Carbon Compliance: A study comparing PHPP and SAP calculations of CO_2 emissions for three of the first Certified Passivhaus dwellings in the UK, to test theoretical correlation with the UK Government's 2011 definition of Zero Carbon.

Nick Newman © bere:architects June 2011.
SAP calculations and consultancy by Brooks Devlin Ltd.

1.0 Introduction

With much attention focused - at the time of writing- on the UK government's decision on the 2016 definition of Zero Carbon, the construction industry now needs to focus on the precise steps that need to be taken towards achieving these targets. There will be particular interest in finding the most cost effective and reliable design methodologies. Developers will be responsible for actual fabric performance, so performance reliability will be a key factor in their choice. The conclusions of this report analyse how closely in practice a certified passivhaus and a 'Spec D' house perform; indicate the most cost effective solutions to achieving compliance (although this is covered seperately in three other reports by bere:architects, now nearing completion); and indicate that at statutory level, it would be sensible, in the interests of efficiency and industry, to accept Passivhaus as an alternative method of meeting -and exceeding- the future regulatory criteria for low energy design.

1.1 Premise of this report

This report aims to investigate the performance of three Certified Passivhaus dwellings in the UK, and through the use of established energy modelling software, compare and contrast these performance outputs with equivalent targets within the 2016 Zero Carbon definition. It is hoped that this exercise will help to inform discussion as to the suitability of Passivhaus dwellings for meeting the UK's low energy building requirements , and potentially stimulate further investigation into this field of research.

1.2 Background

On 18th May 2011, housing minister Grant Shapps reaffirmed the UK government's commitment to the future delivery of low energy housing, by issuing a formal decision on the definition of Zero Carbon [1]. Although some technical details are subject to further consultation, the statement highlights the government's broad intention to follow the recommendations of the Zero Carbon Hub (ZCH) report '*Carbon Compliance – Findings and Recommendations'* [2], published in Feb 2011. The decision puts the government on a path towards fulfilling current European Directive - 2010/31/EU, which instructs that "Member States shall ensure that…by 31 December 2020, all new buildings are nearly zero- energy buildings" [3]

As a result of the decision, developers of housing from 2016 will be required to account for the 'regulated emissions', or those which eminate from the functioning of the building itself, eg. space heating, building services etc. They will not be accountable for the in 'use emissions' of unregulated loads, such as appliances and small electronics. Buildings which conform to this policy will be referred to as Carbon Compliant.

1.3 Carbon Compliance

The Carbon Compliance recommendation - as endorsed by the 18th May decision – comprises a minimum building fabric energy efficiency standard of 39 to 46kWh/m^{2}a dependent on house type and a further allocation of on-site low or zero carbon (LZC) technology. Carbon Compliance equates to approximately 44-60% improvement over the 2006 standard depending on house type, with the requirement that remaining emissions are negated through offsite 'allowable solutions'. The Government has proposed the adoption of three absolute Dwelling Emission Rate limits (DER) in order to demonstrate '2016 Carbon Compliance'. (see Figure i below).

Compliance criterion	Detached houses	Attached houses	Low rise apartment blocks
Dwelling Emission Rate (DER)	10 kg CO_2(eq)/m2a	11 kg CO_2(eq)/m2a	14 kg CO_2(eq)/m2a
Equiv. improvement over 2006 Part L	60%	56%	44%

Figure i: Carbon compliance targets for different building types, summarised from the *ZCH 2016 Carbon Compliance report, 2011*.

1.4 FEES

The Fabric Energy Efficiency Standard (FEES) recommendation for a Specific Energy Demand of 39 to 46kWh/m^{2}a was based on a comparative study of a selection of design performance specfications, ranging from 'current building practice' through to 'EST Advanced Practice', and finally the exacting 'Passivhaus Standard'. The modelling of these performance specifications was carried out using the UK government's 'Standard Assessment Procedure' (SAP), with the passivhaus equivalent 'SPEC D" house influenced by some

1 *Communities and Local Government Buildings and the Environment- Written ministerial statement 17th May 2011. Accessed June 2011 at http://www.publications.parliament.uk*
2 Zero Carbon Hub (2011) *Carbon Compliance – Findings and Recommendations. Accessed May 2011 at http://www.zerocarbonhub.org/resources.aspx*
3 *Council Directive (EC) DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast)*
4 Zero Carbon Hub (2009) Defining a fabric energy efficiency standard for Zero Carbon Homes. *Page 7. Accessed May 2011 at http://www.zerocarbonhub.org/resources.aspx*

additional modelling using the Passivhaus Planning Package (PHPP) [2]. The final outputs for the report were based on a modified version of SAP 2009, with the carbon emissions factors altered as per Figure ii to reflect the theorised carbon intensity of the 2016 energy grid.

Fuel source	SAP 2005	SAP 2009	**ZCH 2016**	PHPP 2007
Grid electricity	0.422	0.517	**0.527**	0.68
Mains gas	0.194	0.198	**0.227**	0.25

Figure ii: Comparing carbon emission factors from the ZCH 2016 report with recent SAP and PHPP methodology.

Although a thorough discussion of the carbon intensity figures is clearly beyond the scope of this report, it is of key importance to note that the highest values for each fuel type are those found in the PHPP model. As all certified Passivhaus dwellings are assessed independently using PHPP, this can be seen to have the effect of ensuring inherently conservative estimates for Passivhaus performance in the UK. It is also interesting to note the increasing carbon intensity factors for the successive SAP based calculations.
If these are to represent a true picture of the UK energy grid in 2016, an increasing burden will be placed on the UK government to provide alternative solutions for those building emissions not negated through building fabric improvements.

2.0 Initial investigations

2.1 Relationship of Carbon Compliance and FEES

The Carbon Compliance and FEES definitions are of great relevance to the findings of this report, so it is of key importance to ensure that the relationship between these two targets is fully established (see below).

