

Lessons from Germany's Passivhaus experience



Informing the debate

NHBC Foundation

NHBC House
Davy Avenue
Knowlhill
Milton Keynes
MK5 8FP
Tel: 0844 633 1000
Email: info@nhbcfoundation.org
Web: www.nhbcfoundation.org



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Written by

Neil Cutland of Cutland Consulting Limited, www.cutlandconsulting.co.uk.
Neil is also a Board member of the Passivhaus Trust, although the views expressed in this report are his own.

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About the NHBC Foundation

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. 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. Research has included a review of microgeneration and renewable energy technologies and the earlier investigation of what zero carbon means to homeowners and house builders.

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.

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Contents

Foreword	v
1 Introduction and summary	1
1.1 Introduction	1
1.2 Summary	1
2 The Passivhaus basics	3
2.1 What is Passivhaus?	3
2.2 Passivhaus requirements	4
2.3 The Passivhaus Planning Package	7
2.4 Quality assurance and certification	7
2.5 What does a Passivhaus building look like?	7
3 The context and drivers	9
3.1 Social context	9
3.2 Historical context	11
3.3 Political/legal targets	11
3.4 Economics	13
4 Construction activity to date	15
4.1 Germany	15
4.2 United Kingdom	17
5 User experience and acceptance	19
5.1 Germany	19
5.2 United Kingdom	22
6 The outlook for Passivhaus in the UK	23
Appendix: The user experience studies	26

About the Zero Carbon Hub

The Zero Carbon Hub was established in the summer of 2008 to support the delivery of zero carbon homes from 2016. It is a public/private partnership drawing support from both Government and the industry and reports directly to the 2016 Taskforce.

The Zero Carbon Hub has developed five workstreams to provide a focus for industry engagement with key issues and challenges:

- Energy efficiency
- Energy supply
- Examples and scale up
- Skills and training
- Consumer engagement.

To find out more about these workstreams, please visit www.zerocarbonhub.org. If you would like to contribute to the work of the Zero Carbon Hub, please contact info@zerocarbonhub.org.

Foreword

Since the announcement of the zero carbon target for new homes back in 2006, there has been much discussion about how this can be achieved. Many different approaches have been tried and tested since that time, and there is now general agreement that achieving the target demands firstly a high specification for the fabric of new homes and then close attention to its detailing and construction on site.

Throughout the discussions, reference has often been made to the Passivhaus standard. Developed in Germany in the late 1980s the standard sets very high requirements for energy efficient design and construction. Many have said that Passivhaus provides an excellent model for us to use in the UK, although some commentators point to a level of complexity and increased costs which they associate with it.

This report provides an objective overview of the experience gained to date from the implementation of Passivhaus in Germany and elsewhere in Europe, where it has been used in the design and construction of tens of thousands of new buildings. It points to the substantial achievements that have been realised by Passivhaus and also to the national context that has helped to promote its popularity in Germany. Conversely, the report also discusses some of the national differences which may tend to hinder the uptake of Passivhaus in volume in the UK.

As the zero carbon homes target looms ever larger, attention is increasingly focusing on the issue of as-built performance. It certainly appears that there are lessons which we in the UK can learn from the attention to detail inherent in the Passivhaus approach, even if the final UK requirements are not quite as exacting as those of the Passivhaus standard.

With final steps being planned for the implementation of zero carbon new homes throughout the UK, I hope that this report helps you to form your own view of the relevance of the Passivhaus standard to house building in the UK.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation

1 Introduction and summary



1.1 Introduction

In 2006 the UK Government announced that from 2016 all new build dwellings would have zero in-use carbon dioxide emissions, with non-domestic buildings following from 2019. The actual definition of 'zero carbon' has evolved in its detail since 2006, but UK house builders, developers and social housing providers have nevertheless been exploring ways of reducing the energy consumption of the homes they build. This search has led some to consider the Passivhaus standard.

The Passivhaus movement in the UK is in its infancy, and while it has many enthusiastic advocates, others question its viability as a standard for volume house building. Worldwide, since the standard emerged from Germany in the late 1980s, some 37,000 Passivhaus buildings have been constructed^[1].

This report examines the political, economic and social drivers, as well as the general attitudes, that have helped or hindered the uptake of Passivhaus in its birthplace. The German context is compared to that of the UK, and the relevance to us of Germany's experience is discussed.

1.2 Summary

The core focus of the Passivhaus philosophy is to minimise the requirement for space heating and cooling via high-specification fabric, and hence achieve low overall energy consumption. A Passivhaus building will typically have a space heating demand half that of one built to UK regulations, and will be 5 to 10 times more airtight.

[1] Estimate from the Passivhaus Institut, Darmstadt, Germany, July 2012.

A rigorous Passivhaus certification process includes quality assurance measures such as strong onsite management, multiple pressure tests during the construction phase, detailed documentation of equipment commissioning and photographic evidence of the as-built elements.

The rise in popularity of Passivhaus in Germany has been largely due to a specific combination of social, political and financial circumstances:

- **Social:** The German population has a strong interest in the environment and an associated inclination to take action. While people in Germany have traditionally lived mostly in rented accommodation, an increase in home ownership is occurring; a general enthusiasm for high product specifications and attention to detail means that building or buying a low energy home is seen as an attractive option.
- **Political:** In addition to national regulations for the energy performance of buildings, many individual cities have chosen to set their own energy and environmental standards which mandate an even higher performance. Failure to comply is treated as a regulatory offence and fines are issued.
- **Financial:** The cost of building a Passivhaus home in Germany is now estimated at 3 to 8% more than building a home to the building regulations (known in Germany as EnEV)^[2], and there is a variety of assistance available for financing this cost. Government and local loans are available at significantly discounted interest rates, and grants are available depending on the level of energy efficiency achieved.

Passivhaus is often described as a 'comfort standard' as well as an energy standard, and studies of occupant satisfaction in 736 Passivhaus dwellings in Germany and Austria are reviewed in this report. Overall the occupants were generally positive about Passivhaus with 92% of them indicating that their expectations had been met.

Germany's experience suggests, however, that educating occupants in the correct operation of the home and its ventilation system is vital – especially in order to avoid overheating in summertime. This is not a Passivhaus-specific problem; the trend towards more airtight homes in general means that mechanical ventilation with heat recovery (MVHR) is likely to become the dominant form of ventilation in new homes.

No one would claim that building Passivhaus homes is easy; the demanding energy performance and quality assurance requirements present a challenge to the designer and builder alike. Some observers question whether Passivhaus is a realistic solution for the volume market, although a number of large scale projects are continuing to inform the debate.

All certified Passivhaus homes built in the UK have to verify compliance with building regulations as well as the Passivhaus quality assurance procedure, which can add time, effort and cost. This problem is less significant in Germany because the Passivhaus Planning Package (PHPP) software also produces an energy compliance report for the requirements of the national building regulations (EnEV).

The high level of compliance of Passivhaus dwellings has led to suggestions that the formal certification process could help to narrow the gap between designed and built performance – although some elements of the process may be hard to apply to volume house building. It has been suggested by some UK proponents that Passivhaus certification be afforded the status of 'deemed to satisfy' the energy component of the UK building regulations.

[2] Energieeinsparverordnung – energy-saving regulations.

