Windows - making it clear

Energy, daylighting and thermal comfort

Guide

NHBC FOUNDATION

Housing research & guidance

NF78

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Image credits:

Page 1 Kinestral

Page 4 (Figure 1) Munster joinery

Page 4 (Figure 2) Eurocell

Page 5 (Figure 4) Green Building Store

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Page 10 (Figure 10) Supplied by the Glass and Glazing Federation

Methodology

The space heating energy demand and overheating risk for the home types used in this guide were calculated for the various scenarios using the software Passivhaus Planning Package v 9.3 (PHPP). Average daylight factors were calculated using Littlefair's method in Site layout planning for daylight and sunlight: a guide to good practice', IHS BRE Press, 2nd edition, 2011. The home types that were used reflect the designs, basic specifications and habitable floor areas shown in Part L 2013 - where to start: an introduction for house builders and designers – timber frame construction, NHBC Foundation, NF59, 2014.

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The NHBC Foundation

The **NHBC Foundation**, established in 2006, provides high-quality research and practical guidance to support the house-building industry as it addresses the challenges of delivering 21st-century new homes. To date, it has published more than 75 reports on a wide variety of topics, including the sustainability agenda, homeowner issues and risk management.

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

To find out more about the NHBC Foundation, please visit **www.nhbcfoundation.org**. If you have feedback or suggestions for new areas of research, please contact **info@nhbcfoundation.org**.

NHBC is the standard-setting body and leading warranty and insurance provider for new homes in the UK, providing risk management services to the house-building and wider construction industry. All profits are reinvested in research and work to improve the construction standard of new homes for the benefit of homeowners. NHBC is independent of the government and house builders. To find out more about the NHBC, please visit **www.nhbc.co.uk**.

The NHBC Foundation Expert Panel

The NHBC Foundation's research programme is guided by the following panel of senior representatives from government and industry:

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Foreword

Window design has traditionally been associated with maximising the amount of daylight entering the home. Architects and designers have aimed to make best use of natural light to enliven interiors and contribute to the better health and wellbeing of occupants.

But windows have a wider and significantly more complex role to play in modern housing. In addition to contributing daylight, windows are required to provide security, resistance to wind and rain, and ventilation, as well as making an important contribution to the energy efficiency of the fabric. Another factor which has been given greater attention in recent years is the need to avoid excessive solar gain within the home which can lead to an increased risk of overheating. This is a problem that needs careful consideration in the design of modern highly-insulated homes.

So there are a number of considerations, quite apart from the aesthetic appearance of the home, which have to be taken into account in the window selection process. To add to the challenge, three key factors - daylighting, energy efficiency and risk of overheating, do not interact in a complementary way. Trade-offs and compromise often need to be made and these can prove a challenge for the design office. This guide, based on new modelling carried out for the NHBC Foundation, aims to help designers respond to the challenge, so they can better explore the interaction between these factors, identify the more promising compromises that can be made in specific circumstances and avoid options that bring less desirable outcomes

The guide reveals the significant and sometimes surprising effects of making changes to glazing type, width of frame, area of glazing and orientation of the home. It provides useful aids to help designers address particular objectives and to identify quickly and economically where the most promising solutions lie for a typical range of home types.

Windows have a hugely important impact on the appearance and performance of the home, and the wellbeing of its occupants. This guide gives a timely steer to help ensure that window selection is well-informed and delivers better outcomes on energy efficiency and comfort. As with all NHBC Foundation publications, I hope it will bring practical benefits to those involved in designing our future homes.

Rt. Hon. Nick Raynsford
Chairman, NHBC Foundation

1 Introduction

Windows are a secure and weathertight way of allowing natural daylight into a home, and can provide a means of ventilating the home with fresh air. Windows can also provide exit from the home in an emergency. As well as daylight, windows allow the sun's heat energy to penetrate the home. This solar gain can be both beneficial and problematic, providing some free heating in winter but also contributing to the home overheating during periods of hot weather.

Housing designers make many technical choices, but few involve as many interactions and trade-offs as those relating to windows. The challenge for the designers of today's new energy-efficient homes is to minimise winter space heating demand while keeping the risk of overheating within acceptable limits and also maximising the amount of daylight entering the home.

Sometimes an optimal window design can be found which achieves a good balance between all three things, but it often happens that achieving the best result for one can have a negative effect on the others.

Using diagrams, charts and tables, this guide presents the results of modelling simulations for four different home types. It illustrates the changes in the space heating, overheating risk and daylighting as various changes are made to the orientation of the home and to key properties of the windows.

The guide will help designers to understand the implications of their design decisions, and to make informed choices based on whether the objective is to achieve lower space heating costs, reduced overheating risk or maximum daylighting.

2 How windows contribute to energy performance, daylighting and comfort

2.1 Types of glazing and frame

The basic specifications of a window include the glazing, the frame and the way in which the window opens.

Glazing

Glazing can be single, double, triple or even quadruple, however most new homes have double glazing, or triple in some cases. Single glazing is no longer used due to its poor thermal performance, and at the other extreme, quadruple glazing can have problems with weight, cost and lower light transmission.

The gap between the glass panes of a multiple-glazed unit typically ranges from 10 mm to 20 mm. The gap provides the insulating properties of the unit, as long as the air (or specific gas) within it remains static. Increasing the width of the gap improves the insulation up to a point, but eventually air circulation occurs within the gap and any further increase is not beneficial. For this reason most modern glazed units are filled not with air but with a denser gas such as argon or krypton, which circulates less within the gap.

Also in the gap between panes, on the inward facing surface(s), some windows have 'low-emissivity' (low-e) coatings which improve thermal performance by reflecting heat back into rooms.

Frames

Frames for domestic windows are normally made of wood, metal or plastic. Wooden frames are often considered to be more sustainable, whereas plastic frames (usually uPVC or glass reinforced plastic) tend to require less maintenance. Metal frames (usually aluminium), tend to have slimmer profiles.

The width of the frame members, and the number of frame members in the window, affect the amount of daylight that passes into the room and the amount of heat that escapes. The insulating property of a modern glazed unit is generally better than that of its frame, so a window with narrower frame members and/or fewer members (e.g. Figure 1) will generally lose less heat, as well as admit more light, than a window with wider frame members or more of them (e.g. Figure 2).

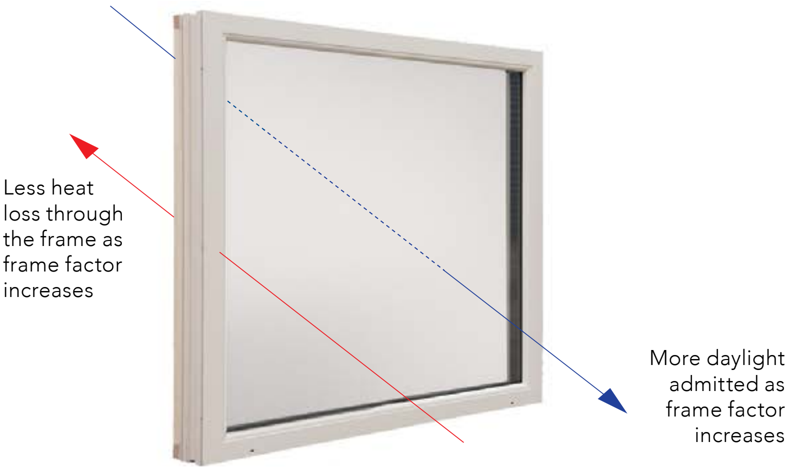
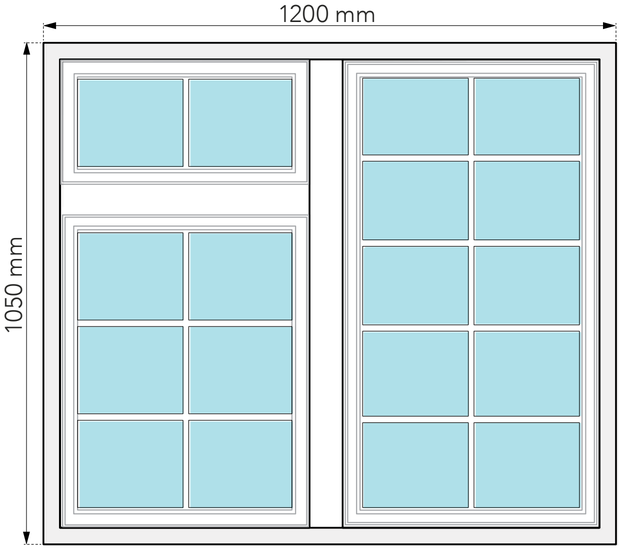


Figure 1 Narrower, and fewer, frame members give a higher frame factor

Figure 2 Wider frame members give a lower frame factor

This effect, known as the 'frame factor', is defined as the proportion of a window's area that is occupied by glass. For example, if 53% of a window area is glazed, the frame factor is said to be 0.53. The calculation is based on the total area of the 'hole in the wall', as shown in Figure 3. Frame factors in practice range from around 50% to 70%. Frame factor is surprisingly sensitive to a small increase or decrease in the width of a frame. For example, if the width of the frame is increased by, say, 25 mm this can reduce the frame factor by more than 10%, changing significantly the performance of the window.



Glass area = 0.67 m²

(Excluding area occupied by frame, rails, transoms and mullions)

Total 'hole in the wall' area = 1200 mm x 1050 mm = 1.26 m²

$$\text{Frame factor} = \frac{0.67\ m^2}{1.26\ m^2} = 0.53$$

Figure 3 Example calculation of frame factor

Frames are often 'thermally broken', where a piece of rigid insulating material is incorporated in the frame to reduce the heat moving from the inner to the outer face. This is shown by the hatched elements in Figure 4. The absence of a thermal break is less important if the frame components are narrower or fewer; this is because the frame will have proportionally less impact on the overall properties of the whole window.

