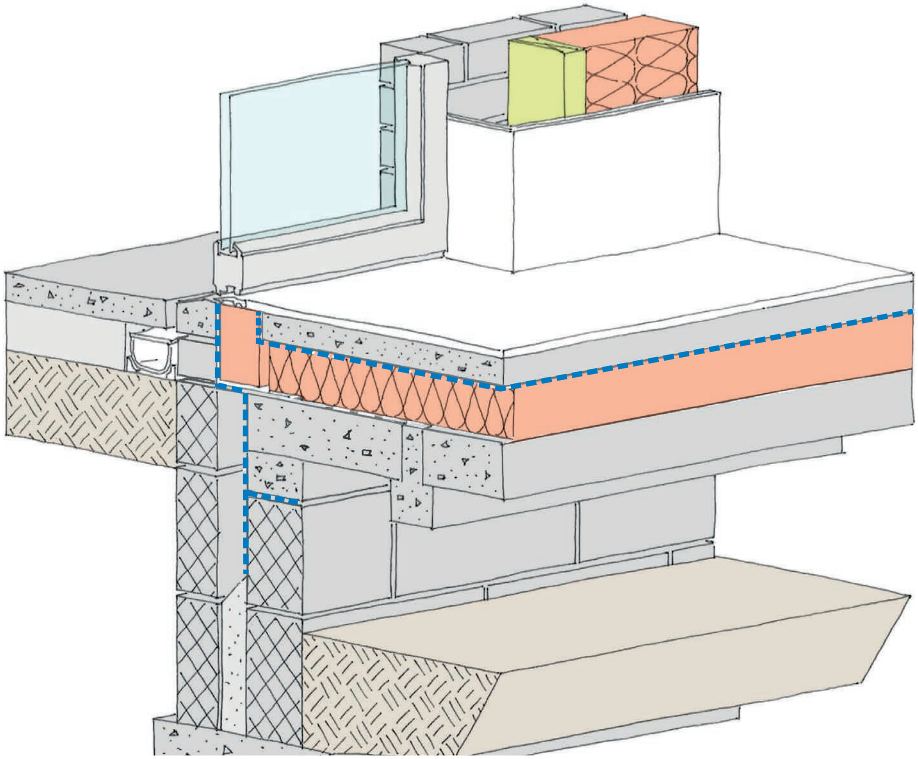


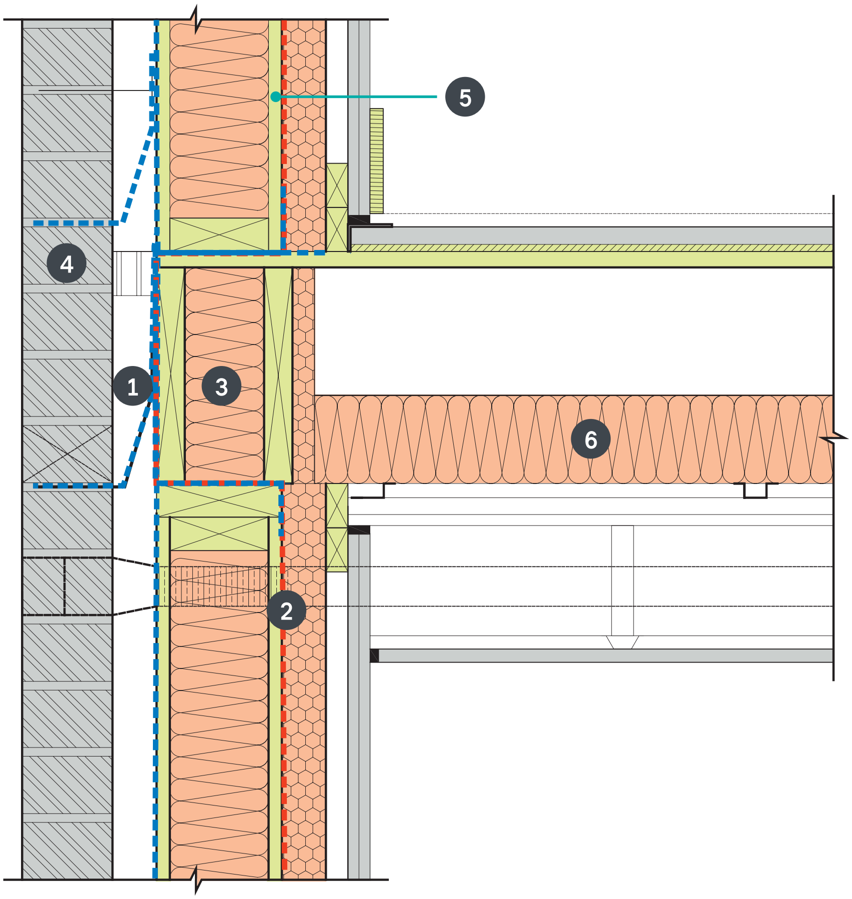
Figure 5.8
3D illustration of level threshold showing structural insulation (e.g. Foamglas) under door frame.

Figure 5.9
Door frame and lintel (left).

Figure 5.10
Door level threshold (right).

Detail 5.2 Intermediate Floor

Ensure the ends of floor joists are fully insulated and airtight with the correct sequencing. Thermal bridging can be reduced by adding an extra layer of insulation to the outside of the timber frame.



KEY

1. Airtight breather membrane to wrap around floor and lapped over cavity tray
2. Airtight grommet taped around ventilation duct (fire rated sleeve)
3. End of floor joists fully filled with insulation
4. Fire-rated cavity barrier
5. VCL lap with airtight breather membrane
6. Acoustic insulation

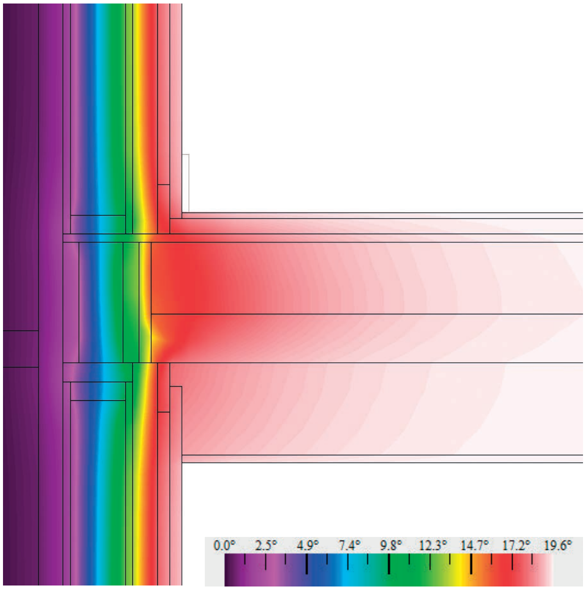


Figure 5.11
Heat flux diagram corresponding to Detail 5.2 (opposite).

SAP Appendix K Reference	E7
psi-value	0.067 W/m.K
temperature factor	f_{Rsi} = 0.94
approved value	0.07 W/m.K
default value	0.14 W/m.K

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through the external wall at intermediate floor level (see Detail 5.2). This is normally an area of significant heat loss, and so the design must allow for insulation in the floor cassette or externally to prevent thermal bridging. This detail has a psi-value of 0.067 W/m.K, which is a 52% reduction in heat loss compared to the default value of 0.14 W/m.K.

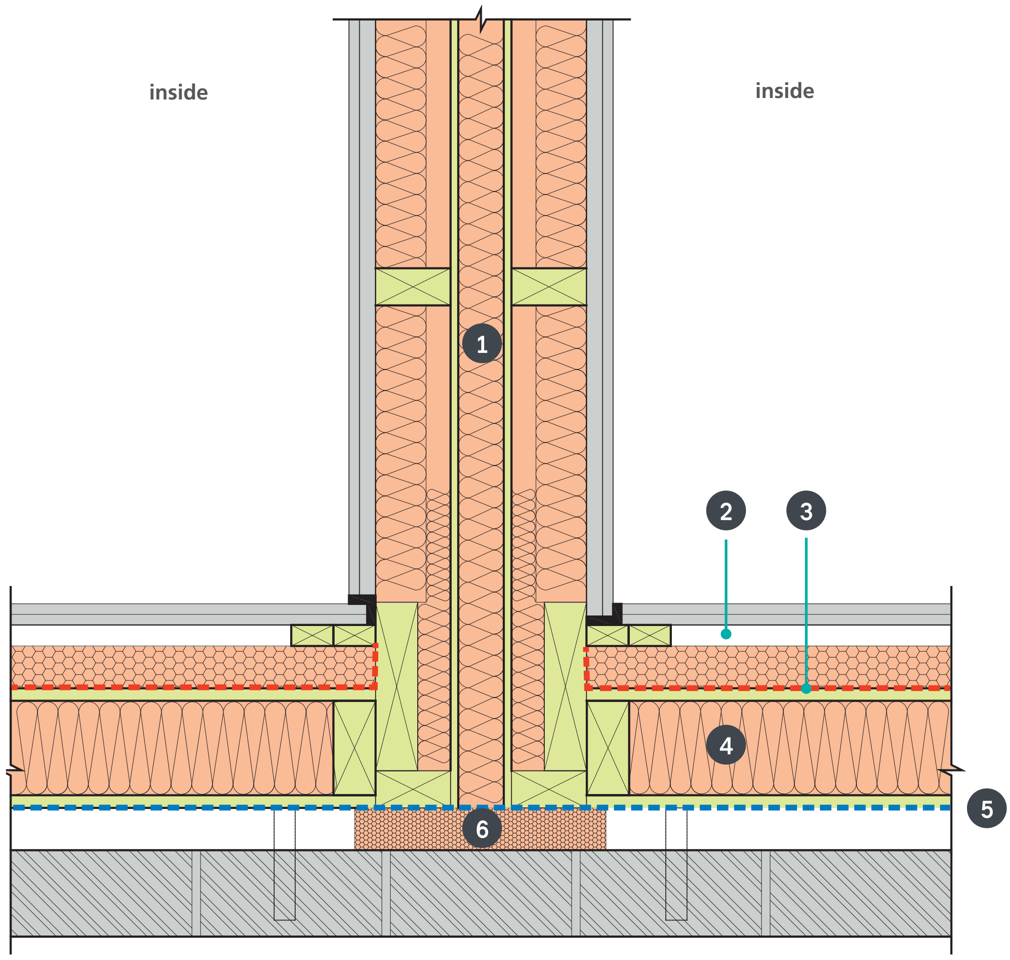
The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth. Please refer to Appendix 3 for further information.

Figure 5.12
Intermediate floor timber cassette (left).

Figure 5.13
Internal view of intermediate floor - I joists (right).

Detail 5.3 Party Wall

Thermal and acoustic performance must be considered in a party wall, so non rigid insulation is preferable. An additional service zone could be added to improve airtightness which improves both acoustic and thermal performance.



KEY

1. Twin timber stud wall fully filled with insulation
2. Service zone
3. VCL
4. SIP
5. Breather membrane (airtight layer)
6. 60 minute fire barrier

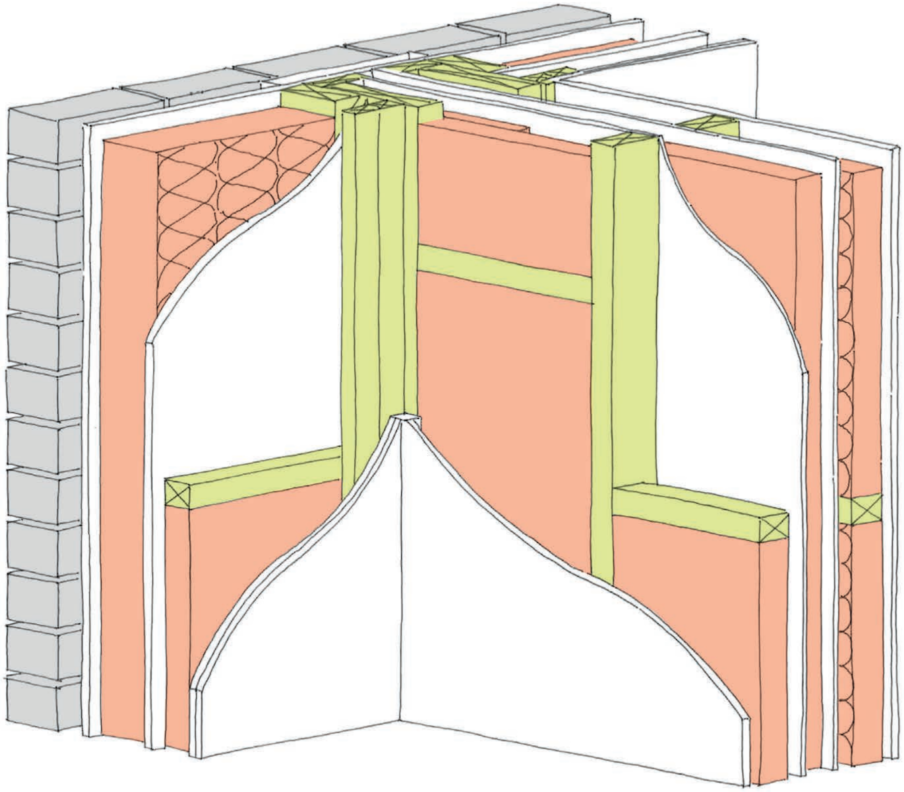


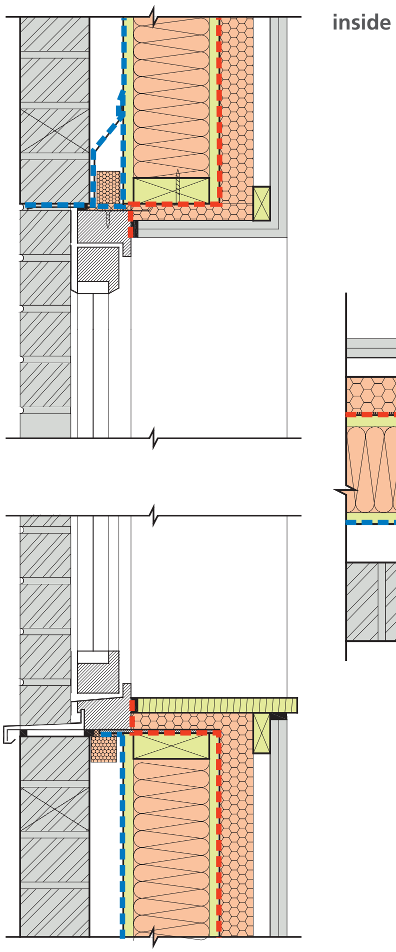
Figure 5.14
3D illustration of the external wall and party wall junction showing the importance of specifying full fill insulation for thermal and acoustic performance.

Figure 5.15
Party wall construction (left).

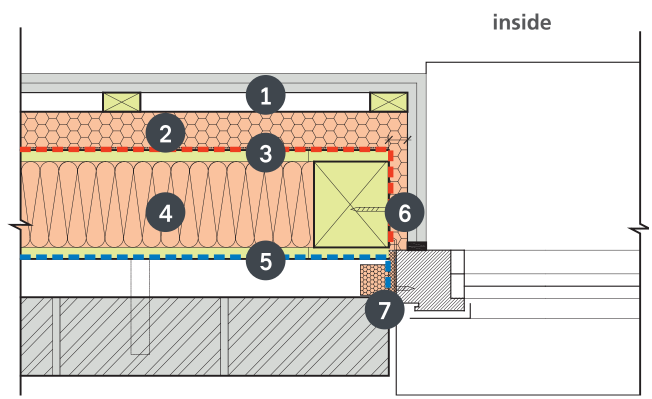
Figure 5.16
Airtightness tape sealing junctions (right).

Detail 5.4 Window Detail

There are three psi-values that should be calculated for a window: the jamb, cill and lintel. There are significant reductions in heat loss when the psi-value is calculated for each detail. Insulating the window reveal results in a significant improvement in the thermal performance. Moving the window in line with the SIP panel will further improve thermal performance.



section detail



plan detail

KEY

1. Service zone
2. Rigid insulation
3. VCL
4. SIP
5. Breather membrane
6. Insulation to reveal, cill and lintel
7. Fully insulated cavity closer

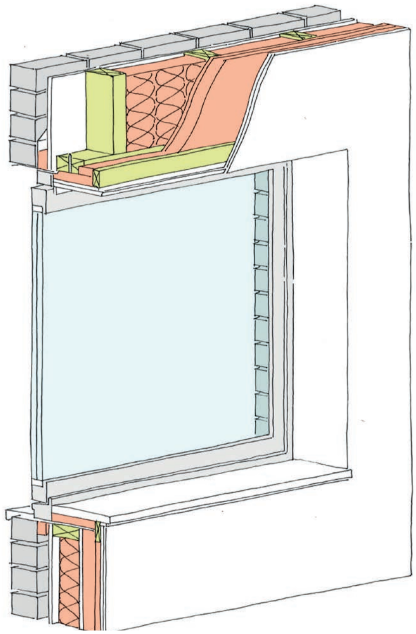


Figure 5.17
3D illustration of the window installation.

Psi-value

The three psi-values that account for the performance of the window junctions in this case are significantly better than the default value.

SAP Appendix K Reference	E2 Lintel	E3 Sill	E4 Jamb
psi-value	0.069 W/m.K	0.028 W/m.K	0.067 W/m.K
temperature factor	$f_{Rsi} = 0.92$	$f_{Rsi} = 0.92$	$f_{Rsi} = 0.91$
approved value	0.3 W/m.K	0.04 W/m.K	0.05 W/m.K
default value	1.0 W/m.K	0.08 W/m.K	0.1 W/m.K

Figure 5.18
SIP window opening from outside (top left).

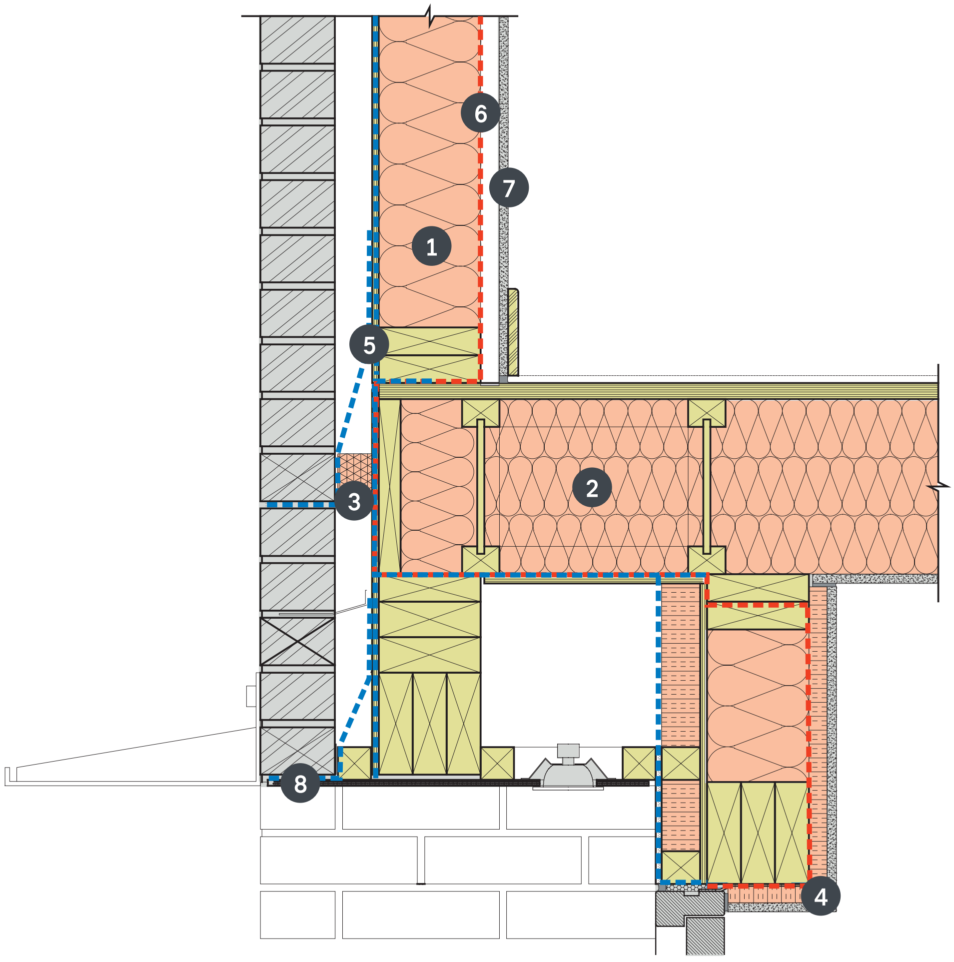
Figure 5.19
EPDM seal adhered to red breather membrane (top right).

Figure 5.20
Complete window from outside (bottom left).

Figure 5.21
Window opening from inside (bottom right).

