EcoTech

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Passivhaus progress

Building physicist Wolfgang Feist founded the Passivhaus Institut in 1996. It does not promote the use of a particular style or technology in sustainable design, but rather a performance standard: 15 kWh per square metre per year for heating. The standard quickly found adherents across northern Europe, and is now spreading further afield, to Japan, the USA and China. Passivhaus is also becoming firmly established in the UK, with local conferences and certification bodies, and a growing body of built work appearing in recent years.

This special report is edited by architect Justin Bere. In his account of his own Passivhaus design experience, he describes the very particular culture that has grown up around the Passivhaus standard, characterised by scientific rigour, mutual support and knowledge-sharing though publication and meetings. Contributions to the issue, by architects and engineers, reflect this spirit of open enquiry.

Above *Gym in Frankfurt designed by D'Inka Scheible, a winner at the 2010 Passivhaus awards (ph: Roland Halbe).*

Passivhaus: an affordable, high-efficiency standard

Passivhaus founder Wolfgang Feist introduces the Passivhaus standard and its benefits.

The Passivhaus approach is neither a building style nor simply a new building technology. It is simply a performance standard, the implementation of which requires a set of experiences, tools, and high quality components available to all building professionals.

Various projects have shown that the standard can be met in a wide variety of climates and with a wide range of architectural styles, construction types (masonry, timber, steel or concrete) and building types (single family homes, large apartment complexes, offices, schools, kindergartens and more).

The Passivhaus performance standard is ambitious and clearly defined: 15 kWh per square metre per year for heating and, if needed, for cooling, combined with an aggressive total primary energy limit, resulting in energy savings of some 75 per cent as compared with existing European new build projects. The remaining energy consumption of a Passivhaus is so low that it can be easily and affordably met with regional energy resources. Even renewable energy, somewhat more expensive than today's cheap oil and gas, becomes an affordable and competetive option when the amount of energy needed is as low as it is with a Passivhaus.

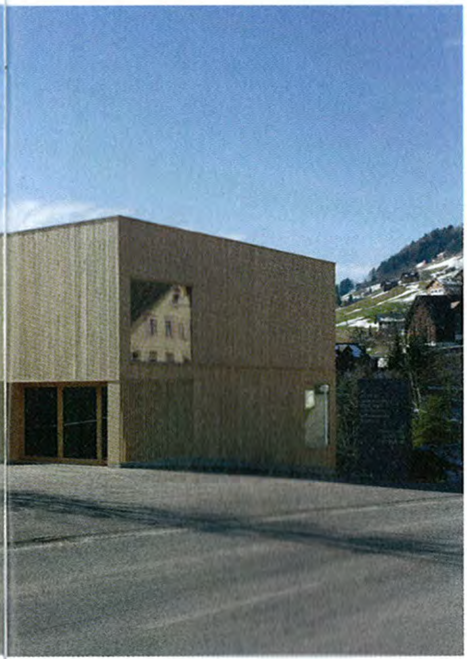
While measures to increase energy efficiency do not come free of charge, a Passivhaus integrates these measures into components that are needed in every new building. Improving the quality of the building envelope, the services, and the on-site project implementation not only results in energy savings, but also ensures greatly enhanced structural integrity, thermal comfort and air quality as compared to existing buildings.

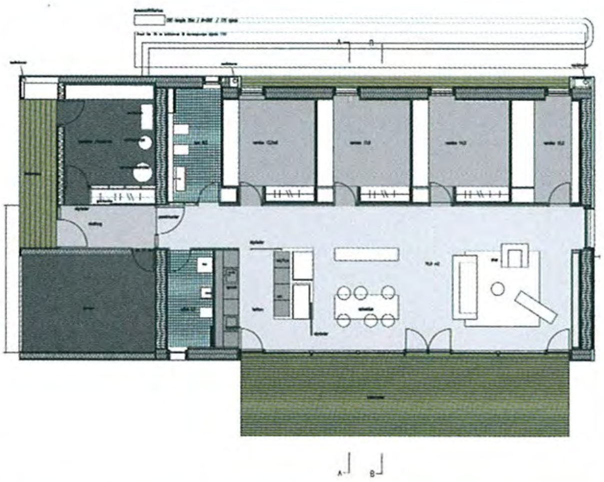
In a Passivhaus, the focus is on the longevity of the components, which will add value to the building during its lifecycle. Additionally, the heating requirement, especially in the UK's climate, will be so low that the heating system can be substantially simplified, thus reducing investment and maintenance costs. Most of the components in a Passivhause are simple to use and easy to maintain, such as high quality insulation, high performance windows and efficient heat exchangers.

Last but not least, the Passivhaus Standard is not an abstract theory; it has been tested and proven time and time again. All that architects and engineers need in order to realise a Passivhaus is know-how. The International Passive House Association has been working with affiliates worldwide, such as the UK's Passivhaus Trust, to further Passivhaus knowledge. Additionally, Passivhaus educational programmes are available in almost all European countries. In short, Passivhaus is the affordable, almost zero-energy building solution.

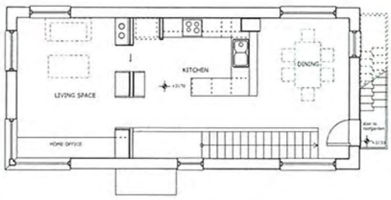
Head of the Unit of Energy Efficient Buildings at the University of Innsbruck, Wolfgang Feist is co-originator of the Passivhaus concept and founder of the Passivhaus Institut in Darmstadt, Germany.

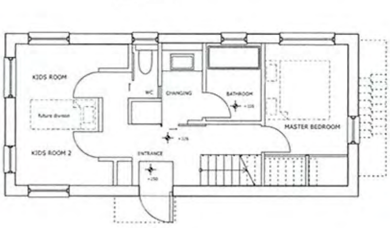
Top right *A residential building in Liebefeld, Switzerland by Halle 58 Architects took first prize at the 2010 Passivhaus Architecture Awards (ph: Christine Blaser).* **Right** *Joint second prize went to the Saint Gerold Municipal Centre in Austria by Bregenz-based practice Cukrowicz Nachbaur Architects (ph: Hanspeter Schiess).*

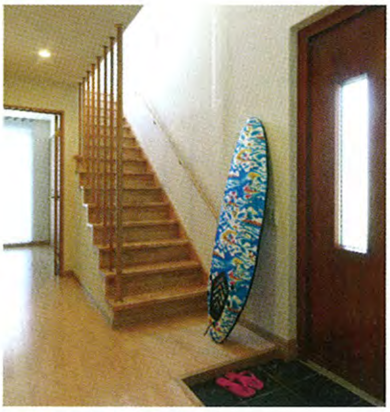




Above *Commended at this year's Passivhaus Architecture Awards, a dwelling in Ebeltoft by Olav Langenkamp is Denmark's first certified Passivhaus (phs: Olav langenkamp, Thomas Søndergaard).*
Below *Joint second at the Passivhaus Architecture Awards was a house in Kamakura, Japan, by Key Architects. The timber-framed structure is filled with wood fibre insulation. Highly durable charcoaled cedar cladding provides protection against moisture and insects. Triple-glazed composite windows were imported from Germany as comparable high performance units are not yet produced in Japan. There is currently no minimum energy efficiency requirement for new residential buildings in Japan.*







Towards a global Passivhaus community

Based on proven scientific methods and backed by a wealth of practical advice, Passivhaus standards are set to be the future, says Justin Bere.

