Designing homes for the 21st century

Lessons for low energy design

Guide

NHBC Foundation

ZERO CARBON HUB

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Acknowledgements

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Special thanks to:
Thomas Lefevre, Director of Etude;
Richard Quincey, Technical Director of IES;
Alan Gilbert, Instrumental Solutions, BSRIA;
Tessa Hurstwyn, Zero Carbon Hub.

Front cover image: Derwenthorpe Housing, York
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photography © Kippa Matthews Photography and courtesy of Joseph Rowntree Housing Trust and David Wilson Homes.

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NF 50
Written and illustrated by Richards Partington Architects on behalf of the NHBC Foundation.
ISBN 978-1-84806-331-0

About the NHBC Foundation

The NHBC Foundation was established in 2006. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target.

The NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

Glossary: Technical terms

Air changes per hour:
The rate of ventilation expressed in terms of the number of times the entire volume of air in a home is replaced within the duration of an hour.

Airtightness:
The descriptive term for the resistance of the building envelope to the leakage of air. The greater the airtightness, the lower the air infiltration.

Cross-ventilation:
Natural ventilation that would generate air flow across a space and is achieved by opening windows on more than one façade of a building.

Mechanical ventilation with heat recovery (MVHR):
A balanced mechanical whole-home ventilation system where stale air is removed from wet rooms and fresh air is supplied to habitable rooms. In the ventilation unit, heat is removed from warm extracted air via a heat exchanger and is used to pre-heat the incoming supply air.

Standard Assessment Procedure (SAP):
The Government's approved method for calculating the energy efficiency and carbon emissions from homes to demonstrate compliance with the Building Regulations.

Stack effect:
The movement of air due to natural buoyancy caused by warm air rising up the height of a space. This would require a low-level inlet for air to enter the space and a high-level opening for the air to escape through.

Fabric Energy Efficiency Standard (FEES):
Fabric energy efficiency is the foundation of the Government's zero carbon homes policy. It will ensure that all new homes are sufficiently well insulated and constructed to meet ambitious energy saving targets, by requiring energy demand to be reduced first.

Foreword

There has always been a need for the design of new homes to adapt to and incorporate new features and new technologies and over recent decades this has been achieved through gradual evolution. Generally, adjusting the fabric to accommodate more thermal insulation or extending the services installation to provide more facilities has been sufficient to meet the expectations of the day.

The challenges we face in designing homes fit for the 21st century are more comprehensive. We need homes that achieve zero carbon performance, whilst providing a healthy indoor environment. We also need homes that are resilient to climate change and are not susceptible to overheating for extended periods of the year.

The extent of these challenges makes some question whether gradual evolution will remain the right approach or whether there is a need for a more fundamental review of housing design.

This guide explores the challenges of designing for the 21st century and helps to identify processes needed to ensure that cost-effective and practical solutions can be delivered. It helps us to understand the need for integrated design, which does not rely upon a 'business as usual' approach with additional technologies being bolted on. It also reminds of the need for the design to take full account at an early stage of the needs of the home's occupants to ensure that they are able to realise all of the benefits of a new home.

I hope that this guide will be helpful to all home builders and designers, but in particular that it will be invaluable to smaller companies.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation

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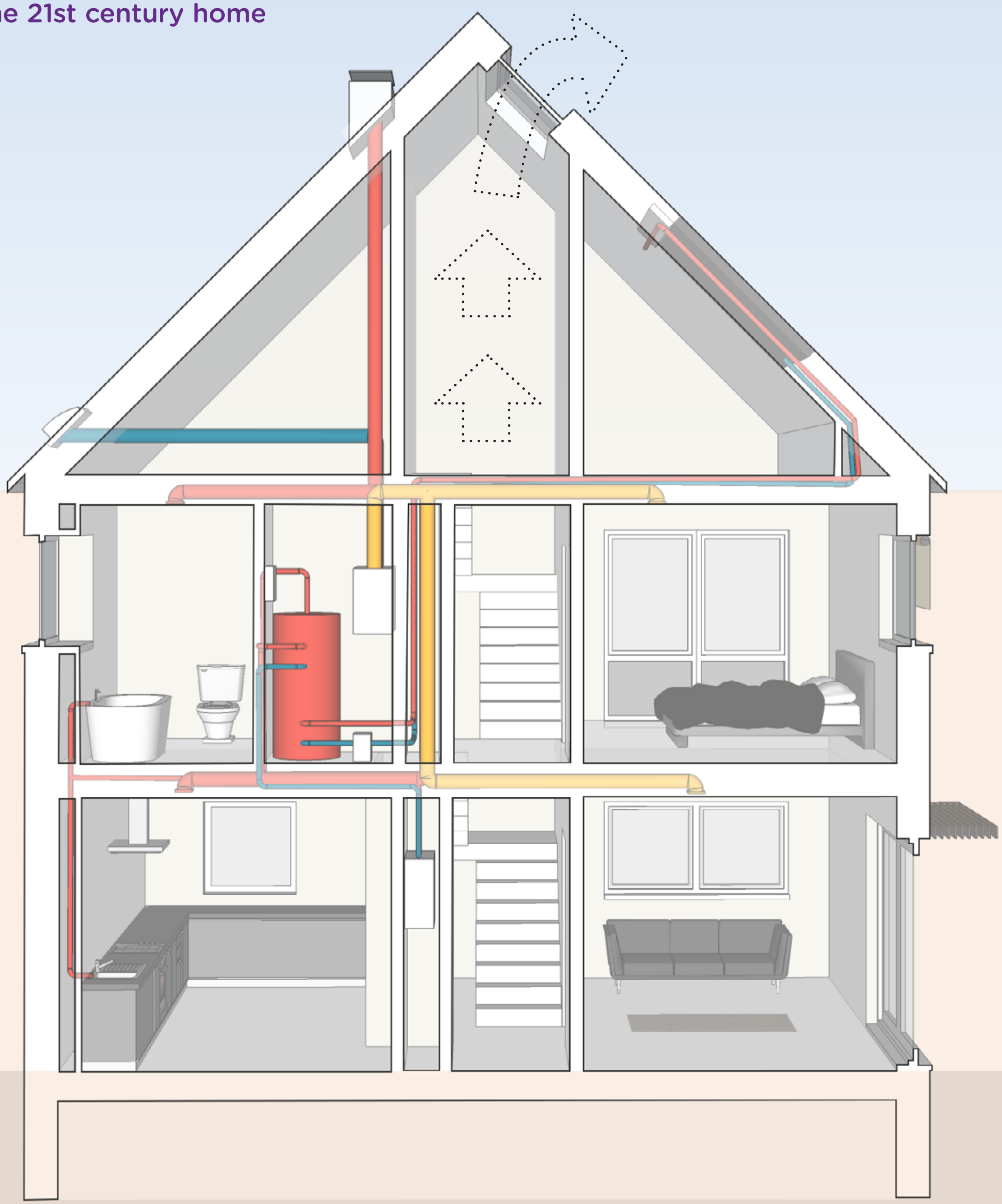


This guide will help you to design and commission homes that include:

1. Simple, efficient services
Homes should be designed around a logical services strategy, providing efficient and accessible routes for ventilation ducts, pipework and wiring.

2. Fabric First
The most robust way to minimise energy use is through the building fabric. Getting the fabric right will save energy for the whole life of the dwelling.

3. Adaptations for climate change
Homes should be designed to adapt to climate change, especially the prospect of higher average temperatures, more frequent, heavy rainfall, and the increased likelihood of flooding.

4. Balanced priorities
Designers should think about insulation, airtightness, ventilation, comfort and acoustics simultaneously as each issue interacts with the others. For instance, heat saving measures should not be pursued at the expense of good ventilation and indoor air quality.

5. Good ventilation
Window design and positioning should take account of overheating (unwanted solar gains), daylighting, security and ventilation.

6. Appropriately sized systems
The design of services (heating and hot water) should be appropriate for the predicted occupancy and fabric performance.

7. Simple and intuitive controls
Homes can only operate efficiently when the occupants understand how they are intended to run and how to get the best performance from them. Controls, switches and displays must be simple, intelligible and intuitive.

8. Passive and active measures
To create an efficient 'system' designers should understand the relationship between passive (fabric, structure, finishes) and active measures (services, ventilation, heating).

9. Low and zero carbon technology
Expensive low and zero carbon technologies should be optimised once the demand has been reduced. Safety factors and overdesign should be minimised, whilst retaining suitable flexibility.

Introduction to the guide

The home-building industry is undergoing unprecedented change and it seems likely that the future home will include more technology than ever before, presenting challenges for construction and operation. Even now, there are concerns that the homes we are building today are difficult to maintain and operate; that technology may not be delivering to its full potential and that, in the drive to conserve energy, we may be inadvertently inviting other problems such as overheating and poor indoor air quality. Current design and procurement practices may need to change if these issues are to be addressed and this has implications for designers, developers and importantly for the end users – the people who have to live in and operate the home.

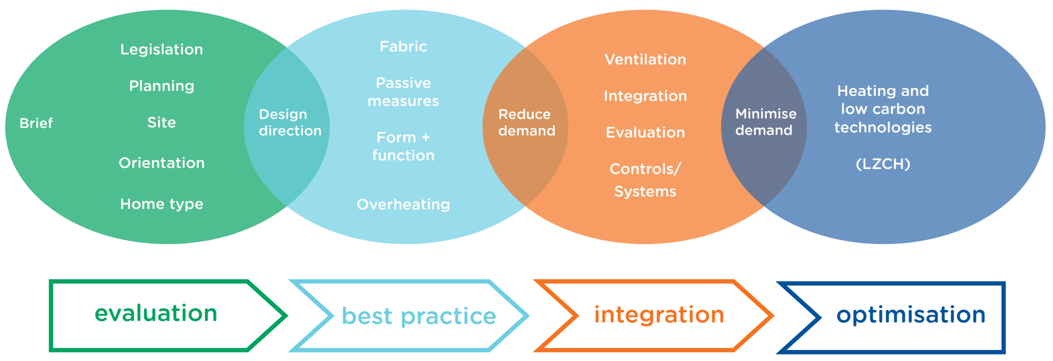
Much of the guidance that has been produced to support the industry has focused on targets and outcomes with little regard for process. This brief overview describes the processes and decisions that should be made to arrive at a robust and functional low energy design. It identifies dependencies between the passive aspects of the home (the fabric of the external walls, the insulation and immovable parts) and the active systems (services, ventilation and heating). It encourages designers to understand that these two aspects have to be planned for concurrently, and the effectiveness of each is highly dependent on the other.

The aim of the guide is to promote a better understanding of the 'whole' without getting drawn into the detail of technological solutions or the regulations they serve.

In the guide we have placed a lot of emphasis on the design of effective ventilation, anticipating the widespread use of mechanical ventilation which is becoming a common feature of very highly insulated and airtight homes.

The guide is divided into four sections corresponding to a logical sequence of steps that ought to underpin the design process. Starting from the very first decisions that need to be made at a planning stage, the guide illustrates practical examples to promote a better understanding of the essential elements of a low energy design.

In the last section, we look at ways of providing heat and hot water to the home and briefly explain the challenges presented by low and zero carbon technologies. This is not a comprehensive survey of all the technologies available but it does identify common issues for the design, installation, commissioning and operation of the systems.



Section 1: Evaluation – policy, planning and context

1.1 Introduction

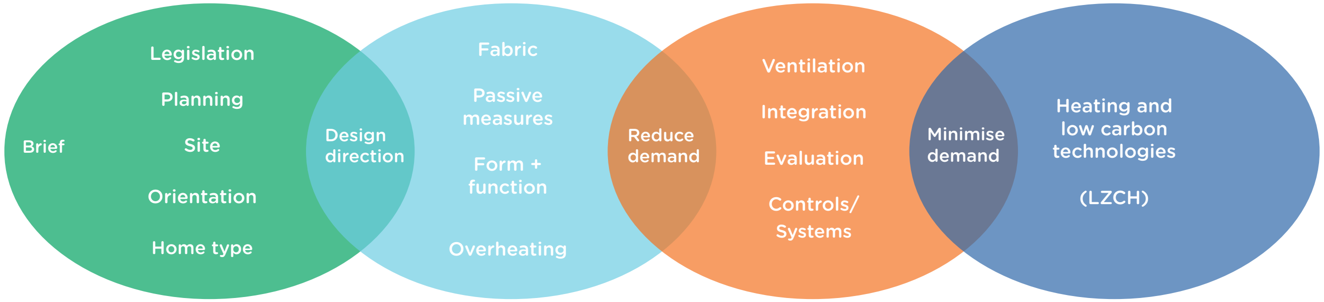
Until quite recently all types of home design, from houses of traditional appearance to fully glazed urban apartments, could be made to comply with Building Regulations. The standards set for conserving energy and achieving adequate ventilation would not necessarily influence the shape or appearance of the home. In most cases, simple ventilation strategies with opening windows and background ventilators would suffice. The low energy home presents a different challenge: glazing area, shape and ventilation strategy will all be critical. Decisions made at the first briefing will continue to impact on the practicality of the design, right through to commissioning and handover of the finished home. Some early thought also needs to be given to low carbon technology and services and their compatibility with the fabric.

This guide advocates a 'fabric first' approach, making sure that insulation, airtightness and ventilation are designed to give the best practical performance before low and zero carbon technologies are applied.

The fixed fabric elements are generally longer lasting and less easily upgraded, so getting the fabric right will also help to future proof the home. Future proofing the home, both against increasing energy costs and the consequences of climate change, is a theme of the first section. A design that achieves planning consent must also be capable of delivering the energy performance without unduly limiting technology choices.

Some questions need to be addressed early on: Has enough space been made for services? If solar renewables are required, is there a large enough southerly roof area? Will there be overshadowing from adjacent trees, adjacent buildings or future development? Will there be adequate ventilation? Are wall thicknesses realistic? Are window areas optimal for daylighting without causing overheating?

This first section deals with these early decisions made at the inception of the project, with the aim of improving the general awareness of all the contributors to the process including policy makers, planners and professional advisers.



1.2 The brief and the project team

Increasingly, developers are required to make energy assessments and calculations to accompany a planning application, often to meet 'Merton Rule' type renewables commitments. With the localism agenda, the ability for different authorities to apply different interpretations is likely to continue so it is important to be alert to the implications of these policies, some of which may seem to contradict other planning requirements that seek to influence materials, appearance and detail. Extensive calculation is not necessarily required but a working outline of the energy strategy and fabric standards should be in place, even if this means that the design has to be developed in a little more detail.

A small builder will probably have a good relationship with advisers and suppliers and will 'evolve' familiar construction systems and details to meet the new standards, but will also have to rely on advice from the architect and energy assessor who must be knowledgeable and competent in low energy design.