Detail 5.5 Recessed Door

Canopies over doors often require additional structural steel which needs to be properly insulated or thermally separate from the thermal envelope. Recessed doors are a point of increased heat loss area and are difficult to insulate. Ensure adequate insulation and sequencing is agreed to achieve performance.



KEY

1. 140 mm timber stud wall fully filled with insulation
2. Full fill floor joists above recessed entrance
3. 60 minute fire-rated cavity closer
4. Rigid insulation around top of door
5. Breather membrane lapped over cavity tray and wrapped around floor
6. Service zone
7. 500 gauge polythene sheet as VCL lapped over airtight breather membrane that is wrapped around floor
8. Steel lintel support for brickwork

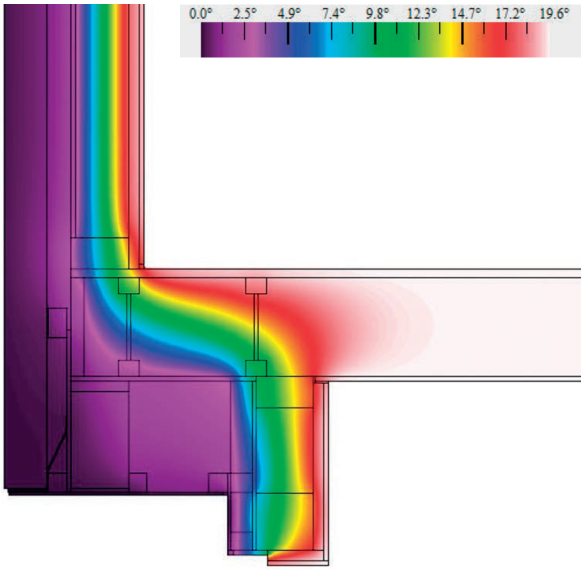


Figure 5.22
Heat flux diagram corresponding to Detail 5.5 (opposite).

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through a recessed external door junction. This is normally an area of significant heat loss and so the design must allow for insulation in the floor cassette to prevent thermal bridging. This detail has a psi-value of 0.071 W/m.K, which is a 78% reduction in heat loss compared to the default value of 0.32 W/m.K.

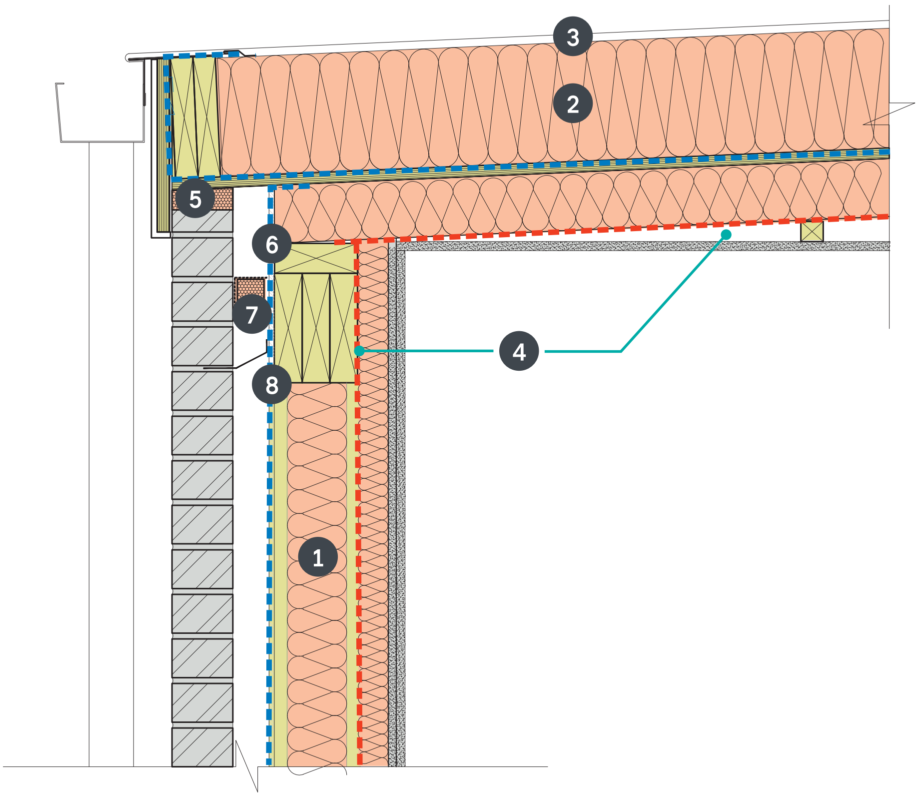
SAP Appendix K Reference	E20
psi-value	0.071 W/m.K
temperature factor	f_{Rsi} = 0.88
approved value	N/A
default value	0.32 W/m.K

Figure 5.23
Recessed entrance with double steel lintel (left).

Figure 5.24
Canopy installed above door with thermally separate structure (right).

Detail 5.6 Flat Roof

Continuous insulation around a timber frame is important to ensure no thermal bridging through the timber.



KEY

1. 140 mm timber stud wall fully filled with insulation
2. 200 mm rigid roof insulation
3. Single ply membrane
4. Intelligent VCL as airtight layer
5. Compressible insulation tape
6. Breather membrane
7. Fire rated cavity barrier with DPC
8. Differential movement gap to sheathing board

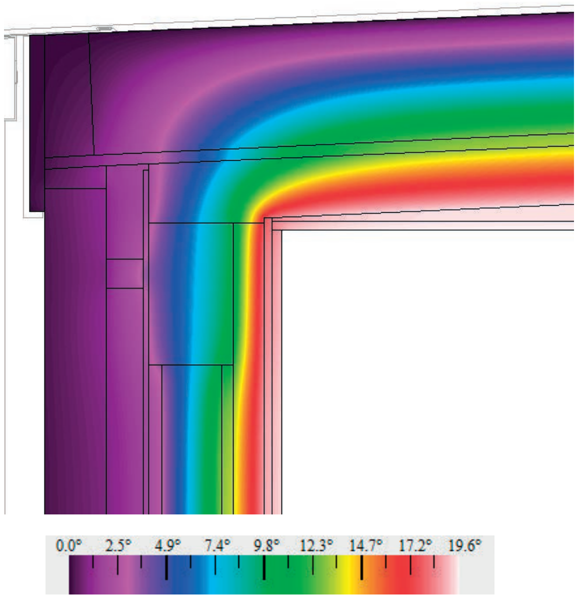


Figure 5.25
Heat flux diagram corresponding to Detail 5.6 (opposite).

Heat flux diagram and psi-value

This heat flux diagram shows heat flow through the flat roof and external wall junction. The top of the wall has a significant amount of timber for structural reasons, which increases the heat loss. The internal insulation has reduced the amount of heat loss to improve on the default. This detail has a psi-value of 0.062 W/m.K, which is 22% better than the default value of 0.08 W/m.K.

The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth.

SAP Appendix K Reference	E14
psi-value	0.062 W/m.K
temperature factor	f_{Rsi} = 0.95
approved value	N/A
default value	0.08 W/m.K

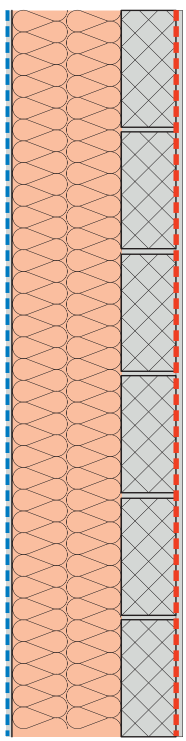
Figure 5.26
Layers of construction on timber flat roof.

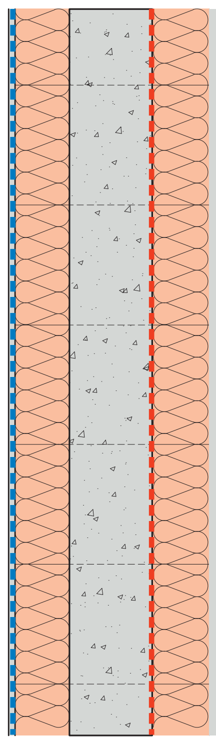
Chapter 6: Insulated concrete formwork

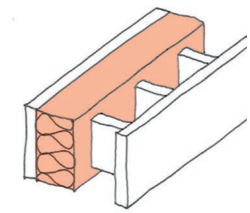
Chapter 6:
Insulated concrete formwork

6

Insulated concrete formwork (ICF) comprises interlocking hollow insulation blocks to make a formwork for in-situ reinforced concrete to be poured in the centre. It is quicker and easier than solid masonry construction and offers a good level of performance and design flexibility. It is popular in Europe and the USA with 8% of market share[7] and has been growing in the UK self-build market owing to its speed and ease of construction. Hollow lightweight blocks are made from different insulation types, commonly expanded polystyrene or wood fibre which interlock to create a permanent formwork for the concrete. Concrete is poured into the empty blocks every 3 metres high, and can be reinforced for multistorey developments. The concrete forms the airtight layer and continuous insulation is easy to achieve with simple detailing.







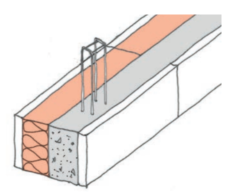


Figure 6.1
Solid masonry, externally insulated and rendered (left).

Figure 6.2
Insulated concrete formwork with render external finish (centre).

Figure 6.3
ICF block (top right).

Figure 6.4
Insulation blocks with concrete pour (bottom right).

Summary

Advantages

- Speed of construction.
- Simple system suitable for self-build.
- Excellent airtightness potential.
- Thermal mass potential with wood fibre blocks and plaster finish.
- Longevity and robustness of concrete.
- Can be EPS or wood fibre blocks.

Disadvantages

- High cost of material.
- Requires significant amounts of steelwork and concrete for structural reasons.
- Requires specialists advice/tools to expand/remodel the house in the future.

Recommendations

- Ensure concrete around steel reinforcements is fully vibrated to ensure full compaction.
- To ensure its longevity, PVC cable should be kept from direct contact with polystyrene by placing it inside plastic conduit in concrete.
- Engage with manufacturer early on.
- Do not pour high lifts as pressure of concrete can burst sides.
- Keep geometry simple and rectilinear where possible.

Figure 6.5
Pouring concrete into formwork (left).

Figure 6.6
Laying first course of blockwork onto steel reinforcement (right).

Common Problems

- » Concrete is airtight, but depends on quality and speed of pouring process.
- » Hollow areas in the concrete can reduce strength of wall, wind-tightness and airtightness.
- » Significant amounts of steel brackets cause thermal bridging at junctions.

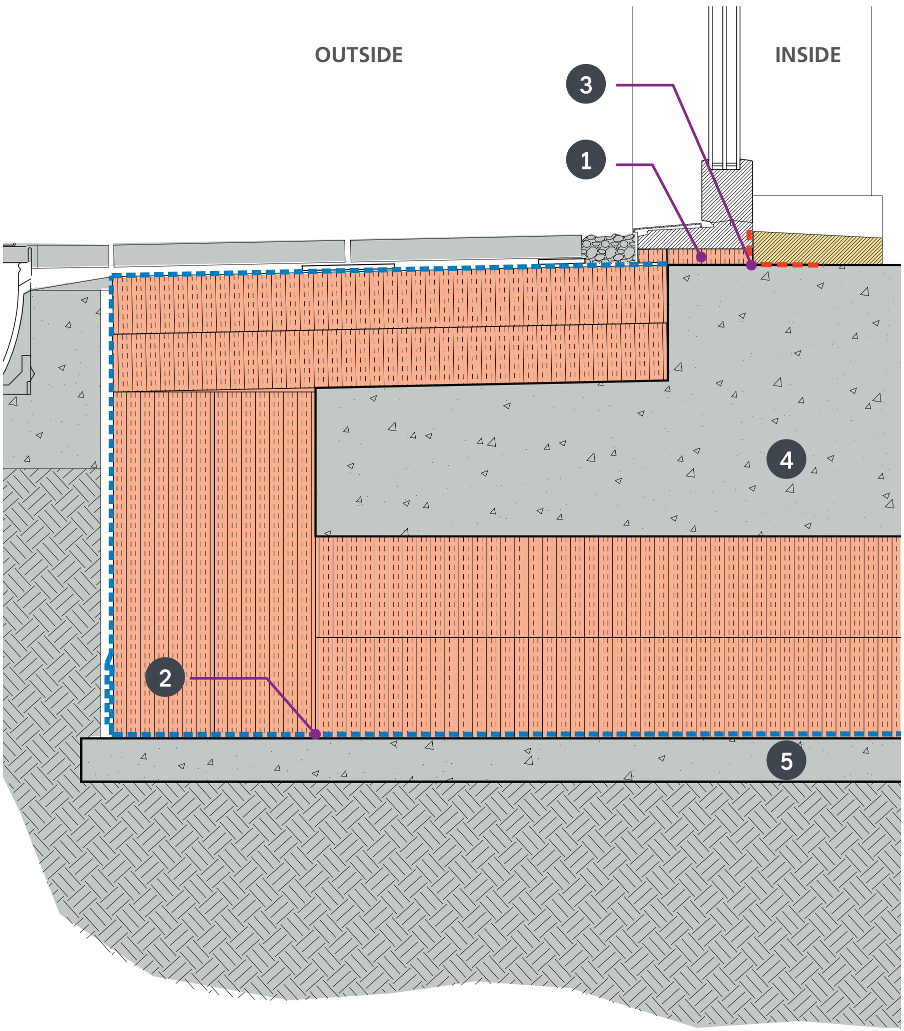
Figure 6.7
Lay blockwork to create formwork around steel reinforcement.

Figure 6.8
ISOSPAN ICF blocks for a house, waiting to be rendered white.

Detail 6.1 Level Threshold

This ground floor construction is good practice and should be specified when ground conditions allow.

The ground floor concrete raft is poured onto a rigid insulation formwork which allows continuous insulation and minimal thermal bridge at ground floor perimeter.



KEY

1. Door threshold on insulation packing blocks
2. Waterproof membrane airtight
3. Sealing tape between threshold and concrete slab
4. Concrete raft on 300 mm EPS insulation
5. Concrete blinding layer

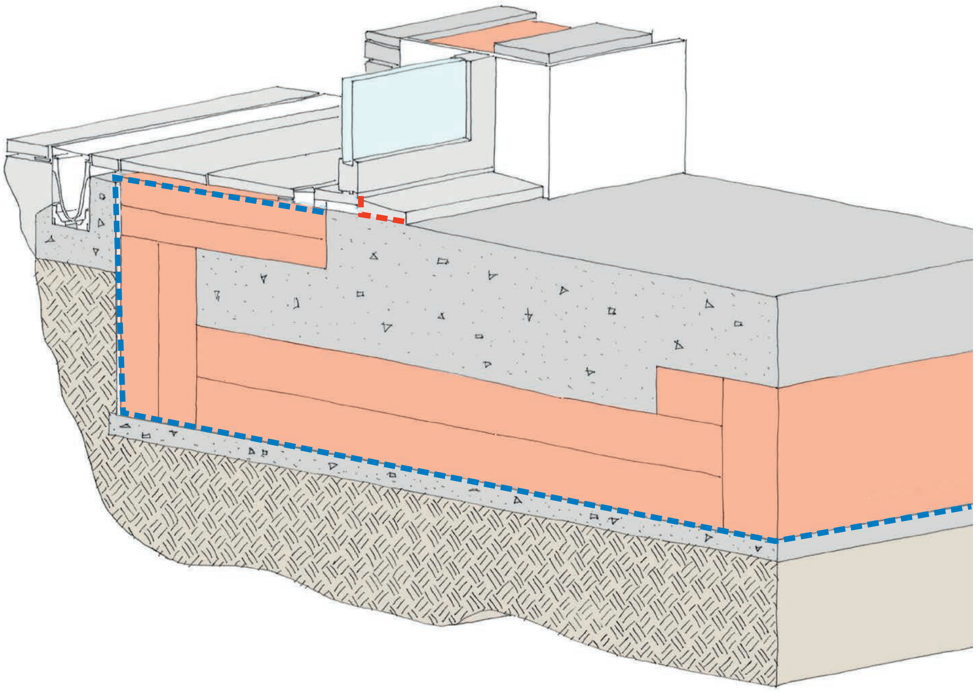


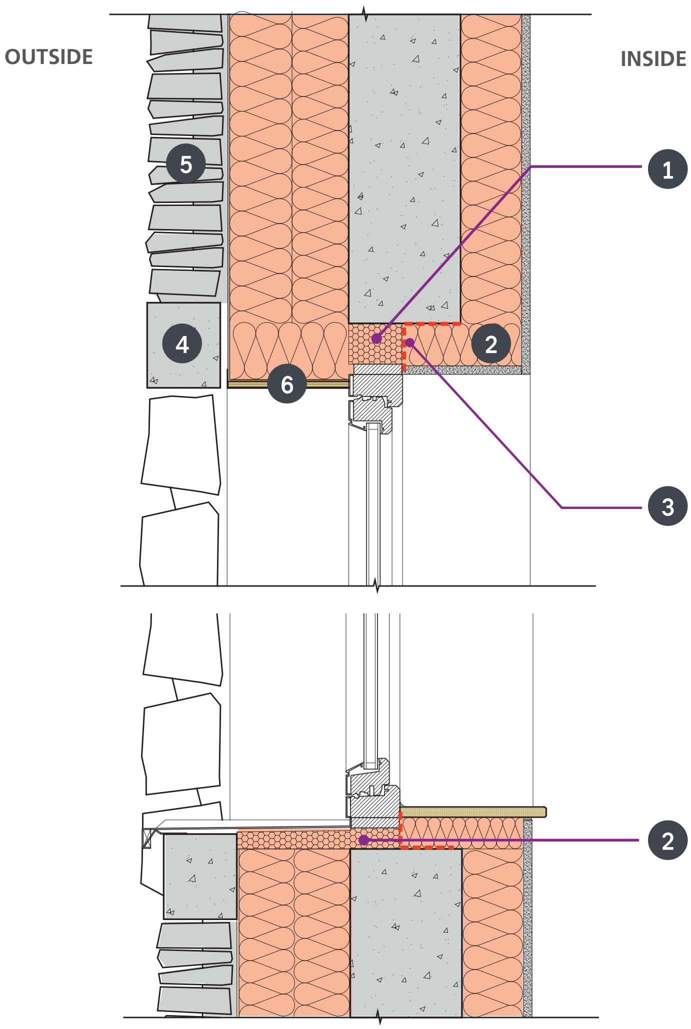
Figure 6.9
3D illustration of level threshold for external door demonstrating the importance of positioning the door in line with the insulation underneath and to the side.

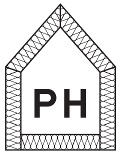
Figure 6.10
Level external door threshold (left).

Figure 6.11
Recessed door opening in external wall (right).

Detail 6.2 Window

The concrete is the airtightness barrier so the window frames should be taped to the concrete. Internal and external insulation to the reveals mean this detail performs 98% better than the normal default detail.





KEY

1. Rigid insulation block
2. EPS insulation reveal
3. Airtight tape sealed to concrete
4. Concrete lintel
5. Stone cladding
6. PPC aluminium reveal on ply backing on 100 mm EPS insulation

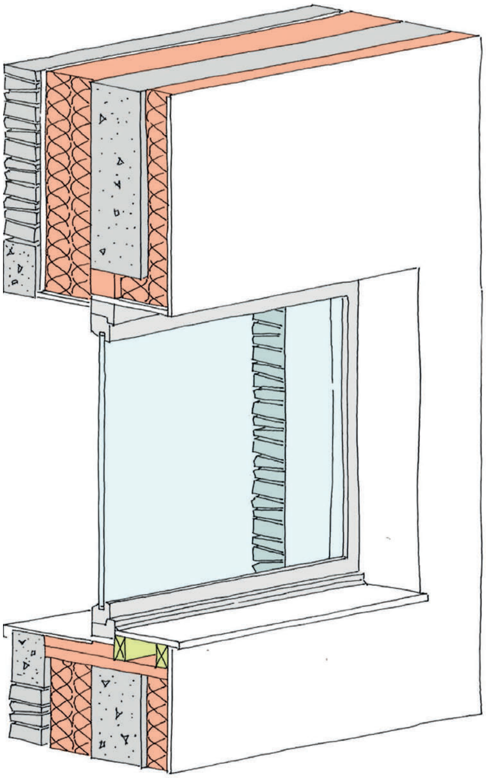


Figure 6.12
3D illustration of the window installation. The window should be taped to the concrete to provide a robust airtight layer.

Psi-value

There are three psi-values that should be calculated for a window but the window sill and lintel have the most significant reductions, e.g. this lintel detail has a psi-value of 0.013 W/m.K which is a 98% reduction from the default value.