2 The Passivhaus basics



2.1 What is Passivhaus?

Passivhaus is a specific, voluntary low-energy performance standard for buildings^[3]. It is owned by the Passivhaus Institut of Darmstadt, Germany, which promotes and controls the standard and defines the associated quality assurance process. The core focus of Passivhaus design is to minimise the requirement for space heating and cooling, and hence overall energy consumption. Passivhaus also aims to provide good indoor air quality and thermal comfort.

While a Passivhaus home, by definition, concentrates on passive design features such as insulation, airtightness and solar orientation, it also allows certain active elements to be included – notably MVHR. The fundamental principle is that a Passivhaus home can maintain its designed internal temperatures and air quality simply by adding a small amount of heating or cooling to the air being circulated by the ventilation system, thereby eliminating the need for a traditional wet central heating system. In practice, for cultural or marketing reasons conventional central heating is often included, but it is important to realise that the Passivhaus standard ensures that it *need not be*.

[3] While Passivhaus is equally applicable to homes and non-domestic buildings, and to retrofit as well as new build, this report will focus mainly on the new build residential sector.



Figure 1 Traditional-style Passivhaus homes in Bridgend, Wales (© Hollbrook Homes Ltd)

2.2 Passivhaus requirements

In most cases an MVHR system is used to supply the home's space heating all year round through the inclusion of a heating element, commonly electric, within the unit. To make this possible, the space heating demand must be reduced to 15 kilowatt hours per square metre of floor area per annum (kWh/m²yr) or less. If an active cooling system is also included, then its additional energy demand must also be no more than 15 kWh/m²yr.

Box 1: Energy or carbon

The UK has chosen to express building regulations requirements in terms of carbon dioxide emissions (in kilograms per square metre per year, kg/m²yr). This focuses attention on the key greenhouse gas, and provides a common currency to compare the various carbon abatement policies designed to meet national reduction targets. Passivhaus, on the other hand, in line with most other European nations uses energy (in kilowatt hours per square metre per annum, kWh/m²yr) as its measure of compliance. This avoids the issue of different carbon intensities of fuels, and the complication of changes in emissions over time as the national electricity generation mix evolves^[4].

It is generally harder for electrically-heated homes in the UK to comply with building regulations than for gas-heated homes, but it has been demonstrated by various parties that a Passivhaus home with electric heating can nevertheless comply in principle (although a Standard Assessment Procedure (SAP) calculation will need to be done to confirm this in each specific case).

It should also be noted that mechanical ventilation and heat recovery (MVHR) systems incorporating fan coils fed by small gas boilers ('circulators') are entirely acceptable within the Passivhaus philosophy; while electric heating is common in Passivhaus, it is not compulsory.

[4] Further discussion is given in *Carbon Compliance for Tomorrow's New Homes: A Review of the Modelling Tool and Assumptions: Topic 2 – Carbon intensity of fuels*. Zero Carbon Hub, Milton Keynes, 2010.

Box 2: Airtightness – what units?

Passivhaus expresses the result of a pressure test as the number of times the entire volume of the house will be replaced in one hour, air changes per hour (ach), with a pressure differential of 50 Pascals (Pa). UK building regulations instead choose to express the result as the absolute volume of air that will be replaced in one hour, divided by the total external envelope area ($\text{m}^3/\text{m}^2\text{h}$), also with a pressure differential of 50 Pa.

Accurate conversion of one system to the other depends on the building size and area/volume ratio, but as an approximation it could be said that the 0.6 ach of Passivhaus corresponds roughly to $1.0 \text{ m}^3/\text{m}^2 \text{ h}$ when expressed in UK terms.



Figure 2 A Passivhaus office in Wales (© JPW Construction)

The airtightness of a Passivhaus home, as measured by a blower door pressure test, must be no worse than 0.6 ach at a pressure differential of 50 Pa.

In addition, the total primary energy demand of a Passivhaus home (ie space heating, cooling, domestic hot water, lighting, fans, pumps, white goods and all appliances) must be no more than $120 \text{ kWh}/\text{m}^2\text{yr}$.

Box 3: A summary of Passivhaus requirements

Space heating demand	$\leq 15 \text{ kWh}/\text{m}^2\text{yr}$
Space cooling demand	$\leq 15 \text{ kWh}/\text{m}^2\text{yr}$
Airtightness	$\leq 0.6 \text{ ach @ } 50 \text{ Pa}$
Primary energy demand	$\leq 120 \text{ kWh}/\text{m}^2\text{yr}$

The UK's building regulations do not mandate a primary energy target – but by way of comparison, homes built to the UK standard will typically have a space heating demand twice that of a Passivhaus home, and will be 5 to 10 times less airtight.

Table 1 shows the comparison between the Passivhaus guidelines and UK building regulations characteristics.

Table 1 Comparison of additional Passivhaus guidelines with UK building regulations

Additional Passivhaus guidelines	UK building regulations characteristics
Insulation	
U-values of walls, floors and roofs $\leq 0.15 \text{ W/m}^2\text{K}$	U-values of walls, floors and roofs around 0.15 to 0.25 $\text{W/m}^2\text{K}$
Glazing	
Triple-pane windows with insulated frames U-values (including doors) $\leq 0.8 \text{ W/m}^2\text{K}$	Double-pane windows U-values (including doors) around 1.20 to 2.00 $\text{W/m}^2\text{K}$
Solar orientation	
Windows largely south-facing	No particular requirement for solar orientation
Thermal bridging	
Minimal (ideally non-existent) psi-(Ψ) values $\leq 0.01 \text{ W/mK}$	psi-(Ψ) values typically 0.05 to 0.24 (or even 0.50 at steel lintels) W/mK
Ventilation	
High-efficiency MVHR system Heat recovery efficiency $\geq 75\%$, specific fan power $\leq 1.62 \text{ W/(l/s)}$	Background ventilators and intermittent extract fans
Appliances	
Low-energy lights and appliances throughout	Low-energy lights in 75% of internal fittings
Overheating	
Special care to avoid summertime overheating	Likelihood of summertime overheating must be calculated

