Passivhaus and Zero Carbon

Technical briefing document

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The Passivhaus Trust supports the aim to reduce carbon emissions associated with new housing, and believes that significant reductions on present UK levels can be achieved through advanced energy efficiency measures.

During early 2011 a series of technical, regulatory and policy developments within the UK led to the situation where there are more synergies between the Passivhaus standard and UK regulations than ever before.

This paper reviews the potential opportunities that Passivhaus offers for achieving the carbon reductions needed to meet the 2016 'Zero Carbon' standard. Evidence demonstrates that Passivhaus delivers real and significant reductions in energy consumption, through detailed energy efficient design, services and construction. Most Passivhaus dwellings will come close to meeting the Carbon Compliance element of the 'Zero Carbon' definition, without additional renewable energy devices.

While the focus of this paper is on housing, it should be noted that many of the issues raised here are also relevant to non-domestic buildings, and the target for new non-domestic buildings to be 'Zero Carbon' by 2019.

Passivhaus

Passivhaus is described as the leading international low-energy design standard, although the design of Passivhaus buildings addresses more than energy efficiency. By considering the ventilation requirements of the occupants as a starting point, Passivhaus design reduces the space heating energy demand to below 15kWh/m^2/yr, and also provides good levels of internal air quality and comfort. This is achieved through the design of a well-insulated, draught-free building that makes use of the available solar and internal heat gains, plus the provision of mechanical ventilation with heat recovery (MVHR).

Additionally, the Passivhaus standard includes a target for unregulated energy demand that is no longer included in the 'Zero Carbon' target and future building regulations. The Passivhaus standard sets a primary energy limit of 120kWh/m^2/yr. In order to achieve this, the primary energy demand for all activities (including cooking and appliances) within the home must be reduced. This can be achieved through specification of energy efficient light fittings and appliances, and well-designed and insulated hot water supply, plus the use of low carbon energy supply.

There is considerable evidence that homes built to Passivhaus standards in Europe have resulted in significant reductions in energy demand and associated carbon emissions[1]. Many of these homes have been monitored and shown to perform extremely close to predictions calculated using the Passivhaus Planning Package (PHPP) design software, as illustrated in Fig. 1.

[1] Passipedia article: *Energy Use Measurement Results* http://passipedia.passiv.de/passipedia_en/operation/operation_and_experience/measurement_results/energy_use_measurement_results (accessed June 16 2011)