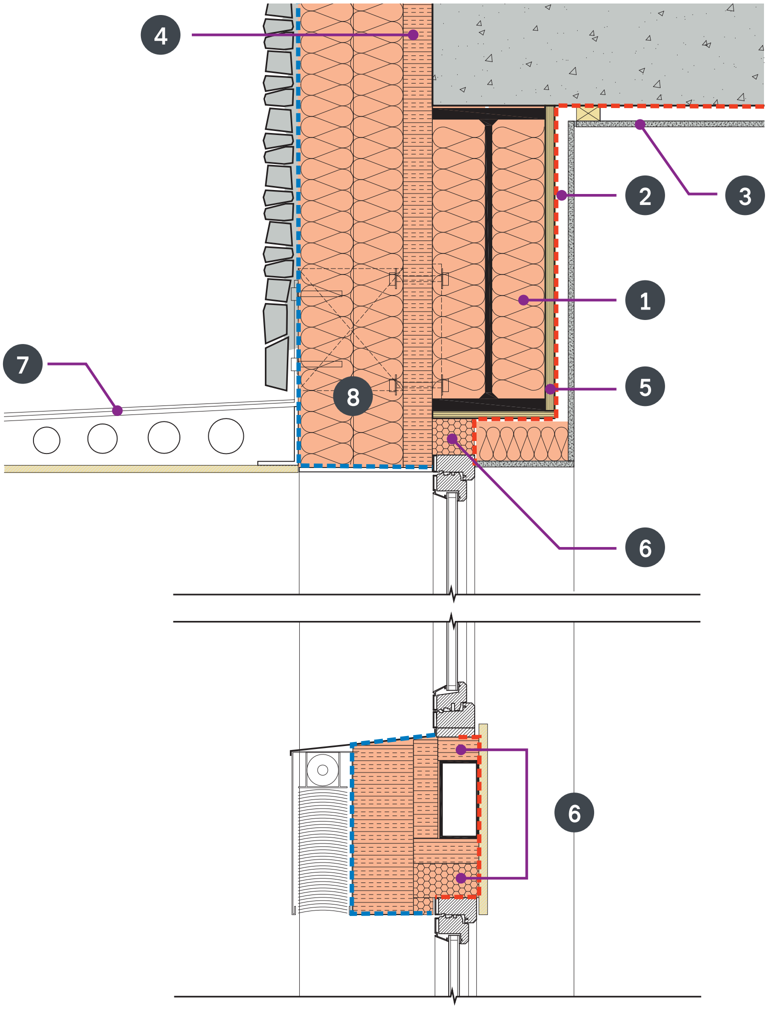
SAP Appendix K Reference	E3 sill	E2 lintel
psi-value	0.049 W/m.K	0.013 W/m.K
temperature factor	f_{Rsi} = 0.95	f_{Rsi} = 0.98
approved value	0.04 W/m.K	0.3 W/m.K
default value	0.08 W/m.K	1 W/m.K

Figure 6.13
Door lintel (left).

Figure 6.14
External wall ready for concrete pour (right).

Detail 6.3 Sunscreen and Door Heads

Sunscreens, louvres or canopies need to be fixed back to the structure. This thermal bridge can be prevented by designing a separate supporting structure or by specifying a thermal break.



KEY

1. EPS insulation board
2. Service zone
3. Plasterboard
4. 50 mm rigid insulation board
5. Airtight membrane fixed to ply sheathing
6. Insulation block at head and cill of window
7. PPC aluminium on ply backing
8. Thermal break fixing block fixed to steel channel

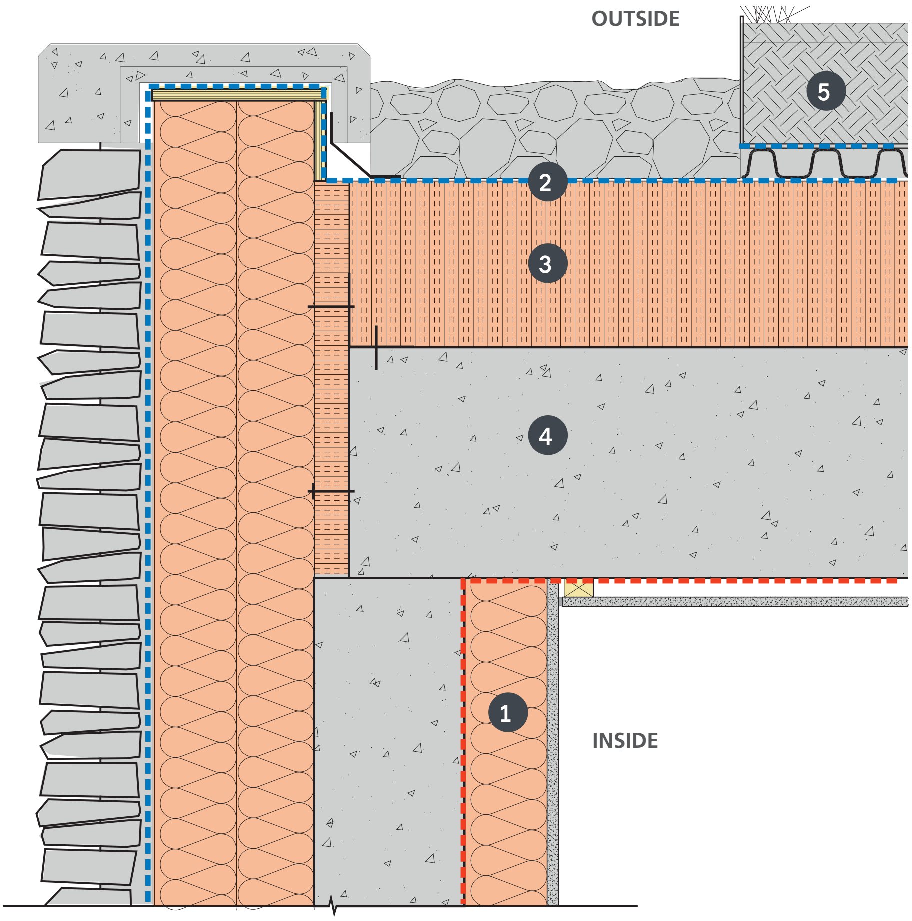
Figure 6.15
External wall beneath window (top left).

Figure 6.16
Window head and jamb (top right).

Figure 6.17
Large door opening – lintel and temporary support (left).

Detail 6.4 Green Roof Parapet

A low roof parapet should be fully wrapped with continuous insulation. Airtightness is provided by the concrete and taped at junctions.



KEY

1. Insulated concrete formwork blocks with in-situ reinforced concrete
2. DPM – waterproof layer
3. 250 mm roof insulation
4. Concrete roof slab
5. Extensive green roof

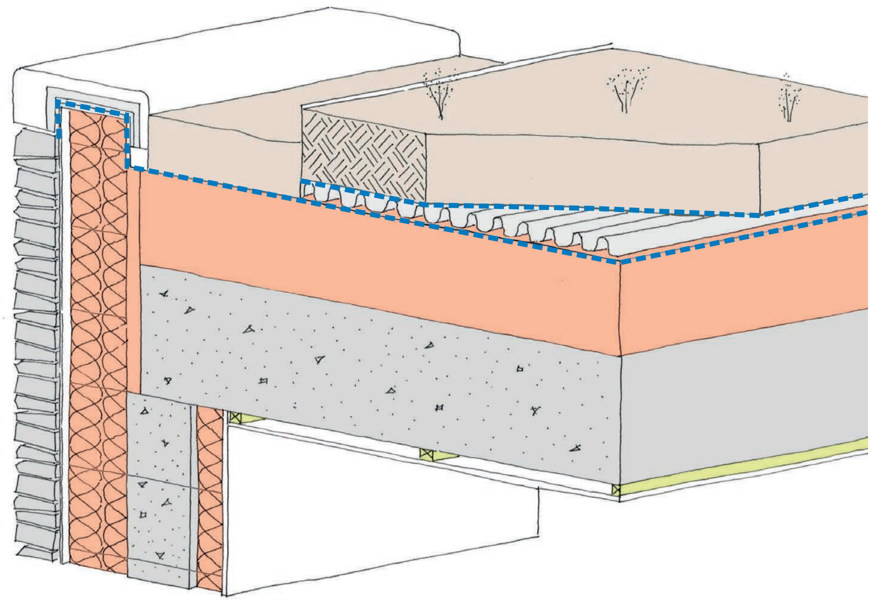


Figure 6.18
3D illustration of the parapet construction.

SAP Appendix K Reference	E15
psi-value	0.099 W/m.K
temperature factor	f_{Rsi} = 0.96
approved value	N/A
default value	0.56 W/m.K

Psi-value

The psi-value for this detail is 0.099 W/m.K, which is an 82% reduction in heat loss compared to the default value of 0.56 W/m.K.

Figure 6.19
Steel bar reinforcement in roof (left).

Figure 6.20
Roof after completion of concrete pour (right).

Chapter 7:
Off-site construction

Chapter 7:
Off-site construction

7

Off-site manufacture of building elements, rooms or whole buildings becomes more attractive as traditional construction gets more expensive and demand outstrips supply. There is a range of off-site construction types, broadly split into three categories:

1. **Elemental or component** – ranging from kitchen and bathroom pods, balconies, floors, roofs, service risers and other identical building elements manufactured in the factory and delivered for assembly on site.
2. **Panelised construction** – either closed or open panels with the option of fixing finishes in the factory. They can use timber, steel or precast concrete systems and include systems like timber SIPs (structural insulated panels) or CLT (cross-laminated timber panels).
3. **Volumetric** – units assembled volumetrically in the factory to dimensions that fit on a lorry. A complete house can be fabricated in the factory in modules to be transported and connected together on site.

These three types can be used in combination with each other and so various hybrid systems can be used like CLT volumetric or SIPs with a concrete frame. They all require an element of standardisation of the design and require the designer to work with the manufacturer at an early stage to understand the requirements of each system. Previous chapters have examined SIPs and CLT panelised construction, so this chapter looks at the volumetric approach. The most common approach for volumetric is to construct the modules with a steel frame with insulated timber infill panels. Steel frame volumetric has some structural benefits, but the steel frame has high thermal conductivity, and so generally does not perform as well as a timber volumetric solution. Any steel structure needs to be fully insulated inside the thermal envelope or fully separated so no thermal bridging occurs. Timber frame has structural span and height limitations, and so CLT is recommended as an optimum solution for volumetric. This chapter provides some key details for volumetric CLT construction.

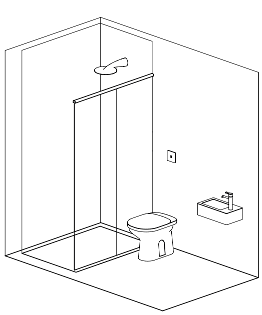


Figure 7.1 Elemental – bathroom, kitchen, services pods. etc. (left).

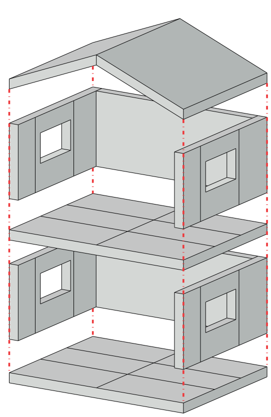


Figure 7.2 Panelised – timber SIPS, timber panels, CLT, pre-cast concrete panels (centre).

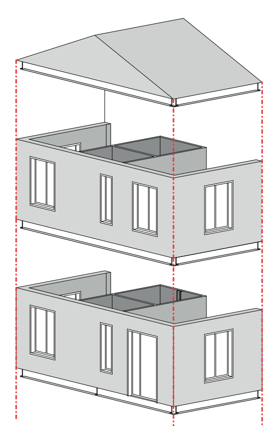


Figure 7.3 Volumetric – steel/ timber, CLT, timber (right).

Summary

Advantages

- Construction of modules in factory allows for better quality assurance.
- Excellent airtightness potential.
- Excellent thermal continuity.
- Fast construction on site – typically 70% less time on site compared with masonry (NAO 2005).
- Steel or timber structure is possible.
- Reduced damage and waste of materials.
- Better working conditions: weather, access, stability and safety.
- Can be delivered in a range of aesthetics to be indistinguishable from traditional housing.

Disadvantages

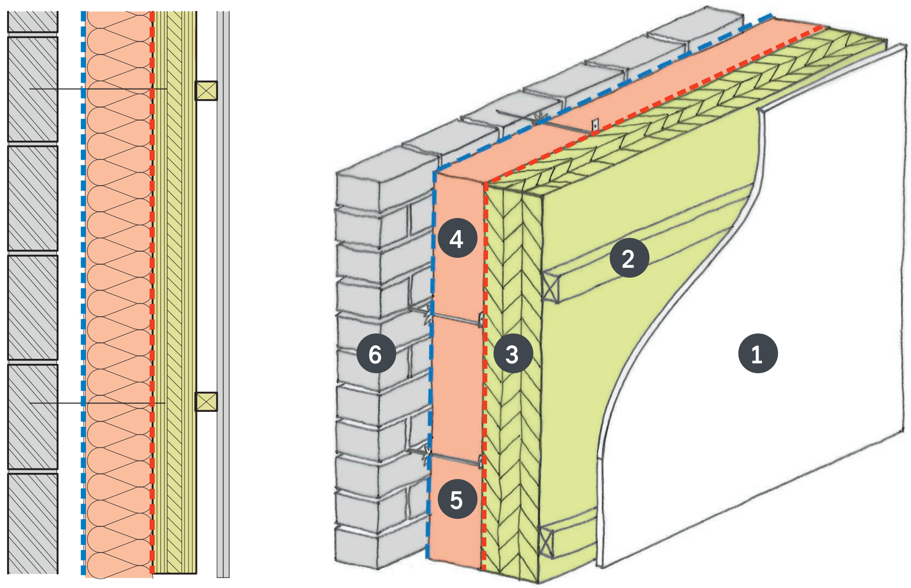
- Designing for modules to fit on a lorry can be restrictive.
- Requires greater investment and coordination up front.
- Coordinatation and design work is needed much earlier.
- Overhead costs of factory production means a consistent supply / demand of housing is preferable to keep cost per dwelling down.
- The quality, performance and aesthetics of modular construction can vary.

Recommendations

- Check the detailed design of the volumetric system to ensure it does not have significant thermal bridges caused by excess steelwork.
- Consider timber structures like CLT for modular construction that can provide continuous thermal performance without a steel structure.
- Design using the standard dimensions and spans of the modules, or agree variations and capabilities with manufacturer.
- Ensure coordination with services is done up front so it can 'plug and play' once on site.
- Designers should work with the manufacturer early on to understand opportunites and limitations in order to improve the design for better performance.

Good practice

This chapter illustrates some good practice CLT detailing used on construction projects. For more information, please refer to technical bulletins available from the Structural Timber Association.[8]



KEY

1. Plasterboard finish
2. Timber batten provides service zone
3. CLT panel (100–140 mm) is dimensionally stable and airtight, so should be taped at junctions and openings
4. External rigid insulation (minimum 100 mm) should be continuous around junctions
5. Low conductivity wall ties required as they puncture insulation back to structure
6. Windtight breather membrane taped over insulation

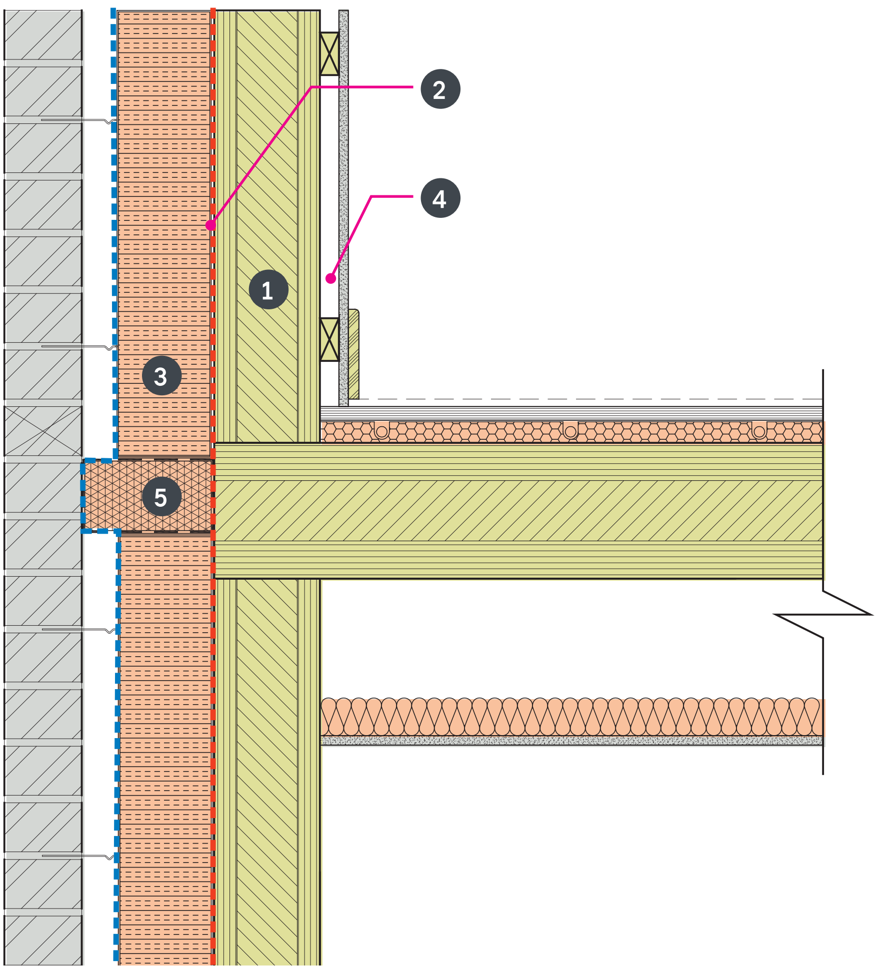
Figure 7.4
CLT provides an airtight structure to be taped at junctions (below left).

Figure 7.5
CLT must be carefully coordinated with services before construction (below centre).

Figure 7.6
CLT is vulnerable to moisture and so needs to have a concrete or masonry upstand and other significant damp-proof detailing (below right).

Detail 7.1 Separating Floor

Thermal insulation must be co-ordinated around the fire barrier and damp proof course, and installed tightly up against it with no gaps.



KEY

1. 120 mm CLT panel
2. Airtight membrane
3. 100 mm rigid insulation; lambda-value = 0.022 W/m.K
4. Service zone
5. Fire rated cavity barrier

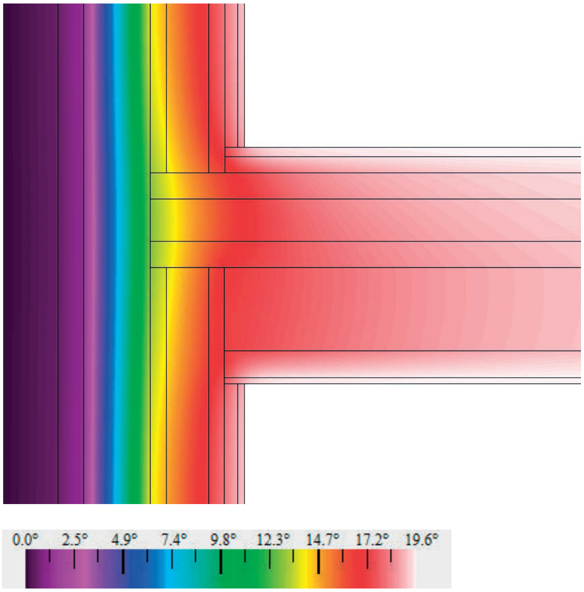


Figure 7.7
Heat flux diagram corresponding to Detail 7.1 (opposite).

Heat flux diagram and psi-value

This heat flux diagram of the external wall and intermediate floor junction shows the importance of continuous external insulation and heat loss that is possible through a timber floor even when it is well insulated. The psi-value for this detail is 0.082W/m.K, which is a 41% reduction in heat loss compared to the default value of 0.14 W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth. Please refer to Appendix 3 for further information.