The first stage is to assess the advice that may be needed and clearly define the scope and responsibilities of advisers. For small projects, this does not necessarily mean that a full 'design team' needs to be assembled but it does mean that the designers, assessors and suppliers need to be aware of the implications of national and local energy policy from an early stage. A clear brief should be set for construction methods, materials and technology choices based on what you know will work for your particular project.

The Parkmount Scheme was originally promoted by a public housing provider who wanted all of the technological 'bells and whistles'. However, a large portion of the budget would have been consumed by costly and untried technology. In the final brief, it was agreed that the building form would respond to solar orientation for renewables, anticipating that they might become affordable in the not too distant future.

All of the effort and resources then went into future proofing the homes by working on improved fabric, insulation and window performance and ensuring that there was excellent daylighting. Small trial areas of new technology were tested.

Parkmount Housing Scheme, Belfast, architects: Richards Partington Architects, photography © Timothy Soar

Arun Crescent aimed to achieve Code for Sustainable Homes level 5. The strategy involved significant amounts of photovoltaics (PV) on the roofs which have a saw tooth profile.

Note, though, that when the sun is low in the sky the roof of one house casts a shadow over the PV array of its neighbour. These effects are often unavoidable but ideally should be modelled and the results factored into the overall performance predictions.

Arun Crescent, Billingshurst, architect: Harrington Designs, developer: Saxon Weald Homes Ltd, photography © Jane Alexander

The Brookwood Farm project sought to achieve Code for Sustainable Homes level 5 with a more traditional appearance.

The specification included very good fabric performance combined with heat recovery and some renewables in the form of integrated PV roof tiles.

Brookwood Farm, Woking, developer: William Lacey Group, photography © William Lacey Group

Define a clear and realistic brief for the project and adhere to it as the project develops.

Key points to consider:

- **Make an appraisal of the project requirements and make sure that you have commissioned or can access the right expertise and advice.**
- **Define the technical brief and likely performance targets as early as possible, taking good advice.**
- **Develop the energy strategy alongside the home design and layout.**
- **Keep up to date with the information issued by organisations including the NHBC Foundation.**

Further reading:

Sustainable Architecture (RIBA Publishing, 2007), presents a variety of case studies demonstrating a range of sustainable design techniques.

Sustainable Urban Design: An Environmental Approach (Spon Press, 2003), gives a balanced overview of the principles of good place making, illustrated by case studies.

Temple Avenue Project: Energy Efficient New Homes for the 21st Century (Joseph Rowntree Housing Trust, 2012), describes the design, construction and testing of two low energy houses in York that were a follow-on from the Elm Tree Mews project.

1.3 Context, landscape and topography

The position of the home within its surroundings and its relationship to the rest of the development, existing or proposed, will have a strong influence on the effectiveness of the overall energy strategy.

Most development sites are constrained in one way or another and occasions where the physical context (overshadowing, privacy and landscape, etc.) can be ignored are rare. So there will be a balance between attractive layout and design and good practice engineering, and it is unlikely that one factor, for instance, solar orientation, should dominate the design entirely. As standards become more demanding it will make sense to use the relatively expensive low and zero carbon technologies efficiently. To make a balanced judgement the actual impacts of the context should be assessed, for instance, accounting for a loss of output from overshading or from less than optimal orientation for solar panels.

Generic home types designed for use in any situation or orientation will need to be reviewed in the context of each site, especially if there is a danger of overheating where large window areas are to face south or south-west (see further reading NF44). Homes built to current standards with high fabric performance and airtightness are more sensitive to orientation for heat loss and for overheating.

Knowledgeable designers will be better at responding intuitively to the context and topography but energy modelling may have to be used earlier in the process to give an outline strategy, or at least a sense check, to ensure that the emerging design can deliver the environmental performance. It is also likely that where modified standard homes are used to suit planning requirements (for instance, adding dormers, varying roof profiles or stepping terraces) the energy performance will change.

At Officers Field biomass heating was chosen as a low carbon fuel, which helped to achieve a roof appearance that is similar to the surrounding areas.

Officers Field, Weymouth, architect: HTA, developer: ZeroC Holdings, photography © HTA

Both Officers Field (page 6) and Chewton Mendip, shown here, were built in areas where planning policy limited the use of renewable technologies, leading to solutions that focused on the fabric performance, heat recovery and the use of heat pumps.

In the case of Chewton Mendip the planners insisted that renewables were not visible on the roofs. A fabric approach was adopted, and the designers targeted a 50% improvement on Approved Document Part L of the 2006 Building Regulations standard.

Chewton Mendip, Somerset, architect: Architecture DH, photography © Arthur Bland

Understand the physical context, landscape, topography and the policy requirements.

Key points to consider:

- An appraisal of the site and its context should be made to establish what the likely constraints will be: are adjacent buildings or trees overshadowing the site, or will they in the future?
- How are the living rooms arranged in relation to sunlight, open space and views?
- Does the arrangement of windows and openings allow for good natural ventilation?
- Does the roof design maximise the opportunities for solar access?

Further reading:

Urban Design Compendium 1 (English Partnerships, 2000), discusses key principles of urban design supported by case studies of living, working and social environments.

Sustainable Urban Design: An Environmental Approach (Spon Press, 2003), gives a balanced overview of the principles of good place making, illustrated by case studies.

Building for life 12 (CABE at the Design Council, 2012), describes 12 criteria that can be used to assess the quality of design of homes and neighbourhoods.

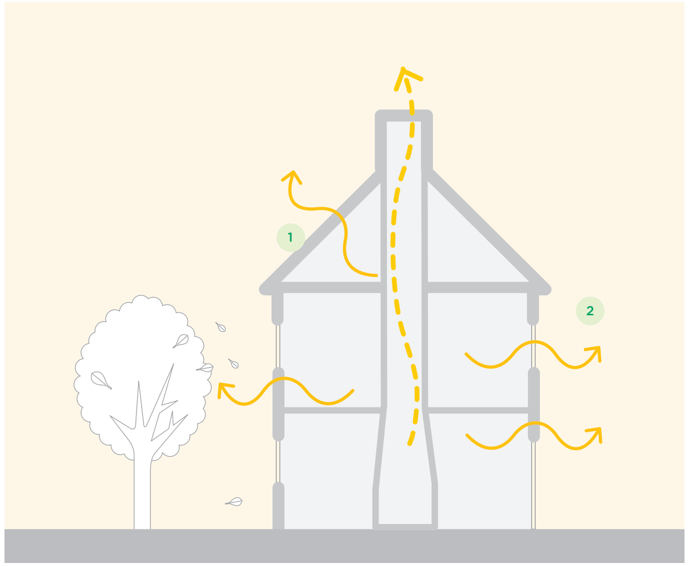
Understanding overheating: Where to start: an introduction for house builders and designers (NF44) (NHBC Foundation, 2012), explains the common conditions that could lead to the potential problem of overheating in new homes and suggests measures that can be incorporated.

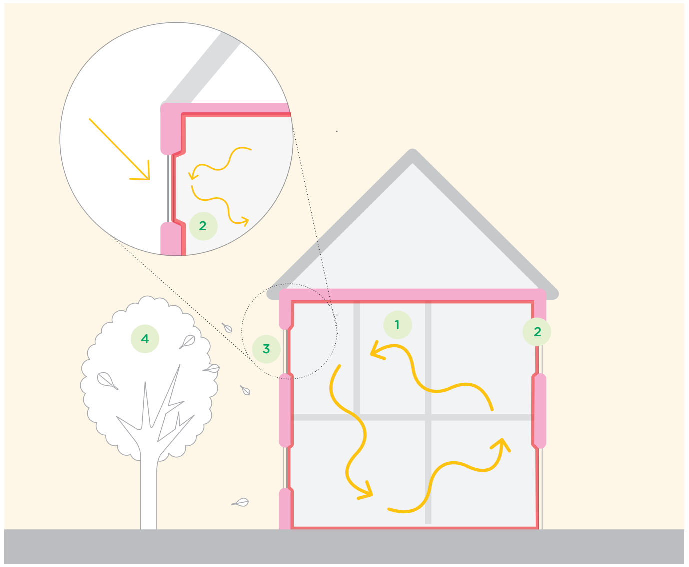
1.4 Adapting to a changing climate

With a changing climate there will be an increased risk of flooding, and the likelihood of more intense storms with high rainfall concentrated over short periods. Flood risk attracts considerable public interest and is now addressed by strategic policies and by local planning authorities who undertake statutory consultations with the Environment Agency. However, increased intensity of rainfall will also affect the design of guttering and downpipes as well as the capacity of site drainage systems.

Although less frequently discussed, overheating will be one of the most serious challenges of climate change. Even conservative estimates suggest that by 2050 London will experience external temperatures equivalent to those of Marseille today. Unless we plan seriously for increased temperatures in the future we are likely to see much greater use of portable and retrofitted air conditioning, both of which are electricity and carbon intensive. The carbon savings achieved in winter by saving heat can easily be undone by air conditioning. Once installed, such systems are likely to be used regularly and in less extreme conditions than those that may have triggered the initial purchase or retrofit.

Many practical measures to reduce overheating are available to us now, for instance, external shading and night cooling combined with thermal mass, but these are not yet routinely incorporated in home designs. It is not realistic for the small home builder to use sophisticated modelling tools to evaluate these measures for every home design, so we are likely to have to rely on a degree of common sense and practical knowledge. Large areas of south facing glazing will need some kind of solar protection (external shading or solar protecting glass). Upper floor corner flats with south and south-west elevations will be more prone to overheating than north facing, mid-floor flats. So, when early studies and checks are being done, potential problem units should be investigated in more detail and possibly, if the designs cannot be altered, with the use of a dynamic tool.





Recent NHBC Foundation research (see further reading NF44) has also highlighted the impact of internal lighting and appliance gains, the excess heat from services and plumbing, and from poorly designed hot water storage and distribution.

Conventional house

1. Heat loss through building fabric due to lower levels of insulation.
2. Heat loss through leaky building fabric such as minor gaps between windows and openings in walls.

Highly insulated house

1. Increased insulation in new homes limits heat losses and gains through the building fabric.
2. Improved airtightness can reduce ventilation heat losses and may also lead to the retention of unwanted heat gains inside the home.
3. Smaller windows in bedrooms help reduce solar gains in spaces occupied at night.
4. Use of obstructions such as optimally located trees can provide solar shading from strong and unwanted sun from the west.

Air conditioning units, providing cooling for a supermarket, discharge heat into the atmosphere. As well as being carbon intensive, their widespread use for cooling is actually adding to the 'urban heat island' effect.

In urban areas, surface materials of landscaping, paving and external finishes to buildings can affect the temperature of the surrounding air. As a result, night-time air temperatures in dense urban areas remain high.

Be aware that in a changing climate there will be increased risk of flooding and overheating.

Key points to consider:

- Be aware of the potential for well insulated, airtight homes to overheat in summer.
- Pay attention to the location and size of window openings and protect large areas with external shading.
- Passive measures to limit overheating, such as shading, are essential if the ability to use the ventilation might be compromised by external factors such as noise or pollution.
- Air conditioning is not a sustainable answer to overheating.
- Pay attention to the location and insulation of heat distribution pipework within the home, and in common areas of flats so that it doesn't increase the risk of overheating.

Further reading:

Design for Future Climate: opportunities for adaptation in the built environment (Technology Strategy Board (TSB), 9th July 2010), looks into the impact of climate change at various scales and discusses mitigation measures.

Understanding overheating: Where to start: an introduction for house builders and designers (NF44) (NHBC Foundation, 2012), explains the common conditions that could lead to the potential problem of overheating in new homes and suggests measures that can be incorporated.

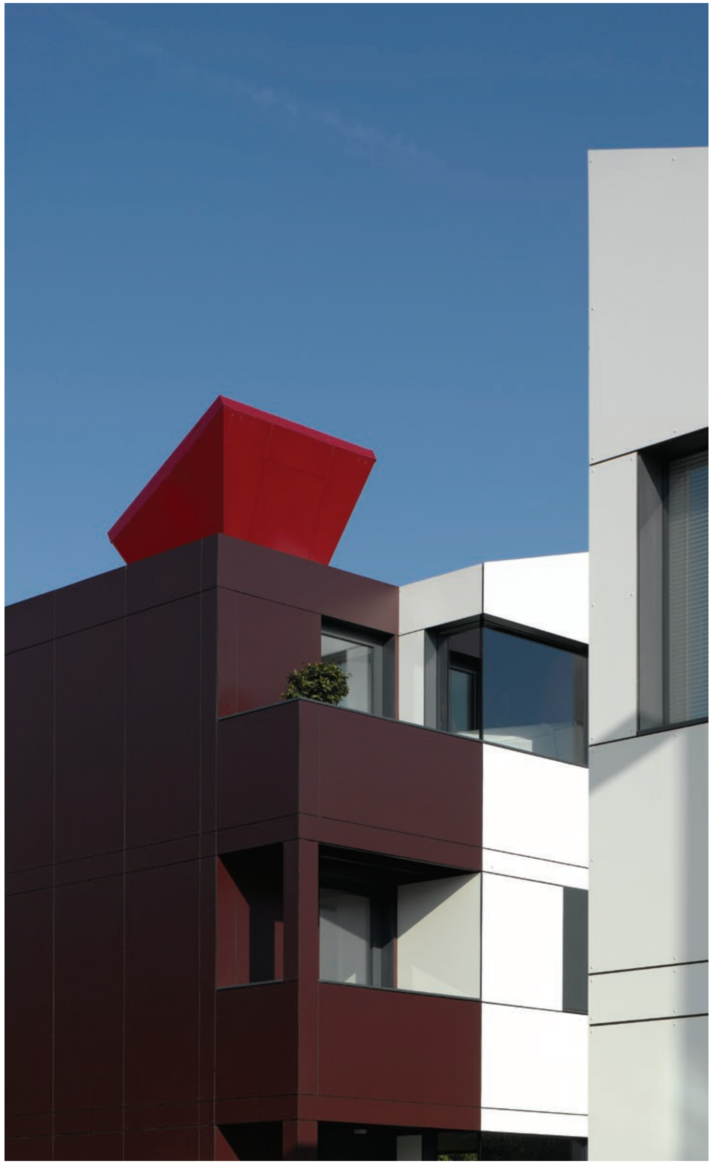
RIBA Climate Change Toolkit : 07 Designing for Flood Risk (RIBA), intended primarily for designers, this comprehensive toolkit covers all aspects of sustainability, available from: http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/Environment/2Designing_for_floodrisk.pdf.