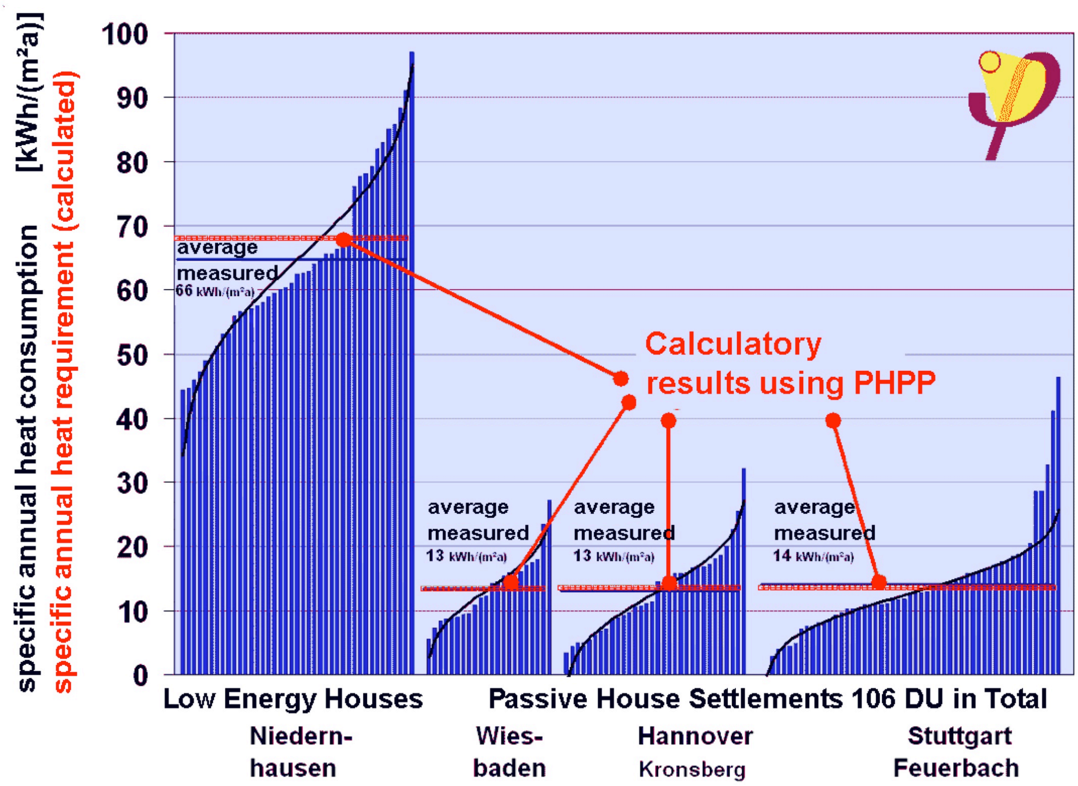

Fig. 1 Measured heating energy compared with PHPP predictions for 4 developments[2]

A range of building types have been built to Passivhaus standard around the world, in cold and in warm climates: Houses, blocks of flats, offices, community centres, schools, health buildings. The principles can be applied to refurbishment projects as well as to new build.

Around 20,000 Passivhaus buildings have been built in Europe, and are generally proven to be:

- Energy efficient – using one tenth of the energy used by an average building[3]
- Quality assured – Designed and constructed using a process that is certified and tested at various stages, to deliver proven performance[4]
- Comfortable – Warm, no draughts or cold surfaces[5]
- Healthy – Good internal air quality[6]
- Affordable – Have lower running costs[7]

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[2] Graph from Passipedia article: *Energy Use – Measured Results* http://passipedia.passiv.de/passipedia_en/operation/operation_and_experience/measurement_results/energy_use_measurement_results (accessed June 16 2011)
[3] Ibid
[4] Passipedia article: *Quality Assurance* http://passipedia.passiv.de/passipedia_en/construction/quality_assurance (accessed June 16 2011)
[5] Passipedia article: *Residents' experiences* http://passipedia.passiv.de/passipedia_en/operation/operation_and_experience/residents_experiences (accessed June 16 2011)
[6] Kah, Schulz *The influence of controlled ventilation on air quality in* classrooms - ventilation systems in Passive Houses (14th International Conference on Passive Houses 2010, p.381)
[7] Passipedia article: *Are Passive Houses cost-effective?* http://passipedia.passiv.de/passipedia_en/basics/affordability/investing_in_energy_efficiency/are_passive_houses_cost-effective?s[]=costs (accessed June 16 2011)

Interest in Passivhaus is growing rapidly in the UK, with at least 70 projects either certified or in progress. This briefing paper focuses on opportunities provided by Passivhaus for reducing energy demand, and investigates how the resulting reductions in carbon emissions can help to meet the 2016 'Zero Carbon' target for new homes.

'Zero Carbon'

The UK Government has set a 'Zero Carbon' target for new housing to be achieved by 2016. Originally, the 'Zero Carbon' target announced in 2006, was defined as including all energy demand in the dwelling, covering both regulated emissions (space heating, hot water and fixed lighting, pumps and fans) and unregulated emissions (cooking and appliances). However, in March 2011 HM Treasury issued a document entitled 'The Plan for Growth' with the Budget, which states that the 'Zero Carbon' homes target will only relate to regulated emissions[8].

This change reflects the split between energy demand influenced by the building design (regulated), and energy demand controlled by user behaviour (unregulated). The new focus on regulated energy brings the UK 'Zero Carbon' target closer to the EPBD 'nearly zero energy building' target, since unregulated energy was never included in the scope of the EPBD[9]. However, this also means that the primary energy savings achieved by Passivhaus buildings are not counted in the reductions needed for Carbon Compliance, but may count towards allowable solutions needed to meet 'Zero Carbon'.

