bere:architects
Mildmay Centre,
Woodville Road,
London, N16 8NA
T +44(0)20 7241 1064
www.bere.co.uk

PassivHaus buildings:

Case study evidence for reduced whole life costs

Caroline Johnstone and Nick Newman

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The UK Government requires that all new houses are to be zero carbon by 2016. However developers have typically been reluctant to move towards this due to a lack of stipulations on how to build the homes and the associated increase in upfront costs. This report suggests that the German PassivHaus standard, which specifies techniques (e.g. airtightness etc) to produce low carbon homes, could provide a suitable method to produce low carbon housing in the UK. Case study evidence from one of the first UK PassivHaus buildings (The Larch house designed by Bere Architects) is used to model whole life costs over a 25 year period for both a PassivHaus and a traditionally build house. Using a variety of Government projections for gas and electricity prices, combined with futures market interest rates, this report shows that the PassivHaus building does have lower whole life costs in all projection scenarios apart from those with continuously high interest rates. This provides the first case study evidence in support of reduced whole life costs for low energy/PassivHaus buildings, and should be a considerable motivator for developers to invest in them. However it is recognised that issues relating to public awareness and appropriate mortgage availability may still hinder this investment. Further research is also needed on the whole life costs of different house types (terrace, high-rise etc), and the implications of maintenance costs.

Introduction

Carbon emissions are the main cause of climate change (CLG, 2007), and have increased globally by 350% since 1960 (The World Bank CO2 emissions, no date). A main source of carbon emissions is from housing, which was expected to account for 13% of all UK emissions in 2010 (CLG, 2008). Reducing this is a national priority, and the UK Government has now pledged that all new homes in the UK will be zero carbon by 2016 (CLG, 2006a). Central to implementing this are the Building Regulations and the Code for Sustainable Homes (the Code). However, the Code only defines target energy use levels to be met, and does not specify the mechanisms to do this (CLG 2006b). Useful lessons can be learnt from the German PassivHaus standard which clearly defines design and construction principles (see Passivhaus Institut, no date) that have been proven to produce low energy buildings (Feist et al., 2005).

The key deterrent for building low energy buildings is the associated increase in build costs (e.g. Schnieders and Hermelink, 2006, Kansal and Kadambari, 2010, McManus et al., 2010). However, these increased upfront costs are offset by reduced energy bills during the building life. Whole life building costs have been promoted by the Government as the best practice for construction procurement (e.g. Egan, 1998, OGC, 2007). Studies have shown specific energy reducing technologies to be effective at reducing whole life costs (e.g. Kneifel, 2010). However with only a handful of PassivHaus buildings existing in the UK (Warm, no date), there have been no studies on the whole life costs associated with UK PassivHaus buildings.

This report summarises what the PassivHaus standard is and provides case study evidence to support the notion of the PassivHaus being a whole life cost effective solution to reducing carbon emissions.

The PassivHaus Standard

The PassivHaus Standard aims to provide, *"an acceptable and even improved indoor environment in terms of IAQ [indoor air quality] and thermal comfort at minimum energy demand and cost"* (Feist et al., 2005). PassivHaus buildings use specific design techniques (e.g. insulation, airtightness and mechanical ventilation systems) to ensure energy consumption during building use is kept to a minimum. For a European house (40^o-60^o Northern latitude) to be certified, it must be designed and constructed to use less than 15 kWh/m^2 per annum for space heating and cooling, and less than 120 kWh/m^2 per annum for total primary energy use (PassivHausUK, no date). In the CEPHEUS study of over 100 passive houses in 5 countries post occupancy it was found that there were savings of more than 50% of the total primary energy consumption (Feist et al. 2005).

In Europe there have been over 20,000 PassivHaus buildings certified to date (Passivhaus Trust, no date), however in the UK there are currently less than ten (Warm, no date), with the first London PassivHaus, designed by Bere Architects, only being completed in 2010 (Camden Council, 2011)

Whole life costs

The Whole life costs (WLC) from the viewpoint of the home owner (and energy bill payer), can be defined as:

Whole Life Costs (WLC) = Property purchase price (PPP) + energy bills (EB) +
non energy bills (N-EB) + maintenance costs (MC)

The PPP occurs when the house is first purchased but the other costs are incurred over the life of the house. A traditional house will be expected to have a lower PPP and higher EB compared to a PassivHaus (e.g. Kneifel, 2010). Energy bills are directly related to energy prices, and as such will be higher when gas and electricity prices are higher. Interest rates will also affect WLC because the higher the long term interest rate, the lower the future energy bill payments are worth in cash values today. As a result, this report proposes the following hypotheses to be tested:

Hypothesis 1: A PassivHaus building will have lower whole life costs compared to a traditionally built new building.

Hypothesis 2: The difference in whole life costs between a PassivHaus building and traditional build will be greater when electricity prices are high compared to low.

Hypothesis 3: The difference in whole life costs between a PassivHaus building and traditional build will be greater when gas prices are high compared to low.

Hypothesis 4: The difference in whole life costs between a PassivHaus building and traditional build will be greater when interest rates are low compared to high.