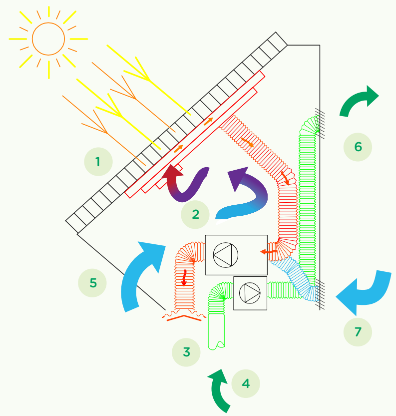
1.5 Predicting overheating

One of the main conclusions of NF44 is that correct ventilation is essential for reducing overheating risk. In most cases, this means providing sufficient cross-ventilation to deliver 4–5 air changes per hour. The uptake of mechanical ventilation systems is steadily increasing and these systems are often mistakenly thought to provide a means of preventing overheating. A domestic ventilation unit or a mechanical ventilation with heat recovery (MVHR) system does not normally deliver sufficient ventilation even on a boost setting, so a correctly designed system of opening windows or vents that can deliver effective ventilation is also needed. To work properly, this ventilation must also be available at night or when the dwelling, or particular rooms, are unoccupied, in other words, 'secure ventilation'. It is also possible to reduce the severity of overheating by modifying the climate immediately adjacent to the home, with shading, awnings, planting or a combination of these measures.

Since 2006, the Building Regulations Approved Document Part L has required designers to demonstrate that homes will not be prone to overheating. There has been some concern regarding the effectiveness of the overheating check in the Standard Assessment Procedure (SAP) and in practice it will often be used rather late in the process, when decisions about window area and orientation have already been fixed. The SAP tool only signals the likely 'risk' that there may be a problem and it is not intended to be a design tool. More complex software can model overheating more accurately, taking account of the effect of the external balconies and planting etc., and the design of the shading can be optimised.

Our recommendation is that all designers should be familiar with the contributing causes and conditions described in NF44 and should ensure that adequate cross-ventilation can be achieved.





1. South facing heat exchanger
2. 'Eco-hat' holding warmed air
3. Air supply diffuser
4. Air extract diffuser in wet rooms
5. Fresh air inlet into 'Eco-hat'
6. Extracted air outlet
7. Fresh air inlet bypassing heat exchanger (summer supply mode)

At Oxley Woods the 'Eco-hat' is a purpose designed, off-site manufactured services pod, which supplies pre-heated air in winter and cooled air at night time. A summertime bypass and a series of manually operated vent panels in each room help to counter overheating. Despite the sophistication of the mechanical system, it is not designed to 'purge' the dwelling for overheating.

Oxley Woods, Milton Keynes, architect: Rogers Stirk Harbour + Partners, photography © Rogers Stirk Harbour + Partners

Work by the Zero Carbon Hub (see further reading) concluded that a dynamic modelling simulation will be more accurate for assessing overheating. Three different methods were tested, but each used different assumptions about thermal discomfort. As the underlying assumptions are different in each model, it is hard to draw conclusions about the absolute 'accuracy' of the different approaches.

The illustration (top right) is the Welsh Passivhaus, designed by Sustainable By Design. When modelled in SAP, which cannot accurately account for the shading devices, an overheating risk was predicted for summer. When modelled with the Passive House Planning Package (PHPP), which accurately accounts for external shading devices, the home did not overheat. However, PHPP uses a different definition of overheating so the results require careful interpretation.

The Old Apple Store (right) is a built example of a home using large areas of south facing glazing but with carefully designed shading from the balcony and roof overhang.

The external retractable awning at Lynn Road (far right) provides shade for a large area of south facing glazing.

In a well insulated home a small amount of additional heat can cause a significant rise in temperature.

Key points to consider:

- **Take account of external factors that may prevent an effective ventilation strategy.**
- **Is the designer aware of the factors contributing to overheating?**
- **Is the home capable of having adaptation measures fitted in the future?**
- **Do not rely on the outputs from simulation tools without considering external factors that may compromise the ventilation strategy.**
- **There are differing interpretations of acceptable comfort used within the simulation tools.**

Further reading:

Carbon compliance for tomorrow's new homes: A review of the modelling tool and assumptions, Topic 3 – Future climate change (Zero Carbon Hub, Aug 2010), evaluates the current methods of assessing overheating, for compliance and design development, and highlights various shortcomings.

Design for Future Climate: opportunities for adaptation in the built environment (Technology Strategy Board (TSB), 9th July 2010), looks into the scientific data available on climate change and how this can be used for predicting overheating.

Overheating in new homes: A review of the evidence (NF46) (NHBC Foundation, 2012), presents evidence of overheating in energy efficient homes, collected from case studies and demonstration projects.

Section 2: Building fabric and the shape of the home

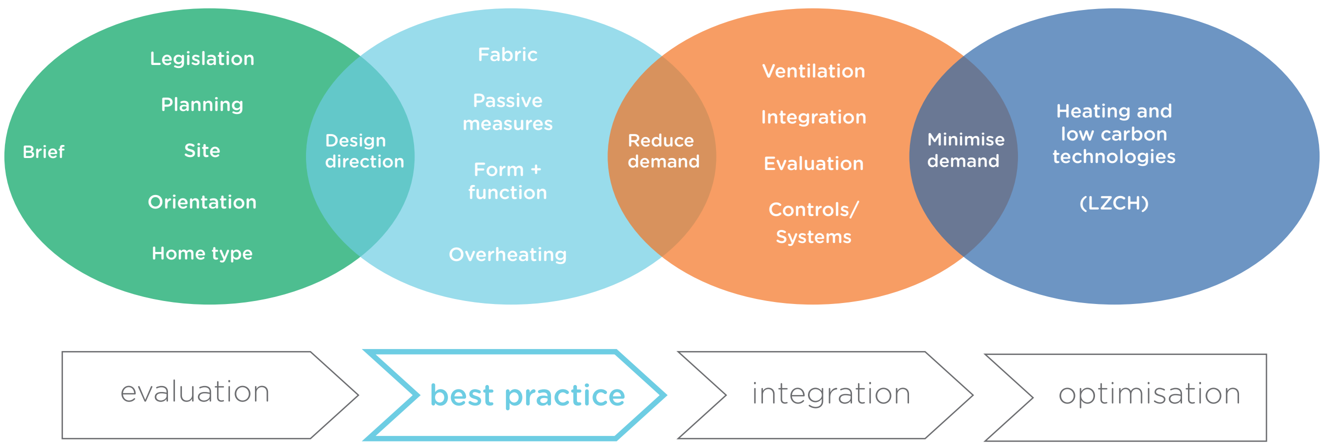
2.1 Introduction

As a result of progressive improvements to the Building Regulations, there is a much better understanding of the benefits of insulation and improving airtightness. However, other aspects of heat loss are less well understood and are less easily solved, for instance, the industry is still developing the solutions for dealing with issues such as thermal bridging. As we approach a point where additional thicknesses of insulation only achieve diminishing returns, it will be necessary to consider these other aspects such as the heat loss from windows and look to areas where further improvements can be made, for instance, with triple glazing.

Fabric energy efficiency should be the foundation of all highly energy efficient homes. The proposed Fabric Energy Efficiency Standard (FEES, refer to glossary) will help ensure that all new homes are sufficiently well insulated and constructed to safeguard occupiers against uncertain future energy costs by creating a minimum standard for all homes. It will also discourage the tendency to use low and zero carbon technologies as an alternative to energy efficiency measures.

For some home builders it has been more economical to meet standards by applying technology to an existing specification, for instance, adding solar thermal or PV instead of revising the specification for external walls and increasing insulation. It should be understood that the FEES is by no means the maximum that can be achieved with fabric, and organisations such as the Association for Environment Conscious Building (AECB) and the Passivhaus Trust argue that even more could be done and that in the longer term this would be a worthwhile investment.

In this section, we identify some of the factors giving rise to heat loss, which are not controlled by the Building Regulations, for instance, building form. However, to understand the actual situation, predict heat loss more accurately, and size heating systems accordingly, we are pointing out what good practice should be rather than the minimum requirement to achieve a Building Regulations 'pass'. In the process diagram below we have moved to 'best practice' for passive measures.



2.2 Fabric first

The most robust way to minimise energy use is through improvements to the building fabric. Designers will understand the importance of good U-values and airtightness, but also need to consider the contribution to heat losses from other mechanisms, such as thermal bridging and thermal bypass, as well as the effect of thermal mass.

Thermal bridges occur where the continuity of the insulation is broken and pathways are created for higher heat loss than through the adjoining elements. The more familiar 'repeating' thermal bridges, due to fixings, frames and joists, are accounted for in the U-value calculations for the particular elements. 'Non-repeating' thermal bridges are less well understood and occur at the junction of different elements (for instance, around windows and doors) or at the junction of different planes (for instance, at eaves and corners). The impact of these needs to be minimised by good design – reducing complex forms, and using thermal breaks at weak points such as balconies and lintels. The additional heat loss of the thermal bridge is calculated by multiplying the linear thermal transmittance of the junction (the 'psi-value') by its length. The psi-value can be obtained from accredited and enhanced accredited details, product manufacturers or by calculation. To avoid a 'thermal bypass', the insulation layer must also coincide with the line of the air barrier to prevent any cold air circulating within cavities or voids within the heated envelope of the home.

The 'thermal mass' of a material refers to its ability to absorb and retain (and eventually re-emit) heat. Typically, dense materials such as concrete have high thermal mass. Thermal mass can be an effective way to capture heat from the sun through south and west facing windows in the winter, thereby reducing demand for heating, but the use of lightweight lining materials such as plasterboard will reduce this effect. However, in summer, unless heat gains are controlled by shading and ventilation, high thermal mass can increase the risk of uncomfortably high temperatures in the home (see NF44).

At Derwenthorpe, the cavity insulation is completed in its entirety before the external leaf is constructed allowing a thorough visual inspection of the whole installation. With this approach it is also possible to use large format insulation boards with fewer gaps.

At the eaves the insulation and inner leaf of lightweight blockwork are carefully profiled so that there will be continuity with the insulation in the roof and no breaks in the 'thermal envelope'.

Derwenthorpe, York, architect: Richards Partington Architects, developer: Joseph Rowntree Housing Trust / David Wilson Homes photography © Kippa Matthews

Thermal bypass

Thermal bypass is the movement of unheated air within cavity party walls or through spaces such as underfloor voids and lofts, resulting in heat loss.

A thermal bypass can occur when the airtightness barrier does not follow the insulation.

This diagram shows a thermal bypass effect at eaves level where cold air is able to permeate the insulation and carry away heat from the void between the insulation and the airtightness barrier.

It is particularly important to ensure that any airtightness barrier follows the line of the insulation to avoid creating unheated spaces between the two.

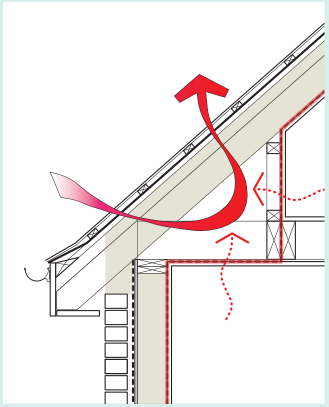
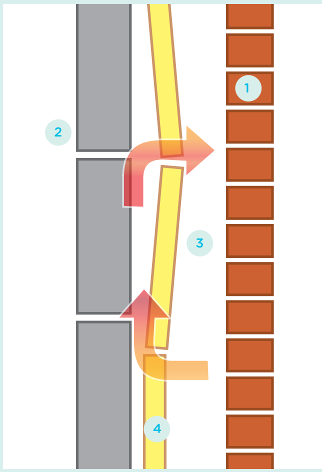


Illustration © Richards Partington Architects

Thermal bypass in conventional cavity wall insulation where air movement occurs behind the rigid insulation.

1. Outer leaf
2. Inner leaf
3. Air movement
4. Insulation



Photograph from *Accredited Construction Details* (see further reading) © Centre for the Built Environment, Leeds Metropolitan University

There are many complex mechanisms for heat loss which cannot be countered with insulation on its own.

Key points to consider:

- **Each 'element' of the building envelope – wall, roof, floor, window or door – has a role to play in minimising heat loss.**
- **Thermal bridges are weak points in the building envelope where heat loss is worse than through the main building elements.**
- **Thermal bypass is the movement of unheated air within cavity walls or through spaces, such as underfloor voids and lofts, which results in additional heat loss.**
- **Construction materials and technology will have an impact on the standard of fabric performance that can be achieved.**

Further reading:

Accredited Construction Details (CLG, July 2007), gives an overview of thermal bridging and airtightness in buildings and how to use the ACD resource available on the Planning Portal.

Enhanced Construction Details: introduction and use (CE279) (EST, 2008), provides guidance on the use of Enhanced Construction Details (ECDs).

Building low carbon homes: Construction guides (1-4) for Masonry, Timber Frame, Concrete Frame and Insulating Concrete Formwork systems (NBS, 2010, 2012), explain the main principles of heat loss through the building fabric.

Online resource: ***Case Study: AIMC4*** (AIMC4, 2011), details materials, products and processes incorporated in the development of the Code for Sustainable Homes level 4 scheme, available from: http://www.aimc4.com/.

Fabric First: Focus on fabric and services improvements to increase energy performance in new homes (CE320) (Energy Saving Trust, October 2010), provides comprehensive technical guidance for designers.

2.3 Geometric complexity

If the home has an elaborate design in plan and section, creating a large external surface area, there will be many pathways for heat loss and the thermal envelope can become too complex. The complexity of the design results in greater heat loss than for a similar sized home with a simple envelope. The features that create this complexity are commonplace – the dormer windows and broken roof lines that add 'interest' in the planner's eye, or the gables and hipped sections used decoratively, or to accommodate a room in the roof. Because we currently model buildings for Building Regulations by demonstrating the improvement of the designed home over a 'notional' home of the same geometry and form, we do not readily recognise the impact that building form has on heat loss. As a result, designers are less aware of the thermal 'compromises' they may be introducing. Other tools such as PHPP (the Passive House Planning Package) steer the designer away from geometric complexity (see further reading NF47).

Where the roof space is occupied (room in the roof) the line of thermal envelope will, by definition, follow the line of the roof construction and any of the dormers or build outs. This usually creates a more complex profile than where the insulation is simply laid across the top of the ceiling joists. With this roof form the services have to be carefully designed to coordinate both with the structure and the line of airtightness, as there is no longer a ready-made void to route services through.

Geometric complexity is not only a cause of reduced thermal performance, it also introduces constructional complexity and increases the likelihood of sequencing and building errors on site. This is not to say that designers in the future should be constrained to only produce simple compact terraces, but the starting point for a low energy home ought to be simple, at least at the line of thermal barrier. Any complexity from projections, balconies, features etc. would ideally be applied outside this layer. If this is not possible the designer should assess the implications and adopt strategies that reduce the overall heat loss, for instance with improved insulation, and compensate for the losses through thermal bridging.

