

## **Abstract**

A rapid transition to 'zero carbon' building was announced by the UK Government in December 2006 as a key step forward in reducing the Green House Gas (GHG) emissions from the domestic and non-domestic sectors. This paper elaborates on whether the revised definition of 'zero carbon' dwellings in the UK (2009) and the approach to implementing this policy, advocated by the Zero Carbon Hub (ZCH) , is coherent with overarching climate change and energy policies. Further, the paper examines the barriers to adopting higher minimum standards of fabric energy efficiency, in particular the German Passivhaus standard. By comparing methodological differences and outcomes associated with these different energy performance standards, an estimate of the real world energy and carbon savings has been determined. The paper concludes that adopting a more robust 'fabric first' approach, would achieve better coherence with UK climate change and energy policies, whilst mitigating the risks associated with carbon offsetting mechanisms.

*Keywords: UK zero carbon; Fabric Energy Efficiency Standards (FEES); Passivhaus standard*

## 1. Introduction: Climate Change and the UK built environment

The UK Government announced a rapid transition to 'zero carbon' new building in December 2006 as a key step forward in reducing the Green House Gas (GHG) emissions from the domestic and non-domestic sectors (DCLG, 2006a; Weaver, 2007). With the built environment accounting for around 36% of the UK's total GHG emissions (Committee on Climate Change, 2010), energy performance in building policies continue to play an influential role in the national GHG inventory. The UK built environment is reflective of the wider situation across Europe where according to the Energy Performance in Buildings Directive (EPBD) "buildings account for 40 % of total energy consumption in the Union" (European Commission, 2010). At a national level the UK Climate Change Act (2008) sets a legally binding target requiring that GHG emissions are reduced by at least 80% by 2050, compared to 1990 levels (DEFRA, 2007). Of significant concern is that the building sector is expanding, which is bound to further increase its energy consumption.

In order to address these compounding issues, the European Parliament developed a resolution entitled 'An Action Plan for Energy Efficiency' (European Commission, 2008). This document attempts to unite multiple European Commission objectives and: 'Calls on the Commission to propose a mandatory requirement that all new buildings needing to be heated and/or cooled shall be constructed to passive house or equivalent non-residential standards from 2011 onwards; including a requirement to use passive heating and cooling solutions from 2008.' It is notable that this document specifically refers to the adoption of the German Passivhaus standard (Feist, 2010) from 2011 onwards.

The German Passivhaus standard is the fastest growing energy performance standard in the world. Since its inception in the early 1990's, over 30,000 buildings have been realised on a voluntary basis across Europe (iPHA, 2012). The Passivhaus standard's strengths lie in the simplicity of its approach: by using passive design principles, providing excellent thermal performance, as well as an exceptional airtightness with mechanical ventilation and heat recovery (MVHR). The low space heating demand of Passivhaus buildings ( $\leq 15\text{kWh/m}^2.\text{yr}$ ) and capped Primary Energy demand ( $\leq 120\text{kWh/m}^2.\text{yr}$ ) means that annual energy costs are reduced by approximately a factor of 5 compared to current UK practice.

Moreover, research accounting for all emissions suggests that even deeper GHG cuts, in the region of 90%, are required by 2050 in order to prevent the consequences of irreversible climate change (Bows, 2006; Forrest, 2005). Set against these overarching reduction targets are proposals to build up to 240,000 new homes per year in order to address current housing shortages and upgrade the existing stock (DCLG, 2007c). Achieving CO<sub>2</sub> emission cuts of 80-90 % from the total stock by 2050 represents an enormous technological and logistical challenge. Historically low rates of demolition and replacement of the UK housing stock means that the majority of new dwellings

create additional stock that adds to the problem. By 2050 it is estimated that there could be as many as 23% (Boardman, 2007) to 40% (DECC, 2010a) more households in the UK. It is evident therefore that any new buildings will need to go well beyond operational zero carbon in order to make a positive contribution to reducing net GHG emissions over the 1990's baseline.

## **2. Background – why a new definition of Zero Carbon?**

The original definition of 'zero carbon' homes was established in the UK in December 2006 when The Code for Sustainable Homes (CSH) was introduced as a voluntary six-tiered sustainability rating system leading to Code Level 6 or a 'zero carbon home' (DCLG, 2006b). The original definition stated that: "Net carbon dioxide emissions from *all* energy used in the dwelling are zero or better". In addition, a 'zero carbon home' is also required to have a Heat Loss Parameter (covering walls, windows, air tightness and other building design issues) of 0.8W/m<sup>2</sup>K or less, as well as net zero carbon dioxide emissions from use of appliances in the homes (i.e. on average over a year)" (DCLG, 2006b).

In July 2007, the Government issued a policy statement which reiterated that: "zero carbon means that, over a year, the net carbon emissions from all energy use in the home would be zero" (DCLG, 2007a). However, by December 2008 the Department for Communities and Local Government (CLG) had initiated a new consultation process on the definition of zero carbon homes. This consultation was purportedly in response to uncertainty over the existing definition and concerns from the construction industry regarding the workability of the definition (ZCH, 2009a). One of the main participants in this process, the UK Green Building Council (UKGBC), is cited by the ZCH as stating that the existing zero carbon definition (based on Level 6 of the Code for Sustainable Homes) would be unattainable for as many as 80% of new homes (ZCH, 2009a). This information is presented slightly differently in the UKGBC Task Group Report, which states that: "According to all the available evidence, anywhere from 10% to 80% of new homes may not be able to meet the current definition of zero carbon" (UK Green Building Council, 2010).

Paradoxically the supporting evidence for these statements is largely based on a report produced for the Renewables Advisory Board (RAB) entitled 'The Role of Onsite Energy Generation in Delivering Zero Carbon Homes' which was published in November 2007 (UK Green Building Council, 2010). According to RAB the main findings of the report are extremely positive with respect to onsite renewable energy generation for Zero Carbon Homes in the UK. As a result RAB (2007) recommended to the Government that they bring forward delivery of the zero carbon policy by creating an even earlier target, in advance of 2016, via the planning system. Furthermore RAB advised that the zero carbon homes policy should "minimise the use of remote offsite energy generation in meeting zero carbon standards e.g. by setting a tight cap on its use and a high 'buy-out' cost for any offsite generation fund" (BERR, 2007). Such recommendations run counter

to the UKGBC and ZCH interpretations of the same report. These conflicting interpretations suggest that economic considerations in the building industry might be a greater determinant to the revised definition of zero carbon than the technical limitations of the renewable energy industry.

Nonetheless on dense urban sites several studies have suggested that it can be both technically challenging and expensive to achieve the original zero carbon definition (DCLG, 2008). According to CLG: “If the definition of zero carbon is too rigid (such as requiring all renewable energy to be onsite) or too costly, it could potentially prejudice smaller urban brownfield developments in favour of larger greenfield sites because larger sites offer greater economies of scale in energy supply technologies” (DCLG, 2008). It is clear that a robust zero carbon policy should not jeopardize wider environmental and social concerns, including preservation of biodiversity and agricultural land, minimization of urban sprawl and carbon emissions from transport, whilst providing good access to community infrastructure.

Evidence that such challenges can be coherently addressed on a large scale is documented in the European Energy Cities project (Energy Cities, 2012a). European case studies of successfully implemented large scale zero carbon developments include: the German Kronsberg scheme with 6000 Passivhaus dwellings proposed for 15,000 people relying mainly on solar and wind energy (Energy Cities, 2012b); the Vauban district, located on a former French barrack site with all buildings meeting the Passivhaus standard (Energy Cities, 2012c); or a recently completed district close to Stockholm, Sweden providing 10,000 apartments for 25,000 inhabitants using 100% renewable energy (RE) systems (Energy Cities EU, 2012d).

In addition to the avoidance of perverse consequences, the current economic downturn is undoubtedly a factor influencing UK zero carbon policy. Direct acknowledgment that financial pressures on major house builders are influencing the UK’s Zero Carbon policy, came from the former Minister of Housing and Planning. In her forward to the CLG 2008 Zero Carbon Definition consultation document, Margaret Beckett (Minister for Housing and Planning in 2008) admitted that ‘the house building industry is facing very difficult conditions,’ but at the same time cautioned: “Yet it is critical that we don’t lose sight of our longer term responsibilities. A failure to invest in reducing climate change now would be disastrous for future generations” (DCLG, 2008).

### **3. The role of the Passivhaus standard in UK climate change and energy targets**

Attempts to quantify the carbon savings achievable by zero carbon homes in the UK have arrived at some ambiguous findings. According to the Energy White Paper (2007) overall carbon reductions from energy efficiency in the residential sector are predicted to be between 4.7 – 7.6 MtC by 2020 relative to a 2006 baseline of 40 MtC (DTI, 2007).

When compared to the 1990 baseline, as used by the UK Climate Change Act, this represents a reduction of only 11 – 18% by 2020 (Boardman, 2007), far short of the 40% reduction needed to follow the trajectory to an 80% GHG emissions reduction by 2050. According to the Energy White Paper zero carbon homes will contribute to saving 1.1 to 1.2 MtC by 2020 (over 2006 levels) however it is notable that this estimate is based upon the original (2007) definition of a zero carbon home (DTI, 2008). Viewed on a meta scale, recent modelling by the Department of Energy and Climate Change (DECC) illustrates that the implementation of an advanced energy efficiency standard (such as the Passivhaus standard - Level 4) is the only approach that leads to a long term reduction in the total domestic heating demand.