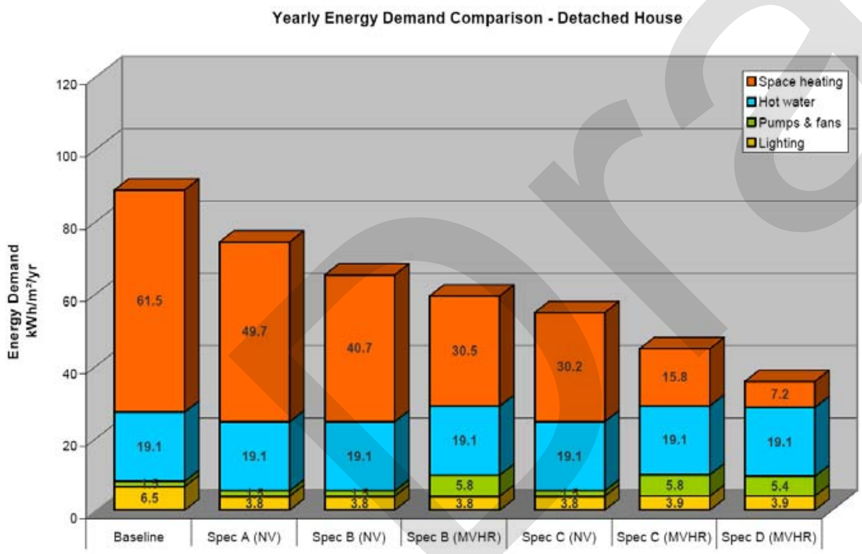

Figure iii: *From ZCH Report*, Energy demand of different detached house specifications

Figure iii is taken from the ZCH 2009 *"Defining a Fabric Energy Efficiency Standard, Appendix A Work Group 1 Form and Fabric".*

It is one of a number of charts showing the regulated energy demand figures (kWh/m^{2}a) of each of the chosen building performance specifications which were modelled in the report. As discussed in section 3.0, these specifications range from current practice (Baseline) to a Passivhaus equivalent (SPEC D MVHR) and in this table are also broken down into each of the regulated emissions: Space heating, Hot water, Pumps & fans, Lighting.

Whilst there is much that can be read from Figure iii, the chart does not make any easily identifiable reference to the Carbon Compliance/DER metric of kg CO_2/m^{2}a, which therefore makes it difficult to compare FEES performance specifications with the DER targets.

Figure iv, taken from the ZCH 2011 "*Carbon Compliance, Setting an appropriate limit for zero carbon new homes, Findings and Recommendations*", is often referred to as a method for clarifying the three steps to net Zero Carbon emissions.

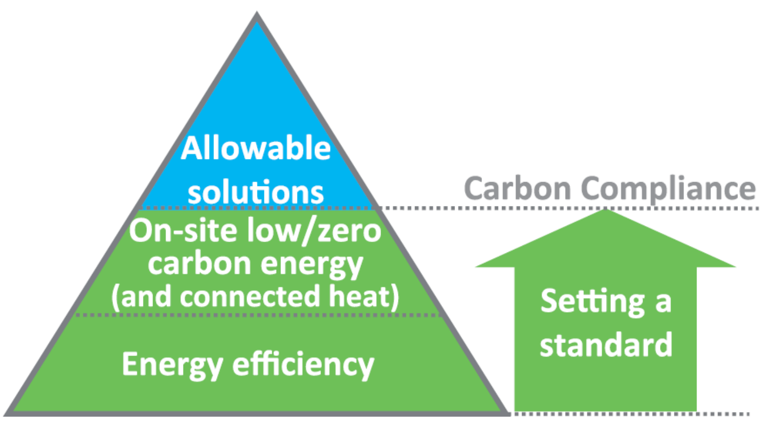

Figure iv: *From ZCH Report*, Diagram showing relationship of FEES, LZC and Allowable Solutions

Whilst this is a useful diagram for explaining the Zero Carbon concept, it is not repeated with any target figures or percentage reductions.

Figure v combines elements of the two previous diagrams to establish a clearer correlation between the two targets. The results have been by converting each of the specific energy demand figures from Figure iii (kWh/m^{2}a) into DER equivalents (kg $C0_2$/m^{2}a), using the ZCH 2016 carbon intensity factors highlighted in Figure ii. See Appendix A.