The homes here, built for Scotland's Housing Expo 2010, were designed using the Passive House Planning Package (PHPP).

Geometrically simple and with low surface area to volume ratio they are inherently good 'forms' for retaining heat.

Passivhaus terrace for Scotland's Housing Expo 2010, architect: HLM, photography © Paul Zanre

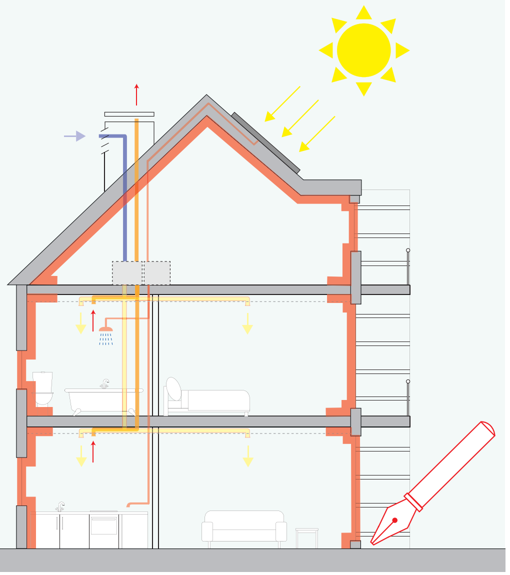
"To achieve a planning consent the original modern designs were replaced with traditional forms and gabled roofs. Height restrictions meant that rooms in the roof were inevitable. A simple construction technology for the external wall helped to mitigate the effects."

LowCarb4Real; Design collection: GHA: Bladon Overview (see further reading).

Lincoln Grove, Bladon © Kingerlee Homes

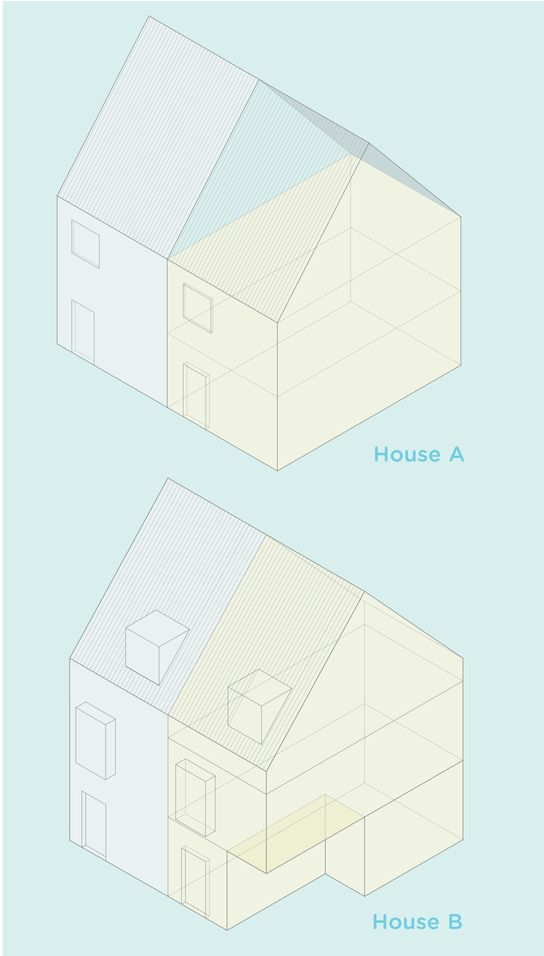
The 'pen on section' test is a helpful tool to establish whether the airtightness barrier is continuous and aligns with the insulation, especially where the barrier is not a dedicated construction membrane or separate layer, or where it is not clearly identified on drawings.

Where the airtightness barrier cannot be continuous, for instance, at the junction of intermediate floor and wall or around windows, special consideration needs to be made while detailing.



Houses A and B, to the right, have the same habitable floor areas. However, house B, with an integral garage and room in the roof has a higher exposed surface area and a larger heated volume.

Illustrations © Richards Partington Architects



	House A	House B
Habitable floor area	120 m^2	120 m^2
Exposed surface area	252 m^2	334 m^2
Heated volume	360 m^3	409 m^3

Geometric complexity is not only a cause of reduced thermal performance, it also creates complexity at the build stage.

Key points to consider:

- **Are the planning designs going to lead to difficult to build details?**
- **Simple rectangular forms are likely to be more efficient.**
- **Has all the complexity of balconies, overhangs, dormers etc. been anticipated? Could these be simplified?**
- **Design tests, for instance, the 'pen on section' tracing of the airtightness barrier, help to gauge the probable complexity.**

Further reading:

Lessons from Germany's Passivhaus experience (NF47) (NHBC Foundation, 2012), explains the principles of Passivhaus and includes case studies.

Online resource: ***CarbonBuzz handbook*** (CarbonBuzz), summarises data from post-occupancy evaluation of projects, available as a downloadable booklet from: http://www.carbonbuzz.org/docs/CarbonBuzz_Handbook.pdf.

Online resource: ***LowCarb4Real; Design collection: GHA: Bladon Overview*** (Leeds Metropolitan University, UCL, Good Homes Alliance, 2008, available from: http://www.goodhomes.org.uk/downloads/pages/Bladon%20LC4R%20case%20study%20(Kingerlee).pdf.

Accredited Construction Details (CLG, July 2007), introduction document which gives an overview of thermal bridging and airtightness in buildings and how to use the ACD resource available on the Planning Portal.

2.4 Possible thermal bridges

In larger homes it is not uncommon for the thermal bridging losses to make up to about one third of the total heat loss, so it is essential that designers understand how these losses occur and account for them properly. This section looks at the increased thermal bridging that occurs because of projections, integral garages, or the inclusion of private garden spaces or terraces above parking or between houses in a terrace. Often this may be an ingenious way of creating more garden on a constrained site (as at ICON, Lime Tree Square in Street shown here) or it may be a way of providing outdoor space directly from an upper floor bedroom, for instance, the Green House built by Barratt at the BRE Innovation Park. Although spatially interesting, these devices add complexity for the detailing and for the continuity of insulation. Service penetrations and pipework, especially for drainage outlets in roof terraces, will also displace the insulation. Other factors complicate the construction, for instance, the change in level which is difficult to avoid if a sufficient thickness of insulation is provided over the terrace construction.

Similar situations occur where heated spaces sit above external areas, for instance, the integral garage or the overhang to create an entrance set-back or recess. In these cases the wall or soffit separating the habitable area from the garage or recess becomes a thermal element. For rooms in the roof, measures also need to be taken to overcome the thermal bridging created by the roof structure itself, usually by over or under-cladding the rafters with additional insulation. Avoiding thermal bridging at the projections and changes in profile caused by dormers is particularly challenging, and appropriate care needs to be applied to the thermal analysis of these complex details. Similar conditions occur where flats are built above garages, or sheltered spaces are created such as porches and archways.

At this award winning project in Street, Feilden Clegg Bradley created external garden spaces and bedrooms above the garage space. The designers were aware that the floor above the garage would be a ‘thermal element’, more like a ground floor above a ventilated void, requiring special attention in the detailed design.

ICON, Lime Tree Square, Street, drawing © Feilden Clegg Bradley Studios, photography © Tim Crocker

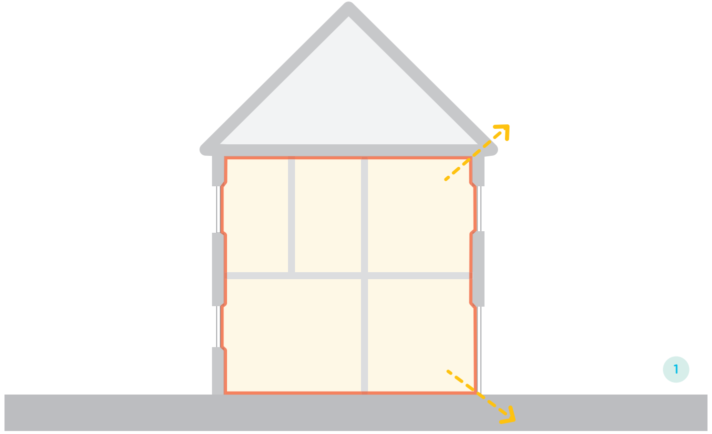
Additional surface area and changes in geometry create potential for additional heat loss (diagram 2).

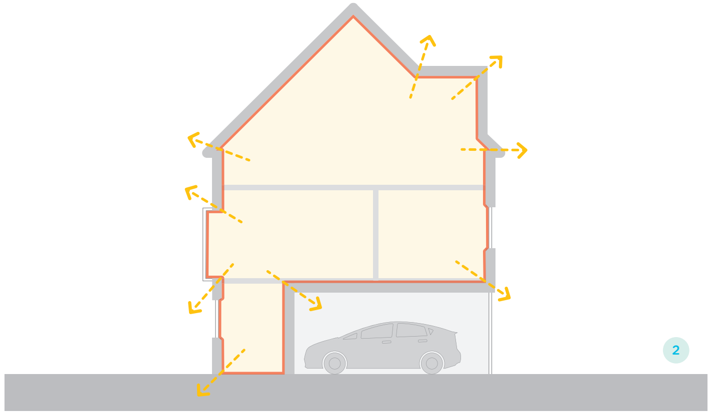
Where an exterior wall enclosing an unheated space meets the soffit or floor construction it is extremely difficult, with cavity construction, to ensure continuity between the internal floor level insulation and the external wall insulation (diagram 3).

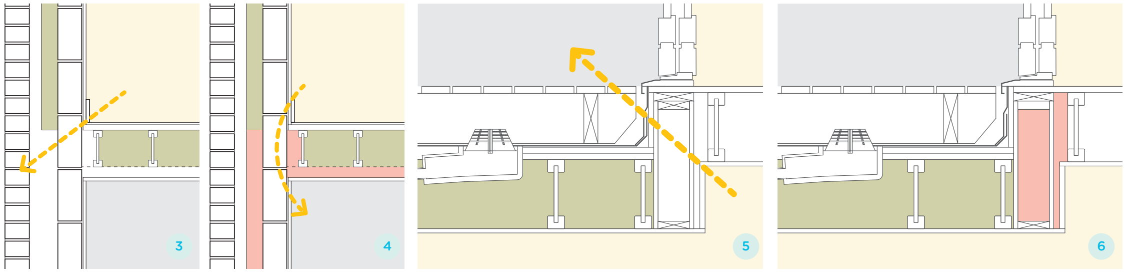
While the floor construction above a garage may be sufficiently deep to accommodate insulation (perhaps 200–250 mm) this may not achieve the required U-value for an external floor which is reduced by the repeating thermal bridge at each joist (diagram 4).

Particular attention needs to be paid to the threshold of roof terraces, especially where level access is required. The potential for rainwater outlets and drainage to displace insulation should also be noted (diagrams 5 and 6).

Illustrations © Richards Partington Architects







In a well insulated home, thermal bridges can contribute up to a third of the total heat loss.

Key points to consider:

- **Enclosing unheated spaces or creating terraces above heated spaces will create complexity for design and construction.**
- **Linear thermal bridges, especially those for which Accredited Construction Details (ACDs) are not available, should be calculated accurately.**
- **Avoid putting bulky services in the floor zone – this will reduce or displace the insulation.**

Further reading:

Online resource: ***LowCarb4Real; Design collection: Thermal bridging*** (Leeds Metropolitan University, UCL, Good Homes Alliance, 2008), explains the different ways in which thermal bridging can take place in buildings, available from: http://www.leedsmet.ac.uk/as/cebe/projects/lowcarb4real/lc4r_des_bridging.pdf.

The Government's Standard Assessment Procedure (SAP) for Energy Rating of Dwellings (BRE, Oct 2010); Appendix K, p. 74, lists commonly occurring thermal bridges that are taken into account in heat loss calculations.

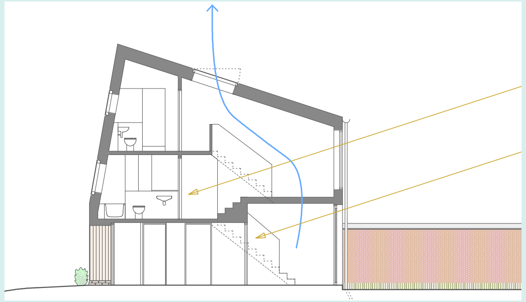
Building low carbon homes: Construction guides (1-4) for Masonry, Timber Frame, Concrete Frame and Insulating Concrete Formwork systems (NBS, 2010, 2012), illustrate commonly occurring thermal bridges and issues of design detail and construction sequencing.

2.5 Secure ventilation

The key to good ventilation is to design openings and pathways that create effective and secure cross-ventilation that can be used when the building is unoccupied or when the household is asleep. Secure ventilation usually requires a louvred or grille-protected opening that allows air in but keeps intruders, insects and birds out. It could be located at a high point, to maximise air movement and make use of natural buoyancy (the stack effect).

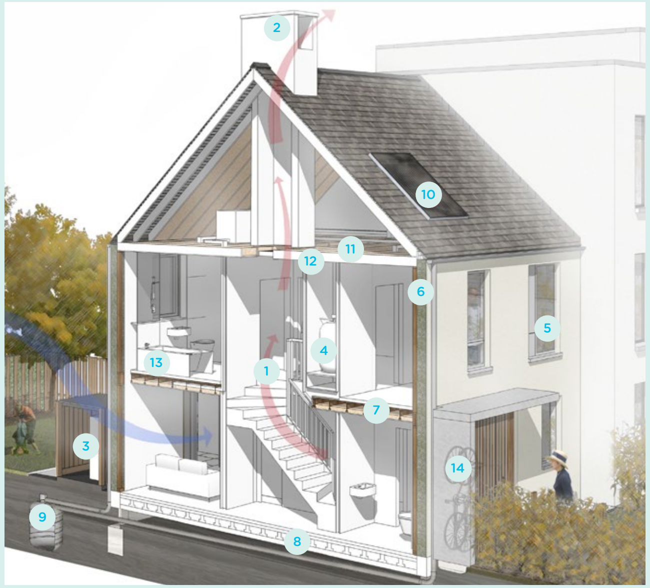
External noise, from aircraft or busy roads, will also influence the effectiveness of conventional ventilation strategies. In certain circumstances, the most obvious solution may be to locate the bedrooms on the protected side of the home away from the noise. In these situations every available means to avoid overheating through orientation and shading needs to be deployed and a customised mechanical solution may be needed.