Method

The study compared whole life costs of a PassivHaus (The Larch House in Wales, see Bere Architects, 2010), with a traditionally built building. As noted above, the Whole life costs (WLC) from the viewpoint of the home owner (and energy bill payer), can be defined as:

Whole Life Costs (WLC) = Property purchase price (PPP) + energy bills (EB) +

non energy bills (N-EB) + maintenance costs (MC)

PPP for this analysis was assumed to be the cost of the building. N-EB and MC were assumed to be zero and thus to affect the different types of houses equally. This is likely to be the case for N-EB however for MC there is no evidence to support or contradict this at present. This is a key limitation of this study as maintenance costs contribute approximately five times more to the WLC than build costs (Evans et al., 1998). For the purpose of this study then, WLC was calculated as follows:

WLC = Build Cost (BC) + energy bills (EB)

All cash flows for BC and EB were discounted using interest rates to calculate the Net Present Value (NPV) of the WLC. Details of how the Build Cost (BC) and Energy Bills (EB) cash flows were calculated, and how they were discounted to NPV are explained below.

Build Cost

The build costs for the PassivHaus, were the costs realised for the Bere Architects designed Larch House in Wales (see Bere Architects, 2010), which were then adjusted to be applicable to a less extreme, Manchester weather climate (£1,317 per sq m). The build costs for the traditional home were then calculated by adjusting the PassivHaus design to replicate that of a traditional house (adjustments are detailed in Appendix 1), resulting in a cost of £1,171 per sq m). The two houses were therefore consistent in size and shape but not in energy efficiency.

To try to be as true to life as possible, it was assumed that a home owner would purchase the houses with a mortgage that included a 15% deposit, and that the mortgage was to be repaid (capital and interest) over 25 years.

BC = mortgage deposit + mortgage interest payments per annum – mortgage loan

The mortgage interest payments were assumed to be annual, and were calculated as the mortgage rate multiplied by the combined mortgage loan minus mortgage deposit. The mortgage rate used was fixed at 3% above the relevant interest rate.

To allow for a fair comparison between the two houses, it was assumed that the initial capital available was the same for both homes, and this was set at 15% of the house with the greatest BC. For the house with the lower BC, it was assumed that the money difference was invested in a bank account for the 25 year duration. The interest rate used was the same as that used for calculating the NPV (see Graph 3).

Energy Bills

The Energy Bills (EB) were assumed to be derived from gas or electricity grid system sources. No on site renewable generation were accounted for because although the higher Code levels require this, they are not required for the PassivHaus standard. The effects of adding on-site renewable generation would be severely impacted by the Feed-in Tariff, which pays on site generators a fee for every kWh of energy they generate. It would therefore be likely that adding renewables would reduce the WLC of a PassivHaus but to be conservative (and because the Feed-in Tariff is due to be reviewed in 2012), it will not be considered here (see Feed-in Tariffs, no date). Therefore, EB was assumed to be as follows:

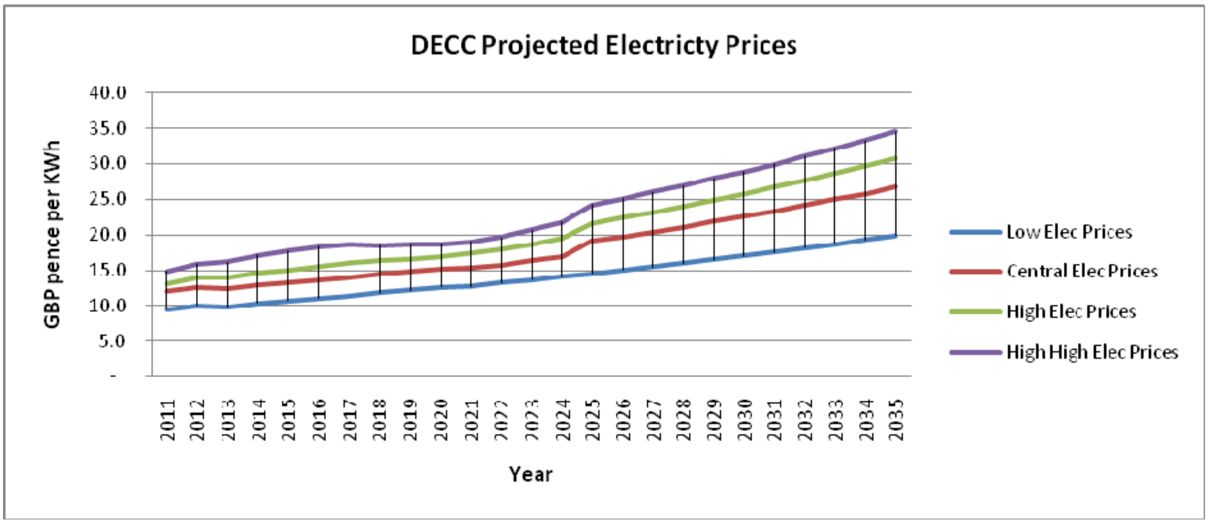
EB = Sum (Gas usage per annum * Gas price per annum) + Sum (Electricity usage per annum * Electricity price per annum)

Gas and electricity usage per annum was based on PHPP modelling of the two houses. The PassivHaus house has a projected annual usage of 1,622kWh electricity and 2,423kWh gas. The traditional house has a projected annual usage of 1,395KWh electricity and 13,249kWh gas. For simplification of calculations, bills were assumed to be paid once annually.