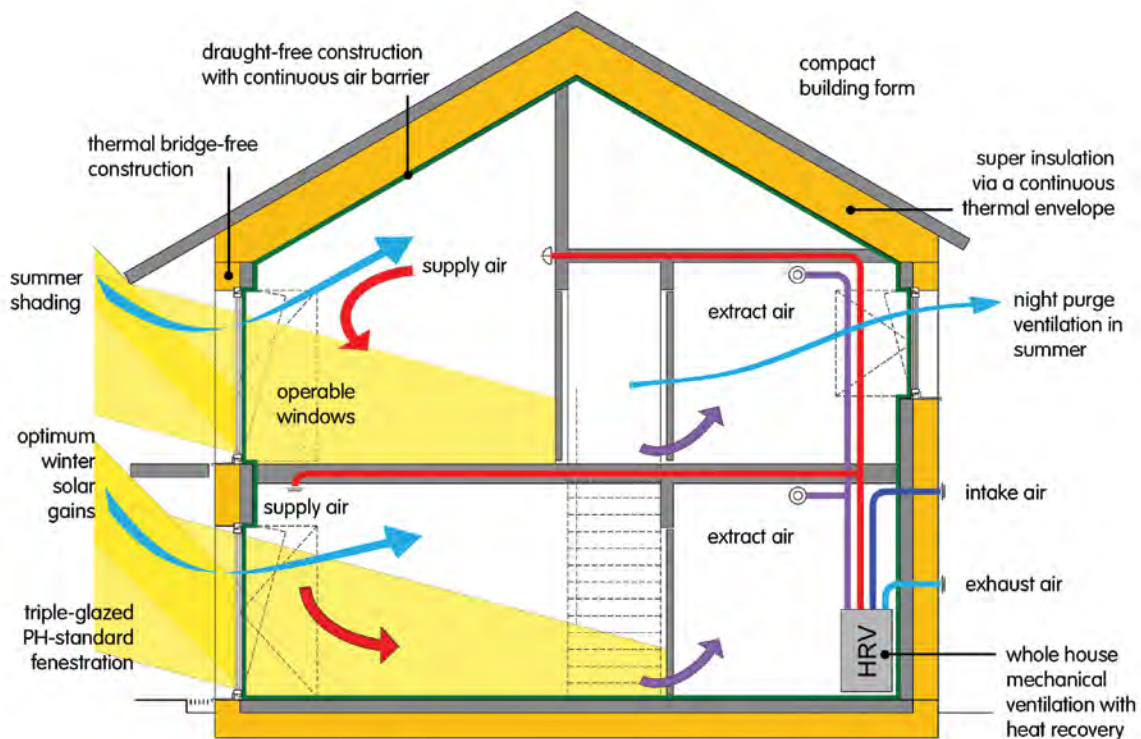


Figure 3 Passivhaus principles (© Passivhaus Trust/ECD Architects)

2.3 The Passivhaus Planning Package

The Passivhaus Planning Package (PHPP) is a spreadsheet-based energy calculation tool produced by the Passivhaus Institut in Germany, and is the only approved method for modelling and certifying the performance of a proposed Passivhaus building. PHPP is based around the same core energy calculation methods used throughout Europe (including SAP in the UK) but takes into account certain additional elements such as household appliances, and includes considerably more detail in some areas of the calculation (notably thermal bridging).

Significantly, the German version of PHPP contains an additional verification sheet which allows it to be used as one of the official energy calculation tools for demonstrating compliance with the energy requirements of the German national building regulations – see section 3.3).

2.4 Quality assurance and certification

The Passivhaus Institut has developed a quality assurance and certification process in order to prevent false claims and abuse of the term 'Passivhaus'. Compliance with the numerical Passivhaus requirements is verified at the design stage, and quality assurance measures are applied during the construction phase. The quality assurance measures include strong onsite management, multiple pressure tests during construction, detailed documentation of the MVHR commissioning and photographic evidence of the as-built construction elements.

As well as certifying complete buildings, the Passivhaus Institut also awards Passivhaus certification to proprietary products and individual components such as windows, wall systems and MVHR units. Designers and installers are not obliged to use certified products, but a penalty is applied to the performance figures of any non-certified products – so there is a strong incentive to use certified products.

2.5 What does a Passivhaus building look like?

In principle, a Passivhaus building can meet almost any aesthetic requirement, and all construction methods can be used. Examples of Passivhaus buildings in the UK and Germany are shown throughout this report.



Figure 4 Contemporary Passivhaus home in Camden, London (© Tim Crocker)



Figure 5 Passivhaus office in Dover, Kent (© Kym Mead, BRE/Dudley Marsh Architects)

3 The context and drivers



3.1 Social context

3.1.1 Predominance of rental accommodation

In comparison to the UK and other western European countries, Germany has the lowest number of owner-occupiers – although home ownership has increased slightly over the past decade. People in Germany have traditionally lived mostly in rented accommodation, 47% of the population living in rented accommodation in 2009 and 45% in owned houses or apartments. By comparison, in France and Britain in 2009, homes were owned by around two thirds of the population, and in Spain and Ireland by 80%.

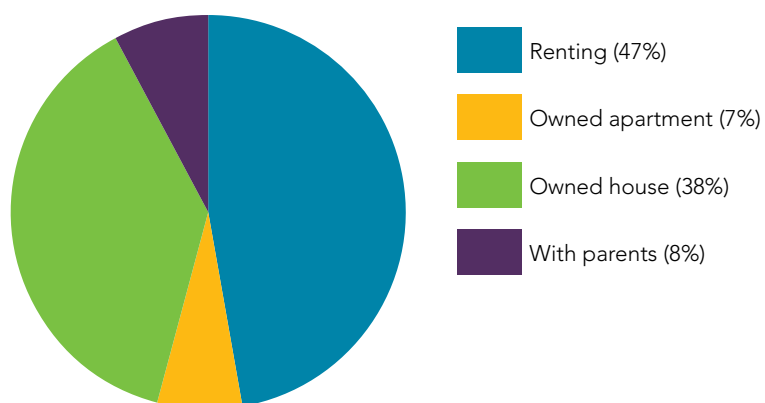


Figure 6 Breakdown of accommodation type, Germany, 2009

The recent increase in home ownership in Germany has been attributed to the belief that owning a home is beneficial in old age, as a viable alternative to a private pension scheme (particularly after the recent recession and with rising fuel prices).

3.1.2 Popularity of self-build and kit houses

The steady rise of fuel prices and the strict enforcement of national regulations on energy efficiency in Germany have made building or buying a low energy home an attractive option for many residents. Moreover, as at 2011 the cost of land in Germany allocated for building, and with infrastructure in place, was less than half the cost of equivalent land in the UK^[5,6].

The growing scale of competitively-priced prefabricated low energy houses, in combination with loans and discounts for energy-efficient new dwellings as described in section 3.4, has also had a strong influence on the trend towards owning a home, and in particular has caused a significant increase in self-build. This is in contrast to the UK, where the majority of house building is speculative.

The prevalence of prefabricated and kit homes over traditional masonry construction is therefore increasing. There are now a large number of companies, often grown out of small family businesses, offering complete homes with different styles and shapes and different levels of energy efficiency from which the buyer can choose. There is a directory of around 30 companies producing and/or distributing Passivhaus homes either as 'shell only' or complete with all technologies fitted and connected^[7].

The marketing of kit houses in Germany revolves around health and wellbeing, thermal comfort and sustainable building materials, as well as the knock-on advantages of short construction time and fixed prices. Many companies collaborate with established partners such as Passivhaus-certified MVHR or window manufacturers. There is a general enthusiasm for high product specifications and attention to detail, and these are exploited as key marketing features.

3.1.3 Architectural preferences

German family homes are generally larger than those built in the UK, the smallest typical units being a 120 m² one-family home or a 100 m² two-person bungalow. Adding to this space, houses are often built above a concrete basement which contains a plant room, laundry room and other storage facilities.

3.1.4 Environmental interest

The German population generally has a stronger interest in the environment, and a greater inclination to take action, compared with UK residents. A growing environmental awareness, focused by The Green Party movement from 1998, led to Germany fulfilling its Kyoto obligations by 2007 – three years early. The renewable energy contribution to Germany's national energy supplies is currently 20%, compared to the UK's current 3 to 4% and policy aspiration to achieve 15% by 2020.

[5] Preise Kaufwerte für Bauland 4. Vierteljahr 2011. Wiesbaden, Statistisches Bundesamt, 2012.