Figure 4 Section through a thermally broken frame

Casements

Outward-opening casement windows have been the traditional choice in the UK, having the advantage that they do not encroach on the useful floor area of the home. In mainland Europe, however, inward-opening windows have always been more common, often due to the restriction imposed by the use of external shutters for shading while the windows are open. This sometimes caused a problem for UK designers who wished to specify very high-performance windows, because the majority of such windows on the market were inward-opening units manufactured in Europe, originally for certification by the Passivhaus Institute.

However, the supply chain has recently improved, and there is now increased availability of both inward and outward-opening high-performance windows. This provides more flexibility, allowing designers to specify windows to best suit the requirements of homes, whether houses or apartments.

Sliding windows are increasingly available, but at this time are not commonly used on typical housing.

2.2 Overall heat loss

The heat loss though a window, as with walls, roofs and floors, is mainly determined by its U-value. Modern window U-values range from around 3.50 W/m^{2}K to 0.80 W/m^{2}K. A comprehensive list of window U-values is available[1], but also see box 'Over-riding the defaults' below.

Over-riding the defaults

The energy calculation method of UK Building Regulations includes tables of default window U-values and other characteristics. Whilst it is convenient to use such defaults, designers and builders need to be aware that the defaults can lead to overly-optimistic or overly-pessimistic calculation results. Therefore it is generally preferable to use manufacturers' specifications where known (although it then becomes more important to guard against product substitutions; see Part 4).

The overall U-value of a window, expressed in watts per square metre of window area per degree kelvin (W/m^{2}K), is a combination of the thermal properties of both the glazing and the frame, with the frame factor significantly affecting the heat loss through a window as discussed in Section 2.1. In thermal calculations used for Building Regulations certification (using the DER/TER methodology in the Standard Assessment Procedure – SAP[2]) and for other purposes, the combined window U-value must be used. In these calculations it is important that designers are aware of the difference between quoted 'centre-pane' U-values (i.e. just the glass) and overall window U-values (which include both the glass and the frame).

Thermal bridging within and around windows must be avoided. Within the window, thermal bridging can be reduced by specifying one or more thermal breaks in the frame, as described in Section 2.1, and by specifying materials such as fibreglass instead of aluminium for the spacer bars around the edges of the glazed units. Around the window frame, designers should ensure that their detailing avoids direct pathways for heat to flow from the inner window frame to the outer leaf of the building. Some examples of detailing are shown in Figure 5.

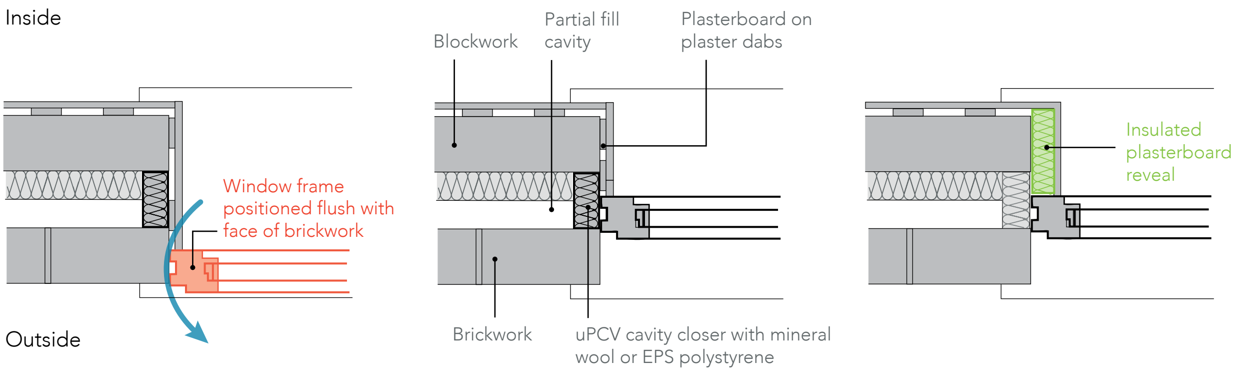


Figure 5 Poor (left), standard (middle) and good (right) detailing for minimising thermal bridges around windows

2.3 Solar gains and overheating

As well as admitting the sun's visible light, windows also admit ultraviolet (UV) radiation. Once inside the home the UV light is converted to infrared radiation (i.e. heat). This process is termed 'solar gain'. On a clear but cold day in winter, solar gains are a benefit because they provide some of the space heating energy needed to keep the home warm. On a hot day, however, solar gains are potentially a problem because they can heat up the home to a level that is uncomfortable for the residents and which, in extreme cases, may affect their health.

Because of the way in which the sun moves through the sky during the day, and the significant differences in the pattern of the sun's movement from season to season, the effect of solar gains on a home's space heating energy and overheating can be far from obvious. Keen gardeners know that a south-facing garden receives the most sunlight. For a home however (which, unlike a garden, has vertical as well as horizontal surfaces) the compass direction from which it receives the most solar gains depends on the time of year.

In addition to the window's orientation, the extent of solar gain depends on the size of the window, the proportion that is glazed (i.e. the frame factor) and a property known as the g-value of the glazed unit. The g-value describes the proportion of solar energy falling on the glazing which will be transmitted through to the inside of the building. It depends on the number of panes of glass in the glazed unit, the gas which fills the gap between the panes and any coatings (e.g. low-emissivity) on the glass. The range of g-values of modern glazing is typically 0.4 to 0.8, meaning that between 40% and 80% of the solar energy will find its way to the inside of the building.

Although not yet used for domestic applications, solar-control glazing is a technology that may in the future have a role in reducing overheating in homes. It reduces the g-value, but can also have the disadvantage of reducing daylight transmission through the window.

Overheating is a complex subject, which also involves the thermal mass of the building's structure, the amount of ventilation, the type of glass and any coatings, whether there is night-time purging of the heat stored in the structure and other factors. Further information on overheating, including how to minimise it in new homes, is available[3,4,5].

2.4 Daylighting

The extent to which a room is lit by natural daylight is expressed as an average daylight factor (ADF) at a defined position within a room.

The average daylight factor is calculated separately for each room, and is a function of the size of the window, the type of glazing[6], the frame factor, the size of the room and the reflectance of the room's surfaces. The calculation also involves the angle of sky that is visible from the centre of the window, which in turn depends upon the positioning of the windows in the walls, the depth of the window reveals and the obstructions outside the windows[7]. Where window reveals can be splayed (Figures 6 and 7) this can increase the penetration of daylight into a room.

Figure 6 Example of externally splayed reveals

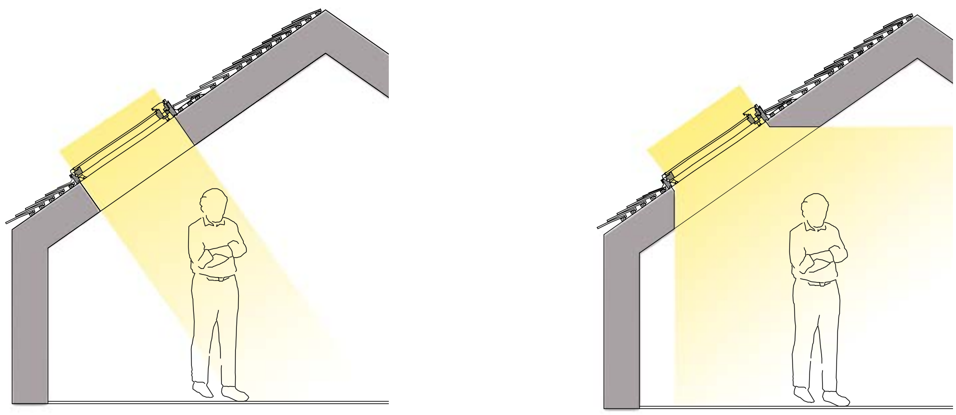


Figure 7 Diagram of the sky angle view from inside a room with internally splayed reveals.

The calculation of average daylight factor assumes a 'standard overcast sky' brightness. It is important to note that the factor is not affected by the orientation of the window, since the sky is assumed to be uniformly overcast and so sun angles are immaterial.

Average daylight factors effectively represent the natural light level within a room as a percentage of the light level outside, and typical values in homes range from 1% to 5%.

2.5 Ventilation, condensation and health

Ventilation provides fresh air for the residents as well as removing unwanted odours and pollutants from the home. Ventilation is also required to remove the water vapour that is produced from normal activities such as cooking, bathing and breathing. A healthy home requires a low level of general-purpose background ventilation, plus the ability to rapidly increase the rate of ventilation when it is necessary to purge the home of moisture or odours. As mentioned in Section 2.3, overnight purging is usually needed if the thermal comfort strategy of the home relies on the weight of the internal structure to absorb excess heat gains during the day.

Background ventilation can be provided by trickle vents in the window frames. Purge ventilation is traditionally achieved simply by opening the windows as needed, and/or operating individual extract fans in key locations such as kitchens, bathrooms and WCs. Where security is a concern, inwardly-opening casement windows are a more secure choice than outward opening ones, however designers should also consider windows with integral louvres that can provide secure openings for purge ventilation. Secure ventilation is discussed in more detail elsewhere[8].

Figure 8 Trickle vents incorporated in a casement window

Figure 9 Example of a secure opening using integral louvres

If a property is likely to be affected by external noise or pollution from traffic, opening windows or louvres may not be a practical solution. In such cases designers may need to consider the use of appropriate whole house mechanical ventilation systems and layouts that minimise noise in sensitive rooms, particularly bedrooms.

Windows and condensation

It used to be the case with single-glazed windows in badly insulated, underheated homes that condensation could form on the inside of the windows – sometimes leading to pools of water on the window sills. The edge seal of double glazing would sometimes fail too, and condensation would then form inside the glazed unit.