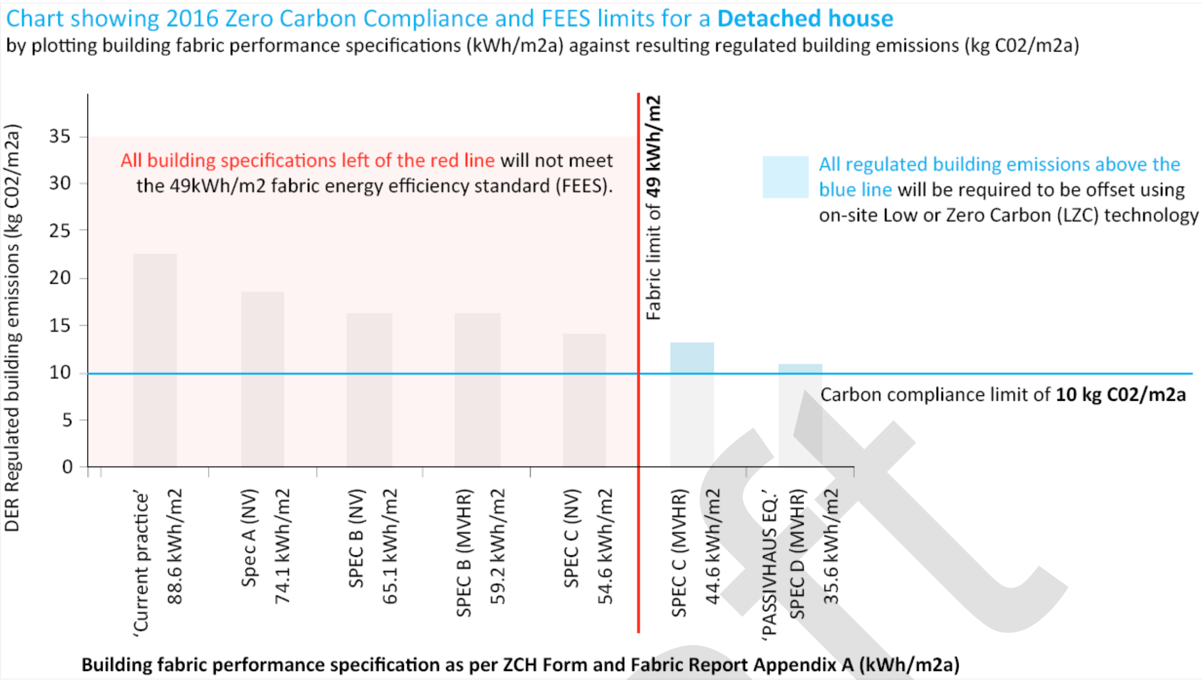

Figure v: Comparing DER and FEES requirements for detached houses (input data from ZCH 2016 report)

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2.2 Initial findings

The first main point to note from Figure v is that, based on these calculations, for a Detached house at least it will only be possible to achieve the 2016 FEES limit with an MVHR ventilated SPEC C or SPEC D building.

An additional point is that the DER of both the SPEC C MVHR (13.0 kg $C0_2$/m^{2}a) and the SPEC D passivhaus (10.9 kg $C0_2$/m^{2}a) are above the limit of 10.0 kg $C0_2$/m^{2}a for a detached house and will therefore require some form of on site LZC technology.

In order to carry out any further analysis of these initial findings towards the report aim, it becomes necessary to contrast the conclusions of the report with the certifed design performances for each of the Certified Passivhaus dwellings. One of the selection criteria for the projects were that they had all been modelled using both PHPP and SAP for Passivhaus Certification and Building Regulations respectively. With data available from two sources, it is hoped that an interesting cross reference can be made with the Zero Carbon hub findings. However before this can happen, it is first necessary to discuss the existing connection between PHPP and SAP.

2.3 PHPP and SAP

At the time of writing, the disparity in approach and output of these energy modelling protocols is a topic of widespread discussion. The following excerpts from the 2008 AECB study "A comparison of PHPP with SAP" [5] give a degree of insight into some of the current debate around this issue.7.2

> *"SAP and PHPP use the same basic principles – steady state heat loss multiplied by degree-days, with internal and solar gains subtracted. However, we find when comparing models of well-insulated houses that the results are very different...*
>
> *...overall, SAP plays down the significance of insulation and airtightness, and assumes high levels of internal gains, leading designers to believe they have reached a sensible lower limit on heat loss when in fact they have not....*
>
> *...the estimation of CO2 emissions in SAP is significantly lower than in PHPP, even allowing for differences between the electricity systems in the UK and Germany."*

The AECB study established key disparities between the approaches and suggested possible methods for normalising SAP and PHPP outputs; indeed there is a good deal of research being carried out currently in this

5 Clarke et al. (2008) *Projecting Energy Use and Co2 Emissions from Low Energy Building:, A Comparison of the Passivhaus Planning Package (PHPP) and SAP. Accessed May 2011 at http://www.aecb.net/publications.php*

field. It is therefore not the aim of this exercise to interpret underlying differences between these two energy-modelling procedures.

It will however be necessary to make certain straightforward adjustments to both of the SAP and PHPP procedures in order to allow both to be compared more directly with the findings of the 2016 ZCH report (see *Method for Comparison* below). Any remaining disparity between the outcomes of the two methodologies will then form a basis for further investigation and discussion.

3.0 Method

3.1 Steps for comparison

i) For each of the sample buildings, copies of the final PHPP and SAP certification worksheets will be obtained.

ii) The differences in carbon intensity highlighted in Figure ii will be normalised for each of the PHPP and SAP worksheets, so that they correlate with the ZCH calculations.

iii) Any calcultion input relating to 'unregulated emissions' will be negated.

iv) All $C0_2$ outputs from PHPP and SAP will be compared with the Compliance criteria highlighted in Figure i.

v) The impact of PHPP regional variation will be investigated by adjusting all PHPP climate data input to the BRE regional data set for East Pennines - considered as the base average weather region in the ZCH report.

vi) An equivalent Part L 2006 compliant building will be modelled in PHPP and normalised as per steps i)-iii) . The $C0_2$ emission output from this PHPP worksheet will be used as an equivalent Part L Target vzEmission Rate, to which all PHPP output then be compared

3.2 Data input for study

All data for the study will be based on three of the UK's first passivhaus dwellings, designed by bere:architects in collaboration with Alan Clarke, Warm Associates, Brooks Devlin, the BRE, et al. The projects were certified by BRE Wales (Larch and Lime house) and Warm Associates (Camden Passivhaus) between April 2010 and March 2011. The details for each of the projects are set out below:

Larch House	Lime House	Camden Passivhaus
		
- Located in **Ebbw Vale, Wales**	- Located in **Ebbw Vale, Wales**	- Located in **North London, England**
- **Exposed** heads of valley location	- **Exposed** heads of valley location	- **Moderately sheltered** urban location
-Space heating demand of **13 kWh/m^{2}a**	- Space heating demand of **17 kWh/m^{2}a**	-Space heating demand of **13 kWh/m^{2}a**
-Primary energy demand of **83 kWh/m^{2}a**	-Primary energy demand of **87 kWh/m^{2}a**	-Primary energy demand of **97 kWh/m^{2}a**
- Detached 3 bedroom house (social)	- **Detached** 2 bedroom house (social)	- **Detached** 2 bedroom house (private)
-**4.7kWp** PV array, flat panel collectors	-**2.5kWp** PV array, flat panel collectors	-**3m^2** evacuated tube solar collectors

Figure vi: Table comparing key details for the three sample buildings, all certified to the Passivhaus standard.