[6] Average valuations of residential building land with outline planning permission, Table 563. Housing Research. London, Department for Communities and Local Government, 2011.

[7] www.top-fertighaus.de/fertighaus-typen/passivhaus/passivhaus.html

3.2 Historical context

The Passivhaus standard originated from collaboration in 1988 between Professors Bo Adamson of Lund University, Sweden and Wolfgang Feist of the Institute for Housing and the Environment^[8], Germany. The first Passivhaus home was built in Darmstadt in 1991, and a period of monitoring and evaluation validated the standard, which was designed to achieve an energy consumption of only 10% of the standard house of the day.

The Passivhaus Institut (PHI) was founded in 1996 to promote and control the standard, and to develop and distribute the PHPP spreadsheet. The Passivhaus Institut also defines and controls the associated quality assurance process.

The pioneering products that had been used in the Darmstadt house, notably triple glazed windows and high-efficiency mechanical ventilation systems, started a new supply chain of Passivhaus-compliant components. The products were further commercialised as a result of the 2001 CEPHEUS (Cost Efficient Passive Houses as European Standards, see www.cephus.de/eng) project, a two and a half year study of 221 housing units built to the Passivhaus standard in five European countries.



Figure 7 The first Passivhaus, built in 1991 in Darmstadt, Germany (© Passivhaus Institut/IPHA)

3.3 Political/legal targets

In Germany, as in the UK, there are national energy conservation targets set through the national building regulations, EnEV. In addition, many cities have chosen to set their own energy and environmental standards which go beyond EnEV.

3.3.1 National energy conservation regulations

EnEV 2009 defines two overarching performance requirements:

- A maximum primary energy target expressed in kWh/m²yr. This includes space heating, hot water and ventilation, but not domestic lighting or appliances. If a cooling system is installed, the associated energy demand is included in the primary energy target, which is subsequently relaxed by a set amount dependent on the type of cooling installed.
- A requirement to demonstrate that the proposed heating system can provide adequate temperatures given the dwelling's specific heat loss (ie the heat loss through the external elements including thermal bridging, expressed in W/m²K).

The maximum primary energy value is determined by reference to a notional house which has the same geometry, size and technical specification as the house in question, and varies with floor area and surface area to volume ratio. Two important general requirements also exist:

- Implementation is strictly controlled
- Failure to comply, or falsification of energy requirement certificates, are treated as regulatory offences and fines are issued.

Changes to EnEV 2009 have been proposed in order to comply with the EU Energy Performance of Buildings Directive^[9], which contains the requirement that all new buildings must be 'nearly zero-energy' by 2020 (public buildings by 2018). The EnEV proposals include a 30% reduction in primary energy.

[8] Institut für Wohnen und Umwelt.

[9] Directive 2010/31/EU of the European Parliament and of the Council.

3.3.2 Local standards

Some cities have ambitious goals, such as Nuremberg which is aiming for a 40% reduction in carbon dioxide emissions between 2007 and 2020. At least seven German cities have made commitments to build to the Passivhaus standard itself.

Leading the municipal Passivhaus movement is the city of Frankfurt. Since 2007 the city has required all buildings built on land sold by the city to be fully certified to the Passivhaus standard, the only exception being if it is proven that the Passivhaus standard cannot practically be met. The city also requires new municipal buildings to meet the Passivhaus standard, and is providing additional funding to housing associations that opt for Passivhaus.

Hamburg made an agreement with the main local housing association for it to build exclusively to the Passivhaus standard, where feasible, from 2010. All other housing associations are being required to meet Passivhaus during 2012 if they wish to receive full funding. The city is also drafting a bill to set standards for new public buildings, with a Passivhaus level being the preferred option.

The city of Freiburg has developed its own standards: the Freiburger Effizienzhaus-Standard 40 (FES 40) is Passivhaus-like, and additionally sets specific heat loss limits below those of EnEV. Since January 2011, FES 40 has been required for all new public buildings, on all public land sold for residential development and on all residential plots within the city's pilot project zones.

The cities of Nuremberg, Cologne, Heidelberg and Wiesbaden as well as the local authority of Lippe have all set Passivhaus as the standard for new public buildings, but this does not extend to the housing sector.

3.3.3 Comparison of Passivhaus and national standards

It is difficult to compare directly the Passivhaus standard with UK building regulations or Germany's EnEV, due to the different metrics and calculation procedures used. However, to a first approximation the space heating load in Passivhaus is around half that of UK building regulations. Similarly, the heat loss of a Passivhaus home is between one-half to two-thirds that of an EnEV 2009-compliant home. This relative performance of current UK building regulations, Germany's EnEV and Passivhaus is shown indicatively in Figure 8, where the level for the UK is shown as 100%.

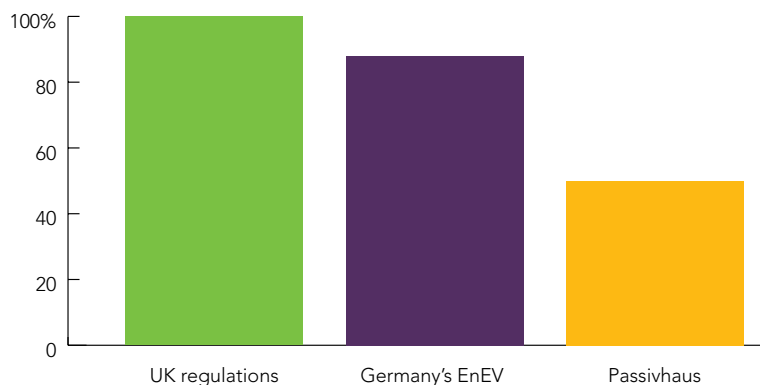


Figure 8 Relative space heating energy use (indicative)

3.4 Economics

3.4.1 Germany

Capital cost

One of the goals of the CEPHEUS project in 2001 was to determine the cost effectiveness of Passivhaus dwellings across Europe^[10]. The project revealed a range of additional costs from zero to 17% above typical new build costs. The average additional cost across the whole of continental Europe was 8%, and in Germany was 10%.

The Passivhaus Institut subsequently estimated in 2012 that to build a Passivhaus home in Germany now costs between 3 to 8% more than building to EnEV; this cost discrepancy would be higher in countries where Passivhaus is less well established and components are not yet readily available. The cost of financing a Passivhaus home depends heavily on the prevailing interest rate as for all construction projects, but in Germany there is a variety of financial assistance available as follows.

Finance

The KfW Bank is a public institution owned by the German federal government. Loans of up to €50,000 are provided towards the cost of a new low energy dwelling (known as an Effizienzhaus), and up to €75,000 towards the cost of refurbishment. The interest rate of the loan is around half that of a standard high street loan^[11], and in addition a grant is available depending on the energy efficiency level which the dwelling achieves. For example, if a home's primary energy demand for space and water heating were around half that of an EnEV building, it would qualify for a 5% repayment grant^[12] as well as the discounted loan.

By further improving energy efficiency to Passivhaus levels, a home could qualify for a repayment grant of 10% in addition to the discounted loan. The combination of grant and lower interest rate means that the additional cost of building a typical dwelling to the Passivhaus standard could be fully recovered over the period of a 10 year loan; savings in fuel bills would further accelerate the payback period.