SAP Appendix K Reference	E7
psi-value	0.082W/m.K
temperature factor	f_{Rsi} = 0.96
approved value	0.07
default value	0.14 W/m.K

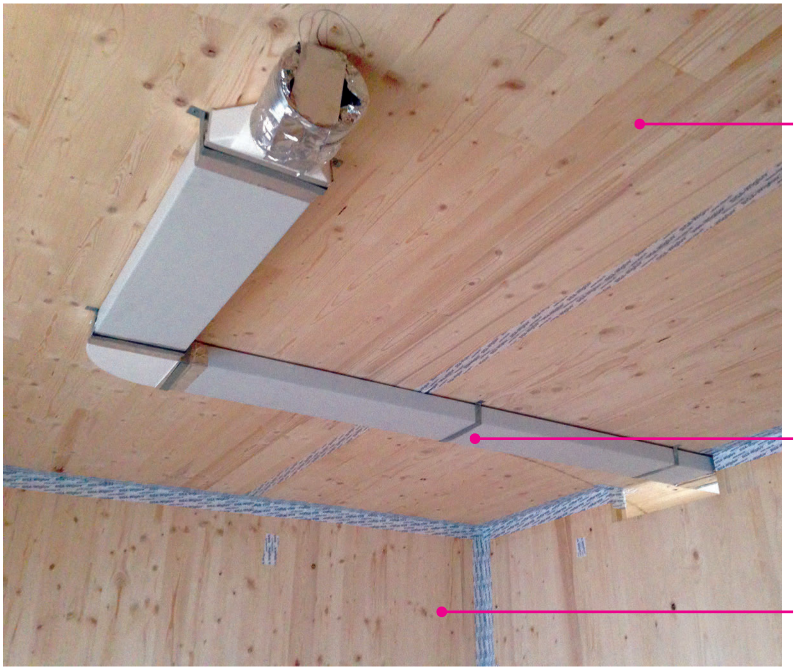
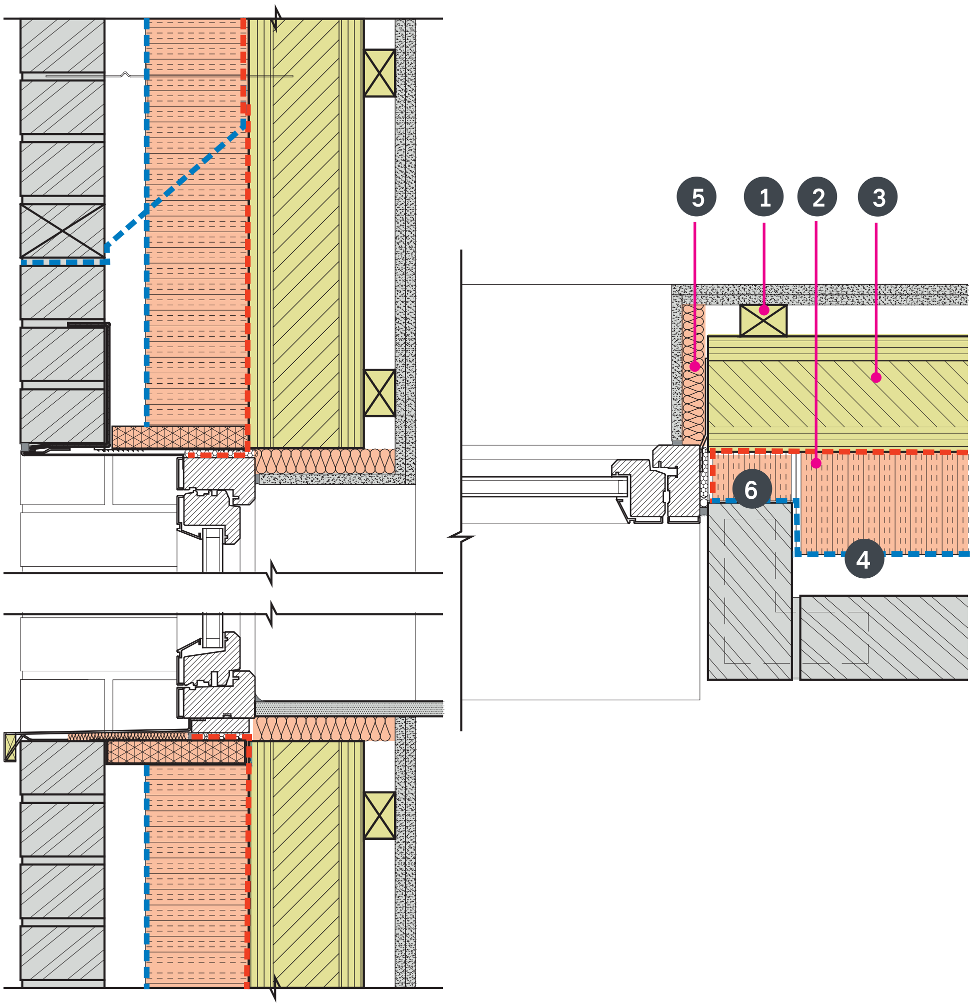


Figure 7.8
CLT separating floor with service zone.

Detail 7.2 Window

The window should be installed in line with the insulation layer to reduce thermal bridging. A half brick reveal would be easier to construct and have improved thermal performance.



KEY

1. Service zone
2. Rigid insulation
3. CLT panel
4. Breather membrane
5. Insulation to reveal, cill and lintel
6. Fully insulated cavity closer

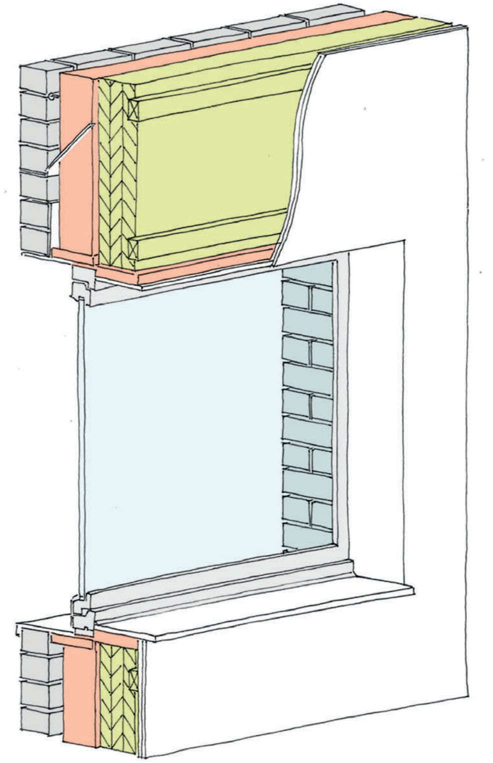


Figure 7.9
3D illustration of the window installation with CLT. The window should be taped to the CLT to provide a robust airtight layer.

Psi value

The three psi-values calculated all show significant improvements over the default value, e.g. the lintel shows a 99% reduction in heat loss.

Insulated window reveals and thermally separate lintel contribute to the lower psi-value and reduction in heat loss.

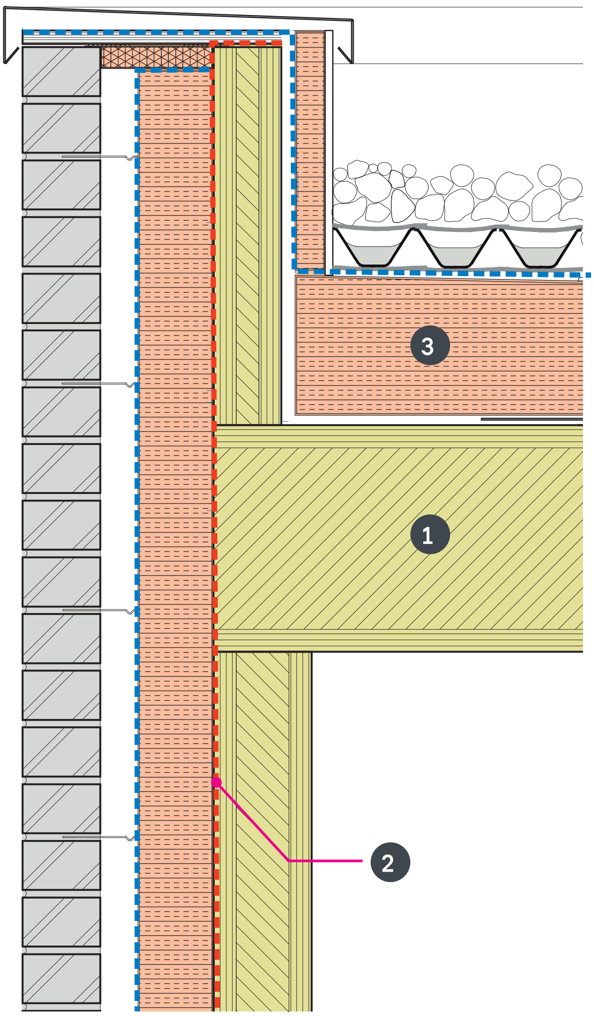
SAP Appendix K Reference	E2 lintel	E3 sill	E4 jamb
psi-value	0.009W/m.K	0.005 W/m.K	0.029 W/m.K
temperature factor	f_{Rsi} = 0.97	f_{Rsi} = 0.96	f_{Rsi} = 0.97
approved value	0.3 W/m.K	0.04 W/m.K	0.05 W/m.K
default value	1.0 W/m.K	0.08 W/m.K	0.1 W/m.K

Figure 7.10
Window head and jamb with cavity closer and thermally separate lintel (left).

Figure 7.11
Window installed in CLT with EPDM seal, before insulation and brickwork are installed (right).

Detail 7.3 Parapet

Wrapping the parapet in insulation significantly reduces heat loss.



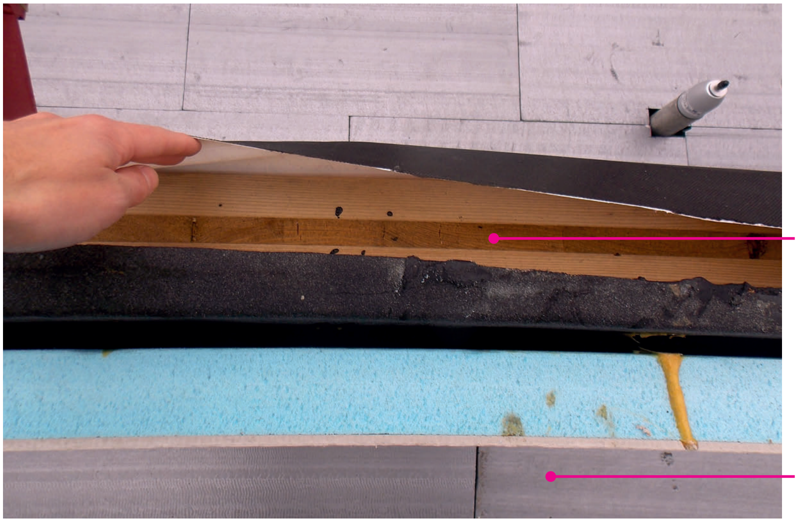
KEY

1. CLT panel
2. Airtight membrane
3. 250 mm rigid insulation = 0.022 W/m.K

SAP Appendix K Reference	E15
psi-value	0.054 W/m.K
temperature factor	f_{Rsi} = 0.92
approved value	N/A
default value	0.56 W/m.K

Psi-value

The psi-value for this detail is 0.054W/m.K, which is a 90% reduction in heat loss compared to the default value of 0.56 W/m.K. The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth. An inverted roof is an alternative construction, but the insulation does not perform as well when it is wet. A warm roof like this will keep the insulation dry and improve performance.



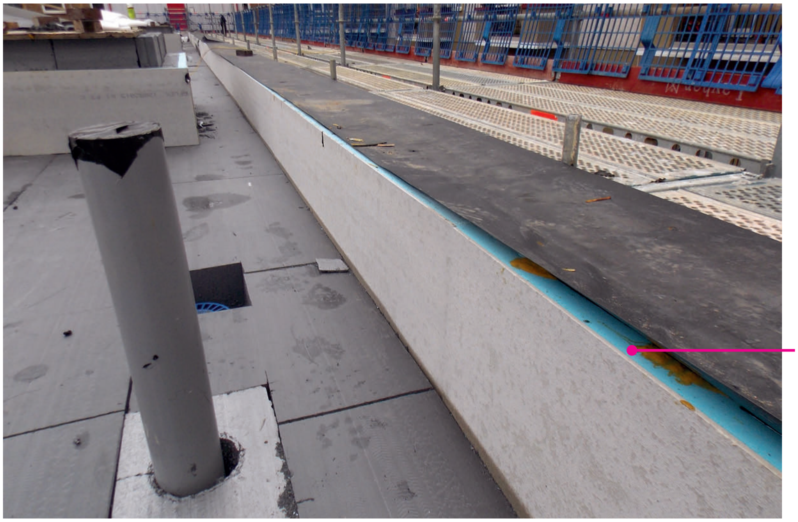
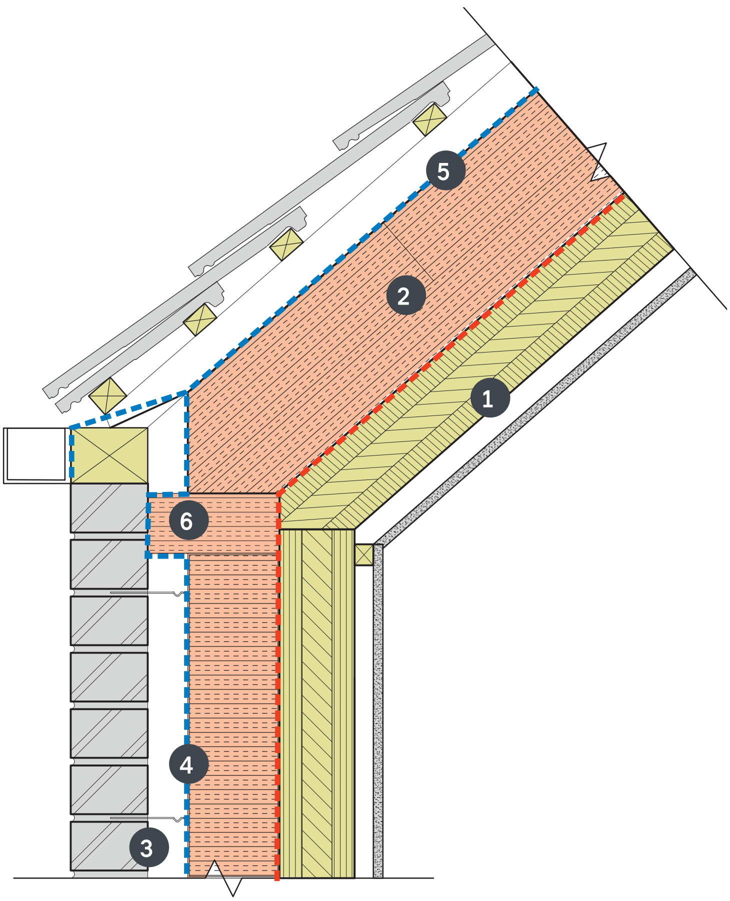


Figure 7.12
Insulation and DPM lining the inside of CLT parapet.

Figure 7.13
Flat roof with tight services penetrations.

Detail 7.4 Eaves

Continuous insulation and airtightness should be achieved at the roof and wall junction. An airtight breather membrane should be taped at junctions and coordinated with fire rated cavity barrier.



KEY

1. CLT panel
2. Rigid insulation board
3. Low conductivity wall ties onto surface-mounted channels
4. Vapour-permeable membrane
5. Vapour-permeable roof membrane
6. Fire stop insulated cavity closer

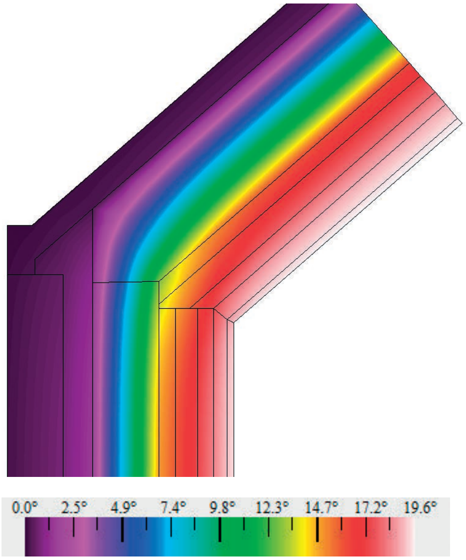


Figure 7.14
Heat flux diagram corresponding to Detail 7.4 (opposite).

SAP Appendix K Reference	E11
psi-value	0.012 W/m.K
temperature factor	$f_{Rsi} = 0.96$
approved value	0.04 W/m.K
default value	0.08 W/m.K

Heat flux diagram and psi- value

This heat flux diagram of the external wall and eaves junction shows the improvement in performance when continuous external insulation is achieved. Heat loss is significantly reduced when continuous insulation can be achieved. The psi-value for this detail is 0.012 W/m.K, which is an 85% reduction in heat loss compared to the default value of 0.08 W/m.K.

The temperature factor is above the critical value of 0.75, and so there is no risk of condensation or mould growth. Please refer to Appendix 3 for further information.

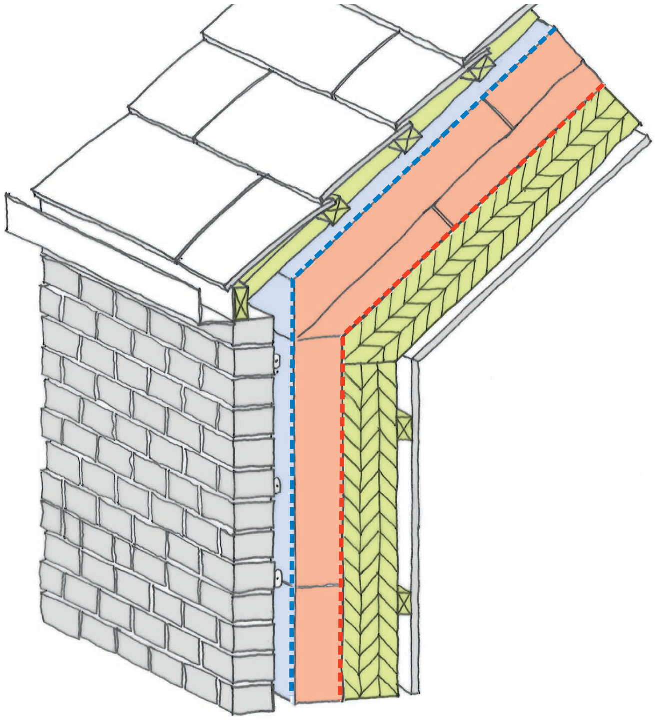


Figure 7.15
3D illustration of this eaves detail.

Chapter 8: Building services performance

Chapter 8:
Building services performance

8

Architects and other non M/E specialists in the project team need a basic understanding of building services so they can successfully design and coordinate services that deliver a comfortable living environment. Early on in the design process, the designers need to know basic characteristics of each option, including the size, location, performance, practical requirements and aesthetics. Following this, architects should work with services engineers, energy assessors and relevant specialists suppliers at RIBA Stage 2 in order to define the services strategy that can be integrated with the architectural design.

This chapter outlines the requirements and recommendations for the most common domestic services illustrated in figure 8.1. It displays these characteristics in a top trump style to assist early stage drawings and decisions. Each technology has a description, requirement and recommendations to assist designers in services specification.

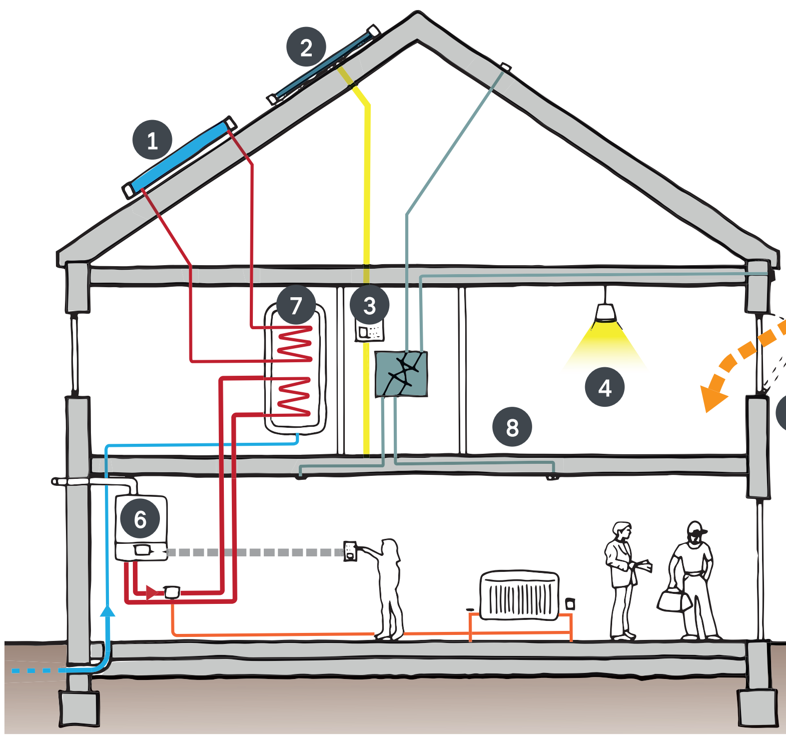


Figure 8.1
Typical services in a new house.

KEY

1. Solar thermal
2. Solar PVs
3. Smart controls
4. Low energy lights
5. Natural purge ventilation
6. System boiler
7. Unvented hot water cylinder
8. MVHR

Some of the services can be grouped together into a services cupboard, which can provide dual use as a utility cupboard and storage, to be as space efficient as possible. The following images show three options for this services cupboard in new dwellings, both with communal heating and mechancial ventilation (MVHR).