Modern gas-filled multiple-glazed windows with low-emissivity coatings are so good at preventing the transmission of heat that the outermost glass surface is sometimes cold enough in winter for condensation to form on the outside of the window. As a result, residents who remember the historic problems of condensation with windows can mistakenly think that their modern windows have failed when they are, in fact, simply doing their job very well.

Window energy ratings

A useful shorthand that sums up the overall performance of a window is the Window Energy Rating defined by the British Fenestration Rating Council (BFRC).

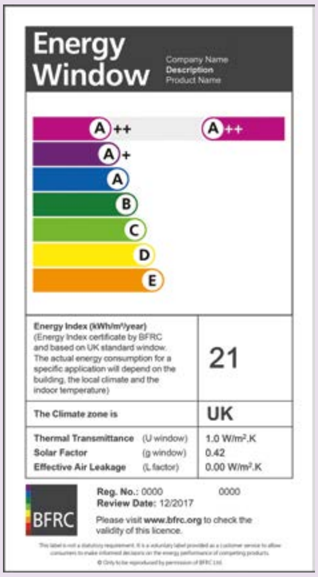


Figure 10 Example window energy rating label

The rating (or index) expresses the net energy contribution or loss of the window. It is a simple function of the solar gains minus the heat losses (including through draughts) which occur through the window. In other words it brings together into a single number the U-value, the g-value and the inclusion of features such as trickle vents. The rating is expressed in kilowatt hours per square metre of window per year (kWh/m^{2}yr), and can be positive (net energy gain) or negative (net energy loss).

The rating (index) can also be translated onto the familiar A++ to E scale which is then displayed on a consumer label.

This labelling is a helpful way to rank windows on an energy efficiency basis and to give consumers confidence. However, the rating itself does not provide the full information required to support the more detailed design considerations relating to the internal environment that are covered in this guide.

For more information see the BFRC website[9].

3 Optimising the window design

3.1 Modelling to support decision making

The challenge for the designers of today's new homes is to minimise winter space heating demand while keeping overheating within acceptable limits and also maximising the amount of daylight entering the home. This ideal situation is not always possible because the window characteristics can compete with each other, where a specification change improves one aspect of performance but makes another aspect worse. It is often necessary to decide what the primary objective is, and accept that the other results might be somewhat less than ideal[8].

To support decision making, modelling simulation runs have been carried out using four home types:

- Two-bedroom mid-floor apartment, habitable floor area 59 m^2
- Three-bedroom mid-terrace house, habitable floor area 76 m^2
- Three-bedroom semi-detached house, habitable floor area 90 m^2
- Four-bedroom detached house, habitable floor area 116 m^2.

For each home type, a 'base case' was specified (which just passed the energy/carbon section of English Building Regulations). These base cases are specified in Part 5.

The four most significant window-related changes that designers commonly make are to the glazing type, the frame factor, the total window area and the orientation of the home. Modelling the practical extremes of such changes can alert designers to the implications of their decisions, highlighting the need to avoid product substitutions and indicating where compromises may be called for in the design.

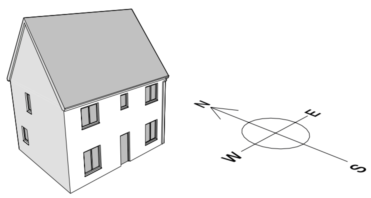
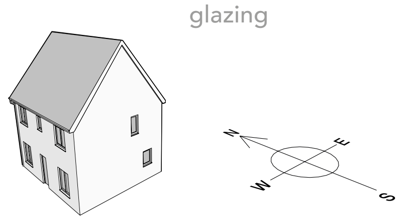
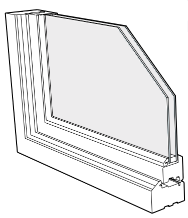
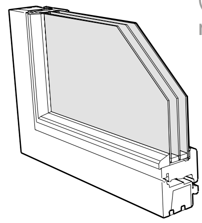
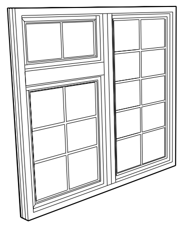
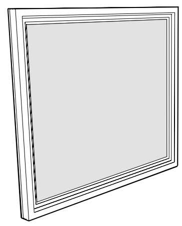
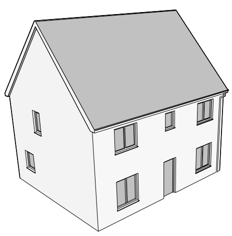
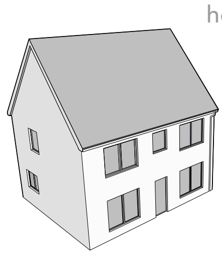
Base Case	Practical extreme
Orientation: Mainly South-facing glazing 	Orientation: Mainly West-facing glazing 
Glazing type: Double, Argon filled, low-emissivity coating (overall U-value=1.40W/m²k, g-value=0.7) 	Glazing type: Triple, Krypton filled, low-emissivity coating* (overall U-value=1.03W/m²K, g-value=0.4) 
Frame factor: 0.53 	Frame factor: 0.7 
Window area: Typical for home type (see section 5) 	Window area: Area increased by 50% above typical for home type 

Figure 11 The base case and practical extremes that have been modelled

The base case and practical extremes that have been modelled are shown in Figure 11.

Each time one of the design changes is made, the model calculates the effect on the following:

- Annual space heating demand, in kilowatt hours per square metre of floor area per year (kWh/m²yr)
- Risk of overheating, expressed as the percentage of hours in the year during which the internal temperature exceeds 25°C (%)
- Average daylight factor for the kitchen (%).

*Correction of original report which specified 'no coating' for this triple glazing.

Assessing overheating risk

Different software models and design approaches assess the risk of overheating in different ways. For example, for building compliance purposes the SAP uses a relatively simple method which calculates the mean internal temperature of the home over the three summer months. An acceptable limit for that mean internal temperature is defined.

The Passivhaus Planning Package (PHPP), which was used for this guide, is one example of a model that is intended for more detailed design work. PHPP contains a more sophisticated overheating assessment which calculates the number of hours in the year on which the mean internal temperature exceeds 25°C. This gives a more detailed indication of likely problems as they start to emerge.

The different methods allow designers to assess overheating at different levels of detail for different purposes. It is not generally possible to compare the results directly.

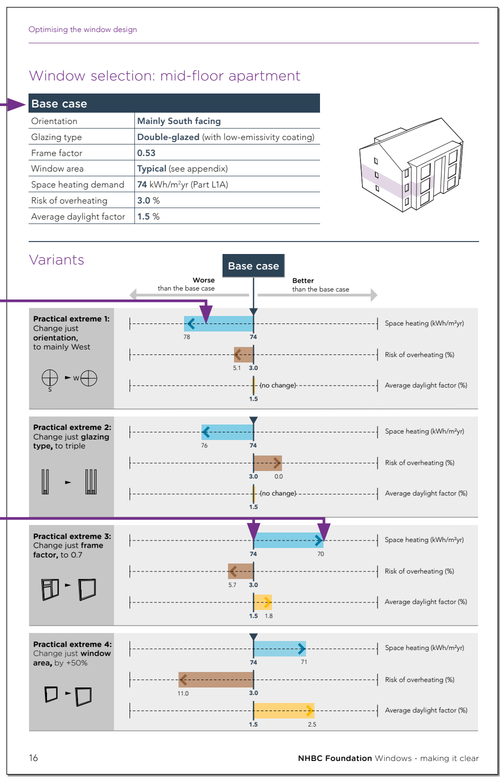
3.2 The effect of making changes

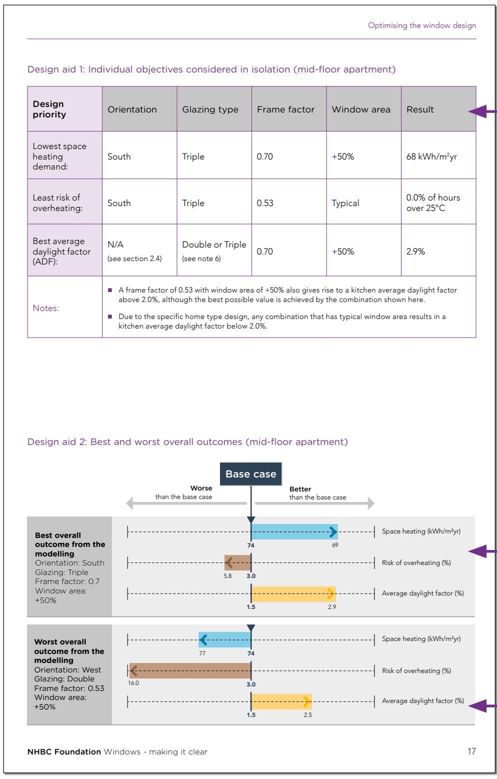
This section has subsections covering four typical house types (pages 16-23). Each summarises the base case, then illustrates what happens when specific window-related changes are made. Charts and tables are used to display the resulting space heating demand, risk of overheating and average daylight factor. These are explained below and on pages 14 and 15.

The base case for the home type is defined.

The coloured bars represent changes to space heating demand (blue), risk of overheating (brown) and kitchen average daylight factor (yellow). The base case is indicated in the centre of the diagrams, and the bars are displayed so that, in all cases, an improvement is indicated by a bar moving to the right of the base case. Conversely a bar moving to the left of the base case indicates a performance worse than the base case. So for space heating demand and overheating, lower numbers to the right of the base case indicate better-performing choices and, for average daylight factor, higher numbers to the right are better. The length of the bars represents the amount of improvement or worsening. (The absolute values are shown on the axis underneath each bar, for information.)

The bars in this chart show the practical extremes of what a designer might commonly explore during the design process or come across in product literature. In this chart the changes are shown one at a time, simply to illustrate the implications of making them. There is no attempt here to meet any specific objective, nor necessarily to achieve the best possible outcome overall.