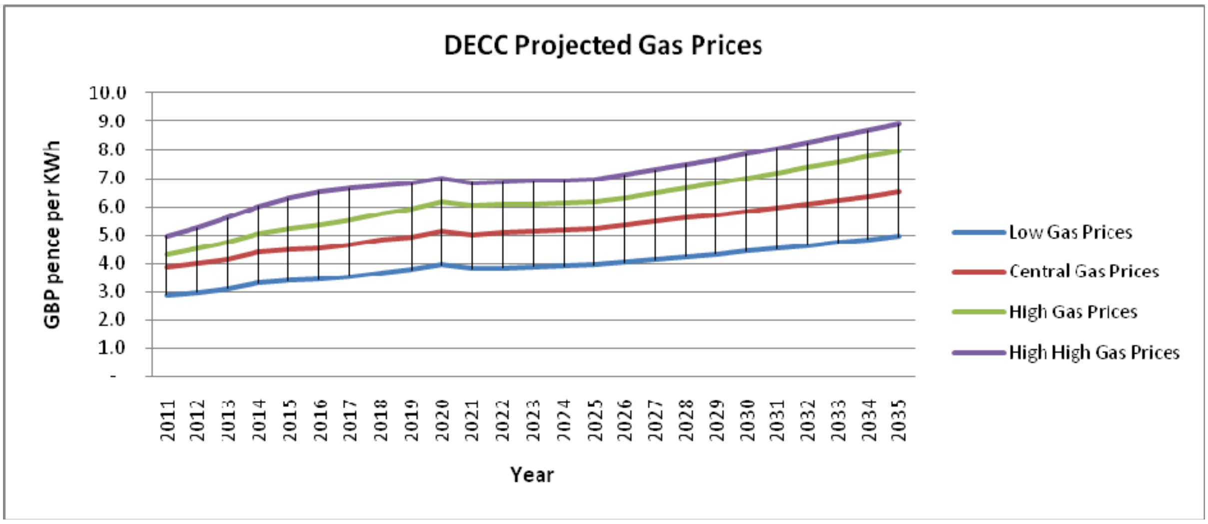
Projected gas and electricity prices were based on possible price scenarios identified by the Department of Energy & Climate Change (DECC, 2010) as follows:

- Low Prices: Reflecting low global energy demand.
- Moderate Prices: Reflecting timely investment and moderate demand.
- High Prices: Reflecting high demand and supplier market power.
- High High Prices: Reflecting high demand and significant market supply constraints.

DECC (2010) projections were for 15 years and to extend to 25 years (the length of a typical mortgage) the prices have been grown at the average percentage increase over the 15 years. The price projections for electricity (Graph 1) and gas prices (Graph 2) are shown below:



Graph 1: Department of Energy & Climate Change electricity price projections in four scenarios.



Graph 2: Department of Energy & Climate Change gas price projections in four scenarios.

Net Present Value
As noted above, the cash flows representative of the WLC were determined to be as follows:

WLC = mortgage deposit + mortgage interest payments per annum – mortgage loan + Sum(Gas usage per annum * Gas price per annum) + Sum (Electricity usage per annum * Electricity price per annum)

As these cash flows will be occurring at different times during the life of the building (e.g. mortgage deposit is upfront, but EB will be paid every year), each cash flow was discounted to get its present value.

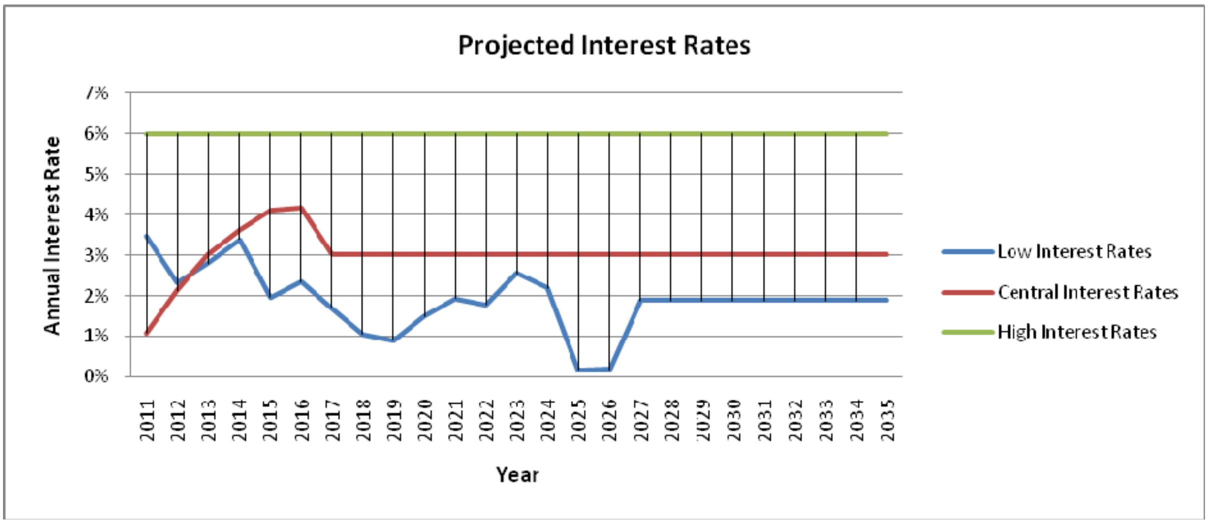
$$\text{Present Value (PV)} = \text{cash flow} / (1 + rate_1)(1 + rate_2)(1 + rate_3).....(1 + rate_n)$$

n = number of years from present until cash flow.