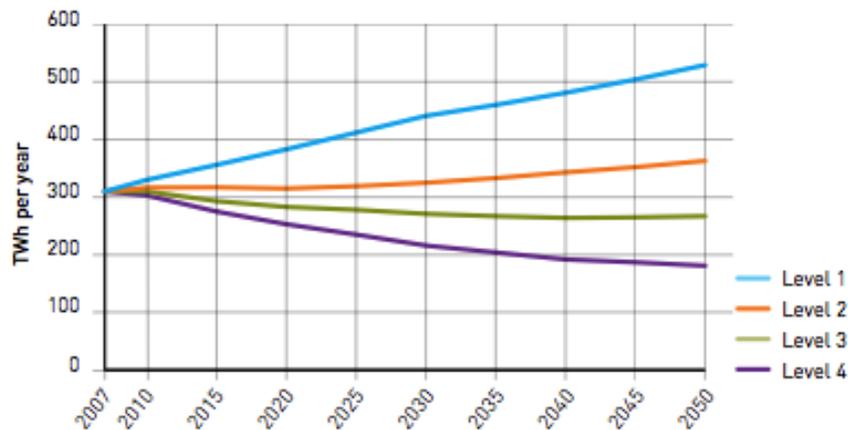


Figure 1: Trajectories for total domestic heat demand under four levels of change in the UK (DECC, 2010a)

Given that the scenario modelled as Level 4 (Passivhaus) requires a contiguous roll out of extensive refurbishment measures to 96% of the existing stock, and an accompanying drop in the average heating set point to 16°C there appears to be no margin to construct new build dwellings to a more lax standard (DECC, 2010). When the projected growth in domestic cooling demand is also considered the importance of adopting the Passivhaus standard becomes even more apparent.

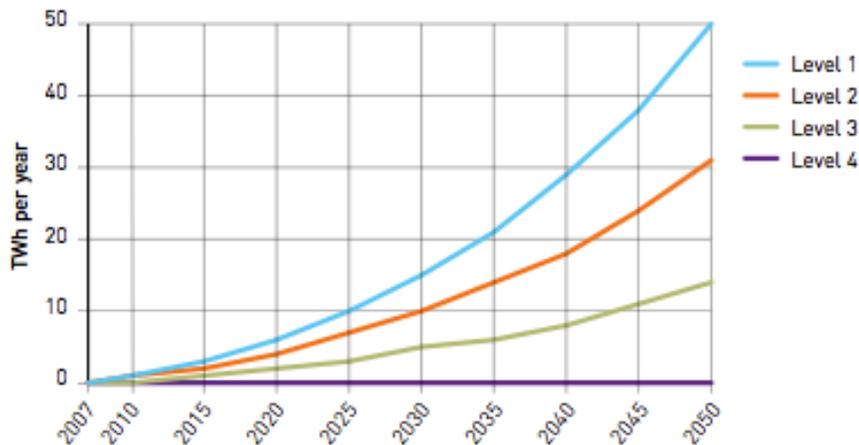


Figure 2: Trajectories for total domestic cooling demand under four levels of change (DECC, 2010a)

The growth in domestic cooling demand forecast to occur by 2050 (Figure 2) could place an additional 50 TWh burden (DECC, 2010a) on the net climate change impacts of the UK dwelling stock, a fact which appears to have been entirely overlooked by the ZCH energy efficiency proposals. According to the recast EPBD (2010) “the methodology for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building. That methodology should take into account existing European standards” (EC, 2010). When total annual energy performance is considered the DECC modelling shows that only the Passivhaus (Level 4) scenario delivers a net overall decrease in heating, cooling and hot water energy demand (DECC, 2010a).

These findings are in agreement with a German study of national emissions reductions scenarios in the built environment (Vallentin, 2009) based upon atmospheric stabilisation in accordance with the Contraction and Convergence (C&C<sub>2050</sub>) model. The C&C mechanism provides a simple and scalable means of implementing GHG emission pathways based on the principle of an equitable per capita distribution of emission rights (Meyer 2000). The C&C model involves a transitional phase in order to achieve convergence on equal per capita emissions in a structured manner. Vallentin’s research has relevance to the UK context since Germany has similar levels of CO<sub>2</sub> emissions per capita to the UK and a parallel trajectory of emission reductions of 40% by 2020 and 80% by 2050. According to his emissions trajectory analysis of the built environment the total primary energy consumption for domestic heating, ventilation, hot water and appliances should be no greater than 100kWh/m<sup>2</sup><sub>TFA</sub>.yr in 2010, and will need to fall progressively to ≤60kWh/m<sup>2</sup><sub>TFA</sub>.yr by 2050 (Vallentin, 2009). In order to meet this stabilization trajectory, Vallentin concluded that: “By 2015 the Passivhaus standard must be applied to all new buildings, and Passivhaus components must be made mandatory in renovation projects” (2009). This view is endorsed by the European Parliament resolution on an Action Plan for Energy Efficiency which called on the EC to ‘propose a binding requirement that all new buildings needing to be heated and/or cooled be constructed to passive house or equivalent non-residential standards from 2011 onwards’ (EC, 2008).

#### **4. The UK Government’s revised approach to zero carbon**

Uncertainty over the existing definition of ‘zero carbon’ and concerns from the construction industry regarding the workability of the definition are cited as the main drivers for a revised definition (ZCH, 2009a). During the 2008 consultation the Government set out their preferred hierarchy for the delivery of Zero Carbon homes in the UK. This tiered approach of progressive solutions was, according to the Government, predicated upon the principle that ‘very high standards of energy efficiency’ should form the basis of this policy (DCLG, 2008). This was followed by on-

site renewables and direct connected district heating solutions forming the second tier. Where the new policy differs from the previous definition is in the inclusion of a third tier based on cost capped 'allowable solutions' (Figure 3).

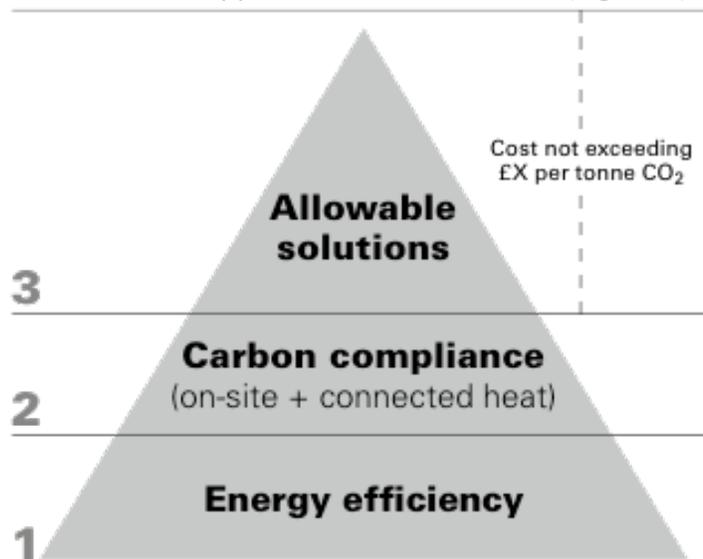


Figure 3: UK government's preferred hierarchy - showing carbon offset measures (CLG, 2008)

Although the Government's Energy Hierarchy appears to be based upon prioritising energy efficiency (Figure 3) the introduction of allowable solutions has effectively introduced a buyout clause. Depending upon what level of Carbon Compliance is finally adopted market based 'allowable solutions' could comprise the majority of the net carbon savings from a 'zero carbon' home. The introduction of 'allowable solutions' was strongly welcomed by the ZCH since "rather than placing reliance solely on the development itself (through energy efficiency and on-site renewable energy) to deliver zero carbon, a range of additional, mostly off-site solutions, would be made available to developers in the new definition" (ZCH, 2009a).

The UK Green Building Council (UKGBC) initially proposed an alternative approach to the concept of 'allowable solutions' based on the concept of a Community Energy Fund. In theory such a concept could have been used to create a relatively simple fiscal mechanism to directly fund off-site carbon savings via regional investment in new large and medium scale renewables infrastructure. The proposal was rejected by CLG however who stated that the Government was not proposing to take forward the concept of a buyout fund (DCLG, 2008).

Under the revised definition of 'zero carbon', the national minimum energy efficiency specification for zero carbon homes becomes all important. This is because it effectively defines the minimum construction quality and energy efficiency as well as the climate change adaptation and the mitigation potential of the UK's future housing stock. The level at which this energy efficiency standard in new buildings is set also

determines the requirement for on site renewables energy and the subsequent volume of allowable solutions (or carbon offsetting) needed to make these buildings zero carbon.

## **5. Overview of the revised approach proposed by the Zero Carbon Hub and CLG**

### **5.1 ZCH Background**

The ZCH was formed as an initiative of the National House Building Council (NHBC) Foundation in 2008 under the premise of “facilitating the mainstream delivery of low and zero carbon homes” (ZCH, 2009a). In response to the Government’s consultation on a revised definition of ‘Zero Carbon’ in December 2008, the ZCH convened a series of meetings across the UK in order to gauge the opinion of industry stakeholders. These meetings were held in parallel with a formal consultation carried out by the Department for Communities and Local Government (CLG). During the ZCH consultation meetings, a series of pre-formulated questions were put to over 500 industry stakeholders; the response to these questions formed the basis of the ZCH ‘Have Your Say’ (2009) report. Based on this industry consultation process the ‘Have Your Say’ report (ZCH, 2009a) presented a series of findings and recommendations many of which differ significantly from the original working definition of ‘Zero Carbon’ (DCLG, 2007b).