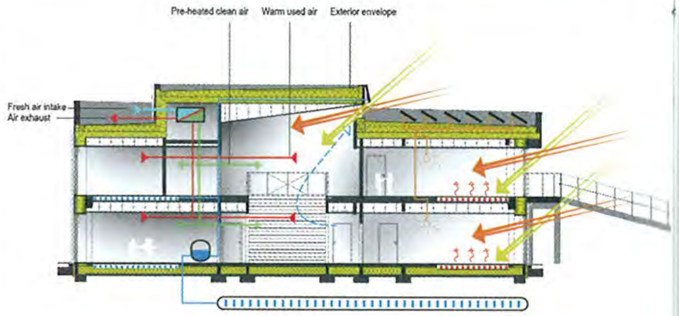
I first came across Passivhaus about ten years ago while designing my own house, based on the best combination of methods to save energy, and aided by the advice of my mentor, services engineer Max Fordham. It seemed sensible, even without doing any maths, to use around 300mm of insulation and to design for draught-free construction with triple-glazed windows. I was very concerned about maintaining a healthy indoor environment and Max suggested I use something then unknown to me called 'heat recovery ventilation'.

Since then I haven't looked back, discovering around 2006 that technical software and advice from the non-profit-making Passivhaus Institut in Germany was available from the BRE and AECB to provide quality assurance in our work. Gavin Hodgson, then head of the BRE's Passivhaus division, visited our Focus House (designed with a similar technical strategy as my house but otherwise very different), and said it was the closest he'd seen in the UK to a Passivhaus. In April 2007 I went to my first Passivhaus conference, at Bregenz in Austria, one of just 13 UK delegates among more than 1000 global attendees. The huge range of technical presentations, often delivered or mentored by building physicists, stood in stark contrast to the vague thinking and unlikely claims often made at home. The extensive exhibition of Passivhaus-approved products was especially inspiring. All the talk was of low consumption, low toxicity construction, low embodied energy and healthy building environments. On the third day of the conference we visited some exemplary projects in the Vorarlberg. I realised that here was a community of like-minded people who were pleased to help a newcomer and who sincerely wanted to walk the talk.

So we purchased PHPP, the Passivhaus Institut's surprisingly low-cost software (its still only £120), and set about designing our first true Passivhaus buildings. We taught ourselves to use the software before there was any formal training in the UK and we learnt how to do cold-bridging thermal-flow calculations, an essential part of Passivhaus design. Eventually we managed to find clients who let us practice on our first certified buildings, and these were completed this year. Now most of our new-build and retrofit projects aim to be certified respectively Passivhaus or Enerphit. No one in the office can imagine designing in any other way. It seems pointless to do anything less than Passivhaus and people who visit our light, bright, airy buildings often ask why we aren't all designing like this in the UK?

The recent growth of interest in Passivhaus in the UK has been phenomenal and this year saw three important milestones: the establishment of the Passivhaus Trust to foster UK research; three Passivhaus conferences in London; and the UK's first student Passivhaus Research Conference. Two years ago few in the UK had even heard about Passivhaus, but now it often seems to dominate questions sustainability conferences. However, the talk at non-Passivhaus events is very mixed, with some unsettled by the tough new standards being advocated, and others showing a fundamental misunderstanding of the building physics that provides the proven foundations of Passivhaus. Some architects tell me they have designed a Passivhaus by 'using Passivhaus principles'. Whether they know what is really involved in a true Passivhaus is perhaps beside the point as long as they are moving in the right direction by saving energy with a 'fabric first' approach. And perhaps next time they will try the more holistic approach necessary to complete a certified, quality-assured Passivhaus.

Justin Bere, principal of Bere Architects, whose recent projects include Camden Passivhaus, the Welsh Passivhaus prototypes and Focus House. He spent his childhood in Africa, England, Ireland and eventually on an organic farm in Somerset, before studying architecture in Canterbury. See www.bere.co.uk and www.bere-blog.co.uk.



Dragen kindergarden, Odense

Designed by CF Møller Architects, the Passivhaus-certified Dragen kindergarden comprises two levels linked by stairs and ramps with small niches for playing, reading or withdrawal. 414 square metres of play space, far more than the minimum standard of 268 square metres, is provided for 88 children, split between a nursery and a creche. Facilities include a theatre, atelier, motor skills room and pedagogical kitchens as well as interconnecting 'loopholes' in the walls. The highly insulated airtight building is constructed from prefabricated insulated timber panels, and glazed facades provide good daylighting and passive solar heating. Integrated solar hot water and electricity generation combine with a mechanical ventilation system with heat recovery. Most components accord with the Nordic Swan Eco-label hitherto associated with consumer goods (photos: Uffe Johansen).

Project

Sarah Lewis, Certified Passivhaus Designer at Bere Architects, explains the process behind the firm's Camden Passivhaus. Photos: Jefferson Smith.

Passivhaus in practice: designing with PHPP

The primary objective of this project was to achieve a comfortable and healthy home for our client's daughter, her boyfriend and small pet dog, Twinkle, while minimising energy consumption.

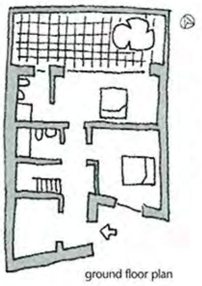
At an early stage in the design process, Bere Architects discussed the possibility of designing the house to Passivhaus standards with the client. The dwelling would eschew a conventional heating system in favour of maintaining warm and comfortable interior temperatures (at standard occupancy and 20°C in winter), while using less than 15kWh/(m²a) for heating. In addition to the prospect of low heating bills, our client was excited by the idea of healthy indoor air quality, as his daughter suffers from asthma. Based on both the low energy and air quality advantages of the Passivhaus model, he agreed to embrace the standard and build London's first Passivhaus.

An initial highly energy conscious design had already been developed prior to the decision to deliver a certified Passivhaus. As one of the first steps towards satisfying the Passivhaus standard, we carried out in-house model analysis of the initial design using the Passivhaus Planning Package (PHPP). This comprises a spreadsheet-workbook and a manual, and is essential for designing a Passivhaus (courses are available from a number of UK-based institutions).

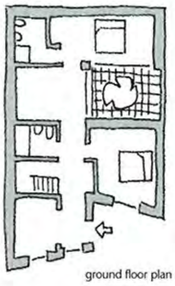
This first PHPP analysis (sketch 1) showed the initial design achieved a very low heat energy demand of 21.2kWh/(m²a). However, this was not low enough to meet the Passivhaus standard and would require a conventional heating system to meet peak demand. By analysing the data in the PHPP, we were able to establish that the initial design had too much north glazing for a small house. The ratio of building envelope to volume was also too high, resulting in excessive heat loss.

With the knowledge gained from the first PHPP investigation, we developed and tested a series of iterations again using PHPP. Initially, none quite achieved the Passivhaus standard (sketches 2-3 show examples of these investigations). It also became apparent that, although supportive in principal of the project, the local planning authority had some reservations about the positioning of the house on the site. Given these conditions, a new

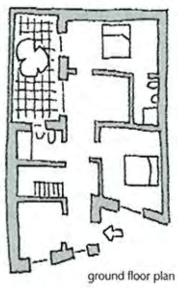
Below *Design development sketches. The proposals were analysed using the Passivhaus Planning Package (PHPP).*



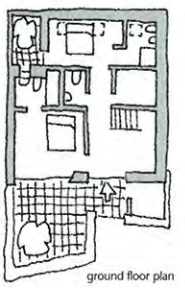
1 Initial design
This scheme has a high percentage of north glazing. The envelope to treated floor area ratio (TFA) is also fairly high. Result = 21.2 kWh/(m²a)

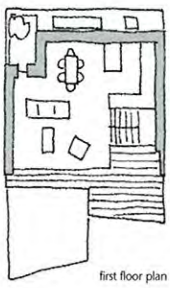


2 Open courtyard within plan
Similar issues to scheme 1, with a high percentage of glazing either not south-facing or heavily shaded. The envelope to TFA in this case is also too high. Result = 21.9 kWh/(m²a). By enclosing the courtyard, the result went down to 11.7 kWh/(m²a). However we did not feel that this would give a good quality of internal daylight or provide the desired links to external spaces.