The interest rates used to discount the cash flows were derived from three sources (see Graph 3 for actual rates). Firstly, the historic interest rates for sterling instant access deposit accounts, from 1995 to 2010, were used (Bank of England, no date). The monthly rates were averaged over the year to get an annual rate. Rates prior to 1995 were not available so for the last 9 years of the 25 year period, the rate was left constant at the average rate over the 16 years (1.89%). This is referred to as the, "Low Interest Rates" model.

Secondly, the three month sterling Euronext future trading prices as at 12 January 2011 was used (see Euronext, 2011). The three monthly rates were averaged over the year to get an annual rate. Prices after 2016 (5 years) were again left constant at the average rate over the 6 years (3.03%). This is referred to as the, "Central Interest Rates" model.

Lastly, a fixed high interest rate ("High Interest Rates" model) was chosen (6%) as a comparison against the two lower rate curves.

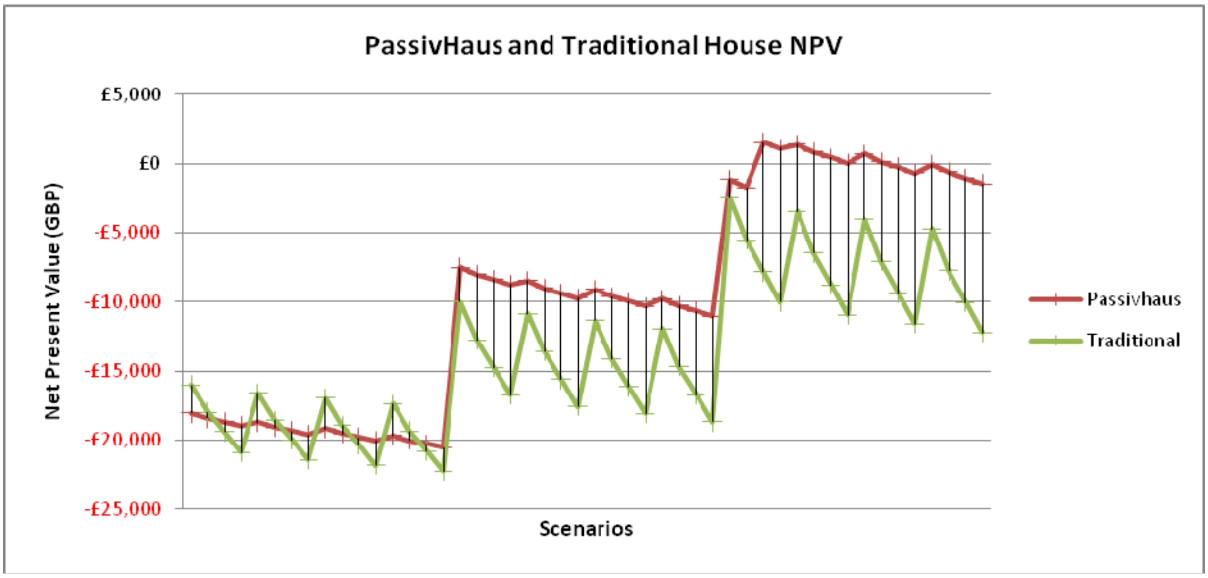


Graph 3: Three projected interest rate scenarios over 25 years.

NPV was calculated for both houses using 48 scenarios of electricity price, gas price and interest rate scenarios.

<u>Results</u>

For 40 out of the 48 scenarios, the NPV for PassivHaus was higher than the equivalent scenario for a traditional house (see Graph 4). Those scenarios where the Traditional house had a greater NPV were all when interest rates were high.



Graph 4: NPV for a PassivHaus and Traditional house in a variety of scenarios.