The ZCH proposals represent a methodological shift from the approach set forth in strategic UK housing reports such as the ‘40% House Report’ (Boardman et al., 2005), the ‘Home Truths’ report (Boardman, 2007) and well documented European approaches to Zero – Energy homes (Voss, 2008). What is most striking about the ZCH recommendations is that despite the increased severity of recent findings on climate science (Pope et al., 2010; Bows et al., 2006; IPCC, 2007) the ZCH have effectively advocated a significant *slackening* of the key energy efficiency parameters required to achieve a ‘Zero Carbon’ dwelling compared to the original definition (DCLG, 2007b).

The question remains whether such an approach is fully consistent with the energy efficiency and carbon reduction targets set out in the UK Climate Change Act (Climate Change Act, 2008), zero-carbon building policies set out in the EU Energy Performance in Buildings Directive (EPBD) and current peer reviewed scientific research. Addressing these issues is fundamental to the successful delivery of legally binding national and international GHG reduction measures. Implementing a revised definition of ‘zero carbon’ that introduces the concept of carbon offsetting to the built environment raises a number of critical uncertainties. The choice of methodological approach, the definition of boundaries used in the reporting of emissions, and ultimately the efficacy of the chosen policy approach in responding to climate change must all be evaluated.

### **5.2 Key Recommendations of the ZCH**

Carbon compliance was a key issue in the CLG consultation on the revised definition of Zero Carbon (HM Government, 2008). On the issue of where the revised carbon

compliance threshold should be set, the ZCH (2009) report concluded that most of the industry participants surveyed favoured a 70% CO<sub>2</sub> compliance target (relative to Part L 2006 levels) (ZCH, 2009a). Based on the assumption that Part L 2006 methodology already omits between one third (Reason and Olivier, 2006), and a half (DCLG, 2007a) of the total CO<sub>2</sub> emissions from a dwelling then a 70% compliance target would imply an actual reduction of 35 - 46% of the dwellings total operational emissions. In other words under such a revised definition more than half of the carbon compliance measures currently required to achieve a 'true zero carbon dwelling' would be permitted to be offset by 'allowable solutions'.

Evidence that the UK government were eager to adopt the ZCH's revised definition of zero carbon was provided in a Ministerial Statement presented by the Housing Minister John Healey in July 2009 (Healey, 2009). Although the definition of an 'allowable solution' has not yet been fully established by CLG, a number of proposals have been put forward in order to gauge the acceptability of the new mechanisms for delivering the revised definition of zero carbon. These solutions were voted upon during the ZCH 'Have Your Say' consultation (ZCH, 2009a) and the results are illustrated in Table 1, below:

Table 1: ZCH Hierarchy of Allowable Solutions and Implementation Potential (ZCH, 2009a)

<b>'Allowable Solution'</b>	<b>Who voted for inclusion? (%)</b>	<b>Potential for implementation*</b>
Energy efficient appliances and controls	82	0.70
Continuing carbon compliance	81	0.73
Off-site renewable – direct connection	74	0.50
Section 106 credit for LZC infrastructure	69	0.57
Improving existing stock fabric	65	0.52
Investment in off-site renewables	65	0.48
Export of LZC heat to existing stock	61	0.36

\*Potential for implementation was ranked on a scale from 0 to 1; where 1.00= high potential and 0.00= no potential

Based on the highest ranking percentage of those in favour of a given solution combined with the potential for implementation of the solution, it appears likely that 'energy efficient appliances and controls' and 'continuing carbon compliance' will feature amongst the 'allowable solutions'. Although not elaborated in significant detail in the ZCH consultation document, it was stated that delegates raised significant concerns over the complexity of some of the 'Allowable Solutions' (ZCH, 2009a).

### 5.3 Implications of the ZCH and CLG recommendations

In order to understand the wider implications of the Government's hierarchy (Figure 3) it is important to understand the framework boundaries and the uncertainties associated with each tier. The hierarchy can be considered robust in the context of addressing climate change abatement targets if it achieves the requisite GHG emission

reductions in an appropriate time step as set out in Meyer (2000) and the Climate Change Act (2008). Besides the discrepancy associated with individual calculation methodologies (for instance how the space heating demand is calculated by PHPP or SAP), there is often a marked difference between what building energy models (NES, 2005) (Bordass et al, 2004) (Norford, 1994) and carbon offsetting reports (Kill et al, 2010) (Haya, 2009) predict and the reality of what is achieved. Hence, consideration not only of the uncertainty associated with predictive models but also potential weaknesses in the overall quality assurance system is central to the final outcome.

### 5.3.1 Framework boundaries and omissions

The revised 'zero carbon' definition, as set out in the 'Have Your Say' report (ZCH, 2009) and confirmed in the Budget 2011 (HM Treasury 2011), suggests that a significant reduction in the overall scale of the new build housing sector's emissions is possible whilst omitting two key sources of GHG emissions. Under the revised definition the appliance energy consumption, that may account for up to 50% (DCLG, 2007a) of the operational emissions from a dwelling; and the emissions released during the manufacture and construction the building, which may account for up to 50% of the net 80 year emissions from an ultra-low energy dwelling (McLeod, 2007), are ignored. Therefore the actual definition does not accord with the emissions that will be registered in the atmosphere

Whilst the truncation of these emissions from the revised 'zero carbon' homes definition may lead to cheaper forms of 'compliance' in the short term; a real question remains as to the efficacy of this approach in the delivery of long term carbon reduction strategies. Sectoral boundaries must be carefully defined and adhered to if real world emission reductions are to play a coherent role in national GHG inventory reporting; wherein the sum of the sectoral emissions must accord with the national target.

Whilst domestic appliances are typically powered by electricity that could theoretically be supplied by large scale renewable sources elsewhere, the UK currently generates only 7% of its electricity from renewable sources (DECC, 2010b). Considering (i) the replacement time of national energy infrastructure, (ii) increasing UK domestic electricity demand (DECC, 2010c) and (iii) the urgency of climate change abatement measures (Bows et al., 2006; Pope et al., 2010), it seems prudent that viable domestic scale renewable energy (RE) production should continue to be incentivised.

There is currently no UK energy performance standard that makes detailed reference to the embodied energy or embodied carbon emissions from a building. Research on embodied energy in Passivhaus and low energy buildings by McLeod (2007), Lazarus (2004) and Marsh (2004) suggests that embodied energy and embodied carbon typically account for between 30 and 50% of the net 80 year lifecycle CO<sub>2</sub> emissions from a Passivhaus standard dwelling depending on the construction type and heating system used. McLeod (2007) determined that up to 50 tonnes of embodied CO<sub>2</sub>

emissions could be avoided from the construction of a single 70m<sup>2</sup> terraced Passivhaus if conventional masonry materials were replaced with locally sourced biomaterials. According to Monahan and Powell (2009) the embodied carbon consequences of building 3 million new homes could range between 110 and 167 MtCO<sub>2</sub> depending on the proportions of all timber to traditional masonry construction used.

Despite the potential magnitude for energy and emissions savings through carbon optimised construction there is no mention of embodied energy or the role which building materials play in the revised Zero Carbon definition. In practice, embodied emissions can be readily quantified and there is at least one documented precedent of embodied energy savings being considered as an acceptable means of exemption from the renewable energy requirement imposed under UK Planning Policy Statement (PPS) 22 (Waugh et al., 2009). Despite the magnitude of these implications the inclusion of a robust life cycle assessment methodology appears one step beyond the current 'zero carbon' debate in the UK, for this reason further discussion of these important issues has been left for a future paper.

#### 5.3.2 'Allowable solutions' and carbon offsetting

The concept of 'allowable solutions' is effectively a form of carbon offsetting. The economic rationale behind this approach is that emission reductions can be made at the least capital expenditure, thus maximising the short term economic benefit to industry (Kill et al, 2010). This type of indirect carbon reduction strategy has the fundamental weakness that it does not directly address the source of the problem and as such is vulnerable to the issues which affect carbon offset mechanisms in general.

For example, accounting for the emissions from the use of domestic appliances is excluded from the revised 'zero carbon' definition (HM Treasury, 2011; however the use of 'energy efficient appliances and controls' achieves a high ranking on the ZCH hierarchy of preferred 'allowable solutions' (Table 1). This is an example of emissions occurring outside the regulatory framework being used to offset emissions occurring within the regulatory framework; despite both emissions occurring within the same physical system (the dwelling).

As with most forms of carbon offsetting, the use of 'allowable solutions' contains two inherent vulnerabilities, (i) additionality and (ii) permanence, which will be explained in the following: Allocating carbon credits for emission reductions that may have occurred anyway, is a problem common to many offsetting schemes and is referred to as 'non- additionality' (i.e., the carbon offsetting did not create additional carbon savings relatively to what would have happened anyway). It is possible that the overall emissions may even increase in the situation where emission reductions are falsely justified with the help of carbon offsetting strategies as explained in Granda (2005, p.59).