Note: The lime house was certified with a peak heat load figure of 10W/m^2 instead of the more conventional space heating demand certification method. More to be added here......

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3.3 Modelling assumptions

SAP only alterations

- All three projects were originally certified using SAP 2005. For this report they have been recalculated using SAP 2009, as per the ZCH technical modelling assumptions [5]

PHPP & SAP alterations

- All three projects have some form of LZC technology installed on their roofs. These have been removed from the calculations, in order to focus attention solely on fabric performance.
- The default carbon emission factors for mains gas and grid electricity have been replaced with the equivalent carbon emission factors set out the ZCH report (see Figure ii)
- All emissions from unregulated electricity (cooking, appliances, consumer electronics, etc.) have been discounted from the calculation.

3.4 Step by step adjustments

Key modelling steps followed in order to arrive at main calculations included in Appendix.

See Appendix A for SAP based calculations
See Appendix B for PHPP based calculations
Note: More to follow, eventual intention to include SAP and PHPP worksheets

3.5 Comparison of PHPP and SAP output with Carbon Compliance criteria

One recommendation of the task group was that the Carbon Compliance standard be expresssed in terms of *"an absolute limit on the predicted emissions of carbon dioxide (and other greenhouse gases expressed as equivalents) per square metre of internal floor space…measured as an amount in kilograms per square metre per year (kg CO2(eq) /m2/year)."* The basis of this change was to dispense with any confusion arising from the 'the percentage improvement over 2006 Part L figure'.

An example of this confusion can even be seen in the 'Determining the Carbon Compliance limit' section of the final Zero Carbon report [5], where the percentage carbon improvements are discussed. The document mentions "% improvements on the 2006 standard", however it is not made clear as to what this actually refers. There is no mention of Part L 2006 requirements, Target Emission Rate (TER),or indeed of the specific notional buildings which has been used for the calculation. It is acknowledged that the intention here is to steer away from percentage improvements, rather than to dwell on existing methods, yet as the current SAP metric is to first derive a TER, this seems a strange omission.

For the purposes of this report a simple calculation has be used to derive the assumed TER (see Figure v below). The results of this exercise appear to show that a single TER equivalent has been used for all three building typologies, although this may of course be coincidental.

Compliance criterion	Detached houses	Attached houses	Low rise apartment blocks
Carbon emissions for house type	**10 kg $CO_{2(eq)}$/m2a**	**11 kg $CO_{2(eq)}$/m2a**	**14 kg $CO_{2(eq)}/m^2a$**
Equiv. improvement over 2006 Part L	60%	56%	44%
Assumed TER - calculated from above figures	60% improvement over 'x' = 10 kg $CO_{2(eq)}/m^2a$ 56% improvement over 'x' = 11 kg $CO_{2(eq)}/m^2a$ 44% improvement over 'x' = 14 kg $CO_{2(eq)}/m^2a$		**'x'= 25 kg $CO_{2(eq)}/m^2a$ = TER**

Figure vii:

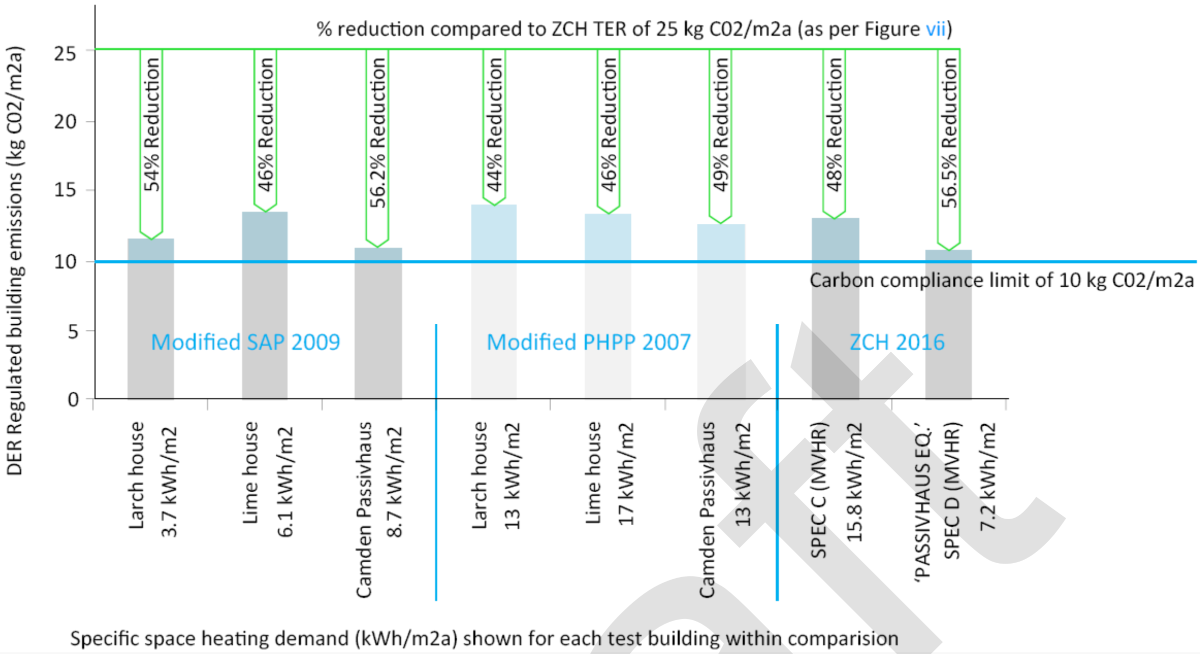
In addition to this assumed TER value, a separate TER has been calculated for each of the projects as part of the Standard Assessment Procedure. More to follow...currents

5 Zero Carbon Hub (2011) *Carbon Compliance: Setting an appropriate limit for zero carbon new homes, Technical Modelling Assumptions. Accessed May 2011 at* http://www.zerocarbonhub.org/resources.aspx

4.0 Results ...notes to be populated and expanded...

4.1 DER output

Chart comparing SAP 2009 and PHPP 2007 Dwelling Emission Rate outputs for each of the sample buildings with two FEES compliant building fabric specifcations from the ZCH 2016 report.