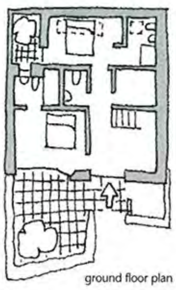


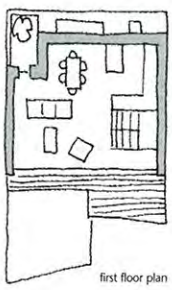
3 Open courtyard in north-west corner
The north west courtyard results in a high percentage of glazing not south-orientated. Again, the TFA is too high. Result = 16.7 kWh/(m²a)



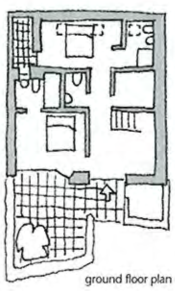


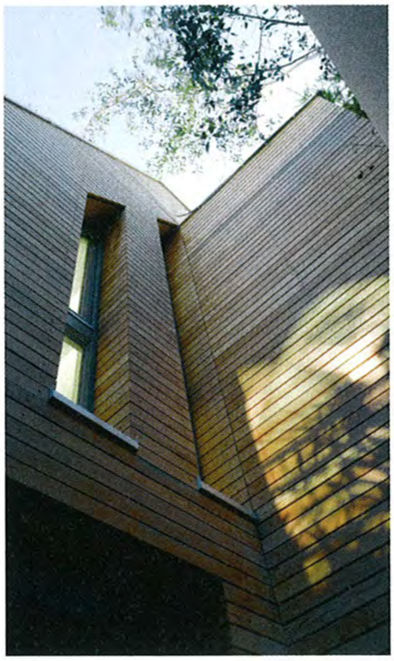
7 With straight wall in bedroom one
This variation improves the ratio of envelope to TFA. It also reduces the shading of the windows in bedroom one. Result = 17.0 kWh/(m²a)

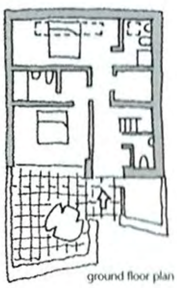




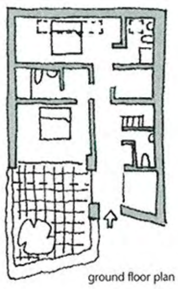
8 With straight wall on first floor
Here the ratio of envelope to TFA is further improved. This time the shading of the windows on the first floor is significantly reduced. Result = 16.3 kWh/(m²a)



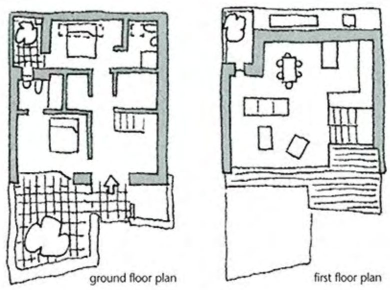




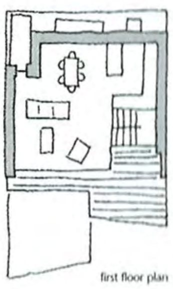
4 South garden
This plan allows for a high percentage of glazing to be south-orientated. It also provides a good ratio of envelope to TFA. However the master bedroom only has roof lights. Result = 13.5 kWh/(m²a).



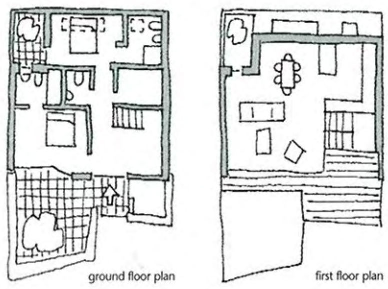
5 South garden with internal bike store
Result = 14.2 kWh/ (m²a)



6 South garden with north courtyard
This option keeps the high percentage of south glazing created in scheme 5. It does however have a higher ratio of envelope to TFA. Also, the second bedroom's main light source is still from roof lights. Result = 17.6 kWh/(m²a)



9 North-west courtyard reduced in width
By reducing the width of the courtyard from 1.5 metres to 1 metre the ratio of envelope to TFA is improved. Result = 16.1 kWh/(m²a)



10 With reduced wall thickness
Using a vacuum insulation the thickness of the walls could be reduced without reducing the overall U-value for the wall. The result of reducing the wall thickness is an improvement in the ratio of envelope to TFA. However this is an expensive option as vacuum insulation is an expensive product. Result = 15.4 kWh/(m²a)

Key dates

- Possesion of site by contractor: 14.09.2009
- Kaufmann Zimmerei first visit: 07.12.2009
- Kaufmann Zimmerei second visit: 25.01.2010
- Passivhaus certification: 30.04.2010.
- Date of completion: Summer 2010

approach to the site was required.

The PHPP studies had highlighted the necessity for a compact shape and south-facing glazing in a small free-standing house (without compensating with very thick walls) and a more efficient relationship between the floor area and building envelope. In the initial design, the house was positioned to the south (front) of the site with a north-facing private courtyard to the rear. The new approach involved moving the house to the north of the site, thereby creating a south-facing enclosed garden and upper terrace, with limited fenestration to the north. This not only reduced the visual impact of the house when viewed from the street (in line with the wishes of the planning department), but it also created internal spaces flooded with natural light and sunshine throughout the year.

A PHPP study confirmed that the design would be able to attain the Passivhaus standard (sketch 4). Using PHPP, we worked through a further ten iterations of this new design (sketches 5-14), to explore the full range of architectural possibilities.

The final design provides bright and airy rooms with large, sliding, triple-glazed windows to the south. The house is designed to be cool in the summer and warm in winter, with perfect air humidity all year round, excellent ventilation, and completely draught-free (0.4 ach at 50pa).

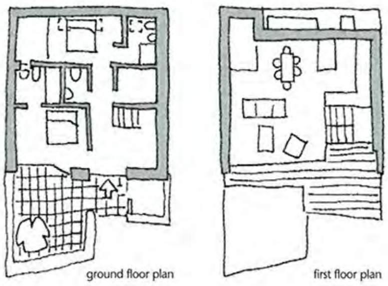
Summer temperatures are controlled using external automatically controlled blinds on the south elevation, natural cross-ventilation with night-time purge cooling by passive ventilation, and high levels of insulation including two green roofs to control heat gain through the fabric. The building also incorporates a solid timber first-floor and roof construction, together with large areas of other heat absorbing surfaces.

Internal air quality is very high due to the specification of non-toxic materials throughout, and in winter the use of a 92 per cent efficient heat recovery ventilation system that continually filters incoming air without the need to waste heat by opening windows. A water filtration system provides clean water for drinking and bathing. Mains water use is reduced by using an underground water harvesting tank, which provides water for the garden.

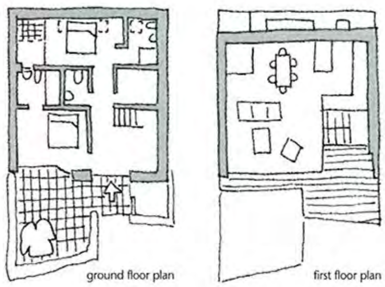
As the design progressed, all the details were thermally modelled to eliminate cold bridging (a net negative Psi value was achieved). The thermal modelling results are an important part of the PHPP energy calculations. The details are subsequently checked for quality control by the UK certifier, in this case Warm Consulting, before being finally approved by the Passivhaus Institute in Germany.

Camden Passivhaus client 'My main requirement was for space and light and this design definately achieved this. The upstairs in particular is a sensation and I am very excited about moving in. There is little doubt in my mind that this type of house is the house of the future and I look forward to seeing more spring up around London'.

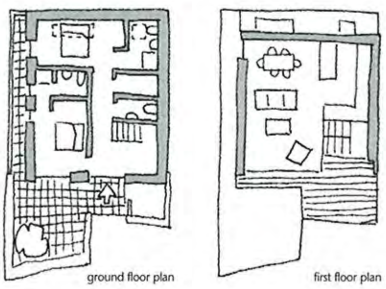
Credits
Architect: Bere:architects; services consultant: Alan Clarke; substructure engineer: Rodrigues Associates; main contractor: Visco; heat recovery ventilation: The Green Building Store; timber superstructure and Engineering (including erection of the timber superstructure): Kaufmann Zimmerei; Passivhaus windows: Double Good Windows (import agent); green roof: Cambridge Polymer Roofing, Sky-garden green roofs (design by Dusty Gedge).