Improved energy performance in new homes

New homes are built to high thermal standards when compared with conventional homes of the 19th and 20th century. Insulation, airtightness and thermal bridging standards have increased so the standard house built in 2016 has a theoretical heat demand that is approximately 50% less than 2000. This calculation does not take into account the realities of building and actual performance, which is subject to the wide spectrum of design and construction quality variables, currently leading to a decline in performance as built. Building services account for a large percentage of the performance gap, of which heating and hot water hold a significant share.

Considering new technologies and controls

Innovate UK's Building Performance Evaluation Programme completed in 2015, demonstrated major teething problems with the inexperience of technology in new homes. Technologies that harmed performance with poor products or installation were solar water heaters, heat recovery ventilation, heat pumps, automatic blinds and heating controls. This was partly down to designers and installers inexperience in setting up unfamiliar systems in different homes. The Energy Saving Trust have also published results from their heat pump trials in 2013, which shows heat pumps performing worse in reality compared to the design figures.

Designers should be wary of specifying innovative systems unless they know the installers are experienced and have used them on similar projects. Designers should also ask for the systems as-built measured performance, instead of the factory measurements of performance, as certain systems can perform a lot worse once installed in a dwelling.

Figure 8.2 Typical services cupboard or utility room in a home (left).

Figure 8.3 Efficient layout for MVHR cupboard (right).

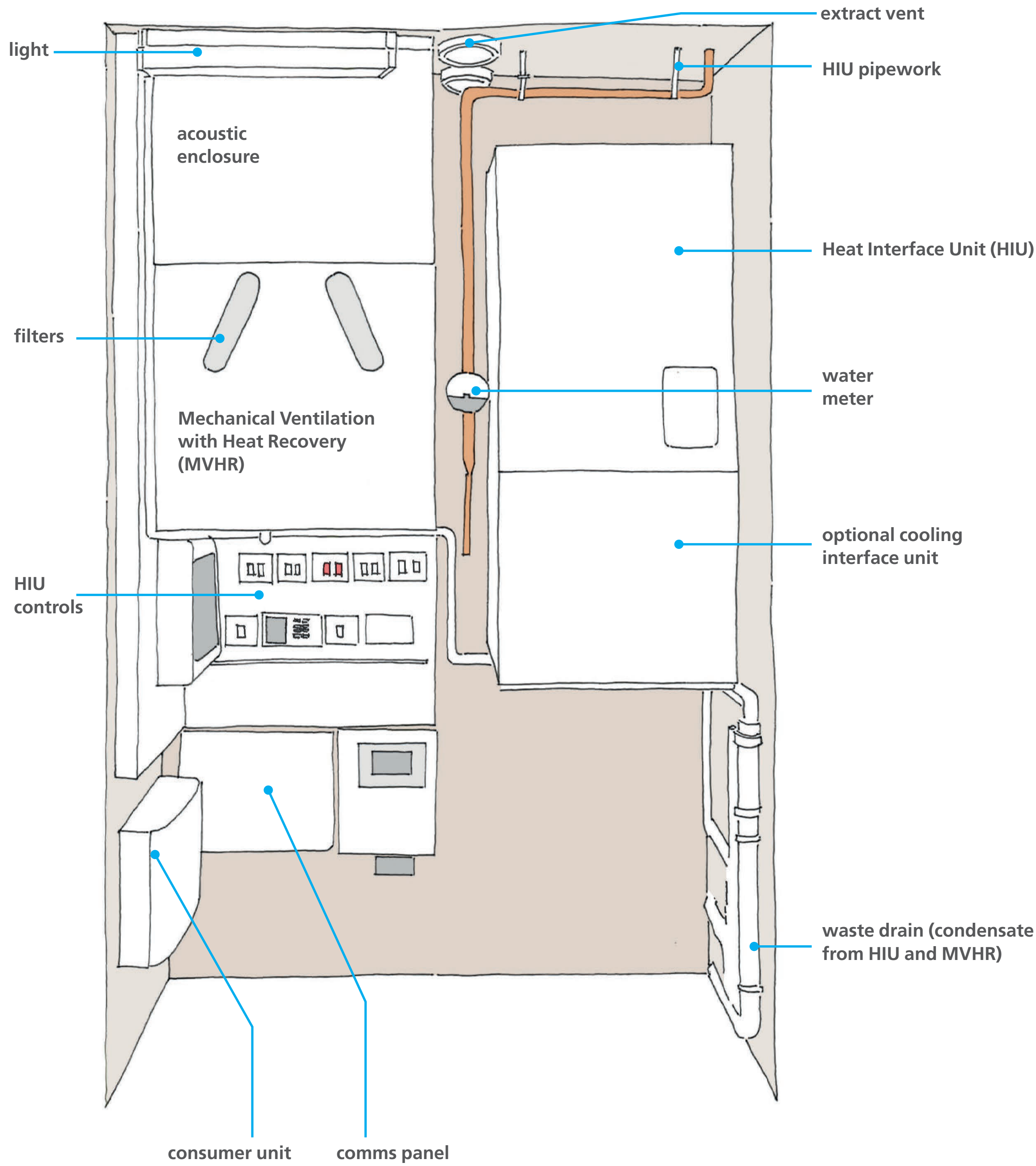


Figure 8.4
Compact services cupboard that can be prefabricated off-site.

Innovate UK and the Zero Carbon Hub studies show that heating, lighting and renewable energy controls are often too complicated for people to use. Residents can be wary of using controls, which can result in using more energy. The operation of building services is also affected by the quality of commissioning and handover to the residents. Commissioning will ensure the system is operating at best efficiency, and a thorough handover to residents will help the smooth running and maintenance of the system into the future. Designers and developers should use 'softlandings' protocol to create a good practice home user guide with effective handover meetings.

Space heating

The 'fabric first' policy means there is less heating demand in new homes. This reduced heat demand can lead to reduced running costs or increased comfort. A reduced heat demand means we can specify a smaller gas boiler with smaller and fewer radiators, which will reduce capital and operational costs.

Heat pumps are also well suited to homes with low heat demand with radiators 'oversized' to work at heat pump temperatures (around 45°C) or underfloor heating if a consistent daily temperature is preferred. Biomass heating is not well suited to highly insulated homes because the heating demand is too small, and these boilers aren't efficient at operating continuously at low output. CHP (Combined Heat and Power) is only suited to large-scale mixed-use developments (500+ units and mixed use) where there is a sufficient base load for the heat produced. As the UK grid increases its share of renewable energy, gas CHP will become less viable in terms of carbon emissions and heat pumps will become more favourable.

Hot water

As the space heating demands reduce through improved fabric performance, the predominant thermal demand is from the domestic hot water system (DHW). This demand can be reduced by the use of efficient water fittings, but total water consumption is mainly determined by the number of occupants.

Hot water often uses more energy than heating in a low-energy home, so it needs an efficient system. This chapter covers traditional hot water systems as well as more innovative technologies like Waste Water Heat Recovery(WWHR) and solar thermal panels.

Hot water losses fall into two categories:

- hot water cylinder losses
- circulation losses through distribution and dead-legs.

These losses can be reduced with efficient design of distribution and a centrally located hot water cylinder. The primary cylinder and distribution pipes should be fully insulated to reduce heat loss.

Services should be grouped together for efficiency so a house layout which groups kitchen, utility and bathrooms minimises energy use and cost. The boiler or heat pump should be next to the cylinder to reduce heat loss. Combination boilers with no cylinders are efficient in small dwellings where there are not more than two bathrooms. System boilers should be specified for dwellings with more than two bathrooms as the cylinders allow for multiple wet-rooms to be used at once.

Electricity

A number of renewable energy systems can supplement or replace grid electricity. Solar energy is generally regarded as the most practicable renewable energy source for homes since it is easily integrated with the building. Wind generation is not feasable for domestic production as it requires high consistent windspeeds and no planning constraints. This does not tend to be where UK homes are being built and so wind power is not normally specified with new homes.

A simple way to significantly reduce regulated and unregulated electric use is by specifying efficient lighting such as LEDs and A+ rated appliances. Smart, simple controls provide the occupant with useful feedback and optimise the services to operate only when needed.

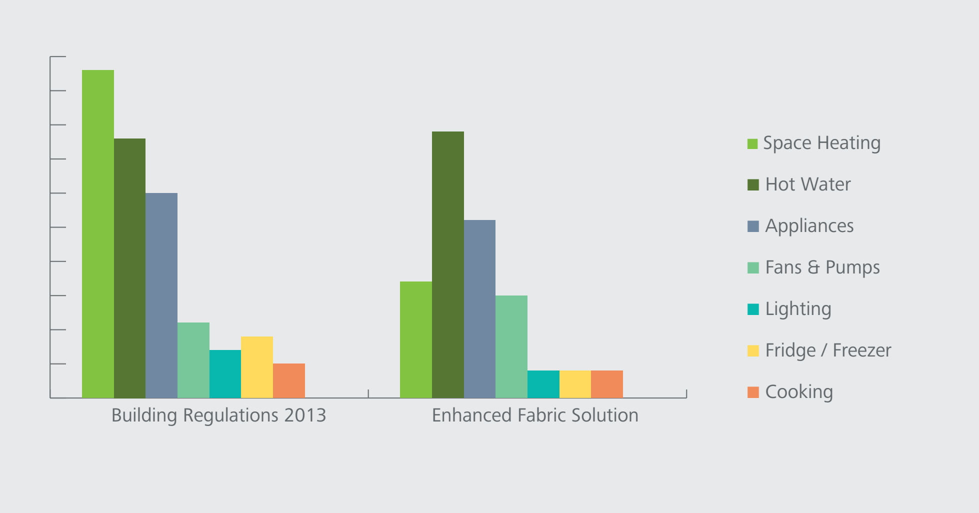


Figure 8.5
Typical services in a new house – refer to services guide for more information.

Ventilation

All homes require a controlled, well-designed and installed ventilation system. A managed infiltration and ventilation strategy is based on the principle of 'build tight, ventilate right', which means minimising infiltration through leaky building fabric, and providing a controlled ventilation system. There are a number of suitable ventilation

Figure 8.6
Flow rate test to commission fans.

systems outlined in this chapter ranging from low tech passive stack to highly efficient heat recovery systems.

All ventilation solutions provide openable windows to provide purge ventilation. All systems should meet and be tested for the ventilation rates set out in Approved Document Part F of the Building Regulations in order to extract moisture and odours at source.

These ventilation rates must be met by a controllable system that must not be turned off by the occupier. Residents can sometimes turn the extract fans off and close trickle vents in an effort to stop draughts and save in heating bills. This is not advisable and will lead to poor indoor air quality and associated health problems.

Sometimes the system itself is perceived as being ineffective, costly or too noisy and is turned off as a result. Very often this is because the systems have not been well designed, installed or commissioned. The Zero Carbon Hub 'Ventilation in New Homes' study found that 83% of new homes are failing Part F minimum requirements when tested. Some of the findings from this report are illustrated in the following chapter.

There are four ventililation systems that can be used in new homes, as described in Part F (Approved Document F), and illustrated on the opposite page:

1. **System 1:** intermittent extract fans. Does not meet the ventilation requirements of an airtight fabric as the area of trickle vents required is normally too large.
2. **System 2:** passive stack. Difficult to meet ventilation requirements without a continuous fan. It also relies on large trickle vent areas and can be dependent on external wind conditions to drive ventilation rates.
3. **System 3:** continous extract (MEV). Mechanical extract ventilation is a suitable solution for airtight fabric and quiet external conditions. It can be combined with CO_2 and moisture demand control systems to reduce the electricity use of the fan.
4. **System 4 (MVHR):** Mechanical vent with heat recovery is the preferred solution for airtight fabric, and ensures a continuous air changes with a balanced supply and extract with heat recovery. MVHR systems are more complex and expensive than MEV systems as they have double the ductwork and fans, and more complicated installation and commissioning. This balanced system does not require trickle vents and so is preferred in noisy or polluted sites. Heat recovery reduces the demands on the heating system further and is beneficial in cold climates.

Passivhaus is a successful example of a 'build tight, ventilate right' strategy using system 4 ventilation combined with an airtight fabric to achieve a good indoor air quality and reduced heat demand. An airtight fabric drastically reduces heat loss through infiltration but requires a mechanical ventilation system, normally a choice between MVHR and MEV. Systems 1 and 2 do not supply the control or the ventilation rates necessary for good indoor air quality in an airtight fabric.

The choice of building services system will depend on required performance, budget, occupancy, dwelling airtightness, area of windows, external noise and pollution, external climate and heat demands. Please refer to the specific recommendations for each technology in the following pages.

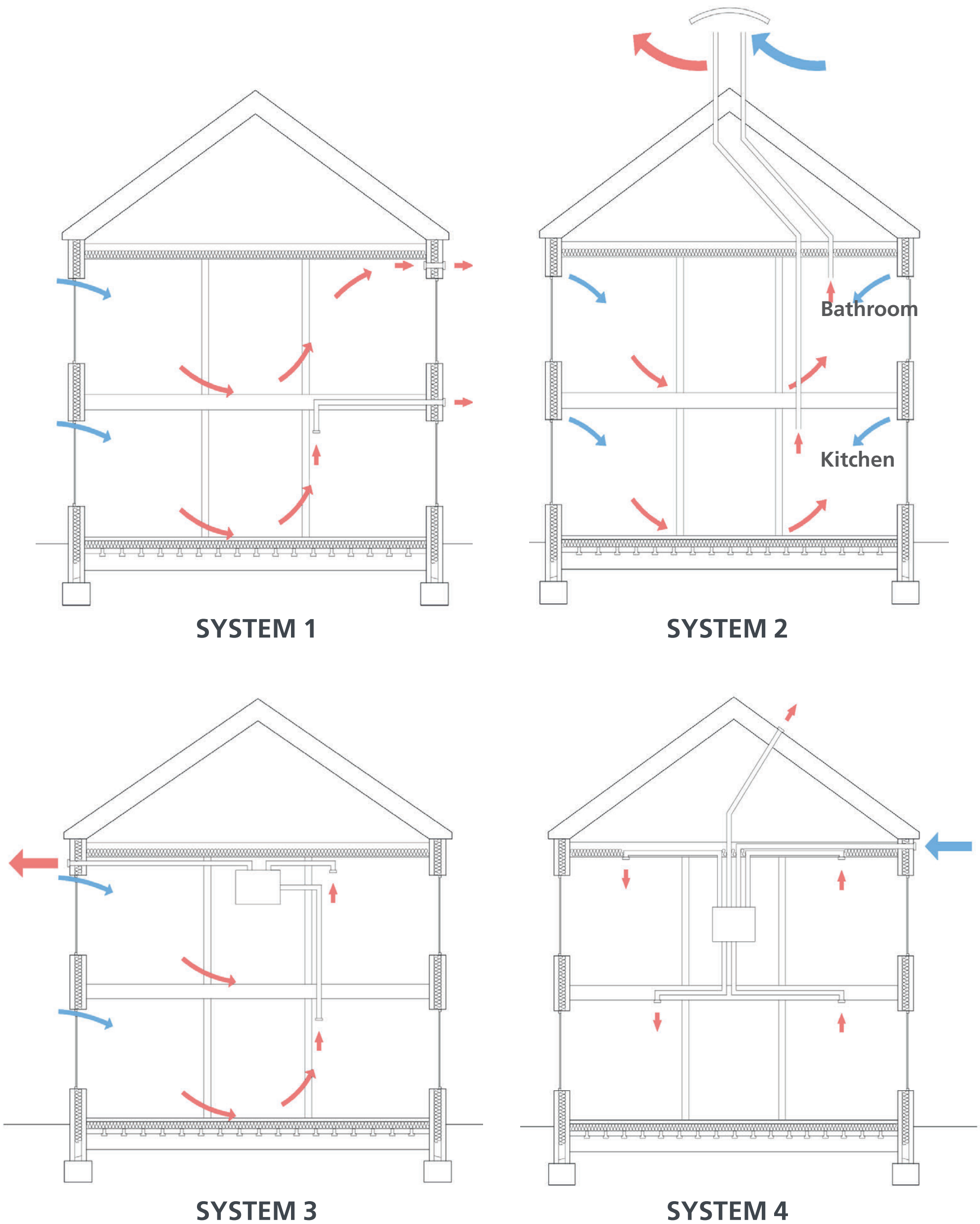
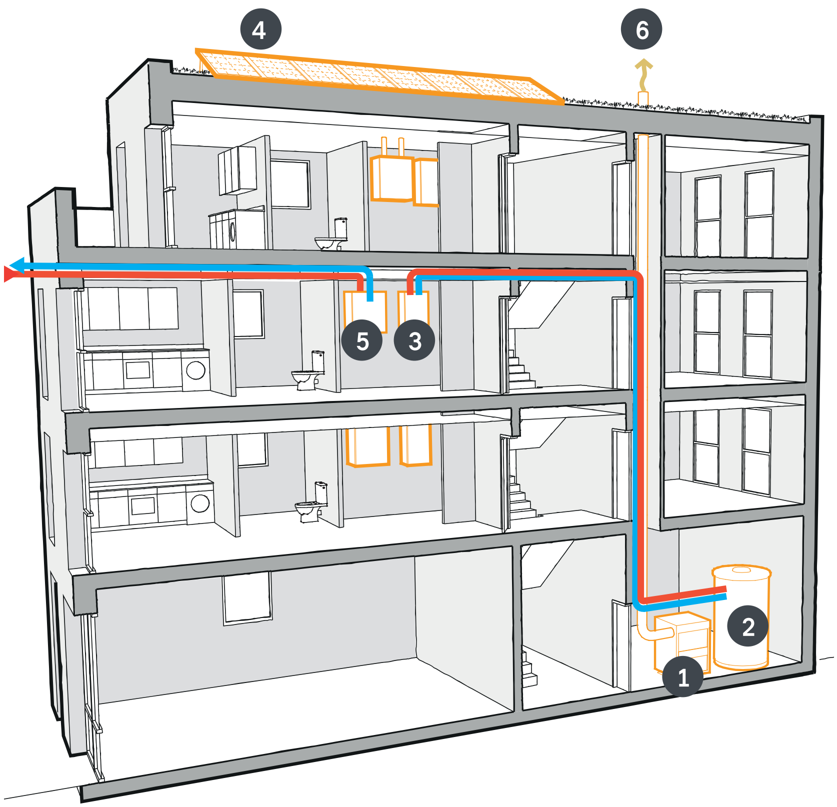


Figure 8.7 Ventilation systems 1, 2, 3 and 4 according to part F of the Building Regulations.

Performance recommendations for all services

- All systems to be commissioned on completion using appropriate testing equipment and accreditation body
- Provide completed commissioning sheets to the site manager and Building Control
- Write a simple Home User Guide to explain maintenance of services and controls (hard copy including images,and version online)
- Label the services, pipework and controls units to demonstrate maintenance
- Other maintenance (cleaning ductwork) will be carried out by a suitably qualified person.



KEY

1. Communal CHP engine
2. Thermal store (hot water)
3. Heat interface unit (HIU)
4. Solar PVs
5. MVHR
6. CHP boiler flue

Figure 8.8 Typical building services for a new apartment block.

Summary

The following table (Table 8.1) and chapter illustrate key performance requirements and recommendations for key services that are most commonly used in new-build homes. The indicative SAP scores are calculated using a standard three bedroom, 85m^2 house with a gas system boiler and ventilation system 1 as the base case, except where noted.

Reference	Description	SAP % improvement	SAP rating	Cost (CAPITAL)
8.1	Combi Boiler	+10%	B 85	£
8.2	System Boiler	0	B 84	££
8.1	Flue Gas Heat Recovery	+5%	B 85	££
8.3	ASHP	+25%	B 83	£££
8.4	GSHP	+25%	B 83	£££££
8.5	CHP	+15%	B 88	£££££
8.7	Solar Thermal	+15%	B 88	£££
8.8	WWHR	+8%	B 86	£
8.9	System 1 Ventilation	0	B 84	£
8.10	System 2 PSV	0	B 84	££
8.11	System 3 dMEV	+3%	B 85	£
8.12	System 3 cMEV	+3%	B 85	£££
8.13	System 4 MVHR	+15%	B 88	££££
8.14	PV - 2kWp	+60%	A 95	£££
8.15	Batteries	N/A	B 84	££££
8.16	LED Lights	N/A	B 84	££
8.17	Smart Controls	N/A	B 85	£££

8.1 Combi Boiler

Description

Gas condensing boiler, has typical efficiency of 85%–90%. Hot water is produced on demand with no hot water cylinder. Provides instant unlimited amount of hot water for a low demand (one to two bathrooms).

Requirement

» 800 mm (h) x 450 mm (w) x 400 mm (d).

» Increase height by 300 mm if flue gas heat recovery is included.

» 25 mm clearances around boiler required for installation and 22 mm condensate drain required.

» Flue must terminate a minimum of 300 mm from openings – see Approved Document J for details.