To be eligible for a KfW Effizienzhaus loan, a dwelling's energy performance must be calculated by an independent accredited energy assessor using the PHPP. KfW provide over 1500 Effizienzhaus loans each year, and by the end of 2008 10,464 loans totalling €1.15 billion had been financed.

In addition to the support available from the KfW bank at least 18 local, regional and state grant programmes for Passivhaus buildings exist within Germany. Grants range from €1000 to €13,000 per dwelling, and usually cover costs additional to normal construction costs. In all but one case the grants are provided by the relevant government department, the exception being the region of Hannover whose grant programme is co-funded by a conglomerate of cities and the local utility company.

3.4.2 United Kingdom

Capital cost

Due to the relative infancy of Passivhaus in the UK, the available cost data tends to be for one-off homes or small schemes, and is often anecdotal and maybe not entirely robust. The immature supply chain means that many products have to be imported, and the learning curve for designers and builders also adds cost in the early days. On the other hand, savings can arise from the simplified built form and

[10] www.cephus.de/eng

[11] At the time of writing, 1.2% where high street rates in Germany are typically 3%.

[12] The repayment grant is the proportion of the borrowed sum which is written off upon complete fulfilment of the Effizienzhaus requirements.

absence of renewable energy technologies in a typical Passivhaus building, and UK practitioners report that a number of projects have been delivered within standard budgets.

Preliminary data from three UK social housing schemes comprising over 50 dwellings indicates that the construction cost ranged from £1500/m² to £1700/m², although it is suggested that subsequent schemes are expected to be built within normal social housing cost constraints as a result of the experience gained from these first schemes^[13].

Finance

There is very little financial assistance available in the UK specifically for energy efficient new build homes. The Ecology Building Society offers an interest rate discount of one percentage point for loans advanced on new Passivhaus homes, which at the time of writing represents a saving of 20 to 30% on the interest payments. In addition there is a range of Government-mandated grant schemes, but all of them are available only for the refurbishment of existing homes. The Government is in the process of establishing a Green Investment Bank, but the scope of its operations has yet to be finalised.

[13] Wimbish and Ditchingham by the Hastoe Group, and Sampson Close by Orbit Heart of England.

4 Construction activity to date



4.1 Germany

As at 2012, over 37,000 units had been designed, built and tested to the Passivhaus standard across the world. Around 20,000 of these units were in Germany, and 4400 units on record with the Passivhaus Institut were fully certified^[14,15].



Figure 9 23-unit scheme in Kassel, 1999
(© Passivhaus Institut)



Figure 10 32-unit scheme in Hannover, 1998
(© Passivhaus Institut)

[14] In this context one unit is defined as 100 m² of living area.

[15] Numbers are based on Passivhaus Institut data and loans advanced by the KfW Bank.

A breakdown of the building types in Germany, as listed on the voluntary database owned by the International Passivhaus Association (iPHA)^[16] shows that most Passivhaus buildings are still mainly residential, and are mainly single family houses/apartments as shown in Table 2.

Table 2 Breakdown of Passivhaus building types in Germany

Building type	Number built
Single family house/apartment	1282
Apartment block	166
Combined flat and office	25
Hotel/hostel/nursing home/hall of residence	15
School/kindergarten/campus/university	50
Office/commercial/industrial	56
Public building (including sports centres and churches)	17
Fire station	1

Two recent German case studies are reproduced below, both from the iPHA database. It should be noted that the cost data was provided by the scheme architects, and has not been independently verified.

Case study 1 Apartment block in Dresden, Germany



© Steffen Lukannek (photograph)/
h.e.i.n.z. Hans (architect)

- Building type: Apartment block (five families) in Dresden, Germany
- Treated floor area: 615 m²
- Construction type: Masonry
- Construction costs (gross): €1900/m² treated floor area (costs include site development, construction, building services, ancillary structures and additional costs)
- Building structure costs (gross): €1520/m² total demand (costs only include the construction and the building services)
- Year of construction: 2011

[16] iPHA is a global membership organisation founded by the Passivhaus Institut in order to promote the standard and provide networking opportunities for its members.

Case study 2 Terraced house in Berlin, Germany



© Werner Hutmacher (photograph)/Schoeningmosca (architect)

- Building type: Terraced house in Berlin, Germany
- Treated floor area: 225 m²
- Construction type: Masonry
- Construction costs (gross): €1950/m² treated floor area (costs include site development, construction, building services, ancillary structures and additional costs)
- Building structure costs (gross): €1800/m² total demand (costs only include the construction and the building services)
- Year of construction: 2010

4.2 United Kingdom

The number of Passivhaus buildings in the UK is currently small. As at July 2012 there were 165 buildings either completed or under construction, including both new build and refurbishment. The breakdown of building types, based on UK and Ireland projects in the voluntary database administered by the Passivhaus Trust^[17] and *The Architects Journal*, is shown in Table 3.

Table 3 Breakdown of Passivhaus building types in the UK

Building type	Number built
Single family house/apartment	149
Hostel/nursing home/hall of residence	3
School/campus/university	5
Office/commercial/industrial	5
Public building (community centres)	2
Boathouse	1

[17] The Passivhaus Trust is a UK membership organisation which exists to preserve the integrity of the standard, promote the corresponding principles and undertake related research and development. It is affiliated to iPHA.

Industry observers estimate that there are likely to be around 500 Passivhaus buildings in the UK by the end of 2013, a rate of growth which is consistent with the German experience 20 years prior to the UK.

Two recent UK case studies are reproduced in case studies 3 and 4^[18], courtesy of the Passivhaus Trust.

Case study 3 Social housing in Wimbish, near Saffron Walden, UK



© Passivhaus Trust/Mark Baigent

A development of 14 new houses and flats, near Saffron Walden. Built to Code for Sustainable Homes Level 4, the dwellings also comply with: Secure by Design, Lifetime Homes, Housing Quality Indicators and Hastoe Housing's Design Brief. The properties use mechanical ventilation with heat recovery (MVHR), and a condensing gas boiler for hot water. The first 6 months of occupation have resulted in gas bills as low as £30 and monitoring is being carried out by the University of East Anglia.

Location: Near Saffron Walden
Construction type: Masonry
Year completed: 2011
Cost: £1555/m²

"We made only one stipulation; that the properties be as 'green' and environmentally friendly as possible. With the design of Passivhaus properties Hastoe has more than exceeded our expectations."

Cllr Mike Young, Chairman, Wimbish Parish Council

Contact: Hastoe Housing Association; Parsons + Whittle Architects

Case study 4 Private housing at High Barn, Somerset



© Passivhaus Trust/Hanse Haus

A 250 m² self-build 4-bed detached house in Somerset. Constructed with the Hanse Haus insulated solid wall system and heated with heat pump and solar thermal. Completed in July 2010, this was the first of this type in the UK.