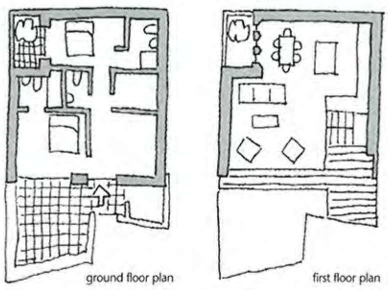
11 With covered north-west courtyard and light scoop to bring south light into back corner
Total envelope increased to include the light scoop. Result = 17.2 kWh/(m^2a).



12 With covered north-west courtyard and reduced light scoop
Ratio of envelope to TFA improved. Result = 16.3 kWh/(m^2a). The specific heat demand would reduce to 15.3kWh/(m^2a), if the insulation was increased in the roof and floor, and the specification of the wall insulation was improved.



13 With 1m gap to west side of building
Provides the opportunity to have windows from all of the rooms towards the back of the plan. However the ratio of south glazing is reduced from both the ground and first floors. Result = 20.1 kWh/(m^2a)



14 With no rooflights above bedroom two and a straight wall to bedroom one.
Ratio of envelope to TFA improved. Shading of windows on ground floor reduced. The second bedroom benefits from daylighting that comes from windows looking into a private courtyard, rather than rooflights. Result = 15.4 kWh/(m^2a) If the insulation was increased the specific heat demand would reduce to 14.5kWh/(m^2a), which achieves Passivhaus standard.

Thermal mass: is more always better?

Rob McLeod, associate of BRE Passivhaus UK and Certified European Passivhaus Designer at Regeneration Partnership, explores the optimal level of thermal mass in Passivhaus design, while overleaf Bill Watts considers the interaction of thermal mass and ventilation. Plus, Passivhaus buildings by Seymour-Smith Architects, Gokay Deveci and Green Building Store that demonstrate the relative merits of precast concrete, timber-frame and cavity wall construction.

There is a popular view among some UK architects and designers that more is better when it comes to thermal mass. Scientific articles on the subject often refer to the vernacular stone buildings around the Mediterranean as evidence to support the 'cold in summer, warm in winter' argument, implying that substantial thermal mass is the key to good building design. But do the inhabitants of solid walled 'hard to treat homes' in Scotland or those living in concrete apartments during the 2003 heatwave in Marseille share this view?

All buildings contain some thermal mass, so this is not an either or question, but rather a question of context – how much, what type and where? How much thermal mass is needed is highly dependent on the type of building, its heat gains and losses, and its climatic context. Passivhaus buildings are a lot more thermally stable than conventional buildings because they are draught-free, super-insulated and the ventilation air supply can be carefully controlled, with options to preheat (and in some cases to pre-cool) the air via a heat exchanger. This means that a Passivhaus has a long thermal time constant, simply because relatively little heat is exchanged with the ambient environment.

Several detailed thermal modelling studies have shown that additional thermal mass plays no significant role in reducing the heating load of Passivhaus and similar low-energy buildings. But what about the converse situation of summer overheating, which we may be faced with as a result of climate change? Here undoubtedly thermal mass plays a role in helping to attenuate swings in internal temperature, but the role of thermal mass in a well-designed Passivhaus is simply one aspect of design optimisation. So what is the optimum amount of thermal mass?

The general advice in Passivhaus design is to use as much thermal mass as is required to dampen the amplitude of the 24 hour internal temperature swing resulting from solar gains to approximately 1°C. In a Passivhaus, the magnitude of the daily internal temperature swing in summer is largely a function of the solar gains entering the building and the ability of the building's thermal mass to absorb these gains. By considering a hypothetical 'worst-case' scenario, that of a 90 square metre detached timber-frame Passivhaus house in a UKCP 2080 medium-high scenario, it is possible to quantify the scale of these influences.

Scenario one

The building fabric is light to medium weight, timber-frame lined with dense woodfibre insulation and plasterboard with an effective specific heat capacity of

Underhill House, Warwickshire

The site of Underhill House is prominently located at the top of a hill in the Cotswolds. Invisible from the surrounding countryside, the house is built into the hillside under an existing barn now converted into a studio for our own use, *writes Seymour-Smith Architects.*

The structure is made entirely of concrete, most of which remains exposed internally, to exploit the benefit of thermal mass. With the joints between the precast concrete retaining wall panels reinforced, the structure is naturally waterproof and airtight – indeed, so airtight that it achieved an impressive n50 result of 0.22ac/hr at 50pa (the Passivhaus requirement is 0.6).

Concrete was also chosen because it is long-lasting, beautiful and strong. Using precast for the walls and roof brought the added benefits of precision, reduced waste and speed – the structure was completed in just over two weeks.

Concrete is probably the only sensible material to use on an underground house, and earth-sheltered construction is an environmentally-friendly way to build.

While more weight was given to reducing the carbon emissions from the building's performance than to the embodied energy in the materials used, we were concerned to select those with recycled content. The concrete contains PFA and GGBS as cement replacements, paving uses the by-product of the china clay industry, the screed contains crushed glass bottles, and the internal blockwork uses recycled sawdust.

Above *Larch House, timber-frame Passivhaus social housing in Wales by Bere Architects (ph: Jefferson Smith).*

110 Wh/m²K. The UKCP 2080 medium-high scenario climate data reveals there is a high probability that the mean daily peak temperature will be around 33°C for prolonged periods, with an external diurnal temperature swing of around 10°C. With overnight lows not dropping much below 23°C there is only a limited possibility to release stored heat overnight from the building.

Solar load depends greatly on the size, orientation and shading of the windows. In this example with large south-facing glazing and only partial shading from external louvred shutters to the south, the maximum solar load is in the region of 21kWh/d. Depending on the ventilation strategy and whether some form of pre-cooling via a ground-air heat exchanger or brine loop system is used, the ventilation gains may be making either a positive or negative contribution to the daily temperature swing, so for the purposes of this example they are ignored.

Daily temp swing due to solar load =

$$\frac{20\text{kWh/d}}{110\text{Wh/m}^2\text{K} \times 90\text{m}^2} = 2.0\text{K}$$

This scenario shows that there is a 2°K internal temperature swing due to the solar gains.

Scenario two

In order to reduce this temperature swing further during this peak period we consider the merits of a heavyweight construction with a specific heat capacity of 205 Wh/m²K.

Daily temp swing due to solar load =

$$\frac{20\text{kWh/d}}{205\text{Wh/m}^2\text{K} \times 90\text{m}^2} = 1.1\text{K}$$

It can be seen by changing the design to a heavyweight masonry construction we are able to reduce the temperature swing by approximately 1°K. Assuming all other factors are constant, the additional thermal mass has contributed to a small but positive reduction in internal temperature.

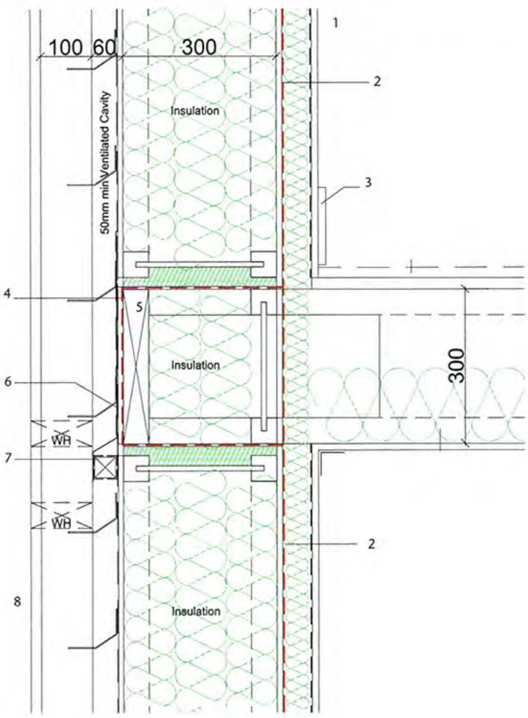
Can we conclude from this that more mass is the solution to preventing overheating? While the additional thermal mass has reduced the peak temperature swing in this scenario it has only slightly reduced the frequency of overheating overall. There is also a consequential risk that as night-time temperatures become even warmer (particularly in an Urban Heat Island) the heavyweight construction may begin to store more heat than it can release in a 24 hour cycle. Therefore, before the decision is made to add more thermal mass we need to first examine other design options and scenarios. Successful Passivhaus buildings have been designed using both heavyweight and lightweight approaches. The finer art is in understanding the buildings particular context and optimising all aspects of the design accordingly.