Several studies have shown that a significant percentage of offset credits awarded under the Clean Development Mechanism (CDM), the mechanism for generating offset credits for countries with reduction commitments under the Kyoto Protocol, were not actually additional (Schneider, 2007; Müller, 2009; Haya, 2009). Although this increase or 'additionality' is central to the concept of carbon offsetting, the Carbon Trust has stated that it can never be scientifically proven (2008).

The second issue affecting the durability of carbon offsetting is what is referred to as 'permanence'. Even if the carbon offsets are truly additional, there is the risk of reversal over time. If the offset mechanisms that are justifying the emissions elsewhere are not permanent, then potentially the atmosphere could receive two sets of emissions: firstly, from the original emissions being offset, and secondly, when the offset mechanism reverts to being an emission relative to the notional baseline. Most appliances have inherently short lifespans (Seiders et al, 2007) and without on-going monitoring there is no guarantee that the 'allowable solution' will actually endure the period for which the offset carbon credit has been claimed. In this context reversal could occur if, for example, a low energy appliance was subsequently sold or replaced with a higher-energy consuming appliance, relative to the baseline emission rate.

In contrast to many appliances and small LZC technologies, which are unlikely to last beyond 10 -20 years (Phillips et al, 2007; Seiders et al, 2007), fabric measures implemented via quality assured design approaches such as the Passivhaus standard are likely to achieve carbon savings that will exceed 60 or even 100 years (BLP, 2007). Such large differences in the permanence of 'allowable solutions' raises further questions regarding how the weighting, monitoring and validation of short term solutions should be dealt with. For the analysis in the impact assessment study which CLG commissioned, it was assumed that only 30 years of residential emissions would need to be covered via an 'allowable solution' (DCLG, 2008). Unless the carbon credit awarded for such short-term 'allowable solutions' is down weighted in proportion to their anticipated life spans this approach is likely to perversely disincentivise long term 'fabric first' approaches to carbon compliance.

According to Kill et al. (2010), most forms of carbon offsetting, are inherently complex to implement and monitor, and the 'allowable solutions' so far proposed are unlikely to be an exception to this. It has been argued that such mechanisms may actually undermine the evolution of coherent sustainability policies by simply allowing the leakage of emissions from one sector to another (Haya, 2009). In practice, there are also many limitations on whether offsets can actually deliver least cost solutions. Both, in the built environment and in the wider response to climate change there is a growing body of evidence suggesting that carbon trading and offsetting does not lead to emission reductions (Müller, 2009; Bullock et al., 2009). If 'allowable solutions' look unlikely to deliver least cost solutions (viewed over the medium to long term) the question remains as to why higher levels of carbon compliance at source, such as the Passivhaus standard, are not being mandated.

### 5.3.3 Continuing carbon compliance

Continuing carbon compliance refers to the voluntary use of an improved building fabric specification or the use of additional onsite Low and Zero Carbon Technologies (LZCT) that would gain benefit in reducing the Dwelling Emission Rate (DER) used in the UK Standard Assessment Procedure (SAP) calculation. Continuing carbon compliance in this sense can be seen as providing credit for steps back towards the original definition of Zero Carbon. In theory such measures are reasonably robust since they can be quantified at the design stage and verified on site by Building Control and do not incur the risks of non-additionality associated with the use of energy efficient appliances or more remote offset measures.

Fabric measures are likely to considerably outlast the lifespan of most LZCT's and should therefore be prioritised to the maximum extent attainable. Since the permanence of emission reductions is integral to achieving deep long term emission cuts, the weighting of improved fabric efficiency measures demands further consideration. Conversely localised climatic factors, poor installation or commissioning pose danger of credit being given for LZT technologies that do not perform as well onsite as theoretical predictions might suggest. Guaranteeing continuing carbon compliance in such cases should require on-going in situ performance verification.

### 5.3.4 The energy efficiency targets

Following the 'Have Your Say' (2009) consultation, the ZCH convened an Energy Efficiency Task Force to investigate the minimum level of energy efficiency that would be required to partially fulfil the 70% Carbon Compliance target. Despite choosing a clear metric from which to define the energy efficiency of the space heating requirement (kWh/m<sup>2</sup>.yr) the actual levels proposed by the ZCH for the specific space heating demand (SHD) of a Zero Carbon dwelling appear to be remarkably high. Two different maximum levels of space heating have been proposed by the ZCH according to the dwelling type: multi residential and mid terraced properties are set at 39 kWh/m<sup>2</sup>.yr; whilst end of terrace, semi-detached and detached dwellings are set at 46 kWh/m<sup>2</sup>.yr (Figure 4) (ZCH, 2009b). These figures are based on the UK SAP methodology minus internal domestic hot water (DHW) gains (ZCH, 2009b). Collectively these energy efficiency standards are referred to as the Fabric Energy Efficiency Standard (FEES).

According to the ZCH task group report, the rationale behind this two tiered approach is that it allows a similar fabric specification to meet the target across the different building typologies (ZCH, 2009b). Given that the performance of low energy buildings is predicated upon a wide number of factors, including orientation, form and micro climate, this logic appears rather simplistic. It is hypothesised that this two tiered

policy, may serve to financially incentivise the continued construction of thermally inefficient detached dwelling formats.

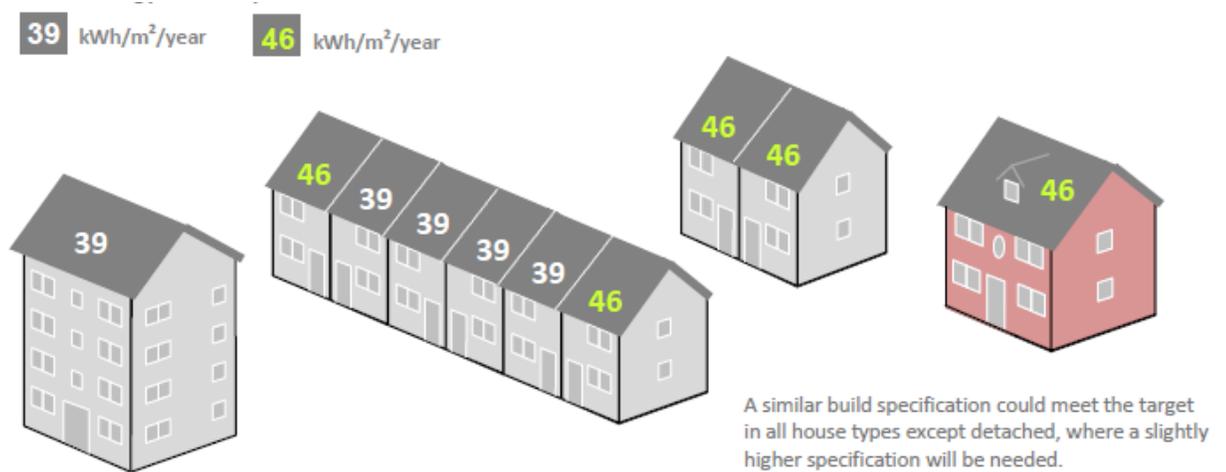


Figure 4: Fabric Energy Efficiency Standard (FEES) levels proposed in the ZCH Standard (ZCH, 2009b)

Despite terraced and semi-detached houses constituting the majority (56%) of the existing UK housing stock (Shorrock and Utley, 2003), more detached houses have been built in the UK since the 1980's than any other dwelling format (Hick and Allen, 1999). Private purchasers continue to demonstrate a clear preference for larger than average living spaces when able to afford them (Boardman et al., 2005). Given the additional build cost involved in building to a zero carbon specification, the demand for detached and semi-detached dwellings driven by more affluent private home buyers is likely to continue. Continuation of this trend suggests it is probable that the majority of the next generation of UK 'zero carbon' dwellings could have a specific heat demand (SHD) in the region of 46 kWh/m<sup>2</sup>.yr or even higher if modelled in PHPP (due to lower internal gains assumed in the calculation).

## 6. Analysis and implications

According to the ZCH Energy Efficiency task force report, the proposed standard "equates to around a 20-25% reduction in carbon dioxide emissions compared to current Part L 2006 compliance" (ZCH, 2009c). In other words, if the ZCH recommendations are implemented many of the nations' future 'Zero Carbon' dwellings may perform little better than buildings currently being constructed to comply with the legal minimum standards permitted by Part L (2010) of the UK Building Regulations. The percentage growth in new households in the UK by 2050 is anticipated to be greater (Boardman, 2007; DECC, 2010a) than the percentage savings achieved by the FEES energy efficiency standards. Accounting for stock expansion means that the net contribution of the new energy efficiency standards to national GHG abatement targets is likely to be negative. If the anticipated 50% growth in the

rate of UK domestic hot water consumption and growth in cooling demand (DECC, 2010a) is also factored into this equation then it is highly unlikely that the FEES standards can make a contribution to the UK climate change abatement targets.