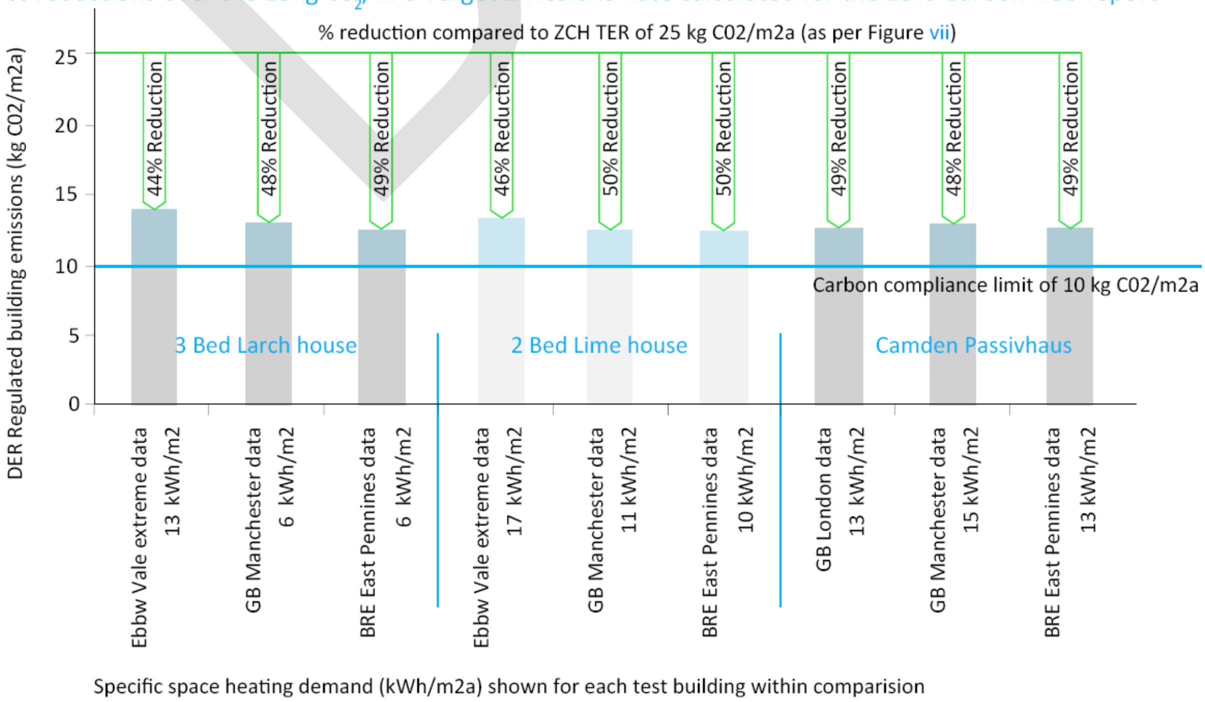


4.2 Regional Variation

To test implication of regional weather data.

Reference to BRE data download page "Global radiation and temperature values can be very site specific, as a result the PHPP outputs can differ for sites which have extreme exposures such as very dense urban, highly exposed or height above sea level compared to the default data sets for the region. This could affect the heating and cooling load results significantly." [6]

Chart showing impact of regional weather data on DER outputs from PHPP 2007 - with associated % reductions over the 25kg CO_2/m^2a Target Emissions Rate calculated for the Zero Carbon Hub report



5 Zero Carbon Hub (2011) *National or Regional Weather: Implications for Carbon Compliance. Accessed June 2011 at* http://www.zerocarbonhub.org/resources.aspx
6 *Building Research* Establishment (2011) *Regional Climate Data Map. Accessed June 2011 at* http://www.passivhaus.org.uk/regional-climate-data