» Flue to outside should be as short as possible.

» Horizontal flue length can be up to 10m but requires inspection hatches every 1.5 m, and a fall of 50 mm per metre run.

» Not compatible with solar thermal.

Performance recommendations

» Recommended for new homes with low hot water demands (one to two bathrooms) and space constraints. Rated between 15 and 34 kW.

» Locate boiler next to external wall to minimise flue length.

» Consider flue gas heat recovery (FGHR) for extra efficiency of +5%.

» Can use radiators or underfloor heating with minimum 50 mm insulation below underfloor pipes.

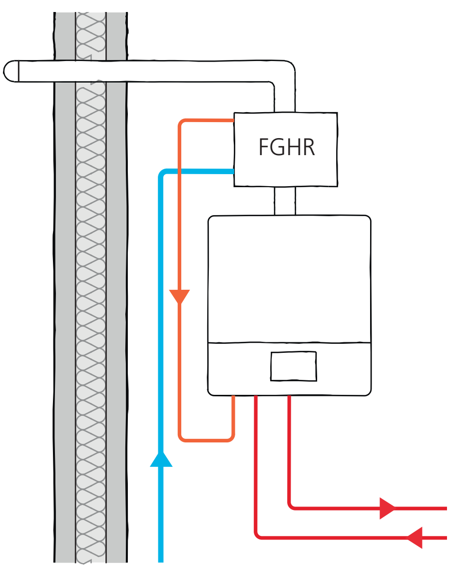


Figure 8.9 a & b Combi boiler with flue gas heat recovery.

8.2 System Boiler

Description

Efficient gas condensing boiler with an unvented hot water cylinder (HWC) to store hot water. An unvented HWC is commonly known as a hot water tank. The cylinder should be compatible and larger for solar thermal systems (twin coil cylinders) and heat pumps. Typically operates at 85%–90% efficiency.

Requirement

» Boiler dimensions: 800 mm (h) x 450 mm (w) x 400 mm (d).

» Cylinder dimensions: 600 mm diameter; height depends on storage capacity:
1 bathroom = 145L= 1250 mm
2 bathrooms = 210L = 1500 mm
3 bathrooms = 300L = 2050 mm

» Primary pipework and valves must be insulated.

» 25 mm clearances required for installation and 22 mm condensate drain required.

» Design should minimise length of pipework with a centralised cylinder position.

» Boiler flue to outside as short as possible; horizontal flue length can be up to 10m but requires inspection hatches every 1.5m and a fall of 50 mm per metre run.

» See Approved Document J for more details.

Performance recommendations

» Recommended for new homes in low-pressure area, or homes with multiple hot water outlets (more than two bathrooms). Rated between 25 and 44 kW.

» Locate boiler next to external wall to minimise flue length.

» Consider combining cylinder with solar thermal or using excess electric from PV panels to heat water.

» Specify cylinder with enhanced insulation thickness round cylinder, valves and all pipework.

» Explain and label all plant, pipes and controls for use and maintenance.

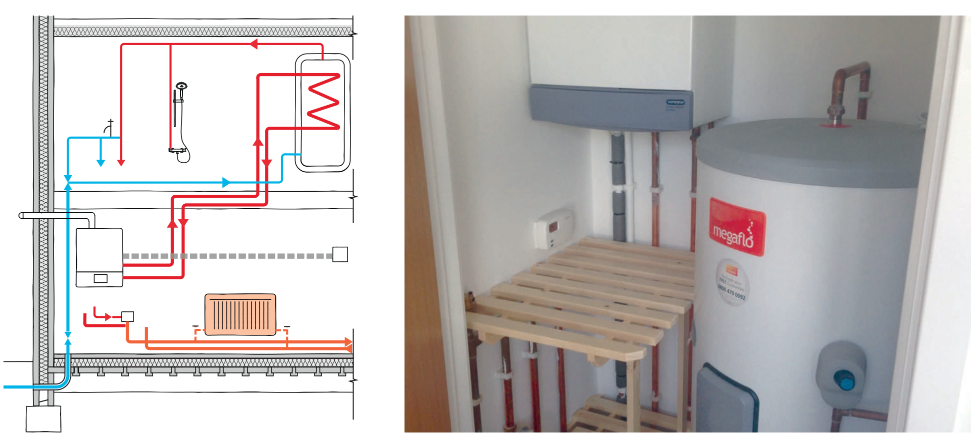


Figure 8.10 a & b
System boiler and hot water cylinder.

8.3 Air Source Heat Pump

Description

- The heat pump uses refrigerant to upgrade low-level heat from outside to heat water or air for internal heating.
- Residential units commonly use the Air to Water system as opposed to Air to Air used more often in offices. Most efficient when used with underfloor heating or large radiators in well-insulated homes.
- The outside condenser unit makes a low-level noise, so needs to be carefully sited.
- It transfers heat by refrigerant to the indoor unit that controls the flow of hot water to the central heating and hot water cylinder. Typical system performance is often significantly less than stated by manufacturer. EST trials showed the average system efficiency at 2.45, compared to 3 or 3.5 stated.

Requirement

- Typical size:
- Indoor unit: 900 mm (h) x 500 mm (w) x 400 mm (d)
- Outdoor unit (fan coil): 750 mm (h) x 850 mm (w) x 350 mm (d)
- External condenser unit must be protected and secure from tampering, leaves or debris and weather.
- Requires hot water cylinder.

Performance recommendations

- Recommended for new homes with low space heating demands and space constraints – rated from 5 to 10 Kw.
- Locate external condenser unit close to external wall, protected from damage but away from noise-sensitive areas like bedrooms.
- Check and use the as-built coefficient of performance (COP = 2.45) from Heat Pump Association.

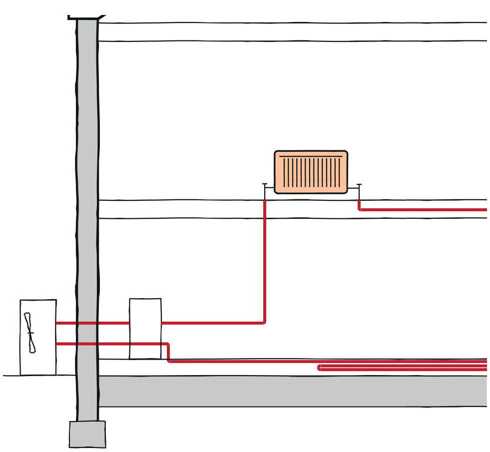


Figure 8.11 ASHP schematic – underfloor heating or oversized radiators (left).

Figure 8.12 Typical outdoor unit (right).

8.4 Ground Source Heat Pump

Description

- Ground-source heat pumps upgrade heat from the earth to use in heating homes through a wet or air system.
- A water system will use underfloor heating or large radiators.
- They can be up to 300% efficient (assuming 3 COP), by converting 1 unit of electricity into 3 units of heat, but EST trials show worse performance in reality with average system performance of 2.82 (COP).

Requirement

- Typical size: Indoor unit is typically 1800 mm (h) x 600 mm (w) x 600 mm (d).
- Outdoor has two options: closed loop boreholes are typically 20–100 m deep depending on geology (thermal conductivity).
- Closed-loop 'slinkies' (ground array) are typically 1m below the surface (1–1.5 m wide); sized to the needs of the dwelling.
- Requires hot water cylinder.

Performance recommendations.

- Recommended for new homes with low, continuous space heating demands.

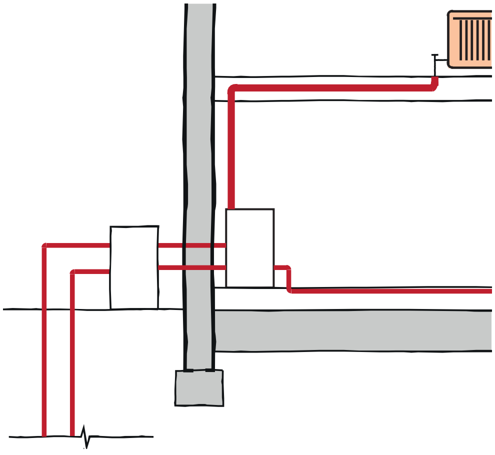


Figure 8.13
GSHP schematic (left).

Figure 8.14
Typical indoor unit (right).

8.5 Combined Heat and Power

Description

Combined heat and power (CHP) is the use of a heat engine to produce both heat and electricity at the same time. The CHP engine runs on gas or biofuels, and distributes the hot water via a pipe network to heat interface units (HIU) in each dwelling. CHP is an efficient method of cogeneration that uses the waste heat from electricity production. It is commonly used on a large scale in district heat networks to power whole urban districts, but Micro CHP can be used for a single dwelling.

Requirement

- Typical size of CHP engine is 1600 mm (h) x 600 mm (w) x 1200 mm (d).
- 500 mm diameter flue, rising 3m above habitable roof or windows.
- HIU = with insulation: 800(h) x 550(w) x 400 (d).
- CHP engine located in ventilated plant room with suitable space for access and maintenance.
- Be careful not to oversize the plant.
- CHP flue will need to rise 3m above habitable roof or opening window.
- Back-up gas boiler required.
- Large thermal store required.

Performance recommendations

- Recommended for high-density schemes, not dwellings with low heat demand.
- Minimise lateral length of pipework.
- Insulate all pipework to best practice, and ensure common areas are well ventilated.
- Specify a fully insulated HIU.
- HIU located close to entrance of flat and riser to minimise heat loss.

Figure 8.15
Insulated Heat interface unit (HIU) in dwelling (left).

Figure 8.16
CHP engines in plant room (right).

8.6 Communal or District Heating

Description

Communal heating can describe a wide range of systems, but commonly refers to a number of dwellings supplied by a communal boiler, CHP or heat pump. Fuel can be gas or biomass or electric. District heating refers to schemes that connect a whole district, 500 units or more, with one energy centre.

Requirement

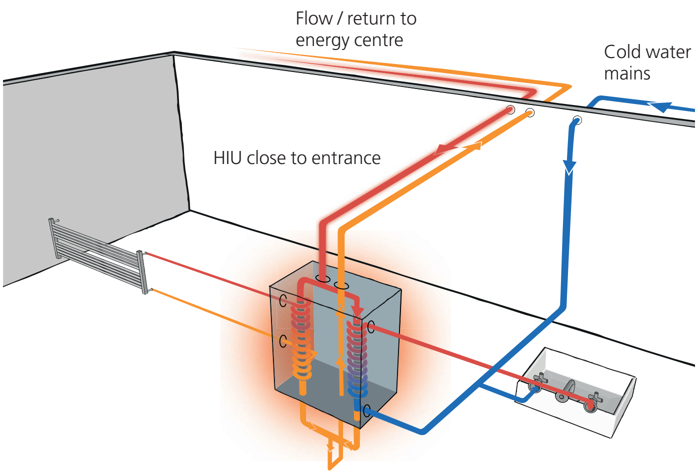
- Typical sizes for heat interface unit (HIU) in each dwelling is 800 mm (h) x 550 mm (w) x 400 mm (d).
- Plant room must be ventilated. Size depends on development, but typically 50–100m^2 for 150 dwellings and minimum 4.5m height for generating plant and thermal stores.
- Hot water pipework rises through and up apartment buildings. Typical water riser is 500 mm x 2000 mm for six dwellings on each floor. Typical ceiling void is 400 mm in corridors for lateral pipe runs.
- Pipework and HIU must be continuously insulated to minimum standards.
- Boiler flue must rise 3m above habitable roof or opening window.

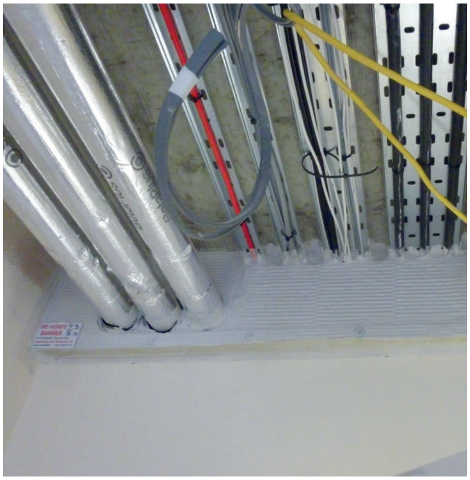
Performance recommendations

- Recommended for high density schemes of above 500 dwellings and mixed use.
- Minimise lateral length of pipework.
- Insulate all pipework and valves to best practice, and ensure common areas are well ventilated.
- Ventilate riser to disburse heat gains. Specify a fully insulated HIU.
- Refer to Heat Networks guide by CIBSE.

Figure 8.17
Heat Interface Unit in flats – insulated and short hot water pipe runs (below left).

Figure 8.18
Insulated primary pipes in ceiling zone (below right).





8.7 Solar Thermal

Description

Solar thermal or solar hot water panels typically use the sun to heat water circulated in evacuated tubes or flat panel collectors. A closed loop of insulated pipework transfers the hot water into a heat exchanger coil at the bottom of a hot water cylinder.

Requirement

- Panels are typically 2m^2, and a typical domestic system will require two panels. Requires a solar rated hot water cylinder, sized to the hot water demand.
- Install pre-insulated flexible solar thermal pipework.
- A solar pump station and controller is required to circulate hot water between cylinder and panel.

Performance recommendations

- Ensure installers are experienced at installing solar thermal and have MCS certification.
- Use in combination with gas boiler or heat pump.
- Recommended for low-density schemes of houses with plenty of south-facing roof space.

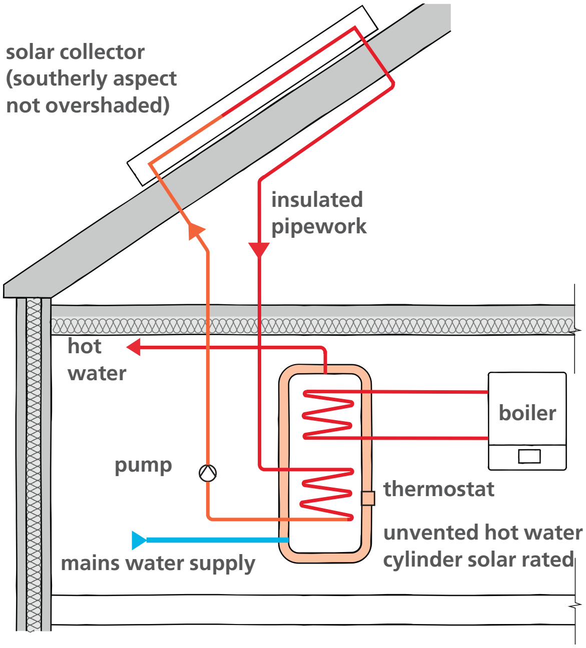


Figure 8.19 Solar thermal system (left).

Figure 8.20 Roof-mounted solar thermal (top right).

Figure 8.21 Pre-insulated hot water pipes (bottom right).

8.8 Waste Water Heat Recovery

Description

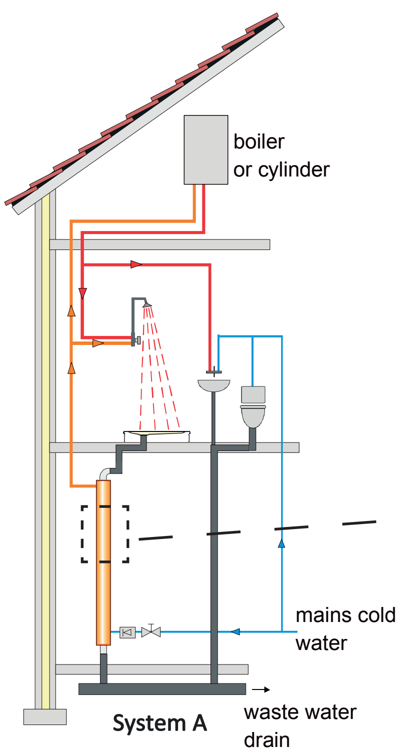
A shower waste heat recovery system is a copper pipe heat exchanger which collects the hot water from the shower waste pipe to preheat incoming mains water. It can recover up to 60% of the wasted heat from showers.

Requirement

- Typical size: 50 mm diameter, 2100 mm height
- Top and bottom connectors
- No maintenance.

Performance recommendations

- Refer to manufacturer's information for detailed design and installation.
- Check the site incoming mains water pressure is suitable for the WWHR unit.
- Install the WWHR pipe vertically within 1° vertical to ensure maximum performance.
- Ensure the top connectors are correctly orientated to achieve maximum distribution of the waste water circulating down the inside face of the inner pipe.



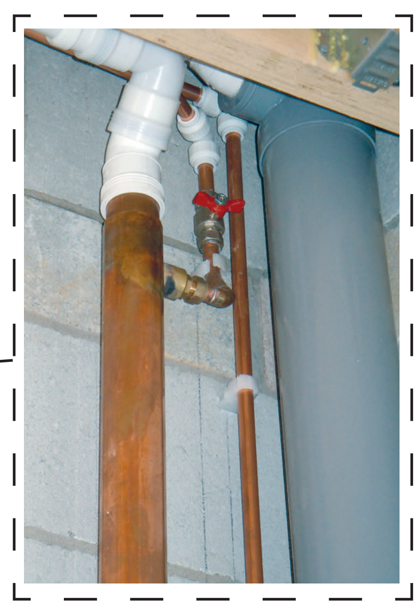


Figure 8.22
WWHR System A (left).

Figure 8.23
Correctly installed WWHR (right).

8.9 System 1 Ventilation – Intermittent Extract Fans

Description

- Background ventilators and intermittent extract fans in wet-rooms.
- Background ventilation is normally provided by trickle vents in the windows, but can be by vents in the wall. There is a large free area requirement for system 1 background ventilation, so it is often difficult to achieve in apartments of dwellings with a small number of windows.
- The extract fans in wet-rooms run at a high fan speed, as they have to extract the required air in a shorter time.
- Purge ventilation is typically by opening windows.

Requirement

- System 1 = large trickle vent areas calculated from AD(F) = 25,000–65,000 mm^2.
- Single – aspect dwellings require double the equivalent area to achieve the required ventilation rate.
- Ensure that at sill level, glazed-in/slot vents have the appropriate profile for this location.
- Minimise use of flexible duct, and ensure rigid duct is straight and short with sufficent free area.

Performance recommendations

- Install the extract fans on external walls to minimise duct resistance.
- Tape up trickle vents during construction to protect from dust.
- Explain use of trickle vents to occupants, to keep open to ensure adequate ventilation.

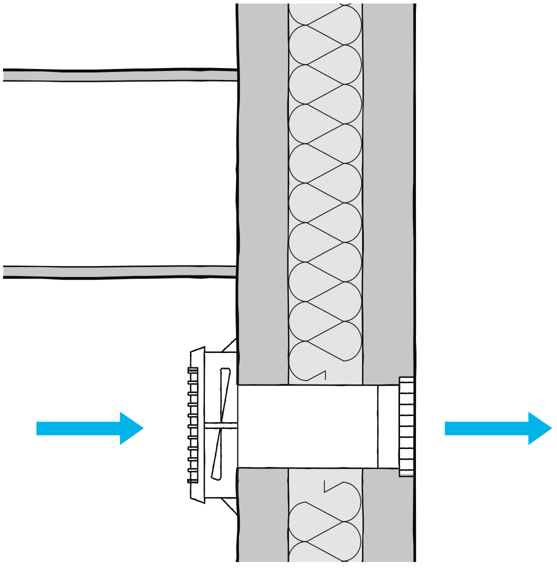


Figure 8.24
Extract fan installed through the wall (left).

Figure 8.25
Trickle vents at window head (right).

8.10 System 2 Ventilation – Passive Stack Ventilation (PSV)

Description

- Extract ventilation is driven by the stack effect and wind, provided by vertical ductwork from all wet-rooms rising to roof level outlets. Air is supplied to the dwelling using background ventilators, typically trickle vents as system 1.
- There are not normally any mechanical components, although some systems have additional fans to guarantee continuous air flow.

Requirement

- All extract vents are sized to have an area of 12,000 mm^2 and minimum duct size of 125 mm diameter.
- Angle of bends should be 45 degrees from vertical or less.
- Ducts need to be insulated in cold spaces like lofts.
- Ducts to be sealed with grommet and tape to airtight layer or mastic between rooms.
- Upper terminals and lower grilles should be fixed in such a manner that there is no reduction in the cross-sectional area of the complete system.
- Trickle vent areas are calculated using Part F.

Performance recommendations

- Duct should be rigid and vertical, with minimum shallow bends only if necessary.
- Consider passive stack systems with heat recovery and no fans.