Location: Somerset
Construction type: MMC SIP panels
Year completed: 2010
Cost: £1495/m²

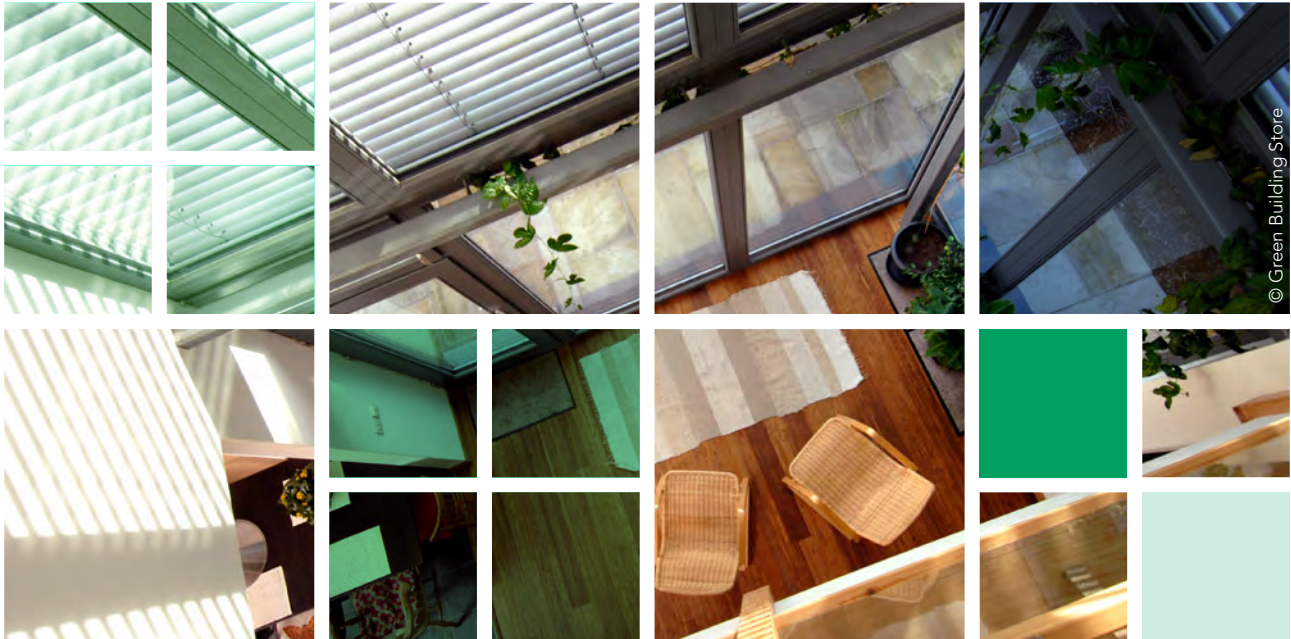
"The super-insulated shell and windows, together with a highly efficient 'Paul' mechanical ventilation heat recovery, take the annual heating consumption down to 13kWh/m²."
Scottish Passive House Centre

"The quality and speed of build is excellent, the crew work with great precision and efficiency. All in all, it's been a really good experience."

Richard Stent, Resident
Contact: Hanse Haus

[18] Taken from *Passivhaus – An Introduction*, Passivhaus Trust publication, 2012, downloadable from www.passivhaustrust.org.uk/guidance.php.

5 User experience and acceptance



5.1 Germany

Passivhaus is often described as ‘a comfort standard, not an energy standard’, and its advocates make claims as much for health and wellbeing as for low environmental impact. Such claims, amid the growing concern that low energy homes may overheat in summer, warrant investigation. Four studies of occupants in 736 Passivhaus dwellings in Germany and Austria (see Appendix) were reviewed for this report. Taking the four studies as a whole, the headline findings were as follows. References to the schemes and the full project reports are given in the Appendix.

5.1.1 Indoor climate

None of the occupants found the indoor climate poor during the heating season, although 8% were dissatisfied with it in summer due to low humidity levels. 56% of occupants found that their dwelling initially overheated in summer, either sometimes or often. To combat this, many occupants undertook various measures. For instance, 40% of the households installed external blinds, three quarters employed night time ventilation, and 72% used the summer bypass in the MVHR unit. Such strategies were generally described in the user handbook provided. It should, of course, be noted that any propensity for overheating in well insulated homes built to high standards of airtightness is not specifically a Passivhaus-related issue^[19,20].

[19] NHBC Foundation. *Understanding Overheating – Where to Start*. NF 44. NHBC Foundation, Milton Keynes, 2012.

[20] NHBC Foundation. *Overheating in New Homes: A Review of the Evidence*. NF46. NHBC Foundation, Milton Keynes, 2012.

5.1.2 Heating system

All dwellings were heated through the MVHR system with an integrated heating element, some having additional radiators installed in the bathrooms. 80% of occupants found the dwelling sufficiently warm in winter. Many occupants struggled to become accustomed to the slower response of the warm air heating system, which led to a lower satisfaction rating on temperature response and controllability. Between 4 and 8% were unhappy with their heating system, either due to the high cost of connecting to the district heating system, problems with the heating controls, or fuel costs. It should be noted, again, that these reasons are not specific to Passivhaus dwellings alone.

5.1.3 Ventilation system

Experiences with the MVHR system showed very little occupant dissatisfaction. All Passivhaus residents found the ventilation system easy to use. The majority of occupants were satisfied with the humidity level inside the dwelling; however some found it too dry.

Ventilation controls were also considered in the surveys. A user handbook was provided which explained the ventilation system and provided recommended settings based on time of year and activity. The investigation showed varying levels of success in controlling the ventilation adequately. This demonstrates the importance and impact of the user handbook, particularly for individuals who have never encountered a mechanical ventilation system before. The studies strongly recommend that a competent person demonstrates how to operate and maintain the system as soon as the occupants move in.

Overall, occupant impressions of the ventilation system were positive, with an average rating of 4.1 out of 6.

5.1.4 Comfort and health

Occupants were generally quite satisfied with comfort (temperatures and air quality) in the living room, bathroom and bedrooms. About 50% of occupants felt that Passivhaus provided a healthier environment than their previous home, while only 10% felt the environment was worse.

5.1.5 Comparison with previous home

Just over a half of occupants found there were one or more issues from living in a Passivhaus home which required adaptation compared with their previous home. General comments about the improvements/reductions in living standards are shown in Table 4.

Table 4 Improvements and reductions in living standards experienced by Passivhaus residents compared with their previous home

Improvements	Reductions
Even and sufficient temperatures	More attention required to closing windows and doors
No cold radiation from walls	Missing cold room/larder
Good indoor climate and air quality	Higher costs for maintenance and repairs of potential damage
Low running costs	
No need for radiators	
Less noise, partially due to triple glazing	



Figure 11 Interior of Plummerswood, a Passivhaus dwelling in the Scottish Borders
(© A Slight Shift photography/Gaia Architects)

5.1.6 Overall impression

Overall, occupants were positive about Passivhaus and their level of satisfaction was high, with 92% of occupants indicating that their expectations had been met. All occupants would make the same purchasing decision given the choice, and indicated that they would recommend Passivhaus to other people – although with the following recommendations:

- Undertake an intensive examination of the technology
- Be clear with regard to the construction process and financing
- Read manufacturers' product information and follow its recommendations
- If possible, test a Passivhaus home in a trial living arrangement
- Ensure tried and tested products are used.

The predominant factors against adoption of Passivhaus were the additional capital costs and increased design and construction effort. Only 17% of responses conveyed negative impressions.