Optimising the window design

Design aid 1: Individual objectives considered in isolation (mid-floor apartment)

Design priority	Orientation	Glazing type	Frame factor	Window area	Result
Lowest space heating demand:	South	Triple	0.70	+50%	68 kWh/m²yr
Least risk of overheating:	South	Triple	0.53	Typical	0.0% of hours over 25°C
Best average daylight factor (ADF):	N/A (see section 2.4)	Double or Triple (see note 6)	0.70	+50%	2.9%
Notes:	■ A frame factor of 0.53 with window area of +50% also gives rise to a kitchen average daylight factor above 2.0%, although the best possible value is achieved by the combination shown here. ■ Due to the specific home type design, any combination that has typical window area results in a kitchen average daylight factor below 2.0%.				

Design aid 2: Best and worst overall outcomes (mid-floor apartment)

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Design aid 1: Meeting specific objectives

This table shows the window-related properties which give the best results when particular objectives are being prioritised – i.e. whether the design is focussed on minimising space heating, minimising overheating risk or maximising daylighting. It is important to realise that prioritising just a single outcome may, inadvertently, compromise the others. For example, increasing the frame factor in order to reduce the space heating demand can also lead to a greater risk of overheating. Designers must pay particular attention to these interactions when changes to the window specifications are made.

Design aid 2: Best and worst combinations

This chart describes the optimal combination for this specific home type, and also shows the corresponding changes in space heating, overheating and daylighting compared to the base case.

This chart describes the least desirable combination for this specific home type, and also shows the corresponding changes in space heating, overheating and daylighting compared to the base case.

Design aid 1

If any particular outcome is the priority (for example if the design objective is to achieve the lowest space heating demand), the best combination of window-related properties depends on the actual objective.

In this guide the following criteria are used to define the success or failure of the outcome:

- If the design priority is to achieve the lowest space heating demand: there is no concept of 'acceptable' or 'unacceptable'. Quite simply, the lowest value of calculated kWh/m²yr is the best outcome.
- If the design priority is to achieve the lowest risk of overheating: if the predicted whole-house mean internal temperature exceeds 25°C on more than 10% of hours in the year, this is the threshold at which the Passivhaus design guidance flags overheating as a potential problem[10]. If more than one combination of window-related properties triggers this threshold, the combination that leads to the lowest percentage of hours above 25°C is considered to be the best.
- If the design priority is to achieve the best average daylight factor: a higher value of average daylight factor is always better than a lower one. A value of 1.5% or more is generally regarded as acceptable for living rooms, while good practice suggests that kitchens should aim to achieve at least 2.0%[11]. This guide assumes that the kitchen average daylight factor is more important than the other rooms.

Design aid 2

It is possible to define an optimal, best overall outcome from the modelling of space heating demand, overheating risk and average daylight factor. It is also possible to define the opposite, the worst overall outcome from the results. The following table shows how the best and worst overall outcomes have been defined. Space heating and overheating risk are likely to be more significant to residents, so have been given more weight than the average daylight factor in selecting the best and worst outcomes.

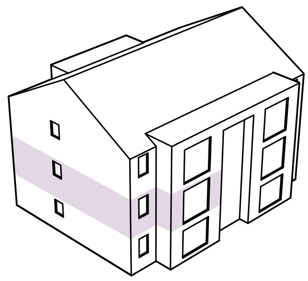
The **best overall outcome window design** is the combination of window-related properties that has:		
Firstly	Space heating demand:	the lowest value of calculated kWh/m²yr
as well as …	Risk of overheating:	fewer than 10% of days over 25°C
and, (as a possible deciding factor)…	Average daylight factor:	at least 2.0% (kitchen)
The **worst overall outcome window design** is the combination of window-related properties that has:		
Firstly	Space heating demand:	the highest calculated value of kWh/m²yr
as well as …	Risk of overheating:	10% or more days over 25°C
and, (as a possible deciding factor)…	Average daylight factor:	less than 2.0% (kitchen)

Table 1 Defining the best and worst overall outcomes from the modelling

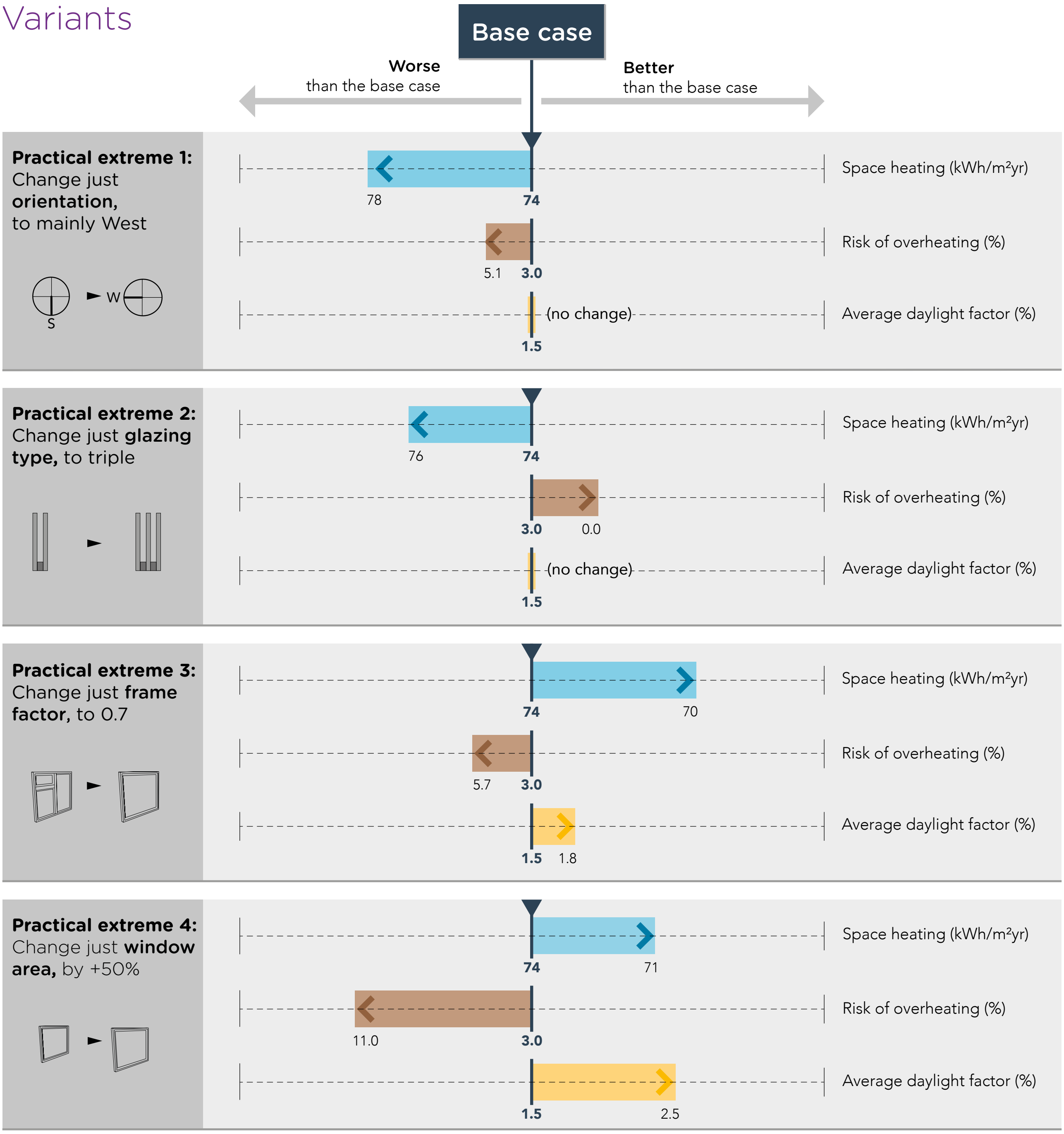
Technical note: the physical interactions which occur when individual changes are combined to produce a best or worst overall outcome are complex. As a consequence the cumulative result is not simply the sum of the individual results (in fact the results tend to multiply rather than add). It is for this reason that sophisticated software is required to model the true effects.

Window selection: mid-floor apartment

Base case	
Orientation	**Mainly South facing**
Glazing type	**Double-glazed** (with low-emissivity coating)
Frame factor	**0.53**
Window area	**Typical** (see appendix)
Space heating demand	**74** kWh/m²yr (Part L1A)
Risk of overheating	**3.0** %
Average daylight factor	**1.5** %