Left/above *Images courtesy of Dow Building Solutions and Sto, photographer: Samuel Ashfield.*

Credits

Architect, main contractor: Seymour Smith Architects; structure: OMK Design; Passihaus consultant: Scottish Passive House Centre; heating engineer, plumbing: Cotswold Green Energy; insulated render, acoustic panels and paints: Sto; Styrofoam insulation: Dow Building Solutions; concrete structure design, supply: Aggregate Industries; internal blockwork: Lignacite; glazing: Optiwin; flooring: The Energy Saving Screed Company; waterproofing: Fosroc; mechanical ventilation with heat recovery: Dynamight Passive Solutions; solar photovoltaic panels: Ecoliving; solar thermal tiles: Solex.

Above *Tigh-na-Cladach (ph: Andrew Lee)*
Below left *detail section through external wall at first-floor level: 1 12.5mm plasterboard with vapour control layer on 50mm Kingspan Thermawall insulation, 2 Proctor Reflectatherm internal air membrane/VC barrier, taped and sealed on 9mm OSB internal sheathing, 3 timber skirting, 4 external sheathing, 5 spaces between joists closed with full timber blocking, 6 breathable paper over continuous cavity trays, 7 firestop wrapped in DPC, 8 Sto render.*
Below *Section and ground-floor plan of three- and two-bed units (left) and first-floor plan of three- and one-bed units (right).*



Tigh-na-Cladach, Argyll

The seafront in Dunoon, location of Tigh-na-Cladach, commands spectacular views of the Clyde across to Inverkip, *writes Gokay Deveci*. The client's aim was to provide affordable, good quality and low-energy one-, two- and three-bedroom family houses to be sold as shared equity.

Inspired by traditional fishing villages, the gables face the sea to reduce exposure to wind and weather. The massing creates a two-storey street of double gables with one-bed units between. Constructed using a prefabricated closed panel timber-frame system, the floor, wall and roof incorporate recyled content glasswool insulation. An important consideration in this cold climate was that the envelope was formed quickly, allowing other trades to carry on inside. Moreover, block and brickwork construction would have been difficult as you should not lay them below -5° C.

Using Scottish weather data, PHPP estimates the primary energy consumption (DHW, heating, auxiliary and household electricity) at 95 kWh(m2a). This is the amount of non-renewable primary energy needed by the energy carrier. It considers energy content of the raw materials as well as losses from distribution, conversion and delivery to the end-user. This is within Passivhaus limits despite the onerous national grid multiplier for electric heating. Although the annual heat demand at 20kWh(m2a) exceeds the 15kWh(m2a) normally required, it achieved Passivhaus certification by compensating with a peak heat demand of less than 10w(m2a). The scheme proves that energy-efficient design is possible on a social housing budget.

Credits
Architect: Gokay Deveci; engineer: Ramage Young; qs: Morham & Brotchie; contractor: Strone; CDM co-ordinator: Pentran; timber frame: RTC Timber Systems; Passivhaus windows: Dynamight Internorm; windows and doors: NorDan; rooflights: Velux; MHRV: Scottish Passive House Centre; client: Fyne Initiatives.

Blowing hot and cold

Bill Watts, senior partner at Max Fordham, examines the role of thermal mass and ventilation in Passivhaus buildings.

It is not hard to understand how the temperature in a building is arrived at. Basically, any heat coming into a room, be it from a radiator, a person, a computer or the sun through a window, will warm it up so it is hotter than outside. The heat then tries to leave the room through the walls and ventilation air, and the absolute temperature in the room is a ratio of the heat gains to the heat loss. The slight complication to this is thermal mass that stores a proportion of the heat in the building fabric, such that if the heat gain and heat loss vary, as they do over a day/night cycle, the swing in room temperature is reduced. It is important to remember that the heat does not disappear into the thermal mass for good. What it absorbs, normally in the day, it must release at some point, normally at night.

Passivhaus prides itself on having extremely small heat losses, such that the heat gains from the people, electrical equipment and the sun is enough to warm the building in all but the very coldest times of year, reducing the imported energy requirement for heat to very little. Being able to store some of the heat from the day and use it at night does have advantages, but if the simple act of being in the building and using it is enough to heat it, the benefit of storing more heat is limited.

In the summer there is a surfeit of heat. If the occupants can heat the building in the winter when it is cold outside and there is not much sun, it will overheat at warmer times of the

The Denby Dale Passivhaus, Yorkshire

Green Building Store's construction division, Green Building Company, completed the UK's first cavity wall Passivhaus in April, *writes Bill Butcher of GBC.*

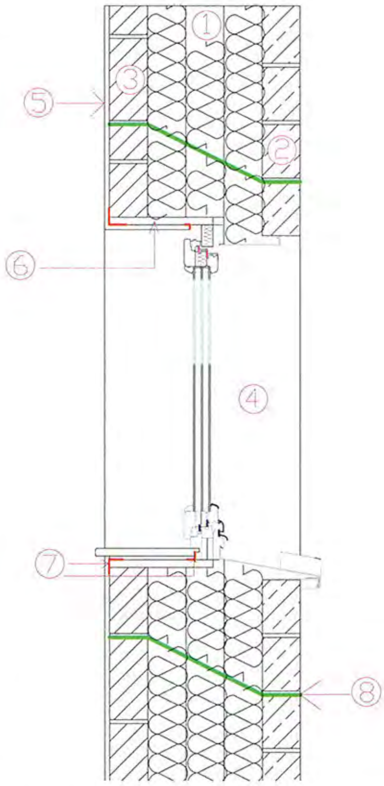
Cavity wall construction was chosen for several reasons. First, masonry wall construction, including cavity wall, contributes to a high thermal mass within the insulated building envelope, allowing a more even living environment in terms of both acoustics and temperature. Using dense concrete blocks and ground-floor slab, the house has a high thermal mass, stabilising temperatures and optimising passive solar gains.

Second, cavity wall construction was the method with which the building team was most familiar. The project aimed to build a Passivhaus using British construction techniques, with, as far as possible, materials that could be found in any local builder's yard.

Third, West Yorkshire planning rules required natural stone facing on the exterior of new buildings and so ruled out the option of block-built construction with rendered finishes.

Cost was also an important factor. The project was built to a tight budget of £141,000. From previous experience with exterior stone slips, the team felt that cavity wall construction offered the most cost-effective route.

Among the disadvantages of this approach is that in order to meet the Passivhaus airtightness requirements, cavity wall construction relies on wet plastering as the airtightness barrier. In some ways the timber frame route can be more straightforward, achieving airtightness by lining with vapour barriers and airtightness tapes, enabling airtightness to be tested earlier on in the build. However, wet plaster offers a perfectly good airtightness barrier – the final airtightness results at the Denby Dale Passivhaus came in at 0.33 ach at 50 Pa.



We believe that cavity wall is one option for Passivhaus construction in the UK, with timber-frame and block and render offering equally valid solutions for achieving the standard, dependent on the specific needs of the project. The cost-effectiveness of cavity wall is being borne out in other current Passivhaus projects, where it is proving cheaper than timber-frame due to its familiarity in the UK construction industry.