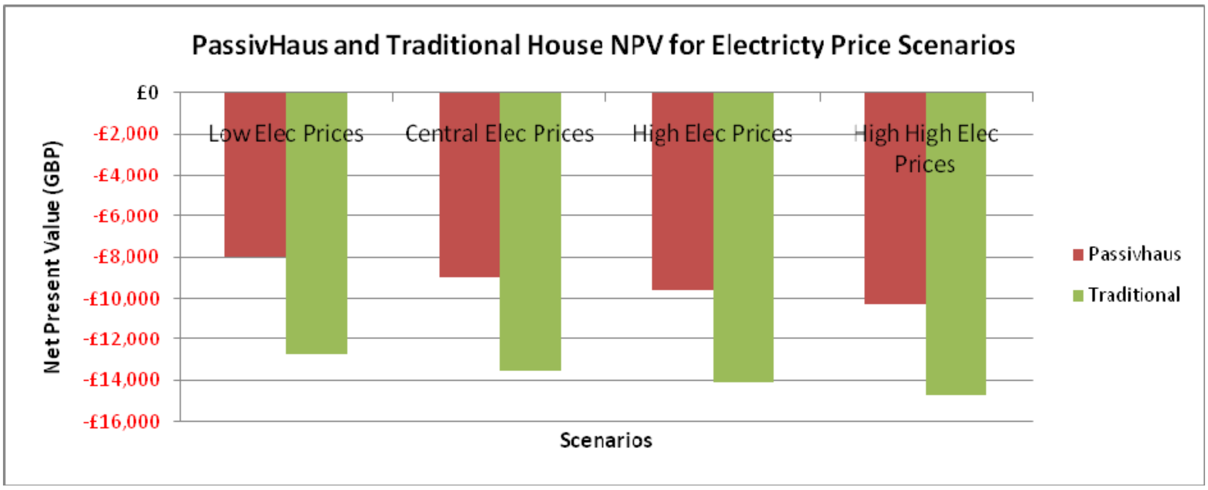
Impact of Electricity Prices

Electricity prices did not have a great impact on NPV for a PassivHaus or traditional house, regardless of the gas prices and interest rates (see Table 1). For a PassivHaus, the maximum change in NPV for a change in electricity prices is £2,582, and the minimum impact is £1,597. For a Traditional house, the maximum change in NPV for a change in electricity prices is £2,218, and the minimum impact is £1,374.

Variable	PassivHaus Minimum NPV Change (£)	PassivHaus Maximum NPV Change (£)	PassivHaus Range of NPV Change (£)	Traditional Minimum NPV Change (£)	Traditional Maximum NPV Change(£)	Traditional Range of NPV Change(£)
Electricity Prices	£1,597	£2,582	£985	£1,374	£2,218	£844
Gas Prices	£892	£3,273	£2,381	£4,877	£7,535	£2,658
Interest Rates	£16,691	£20,228	£3,536	£10,027	£13,530	£3,503

Table 1: Impact of electricity prices, gas prices and interest rates on NPV in various scenarios.

Although the impact of electricity prices is not large, the higher the electricity prices, the lower the NPV for both house types (see Graph 5). The difference between the NPV of the two houses however remains relatively constant in absolute terms at all electricity prices.

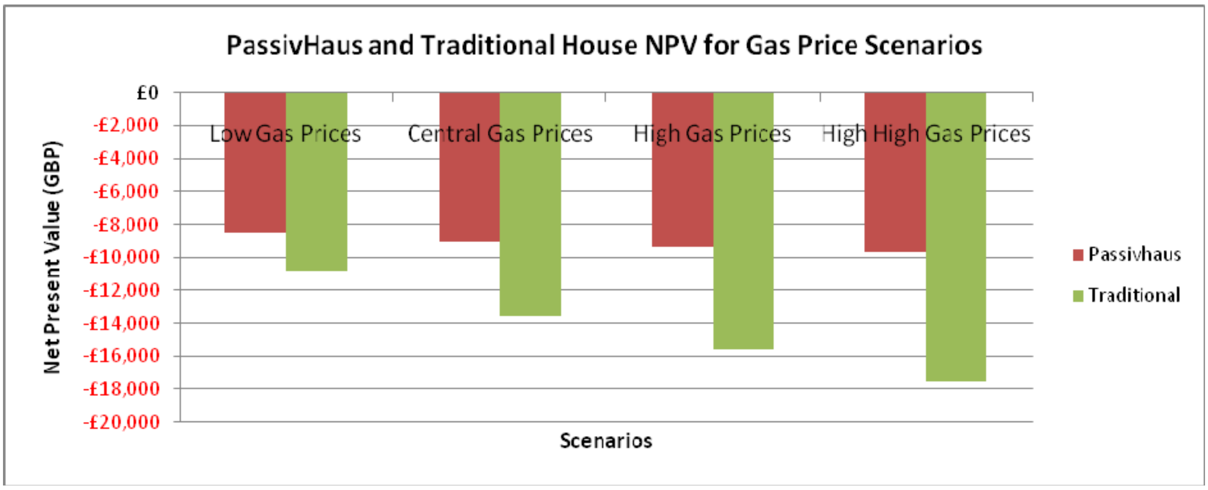


Graph 5: NPV change for a PassivHaus and Traditional house in different electricity price scenarios (using central gas prices and interest rates).

Impact of Gas Prices

Gas Prices have a greater impact on NPV than electricity (see Table 1), especially for a Traditional house. In absolute terms they can change the NPV on a Traditional house by up to £7,535, but for a PassivHaus the maximum impact is £3,273. This is unsurprising considering the greater proportion of gas used compared to electricity in these houses (60% gas for the PassivHaus and 90% gas for the Traditional house), and the absolute greater use of energy by the Traditional house compared to the PassivHaus.