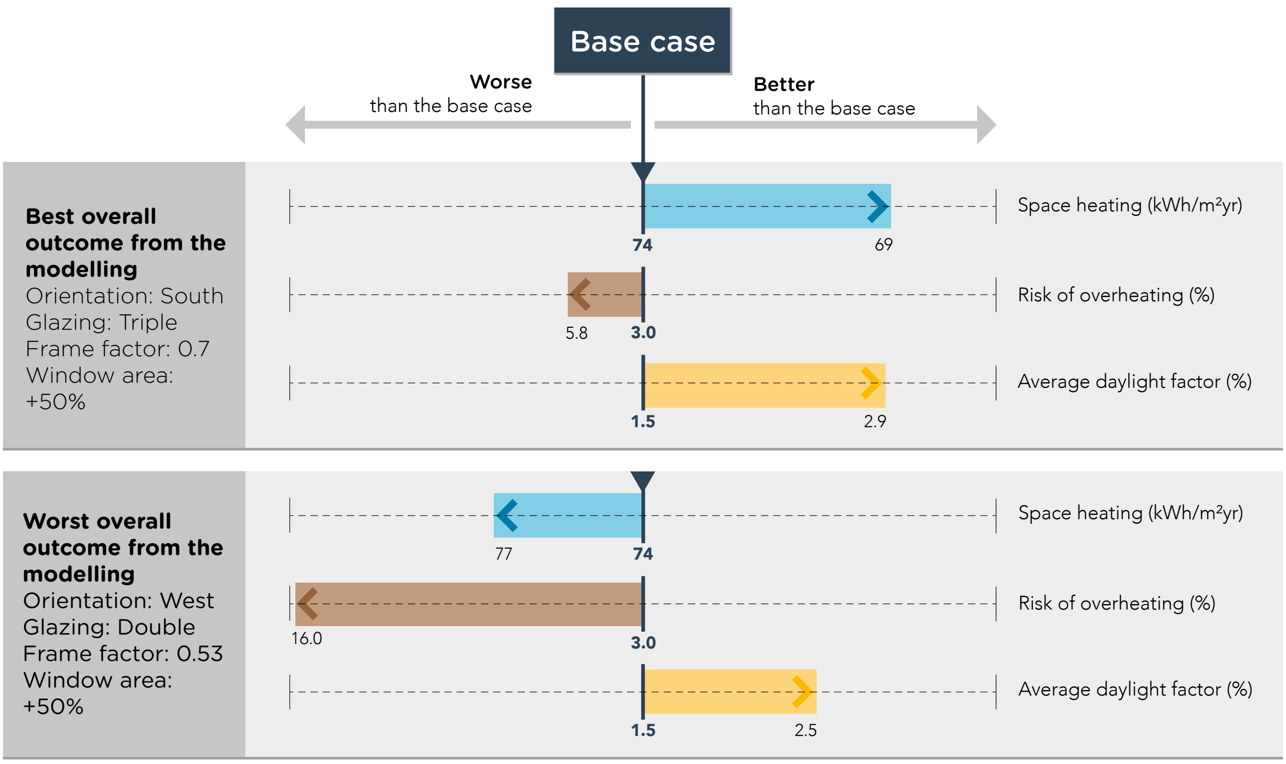
Variants



Design aid 1: Individual objectives considered in isolation (mid-floor apartment)

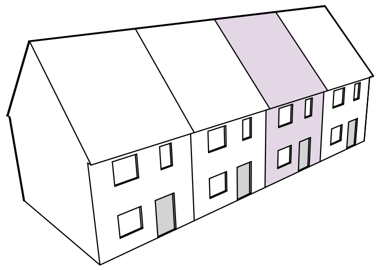
Design priority	Orientation	Glazing type	Frame factor	Window area	Result
Lowest space heating demand:	South	Triple	0.70	+50%	68 kWh/m²yr
Least risk of overheating:	South	Triple	0.53	Typical	0.0% of hours over 25°C
Best average daylight factor (ADF):	N/A (see section 2.4)	Double or Triple (see note 6)	0.70	+50%	2.9%
Notes:	■ A frame factor of 0.53 with window area of +50% also gives rise to a kitchen average daylight factor above 2.0%, although the best possible value is achieved by the combination shown here. ■ Due to the specific home type design, any combination that has typical window area results in a kitchen average daylight factor below 2.0%.				

Design aid 2: Best and worst overall outcomes (mid-floor apartment)

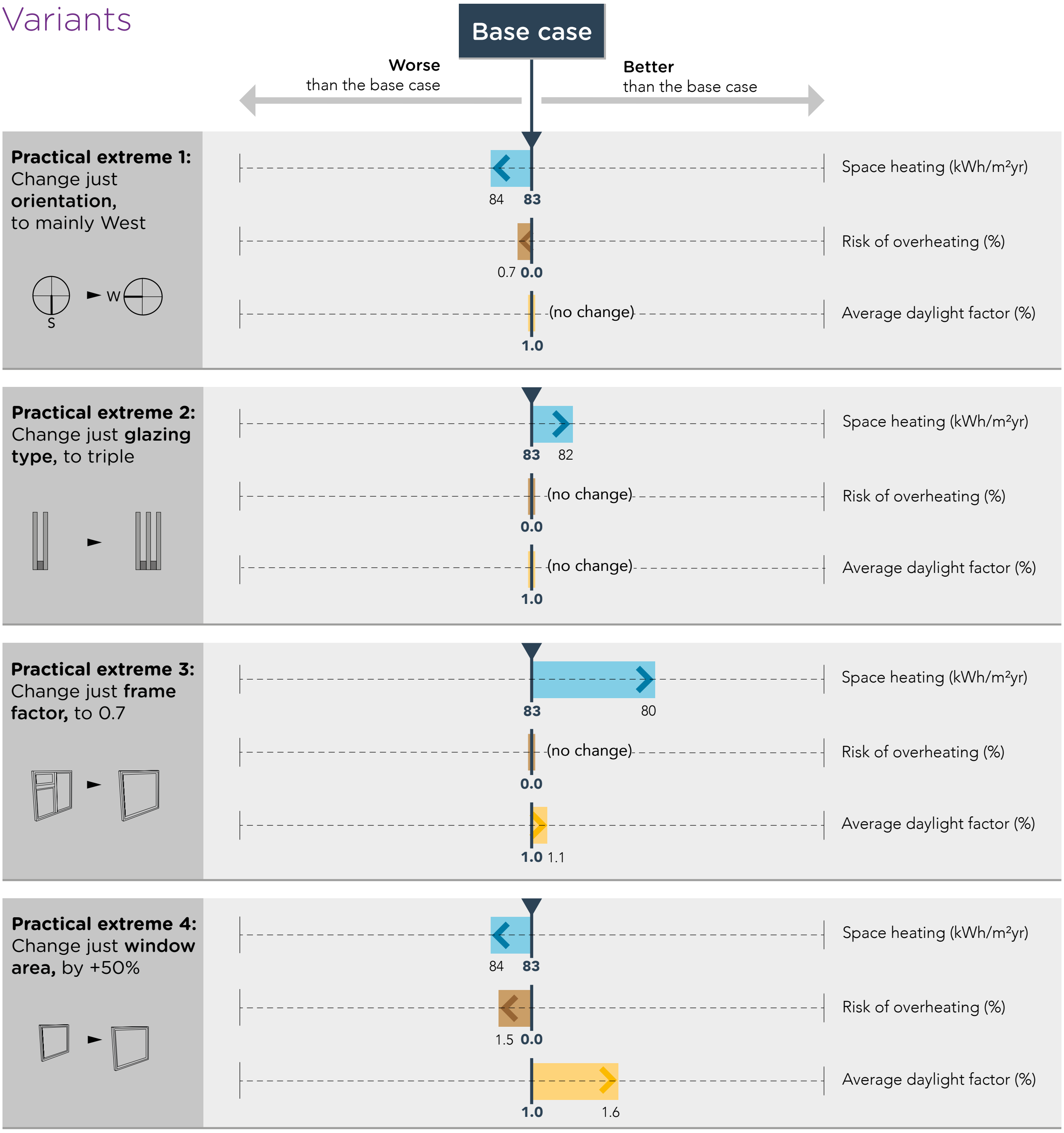


Window selection: mid-terrace house

Base case	
Orientation	**Mainly South facing**
Glazing type	**Double-glazed** (with low-emissivity coating)
Frame factor	**0.53**
Window area	**Typical** (see appendix)
Space heating demand	**83** kWh/m²yr (Part L1A)
Risk of overheating	**0.0** %
Average daylight factor	**1.0** %



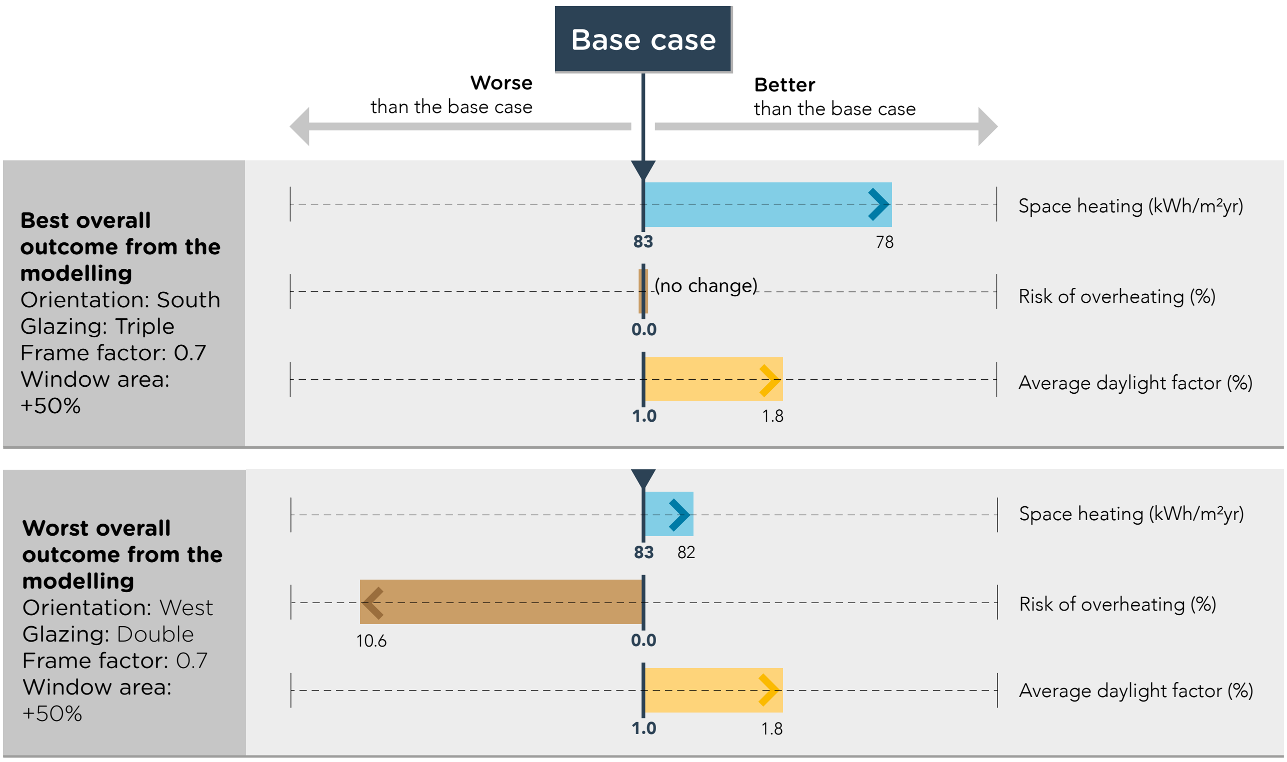
Variants



Design aid 1: Individual objectives considered in isolation (mid-terrace house)