In contrast to the proposed FEES standard the German Passivhaus standard achieves at least threefold better levels of fabric energy efficiency (Figure 5) by limiting the maximum specific SHD to less than  $15\text{kWh}/\text{m}^2_{\text{TFA}}\cdot\text{yr}$  and further limiting the total primary energy consumption to  $120\text{kWh}/\text{m}^2_{\text{TFA}}\cdot\text{yr}$  (Feist, 2007). It should be noted that there are inherent inaccuracies when attempting to directly compare predicted SHD calculated according to SAP methodology and those determined using the Passive House Planning Package (PHPP), which is the accepted software for demonstrating compliance with the Passivhaus standard. The SHD determined by the Passivhaus standard generally follows the EN13790 methodology (Feist, 2007) but is based upon far lower internal gain assumptions and different climatic datasets than the UK SAP methodology, making direct comparisons invalid. As a result of the significantly higher internal gains assumptions used in SAP (which are approximately three times higher in SAP (Henderson, 2009) compared to the  $2.1\text{ W}/\text{m}^2$  used in PHPP (AECB, 2009); the SHD predictions in SAP will appear artificially low when compared to PHPP. This situation is further amplified by a number of other modelling conventions including the methodology used to determine the Treated Floor Area (TFA) in PHPP (Hopfe and McLeod, 2010) which tends to underestimate the treated floor area resulting in a higher SHD relative to SAP (Clarke, 2008) .

The magnitude of these different methodological assumptions in skewing valid comparison of the results in the context of Passivhaus and ultra-low energy buildings can be easily demonstrated. Assuming for example a notional Passivhaus dwelling based in mid England such as Manchester then a  $4\text{W}/\text{m}^2$  increase in useful internal gains would - assuming a 100% utilisation factor over the heating season - reduce the effective SHD by as much as  $(4\text{ W}/\text{m}^2 \times 205\text{days}/\text{yr} \times 0.024\text{ kh}/\text{day} = 19.7\text{ kWh}/\text{m}^2\cdot\text{yr})$  (McLeod et al., 2010). The predicted SHD of dwellings approaching the Passivhaus energy standard is therefore highly sensitive to the internal gains assumptions. As UK lighting, appliances and hot water systems become more efficient, there will be less 'free' heat available and the benefits of higher fabric performance specifications and highly efficient MVHR systems will become more pronounced.

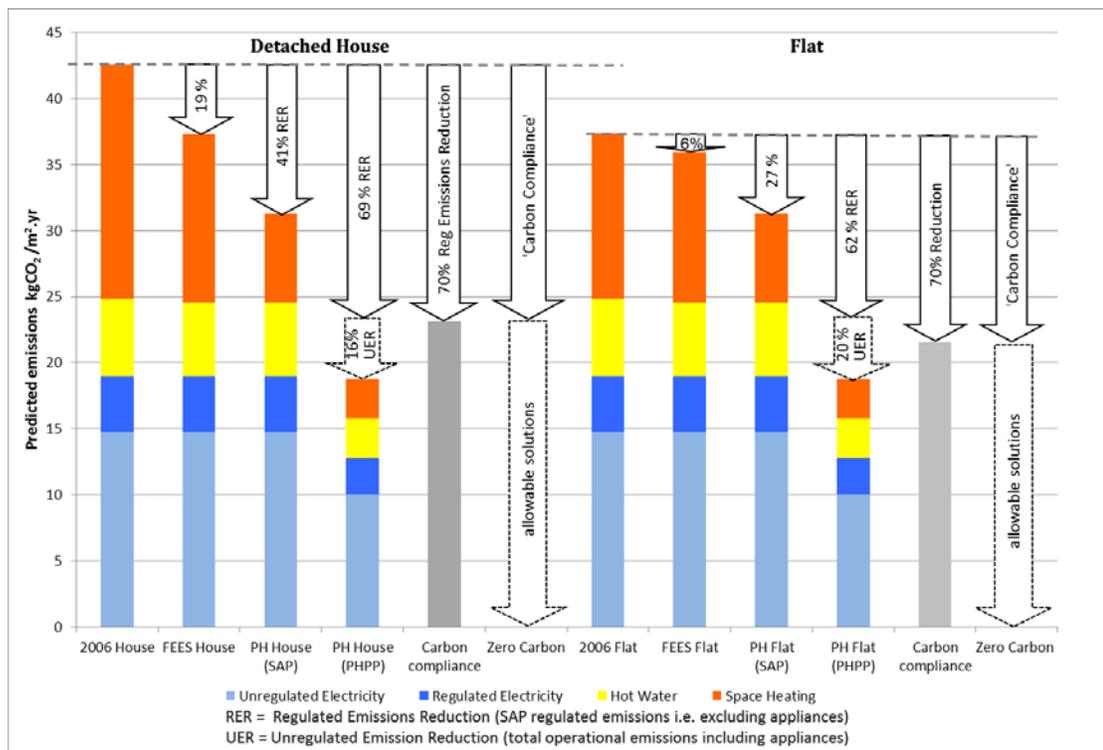
For comparative purposes it is possible to attempt to normalize the internal gain assumptions of SAP models to the level of those permitted by PHPP<sup>i</sup>. Using this approach an indication of the scale of the operational carbon emission reductions required by the ZCH framework to achieve 'carbon compliance' and 'zero carbon', for two different dwellings standards (FEES and Passivhaus), relative to the Part L (06) baseline is illustrated in Figure 5. By comparing the Passivhaus and FEES SHD's on a

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<sup>i</sup> More precise comparisons would require parametric modelling using a common model with realistic internal gains assumptions for each standard across a range of climatic locations

normalised 'like for like' internal gains basis it can be shown that significant potential gains in energy efficiency and corresponding reductions in carbon emissions (circa 40%) will be lost by the adoption of the weaker FEES standard.

The additional unregulated energy savings that would be achieved by the Passivhaus standard as a result of the inclusion of a primary energy limit (using representative data from the Camden, London Passivhaus (Camden Passivhaus, 2010)) was included as scenario PH (PHPP) and included in Figure 5. The Baseline data for this figure is taken from the ZCH 'Defining a Fabric Energy Efficiency Standard' report (2009c) with the SHD of the dwellings normalised in accordance with internal gains as described above and with the exclusion of DHW gains as per the ZCH report (ZCH,2009c, p 65).



† assumes gas used for heating and hot water, electricity for lighting and appliances using SAP 2006 emissions factors Gas 0.194 kgCO<sub>2</sub>/kWh, electricity 0.422 kgCO<sub>2</sub>/kWh

Figure 5: Indicative CO<sub>2</sub> emission reductions for different performance standards – with internal gains normalised to PHPP levels.

When the SAP outputs are normalised to account for the reduced PHPP internal gains assumptions, the magnitude of the regulated emissions reductions in the Passivhaus dwellings falls only marginally short of the 70% Carbon Compliance level. If the TFA was also normalised for parity with PHPP the projected savings would be even greater. It should be noted that a significant additional reduction in unregulated emissions (16%) in the Passivhaus modelled has also been achieved as a result of the PHPP primary energy limit. Therefore when viewed in context the use of the Passivhaus standard (when correctly modelled in PHPP) results in approximately a 56% further reduction in

net operational carbon emissions relative to the FEES standard for a detached house and a 76% reduction for a flat. In both cases the combined (regulated and unregulated emissions) reductions would significantly exceed the actual carbon savings required to meet a 70% 'Carbon Compliance' target.

#### 6.1 Resistance to adopting the Passivhaus standard

In an independent report published in May 2009, The Energy Saving Trust (EST) investigated the suitability of the proposed energy efficiency metrics to be used in the revised Zero Carbon definition. The EST report primarily focused upon evaluating a number of different energy efficiency metrics whilst also investigating the level at which the SHD (kWh/m<sup>2</sup>.yr) should be set. Despite concurring with the ZCH task force report regarding the use of the kWh/m<sup>2</sup>.yr metric, the EST report proposed that the limit to the SHD was set to a level between 15 and 25 kWh/m<sup>2</sup>.yr; with adjustment occurring to take account of the building form (Hodgson, 2009).

Justification given by the ZCH task force for dismissing the Passivhaus standard and the Energy Savings Trust Advanced Practice Standard in favour of significantly weaker standards of energy efficiency are presented in the full report from the Energy Efficiency Task Group (ZCH, 2009b). Notably the comparative analysis of the energy performance standards presented in this report appears to overestimate the SHD of the Passivhaus (Spec D), suggesting that it would result in a SHD between 23 and 29 kWh/m<sup>2</sup>.yr when modelled in SAP (ZCH, 2009b, p66).

When the ZCH consultees were asked to express an opinion on the buildability of Passivhaus the outcome was divided: "One being that the Passivhaus range of performance (Spec D) represented the 'level' of ambition required and that the resulting construction specifications were indeed buildable (...). Whilst 47% of people had serious concerns about the buildability of Specification D (Passivhaus) at mass scale in 2016" (ZCH, 2009b p. 39). The survey size and relevant experience of the 47% who expressed serious concerns about the buildability of Passivhaus dwellings on a mass scale is not given. However, the report itself acknowledges that the audience "did not see themselves as experts and many underestimated significantly the challenge of zero carbon" (ZCH, 2009a, p13).

Under prediction of the energy savings potential, combined with uncertainty regarding the buildability of the Passivhaus concept, appear to be key barriers to its widespread adoption.

#### **6.2 Preconceptions with respect to Mechanical Ventilation and Indoor Air Quality (IAQ)**

A second major concern outlined by the ZCH as a barrier to adopting Passivhaus standards of energy efficiency was the issue of Indoor Air Quality (IAQ) associated with air tight dwellings reliant upon mechanical ventilation systems. The ZCH report states that "there is currently a lack of detailed understanding across industry in this area"

and concludes that “the link between reduced air permeability and suitable ventilation systems requires increased levels of monitoring and technical research” (ZCH, 2009b).