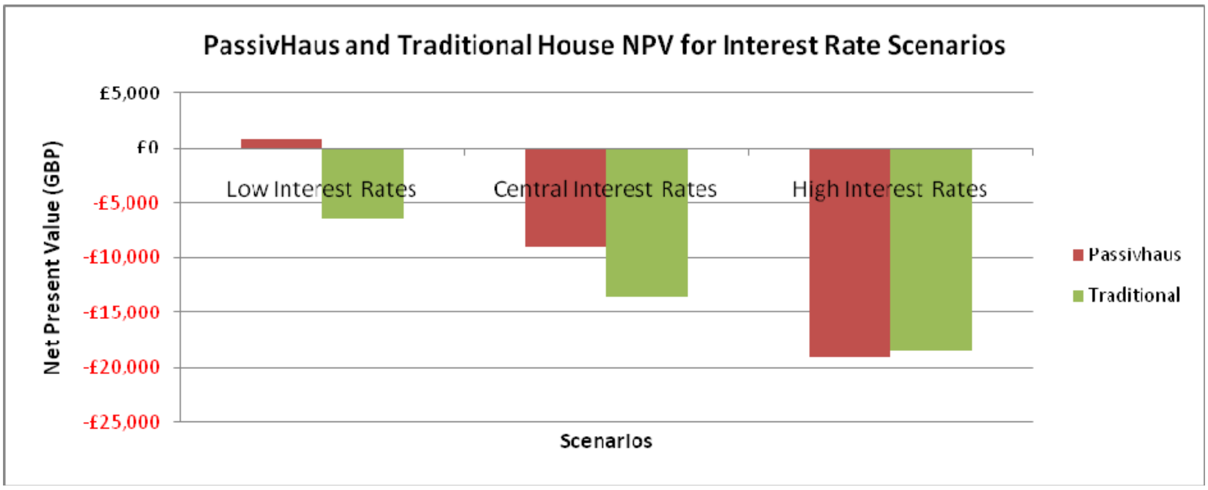
Similar to the impact of electricity, the higher the gas prices, the less the NPV becomes for both the PassivHaus and the Traditional house. The difference in NPV between the two properties also increases, with 'high high gas prices' causing a significantly worse NPV for the Traditional house compared to the PassivHaus.



Graph 6: NPV change for a PassivHaus and Traditional house in different gas price scenarios (using central gas prices and interest rates).

Impact of Interest Rates

Interest rates have a much more significant impact of NPV than either electricity or gas prices. Interest rates changed the NPV for the PassivHaus by between £17k and £20k, but only changed the NPV for the Traditional house by between £10k and £14k. For both, the higher the interest rate, the lower the NPV (see Graph 7). As interest rates increase, the Traditional house's NPV lowers at a slower rate to the PassivHaus', such that with low interest rates the PassivHaus' NPV is the higher of the two, but with high interest rates the Traditional house's NPV is higher (see Graph 7).



Graph 7: NPV change for a PassivHaus and Traditional house in different interest rate scenarios (using central gas prices and electricity prices).

Analysis

Hypothesis 1: A PassivHaus building will have lower whole life costs compared to a traditionally built new building.

In support of this, our study found that in 40 out of 48 scenarios this was the case. In the 8 situations when the Traditional house had a higher NPV, the interest rates were high. The only high interest rates scenarios to result in the PassivHaus having a higher NPV occurred when the gas prices were 'high' or 'high high'. This occurred regardless of the electricity price.

Higher interest rates mean that future cash flows are worth less in today's money terms compared to low interest rates. As the Traditional house has a greater proportion of its cash flows during the life of the house rather than upfront, it is to be expected that when interest rates are high its NPV will be reduced to less than that of the PassivHaus. The significance of the gas prices is due to the higher proportion of gas used compared to electricity in the two houses (90% of energy comes from gas in the Traditional house).

Hypothesis 2: The difference in whole life costs between a PassivHaus building and traditional build will be greater when electricity prices are high compared to low.
Again our study shows support for this but only weakly. Even though electricity prices are higher than gas prices, due to the proportion of electricity being used being low, the significance of electricity prices is only small, with prices effecting the NPV by only £1000 for both homes. The impact on the prices is approximately the same for the two houses because in absolute terms they use a similar amount of electricity per annum (1622 kWh for the PassivHaus and 1395 kWh for the Traditional house).

Hypothesis 3: The difference in whole life costs between a PassivHaus building and traditional build will be greater when gas prices are high compared to low.
Our study again shows support for this, with the PassivHaus NPV only changing slightly when the gas prices increased, however the Traditional house's NPV reduced more dramatically when gas prices increased.

Hypothesis 4: The difference in whole life costs between a PassivHaus building and traditional build will be greater when interest rates are low compared to high.
The NPV advantage of the PassivHaus is most significantly affected by interest rates compared to gas and electricity prices. When interest rates increase, the financial advantage of the PassivHaus decreases and it can result in the Traditional house having a greater NPV. This is a result of the future energy bills being worth less in terms of today's money when interest rates are high. In absolute terms, the energy bill's value today keeps lowering as interest rates rise and can then become less than the extra build costs associated with the PassivHaus.