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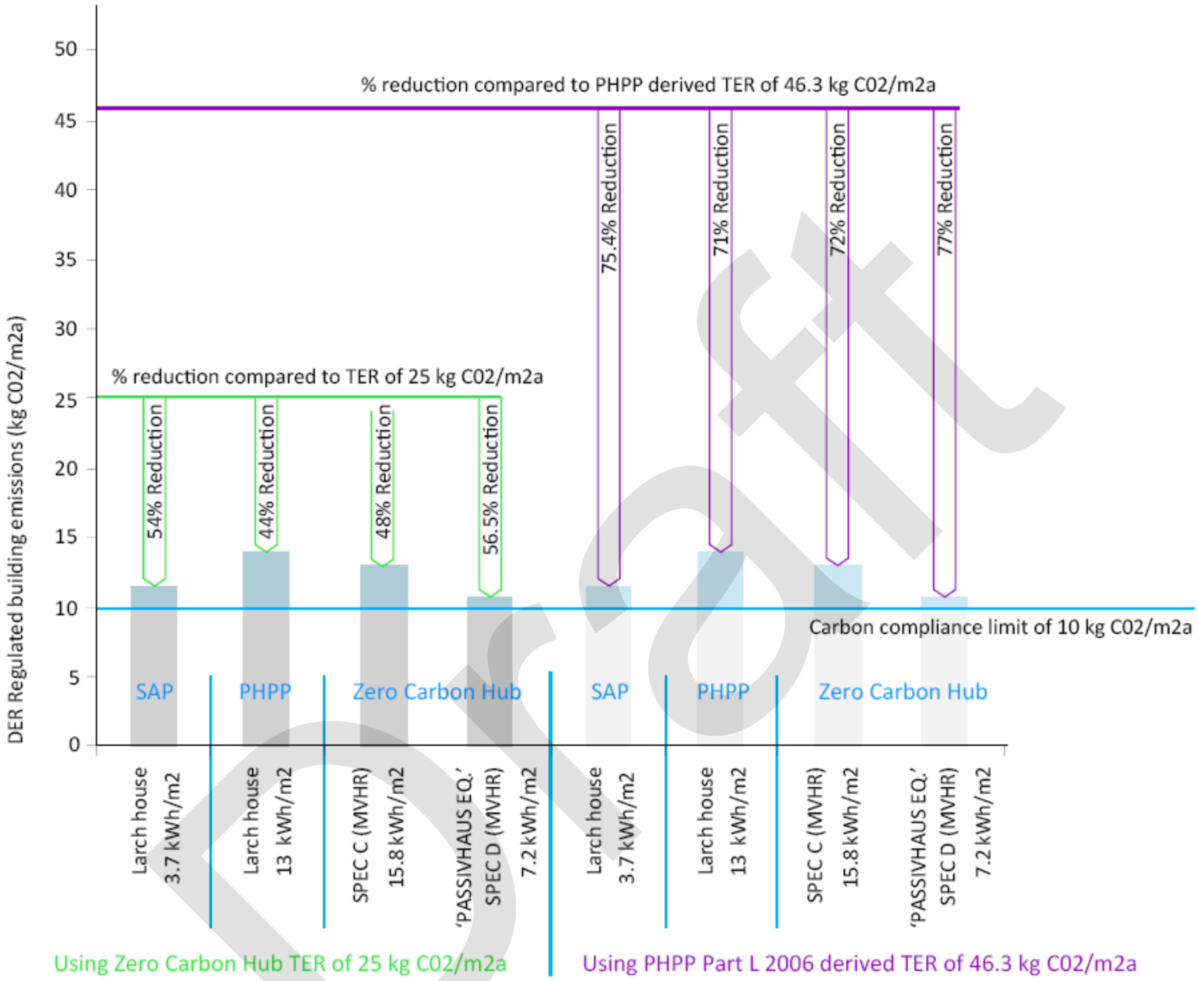
4.3. Creation of a 2006 Part L equivalent building in PHPP

The outputs in steps 4.1 and 4.2 show a clear range of percentage improvements of PHPP outputs of 44-50% even taking into account regional differences. However whilst the figures for CO_2/m^2a remain absolute, the 2006 Part L base figure (from which the percentage improvements are calculated) was established using SAP. The following exercise aims to calculate an equivalent TER building in PHPP, and compare all PHPP results to this figure. See Appendix B for full workings

Chart illustrating % reduction over Target Emission Rates for a 2006 Part L building modelled in PHPP, as compared with a TER of 25kg CO_2/m^2a calculated for the Zero Carbon Hub report



Specific space heating demand (kWh/m2a) shown for each test building within comparision

5.0 Analysis, 6.0 Conclusion ...to be populated.....

...Initial findings and recommendations (to be expanded)

- DER results between SAP, PHPP and ZCH report are surprisingly similar, suggesting that from this limited data set the ZCH modelling of the detached 'SPEC D' PH equivalent dwelling was indeed a good representation of a Passivhaus.
- Regional variation – ie the same building placed in different weather data produces significant enough an effect on the overall C02/space heat demand for the report to recommend regional variation being accounted for within the Carbon Compliance calculation.
- The amount of confusion generated from the research and discussion of percentage improvements over TER figures was such that any future work by bere:architects is unlikely to refer to them. The report will show examples to support the ZCH recommendation for the adoption of absolute figures in place of relative improvements. Calls will be made for this to be incorporated as early as possible – the earliest date realistically being the 2013 Part L review.
- Comparing space heating demand kWh/m^2a figures and DER kg CO_2/m^2 on the same graph has allowed for simpler correlations to be drawn between results than if two separate graphs were used.

- Regardless of scenario/ modelling protocol, the Certified Passivhaus dwellings typically range have between 11 and 14kg CO_2/m^2. Although the report does not intend to express a stance on the use of LZC technology, it will be acknowledged
- It is of key importance that the Government adopts the ZCH recommendation for built performance targets as opposed to as designed targets.
- Although the creation of a 2006 Part L equivalent building in PHPP may be considered by some as 'comparing Apples with Pears' it is felt that the exercise highlights the potential underestimation of regulated emissions for past and current building regulations standard construction.

Appendix A – SAP Calculations

Calculations for Figure iv
Input data from Page 50 of ZCH *"Defining a Fabric Energy Efficiency Standard for zero carbon homes"*, Appendix A Work Group 1 Form and Fabric (2009).
Carbon intensity factors from ZCH as per Figure ii

	Baseline Page 50 Detached house form fabric final						
	As adjusted to ZCH carbon emissions factors						
	kWh/m2						
Space heating	61.5	x	0.227		13.9605		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	1.5	x	0.527		0.7905		
Lighting	6.5	x	0.527		3.4255		percentage improvement
				DER	**22.5122**	If TER = 25....	10.0%
Total	88.6						

	SPEC A (NV) Page 50 Detached house form fabric final						
	As adjusted to ZCH carbon emissions factors						
	kWh/m2						
Space heating	49.7	x	0.227		11.2819		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	1.5	x	0.527		0.7905		
Lighting	3.8	x	0.527		2.0026		percentage improvement
				DER	**18.4107**	If TER = 25....	26.4%
Total	74.1						