Above *Section through external wall: 1 300mm glass fibre insulation, 2 100mm natural Yorkshire stone, 3 100mm dense concrete block in cement/sand, 4 pre-formed aluminium cavity closer, 5 two-coat wet plaster, 6 18mm ply permanent formwork box, 7 airtightness tapes, 8 cavity tray.*

Credits

Architect: Derrie O'Sullivan; energy consultant: Pete Warm; project leader and director of Green Building Store: Bill Butcher; technical leader and director of Green Building Store: Chris Herring; Ecopassiv windows and doors, PAUL MVHR system, Lindab ducting system, TeploTie cavity wall ties; Pro Clima airtightness tapes and membranes: Green Building Store; insulation: Earthwool, Knauf; concrete products, plaster, timber: Naylor Myers; solar thermal system: EcoHeat.

year unless the heat loss of the building can be increased. Assuming that the insulation of the fabric cannot be changed, ventilation is the only way to do this. With Passivhaus this means that the heat recovery system is disabled or bypassed. This system on its own is not likely to provide enough external air to dissipate the heat and some openings in the facade are required. The size of void is substantial. As a very rough calculation, four per cent of the facade of a Passivhaus would need to be an opening for natural ventilation to get the equivalent heat loss of a uninsulated Victorian house with its leaky windows shut.

The thermal mass will smooth out the temperature swings, but the absolute temperatures will be a function of the heat gains and losses. If the gains are higher than the losses the average temperature will be higher and vice versa. To a certain extent, the desirability of thermal mass depends on whether you want an average temperature to avoid a daytime peak or alternatively a night-time trough. If combined with a night-time ventilation strategy, thermal mass is beneficial in a place of work to avoid the peak daytime temperature. A dwelling is used at night, however, when it would be better to get the full benefit of the cool night air without having to deal with the stored heat in the fabric that will keep the temperature up. Having said this, the thermal mass is constrained by 'normal' building materials which will always provide some mass. The question is how much more is required and what benefit does this confer?

Passivhaus and retrofit

Robert Prewett and Mark Elton consider the merits of the Passivhaus standard for retrofit projects.

The enormous quantity of poorly performing building stock in the UK accounts for almost half of UK carbon emissions. In order to achieve our 80 per cent carbon reduction goal by 2050, the performance of existing buildings will need to be dramatically improved.

The UK government has recently announced its commitment to tackling emissions from our existing housing stock through the Green Deal finance mechanism. Commencing in 2013, the initiative is intended to offer funding for upgrades to virtually every house in the country through public or private investment – the cost being recouped through utility bill payments. The 'golden rule' states that residents should always realise a net saving because of the reduction in fuel demand from the improvement measures. The figure that the Department of Energy and Climate Change (DECC) has in mind is around £6000 per property.

Another government-funded organisation, the Technology Strategy Board (TSB) is currently funding 86 pilot retrofit projects across the UK, aimed at meeting or exceeding a benchmark emissions target of $20kgCO_2/m^2/yr$, which equates to an 80 per cent reduction compared to the average UK stock. The focus is on pushing the boundaries and trialling new techniques or technologies (many aspire to the Passivhaus standard) within the context of a whole- house approach, with an average spend of around £120,000. It should be noted that these costs often include research and development of products and skills, as well as the support of supply chains for specialist materials. What is more remarkable is that many of the projects look likely to achieve Passivhaus certification.

So which is the correct approach? A piecemeal improvement based largely on solid wall insulation measures, or a comprehensive overhaul at considerable expense?

Above left/right *Triple-glazed windows, super-insulation and airtight details eliminate draughts and condensation, and ensure low levels of heat loss; super-insulation standards can be achieved without affecting the external appearance.* **Below** *Teaching the skills of airtight construction will be crucial in the retrofit roll-out.*

The importance of whole-house solutions

Most of the UK's exemplar retrofit projects completed to date have either been carried out by particularly enthusiastic private individuals or social landlords. To reach the public at large, retrofit will need to be something that is desirable enough to overcome the disruption that is an inevitable part of the process. The incentives are first, greatly reduced energy bills (and energy security); second, substantially improved comfort conditions; and third, potentially increased property values.

It is important to understand that there is a relationship between the first two. The level of spend proposed by DECC may lead to solutions that only deliver theoretical energy savings. Users may take the 'saving' to 'pay' for improved comfort, continuing to use just as much energy as before – a phenomenon known as the 'rebound effect'.

A wiser approach is to tackle both simultaneously – as Passivhaus design insists upon. The emphasis on achieving a constant air temperature, uniform surface temperatures, draught-free spaces and managed humidity ensure that comfort is delivered with efficiency. This is why actual energy use in certified Passivhaus projects corresponds very closely with the calculated values. It is also why Passivhaus projects do not fall victim to building defects, such as condensation and mould growth – problems that can arise in new build and retrofit when ventilation and cold bridging are not managed effectively.

DECC has partially acknowledged the need for whole-house thinking by advising that one comprehensive visit be made to each. However, it does not seem to have grasped yet the importance of tackling air leakage and ventilation at the same time as thermal upgrades. At the UK Passivhaus conference, the Secretary of State for Energy and Climate Change, Chris Huhne described heat recovery ventilation as a luxury. However, the TSB projects are showing that we can, and in fact must consider controlled ventilation simultaneously. Heat recovery ventilation can be installed cost-effectively, even with tenants in-situ, and the Green Deal should not exclude it.

The ideal and the possible

Meeting Passivhaus standards may at present be beyond what can economically be achieved for large-scale retrofit proposals. But its method has a lot to teach us about the quality of the retrofit work that we should demand and just as importantly, about the comfort criteria we should aspire to if the energy savings are to be achieved in reality.

Works to buildings must be undertaken with a whole-house approach in mind, so that they can be carried out sequentially over time if need be. What we must avoid at all costs is doing work to houses now that has to be re-done in a few years time because it was ill thought through. The endgame possibility for all houses should be approaching Passivhaus.

Robert Prewett of Prewitt Bizley Architects and Mark Elton of ECD Architects have been involved in a number of the TSB retrofit schemes as well as other pilot work for the Energy Saving Trust where the spend was more akin to Green Deal levels.

Compare and contrast: Passivhaus and the UK building standards

Can or should we compare the Passivhaus standard with UK building codes? Report by Jonathan Hines, director of Architype and member of the Passivhaus Trust zero-carbon working party.

Passivhaus and UK standards such as the Building Regulations, the Code for Sustainable Homes, and BREEAM were developed for different purposes and consequently have fundamentally different aims.

UK standards were designed to meet 'top down' political aspirations – currently a broad range of environmental issues, including water and waste, but most significantly 'zero-carbon' building targets.

Passivhaus was developed from the 'bottom up' by building physicists seeking effective ways to design low-energy buildings and ensure that they perform as predicted, in response to evidence that they were not. Passivhaus has a simple aim – to achieve, by good design, optimum internal comfort for the lowest possible energy consumption.

It is not possible to say that Passivhaus is the equivalent of a certain Code level or vice versa. Whilst the heat loss of Passivhaus meets the heat loss parameter requirement for Code 6, a house designed to meet any Code level, even 6, won't meet the Passivhaus energy standard. Given Code's zero carbon targets, Passivhaus cannot achieve Code 5 or 6 without adding renewables. Rather than trying to calibrate between such different standards, it is more useful to highlight discrepancies.

Zero-carbon buildings – a flawed target?

The core idea of Code and the Building Regulations, that buildings are isolated 'zero-carbon' islands, is conceptually flawed. First, it is based on 'offsetting' carbon emitted by continued energy consumption, rather than actually 'cutting' the emission of carbon by reducing energy use.

Second, it requires renewables on buildings despite the reality that these are generally less efficient and less cost effective than renewables at a community, regional or national scale.

Third, carbon targets encourage the design of less, rather than more efficient buildings. The easy option of adding renewables or changing the heat source enables poor design to achieve compliance, regardless of whether the renewables or specified heat source are actually used.