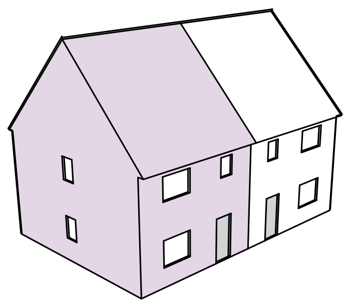
Design priority	Orientation	Glazing type	Frame factor	Window area	Result
Lowest space heating demand	South	Triple	0.70	+50%	78 kWh/m²yr
Least risk of overheating:	South	Double	0.53	Typical	0.0% of hours over 25°C
or	South	Triple	0.53	Typical or +50%	
or	South	Triple	0.70	Typical	
or	West	Triple	0.53	Typical	
Best average daylight factor (ADF):	N/A (see section 2.4)	Double or Triple (see note 6)	0.70	+50%	1.8%
Notes:	■ All combinations except one have an acceptably low risk of overheating. ■ Due to the specific home type design, no combinations achieve a kitchen average daylight factor of 2.0%. The highest modelled value, 1.8%, would however fall within good practice for any room other than a kitchen.				

Design aid 2: Best and worst overall outcomes (mid-terrace house)

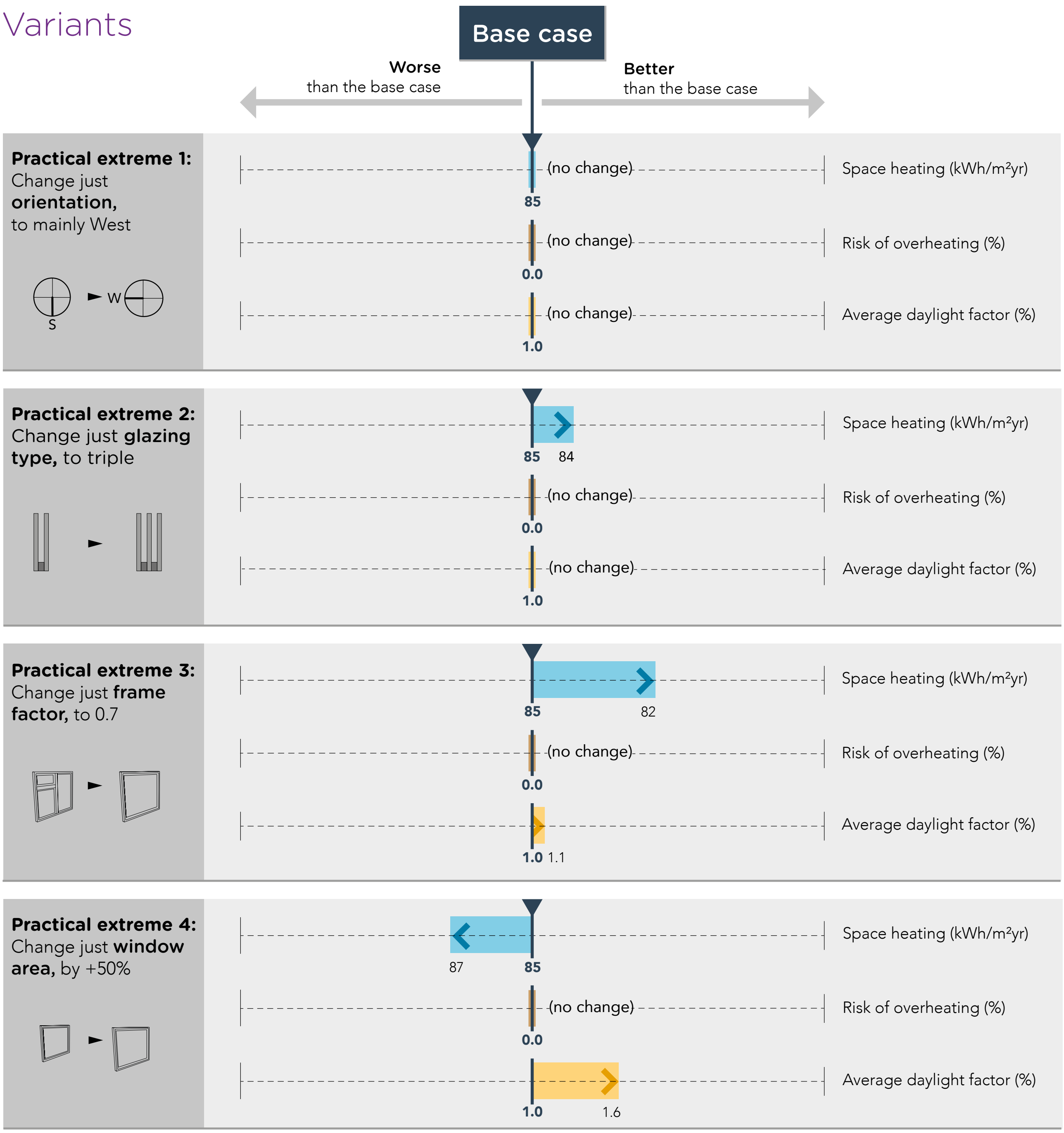


Window selection: semi-detached house

Base case	
Orientation	**Mainly South facing**
Glazing type	**Double-glazed** (with low-emissivity coating)
Frame factor	**0.53**
Window area	**Typical** (see appendix)
Space heating demand	**85** kWh/m²yr (Part L1A)
Risk of overheating	**0.0** %
Average daylight factor	**1.0** %



Variants



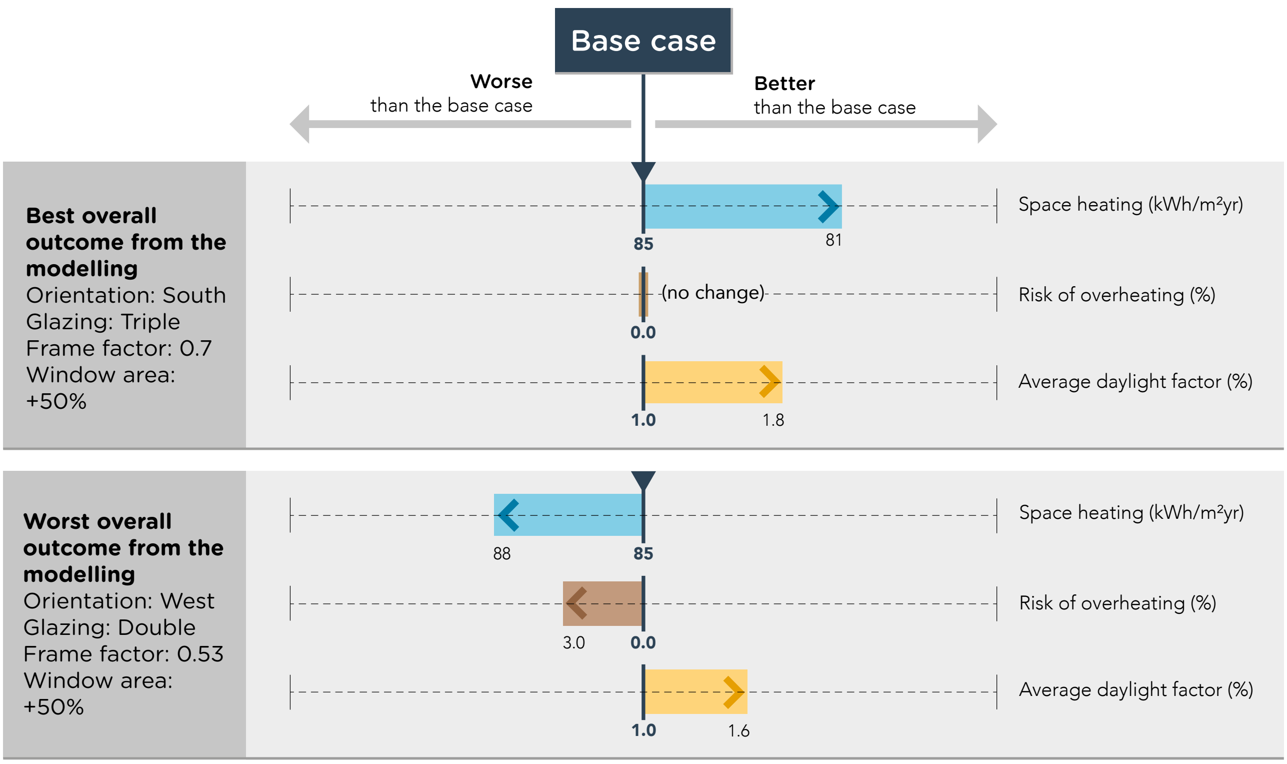
Design aid 1: Individual objectives considered in isolation (semi-detached house)

Design priority	Orientation	Glazing type	Frame factor	Window area	Result
Lowest space heating demand:	South	Triple	0.70	+50%	80 kWh/m²yr
or	West	Triple	0.70	Typical	
Least risk of overheating:	Little risk with any combination				0.0% of days over 25°C
Best average daylight factor (ADF):	N/A (see section 2.4)	Double or Triple (see note 6)	0.70	+50%	1.8%

Notes:

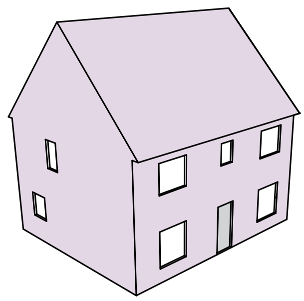
- Two combinations 'tie' with equal lowest space heating. For this home type, the reduction in useful wintertime solar gains caused by Westerly orientation is exactly compensated by the improved heat losses arising from smaller windows.
- All 16 combinations have an acceptably low risk of overheating. However designers are advised to verify overheating risk if intending to use large, double-glazed windows in a West-facing situation.
- Due to the particular home type design, no combinations achieve a kitchen average daylight factor of 2.0%. The maximum value, 1.8%, would however fall within good practice for any room other than a kitchen.