Work carried out by the Zero Carbon Hub recommended specific carbon reductions that can feasibly be achieved by different housing types. The Zero Carbon Hub's final report on Carbon Compliance[10] recommends that regulated emissions be reduced to 10kg/m^2/yr for a detached house, 11kg/m^2/yr for an attached house, and 14kg/m^2/yr for a flat, based on calculations using an adjusted SAP 2009. It is expected that this will be achieved through Carbon Compliance measures such as energy efficiency and supply of on-site low and zero carbon energy. The remainder of regulated carbon emissions must then be reduced to 'Zero' through provision of 'Allowable Solutions' (which have not yet been defined, but may include energy efficient appliances, off-site renewables and community energy funds).

At least some of the Carbon Compliance reduction must be achieved through fabric energy efficiency measures that reduce space-heating and cooling demand. A 'Zero Carbon' home must also meet the Fabric Energy Efficiency Standard (FEES). This has been set as a limit for energy demand for space heating and cooling of 39kWh/m^2/yr for flats and terraced houses, and 46kWh/m^2/yr for detached and semi-detached houses. Further reductions can be achieved through energy efficiency measures beyond this standard, which would help towards Carbon Compliance. Passivhaus effectively amounts to one such energy efficiency measure, by offering a robust method for exceeding the FEES, whilst also contributing to unregulated carbon reductions through the Primary Energy limit.

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[8] HM Treasury & BIS The Plan for Growth (March 2011), p. 117
[9] ZCH & NHBC Foundation, *Energy Performance of Buildings Directive: introductory guide to the recast EPBD-2* (April 2011), p.7
[10] Zero Carbon Hub, *Carbon Compliance: Setting an appropriate limit for zero carbon new homes – Findings and Recommendations* (February 2011)