Ventilation stacks, or custom designed ventilation 'chimneys', have been trialled in many homes and have generally worked well, with the air movement helping to create a comfortable breeze as well as removing the warm air. Generally, higher temperatures can be tolerated when there is a perception of air movement and the ventilation can be controlled by the occupants. Ventilation stacks or shafts were built into both Stewart Milne's 'Sigma' homes and the Lighthouse at BRE's Innovation Park, and use weather and temperature sensors to open a high-level vent but also ensure that it closes automatically during a rain shower. More sophisticated weathered ventilators are used in non-domestic construction, particularly schools, where good air quality is an important design parameter. These can introduce fresh air, and exhaust stale air through the same carefully designed cowl. It is likely that similar strategies will find their way into domestic construction. However, access to the ventilator and its actuator are essential but often difficult to achieve, with the vent usually being at the highest point on the roof or above the internal stairwell.



Clay Field, Elmswell, architect: Riches Hawley Mikhail, photography © Tim Crocker

1. Stack effect ventilation
2. Ventilation cowls
3. Air sourced heat pump
4. Thermal store
5. Triple glazed windows
6. Wall built from hemp
7. TJI joist
8. Minimal concrete usage to foundations
9. Rain water harvesting
10. Potential to retrofit solar panel
11. Recycled newspaper used for loft insulation
12. Thermal mass to ceilings
13. Low water usage bathroom fittings
14. Bicycle storage to front canopy



The Triangle, Swindon, architect: Glenn Howells Architects, photography © Paul Miller

Secure ventilation

At The Triangle (above), secure night ventilation is achieved at high level through a dedicated shaft and louvred opening.

At Clay Field (page 20), a vent above the stairway provides secure ventilation.

This photograph shows a secure ventilation opening at ground floor with a weather protecting louvre.

61 Warwall, London, architect: Penoyre & Prasad, photography © Morley von Sternberg

To reduce overheating, effective and secure cross-ventilation is necessary even when mechanical systems are used for background ventilation.

Key points to consider:

- **In homes, particularly those with a deep plan, a purpose designed ventilation stack or roof outlet will help induce air movement.**
- **Secure ventilation allows heat to be expelled at night and when rooms are unoccupied.**
- **Passive measures to limit overheating, such as shading, are essential if the ventilation could be compromised by external factors such as noise or pollution.**
- **Safety devices and restrictors reduce the ventilation opening and should be accounted for when sizing the ventilation area.**

Further reading:

Understanding overheating: Where to start: an introduction for house builders and designers (NF44) (NHBC Foundation, 2012), explains the common conditions that could lead to the potential problem of overheating in new homes and suggests measures that can be incorporated.

Overheating in new homes: A review of evidence (NF46) (NHBC Foundation, 2012), presents evidence of overheating in energy efficient homes collected from case studies and demonstration projects.

Section 3: Integrating services and mechanical ventilation

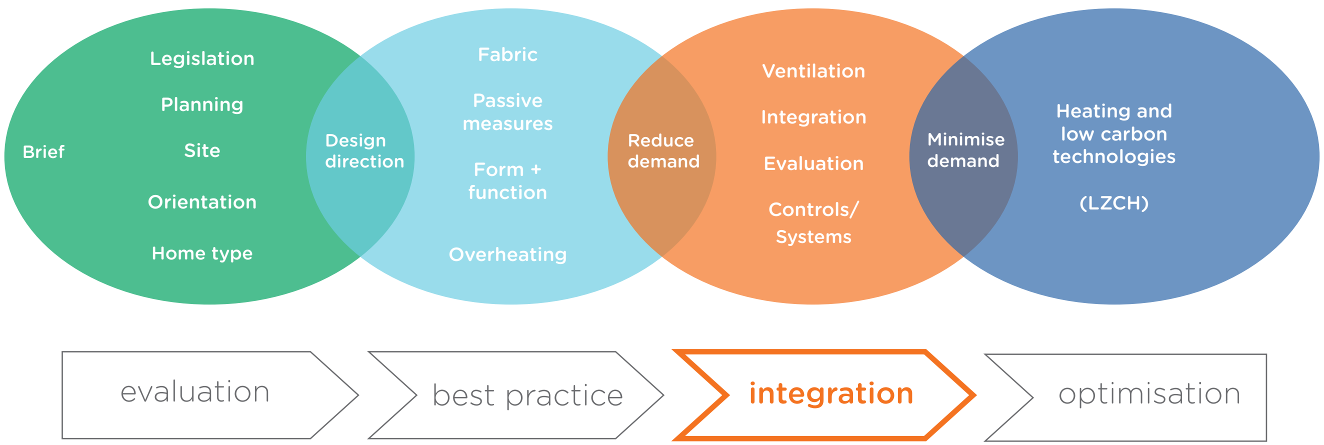
3.1 Introduction

Progressive improvements in airtightness and insulation levels have led to the widespread use of mechanical ventilation to provide the background air that would previously have been supplied by a combination of relatively 'leaky' fabric and trickle ventilators in windows. A home with very low space heating demand only requires a small amount of input heat and mechanical systems can help distribute this heat evenly as well as 'recover' heat by warming incoming fresh air in a heat exchanger, as is the case with mechanical ventilation with heat recovery (MVHR) systems.

The increasing use of MVHR presents many challenges, both for the home-building industry, which needs the skills required to install and commission these systems, and for the occupiers, who must alter their wintertime behaviour to get the best out of the system.

The efficiency of MVHR is highly dependent on the airtightness achieved (an airtightness of less than 3 $m^3/(h.m^2)$ @ 50 Pa is desirable) and can be compromised by poor design, poor insulation and poor understanding of the technology in use. In our relatively benign climate we enjoy opening windows for fresh air, even in winter. However, when heat recovery is incorporated such 'uncontrolled' ventilation undermines the efficiency of the heat exchanger.

This section explains how a well designed ventilation system will work in conjunction with the building fabric and the considerations that should be foremost in the designer's mind in terms of buildability (how the system is installed and commissioned); accessibility (for installation and for maintenance); and practicality (for the occupier and operator of the system).



3.2 Designing around the services

In the past it has been common practice to fit the services around the shell of the home, working around what has already been built on site. In the future, designers will need to think in advance about how to design the home around the services. Decisions about the position of the boiler, the hot water storage and the ventilation unit and its ductwork will need to be integrated with decisions about the structure of the home and its layout. Without this forethought, the component parts may not fit or will be adapted and modified on site, reducing their performance and serviceability. In the worst instances of site 'improvised' design it can prove impossible to commission the system correctly, for instance, where an MVHR fan unit is incapable of delivering the necessary flow rates through poorly designed and installed ductwork.

Design input from the ventilation supplier or subcontractor is essential and needs to be made before the structure and layout are finalised. Construction drawings will be needed, describing the position of the MVHR fan unit, the ductwork, air valves and supply air inlets, all of which have to be coordinated with other components such as structural beams, floor joists, light fittings and roof timbers. As the subcontractor is being asked to design parts of this system their appointment will have to be made early enough to allow this coordination.

Designers can make the construction details more robust by clearly identifying dedicated zones for elements, and their purpose. As well as the primary riser, secondary services should ideally be located in a dedicated zone. On perimeter walls and ceilings this usually takes the form of a services void, deep enough to accommodate pipe runs, cabling, back boxes for sockets etc. and their supports and insulation without penetrating the airtightness barrier. In conventional masonry construction labelling the services zone and the airtightness barrier, which may not be an obvious membrane, helps to communicate their function to the trades people. The use of off-site systems with greater standardisation can also reduce the number of sequencing issues.

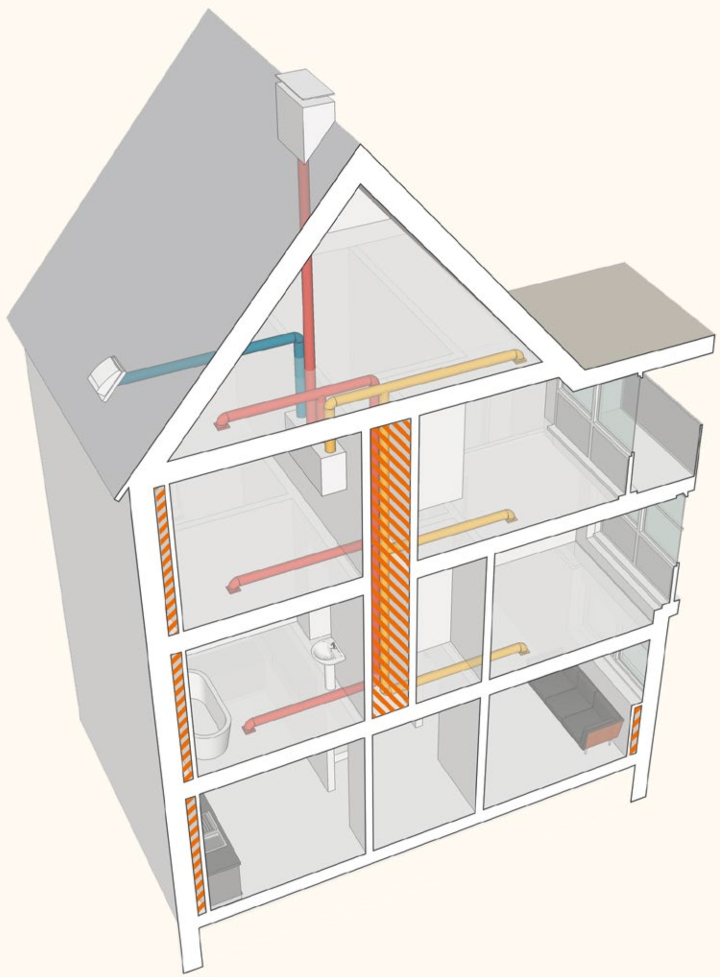


Illustration © Richards Partington Architects

Planned services:

MVHR fan unit is in an accessible location;

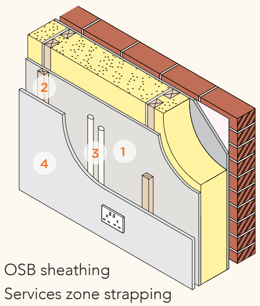
Exhaust duct terminates through a single terminal at the roof;

Bathrooms and kitchens are aligned to minimise the number of offsets in ductwork.

Services zone at perimeter wall

Vertical riser for ventilation, soil and vent pipes

The dedicated services zone on the inside of the airtightness barrier provides space for pipes, conduits and back boxes that would normally penetrate the barrier itself.



1. OSB sheathing
2. Services zone strapping
3. Services
4. Foil back plasterboard

Sigma II build system c-stud closed panel (static insulation) © Stewart Milne

1. Improvised design – ductwork passing through a composite floor joist. The hole for the joist is only just large enough if the ductwork is accurately positioned. No tolerance has been allowed so the installation has been improvised with a short length of reduced cross-section.

Although neatly executed, this construction will reduce the fan performance. In the worst instances of site 'improvised' design it may prove to be impossible to commission the ventilation unit correctly and the MVHR fan unit itself could well turn out to be undersized for the job of pushing air around a convoluted network of ducts.

Failure to get the components of the ventilation system right can have more profound consequences than unrealised energy savings. If the user finds the system too costly to run or intrusively noisy as a result of poor design or installation, then the temptation will be to turn it off completely – inviting condensation, poor air quality and health problems.

2. Improvised construction – a short piece of flexible ductwork used to negotiate a difference in levels. Due to a lack of coordinated design information, the rigid ductwork runs below the top of the internal partition.

photography © Jez Wingfield

Design the home around the services.

Key points to consider:

- Appoint the subcontractors and system designers early enough to allow the coordination of the services with other components.
- Fix positions of MVHR fan units, ductwork and air valves on installation drawings and ensure these are used on site.
- Discourage design 'improvisation' and unapproved amendments to the installation drawings.
- Audit the ductwork installation as it proceeds before secondary finishes prevent any simple remedial work.
- Identify dedicated zones for services and essential components.
- Indicate on drawings what part of the construction (plaster, parge coat, membrane) forms the airtightness barrier.

Further reading:

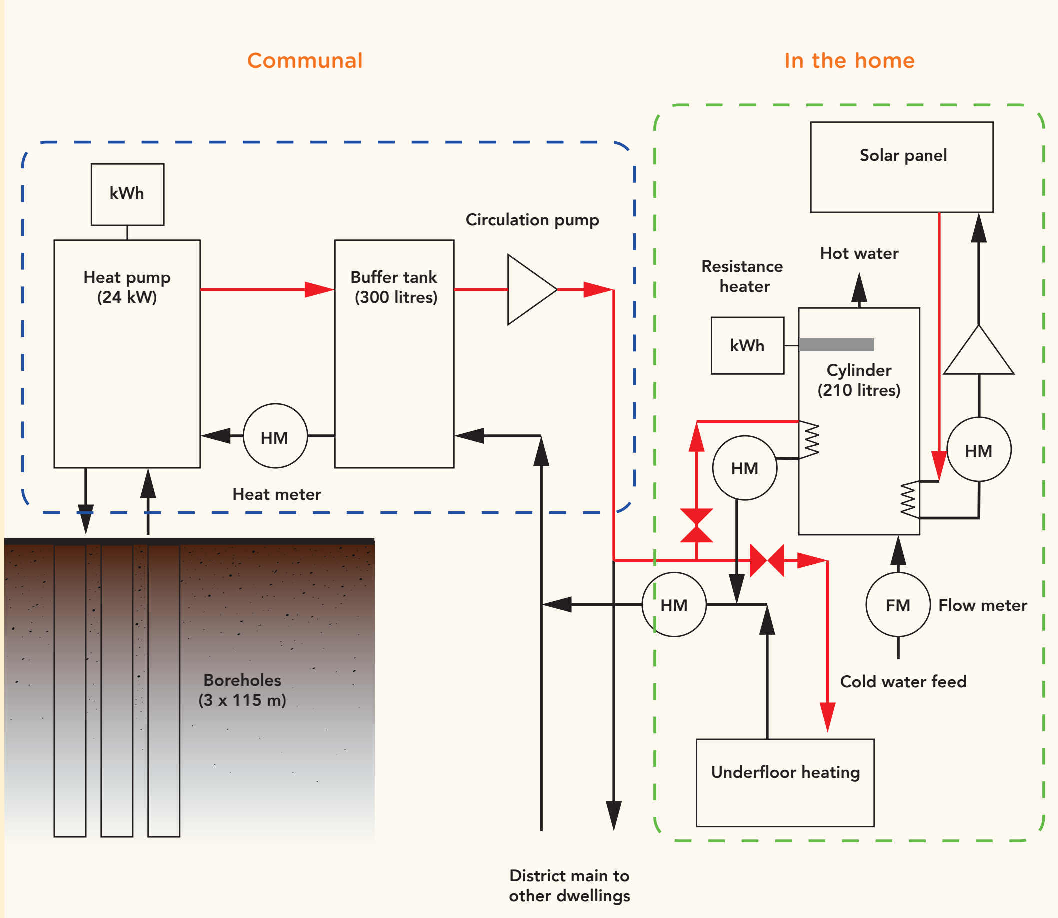
Mechanical Ventilation with Heat Recovery in Homes – Interim report, Ventilation and Indoor Air Quality Task Group (Zero Carbon Hub, Jan 2012), sets out key considerations for the design, installation and commissioning of MVHR units in homes.