Contrary to the ZCH findings there is a growing body of post-occupancy research studies correlating improved IAQ and occupant wellbeing in both, domestic and non-domestic low energy buildings ventilated by means of mechanical ventilation (MV) systems. Snijders et al (2001) found that dedicated ventilation systems may slow down the development of Chronic Obstructive Pulmonary Disease (COPD) and prolong the independence of those affected by the condition. Whilst Harving et al (1994) demonstrated that the number of allergen producing dust mites and fungi in buildings was reduced by low indoor RH levels induced by a suitable ventilation system.

The vast majority of post occupancy studies concerning Passivhaus dwellings show that consistently high levels of occupant satisfaction and very good IAQ levels are typically reported in dwellings served by whole house MVHR systems (Feist et al., 2001; Feist et al., 2005; Brunsgard and Jensen, 2008; Larsen and Jensen 2009). Similar findings have also been confirmed in MVHR ventilated Passivhaus schools, a context characterised by high occupant densities typically necessitating higher rates of ventilation air changes as a result (Bretzke, 2010).

In 2009, the NHBC commissioned a well referenced review of the international literature on IAQ and ventilation systems. This report provides significant evidence of the IAQ and user satisfaction of properly commissioned whole house MVHR systems when installed in low energy dwellings (Crump et al., 2009). One example of such a low energy standard is the Canadian R-2000™ which is an energy performance standard approaching Passivhaus performance levels where whole house MVHR is required. It is significant that the National Building Code of Canada has for the past 20 years permitted ventilation systems in such dwellings to be sized to mechanically deliver supply air at a similar base level to the minimum level recommended by the Passivhaus standard (0.3 ach) (Feist et al., 2010) without apparent concern of any health risks. According to the report, “The National Building Code of Canada (1985) requires all dwelling units to have a MV system capable of providing 0.5 ach and this was modified in 1990 to 0.3 ach. CSA standard F326 was adopted as the ventilation standard for R-2000™ in 1991 (...). A substantial majority of occupants considered the indoor climate to be good or very good in winter and 88% were satisfied or very satisfied in summer. Air quality was rated as good or very good by 95% of occupants” (Crump et al., 2009, p29).

Similarly high levels of occupant satisfaction with the MVHR systems are recorded in the Kronsberg (Hanover) Passivhaus development (Schnieders and Hermelink, 2006; Energy-cities EU, 2012). When asked about their satisfaction with their ventilation system, 96% (55%) of the Passive House occupants stated that they were very satisfied or satisfied (Feist et al., 2001, p.79 ). This research was carried out as part of the CEPHEUS project (Cost Efficient Passive Houses as EU Standards) that involved the

construction and evaluation of 221 housing units built to Passivhaus standards in five European countries (Germany, Austria, Switzerland, Sweden and France) (Feist et al., 2001). A critical requirement of the Passivhaus standard is the attainment of a highly airtight envelope demonstrated by an  $n_{50}$  pressure test value of  $\leq 0.6 \text{ ach}^{-1}$  (Feist et al., 2010). Although there was little detailed evaluation of individual air pollutants in the CEPHEUS reports, several projects included measurements of temperature and relative humidity (RH) as well as post-occupancy satisfaction with the ventilation system and IAQ (Feist et al., 2001; Schnieders and Hermelink, 2006).

Despite the wealth of international literature on this subject there have been very few peer reviewed studies published specifically addressing the IAQ of highly energy efficient homes in the UK (Crump et al., 2009). One of the main criticisms levelled at the existing data and post occupancy studies however, is that they focus primarily on  $\text{CO}_2$  and RH as proxy indicators of IAQ and not formaldehyde's and volatile organic compounds (VOC's) (Swainson, 2010). One of the few UK research papers investigating formaldehyde, VOC's and other key IAQ indicators ( $\text{CO}_2$ , CO,  $\text{NO}_2$ , TVOCs) was a monitored study of 6 low energy dwellings carried out in 2006). Notably only the two dwellings that were ventilated using MVHR systems in this study achieved the highest possible IAQ rating across a range of measured indicators (Mawditt, 2006, p63). Mawditt makes the important observation that "Minimising the source of the pollutant has a far greater effect on overall concentration than relying on dilution by ventilation" (Mawditt, 2006, p62).

It seems likely that detailed MVHR design guidance, quality assurance and commissioning protocols issued by organisations such as the Passivhaus Institut, R-2000 and Minergie are partially responsible for ensuring high levels of occupant satisfaction and IAQ associated with these systems. The need for on-going maintenance with MVHR systems is a critical point, which was highlighted by comments in the Sullivan Report (Scottish Building Standard Agency, 2007). These comments came from Austrian contributors, with direct experience of Passivhaus buildings; who emphasised the need for occupants to maintain the filters on MVHR systems to ensure continued adequate ventilation.

Whilst further research on VOC's, formaldehyde concentrations in both, naturally and mechanically ventilated airtight dwellings in the UK is warranted, it seems unlikely this issue will present a real barrier to the widespread adoption of properly installed MVHR systems in the UK. Indeed, a recent report by the ZCH Ventilation and Indoor Air Quality (VIAQ) Task Group states that "the use of MVHR will continue to grow and become the dominant form of ventilation, standard in most new homes post-2016 (ZCH, 2012, p42).

## 7. Conclusions and recommendations

Zero carbon building policy is still evolving and a final decision is awaited on several key aspects including the definition of 'allowable solutions'. Recent revisions to the definition of 'zero carbon' in the UK have resulted in a significant weakening of the minimum energy efficiency standard used to define a zero carbon dwelling. If the current working definition becomes policy (circa 2012) the proposed methodology will make it possible to offset in excess of 50% of a UK 'zero carbon' dwelling's emissions by purchasing market based 'allowable solutions'. Although these 'allowable solutions' are not yet clearly defined the transition away from meeting the balance of the annual energy requirement through high levels of energy efficiency and from directly connected renewable energy infrastructure will have significant implications, both for GHG emissions as well as for a number of wider social and sustainability indicators.

A number of dynamic factors including significant increases in the absolute number of UK households, increasing hot water demand, appliance consumption and a growing cooling demand appear to have been overlooked during the recent review of UK zero carbon dwelling standards. The assumption that the 'residual emissions' are static and can simply be offset elsewhere, appears to be a dangerous and short sighted argument which is not supported by evidence on the efficacy of carbon offsetting mechanisms. Recent scenario modelling by DECC (2010a) clearly illustrates that the Passivhaus standard is the only energy efficiency standard capable of delivering long term reductions in space heating, cooling and hot water energy consumption.

Limitations with the existing UK SAP methodology are currently masking significant energy and carbon savings that can be achieved by Passivhaus dwellings when they are correctly modelled. This is due to differences in the underlying assumptions (including internal gains and Treated Floor Area assumptions) between PHPP and SAP, and the fact that the SAP model relies upon a single climate data set (East Pennines) for predictive modelling of the heating demand across the entire UK (ZCH, 2011). Preliminary modelling suggests that nearly 90% of Part L 2006 regulated emissions could be saved by adopting the Passivhaus approach, if both regulated and unregulated emissions savings were included in the carbon compliance total (Figure 5).

Significantly higher standards of air tightness and controlled ventilation rates by mechanical means are likely to play an increasing role in the delivery of low energy housing in the UK (ZCH, 2012). Currently there is a scarcity of research regarding health issues associated with internal air borne pollutants in airtight UK dwellings using mechanical ventilation. Further research is needed in order to strengthen UK domestic ventilation guidance and regulations.

If the UK is to meet its GHG reduction targets, and converge upon a harmonised European standard for zero carbon buildings, the evidence points to the need to

mandate significantly increased levels of energy efficiency. Adopting a 'fabric first' approach with higher minimum energy efficiency and carbon compliance levels is consistent with the CLG energy hierarchy and DECC scenario modelling and avoids many of the pitfalls and uncertainty associated with the extensive use of carbon offsetting mechanisms. Over the past two decades more than 30,000 Passivhaus buildings have been successfully constructed across continental Europe (iPHA, 2012), demonstrating that such a standard could be practically implemented as a template for a more robust UK zero carbon policy.

## References

AECB. 2009. Comparing energy use and CO2 emissions from natural ventilation and MVHR in a Passivhaus house. A CarbonLite Information Paper, 2009. Available at: [www.carbonlite.org](http://www.carbonlite.org)

BERR, Renewables Advisory Board Annual Report 2007. Available at: [www.berr.gov.uk/files/file48125.pdf](http://www.berr.gov.uk/files/file48125.pdf).

BLP. Building Life Plans Construction Durability Database (available) [www.componentlife.com/](http://www.componentlife.com/) (accessed April 07)

Boardman, B., 2007. Home Truths: A Low Carbon Strategy to reduce UK Housing emissions by 80% by 2050. Environmental Change Institute Report 34, University of Oxford, 2007

Boardman, B., Darby, S. Killip, G. Hinnells, M. Jardine, C. Palmer, J & Sinden, G., 2006. 40% House Report. Environmental Change Institute. University of Oxford 2005, (p29)

Bordass, W., Cohen, R., and Field, J., 2004. Energy Performance of Non-Domestic Buildings: Closing the Credibility Gap. Proceedings of Building Performance Congress 2004 (IEECB'04) Frankfurt, Germany, 19-22 April 2004.