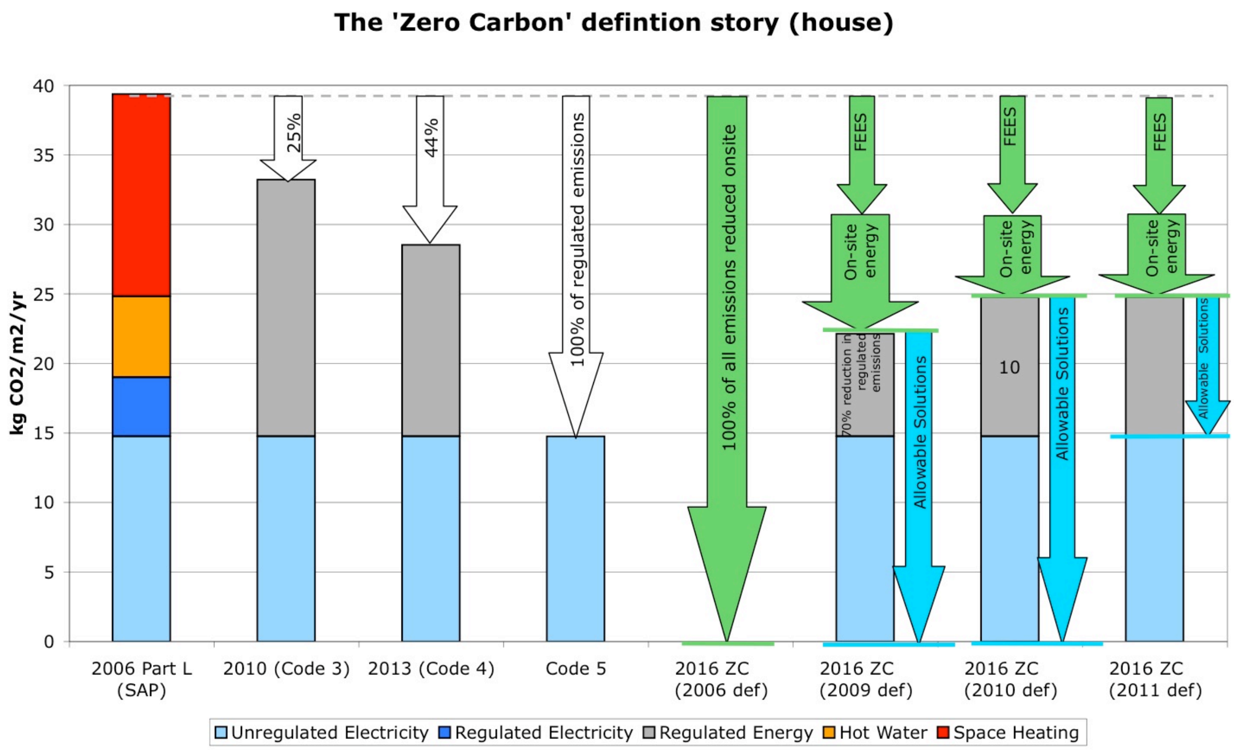

Fig. 2 The 'Zero Carbon' definition story

Proof of performance

There is evidence from some studies that the attention to detail required in the construction of UK new homes, especially as energy standards become more onerous, means that they may not perform as well as predicted. As well as higher energy demand[11], problems with air quality[12] and overheating[13] are emerging as growing risk factors. This is addressed by various Zero Carbon Hub reports, which broadly recommend that (i) the SAP's treatment of overheating be improved, and (ii) performance be measured at the 'as-built' stage rather than 'as-designed'.

Evidence overseas indicates that Passivhaus design addresses these concerns. It reduces the risk of underperformance beyond that achieved in typical homes designed to other standards, and provides high quality buildings with healthy and comfortable internal conditions. The PHPP model is a design tool, rather than a compliance tool, and is more detailed than the SAP. This allows a more informed prediction to emerge, which is likely to be closer to reality. The basic Passivhaus requirements lead to an improved draught-free building, and the Passivhaus philosophy demands a total absence of thermal bridges, areas of heat loss through the fabric that can result in cold and condensation problems internally. Carbon savings resulting from a PHPP modelled building design are more likely to be delivered than those promised by renewable energy devices, which may depend on maintenance, climate, location etc. Finally, the requirement that for Passivhaus *certification* a series of site observations and tests must be carried out inevitably leads to better as-built performance.

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[11] Good Homes Alliance (GHA) event: *Closing the Performance Gap – Low Carbon 4 Real* (April 2011) http://www.goodhomes.org.uk/library_files/105

[12] Crump, Dengel & Swainson, *Indoor Air Quality in highly energy efficient housing* (NHBC Foundation, July 2009)

[13] Good Homes Alliance (GHA) event: Health & Wellbeing for occupants – Ventilation, Condensation and Internal Air Quality (London, Nov 2010) http://www.goodhomes.org.uk/library_files/83

How a Passivhaus dwelling might meet Carbon Compliance and 'Zero Carbon'

It is not easy to directly compare Passivhaus with the DER/TER method of Part L. Firstly, Part L is essentially carbon-based, whereas Passivhaus is an energy standard. Moreover, Part L is concerned with regulated emissions (those due to heating, hot water, fixed lighting and ventilation) whereas Passivhaus includes targets for both heating demand and primary energy (including household appliances). Nevertheless, with careful attention to the technical detail and diligent application of appropriate assumptions, it is possible to carry out calculations, which enable reasonably accurate comparisons.

The Passivhaus standard sets a limit of 15kWh/m^2/yr for the energy used for space heating and 15kWh/m^2/yr for cooling. Energy demand for hot water, lighting and appliances is also reduced through energy efficient design and specification. Electricity demand for fans is increased slightly, due to reliance on mechanical ventilation with heat recovery, however this is offset by the ventilation heat energy, which is recovered.

In order to look at how the energy demand reductions of a Passivhaus home might help to meet the 'Zero Carbon' standard, various sources have been examined:

1. **A simplified exercise** – Initially, a simplified exercise was carried out comparing what routes might be available for a house and a flat designed to Passivhaus standard (Appendix A). The limited nature of the exercise means that it can only help to build a picture of the possibilities, and firm conclusions cannot be drawn from it. The results indicate that a reduction in regulated CO_2 emissions (kg/m^2/yr) of around 47% can be achieved by reducing the space heating energy demand of a house to 15kWh/m^2/yr (Fig. 1), and a reduction of at least 23% is possible for a mid-floor flat (Fig. 2). The exercise also indicates that if calculated by PHPP, a reduction of 65% in regulated emissions might be possible. Additionally, if the combined benefit of both regulated and unregulated carbon savings are considered, a level equivalent to the 'zero carbon' target might be reached with minimal additional renewable devices. (Appendix A)

2. **Zero Carbon Hub Appendices** – In a far more detailed piece of work, the Zero Carbon Hub has investigated different levels of carbon reductions achieved by various design specifications, by modelling a range of house types. They then added a range of different renewable solutions to achieve Carbon Compliance levels, using SAP 2009 with 2016 emission factors, and four UK climate regions. This work is presented in the document 'Defining a Fabric Energy Efficiency Standard for zero carbon homes'[14], and presents reductions in regulated emissions achieved by Spec C (close to Passivhaus) and Spec D (Passivhaus) with gas heating and grid electricity: 30% and 32% for a small ground floor flat[15]; 32% and 40% for a semi-detached or end terrace house; and 36% and 46% for a detached house.