Indoor air quality in highly energy efficient homes – a review (NF18) (NHBC Foundation, July 2009), looks at the relationship between building to high standards of airtightness, the use of MVHR and indoor air quality.

3.3 Coordinating the services design

This guide emphasises the importance of passive and active elements, the fabric and the services, working together. In the past, the designers of these elements have acted independently and quite often an amount of 'overdesign' has been incorporated into the heating system (boiler and radiator sizing etc.) to make sure it can cope with different user expectations and unknown heat losses through the walls and windows. The low and zero carbon technologies that will be featured in future homes are relatively expensive and their performance should be 'optimised', to match the predicted demand. The designer of the system needs to be confident that assumptions about heat losses (fabric and ventilation losses) are correct, because although overdesign is wasteful, if the system is underdesigned (for instance, as at Elm Tree Mews, illustrated here) then there is a danger that the home will never get up to the desired temperature (and if the shortfall is made up with a portable or plug-in fan heater then all of the intended carbon savings will not be realised).

There are many potential contributors to design: the architect, services designer, suppliers, energy consultant, buyers and site operatives (possibly making ad hoc decisions as the build proceeds). The question therefore arises as to who coordinates this design, assigns tasks and responsibilities, and ensures that each contribution is correct. As future homes become more complex, with each element relying for its effectiveness on another, it is likely that builders will increasingly become more knowledgeable about each of the contributions to the design process. The procurement and construction processes also need to be aligned with overall design objectives especially when less expensive, but technically inferior alternatives to the specified designs and equipment, are substituted. Product substitution is one of many factors that contribute to homes failing to achieve their designed and as-built performance. The 'performance gap challenge: design vs as-built' is the subject of a major study now underway for Department for Communities and Local Government (DCLG), and was discussed in NF41 (see further reading), which introduces many of the challenges to the home-building industry.



Schematic of services for Elm Tree Mews.

The schematic on page 26 shows the heating and hot water system for six terraced houses at Elm Tree Mews. Communal ground source heat pumps provide heating and hot water, and individual solar thermal panels with water storage and immersion heaters top up the hot water systems.

The designers made optimistic assumptions about the fabric performance, which was undermined during the construction process. The space heating load was therefore much higher than the services were sized to meet. The controls that coordinated the interaction of the different systems were very complex and the performance of the heating system failed to match the designer's predictions.

The efficiency of the services was monitored in a post-completion study conducted by the Centre for the Built Environment (CeBE) at Leeds Metropolitan University.

Plant room at Elm Tree Mews showing the main components of the communal heat pump.

Match the design of the services to the performance of the fabric but make sure that the design performance can be met in reality.

Key points to consider:

- **Define the performance of the fabric carefully and set a clear design brief for suppliers and subcontractors.**
- **Procure design services from suppliers and subcontractors in good time to coordinate their input with other designers.**
- **Do not alter the design or specification without understanding the implications for other components and services.**

Further reading:

Low Carbon Housing: Lessons from Elm Tree Mews (Joseph Rowntree Foundation, Nov 2010), a comprehensive study of building performance.

Temple Avenue Project: Energy Efficient New Homes for the 21st Century (Joseph Rowntree Housing Trust, 2012), describes the design, construction and testing of two low energy houses in York that were a follow-on from the Elm Tree Mews project.

Domestic Building Services Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the installation of fixed building services in new and existing homes, available from: http://www.planningportal.gov.uk.

Domestic Ventilation Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the installation, testing and commissioning of ventilation systems, available from: http://www.planningportal.gov.uk.

Low and zero carbon homes: understanding the performance challenge (NF41) (NHBC Foundation, 2012), introduces the 'performance gap challenge: design vs as-built'.

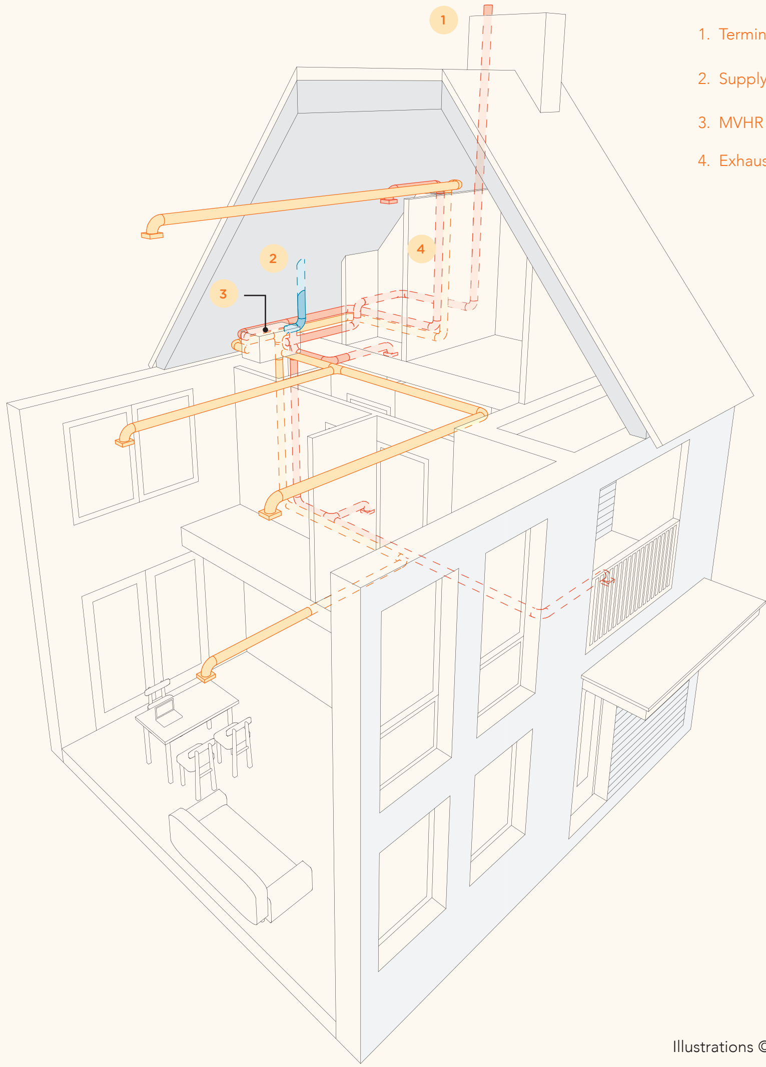
3.4 Planning the services distribution

A mechanical ventilation system takes up physical space. Unlike a window vent or a through-wall extract fan, which can be fitted once the building work is complete, the mechanical system needs to be integrated with the other parts of the home. The system will have a fan unit of substantial weight and a network of rigid extract and supply ducts.

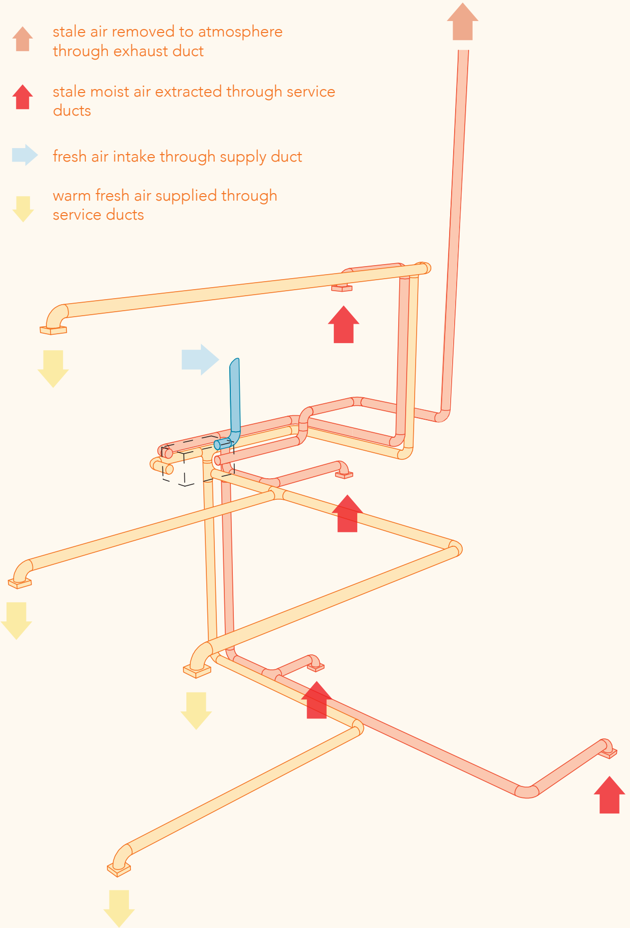
The location of the ventilation unit will be determined by several factors, including space constraints, accessibility and noise. If the unit is planned to be in an unheated loft space (a common solution in small dwellings but not one that is recommended), there will be implications for the ongoing maintenance and operation of the equipment. There will also be requirements for insulation both to the unit and the ductwork. Insulation has to be installed competently, as any exposed ductwork, ductwork supports and fixing straps could be prone to condensation (for ducts containing cold intake air) or to heat loss (for ducts supplying warm air).

The MVHR fan unit has controls and other connections that require its positioning to be convenient for the occupier. For instance, the main settings for fan speed (needed during commissioning), the indicators for filter replacement, and the heat exchanger override for summer operation must all be visible or accessible. A condensate drain also has to be planned for. In operation the unit must be safely accessed by the occupants so that filters can be replaced. In general, the unit should be in a cupboard or dedicated space within the insulated area of the home itself. NHBC Standards guidance for MVHR is currently being developed for publication later in 2013.

If ductwork is to be concealed, the space needed has to be found within the floor and ceiling zones. Vertical space in a riser or a cupboard will also be required between floors. There is a strong case for aligning all of the vertical distribution around a single vertical riser, possibly also accommodating the soil and waste pipe.



Illustrations © Richards Partington Architects



Above, the component parts of the MVHR system. Note that even when the vertical ductwork has been rationalised there are still extensive lengths of horizontal ducts at each floor level, which must be coordinated with floor joists and horizontal structural beams.

The insulation here is in the line of the roof. The space behind the knee wall at the base of the roof is used for distributing services but the fact that this is a heated space has not been communicated to the subcontractor.

This ductwork is supplying fresh air to an MVHR fan unit but it could just as easily be a soil and vent pipe. In either instance, condensation will form on the ductwork if it is not insulated and this could be particularly costly to remedy as it is within a concealed space – the problem perhaps not becoming obvious until serious damage has occurred to the flooring below.

The ventilation unit should be in a cupboard or dedicated space within the insulated area.

Key points to consider:

- **Locate the MVHR fan unit where it is readily accessible for filter replacement and maintenance.**
- **Allow enough space and tolerance for the ventilation ductwork including any insulation.**
- **Insulate ductwork that carries cold air through heated spaces to avoid condensation.**
- **Insulate ductwork that carries warm air through unheated space to avoid heat loss.**
- **Many of these points also apply to centralised mechanical extract ventilation (MEV).**

Further reading:

Online resource: video guidance (Titon, 2011), shows the typical layout of an MVHR system within a home, available from: http://www.titon.co.uk/pages/knowledge-support/building-regulations/part-f-ventilation-england-wales/system-4.php.

Online resource: video guidance (Titon, 2011), shows the typical layout of a continuous mechanical extract ventilation (MEV) system within a home, available from: http://www.titon.co.uk/pages/knowledge-support/building-regulations/part-f-ventilation-england-wales/system-3.php.

3.5 Services installation and commissioning

Working properly, MVHR can deliver excellent air quality with fresh air, introduced at a comfortable temperature with no draughts or discernible noise. To deliver the benefits, it is essential that the design and installation of the MVHR fan unit and its ductwork follow best practice recommendations. Failure to get all the components right has more serious consequences than merely failing to achieve the intended carbon reduction or promised energy savings.

The illustrations on page 31 show how ductwork is frequently installed in differing profiles (some flexible, some rigid), threaded through ceilings and around beams, in an unplanned 'ad hoc' manner. Frequently, the ductwork displaces insulation or compromises the integrity of the airtightness. If the ductwork is not fixed rigidly or supported correctly, the fan in the MVHR unit will have to work harder to push the air around the ductwork, making the system less efficient than intended. The air, moving at greater speed to overcome the constrictions in the ductwork, will also cause more noise. If the system is expensive to run, or if noise becomes a nuisance, there may be a temptation for the occupant to turn the unit off entirely, possibly leading to more serious indoor air quality and health consequences.

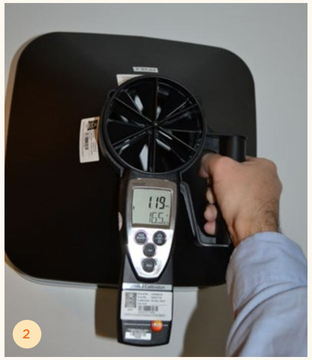
The *Domestic Ventilation Compliance Guide* (see further reading) makes general recommendations for the installation of ductwork and the other components in the system, but is not prescriptive, leaving too many areas open for interpretation whilst working on site. Ductwork routing and design should be decided in advance and communicated through the drawings and the assembly instructions. As-built drawings should be developed as the installation proceeds, because much of it will be concealed by second fix and finishing trades. Making checks during installation avoids repeated sequencing or construction errors.

1. Powered flow hood measures air flow while commissioning domestic ventilation installations using the 'unconditional method', which is independent of site-specific characteristics and more robust.

2. Rotating vane anemometer measures air flow while commissioning domestic ventilation installations using the 'conditional method', which takes into account site-specific characteristics and correction factors and requires greater care.

3. Extract fan that can be used in an intermittent or continuous installation; this product allows easy adjustment of the air flow volume at point of extract.

4. Services void incorporated behind the internal plasterboard finish allows for the airtightness membrane, clearly visible in blue, to remain protected and intact.



1, 2 and 3 © BSRIA; 4 © Richard Quincey

5. Unsupported flexible ductwork used to connect with MVHR fan unit below ceiling. Ductwork routing has been 'improvised' on site.
6. Supply air valve position fixed by trial and error. The first hole clashed with the roof structure and electrical wiring.
7. Loft insulation removed by the ductwork installer. Note that flexible ductwork running through the insulation has been compressed and air flow is likely to be restricted.

Ventilation systems must be balanced and commissioned accurately.