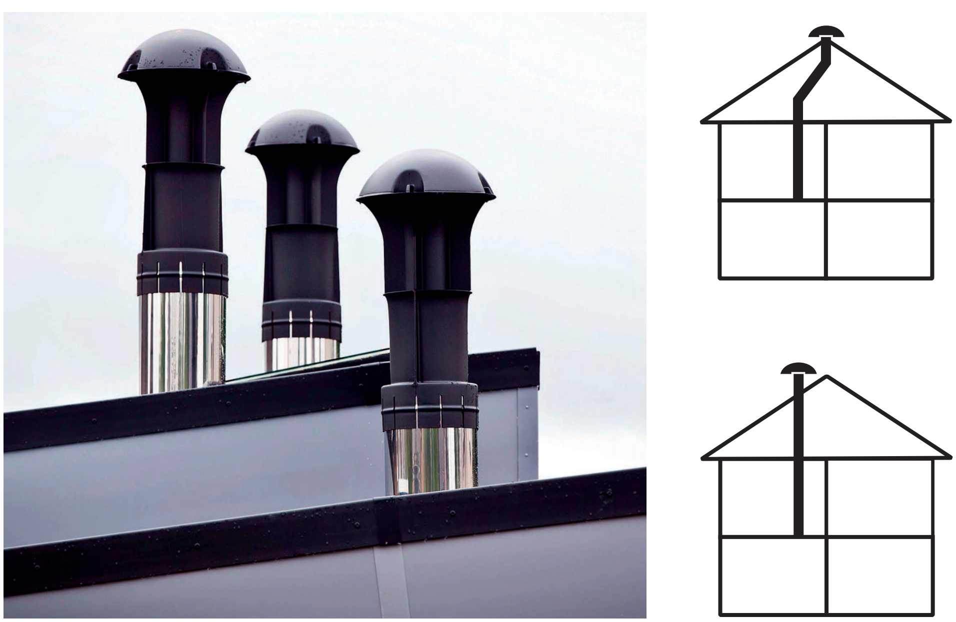


Figure 8.26-28 Passive stack ventilation with heat recovery.

8.11 System 3 Ventilation – Decentralised Mechanical Extract (dMEV)

Description

- Continuous mechanical extract (MEV) uses mechanical fans to extract air from the dwelling.
- The decentralised type consists of individual fans in each wet-room.
- Supply air is drawn in through trickle vents in the windows or other vents in the wall. The fans are continuous and create negative pressure in the home, which allow the trickle vents to have a smaller area. The fans have a temporary boost rate to extract odour and moisture when necessary.

Requirement

- Extract fans are typically 150 mm square and fixed to the external wall or ceiling mounted.
- Trickle vents: 2,500 mm^2 for each room except wet-rooms. No trickle vents in wet-rooms.

Performance recommendations

- Extract fans should be mounted on the external wall in order to minimise duct length and resistance.

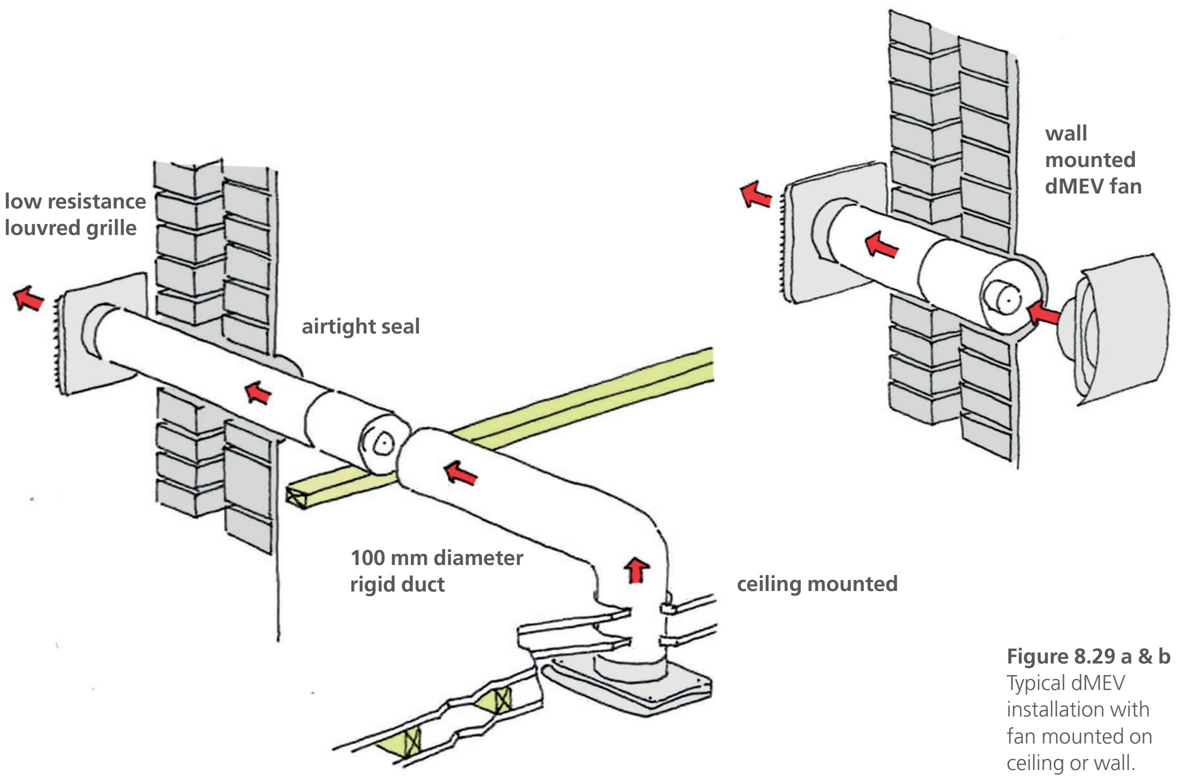


Figure 8.29 a & b Typical dMEV installation with fan mounted on ceiling or wall.

8.12 System 3 Ventilation – Centralised Mechanical Extract (cMEV)

Description

- This centralised system consists of one central fan unit that extracts air through ductwork from the wet-rooms.
- The fans continuously extract at a low rate to the outside, creating a negative pressure in the home which draws in supply air through trickle vents. As the fan is continous, the trickle vents are smaller area. The fan has a boost rate that can be controlled in a variety of ways.

Requirement

- MEV units can be mounted in the ceiling void, or wall hung in a cupboard.
- A typical ceiling-mounted MEV unit is 500 x 500 mm x 350 mm deep.
- Access for cleaning and maintenance to be provided.
- Trickle vents: 2,500 mm^2 for each room except wet-rooms. No trickle vents in wet-rooms.

Performance recommendations

- Ductwork should be rigid and as straight as possible with condensate traps for vertical installations.
- Filters do not have to be installed as it is extract only.
- Do not locate unit in a cold loft or garage.
- Long ductwork and poor installation will cause the fans to be noisy, so consider mounting the unit on 18 mm ply pattress in an acoustically treated cupboard away from bedrooms.
- Specify CO_2 and moisture demand controlled systems.

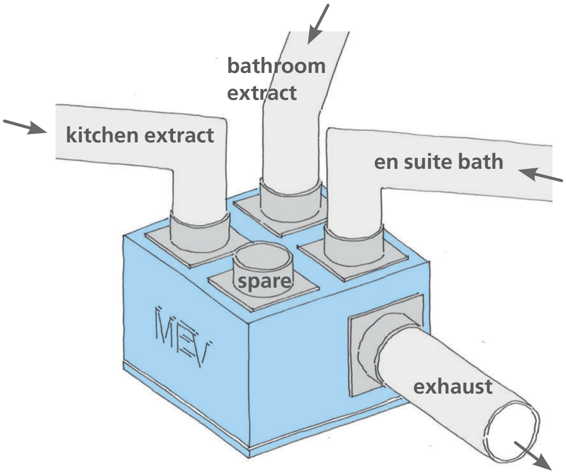


Figure 8.30 a & b
MEV unit installed with demand control.

8.13 System 4 – Mechanical Ventilation Heat Recovery (MVHR)

Description

A balanced whole house system, where air is supplied and extracted at a continuous rate. Stale air is extracted from wet-rooms, and fresh air is supplied to all habitable rooms mechanically. The unit includes a heat exchanger that pre-heats the incoming supply air with the warmth of the extract air. This reduces the amount of heat loss due to ventilation by 70–90%. There is a boost operation and summer bypass control is common on most units.

Requirement

- Part F requires minimum extract rates for individual wet-rooms in boost operation. Normal rates are met by balancing the system to achieve whole house supply rate.
- A condensate drain is required close to the unit.
- Intake terminals should be separated from exhaust terminals and other sources of pollution by a minimum of 1m. Increased separation distances are required between intake and any SVP, binstore, boiler flue or chimney.
- No trickle vents in windows or doors
- Terminal should provide sufficient free area. Ensure grille is coordinated with elevation, including lintels, brick dimensions and other services.
- Supply air should be taken from the least polluted elevation.

Performance recommendations

- Ductwork should be rigid, short and as straight as possible with condensate traps for vertical installations.
- Filters must be accessible for regular cleaning and replacement.
- Do not locate unit in a cold loft or garage, but in a heated space.
- Long ductwork and poor installation will cause the fans to be noisy, so consider mounting the unit on 18 mm ply pattress in an acoustically treated cupboard away from noise-sensitive rooms.
- Locate unit adjacent to external wall/roof to minimise lengths of cold ducts.
- Specify simple, accessible control panel with usage pattern adjustment and filter change notification
- Decentralised systems can work well in smaller houses or rooms.
- Check performance of summer bypass function to minimise import of warmer outside air.

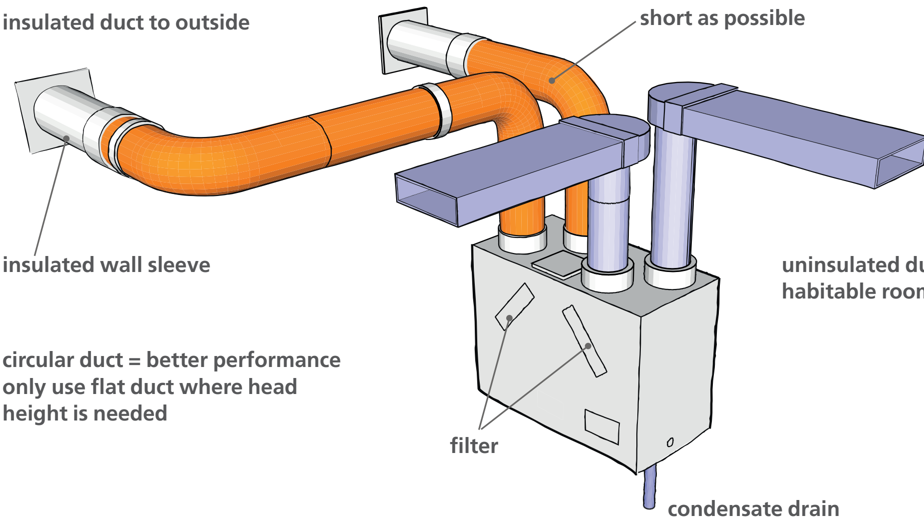


Figure 8.31
MVHR and main ducts.




Figure 8.32
MVHR filter change (top left).

Figure 8.33
Galvanised steel circular ducting in ceiling zone (top right).

Figure 8.34
MVHR installed in cupboard (bottom left).

Figure 8.35
MVHR grille from outside with correct free area (bottom right).

8.14 Photovoltaic Solar Panels

Description

Photovoltaic (PV) solar panels convert sunlight into electricity. The panels produce direct current (DC) that is converted into alternating current (AC) for use in the home, or sold to the National Grid using an inverter.

There are different grades of panels which use either monocrystalline or polycrystalline silicon, and have different efficiency ratings. PV is the most common renewable energy for new-build housing in the UK owing to the simple, low-maintenance technology.

From 2017 to 2019, the Feed in Tariff (FIT) available from Ofgem is paying around 4p per kWh for domestic systems up to 10kW. The electricity produced typically meets design figures.

Requirement

- Position PVs to receive direct sunlight throughout the day.
- Size inverter to meet PV kWp output.
- Typical dimensions of a wall-mounted inverter in the riser cupboard on top floor are 350 mm x 580 mm x 150 mm.

Performance recommendations

- Install energy feedback displays to enable occupants to optimise use of renewable energy.
- Design for current and future overshading.

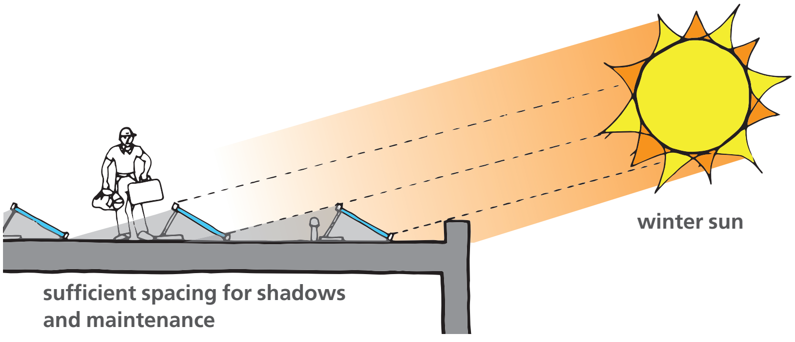


Figure 8.36
PV inverter accessible in top floor riser cupboard (top left).

Figure 8.37 & 8.38
Flat roof PV panels at 10 degrees (top right and bottom).

8.15 Batteries

Description

Electrical energy is stored in large batteries or banks of batteries. Batteries are designed to capture surplus electricity generated by a solar PV system and allow the storage of solar electricity for use later in the day or at night. Whole house shutdown control can reduce energy consumption of appliances and devices.

Requirement

- Battery systems can vary considerably in shape, size and weight, depending on battery capacity. Typical domestic systems vary from being the size of a small computer to the size of a washing machine.
- Batteries can pose a fire and explosion risk if mistreated, so ensure sufficient fire protection.
- They can be heavy and difficult to move.
- Batteries must be installed in suitable locations for safe battery operation and out of the reach of children.
- The typical size for a 6kWh system is 800 mm x 600 mm x 500 mm.

Performance recommendations

- Specify batteries as part of a solar PV system that generates excess electricity during the day, and can be used later at night to increase usage of the solar generation on site.
- Lithium-ion batteries are more efficient and longer lasting, but more expensive.
- Check warranty and expected life of battery.

Figure 8.39 ENPHASE lithium-ion battery (left).

Figure 8.40 WATTSTOR lead-acid battery (right).

8.16 Lighting

Description

Low-energy lighting is required for all new homes. Approved Document L of the Building Regulations requires at least 75% low-energy light bulbs. These are typically LEDs (light emitting diodes) or CFL (compact fluorescents). All traditional filament (incandescent) or tungsten are banned, and only efficient halogens can be specified.

Requirement

» Specify low-energy lights such as CFL and LEDs to greater than 400 lamp lumens.

Performance recommendations

» Aim for 100% low-energy lights, but realise this will mean LED downlights.

» Ensure airtightness for all light fittings with back box seal or sacrificial service zone with an airtightness layer behind.

» Consider smart controls such as PIR or daylight sensors.

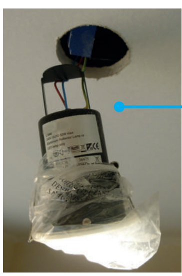


Figure 8.41
LED downlight with insulation cap.

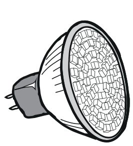
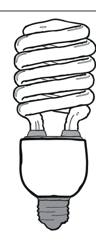
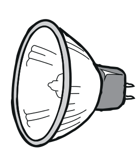
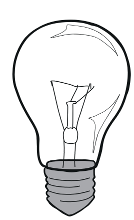
	LED	CFL	Halogen	Incandescent
Lifespan	Very long (20 years)	Long (6 years)	Medium	Short
Energy use	Very low	Low	Medium	High
Energy savings	85%	75%	25%	0%
Operating cost	Very low	Low	Medium	High
Low energy?	Yes = 8W	Yes = 15W	No = 50W	No = 60W
Internal heat gain?	Low	Low	High	High
				

Table 8.2
Light bulb performance.

8.17 Controls

Description

Simple, smart controls can reduce total energy use in homes by up to 30%. There are a variety of types of smart controls and feedback displays that enable improved comfort, air quality and reduced energy use. Full home automation can control lights, heating, ventilation, socket power, kitchen appliances, music, alarms through sensor, timed or manual control by phone or switch.

Requirement

- » Specify controls that are compatible with the building services, e.g. some boilers do not work with load compensation.
- » Specify smart meters with simple feedback displays.

Performance recommendations

- » Specify controls that are simple and self-explanatory in their use. Do not specify complicated programmers or room thermostats.
- » Consider weather compensation for heating and demand control for ventilation.
- » Specify a system with display screen or device that gives useful feedback to residents.
- » Controls should have a manual on and off switch as well as the automatic function.
- » Provide a simple user manual with images and hang labels on the services for future maintenance guidance.

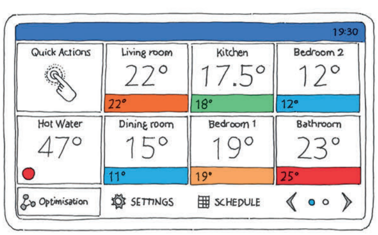


Figure 8.42 Simple feedback display (top).

Figure 8.43 Indoor air quality monitor (bottom right).

Figure 8.44 Whole house shutdown control can reduce energy consumption of appliances and devices (left).

Integration of building services

The building fabric should incorporate service routes and dedicated locations for ventilation and heating plant. The plant should be positioned on the drawings at RIBA Stage 2, so the design team is aware of effects this has on layout, storage and other practical constraints. Space for plant should not come out of the general storage allowance and is in addition to space standards for dwellings. A typical house will require an extra 1–2 m2 to accommodate plant in each dwelling.

Primary risers are located in common areas of apartment blocks, so they can be accessed at all times. Apartment blocks typically require risers for water, gas, electric and other services for phone, internet and drainage. A typical riser for communal heating is 500 mm by 2000 mm for six flats per floor, and should be allowed for in early designs.

Secondary services should be located in a dedicated zone as well. A services void can be designed in perimeter walls and ceilings, deep enough to accommodate pipe runs, cabling and back boxes for sockets without penetrating the airtightness barrier. The ceiling service void should be deep enough for crossover of ducts and pipework, and allow for the optimum layout (short and straight) and size (large) of ventilation duct. The services should be coordinated with the airtightness barrier to keep penetrations to a minimum. Any necessary holes for incoming services should be sealed with suitable tapes, membranes and grommets. For a successful integration, a suitable strategy should be agreed with the M/E designer and contractor, and followed through on site with first, second and final fix inspection.

Designers should also consider off-site manufacture of service risers and cupboard, which can improve speed and quality of on-site installation and as-built performance.

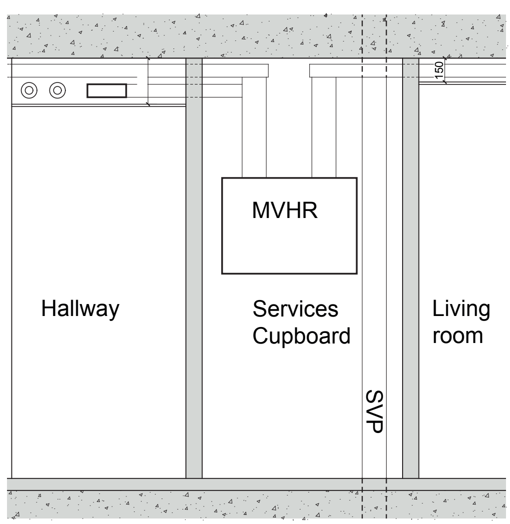


Figure 8.45 Insulated hot water pipes in ceiling void (left).

Figure 8.46 Adequate depth of ceiling service zone: 150–400 mm (right).

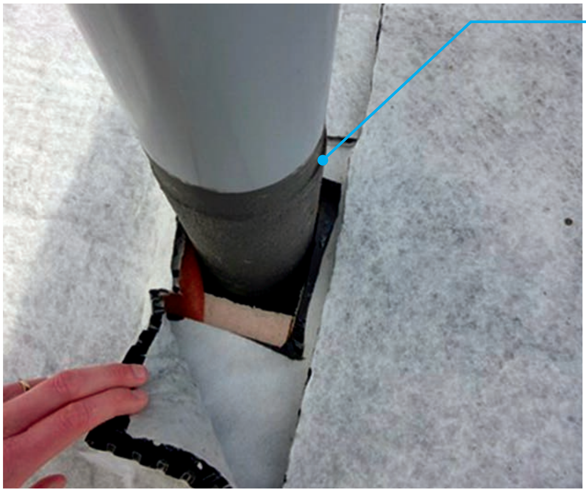


Figure 8.47
Gaps in insulation layer cause extra heat loss. Penetrations in external envelope need to be cut accurately, with no gaps in insulation.

Figure 8.48
Minimal services zone in ceiling can cause problems for clashing services and worse performance because of narrow, squashed ducts.