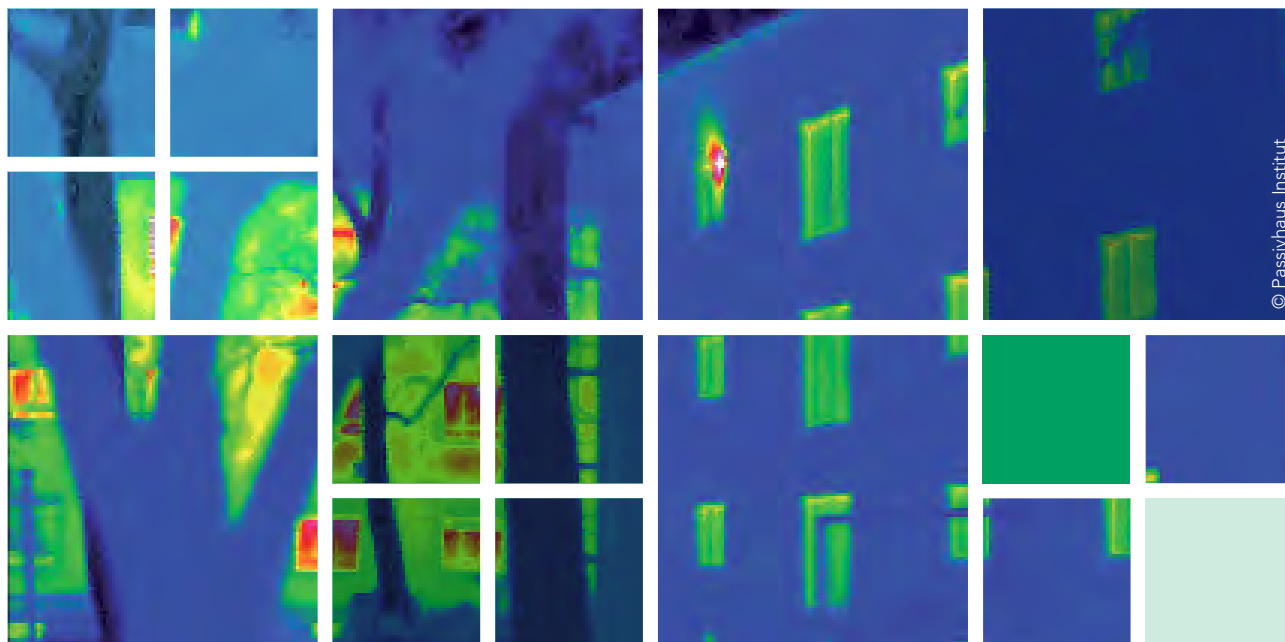
5.2 United Kingdom

As Passivhaus has only recently been introduced in the UK, user experience is currently limited. Anecdotal evidence from the owners of one-off Passivhaus homes is invariably positive, but this is a self-selecting sample who may be unlikely to criticise a home which they have commissioned (and sometimes even built) themselves.

Again anecdotally, builders have sometimes found it initially hard to achieve the very stringent airtightness and thermal bridging targets of Passivhaus, although it is generally felt that this is a learning curve which can be climbed. The general quality assurance requirements have led some developers to employ 'airtightness champions' and/or full time clerks-of-works, which may not be viable across the wider industry.

Designers and consultants have expressed mixed opinions on the Passivhaus Planning Package (PHPP) software tool. On the negative side it requires lengthy training, is lacking in user-friendliness, and the data entry requirements are onerous. There are also hidden costs (eg the need to carry out additional air tightness detailing and thermal bridging calculations). On the positive side, the tool is reckoned to produce more accurate estimates of energy consumption than the UK's SAP methodology, and to provide better estimates of thermal comfort, air quality and overheating risk.

6 The outlook for Passivhaus in the UK



Experience in Germany since 1990 has shown that designing and building to the Passivhaus standard is a viable means of delivering low carbon housing. The German Government and major banks have placed their support behind the standard, and there are several local authorities who mandate Passivhaus for new housing developments.

Yet there are still major issues to overcome if Passivhaus is to be readily acceptable to the majority of homeowners, tenants, housing associations, builders and policy makers. No one would claim that building a Passivhaus home is easy; the demanding energy performance and quality assurance requirements present a challenge to the designer and builder alike. It is questionable whether Passivhaus is a realistic solution for the volume market, although large scale projects such as a 740 dwelling development planned for the Landstrasse district in Vienna will inform that debate.

Germany's experience also suggests that there can be issues with MVHR systems, such as noise and maintenance, which may need to be addressed. Linked to this is proper education of occupants in the operation of the house and its ventilation system, which is borne out by NHBC Foundation research in the UK^[21,22]. However, this is not a Passivhaus-specific problem; there is a trend towards more airtight homes in the UK, and MVHR is likely to become the dominant form of ventilation in all new homes as a result.

[21] NHBC Foundation. *Today's Attitudes to Low and Zero Carbon Homes: Views of Occupiers, House Builders and Housing Associations*. NF 40. NHBC Foundation, Milton Keynes, 2012.

[22] Zero Carbon Hub. *Mechanical Ventilation with Heat Recovery in New Homes – Interim Report*. Zero Carbon Hub, Milton Keynes, 2012.



Figure 12 Plaque for PHI-certified refurbishment project, Totnes, Devon
 © passivhaushomes.co.uk

It is unclear whether many UK homebuyers would be willing to pay extra for a Passivhaus home, although as expertise and the UK supply chain matures the additional cost should clearly reduce. Further built examples and research are needed to enable a proper evaluation of the long term social and economic viability of the standard in the UK.

A significant factor in the uptake of Passivhaus in Germany has been the availability of reduced interest rate loans and capital grants. One such loan scheme is available in the UK – although the discount is not as significant as in Germany – and no capital grants are available for energy efficient new build projects in the UK.

All certified Passivhaus homes built in the UK have to verify compliance with building regulations as well as the Passivhaus quality assurance procedure. This adds time, effort and cost, and some within the UK Passivhaus community argue that it in effect penalises those who wish to build to the standard. The additional burden would clearly be reduced if either:

- a) the suppliers of UK compliance (SAP and Energy Performance Certificate) software were to provide an import facility which reads in and converts a PHPP dataset, or
- b) the PHPP software were enhanced to calculate and print a UK Energy Performance Certificate. This is effectively the case in Germany, where PHPP can produce an EnEV compliance report.



Figure 13 Passivhaus certificate issued to a Passivhaus building in Ebbw Vale, Blaenau Gwent (© BRE)

It has been demonstrated^[23] that the Passivhaus standard goes beyond that set by the 2010 edition of Approved Document L1A to the Building Regulations (England and Wales), also meets the Government's preferred option for the 2013 regulations, and moreover meets the Fabric Energy Efficiency Standard (FEES) component of the 2016 zero carbon standard (and in many cases carbon compliance too). It has therefore been suggested by the Passivhaus Trust that it would be appropriate in principle for Passivhaus certification to be afforded the status 'deemed to satisfy' in relation to the energy component of the UK building regulations. Some further work is necessary to ensure that this is technically valid in all circumstances, although it is clear that granting such a status would have a significant impact on the uptake of Passivhaus within the UK.

Closing the gap between as-designed and as-built performance is a key aim for the UK^[24], as has been identified by the January 2012 Government consultation on proposals for the 2013 edition of Approved Document L1A. The high level of compliance of Passivhaus dwellings has led to suggestions that the Passivhaus certification process could help to narrow the performance gap, although some elements of the process (eg compliance of each dwelling as opposed to dwelling type, multiple pressure tests and photographic records) may be hard to apply to volume house building. There is also increasing interest in component-level (as opposed to whole-house) certification schemes, including that of Passivhaus.