Design aid 2: Best and worst overall outcomes (semi-detached house)

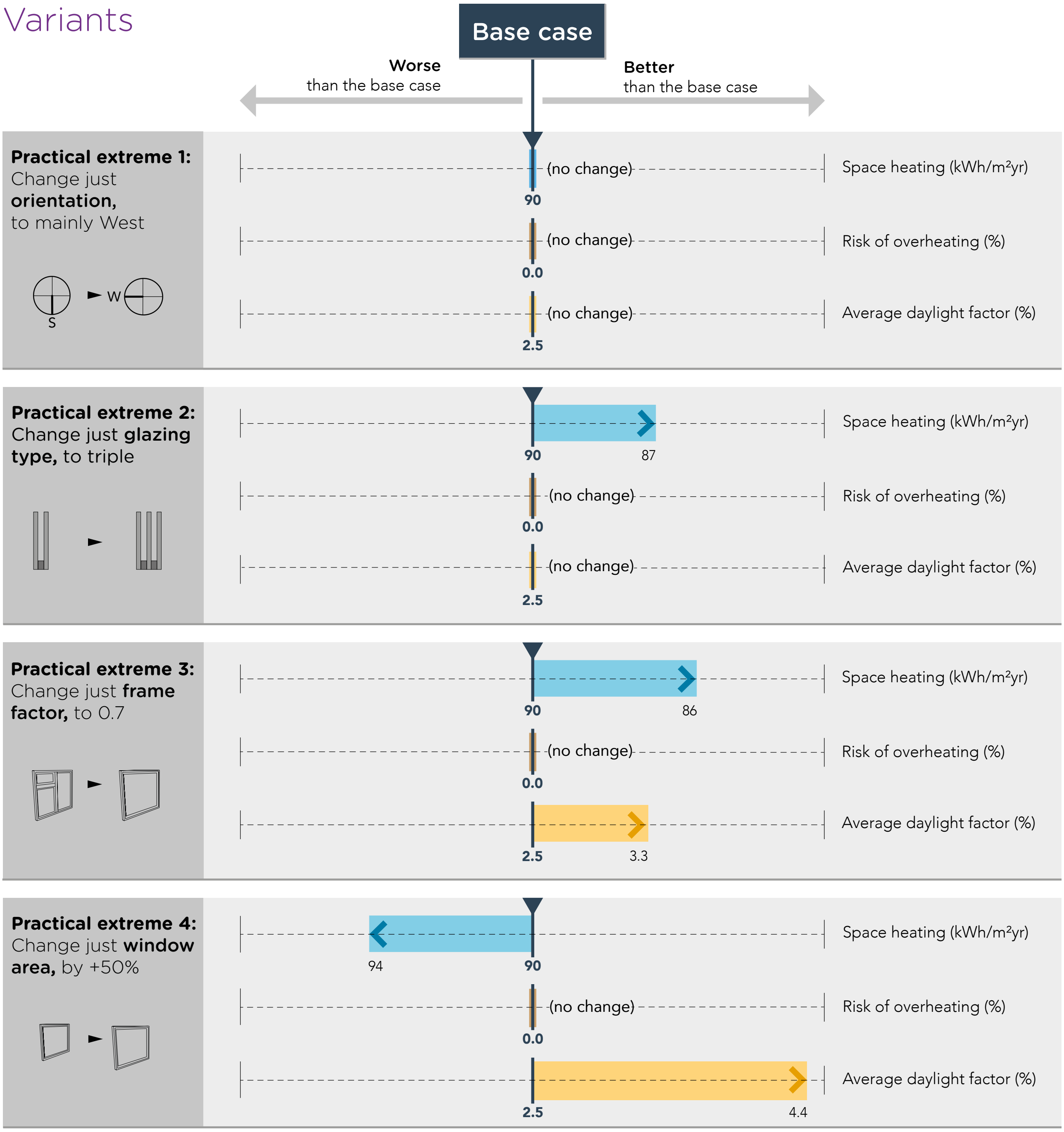


Window selection: detached house

Base case	
Orientation	**Mainly South facing**
Glazing type	**Double-glazed** (with low-emissivity coating)
Frame factor	**0.53**
Window area	**Typical** (see appendix)
Space heating demand	**90** kWh/m²yr (Part L1A)
Risk of overheating	**0.0** %
Average daylight factor	**2.5** %



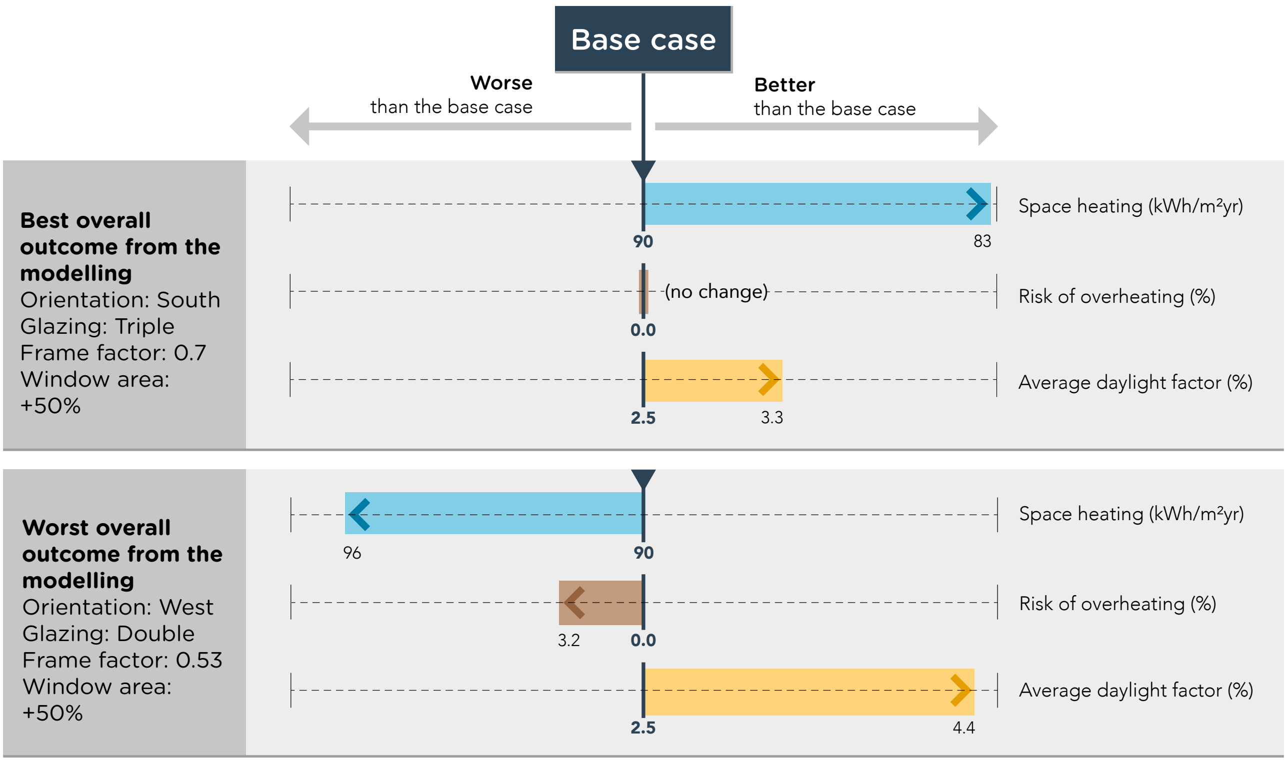
Variants



Design aid 1: Individual objectives considered in isolation (detached house)

Design priority	Orientation	Glazing type	Frame factor	Window area	Result
Lowest space heating demand:	South	Triple	0.70	Typical	83 kWh/m²yr
Least risk of overheating:	Little risk with any combination				0.0% of hours over 25°C
Best average daylight factor (ADF):	N/A (see section 2.4)	Double or Triple (see note 6)	0.70	+50%	5.4%
Notes:	■ All 16 combinations have an acceptably low risk of overheating. However designers are advised to verify overheating risk if intending to use large, double-glazed windows in a West-facing situation. ■ Due to the particular home type design, all combinations easily achieve a kitchen average daylight factor above 2%.				

Design aid 2: Best and worst overall outcomes (detached house)



4 Final reflections

4.1 Broad considerations

- The modelling results presented in this guide will help designers to make good decisions on the selection of windows, and ensure that they contribute successfully to a home's overall performance. However, the technical optimisation presented is clearly only one aspect of the design process. Financial considerations may, for example, lead a builder or client to decide against the use of a particular window type yet still achieve their own particular definition of an optimal outcome.

- The effects of making changes to windows are dependent upon the type of home, its basic specification, its surroundings and its geographical location. The results in this guide are specific to the home types modelled, and while they are typical of those found in practice, designers must take care not to over-generalise. In any home type the solar gains and heat losses interact in a complex fashion, in reality as well as when modelled. The purpose of this guide is to highlight what can be achieved with careful design and to identify broadly where the good solutions can be found (and conversely to help avoid solutions that are likely to be suboptimal or poor, compared to the best). In all cases, follow-up detailed modelling is recommended in order to be sure of making the best design decisions.