3. **Work carried out by bere:architects** – A detailed study that has been carried out by bere:architects, with the help of Brooks Devlin Ltd, comparing PHPP and SAP calculations of three of the first certified Passivhaus dwellings in the UK.[16]. This indicates that a best practice Passivhaus modelled with PHPP is capable of achieving regulated carbon

[14] Zero Carbon Hub, Defining a Fabric Energy Efficiency Standard for zero carbon homes – Appendix A, Work Group 1, Form and Fabric (23 Nov, 2009). Page 60.
[15] This figure is higher than the 23% presented in the exercise, since a medium sized mid-floor flat already has a lower kwh/m^2 space heating demand than a small ground floor flat.
[16] bere:architects, Nick Newman, *Zero point zero carbon: A study comparing PHPP and SAP calculations of CO2 emissions for three of the first certified Passivhaus dwellings in the UK, to test correlation with the UK government's definition of Zero carbon 2016.* (June 2011)

reductions of up to 70% compared to a Part L 2006 dwelling also modelled with PHPP, without onsite low and zero carbon energy provision. This compares with a 54% reduction if modelled with SAP. The three houses modelled for this study reveal predicted regulated carbon emissions ranging between 10.8 and 12.2kgCO2/m2/yr, if modelled with PHPP, and between 10 and 12.4kgCO2/m2/yr if modelled with SAP 2009 (the Carbon Compliance standard for a house is 10kgCO2/m2/yr). This indicates that Carbon Compliance can be achieved, with minimal renewable energy provision.

Findings

According to the evidence examined, it is clear that Passivhaus dwellings will meet whatever energy efficiency target might credibly be proposed for the 2013 Part L, and will normally meet whatever carbon target is proposed without renewable devices[17], if calculated using PHPP[18].

The evidence examined so far also indicates that most Passivhaus dwellings, will come close to meeting the Carbon Compliance standard within 'Zero Carbon' without renewable energy devices, and will achieve the Carbon Compliance level with minimal renewable energy. It is not yet clear whether every Passivhaus dwelling will be able to meet Carbon Compliance in this way, and this would require further investigation. Additionally, if the combined benefit of both regulated and unregulated carbon savings are considered, a level equivalent to the 'Zero Carbon' target might be reached with minimal additional renewable energy.

It should be noted that this paper compares, and draws its findings from, the calculated performance of dwellings. In addition, the Passivhaus standard, and quality assurance process offers improved measured performance and comfort.

Acknowledgements

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[17] Dependent on carbon emission factors used.
[18] This assumes that a similar approach is taken for 2013 Part L compliance regarding flats, as has been taken with suggested Carbon Compliance levels.

Appendix A

Carbon compliance and Passivhaus – an exercise
This simplified exercise aims to investigate how a Passivhaus design might help to achieve carbon reductions to the level required for the 2016 'Zero Carbon' target. At this stage, the exercise is carried out using estimates and simplified assumptions, and would need to be supported by detailed modelling to confirm the issues discussed below.

This exercise
The following charts illustrate the possible impact on CO_2 emissions of the Fabric Energy Efficiency Standard (FEES), and the Passivhaus Standard (PH) applied to the heating demand only. This exercise is carried out on both a semi-detached house (with 75kWh/m^2 space heating demand), and a mid-floor flat (with 35kWh/m^2 space heating demand). The energy demand for space heating is calculated differently for compliance with Part L and for FEES. The level required for Part L includes benefits of MVHR and hot water gains, while the figures for FEES do not. For the purpose of this exercise, energy demand reductions for FEES have been adjusted downward.

The results
According to this exercise, a reduction in regulated CO_2 (kg/m^2/yr) of around 47% is achieved by reducing the space heating energy demand of a house to 15kWh/m^2/yr (Fig. 1), and only around 23% reduction is achieved for the flat (Fig. 2). This lower percentage reduction results from the flat already being an efficient building form with minimal exposed external envelope, and limited opportunity for reducing the space heating demand further. However, it should be noted that the extra energy demand for common areas in a block of flats (such as lifts, and lighting to corridors, car parks and lobbies etc) are not considered in SAP calculations and compliance with Part L.