Conclusions

This is the first study to apply expectations of gas prices, electricity prices and interest rates to the whole life costs of a real PassivHaus building. It clearly shows that PassivHaus buildings are financially viable in all situations except for when there are continued high interest rates. As expected, the benefits were greatest when gas and electricity prices are low. This study took a conservative approach, ignoring the resale value of the houses (which would be expected to be greater for the PassivHaus due to the higher initial cost), looking at only a 25 year life span, and importantly not including the feed-in tariff. With these included the financial benefits of the PassivHaus are potentially even greater.

This study should provide encouragement to developers to produce houses of a PassivHaus quality, to not only comply with Government regulations but also to gain whole life cost benefits. However there remain difficulties because the public must be willing to purchase more expensive properties in the knowledge that they will benefit financially over the life of the house ownership. Not only will this require greater public awareness but it will also require financial mechanisms to be designed to support greater initial upfront investment. Financial institutions must be able to tailor mortgage requirements to PassivHaus buyers who will inevitably be able to pay more back per month towards their mortgage compared to ordinary home buyers (assuming they put the money they would have spent on energy bills towards their mortgages). Without this, buyers will be limited in their ability to afford PassivHaus buildings despite the overall cost saving benefits.

Further research needs to be conducted to validate these findings, and to expand their application to different house types (flats, terraces, multi-house developments etc). In addition, the key element missing from the calculation of whole life costs is the expected maintenance costs for the two types of houses. A review of the literature has revealed that there are currently no studies comparing the maintenance costs of PassivHaus (or low energy homes) against traditionally built homes and until this has been done no true picture of the true life costs can be gained.

Appendix 1

Energy analysis of the PassivHaus and Traditional House

PassivHaus (Larch House adjusted for Manchester climate)		
Build up of thermal envelope from interior to exterior.	**Thickness (mm)**	**U value W/(m2k)**
Flooring	20	**0.100**
Screed	75	
Concrete	225	
Floormate 500-A	360	
Total	**680**	
Plasterboard	15	**0.132**
Timber studs w/wood fibre ins.	100	
OSB	18	
Timber studs w/Knauf frame ins.	200	
Panelvent	9	
Wood fibre insulation	0	
Total	**342**	
OSB	18	**0.074**
Timber truss w/Knauf frame ins.	560	
Total	**578**	
Plasterboard	15	**0.136**

Traditional House		
Build up of thermal envelope from interior to exterior.	**Reduced build up (mm)**	**Resulting U value (equal to 2010 fabric limits)**
Flooring	20	**0.250**
Screed	75	
Concrete	225	
Insulation	80	
Total	**400**	
Plasterboard	15	**0.300**
Air gap	25	
OSB	18	
Timber studs w/Knauf frame ins.	127	
Total	**185**	
OSB	18	**0.200**
Timber truss w/Knauf frame ins.	236	
Total	**254**	
Plasterboard	15	**0.300**

Softwood panel	20		Air gap	25	
Timber studs w/wood fibre ins.	75		Timber studs w/Knauf frame ins.	127	
OSB	18		OSB	18	
Timber studs w/Knauf frame ins.	200				
OSB	15				
Wood fibre insulation	0				
Total	**343**		**Total**	**185**	

Window area on South Facade	16.30m2	**Window area on South Facade**	16.30m2
Window area on East Facade	1.66m2	**Window area on East Facade**	1.66m2

Photovoltaics	Not included for study	**Photovoltaics**	Not included for study
Airtightness	0.2 h-1	**Airtightness**	10 h-1

Space heating demand	13Kwh/m2a	**Space heating demand**	139Kwh/m2a
Annual electricity demand	1621.91 Kwh	**Annual electricity demand**	1394.76 Kwh
Annual gas demand	2423.48 Kwh	**Annual gas demand**	13249.18 Kwh

Cost analysis of the PassivHaus and Traditional House

PassivHaus (Larch House adjusted for Manchester climate)	
Substructure	**147**
Frame	232
Upper Floors	5
Roof	54
Stairs	19
External Walls	174
External Windows and Doors	162
Internal Walls and Partitions	33
Internal Doors	24
Superstructure	**703**
Wall Finishes	46
Floor Finishes	40
Ceiling Finishes	17
Finishes	**103**
Fittings and Furnishings	18
White goods	20

Traditional House	
Substructure	**112**
Frame	66
Upper Floors	34
Roof	152
Stairs	21
External Walls	127
External Windows and Doors	105
Internal Walls and Partitions	33
Internal Doors	44
Superstructure	**582**
Wall Finishes	57
Floor Finishes	38
Ceiling Finishes	31
Finishes	**126**
Fittings and Furnishings	50

Sanitary Appliances	77
Services Equipment	0
Disposal Installations	0
Water Installations	0
Solar water heating installation	22
Heat Source	0
PV installation	0
Space Heating and Air Conditioning	0
Ventilating Systems	99
Electrical Installations	84
Fuel Installations	0
Lift and Conveyor Installations	0
Fire and Lightning Protection	0
Communications and Security Installations	0
Special Installations	0
Sprinkler installation	32
Builder's Work in Connection	11
Management of the Commissioning of Services	0
Services	**325**
BUILDING COST excluding Preliminaries	**1317**