	SPEC B (NV) Page 50 Detached house form fabric final						
	As adjusted to ZCH carbon emissions factors						
	kWh/m2						
Space heating	40.7	x	0.227		9.2389		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	1.5	x	0.527		0.7905		
Lighting	3.8	x	0.527		2.0026		percentage improvement
				DER	**16.3677**	If TER = 25....	34.5%
Total	65.1						

	SPEC B (MVHR) Page 50 Detached house form fabric final				
	As adjusted to ZCH carbon emissions factors				
	kWh/m2				
Space heating	30.5	x	0.227		6.9235
Hot Water	19.1	x	0.227		4.3357

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Pumps & fans	5.8	x	0.527		3.0566		
Lighting	3.8	x	0.527		2.0026		percentage improvement
				DER	**16.3184**	If TER = 25....	34.7%
Total	59.2						

SPEC C (NV) Page 50 Detached house form fabric final

As adjusted to ZCH carbon emissions factors

	kWh/m2						
Space heating	30.2	x	0.227		6.8554		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	1.5	x	0.527		0.7905		
Lighting	3.8	x	0.527		2.0026		percentage improvement
				DER	**13.9842**	If TER = 25....	44.1%
Total	54.6						

Spec C (MVHR) Page 50 Detached house form fabric final

As adjusted to ZCH carbon emissions factors

	kWh/m2						
Space heating	15.8	x	0.227		3.5866		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	5.8	x	0.527		3.0566		
Lighting	3.9	x	0.527		2.0553		percentage improvement
				DER	**13.0342**	If TER = 25....	47.9%
Total	44.6						

Spec D (MVHR) Page 50 Detached house form fabric final

As adjusted to ZCH carbon emissions factors

	kWh/m2						
Space heating	7.2	x	0.227		1.6344		
Hot Water	19.1	x	0.227		4.3357		
Pumps & fans	5.4	x	0.527		2.8458		
Lighting	3.9	x	0.527		2.0553		percentage improvement
				DER	**10.8712**	If TER = 25....	56.5%
Total	35.6						

Calculations for SAP DER outputs – adjusted to take into account Carbon emissions factors
Input data from Brooks Devlin, SAP worksheets to follow
Carbon emission factors from ZCH as per Figure ii

	SAP As prepared by Brooks Devlin		**3 Bed Larch house**	Area	99	**SAP** As adjusted to ZCH carbon emissions factors		**3 Bed Larch house**	
Space heat	372.58	x	0.198	73.77084		372.58	x	0.227	84.57566
water heat	2749.82	x	0.198	544.46436		2749.82	x	0.227	624.20914
pump fan etc	393.97	x	0.517	203.68249		393.97	x	0.527	207.62219

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lighting	401.01	x	0.517		207.32217		401.01	x	0.527		211.33227		
					1029.23986						1127.73926		percentage improvement is ....
				DER	10.39636222					**DER**	**11.39130566**	If TER 25....	54.4%
				TER	19.32					TER	19.32	If TER is (Y11)	41.0%

	SAP	**2 Bed Lime house**			Area	77.58	**SAP**	**2 Bed Lime house**					
	As prepared by Brooks Devlin						**As adjusted to ZCH carbon emissions factors**						
Space heat	475.02	x	0.198		94.05396		475.02	x	0.227		107.82954		
water heat	2583.85	x	0.198		511.6023		2583.85	x	0.227		586.53395		
pump fan etc	335	x	0.517		173.195		335	x	0.527		176.545		
lighting	350.26	x	0.517		181.08442		350.26	x	0.527		184.58702		
					959.93568						1055.49551		percentage improvement
				DER =	12.3734942					**DER =**	**13.60525277**	If TER 25....	45.6%
				TER =	20.57					TER =	20.57	If TER is (Y11)	33.9%

	SAP	**Camden Passivhaus**			Area	117.1	**SAP**	**Camden Passivhaus**					
	As prepared by Brooks Devlin						**As adjusted to ZCH carbon emissions factors**						
Space heat	1024.6	x	0.198		202.8708		1024.6	x	0.227		232.5842		
water heat	2573.91	x	0.198		509.63418		2573.91	x	0.227		584.27757		
pump fan etc	437.97	x	0.517		226.43049		437.97	x	0.527		230.81019		
lighting	443.03	x	0.517		229.04651		443.03	x	0.527		233.47681		
					1167.98198						1281.14877		percentage improvement is ....
				DER =	9.974226985					**DER =**	**10.94063851**	If TER 25....	56.2%

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If TER is (Y1 42.0%

TER = 18.86

TER = 18.86

Appendix B – PHPP Calculations

Calculations to removing unregulated emissions from all PHPP worksheets and to insert ZCH carbon emissions factors

Worksheet	Cell Range	Description	Adjustment	Units	Notes
Solar DHW	F11:F18	Selection of collector for solar DHW	Values cleared	N/A	Removal of solar thermal collectors - to demonstrate performance of fabric without addition of LZC technology
	F27,F33	Secondary Calculation of Storage Losses	Values cleared	N/A	No solar collectors - storage losses related to solar storage tank no longer relevant
Electricity	D11:F21, D24:F25	Usage for cooking, electronics, appliances etc (Binary Selection)	Values changed to “0”	N/A	Note: All lighting left unchanged (Row 23) as the lighting detailed on these projects is fixed and therefore part of regulated emissions
Aux Electricity	F30	Electricity for solar DHW pump (Binary Selection)	Value changed to “0”	N/A	Electricity use for solar DHW pump no longer relevant
PE Value	F107	Planned Annual Electricity Generation (Solar PV)	Value cleared	kWh	PV array removed for clarity (calculation is actually separate, meaning this step is not strictly necessary)
Data	E6	Natural gas, CO_2-equivalent emission factor	Value changed to “0.227”	kg/kWh Final	Emission factor adjusted to align with ZCH calculation, as per ZCH 'Modelling_2016_using_SAP_2009_Technical_Guide'
	E10	Electricity-mix, CO_2-equivalent emission factor	Value changed to “0.527”	kg/kWh Final	Emission factor adjusted to align with ZCH calculation, as per ZCH 'Modelling_2016_using_SAP_2009_Technical_Guide'