Note: for 2006 house with PH level space heating reduced to 15kwh/m^2/yr based on level calculated by PHPP. SAP contains different assumptions so the number would be different if modelled by SAP. These discrepancies have been ignored for the purpose of this exercise.

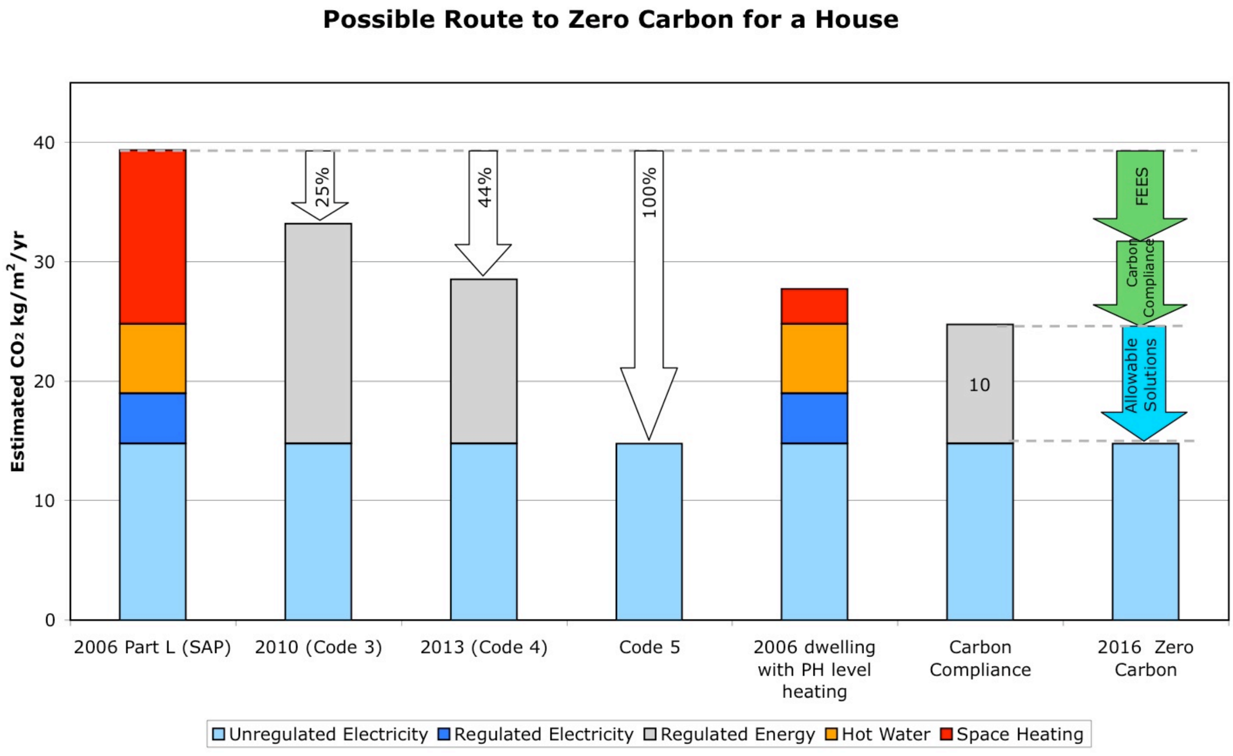

Fig A1: Estimated CO_2 reductions achieved by efficiency standards for a house

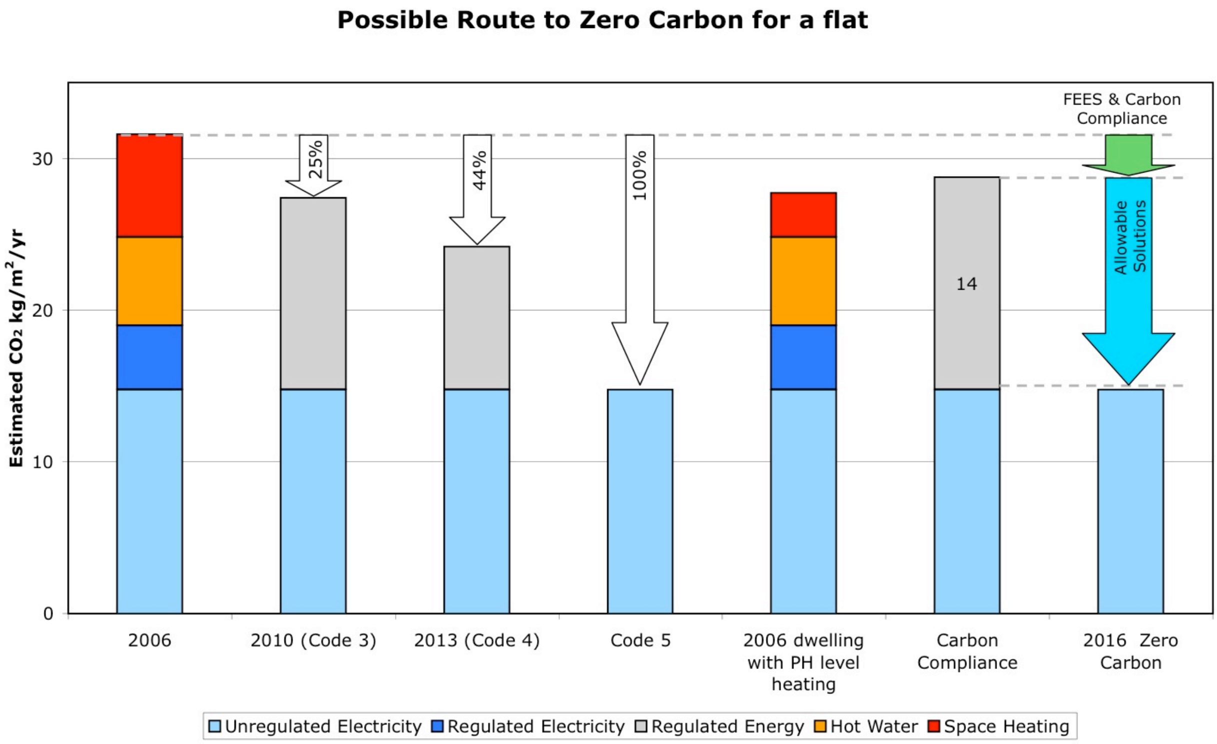

Fig A2: Estimated CO_2 reductions achieved by efficiency standards for a flat

When these levels are compared with the carbon compliance level set as part of the 'Zero Carbon' definition, it appears that the flat may be able to meet the limit of $14kgCO_2/m^2/yr$. Whereas, the house may not quite meet the $10kgCO_2/m^2/yr$ carbon compliance target, and would require onsite low or zero carbon energy provision to do so.

SAP and PHPP

Passivhaus buildings are designed using a tool called Passivhaus Planning Package (PHPP). The SAP is a compliance tool used to demonstrate that a dwelling meets the requirements of building regulations Part L and is intended to be usable. Secondly, both rely on assumptions to varying degrees, in order to reduce complexity[19]. In the latest update, revisions were made to Part L in order to make it more robust, by aligning the methodology more closely with Passivhaus.