Bows, A Mander, S., Starkey, R., Bleda, M., & Anderson, K., 2006. Living within a carbon budget. Tyndall Centre, Manchester 2006. Available at: [www.foe.co.uk/resource/reports/living\\_carbon\\_budget.pdf](http://www.foe.co.uk/resource/reports/living_carbon_budget.pdf) (accessed June 07) (p9)

Bretzke, A., 2009. UK Passivhaus Schools Conference. 2009. Available at: <http://aecb.net/phschools2009.php> (Accessed October 22, 2010).

Brunsgaard, C., & Jensen, R., 2008. Necessary Air Change Rate in a Danish Passive House. 12th International Conference on Passive Houses 2008 (April 12, 2008): 369-374.

Bullock, S., Childs, M., Picken, T. A, 2009. Dangerous Distraction. Why offsetting is failing the climate and the people: The evidence. 2009. Friends of the Earth, England, Wales and Northern Ireland. Available at:  
[http://www.foe.co.uk/resource/briefing\\_notes/dangerous\\_distraction.pdf](http://www.foe.co.uk/resource/briefing_notes/dangerous_distraction.pdf)

Camden Passivhaus, 2010. Primary Energy 98 kWh/m<sup>2</sup>.yr (source):  
<http://blog.emap.com/footprint/2010/07/27/passivhaus-at-the-building-centre/>  
(accessed June 2010)

Carbon Trust, 2008. Global Carbon mechanisms: emerging lessons and implications.2008 Available at:  
<http://www.carbontrust.co.uk/Publications/pages/publicationdetail.aspx?id=CTC748&respos=2&q=global+carbon+market&o=Rank&od=asc&pn=0&ps=10>

Clarke, A., 2008. Projecting energy use and CO<sub>2</sub> emissions from low energy buildings- a comparison of the Passivhaus Planning Package (PHPP) and SAP. AECB CarbonLite, Available at: [http://www.aecb.net/PDFs/Combined\\_PHPP\\_SAP\\_FINAL.pdf](http://www.aecb.net/PDFs/Combined_PHPP_SAP_FINAL.pdf)

Climate Change Act 2008, Available at:  
[http://www.opsi.gov.uk/acts/acts2008/ukpga\\_20080027\\_en\\_1](http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1).

Committee on Climate Change, 2010. Fourth Carbon Budget. Available at:  
<http://www.theccc.org.uk/reports/fourth-carbon-budget> [Accessed January 5, 2012].

Crump, D Dengel, A., Swainson, M., 2009. Indoor air quality in highly energy efficient homes – a review. Available at: [www.nhbcfoundation.org](http://www.nhbcfoundation.org)

DCLG, 2006a. Building A Greener Future: Towards Zero Carbon Development. Communities and Local Government Publications. December 2006. Available at:  
[www.communities.gov.uk](http://www.communities.gov.uk)

DCLG, 2006b. Code for Sustainable Homes: A step change in Sustainable Home Building practise. Dec 2006, p6. Available at:  
[www.planningportal.gov.uk/uploads/code\\_for\\_sust\\_homes.pdf](http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf)

DCLG, 2007a. *Building a Greener Future: policy statement*. 2007 Available at:  
[www.communities.gov.uk/.../planningandbuilding/.../building-greener.pdf](http://www.communities.gov.uk/.../planningandbuilding/.../building-greener.pdf)

DCLG, 2007b. Code for Sustainable Homes: Technical guide- October 2007. Available at: <http://www.communities.gov.uk/archived/publications/planningandbuilding/codeguid/october2007>

DCLG, 2007c. Homes for the future: more affordable, more sustainable. Available at: [www.communities.gov.uk/documents/housing/pdf/439986.pdf](http://www.communities.gov.uk/documents/housing/pdf/439986.pdf) (Accessed January 4, 2011).

DCLG, 2008. Definition of Zero Carbon Homes and Non-domestic Buildings - Consultation.2008 Available at: [www.communities.gov.uk](http://www.communities.gov.uk)

DECC, 2010a. 2050 Pathways Analysis. Available at: [www.decc.gov.uk](http://www.decc.gov.uk) (Accessed January 15, 2011).

DECC, 2010b. Digest of UK Energy Statistics 2010. Available at: <http://www.decc.gov.uk/en/content/cms/statistics/publications/publications.aspx>

DECC, 2010c. Energy Consumption by Final User, 1970 to 2009 (DUKES 1.1.5). 2010. Available at: <http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx>.

DEFRA, 2007. *Climate Change Bill Summary*. 2007. Available at: [www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/CCBill-summary.pdf](http://www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/CCBill-summary.pdf) (accessed June 07) p2

DTI, 2007. Meeting the Energy Challenge: A White Paper on Energy. Available at: [www.berr.gov.uk/files/file39579.pdf](http://www.berr.gov.uk/files/file39579.pdf) (Accessed January 14, 2011).

Energy Cities, 2012a. Available at: <http://www.energy-cities.eu/> [Accessed January, 2012].

Energy cities EU, 2012b. Kronsberg, Germany. Available at: ([http://energy-cities.eu/IMG/pdf/Sustainable\\_Districts\\_ADEME1\\_Kronsberg.pdf](http://energy-cities.eu/IMG/pdf/Sustainable_Districts_ADEME1_Kronsberg.pdf))

Energy cities EU, 2012c. Vauban/ France. Available at: ([http://energy-cities.eu/IMG/pdf/Sustainable\\_Districts\\_ADEME1\\_Vauban.pdf](http://energy-cities.eu/IMG/pdf/Sustainable_Districts_ADEME1_Vauban.pdf))

Energy cities EU, 2012d. Stockholm, Sweden. Available at: ([http://energy-cities.eu/IMG/pdf/Sustainable\\_Districts\\_ADEME1\\_Hammarby.pdf](http://energy-cities.eu/IMG/pdf/Sustainable_Districts_ADEME1_Hammarby.pdf))

European Commission 2008. Action Plan for Energy Efficiency: Realising the Potential. European Parliament resolution of 31 January 2008 on an Action Plan for Energy Efficiency: Realising the Potential (2007/2106(INI)). P6\_TA(2008)0033. Available at: [www.europarl.europa.eu/sides/getDoc.do?pubRef=-//...2008](http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//...2008).

European Commission, 2009. Low Energy Buildings in Europe: current state of play, definitions and best practice. 2009. Available at:  
[http://ec.europa.eu/energy/efficiency/doc/buildings/info\\_note.pdf](http://ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf)

European Commission, 2010. Recast Energy Performance in Buildings Directive. (May 2010) Available at [http://ec.europa.eu/energy/efficiency/doc/buildings/info\\_note.pdf](http://ec.europa.eu/energy/efficiency/doc/buildings/info_note.pdf)

Feist W, Peper S, Gorg M., 2001. CEPHEUS Project Information No.36: Final technical report. PassivHaus Institute, 2001. Stadtwerke Hannover AG, July 2001

Feist, W., Pfluger, R., Kaufman, B., Schnieders, J., Kah, O., 2010. Passive House Planning Package 2007: Requirements for Quality Approved Passive Houses. Technical Information PHI-2007/1 (E), 2<sup>nd</sup> edition May 2010. Passivhaus Institute, Darmstadt.

Feist W., 2007 Passive House Planning Package 2007: Specifications for Quality Approved Passive Houses. Technical Information PHI-2007/1 (E). Passivhaus Institute, Darmstadt.

Feist W. Schnieders, J., Dorer, V., & Haas, A., 2005. Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept. 2005. *Energy and Buildings* 37

Forrest, C., 2005. The Cutting edge: Climate Science to 2005. Available at:  
[www.portal.campaigncc.org/files/THE\\_CUTTING\\_EDGE\\_CLIMATE\\_SCIENCE\\_TO\\_APRIL](http://www.portal.campaigncc.org/files/THE_CUTTING_EDGE_CLIMATE_SCIENCE_TO_APRIL) (p8)

Fourth Carbon Budget, 2010. Available at: <http://www.theccc.org.uk/reports/fourth-carbon-budget> (Accessed December 7, 2010).

Granda, P., 2005. Carbon sink plantations in the Ecuadorian Andes - Impacts of the Dutch FACE-PROFAFOR monoculture tree plantations' project on indigenous and peasant communities, p.59, Available at:  
<http://www.wrm.org.uy/countries/Ecuador/face.pdf>

Harving, H., Korsgaard, J., & Dahl, R. 1994. Clinical efficacy of reduction of house-dust mite exposure in specially designed mechanically ventilated "healthy" homes. *Allergy* 49 (10): 866-870

Haya, B., 2009. Measuring emissions against an alternative future: Fundamental flaws in the structure of the Kyoto Protocol's Clean Development Mechanism. 2009. Energy and Resources Group Working Paper Series, University of California, Berkeley. Available at: <http://bhaya.berkeley.edu/>

Healey, John. 2009. Eco Towns and Zero Carbon Homes 16<sup>th</sup> July 2009

Henderson, J., 2009. Review of Auxiliary energy use and the internal heat gains assumptions in SAP 2009. BRE, March 2009

Herring C., 2010. Passivhaus Trust. Available at:  
<http://www.aecb.net/passivhaustrust/default.html> (Accessed August 20, 2010).