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PHPP and SAP outputs for main calculations

Larch House	Lime House	Camden Passivhaus
		

Carbon compliance result using results from PHPP (Target for ‘Zero Carbon Compliance’ 10kg CO_2/m^2)		
14.0 kg CO_2/m^2a	**13.5 kg CO_2/m^2a**	**12.7 kg CO_2/m^2a**
Equivalent % improvement over TER of 25 kg $CO_{2(eq)}/m^2a$ (Target 60%)		
44% improvement	**46% improvement**	**49% improvement**

Carbon compliance using results from SAP (Target for ‘Zero Carbon Compliance’ 10kg CO_2/m^2)		
11.4 kg CO_2/m^2a	**13.6 kg CO_2/m^2a**	**10.9 kg CO_2/m^2a**
Equivalent % improvement using TER of 25 kg $CO_{2(eq)}/m^2a$ (Target 60%)		
54% improvement	**46% improvement**	**56% improvement**
Equivalent % improvement over TER individually calculated for each project (as per SAP convention)		
TER of 19.32 C02(eq)/m2a	TER of 20.57 C02(eq)/m2a	TER of 18.86 C02(eq)/m2a

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41% improvement	**34% improvement**	**42% improvement**

Regional Variation

Larch House	Lime House	Camden Passivhaus
		
Decrease of 1.0 kg CO_2/m^2a in Manchester weather data	Decrease of 0.9 kg CO_2/m^2a in Manchester weather data	Increase of 0.1 kg CO_2/m^2a in Manchester weather data
Carbon compliance result using 'average climate' (East Pennines) - Target for detached house 10kg CO_2/m^2		
13.0kg CO_2/m^2a	**12.6kg CO_2/m^2a**	**13.0kg CO_2/m^2a**
Equivalent percentage improvement over 2006 Part L - Target for detached house 60% improvement		
48% improvement	**50% improvement**	**48% improvement**

Larch House	Lime House	Camden Passivhaus
		
Decrease of 1.2 kg CO_2/m^2a in East Pennines weather data	Decrease of 1.0 kg CO_2/m^2a in East Pennines weather data	Increase of 0.1 kg CO_2/m^2a in East Pennines weather data
Carbon compliance result using 'average climate' (East Pennines) - Target for detached house 10kg CO_2/m^2		
12.8kg CO_2/m^2a	**12.5kg CO_2/m^2a**	**12.8kg CO_2/m^2a**
Equivalent percentage improvement over 2006 Part L - Target for detached house 60% improvement		
49% improvement	**50% improvement**	**49% improvement**

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Calculations to create a PHPP 2006 TER equivalent for the 3 bed Larch house
Achieved by modelling to 2006 Part L fabric regulations, - planned extension exercise to model an equivalent 2006 TER as per Notional building specifications.

Certified Larch house				Reductions to create Part L 2006 equivalent		
Element	**Build up of thermal envelope from interior to exterior.**	**Thickness (mm)**	**U value W/(m2k)**	**Build up of thermal envelope from interior to exterior.**	**Reduced build up (mm)**	**Resulting U value W/(m^2K)**
Floor slab	Flooring	20		Flooring	20	
	Screed	75		Screed	75	
	Concrete	225	**0.076**	Concrete	225	**0.250**
	Floormate 500-A	480		Floormate 500-A	**80**	
	Total	**800**		**Total**	**400**	
Exterior Walls	Plasterboard	15		Plasterboard	15	
	Timber studs wood fibre ins.	100	**0.095**	Air gap	25	**0.350**
	OSB	18				
	Timber studs w/ frame ins.	225		Timber studs w/ frame ins.	104	

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	Panelvent	9	
	Wood fibre insulation	100	
	Total	**467**	
Roof	OSB	18	
	Timber truss w/ frame ins.	560	**0.074**
	Total	**578**	
Exterior wall behind kitchen unit	Plasterboard	15	
	Softwood panel	20	
	Timber studs w/ fibre ins.	75	
	OSB	18	
	Timber studs w/ frame ins.	225	**0.098**
	OSB	15	
	Wood fibre insulation	100	
	Total	**468**	
Thermal envelope	$343.29m^2$		
Window U-values	$0.8\ W/(m^2K)$		
Window shading	Window reveal depth ranging from 0.30-0.32m		
LZC technology	4.7 kWp PV array, flat panel solar thermal collector		
Airtightness	q_{50} Air permeability $0.24m^3/(hm^2)$	n_{50} Air changes $0.23\ h^{-1}$	
Space heating demand	$13\ kWh/m^2a$		
CO_2 emissions factors	Natural gas 0.25	Electricity Mix 0.68	
Ventilation	MVHR, Passivhaus certified, 85% efficiency		

OSB	18		
Total	**162**		
OSB	18		
Timber truss w/ frame ins.	185	**0.250**	
Total	**203**		
Plasterboard	15		
Air gap	25		
Timber studs w/ frame ins.	104	**0.350**	
OSB	18		
Total	**162**		
Thermal envelope after fabric reductions (as above)	$294.39\ m^2$		
Window U-values	$2.2\ W/(m^2K)$		
Window shading	Reveal depths reduced by 0.2m		
LZC technology	Removed from calculation		
Airtightness	q_{50} Permeability $10m^3/(hm^2)$	n_{50} Air changes $10.55\ h^{-1}$	
Resulting space heating demand	$155\ kWh/m^2a$		
CO_2 emissions factors	Natural gas 0.227	Electricity Mix 0.527	
Ventilation	Extract only no heat recovery		

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