It seems that if a house designed to the Passivhaus standard is assessed using SAP, the true potential carbon reductions may not be reflected. Firstly it underestimates the role of an efficient building fabric and assumes high internal gains, resulting in misleadingly low predictions for space heating demand. Secondly, the potential energy savings from hot water and regulated electricity efficiencies are underestimated, leading to higher than necessary predictions for hot water and electricity demand.

As PHPP was developed as a design tool, it utilises more information to predict the energy performance of a building, and many of the assumptions are based on data from monitored buildings. This makes PHPP a more complex tool to use, but a tool that produces more informed predictions that have been demonstrated to be close to the performance of the real building.

[19] A detailed comparison of PHPP with SAP can be found in the AECB Carbon Lite report, *Projecting Energy Use and CO2 Emissions from Low Energy Buildings: A comparison of the Passivhaus Planning Package* (PHPP and SAP (Oct 2008)

Additionally, the Passivhaus standard includes a target for unregulated energy demand that is no longer included in the 'Zero Carbon' target and future building regulations. The Passivhaus standard sets a primary energy limit of 120kWh/m^2. PHPP includes a factor to account for the high carbon content of UK electricity, which makes this target particularly challenging to reach. In order to achieve this, primary energy demand for all activities (including cooking and appliances) within the home must be reduced. This can be achieved through specification of energy efficient light fittings and appliances, and well-designed and insulated hot water supply, plus the use of low carbon energy supply.