Figure 8.49
Service routes need to be designed at RIBA Stage 3, coordinated and installed following the building structure, before cladding and finishes. This ventilation duct was installed early enough for a bird to nest!

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Chapter 9:
How to deliver
improved
performance

Chapter 9:

How to deliver improved performance

9

Design for performance?

Designing for performance requires rigour in the specification and design process. It requires the project team to challenge typical assumptions and investigate the difficult details. It needs design teams to engage with the specialists at the right stages with an iterative modelling and design process that is followed to its conclusion.

This book has shown a number of common problems and performance issues when designing and constructing new homes. The details illustrated are an aid for designers to improve their own specific drawn information for new homes. They should help draw, write and test production information that is based on the realities of the building site to improve performance. In addition to making use of the good practice details in this book, designers need to challenge the way they currently work and enact the following:

1. Engage with suppliers, sub-contractors and site manager to ensure detailing is sympathetic to build process, systems and the as-built performance of materials.
2. Stop 'insulating by Autocad' which creates difficult or impossible operations for the site worker, leading to poor performance. Consider more robust methods and products that offer increased performance with easier installation processes.
3. Engage with the difficult detail, instead of just drawing the typical details that do not deal with the odd corner, junction or special case. These decisions can't be made on site, with contractors having to 'make it work', leading to poor performance.
4. Challenge the standard assumptions and use realistic values e.g. thermal conductivity of materials if wet and installed with realistic tolerance.
5. Engage with the construction stage and quality assurance on site. Designers should have an active role throughout the construction, assisting the contractor and client to improve quality of construction.
6. Engage with specialists at the right time to test the design and provide feedback e.g. overheating model at Stage 2 and thermal bridge calculations at Stage 4.

Construction for performance

The introduction to this book asks what contractors can do to improve performance of the building, and gives some solutions to the performance gap. The most effective solution improves both the energy performance and also the construction quality relating to structural, fire, acoustic, damp, moisture, longevity, services and aesthetics;

the complete performance of the building. The key reccommendation for contractors to ensure complete performance is to enact a rigorous quality management system with greater responsibility and role for the design team, sub-contractors, warranty providers and clerk of works on site. Effective step change can be brought about by revising sub-contractor tender packages, consultant appointments, meetings and checking processes to align with quality and performance. An insulation installer who is paid per complete house is unlikely to prioritise quality, especially if they know the site manager is too busy to check the continuity of the insulation. To improve quality, the tender requirements need to outline some simple performance checks, and rates of payment linked to these checks, rather than just getting the job done quickly. In addition the site manager and design team should discuss these performance requirements, checks and payment terms with the sub-contractors at a pre-start meeting.

This revised quality management system should include a quality manual for the site that explicitly sets out the performance requirements and offers illustrated examples of good practice and unacceptable standards. The contractor can engage with the design team in an iterative, continuous process, giving feedback on the designs and getting specialist input where necessary. The quality management system should ensure that commissioning is robust and transparent, and has a third-party check by a specialist or experienced clerk of works. It should require a sustainable design champion in the form of a site architect, engineer or technical manager to ensure consistent quality of products and installation.

Client's role: how to get a home that performs!

Homes should meet their intended comfort and energy consumption in order to meet their function; a comfortable shelter to live. In the U.K. most homes are delivered speculatively without a resident to engage with. However, some developers, clients and future residents have control over the brief and can set the parameters for success, which should include:

1. Ask design team and contractor how they will ensure the performance of the new home? Ask them to set, measure and meet performance targets for energy use and comfort. Possible options include Passivhaus certification, post-completion monitoring, Home Quality Mark or a performance assured or related contract.
2. For larger developments, ensure the facilities manager or user group is consulted at design stage and has an active role in the handover.
3. Ask for simple controls and building systems to meet your needs. If relevant, this could include smart systems to report actual comfort and energy data for breakdown of uses.
4. Use a procurement method and contract that puts more emphasis on quality and performance.
5. Employ a site architect or clerk of works as client representative to carry out site inspections. Use Appendix 1 as a template for inspection.
6. At handover stage ask for a home user guide, ask plenty of questions, file all the warranties and test all systems.
7. Establish a mechanism for feedback and monitoring of the building in the first year, and ensure any defects are dealt with in the correct time period.

This book has highlighted a number of practical ways in which the quality of new-build homes can be improved. The drawings, photos and appendices can be used in practice to improve the design and construction process. The recommendations in the book should assist design teams, contractors, policy makers and clients to recognise poor performance and deliver better homes. Wide-scale improvement will need further training and guidance, but crucially it will require renewed regulation, enforcement and a culture that demands homes to perform.

Appendices

Appendix 1: Site inspection checklist

This is a site inspection checklist to improve the construction quality of new homes to meet their intended performance.

It should be adapted to suit the project construction type and programme. Record all findings and photograph items that will affect build quality and energy performance in operation. Obtain copy of Part L SAP, EPC, Part F DVCG checklist, airtest and all commissioning certificates as a record of dwelling performance.

Development name:

Date:

General site conditions

A review of the site presentation including tidiness, recycling and waste segregation, working room (adequate scaffold, etc.), availability of information, toolbox talks and posters, quality inspection regime, materials protection and storage, etc.

No	Inspection item	Findings on site	Photo and drawing reference
1	Site presentation and tidiness		
2	Materials compound and storage		
3	Waste segregation and recycling		
4	Working room including adequate scaffold provision		
5	Availability of design information		
6	Security and changing, office facilities		
7	Energy-efficient site office and operations?		
8	Insulation, blocks, windows and other thermally sensitive materials stored correctly for performance?		
9	Is there a design guardian on site with quality management role, e.g. site architect or clerk of works?		
10	Is there an energy champion on site checking airtightness, insulation and services?		
11	Weather conditions and location (city, suburb, rural)		
12	Other comments		

Build Stage 1: Substructure floor

Inspection from the top of the concrete foundation to the top of the finished floor (beam and block, concrete slab, etc.); including insulation and screed where this is laid on top of the floor. Inspection to be conducted prior to screed pour and post screed pour.

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	Are the blocks/structural elements of the floor the correct thermal conductivity?		
2	Is the installation of the floor to manufacturer guidelines and free of debris, mortar snots or excess material?		
3	Has the correct insulation been installed in the floor and wall below DPC level (type and thickness)?		
4	Has the insulation been installed in tricky to reach areas like behind cavity trays, subfloor vents and under level thresholds?		
5	Has the insulation been installed continuously to the correct depth around the whole perimeter?		
6	Are there any significant cold bridges not accounted for in the design?		
7	Has all insulation generally been fitted tight to the substrate with no gaps between boards?		
8	Has the correct perimeter floor insulation upstand (type andand thickness) been installed?		
9	Has the perimeter floor insulation been fitted with tight butt joints between boards and against perimeter blockwork?		
10	Have incoming services been suitably insulated and sealed at floor level?		
11	Do the threshold junctions follow the detail; consider maintaining cavity width, cavity closer, insulation butted up to underside of closer?		
12	Has the screed ‘bridged’ the perimeter insulation or thresholds in any locations?		
13	Has the floor been overlaid with a min 500g DPM separating layer to prevent screed bleeding through joints?		
14	Any other performance gap issues? Any other comments?		

Build Stage 2: Ground floor to roof

Inspection from the top of the ground floor screed to top of external wall (sole plate level) not including roof structure.

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	External wall block or stud type (thickness and conductivity)		
2	External wall insulation type (thickness and conductivity) as design?		
3	External wall insulation installation quality; tight to substrate and board joints lightly butted / taped?		
4	Party wall block or stud type (thickness, density and conductivity) as design?		
5	Party wall insulation type (thickness and conductivity) as design?		
6	Party wall insulation installation quality; fully filling cavity and joints tightly butted?		
7	Party wall edge seals (type, position, thickness) as design?		
8	Quality of mortar joints or timber connections?		
9	Cleanliness of cavity/wall ties		
10	Is cavity or timber wall of consistent width and in line with design?		
11	Are floor joists on hangers that are tightly fitted with joints fully pointed up?		
12	If floor joists built into wall are they tightly fitted with joints fully pointed up and then mastic sealed?		
13	If timber cassette floor is supported into wall, is this junction insulated as design?		
14	Have cavity closers been installed in line with the specification; do they fit the cavity tightly?		
15	Is lintel installed as the design?		

Build Stage 4: First fix

Inspection from weathertight to completion of first fix.

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	Are any internal movement joints sealed fully with airtight expanding barriers (compriband)?		
2	Has gap between staircase string and wall been packed out and sealed?		
3	Has ventilation ducting been installed in line with design layout (type, location, number of bends)?		
4	Have service penetrations in the floor slab and wall been sealed airtight?		
5	Have any 'other' holes in the structure been formed and sealed?		
6	Have all heating controls been first fixed (programmers, weather compensator, etc.)?		
7	Has pipework (that will become concealed) been insulated to site specification and DHCG?		
8	Does the heating distribution network follow the basic principles of the design and manufacturer guidelines?		
9	Have pattress boxes on timber construction been sealed with rubber grommets?		
10	Any other performance gaps or quality issues?		

Build Stage 5: Drylined or plastered

Inspection from completion of first fix to fully skimmed, or tape and jointed, or fully plastered.

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	If external temp. less than 5 degrees is heating provided?		
2	Is all timber max. 20% moisture content prior to drylining? (BS8212)		
3	Is roof insulation in line with design; depth and type?		
4	Has roof insulation been installed cross-lapped, tightly butted to timber elements and between individual rolls?		
5	Has roof insulation been installed correctly at eaves and gable perimeters?		
6	Is there full depth of insulation at eaves?		
7	Where ventilation ducts or other plant installed in roof space has insulation thickness been maintained throughout?		
8	Is the loft hatch in line with design; opening direction, U-value or insulation thickness/type?		
9	Prior to drylining have all penetrations/gaps been foam filled to full depth?		
10	Are ceiling boards staggered and have boards over door openings been extended beyond jamb positions?		
11	Has the correct type and thickness of insulated plasterboard been used?		
12	Has a continuous ribbon of adhesive been applied around all openings, along the top and bottom and at internal and external corners of walls?		
13	Has a continuous ribbon of adhesive been applied over all service chases (best practice)?		
14	Have all penetrations been tightly sealed?		
15	Have all ventilation grille positions been maintained during drylining i.e. ducts not damaged or moved?		
16	Has any insulation or first fix work been disturbed by drylining, that may impact on performance?		
17	Any other performance gaps or quality issues?		

Build Stage 6: Second fixed

Inspection from completion of drylining to completion of second fix joinery, plumbing and electrical work

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	Has boiler been installed as specification, SAP and design?		
2	Is the hot water storage cylinder (HSWC) or thermal store in line with the design and SAP (make, model, size)?		
3	Are programmable room stats (or programmer and room stat) make and model in line with the design and SAP?		
4	Has boiler pipework been insulated to site specification and DHCG – min. 25 mm pipe insulation?		
5	Does PV panel array meet design assumptions like size, number, angle, specification, KwP, overshading?		
6	Is PV inverter suitably sized for array?		
7	Does solar hot water (SHW) system meet design assumptions and specification?		
8	Is SHW pipework fully insulated and correctly fitted to cylinder?		
9	Have ventilation fans (make and model) been installed in line with design?		
10	Has ventilation ductwork been installed as design and specification? Rigid, insulated, length?		
11	Have recessed downlights been fitted appropriately to the ceiling to maintain insulation thickness and airtightness whilst preventing overheating / burn out of lights?		
12	Have all gaps been fully sealed in wet-rooms and kitchens (under bath, shower, boxings, etc.)?		

Build Stage 7: Finals, commissioning and handover

Inspection from completion of second fix to completion of dwelling including test and commission stage.

Description of construction:

No	Inspection item	Findings on site	Photo and drawing reference
1	Have any ventilation grilles been moved or adjusted during decoration?		
2	Have ventilation ducts and terminals been sealed to prevent dust entering the unit and ducts during construction?		
3	Are all kitchen appliances fitted in line with specification, e.g. A rated?		
4	Have all doors been trimmed to achieve a clear gap underneath of 10 mm; 25 mm where no floor covering provided?		
5	Has the room stat been fitted a minimum of 1m away from any radiator and ideally on opposite wall?		
6	Have any sales extras been fitted that were not included in the design or specification but would impact on SAP, e.g. fireplace, downlighters, secondary heating?		
7	Are any shrinkage cracks visible?		
8	Have the DVCG commissioning sheets been completed for the ventilation?		
9	Are ventilation flow rates correct on commissioning sheet?		
10	For MEV and MVHR check fan power; is it set at, or near to, 100%? If so record approx. figure and check designed power rating with ventilation designer. Also check and note if fan is noticeably noisy (should not be above 30db).		
11	Have filters to MVHR units been replaced or cleaned following the construction stage?		
12	Have all duct terminals/grilles been locked into position using lock nuts?		
13	Has heating system been commissioned using manufacturer commissioning requirements?		

Appendix 2: Designed to Perform checklist

RIBA Stage 0 – Strategic Definition

» Understand client and their vision – reduced energy costs, low maintenance, health and wellbeing, reputation/image?
» Revisit previous projects with client to understand success factors and performance gaps.
» Building performance workshop with all stakeholders to analyse previous projects to bed in lessons learnt and clarify objectives for future development.
» Obtain energy data for previous projects either by meters or household bills and compare with EPC.
» Can you reuse or refurbish buildings on site instead of new build?
» Calculate life-cycle carbon emissions and costs of both new-build and refurbishment options.

RIBA Stage 1 – Preparation and Brief

» Agree formal energy targets / standards with regards to capital and operational costs. Possible energy targets to consider should be: Passivhaus, zero-carbon or Home Quality Mark. Engage with assessor or advisor at this stage for initial advice.
» Check local authority planning requirements for energy targets, e.g. London Plan or local SPGs.
» Carry out relevant surveys to meet sustainability targets or assessment procedures, e.g. ecological surveys, building services survey, existing building energy data.
» Confirm that handover strategy, commissioning check and post-completion services are included in the schedule of services for design team.
» Choose modelling tools and appoint relevant consultants to carry out environmental modelling work at next stage.
» Determine procurement route with regards to quality and as-built performance. Ask designers and contractor how they will assure performance. Is there a performance guarantee?
» Ensure that procurement route and appointment include quality checking on site.

RIBA Stage 2 – Concept Design

» Carry out the relevant draft energy assessment for initial design, e.g. PHPP and SAP.
» Ensure the initial Part L assessment uses SAP with realistic figures including services, U-values and psi-values.
» Carry out dynamic thermal modelling on all apartment blocks, and where SAP or PHPP highlights more than a slight overheating potential.
» Ensure that orientation, form and glazing are optimised with feedback from previous projects, rules of thumb and environmental modelling on the design.
» Issue a sustainability strategy drawing (section and site plan) to highlight key sustainable design features and clearly annotate in plain English.

- Dwelling form, location and orientation should account for: overshadowing from adjacent buildings or trees; minimal single-aspect dwellings; windows and rooflights to allow natural ventilation and daylight in habitable rooms (min. 2% average daylight factor); roof that maximises solar access; space for building services designed with future demands and climate; habitable rooms with sunlight and views; overheating risk; compact form to minimise heat loss.
- Agree a construction type with client and wider project team that is suitable for the building type, form, procurement and contractor.

RIBA Stage 3 – Developed Design

- Review energy performance of design against targets and update energy models including PHPP, daylighting or dynamic thermal simulation using CIBSE TM59 for overheating.
- Carry out a formal energy assessment using Building Regulations and declare the design stage carbon/energy performance with a design stage SAP certificate.
- Draw a continuous red line to represent the airtightness layer around the building section.
- Review thermal bridging potential for SAP and appoint specialist to calculate psi-values of key details at next stage.
- Specify simple building services with space for ease of installation, use and maintenance.
- Compile energy performance targets into the Stage 3 drawings and specifications for tender. This will include SAP calculation and inputs, Part F ventilation strategy, PHPP model report, dynamic thermal simulation, building handover and monitoring strategy, key envelope detail drawings with airtightness target and specialist subcontractor design.
- Specify as-built monitoring or performance using measurable targets.

RIBA Stage 4 – Technical Design

- Check construction details for continuous airtightness and insulation and specify products and installation method on drawings.
- Coordinate drawings and specification with all consultants for a building control submission to include any agreed changes in an updated energy assessment.
- Ensure construction drawings are fully co-ordinated with energy specification and assessments, and have key specification notes on drawings.
- ‘Build tight, ventilate right’ – match airtightness strategy with a controlled ventilation strategy.
- Discuss with ventilation specialists to ensure a suitable, robust ventilation system is specified and design is coordinated.
- Check compliance of energy performance of all drawings and specifications from specialist subcontractors.

- Specify suppliers and installers that are adequately experienced and qualified including: MCS certified – renewable technology; BPEC – ventilation, plumbing, electrics, Gas Safe register, etc.
- Ensure performance targets are met by any product substitution and check with client, design team and energy assessor before agreeing to a substitution.

RIBA Stage 5 – Construction

The architect's role is to be:
A. Client's quality monitor, or
B. Contractor's designer.

A. Client's quality monitor

- Use the 'Designed to Perform site checklist' in Appendix 2 to check construction quality and performance.
- Monthly site progress report to include evidence of performance gaps and recommendations for improvement.
- Take photos as a record of completed work at different stages.

B. Contractor's designer

- Appoint an energy champion on site to ensure performance of airtightness, insulation and services.
- Draft a non-technical home user guide that is easy for all to read, including diagrams, photos and specifications.
- Meet and work with facilities manager/sales team/residents for successful handover.
- Agree responsibilities for monitoring and data recording methods.
- Assist contractor with updates/changes affecting issue of the Part L Energy Performance Certificate (EPC) issued once the air test is complete.
- Contractor to complete domestic ventilation compliance guide checklist with commissioning of ventilation units.

RIBA Stage 6 – Handover and Close Out

- Collate information for final sustainability certification or planning conditions, e.g. Passivhaus certification or HQM.
- Check all commissioning certificates including the EPCs and the Part F Domestic Ventilation Compliance Guide Checklist.
- Complete and issue the home user guide with all information on building services warranties, operation and maintenance.
- Label services with information on future maintenance.
- Give occupants a home welcome visit and return 6 weeks later to check operation.
- Encourage occupants to try out systems and controls.

RIBA Stage 7 – In use

- Return to residents and client 8–12 months after completion to check satisfaction, ask for feedback on the design and services in operation and observe dwellings and communal space in use. Check energy bills are as expected and compare with EPC.
- Carry out post-occupancy evaluation using resident surveys and environmental monitoring in years 1–3.
- Declare as-built energy performance after 2 or 3 years in operation and share with project team and online with website such as www.carbonbuzz.org
- Review successes and lessons learnt with client to inform Stage 0 and improve brief for next project.

Appendix 3: Thermal conductivity assumptions

The psi-values have been calculated according to BR 497[9] using internal boundary conditions and are compliant with Part L of the Building Regulations. THERM 7.4.3 has been used to calculate the 2D models and TRISCO 13.0 has been used for the 3D models. Details noted with the PH icon are also suitable for Passivhaus standard, but the psi-values must be recalculated with external measurements for use in the PHPP.

The table below shows the material thermal conductivities that have been used for the calculations.

The U-values of the thermal elements have been calculated according to BR 497,

Material	Thermal conductivity (W/m^2K)
Insulation board (PIR or PU)	0.022
Insulation (generic)	0.040
Mineral wool insulation	0.044
Plywood sheathing	0.130
Timber	0.130
Concrete block (lightweight, high strength)	0.190
Plasterboard	0.210
EDPM membrane	0.250
Brick outer leaf	0.770
Concrete screed	1.15
Concrete block (dense)	1.13
Soil	1.5
Reinforced concrete	2.3
Stainless steel	17
Steel	50
Aluminium	160

section 3.1.3 and repeating thermal bridging elements have been included in the model when required. The psi-values show heat loss of each junction and provide a useful comparison and improvement to the SAP default values. The details are to be treated as good practice examples and are not accredited details.

The psi-values should not be used in SAP calculations for compliance purposes. There are a number of industry-sponsored online libraries that can be used for standard construction detailing, e.g. LABC.[10] Alternatively, bespoke calculations should be carried out by a competent person using BR 497.

According to the BRE, the critical temperature factor for avoiding mould growth in dwellings is 0.75. The critical temperature factor for limiting the risk of surface condensation is 0.80.

Further Reading

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Endnotes

1. ZCH thermal bridging guide appendix jamb psi-value from 0.05 to 0.120 (140% worse) – page 3.
2. Thermal bridge example (Figure 0.2). Taken from Builder's Book, Zero Carbon Hub. 2015. – page 3.
3. Zero Carbon Hub, Ventilation in new homes study – page 5.
4. https://www.rehva.eu/fileadmin/hvac-dictio/01-2013/Research_into_the_effect_of_improving_airtightness_in_a_typical_UK_dwelling.pdf – page 17.
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