Hick, J., & Allen, G., 2006. A Century of Change: Changes in UK statistics since 1900. Research Paper 99/111. 1999, House of Commons Library. Available at:  
[www.parliament.uk](http://www.parliament.uk) (accessed Nov 06) p14

HM Government, 2008. Definition of Zero Carbon Homes and Non-Domestic Buildings: Consultation. 2008. Available at:

<http://www.zerocarbonhub.org/resourcefiles/1101177.pdf>.

HM Treasury, 2011. The Plan for Growth. Available at: [hm-treasury.gov.uk](http://hm-treasury.gov.uk).

Hodgson, G, 2009. Zero Carbon Definition: Energy Efficiency metrics, Energy Savings Trust.

Hopfe, C.J., & McLeod, R., 2010. Passivhaus Treated Floor Area for Dwellings. Available at: <http://www.aecb.net/forum/index.php?action=dlattach;topic=2652.0;attach=502>

IPCC., 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, Available at: [www.ipcc-wg1.ucar.edu/wg1/Report/AR4WG1\\_Pub\\_SPM-v2.pdf](http://www.ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf)

iPHA, International Passive House Association. Available at: [http://www.passivehouse-international.org/index.php?page\\_id=151](http://www.passivehouse-international.org/index.php?page_id=151). (Accessed 15 Jan 2012)

Kill, J., Ozinga, S., Pavett, S., & Wainwright, R., 2010. Trading carbon: How it works and why it is controversial. 2010. FERN, UK. Available at:  
[http://www.fern.org/sites/fern.org/files/tradingcarbon\\_internet\\_FINAL.pdf](http://www.fern.org/sites/fern.org/files/tradingcarbon_internet_FINAL.pdf)

Kraus, K. 2009. Contraction and Convergence and Greenhouse Development Rights: A critical comparison between two salient climate-ethical concepts. Diploma thesis in Studiengang Landschaftsökologie und Naturschutz am Botanischen Institut der Ernst-Moritz-Arndt-Universität Greifswald. Available at: [www.gci.org.uk/publications.html](http://www.gci.org.uk/publications.html)

Larsen, T., & Jensen, R., 2009. Measurements of energy performance and indoor environmental quality in 10 Danish passive houses. Healthy Buildings 2009, 9th International Conference and Exhibition. Syracuse, USA. Available at

<http://vbn.aau.dk/en/publications/measurements-of-energy-performance-and-indoor-environmental-quality-in-10-danish-passive-houses>

Lazarus N., 2004. Movement for Innovation Best to Worst Case Data. Bed ZED-Construction Materials Report, Part 1 .2004. London: Bioregional Development Group

Marsh, R., Lauring, M., Petersen E.H., 2001. Passive solar energy and thermal mass: the implications of environmental analysis. In arq 5 (1) 2001, p81

Mawditt, I., 2006. A Field investigation of Indoor Air Quality and Ventilation in Low Energy Homes in England. MSc thesis, University of East London (July 2006)

McLeod, R., 2007. Passivhaus Local House. MSc thesis, 2007 University of East London

McLeod, R.S., Hopfe, C.J., Rezgui, Y., 2010. Passivhaus and PHPP – Do continental design criteria work in a Welsh climatic context? 3rd BauSIM Conference, 22.-24. September 2010, Vienna, Austria

Meyer, A. 2000. Contraction and Convergence: The Global Solution to Climate Change. Green Books Ltd, Dartington.

Monahan, J., & Powell, J.C., 2009. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework Energy and Buildings 43 (2011) 179–188. Available at: [www.elsevier.com/locate/enbuild](http://www.elsevier.com/locate/enbuild)

Müller, B., 2009. Additionality in the Clean Development Mechanism: Why and What? March 2009. Available at: <http://www.oxfordenergy.org/muller.php>

National Energy Services., 2005. Assessing the impact of the proposed building regulation revisions for new dwellings: Part L1A. Available at: <http://www.nesltd.co.uk/>

Norford, L., Socolow, R., Hsieh, E. Spadaro, G. 1994. Two-to-one discrepancy between measured and predicted performance in a 'low energy' office building: insights from a reconciliation based on the DOE-2 model. Energy and Buildings, 21 pp 121-131

Phillips, R., Blackmore, P., Anderson, J., Clift, M., Aguiló-Rullán, A., Pester, S., 2007. FB 17 – Micro wind turbines in urban environments: an assessment. IHS BRE Press, Watford. Available at: [www.brepress.com](http://www.brepress.com)

Pope, V., Kendon, L., Lowe, J., Carroll, F., Tempest, S., 2010. Evidence: the state of the climate. Available at: <http://www.metoffice.gov.uk/research/media/pdf/m/6/evidence.pdf>.

Reason, L., & Olivier, D., 2006. Minimizing CO<sub>2</sub> Emissions from New Homes: A review of how we predict and measure energy use in new homes 2<sup>nd</sup> Edition. 2006, Available at: [www.aecb.org](http://www.aecb.org) (accessed 10 Sept 06)

Sanders, C., & Phillipson, M., 2006. Review of Differences between Measured and Theoretical Energy Savings for Insulation Measures. Centre for Research on Indoor Climate and Health, Glasgow Caledonian University December 2006.

Schneider, L., 2007. Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and options for improvement 2007 Available at: [http://www.panda.org/what\\_we\\_do/footprint/climate\\_carbon\\_energy/energy\\_solutions/resources/?118000/An-evaluation-of-the-CDM-and-options-for-improvement](http://www.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/resources/?118000/An-evaluation-of-the-CDM-and-options-for-improvement)

Schnieders, J. & Hermelink, A., 2006. CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. *Energy Policy*, 34(2), pp.151-171.

Scottish Building Standards Agency, 2007. A Low Carbon Building Standards Strategy for Scotland (The Sullivan Report). Available at: <http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/sullivan>.

Seiders, D., Ahluwalia, G., Melman, S., Quint, R., Chaluvadi, A., Liang, M., Silverberg, A., Bechler, C., Jackson, J., 2007. Study of Life Expectancy of Home Components. Available at: [www.nahb.org](http://www.nahb.org) [Accessed February 21, 2011].

Shorrocks, L and Utley, J, 2003. Domestic Energy Fact File 2003. BRE Housing Centre, Watford. Available at: [www.BREBookshop.com](http://www.BREBookshop.com) (accessed Nov 06)

Snijders, M.C., Koren, L.G.H., Kort, H.S.M., Bronswijk, J.E.H. van., 2001. Clean indoor air increases physical independence. A pilot study. *Gerontechnology* 1 (2): pp124-127

Swainson, M., 2010. Personal conversation 15 Nov 2010.

The European Parliament and the Council of the European Union, 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. *Official Journal of the European Union*, 53(L 153). Available at: <http://eur-lex.europa.eu/JOHtml.do?uri=OJ:L:2010:153:SOM:EN:HTML> (Accessed October 26, 2010).

UK Green Building Council, 2010. Zero Carbon Task Group Report: The Definition of Zero Carbon. 2008 Available at: <http://www.ukgbc.org/site/taskgroups/info?id=4> (Accessed December 23, 2010).

Vallentin, R., 2009. Energieeffizienter Stadtebau mit Passivhausern- Herleitung belatbarer Klimaschutzstandards im Wohnungsbau. PhD thesis Technical University of Munich, 2009.

Voss, K., 2008. What is Really New about Zero-Energy homes? Conference Proceedings 12<sup>th</sup> International Conference on Passive Houses 2008. Available at: [www.passiv.de](http://www.passiv.de)

Waugh, A., Weiss, K.H., Wells, M., 2009. A Process Revealed/ Auf Dem Holzweg. 1455 Fine Art Printers, Belgium. ISBN 978-0-9558620-6-9, 2009

Weaver, W., 2007. Brown pledges to build zero carbon homes. Guardian Unlimited, Dec 6, 2006. Available at: [money.guardian.co.uk/prebudgetreport/story/](http://money.guardian.co.uk/prebudgetreport/story/) (accessed June 07)

Zero Carbon Hub (ZCH), 2009a. Defining Zero Carbon Homes: 'Have Your Say' Report 2009, Available at: <http://www.zerocarbonhub.org/resourcefiles/ZCH-HaveYourSay.pdf> (Accessed August 4, 2010).

Zero Carbon Hub (ZCH), 2009b. Zero Carbon Hub Task Group: Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes: Task Group Recommendations November 2009. Available at: <http://www.zerocarbonhub.org/resourcefiles/ZCH-Defining-A-Fabric-Energy-Efficiency-Standard-Task-Group-Recommendations.pdf> (Accessed August 20, 2010).

Zero Carbon Hub (ZCH), 2009c. Zero Carbon Hub Task Group: Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes: executive summary. 2009. Available at: [http://www.zerocarbonhub.org/resourcefiles/FEES\\_ExecSummary\\_15\\_3\\_10.pdf](http://www.zerocarbonhub.org/resourcefiles/FEES_ExecSummary_15_3_10.pdf).

Zero Carbon Hub (ZCH), 2011. National or Regional Weather Implications for Carbon Compliance. April, 2011. Available at: <http://www.zerocarbonhub.org/definition.aspx?page=8>

Zero Carbon Hub (ZCH) 2012. Mechanical Ventilation with Heat Recovery in New Homes. Interim report of the VIAQ task group. Available at: <http://www.nhbcfoundation.org/NewsMediaCentre/VIAQtaskgroupinterimreport/tabid/501/Default.aspx> [Accessed February 20, 2012].