Comparisons with Passivhaus modeled with PHPP

Fig. 3 shows how primary energy reductions to 120kWh/m^2/yr might be achieved without LZC energy. According to this exercise, it seems possible that, if assessed by PHPP, a house designed to the Passivhaus standard could achieve a 65% reduction in regulated emissions.

In order for a 2006 dwelling with Passivhaus level space heating to achieve the required reduction in regulated emissions for carbon compliance, it appears that it is still necessary to supply some energy from low and zero carbon energy sources on site. The PHPP Passivhaus illustrated here achieves carbon reductions to below the Carbon Compliance level, even when only the regulated emissions are considered. As indicated above, a best practice example should be able to achieve this reduction in primary energy through energy efficiency measures only. But others will require onsite renewable energy supplies in order to achieve reductions in primary energy to the 120kWh/m^2 level.

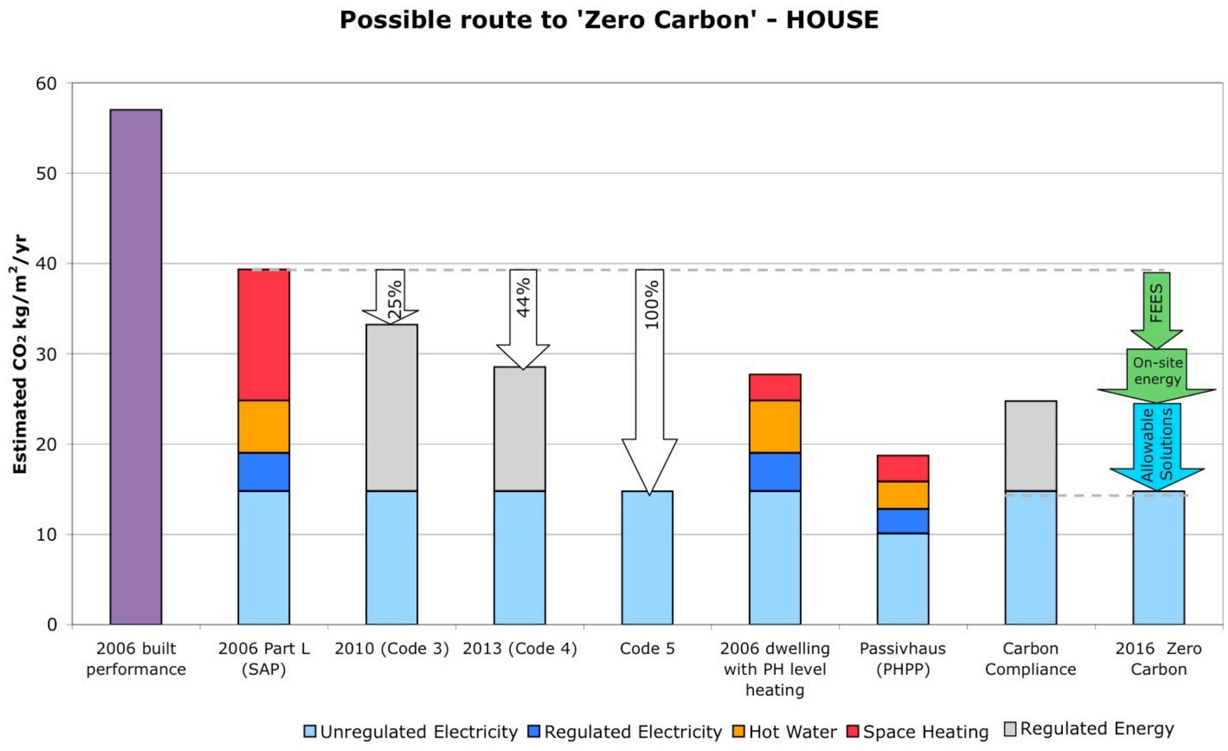

Fig A3: House only – CO_2 reductions achieved by Passivhaus design