[23] Passivhaus Trust. *Passivhaus and Zero Carbon – Technical Briefing Document*. Passivhaus Trust, London, 2011 (updated 2012).

[24] See, for example, NHBC Foundation. *Low and Zero Carbon Homes: Understanding the Performance Challenge*. NF 41. NHBC Foundation, Milton Keynes, 2012.

Appendix

The user experience studies

The German and Austrian studies reviewed in section 5 of this report were as follows.

- Survey of occupants of 225 Passivhaus dwellings within Vienna (see refs A.1, A.4 and A.5 below).
- Lummerland development in Hannover Kronsberg. Study by Stadtwerk Hannover. 32 terraced houses, occupants surveyed twice over four months (see ref A.2).
- Low income tenants of two blocks of flats containing a total of 40 units. Study by University of Kassel. Tenants interviewed three times (see ref A.3).
- Grossschoenau, Austria, 'Passivhaus village'. Study by Sonnenplats Großschönau GmbH. 439 families surveyed, of whom 429 were short-stay residents and 10 had built their own Passivhaus (see ref A.6).

Full project reports

- A.1 Treberspurg M et al. Endbericht: Nachhaltigkeits-Monitoring des Passivhausstudentenheims Molkereistrasse. Universität für Bodenkultur Wien, December 2007.
- A.2 Danner M and Vittar C. Wohnen in der Passivhaussiedlung Lummerlund im Neubaugebiet Hannover – Kronsberg: Abschlußbericht zur Sozialwissenschaftlichen Evaluation. U Konzept.
- A.3 Hermelink A and Hübner H. Is one litre enough – tenants' satisfaction in passive houses. ECEEE 2003 Summer Study, 2003.
- A.4 Keul G and Salsmann R. Subjektive/objektive Temperatur/Feuchte im Wiener Passivwohnbau Kammelweg B. International Passivhaus Conference, Dresden 2010.
- A.5 Treberspurg M et al. Nachhaltigkeits-Monitoring Ausgewählter Passivhaus-Wohnanlagen In Wien. Universität für Bodenkultur Wien, December 2009.
- A.6 Siska M et al. Strategie zur Verstärkung des Passivhaus – Trends in Niederösterreich am Beispiel von Sonnenplats Großschönau. Sonnenplats Großschönau GmbH, March 2010.

NHBC Foundation recent publications

Overheating in new homes: A review of the evidence

There is increasing evidence that new and refurbished properties are at risk of overheating, especially small dwellings and predominantly single-sided properties where cross ventilation is not possible. Further, there is evidence of overheating in prototype houses built to zero carbon standards, indicating a lack of cross ventilation in lightweight, airtight houses with little or no solar shading.

This report reviews this evidence, the causes of overheating and the consequences for health. It gives guidance on reducing overheating and calls for a universally accepted definition of overheating in dwellings and threshold temperature levels for use by planners, designers, builders and local authorities. **NF 46** November 2012



The use of recycled and secondary materials in residential construction

The use of recycled and secondary materials as aggregates in construction for applications such as pipe bedding and concreting aggregate (as well as in the more 'traditional' uses as 'hardcore', fill and road materials) is increasing.

This clear, detailed and practical guide describes how to source, correctly specify and use secondary and recycled materials in residential construction (illustrated by case studies and examples). It also provides key information on how to avoid incorrect use (and consequent unsatisfactory performance) of recycled and secondary materials. **NF 45** August 2012



Understanding overheating – where to start: An introduction for house builders and designers

This new guide is a useful introduction to the topic of overheating and covers the principles of overheating as well as factors that increase or reduce the risk. Seven case studies are provided to demonstrate a number of reasons for overheating, including location of the site, errors in design or the way in which the home is being used by its occupants. **NF 44** July 2012



NHBC Foundation publications can be downloaded from www.nhbcfoundation.org

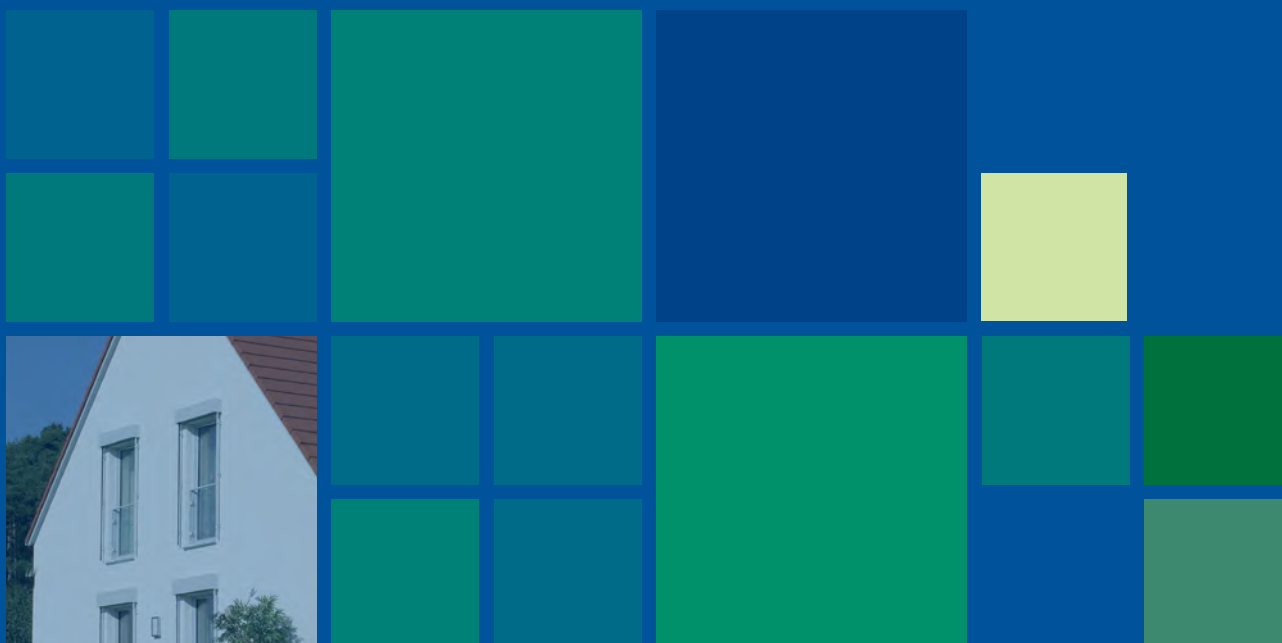
NHBC Foundation publications in preparation

- Building sustainable homes at speed: Risks and rewards
- Cellulose-based building materials

Lessons from Germany's Passivhaus experience

The Passivhaus movement in the UK is in its infancy, and while it has many enthusiastic advocates, others question its viability as a standard for volume house building. Worldwide, since the standard emerged from Germany in the late 1980s, some 37,000 Passivhaus buildings have been constructed.

This report examines the political, economic and social drivers, as well as the general attitudes, that have helped or hindered the uptake of Passivhaus in its birthplace. The German context is compared with that of the UK, and the relevance of Germany's experience to the UK is discussed.



The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It 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 UK'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 house builders in developing strong relationships with their customers.