- All modelling results depend on the accuracy of the input data. In order to avoid drawing incorrect conclusions, default values should be avoided wherever possible in design. Using manufacturers' specifications will reduce the likelihood of overly-optimistic or overly-pessimistic calculation results. However as highlighted in this guide it is important to understand the significance of slight changes to specifications and to be conversant with the more significant performance characteristics.

- Any product substitution must be carefully evaluated and monitored during both the design and construction phases. Window products that are outwardly similar may have very different U-values, g-values, frame factors, etc., all of which can potentially reduce performance. For example it is particularly easy to confuse centre-pane U-values and overall window U-values, or for the impact of slight changes in frame factor to be underestimated.

4.2 The modelled home types – how do they differ?

- The results for the **mid-floor apartment** show it to respond somewhat differently to the other home types modelled. For example, this apartment has a generally higher tendency to overheat (including a minor risk even in the optimal case), and it is the only home type where increasing the window area causes the space heating demand to improve. This is because, compared to the other home types:

  (a) the majority of the walls, roofs and floors are party as opposed to external, and
  (b) a much greater proportion of the external walls consists of windows.

  These characteristics are typical of many apartments and the interaction between solar gains and heat losses shown in this example is likely to be quite typical in this home type.

- In the **mid-terrace house** that was modelled, the worst combined case shows a small improvement in space heating demand over the optimised case. This case is nevertheless still defined as the worst overall outcome because the overheating risk exceeds the 10% threshold set out in Section 3.2, Table 1.

- The **semi-detached** and **detached houses** which were modelled are particularly immune to overheating. This is fundamentally because they have a greater heat loss area and more ventilation than the smaller home types, so unwanted solar gains can be dissipated more effectively.

4.3 Specific features of windows

- Generally speaking, a glazed unit with more panes of glass will give rise to a lower average daylight factor. However, the two types of glazing used in this guide (double glazed with low-emissivity coating and triple glazed with no coating), chosen to represent the practical extremes that are generally found in today's new home designs, happen to have identical values of light transmittance. So it may appear from the modelling results that changing the type of glazing has no effect on the average daylight factor, but this is not always the case.

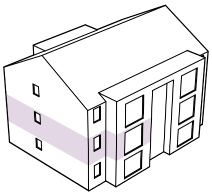
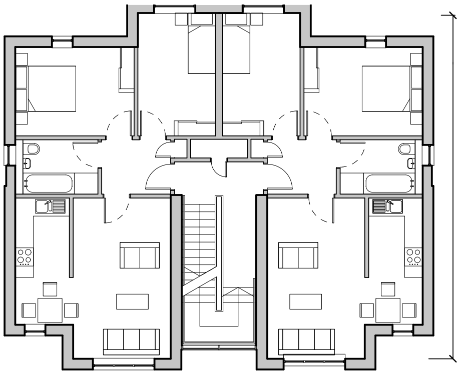
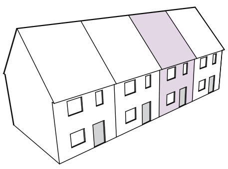
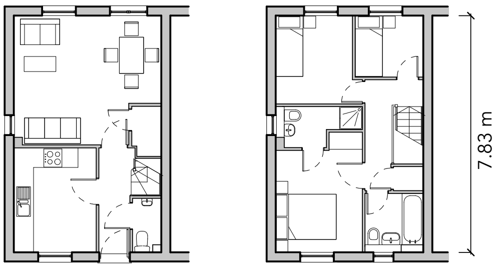
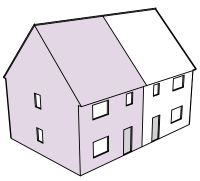
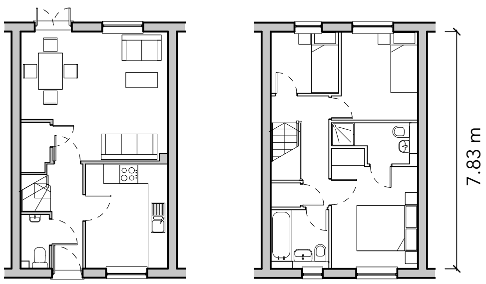
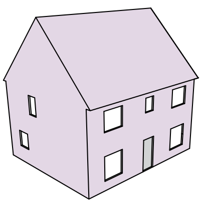
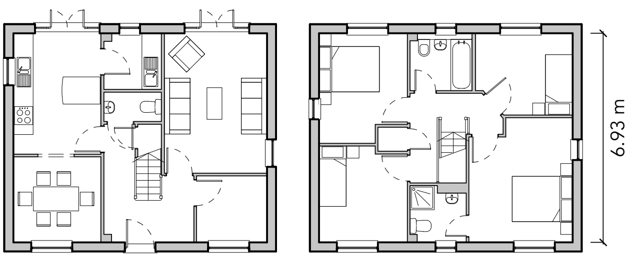
- In modern windows such as those modelled, frame factor can have a more significant effect on space heating consumption than is often realised.

- The maximum size of available windows is constrained by the engineering challenges associated with the weight of very large windows.

- Increasing the size of windows, for example in pursuit of greater daylighting, can ultimately lead to the home failing the energy/carbon requirements of the Building Regulations.

- Specifying windows without trickle ventilators (which is acceptable in conjunction with a whole-house balanced system such as mechanical ventilation with heat recovery) could lead to inadequate background ventilation if the mechanical system is used incorrectly (or not at all) by the residents.

5 Home type specifications and modelling assumptions [12]

Home type	
Mid floor apartment  Total habitable area **59m^2** Window area **12.9m^2** (20% of floor area)	
Mid-terrace house  Total habitable area **76m^2** Window area **13.7m^2** (18% of floor area)	
Semi-detached house  Total habitable area **90m^2** Window area **15.5m^2** (17% of floor area)	
Detached house  Total habitable area **116m^2** Window area **27.6m^2** (24% of floor area)	

Modelling assumptions				
U-values, W/m²K				
	Mid floor apartment	Mid-terrace house	Semi-detached house	Detached house
Wall	0.22			
Roof	(n/a)	0.15	0.13	0.13
Floor	(n/a)	0.15	0.15	0.14
Windows (base case) [13]	1.40			
Doors	1.20			
Air permeability (m^3/m^2@50Pa)	5.0			
Thermal bridging (W/m^2K)	0.09	0.09	0.08	0.08
Thermal mass	Medium weight (including solid floor, timber upper floors and roof)			
Ventilation	Natural, via trickle vents			
Lighting	Default internal heat gains assumed			
Climate	Default setting to East Pennines [14]			
Reflectance of room surfaces	0.5 (area-weighted average)			
Terrain and shading				
It is assumed that the houses are within a typical development, with a 2.1m fence around the plot and nearby houses set at 20m from the rear of the property. Apartments will have a similar development opposite to create a street. Eaves project 300mm.				

Notes and references

1 For default values for use in UK Building Regulations, see Table 6e of the government's standard assessment procedure for energy rating of dwellings www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf.

2 The government's standard assessment procedure for energy rating of dwellings 2012 edition version 9.92, dated October 2013 revision June 2014. Department of Energy and Climate Change. 2014. www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf.

3 Understanding overheating – where to start: an introduction for house builders and designers. NF44. NHBC Foundation. July 2012.

4 Overheating in homes – the big picture. Zero Carbon Hub. June 2014.

5 Overheating in new homes: a review of the evidence. NF46. NHBC Foundation. November 2012.

6 The light transmittance values for the two types of glazing modelled in this study (double glazed with a low-emissivity coating and triple glazed with low-emissivity coatings*) happen to be identical. These types of glazing were selected to represent the practical extremes that are generally found in today's new home designs. It should not be concluded from this study that changing the type of glazing has no effect on average daylight factor. It can have an effect in some situations, and design calculations for average daylight factor should be carried out for the specific type of glazing used.

7 See calculation method in Site layout planning for daylight and sunlight: a guide to good practice. PJ Littlefair. IHS BRE Press. 2nd edition. 2011.

8 Designing homes for the 21st century: lessons for low energy design (page 20). NF50. NHBC Foundation. May 2013.

9 See the BFRC (British Fenestration Rating Council) website http://www.bfrc.org

10 See section 2.4 of Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard. Passive House Institute. 2016. Note that a change of just 1% represents 88 more or fewer hours per year, i.e. 3.7 full days. This Passive House guidance has been used because Building Regulations in the UK do not contain a method for assessing overheating in as much detail.

11 Lighting for buildings – Code of practice for daylighting. BS 8206- 2:2008. British Standards Institution. 2008.

12 Designs and assumptions based on Option 2 in Part L2013 where to start: An introduction for house builders and designers – timber frame construction (for England). NF59. NHBC Foundation. 2014.

13 Double glazed with low-emissivity coating, g=0.7, visible light transmittance=0.6, uPVC frame.

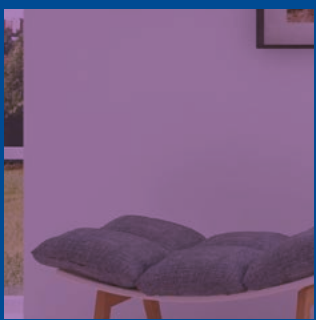
14 East Pennines is chosen to represent 'typical' mid-UK weather conditions. The calculated results would be different in absolute terms if a different location were used, but the trends and conclusions would be the same.

*Correction of original report which specified 'no coating' for the triple glazing.

Windows- making it clear

Energy, daylighting and thermal comfort

Housing designers make many technical choices, but few involve as many interactions and trade-offs as those related to the selection of windows. A particular challenge today is how to achieve a good balance between energy efficiency and daylighting, while keeping the risk of overheating to a minimum. Based on new modelling carried out on a range of typical types of new home, this guide provides graphics and design aids to steer a path towards the best solutions - showing how choice of glazing type, frame width, glazing area and orientation influence the outcome.



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