A more effective strategy to reduce national carbon emissions would focus on improving building design to reduce energy consumption regardless of heat source, and separately generating low carbon energy on the most effective and efficient scale. That is what Passivhaus offers – a rigorous way of designing efficient buildings that consume less energy.

Broad issues

To ascertain overall environmental ratings, BREEAM and Code give universal weightings to very different factors. This can result in anomalies, and the addition of features in order to score points that are inappropriate for that particular building.

For example to achieve Code Level 5 or 6, most dwellings require rainwater-harvesting or greywater recycling even when this increases carbon emissions or

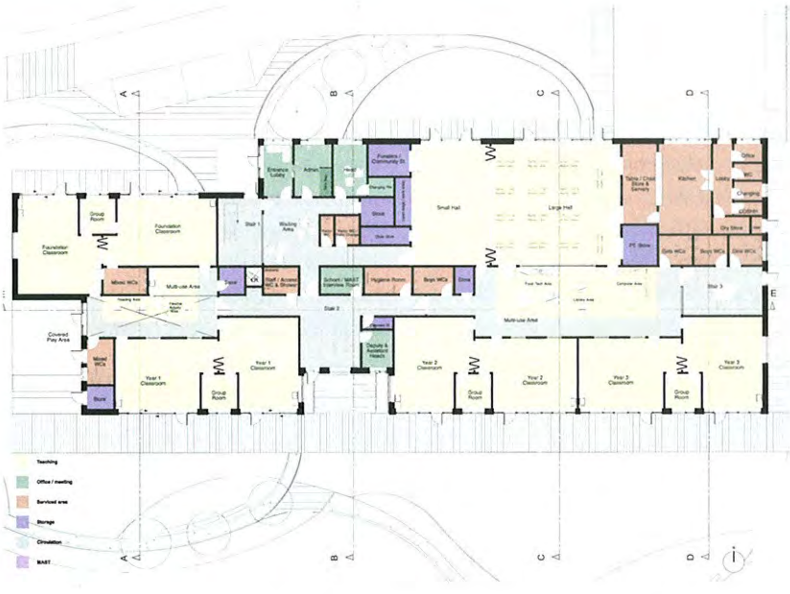
is sustainably questionable. Cycle racks, nearby shops and considerate contractors are important, but should they offset more energy-efficient building design? Money can be spent on tick box procedures, rather than actually improving building performance.

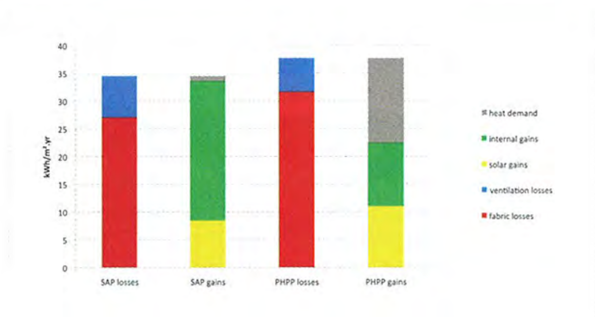
Based on achieving a percentage carbon improvement compared to a notional base building, Building Regulations encourage inefficient design. With a poor base design you can more easily achieve notional improvement and compliance. By setting an energy target per square metre per year for all buildings, Passivhaus eliminates this anomaly. Buildings then have to be designed to reduce energy.

Accurate prediction

Compared to Passivhaus, SAP uses optimistic assumptions, including over-generous incidental internal gains and underestimated heat losses for thermal bridges. This results in inaccurately low predictions of required thermal energy and reduces the incentive to improve design, making it a poor design tool.

Passivhaus uses pessimistic and cautious assumptions, which makes compliance harder and incentivises





design improvements over and above other measures. Developed through many years of real-life monitoring, it allows for the fact the built reality will fall short of estimated theory, and achieves buildings that perform as well or better than predicted, making it an effective design tool.

Conclusion

The broad box-ticking environmental aims and zero-carbon targets of UK standards encourage contradictory solutions and complex design. The radically low-energy target of Passivhaus, and its rigorously accurate process, encourage simple solutions and integrated design.

Because Passivhaus aligns with Architype's long-standing belief that the basic architecture should, by design, do all the hard work in saving energy, we have integrated Passivhaus into our standard design approach.

In 2009 St Luke's in Wolverhampton was the first primary school in Britain to achieve BREEAM Excellent. We are now on site with two further primary schools for the same client and the same budget, designed instead to Passivhaus standards, because it offers greater long-term financial benefits to our client, a more comfortable internal environment for users and, most importantly, more effective long-term energy and carbon reductions.

Above/opposite
Designed to Passivhaus standards, Architype's Oak Meadow Primary School in Wolverhampton is due to complete in August next year.

Passivhaus: what's not to like?

Passivhaus has developed a large and growing body of support among those interested in creating sustainable architecture, but some architects and engineers question the appropriateness and practicality of the standard. Here, sceptic **Ewan Willars** asks **Henrietta Lynch** for some answers.

Ewan Willars is policy director at the RIBA, which supports the Passivhaus standard as one of a number of methodologies that can help to reduce energy use and begin to address climate change.

Henrietta Lynch is currently undertaking doctoral research into the UK uptake of Passivhaus design at the UCL Energy Institute.

Is Passivhaus the ideal model for sustainable building? Does it target the right things? Is it practical? Are the buildings comfortable? Ewan Willars and Henrietta Lynch detate the issues.

Ewan Willars The Passivhaus standard moves the focus away from carbon, and struggles to provide a fit with UK Building Regulations. The Passivhaus maximum allowance for space heating for each house is expressed in kilowatt-hours per square metre per annum – thereby focusing solely on energy use, not carbon emissions (which are determined by both the quantum of energy used and the type and source of energy). In contrast, UK regulations work in terms of carbon dioxide emissions per square metre per annum. Passivhaus doesn't directly address carbon emissions, which at the end of the day are the main target.

Henrietta Lynch *While the Passivhaus standard uses energy expressed in kilowatt-hours as a target of performance, the PHPP (Passivhaus Planning Package) software which is used to design Passivhaus buildings also provides a calculation sheet showing performance in carbon dioxide emissions.*

Recent iterations of Part L measure performance in carbon dioxide emissions. This is achieved by first calculating energy use in kilowatt-hours. This impacts on the design of building energy systems, the sizing of heating, cooling and electrical equipment, the measurement of solar gain and fabric performance, but also to the units by which grid heat and power are supplied.

The amount of carbon dioxide emissions associated with grid supply of electricity and gas varies over time according to the different mixes of fuel used for generation. Because of the changing nature of our energy supply, a building designed to have one level of carbon dioxide emissions may in reality produce more or less in practice.

Using carbon dioxide as a metric for the building regulations raises awareness of our greenhouse gas emissions reduction targets, but using kilowatt-hours allows individual building performance to be linked back to supply, thus enabling an understanding of the number of power stations or wind farms we need. It also better enables the use of smart meters, which will hopefully help to regulate future building energy performance.

EW Passivhaus standards require a high degree of airtightness. Of the buildings that I know that have been tested post-construction, very few get close to their intended air-tightness or the Passivhaus standard without significant modification, even if the design performance looked right on paper. Is it practical, or even possible, for buildings to be built to these exacting tolerances in anything other than a small number of bespoke cases? If not, then Passivhaus cannot be considered a mass-market solution.

HL *Unfortunately in the UK we are not currently good at draught-free buildings. This is different in countries which have more stringent building regulations – Sweden, for example, where current regulations correspond to Passivhaus good practice recommendations. Passivhaus airtightness parameters are even more stringent than Swedish building regulations, but to date around 22,500 Passivhaus buildings have been constructed, all of which have had to undertake air-pressure tests to prove their performance.*

Recent experience in the UK suggests that airtightness parameters are achievable through rational design, on-site teamwork and careful attention to detail, but mass-market Passivhaus solutions may best be achieved by using Modern Methods of Construction.