Key points to consider:

- **Do all components of the system comply with the specification provided by the manufacturer to ensure efficient performance of the system?**
- **Has a competent person been appointed to carry out the commissioning of the heating and ventilation system?**
- **Pay attention to the sequencing of construction operations and coordination of different trades.**
- **Be aware of the possibility that follow-on trades can compromise earlier construction.**
- **Use testing for quality assurance and cost control as well as for compliance.**

Further reading:

Domestic ventilation systems: A guide to measuring airflow rates (ED46/2013) Exposure draft (BSRIA, 2013).

Domestic Building Services Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the installation of fixed building services in new and existing homes, available from: http://www.planningportal.gov.uk.

Domestic Ventilation Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the installation, testing and commissioning of ventilation systems in new and existing homes, available from: http://www.planningportal.gov.uk.

Section 4: What the future holds – heating and low carbon technologies

4.1 Introduction

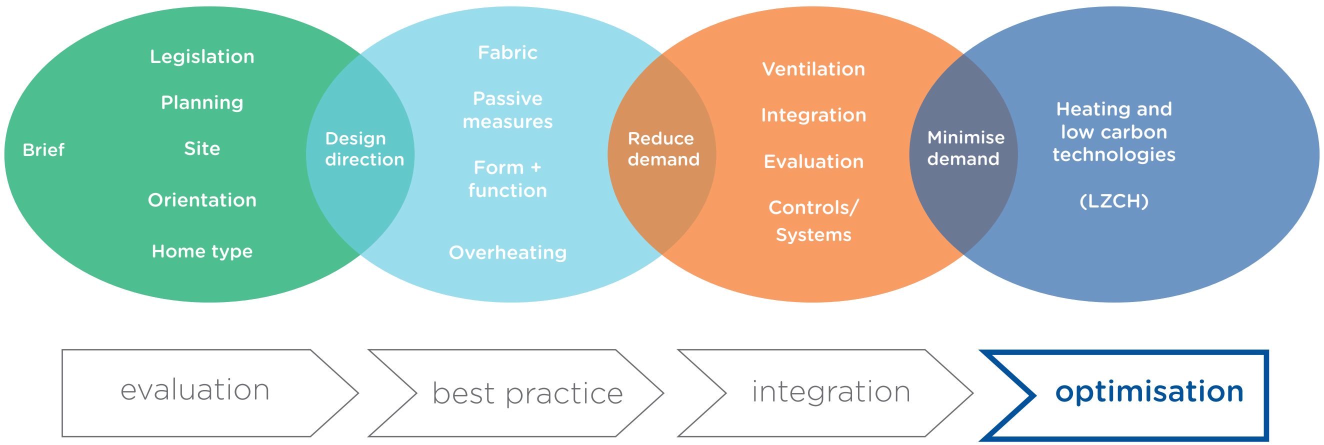
By concentrating first on the building fabric, the home builder will reduce the demand for space heating and help safeguard the occupants against increasing energy prices.

Current conventions for sizing heating systems generally incorporate a safety margin to allow for different internal temperature preferences and to overcome any variability in fabric performance. However, heating systems are generally more efficient when they operate close to their maximum rating, so any unnecessary oversizing can lead to reduced energy savings.

Although estimating tools and 'rules of thumb' are often used to approximate the dwelling's heating load, detailed heat loss calculations should ideally be carried out for each dwelling type based on its fabric, ventilation requirements, and weather data for the location.

Heating loads based on actual calculations are likely to be considerably lower than predictions from 'rules of thumb'. A close matching of heating system design and likely demand will lead to efficient performance, especially where alternatives to conventional boilers, such as heat pumps, are used. However, an overcautious estimate may also limit the opportunities for more innovative approaches, for instance, the low and zero carbon alternatives to conventional 'wet' systems.

In the future, homes requiring very low heating input will benefit from smaller heating systems with lower installation and running costs. However, there may also be serious consequences if the system is underdesigned. In trying to optimise the system, and make best use of low and zero carbon technologies, the designer has to balance the different factors including the increasingly significant proportion of heat taken by the hot water requirements.



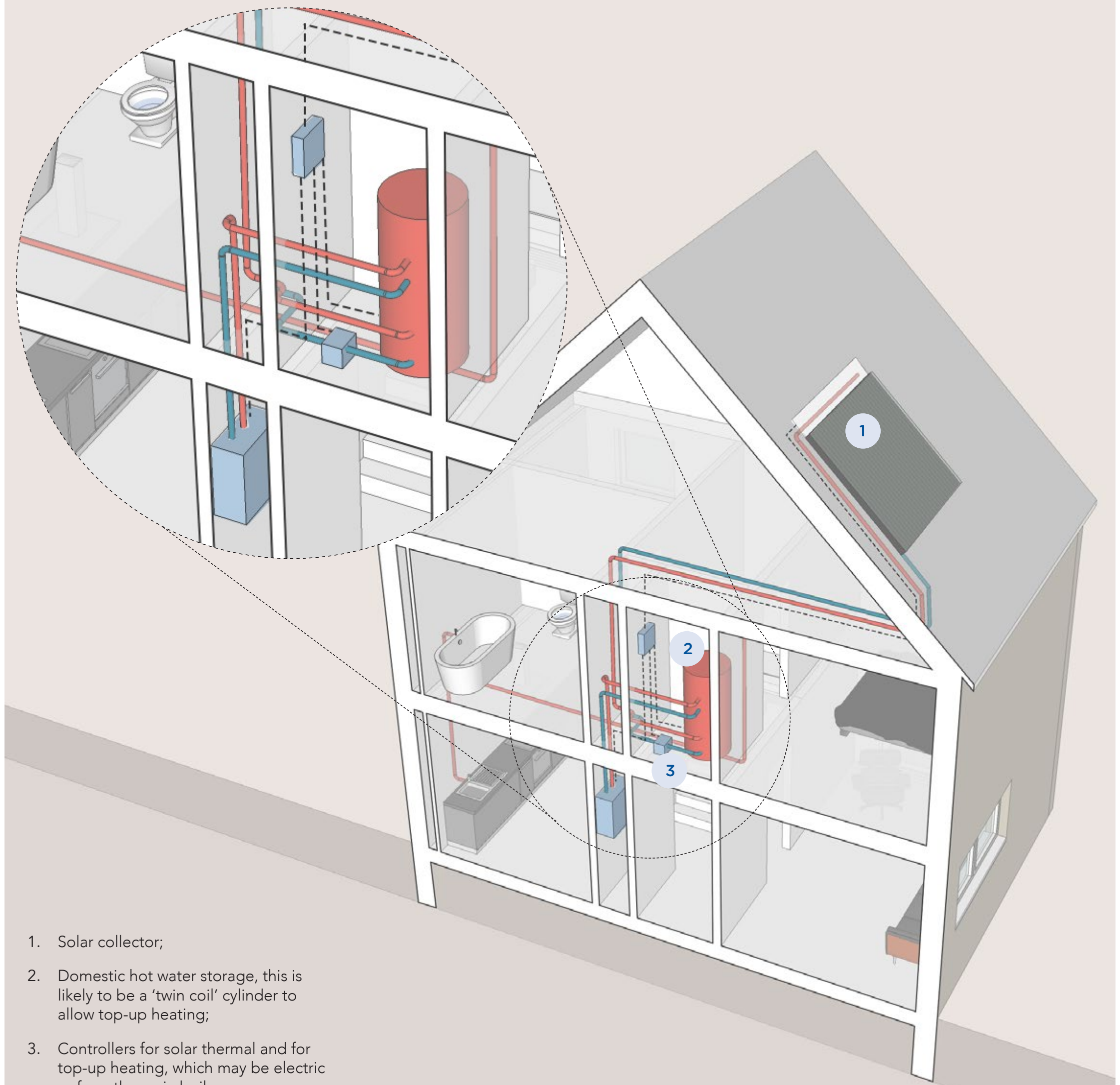
4.2 The importance of domestic hot water

As the space heating reduces through improved fabric performance, the predominant element of the overall heat 'demand' will be from the domestic hot water system (DHW). Although this demand can be reduced by the use of efficient water fittings, there is a practical limit to the savings that can be made as water consumption is mainly determined by the number of occupants.

The calculation of hot water demand should consider the number of people in the dwelling and the number of baths, showers and taps installed and their flow rates, the standing losses from storage and distribution. NHBC recommends design flow rates in their standards but higher flow rates are often assumed for water heating load predictions.

The design of the hot water storage is also important. A solar thermal system can be an efficient way to generate hot water (up to 50% of annual requirements), providing the system has adequate storage and an 'intelligent' interface with the other heat supplying systems.

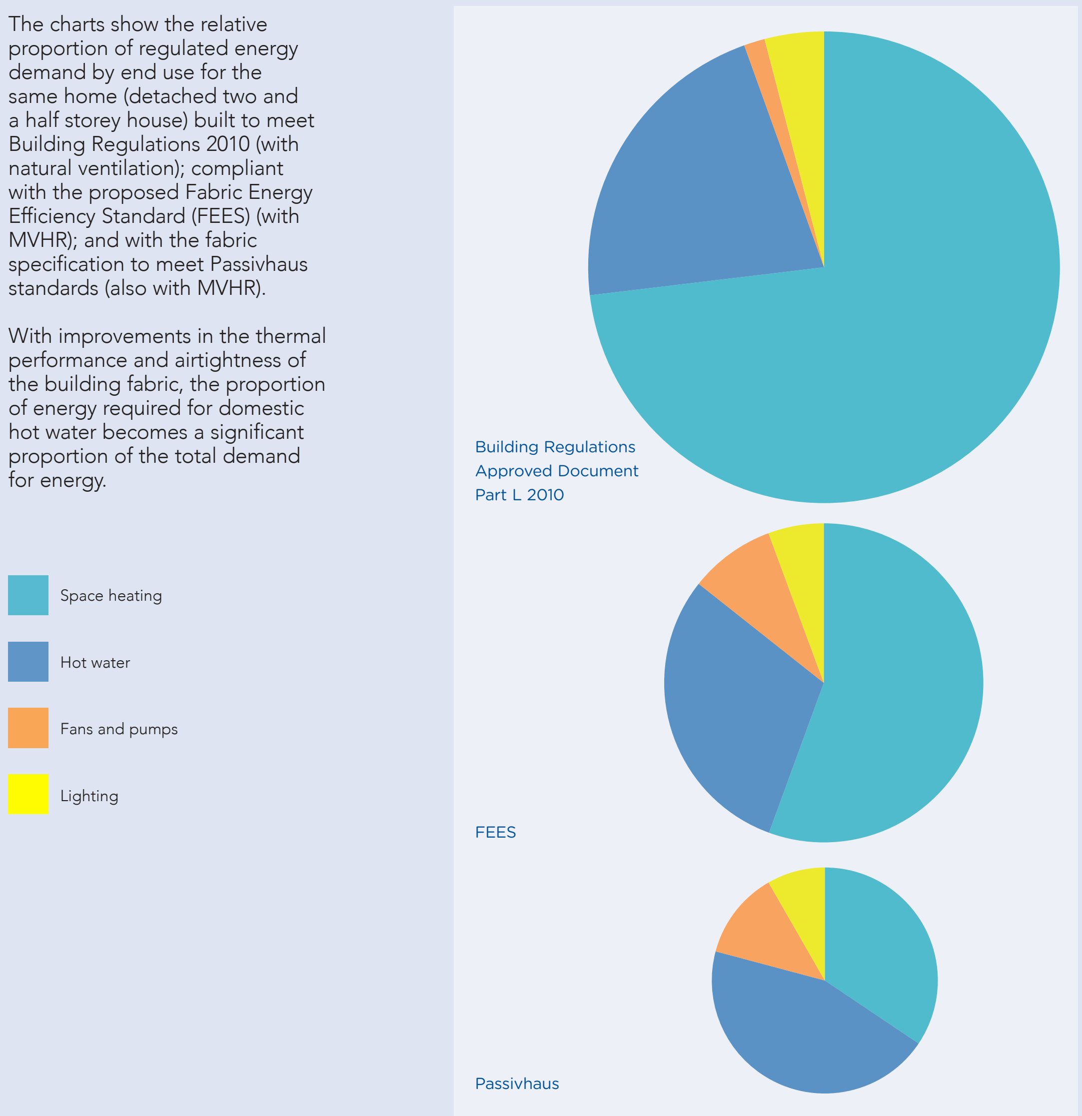
Some of the other low carbon technologies, such as heat pumps, are generally more efficient for providing space heating than domestic hot water. This is mainly because they produce hot water at lower temperatures. Installation, commissioning and correct operation of the whole system is essential to the overall performance as illustrated by the EST field trials (see further reading). Heat pumps are often combined with a solar water heating system, as these two systems complement each other well. Using an integrated manufacturer's system that controls both the heat pump and auxiliary heater may also help to reduce the risks identified in the EST study.



1. Solar collector;
2. Domestic hot water storage, this is likely to be a 'twin coil' cylinder to allow top-up heating;
3. Controllers for solar thermal and for top-up heating, which may be electric or from the main boiler.

The charts show the relative proportion of regulated energy demand by end use for the same home (detached two and a half storey house) built to meet Building Regulations 2010 (with natural ventilation); compliant with the proposed Fabric Energy Efficiency Standard (FEES) (with MVHR); and with the fabric specification to meet Passivhaus standards (also with MVHR).

With improvements in the thermal performance and airtightness of the building fabric, the proportion of energy required for domestic hot water becomes a significant proportion of the total demand for energy.



The energy required for domestic hot water (DHW) will be the predominant element of the home's energy requirements.

Key points to consider:

- **Water heating load calculations should reflect the use of water efficient fittings, which will be installed to meet the requirements of Building Regulations Approved Document Part G and the Code for Sustainable Homes.**
- **Solar water heating can be an efficient way to generate a proportion of the home's annual DHW requirements.**
- **Where heat pumps are used for space heating and hot water heating, the interaction of all the components in the system should be considered.**

Further reading:

Here comes the Sun: a field trial of solar water heating systems (Energy Saving Trust, 2011), gives good advice on the commissioning of systems and interaction of solar water heating, back-up and water usage.

Getting warmer: a field trial of heat pumps (Energy Saving Trust, 2010), available from: http://www.heatpumps.org.uk/PdfFiles/TheEnergySavingTrust-GettingWarmerAFieldTrialOfHeatPumps.pdf.

Detailed analysis from the first phase of the Energy Saving Trust's heat pump field trial (Department of Energy & Climate Change, 2012), available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48327/5045-heat-pump-field-trials.pdf.

Water efficiency in new homes – an introductory guide for housebuilders (NF20) (NHBC Foundation, July 2010), describes technologies that may be used to achieve water efficiency and key issues associated with these.