Sanitary Appliances	30
Services Equipment	0
Disposal Installations	9
Water Installations	23
Heat Source	0
Space Heating and Air Conditioning	66
Ventilating Systems	7
Electrical Installations	46
Fuel Installations	0
Lift and Conveyor Installations	0
Fire and Lightning Protection	8
Communications and Security Installations	6
Special Installations	37
Builder's Work in Connection	11
Management of the Commissioning of Services	8
Services	**301**
BUILDING COST excluding Preliminaries	**1171**

References

Bank of England (no date). *Monthly interest rate of UK monetary financial institutions (excl. Central Bank) sterling instant access deposits from households (in percent) not seasonally adjusted (*1).* Available at: http://www.bankofengland.co.uk/mfsd/iadb/index.asp?Travel=NIxSTxTIx&levels=1&XNotes=Y&C=EC1&XNotes2=Y&Nodes=X40727X40728X40754X40755X45786X40759X40783&SectionRequired=I&HideNums=-1&ExtraInfo=false&G0Xtop.x=31&G0Xtop.y=8 (Accessed: 17 January 2011).

Bere Architects (2010). *First Welsh Passivhaus prototype – Fenestration Calculations & Cost Data.* Available at: http://www.bere-blog.co.uk/blog/first-welsh-passivhaus-prototype-%E2%80%93-fenestration-calculations-cost-data (Accessed: 20 January 2011).

Camden Council (2011). *Low Carbon Buildings*. Available at: http://www.camden.gov.uk/ccm/content/environment/energy/low-carbon-buildings.en?page=8 (Accessed: 17 January 2011).

CLG (2006a). *Building a Greener Future: Towards Zero Carbon Development.* Available at: http://www.communities.gov.uk/documents/planningandbuilding/pdf/153125.pdf (Accessed: 13 January 2011).

CLG (2006b). *Code for Sustainable Homes. A step-change in sustainable home building practice.* Available at: http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf (Accessed: 4 January 2011.

CLG (2007). *Building a Greener Future: Policy Statement.* Available at: http://www.communities.gov.uk/documents/planningandbuilding/pdf/building-greener.pdf (Accessed: 13 January 2011).

CLG (2008). *Housing and planning: The crucial role of the new local performance framework.* Available at: http://www.communities.gov.uk/documents/localgovernment/pdf/741935.pdf (Accessed: 13 January 2011).

DECC (2010). *Energy and emissions projections.* Available at: http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx (Accessed: 20 January 2011)

Department of Trade and Industry (1998). *Rethinking Construction*. Available at: http://www.constructingexcellence.org.uk/pdf/rethinking%20construction/rethinking_construction_report.pdf (Accessed: 17 January 2011).

Euronext (2011). Three Month Sterling (Short Sterling) Futures. Available at: http://www.euronext.com/trader/summarizedmarketderivatives/summarizedmarketderivatives-3643-EN.html?contractType=9&mnemo=L&selectedMepDerivative=7 (Accessed: 13 January 2011).

Evans, R., Haryott, H., Haste, N. and Jones, A. (1998). The Long-Term Costs of Owning and Using Buildings. London: The Royal Academy of Engineering. Available at: http://www.raeng.org.uk/news/publications/list/reports/The_Long-Term_Costs_of_Buildings.pdf (Accessed: 28 October 2010).

Feed-in Tariffs (no date). Available at: http://www.fitariffs.co.uk/ (Accessed: 17 January 2011).

Feist, W., Schnieders, J., Dorer, V. and Haas, A. (2005). Re-inventing air conditioning: Convenience and comfortable within the frame of the Passive House Concept. *Energy & Buildings.* 27(11), pp. 1186-1203.

Kansal, R. and Kadambari, G. (2010). Green Buildings: An Assessment of Life Cycle Cost. *Journal of Infrastructure.* 8(4), pp. 50-57.

Kneifel, J. (2010). Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. *Energy and Buildings*. 42(3), pp. 333-340.

McManus, A., Gaterell, M.R. and Coates, L.E. (2010). The Potential of the Code for Sustainable Homes to deliver genuine 'sustainable energy' in the UK social housing sector. *Energy Policy.* 38(4), pp. 2013-1019.

OGC (2007). *Achieving Excellence in Construction Procurement Guide: Whole-life costing and cost management.* Available at: http://www.ogc.gov.uk/documents/CP0067AEGuide7.pdf (Accessed: 17 January 2011).

Passivhaus Institut (no date). Available at: http://www.passiv.de/ (Accessed: 16 January 2011).

Passivhaus Truct (no date). Available at: http://www.passivhaustrust.org.uk/about.php (Accessed: 17 January 2011).

PassivHausUK (no date). Available at: www.passivhaus.org.uk (Accessed: 4 January 2011).

Schnieders, J. and 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.

The World Bank CO2 emissions. (no date). *CO2 emissions (kT).* Available at: http://data.worldbank.org/indicator/EN.ATM.CO2E.KT (Accessed: 19 November 2010).

Warm (no date). Available at: http://www.peterwarm.co.uk/ (Accessed: 16 January 2011).