EW Alongside airtightness and high levels of insulation, mechanical ventilation, heat recovery, renewable technologies and hot water systems are usually required. Such systems are often overcomplicated for residents, and unless used and correctly calibrated, quickly lose their energy-effectiveness, and may actually use more energy than they save.

HL *All buildings require that mechanical, electrical or renewable energy systems are correctly, designed, installed and calibrated to work. This is not just the case for Passivhaus.*

Passivhaus does not rely on renewable energy technologies, instead using heat recovery ventilation (HRV). though many Passivhaus designs do also employ renewables). Arguably living with a ventilation system is actually less complicated than living with a conventional wet heating system, but residents do need to learn the associated new operational requirements.

HRV systems installed into leaky buildings will not save energy. If they are installed and calibrated correctly and a building has very low air-permeability, then they have the capacity to save 'more than 10 times the energy used for their operation', according to Active for More Comfort: The Passive House, a report produced by the Passivhaus Institut.

Below *Headquarters of CIT-Blaton, a construction company based near Brussels. Architect A2M won an invited competition for the project by proposing that the rear part be renovated according to the Passivhaus standard. The building is used by CIT-Blaton to demonstrate that the standard is applicable to offices. The building envelope was dismantled entirely, with only the structure retained. The facades were reconstructed with highly insulated timber sandwich panels and triple-glazed windows.*
Left *The Passive House in the Woods, a 3-bed single-family home with walk-out basement level and a rooftop terrace in Wisconsin, designed by TE Studio. The exterior wall assembly consists of 280mm Insulated Concrete Forms for structure, and a 280mm Exterior Insulation and Finish System facade. Windows have triple pane low-E coated glazing.*

EW A successful Passivhaus requires a balanced interplay between the building, the sun and the climate. Therefore architects need to be careful about site selection, and many sites in the UK are, at best, challenging.

HL *To perform, Passivhaus buildings rely on a combination of fabric performance, system design, the use of casual heating loads and passive solar design. All these different elements are weighted to produce an holistic design, relative to the positive and negative impacts of a site, so one site may need larger windows or more insulation than another to balance the design loads.*

EW A system dependent on predictable climate and tight tolerances may find problems as one of the variables – climate – changes over time due to global warming. Will the Passivhaus of today still be liveable in the climate of tomorrow?

HL *Passivhaus buildings should be future-proof considering current climate change projections for temperature rises by the end of this century. They are designed to reduce both heating and cooling loads. A Passivhaus building is more likely to cope with climate change than many other low-energy building design types.*

EW It is tough (but admittedly not entirely impossible) to have rooms that vary significantly in temperature – for example cooler bedrooms. If inhabitants are forced to open windows to be comfortable, is this not rather defeating the object?

HL *Passivhaus buildings are usually designed as one zone with a constant temperature. It is however possible to design them with different temperature zones.*

Most Passivhaus buildings are designed with a 'mixed-mode' ventilation strategy. This means that while they may employ HRV in the heating season, they use natural ventilation in the summer when windows are opened (or vice versa for warmer climates).

Contrary to some popular myths, it is possible to open windows in a Passivhaus when the HRV system is operating. This can work as an additional cooling strategy to complement HRV. Excessively opening windows while HRV systems are in operation would lead to increased energy use, but against a low base of consumption.

EW Creating the necessary step-change to enable true low-energy, low-carbon lifestyles is at least 80 per cent about people's behaviour, and only 20 per cent based on technological fixes. Passivhaus does little or nothing to address the bigger part of the problem.

HL *Behaviour is crucial to carbon reduction. Living in a Passivhaus requires behaviour change because it is slightly different from living in a conventional house, but extensive research shows that Passivhaus buildings on average perform as predicted.*

Carbon emissions associated with the UK domestic stock equate to around 27 per cent of our total. The Passivhaus standard, which is appropriate for domestic, non-domestic and renovation projects, has the potential to deliver around 80 per cent reductions in heating/cooling demand together with reduced electrical consumption. This is not insignificant.

Directory

Passivhaus information

Passivhaus Institut
Founded in 1996 as an independent research institute under the leadership of Dr Wolfgang Feist, the PHI is responsible for developing and promoting the Passivhaus concept in Germany and around the world. Located in Darmstadt, Germany, the organisation develops tools for designing to Passivhaus standards (including the Passivhaus Planning Package or PHPP), provides quality assurance, certifies manufacturers' products and accredits Passivhaus certifiers.
www.passiv.de

International Passive House Association
iPHA and its German counterpart, IG Passivhaus are affiliated with the Passivhaus Institut (PHI) in Darmstadt, Germany. iPHA is a global network of passivhaus stakeholders, including architects, planners, scientists, suppliers, manufacturers, contractors and property developers. Its aims are to promote the Passivhaus standard, foster greater public understanding of Passivhaus and to encourage the exchange of Passivhaus knowledge and ideas.
www.passivehouse-international.org

Passivhaus Project
Passivhaus Project is an online database of completed Passivhaus projects from around the world. Each project has its own data sheet including construction and performance information.
www.passivhausprojekte.de

PassivHaus UK
Forming part of the BRE, PassivHaus UK provides Passivhaus design and PHI-approved certification services. Compliance with the Passivhaus standard is assessed using the Passivhaus Planning Package (PHPP). The BRE also provides training for people wishing to attain the Certified European PassivHaus Design Consultant qualification, recognised across Europe.
www.passivhaus.org.uk

There is a wealth of material available on both Passivhaus design and the Passivhaus standard from national and international organisations, as well as on the web.

Above *Forming part of Expo 2010 in Shanghai, the Hamburg House by Spengler Wiescholek is an exemplar energy-efficient office and the first certified Passivhaus building in China (ph: Spengler Wiescholek).*

PassivHaus Trust
Established as an independent, non-profit organisation, the PassivHaus Trust is a subsidiary of the AECB that is aimed at promoting and preserving Passivhaus standards and methodology. It also facilitates education and training events and undertakes research and development on Passivhaus standards in the UK.
www.passivhaustrust.org.uk

CarbonLite Programme
Covering both domestic and non-domestic projects, AECB's CarbonLite Programme aims to provide the tools and knowledge to create low energy buildings that comply with existing and future legislation, including the Passivhaus Standard. AECB is also a PHI-approved certifier.
www.carbonlite.org.uk

UK Passivhaus Certifiers
Current UK-based Passivhaus certifiers include the BRE, Warm, InBuilt, Mosart, and The Scottish Passivhaus Centre.
www.bre.co.uk; www.peterwarm.co.uk; www.inbuilt.co.uk; www.sphc.co.uk; www.mosart.ie

Pass net
Co-ordinated by the Austrian Society for Environment and Technology, the Pass net project promotes the Passivhaus standard across Europe, especially in new EU member states. Its activities include publishing guidance and training information.
www.pass-net.net www

Passipedia
iPHA's wiki-based web resource Passipedia covers many aspects of Passivhaus design and construction, from basic definitions to calculating energy efficiency and finding a Certified Passive House Consultant. The site also contains useful information on upcoming Passivhaus training programmes.
www.passipedia.passiv.de/passipedia_en/

Passivhaus map
Online map showing all current certified Passivhaus projects in the UK.
http://blog.emap.com/footprint/passivhaus-map/

International Passivhaus Conference
Organised by the Passivhaus Institut, the 15th International Passivhaus Conference and exhibition runs from 27-28 May 2011 at the Passivhaus Institut in Innsbruck, Austria.
www.passivehouseconference.org

UK Passivhaus Conference
The first UK Passivhaus Conference was held in October this year, and included case studies, workshops, and an exhibition. The next conference will be hosted in the autumn 2011.
www.ukpassivhausconference.org.uk

UK Passivhaus Research Conference
Passivhaus conference enabling architecture and environmental design students, researchers and their lecturers to share, debate and discuss their work
www.ukpassivhausresearchconference.org.uk