4.3 Different ways of emitting heat

With a reduced heating demand, the future home can benefit from the use of low temperature water systems fed by heat pumps or condensing boilers, which supply heat more efficiently at these temperatures.

Suitable emitters for these systems are low surface temperature radiators and underfloor heating, both of which work with temperatures as low as 40–45°C. Underfloor heating is often used with heat pumps and can be controlled on a zone-by-zone basis. Underfloor heating generally produces an even distribution of heat throughout a room. However, underfloor systems are not as responsive as radiators and require suitable controls because the well insulated home is more 'thermosensitive' (small incidental and solar gains can increase temperatures rapidly). Radiator manufacturers are now able to supply responsive 'low thermal mass' radiators that are also suitable for use with heat pumps.

Very low space heating loads can also potentially make some innovative systems feasible. For example, the space heating load in dwellings designed to meet the super-insulated Passivhaus standards can be very low and the mechanical ventilation system can be used to meet this entire demand if combined with a heating element. In this system, air is heated at the MVHR unit and is distributed to each room via the ventilation system ductwork. One main feature of this strategy is that all rooms are heated to the same temperature, which may make it less suitable for instances of very low occupancy or for very large homes.

Denby Dale Passivhaus
photography © Green Building Store

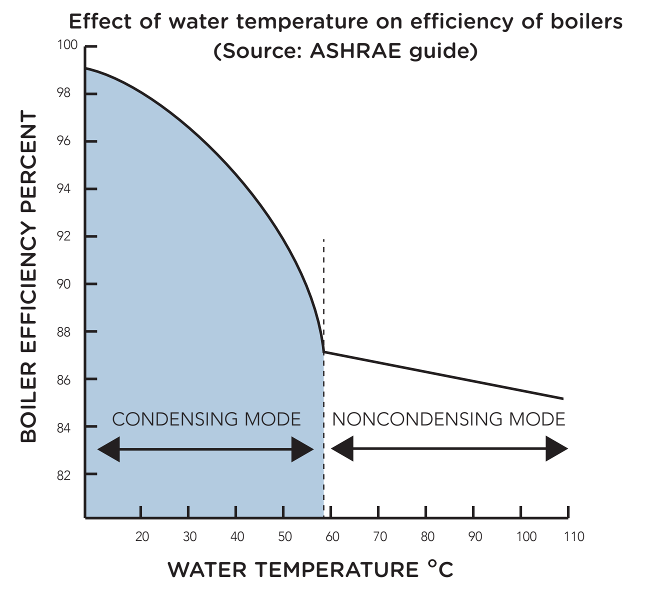
Denby Dale Passivhaus.
Very high levels of insulation and airtightness reduce the heating demand so that heating can be provided from the ventilation system alone. The specification and design process for the home is documented at the Green Building Store website.

1. MVHR fan unit
2. Heater battery

Denby Dale Passivhaus
photography © Green Building Store

The efficiency curve of a gas condensing boiler.

The boiler works efficiently in condensing mode when water temperature is below 55°C. Low surface temperature or 'low thermal mass' radiators make best use of this technology.



Use integrated designs that respond to the particular situation, to deliver energy efficiency and comfort.

Key points to consider:

- **The heating system must be able to react to incidental gains.**
- **Heat pumps and condensing boilers are most efficient when they supply low temperature water systems.**
- **Only a small amount of heat is required in super-insulated homes but this needs to be carefully distributed, often by the ventilation system.**

Further reading:

Control for end users: a guide for good design and implementation (BSRIA, May 2007), discusses the requirements of good controls systems and provides guidance for designers, manufacturers and installers.

Domestic Building Services Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the controls systems and information to be provided to users, available from: http://www.planningportal.gov.uk.

Domestic Ventilation Compliance Guide (DCLG, 2010), supports the Building Regulations and provides guidance for the installation, testing and commissioning of fixed building services in new and existing homes, available from: http://www.planningportal.gov.uk.

4.4 Low or zero carbon technologies: ground source heat pumps

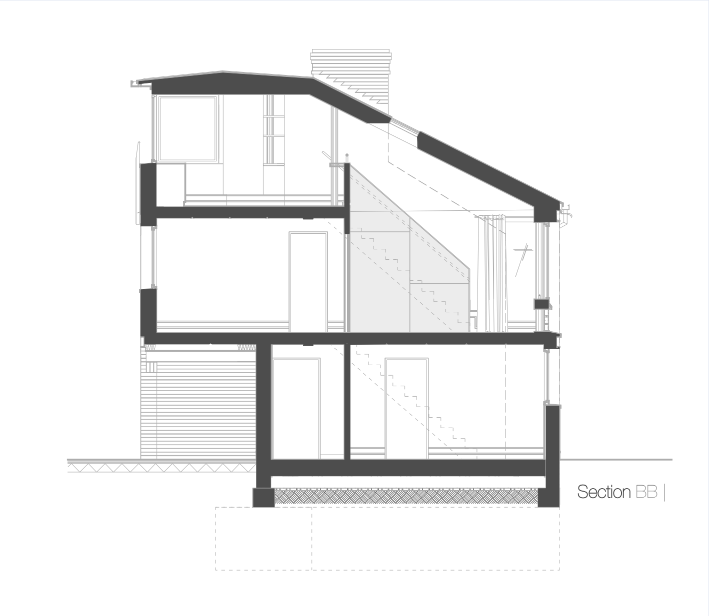
There are alternatives to individual gas boilers, which include air and ground source heat pumps and compact units (combined space and water heating and ventilation systems). The capital cost of a ground source heat pump system is generally higher than for a conventional heating system, mainly because of the costs associated with trenching or drilling for the ground coupling element. Heat exchange with the ground is usually achieved through a closed loop of pipe containing a transfer medium (usually a solution of water and anti-freeze). The loop can be laid out horizontally about 1.5 m below ground over a large area, or contained vertically within boreholes that can be anything from 20 to 150 m deep. Sizing of the ground coupling is critical: the more pipe used in the ground collector loop, the greater the output of the system. Oversizing is uneconomical but undersizing can simply fail to deliver the required amount of heat, impact on the ground temperatures and reduce the efficiency of the system over time. Design of the ground heat exchanger is therefore very important and will normally be the responsibility of the installer or the heat pump manufacturer.

Air source heat pumps are another alternative but, as they are using the outside air as a heat source, they are usually a little less efficient. The need to run defrost cycles to protect the outside unit in some conditions when the temperature is between 0°C and 5°C can also reduce the overall efficiency of the heat pump. The Energy Saving Trust's field trials into heat pumps (EST, 2010 and the further analysis of the results by DECC, see further reading) revealed a high variability in the performance of the technology caused by a range of factors, including poor design and installation, and a general misunderstanding of how the technology interacts with the 'real-life' heating and hot water demands of an occupied home. To get a heat pump to work efficiently, the designer needs to understand the external conditions and heat capacity of the ground (for GSHP), the efficiency of the exchanger, the characteristics of the emitters (radiators and underfloor heating), the likely demand profiles for heat and water, and the interaction with other potentially competing technologies such as solar thermal collectors.

CG Houses, Cambridge, architect: NRAP Architects, photography © Timothy Soar

A borehole is usually used where there is insufficient area for a horizontal heat exchange loop. A U shape of polyethylene pipe is inserted in the bored hole and the voids filled with bentonite grout to aid heat exchange and prevent rising ground water. The drilling rig is substantial and other site operations usually have to be suspended.

The homes in Cambridge, illustrated here, use ground source heat pumps and exposed thermal mass, with cross-ventilation. Shading for the south facing windows is provided by the roof overhang and mature tree.



CG Houses, Cambridge, architect: NRAP Architects, photography © Timothy Soar

The heat pump, the type of emitter and the distribution all have to be designed as a single system.

Key points to consider:

- **The ground coupling element is a vital component of the system and must be sized and installed by a specialist.**
- **Installation and commissioning of heat pumps is critical for efficient operation as intended, and to prevent overuse of direct electrical back-up.**
- **Many of the points regarding system design for ground source heat pumps (GSHP) also apply to air source heat pumps (ASHP).**

Further reading:

Getting warmer – a field trial of heat pumps (Energy Saving Trust, 2010), provides a very comprehensive and clear introduction to the design and installation of heat pumps.

Detailed analysis from the first phase of the Energy Saving Trust's heat pump field trial (Department of Energy & Climate Change, 2012), available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48327/5045-heat-pump-field-trials.pdf.

Low Carbon Housing: Lessons from Elm Tree Mews (Joseph Rowntree Foundation, Nov 2010), discusses findings from the project including issues with the ground source heat pump.

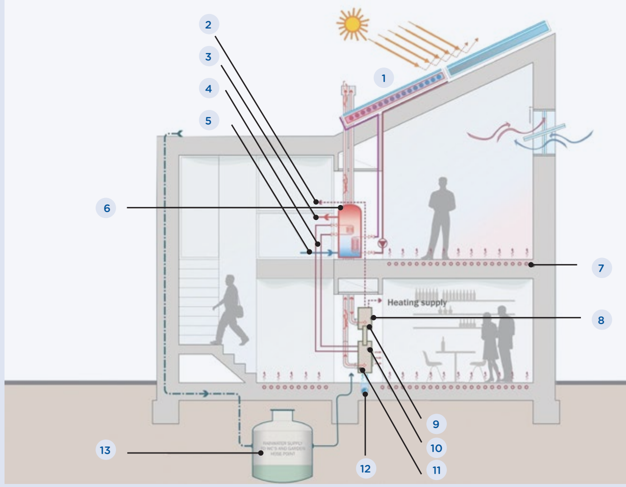
Domestic Ground Source Heat Pumps: Design and installation of closed-loop systems (CE 28) (Energy Saving Trust, 2007), explains different heat pump systems and discusses benefits and issues associated with these.

4.5 Low or zero carbon technologies: solar

Solar water heating can be used to generate up to 50% of the annual water heating requirements, and is relatively easy to install and commission. However, to get the maximum benefit a certain amount of interaction (changes to bathing habits, for example) and maintenance are required by the occupants. It is also important to design the hot water storage system properly, including storage capacity and insulation, to ensure that the system works to its maximum efficiency. Typically, solar panels will be able to heat water to a certain temperature and a top-up, usually from a boiler or electric immersion, will be required to achieve the desired temperatures. The timing of the heat input from the back-up has to be carefully controlled and integrated with the input from the solar panel.

Solar PVs use the sun's energy to generate electricity for use in the home, with the excess electricity being exported to the grid. Solar PV is generally considered to be a reliable 'fit and forget' technology.

If the roof is going to be used to support a large area of solar water heating or PV panels then the roof form and available roof area become critical, often resulting in the 'saw tooth' or monopitch roof profiles of many very low energy homes. Although solar renewables will work in a range of positions and angles the optimum is generally within 15 degrees of due south and at about 30 degrees tilt. It is also important to consider whether other roof penetrations and projections (dormers, vent pipes etc.) have been coordinated with the solar array and whether they are going to cause overshadowing and the resulting loss of output.



1. Solar hot water and PV panels
2. Heating supply
3. Hot water supply
4. Boiler connection
5. Cold water supply
6. Solar hot water preheat cylinder, water fed to combi-boiler
7. Underfloor heating
8. Back up gas fired combi-boiler
9. 6 kW boiler
10. Fireplace
11. Wood burning stove with back boiler
12. Vent duct supplying air to fireplace
13. Filtration, packaged rainwater storage and distribution unit

Whitehill Borden Eco Terrace entry © Proctor and Matthews

Whitehill Borden Eco Terrace winning scheme © Ash Sakula

The Whitehill Borden Eco Terrace is on a constrained site with mature trees to the west and an existing building to the east. Ambitious but realistic energy targets were set and the housing association, Radian, limited the choice of heating systems that could be used based on its own experience in trialling and managing innovative technologies.

The winning scheme by Ash Sakula (above) required a lot of PV to meet the targets, resulting in the 'folded' roof form. More than half of the competition entrants concluded that this was the optimum profile – a similar section was used in the Proctor and Matthews entry (page 40).

Here, in a recent project in Letchworth, each home has a roof area facing south, achieved by an ingenious reworking of the roof scape for similar house types in different positions. The roofs make good use of solar energy but introduce geometric complexity.

Hartington Place, Letchworth, architects: Cole Thompson Anders, photography © Morley von Sternberg

The roof design and orientation becomes critical when large areas of solar panels are installed.

Key points to consider:

- Factors that may reduce the efficiency of the system, for instance, shading from buildings and trees need to be considered.
- Consider how the installation is supported on the roof and how is it integrated with the roof coverings.
- To get the best from solar thermal systems the tuning of hot water usage and back-up heating must be understood.
- Solar systems should comply with the microgeneration certification scheme.

Further reading:

Photovoltaics and Architecture (Spon Press, 2001), even though the efficiencies of PV have improved since this guide was published, this book gives good clear advice on designing with PV and includes charts to estimate the reduction in performance of the systems in less than optimal conditions.

Here comes the Sun: a field trial of solar water heating systems (Energy Saving Trust, 2011), gives good advice on the commissioning of systems and interaction of coheater, back-up and water usage.

Conclusion

Although this guide has explored the complex challenges faced by the home-building industry, we believe that some simple principles will always apply: designing the building fabric correctly must be the highest priority. From this starting point, strategies for good ventilation, efficient services and for reducing overheating can be developed in a way that will ensure they will be integrated within a single well thought-out 'whole'.

In the face of progressively demanding carbon targets, the designer's attention can easily be diverted towards solutions that comply with regulations but do not take sufficient account of the needs of the occupier. These needs are easily overlooked, but our aim should be always be to create homes that are energy efficient; attractive and comfortable to occupy; and easily operated and maintained.

This guide shows that with some forward thinking and coordinated processes, unnecessary complexity can be 'designed out', to the benefit of everyone who follows the design through construction and handover. However, good communication, supported by accurate calculation, drawing and modelling, is essential.

We recognise that we are relatively inexperienced at delivering low energy homes in volume, and the right knowledge and skills are still being acquired. We hope that this brief introduction to our vision for homes for the 21st century, and the references we have highlighted, will help you on your journey.

Designing homes for the 21st century

There are many challenges in designing homes fit for the 21st century. We need homes that achieve zero carbon performance, whilst providing a healthy indoor environment. We also need homes that are resilient to climate change and are not susceptible to overheating for extended periods of the year.

However we tackle these challenges, there can be little doubt that a 'business as usual' approach with bolt-on technologies is unlikely to be the most practical or cost-effective. This guide helps us to understand the need for integrated design and reminds us to take full account of the needs of the home's occupants to ensure that they are able to realise all of the benefits of a new home.

The NHBC Foundation facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports home builders in developing strong relationships with their customers.

Written and illustrated by Richards Partington Architects on behalf of the NHBC Foundation
ISBN 978-1-84806-331-0

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