Eight Associates
178 Ebury Street
London SW1W 8UP

+ (44) 020 7881 3090 Telephone
+ (44) 0845 458 1522 Fascimile

www.eightassociates.co.uk
info@eightassociates.co.uk

Princedale Road

Post Occupancy Evaluation

Prepared by:
Eight Associates
The Old School House
London SW1W 8UP

Prepared for:
Lewis Lowe
Octavia Housing

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Prepared by:	Pierre-Luc Joffre
Company Name:	Eight Associates
Signature:	PLJ
Quality Assured by:	Jean-Pierre Wack
Signature	JPW

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Summary

Introduction
Princedale Road

Aim of the report

The aim of this report is to undertake a Post Occupancy Evaluation of three schemes (a certified Passivhaus, a 'Decent Home Plus', and a typical UK house) to analyse carbon emissions, Final Energy Demand, water consumption, thermal comfort and indoor air quality in both summer and winter.

The data presented in this report covers a one-year period of occupancy in the three schemes (from June 2011 to May 2012, with some data gaps (See Appendix 3)).

Context

In 2009, the UK semi-public body Technology Strategy Board launched the government's 'Retrofit for the Future' programme, which aims to understand the implications of retrofitting UK social housing stock in order to meet future targets in reduction of $C0_2$ and energy use.

The house at number 100 Princedale road is part of this initiative. The dwelling is a small, terraced house built around 1840, owned by Octavia Housing, registered social landlords. It was in need of a full refurbishment when the government put the 'Retrofit for the Future' programme forward in 2009.

Scheme description - Passivhaus

The retrofit project of 100 Princedale Road is following the Passivhaus philosophy based on solid physics. The design challenge was to meet the rigorous Passivhaus standards in the retrofit of a Victorian house in a Conservation Area. Aimed at social housing, the design had to be functional and robust with detailing kept neutral and simple to allow all families to feel welcome.

The Passivhaus Institut delivered the Passivhaus certificate for the house in February 2011, and the current family (composed of Mrs. Bakali and her three children aged 16, 11 and 5) moved into the house one month later, in March 2011.

Since then, the site has been monitored for operational performance in terms of electricity, water, temperatures and relative humidity and $C0_2$ concentrations.

Introduction
Princedale Road

Comparative schemes description

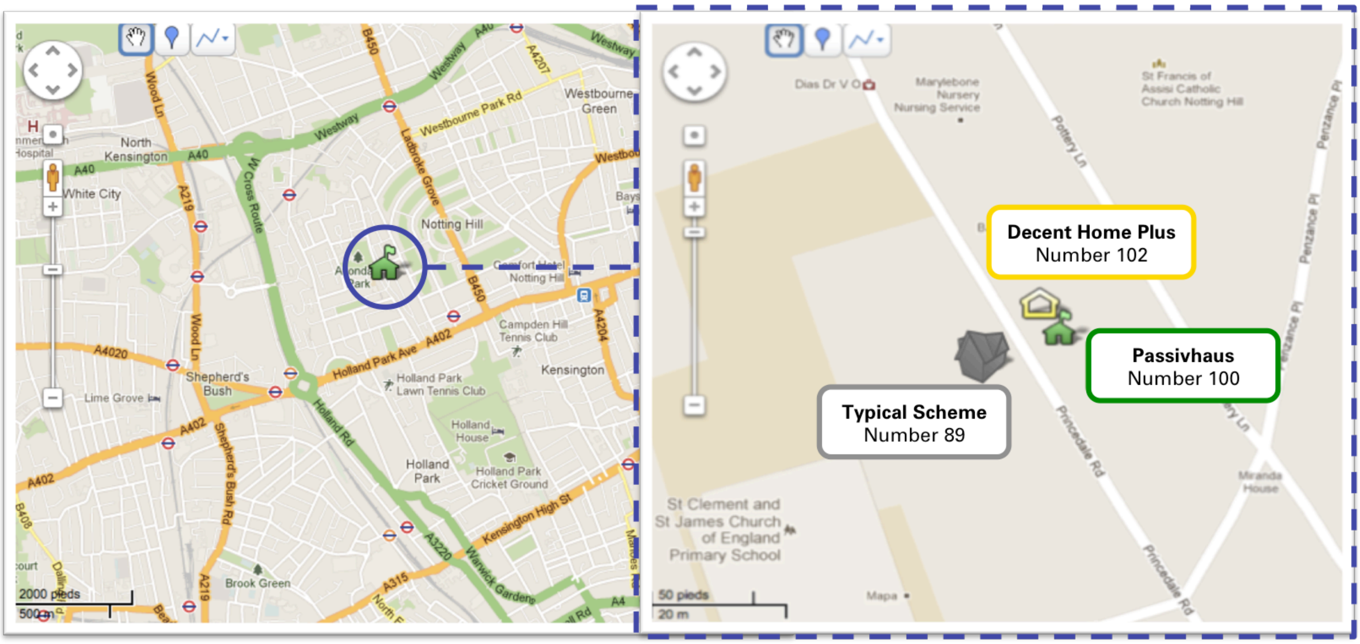
In addition, two properties have been put forward to act as comparative tools for monitoring purposes. These have been monitored for a similar period to the primary scheme (June 2011 – May 2012).

First, the building at number 102 Princedale Road is of similar period and geometry. It is located next door and the orientation and build-ups of the standard are exactly the same. Although there is the same number of bedrooms and the living areas are similar, the layouts are slightly different. The scheme has been retrofitted to the ‘Decent Homes Plus’ specifications, which mainly consists in installing high performance insulation on roof, floors and walls, alongside an energy efficient heating system. The dwelling will be referred to as the “Decent Home Plus” throughout the report.

Secondly, the building at number 89 Princedale Road is also of similar period and geometry but is located on the opposite row of terraces to the Passivhaus. This site is also part of the Octavia Housing’s stock. No retrofit work has been undertaken for this building. Hence it will stand as the “typical” baseline to which the benefits of the retrofit projects at number 100 and 102 Princedale Road will be compared. The dwelling will be referred to as the “Typical Scheme” throughout the report.

Houses location

The three houses are located on Princedale Road in London, close to Holland Park (W11 4NH).



Executive Summary
Princedale Road

Final Energy Demand

The analysis of monitored Final Energy Demand in the three houses highlights huge savings for both the Passivhaus and the Decent Home Plus compared to the typical scheme. Final Energy Demand for the Passivhaus was 63 kWh/(m^2a) as against 198 kWh/(m^2a) for the Decent Home Plus and 366 kWh/(m^2a) for the typical scheme, which yields a 83% reduction for the Passivhaus and 46% for the Decent Home Plus compared to the typical scheme.

CO_2 emissions

The Passivhaus achieved a 70% reduction in carbon emissions compared to the typical scheme, which is equivalent to a reduction of 5.5 tons of $C0_2$ emitted per year.
The Decent Home Plus reduction in carbon emissions was 37%, equivalent to 2.8 tons of CO_2 saved per year.

Energy bills

For one year of electricity consumption, the Passivhaus energy bills added up to £772, resulting in a 62% reduction in energy bills compared to the standard house. This is equivalent to £1,255 saved per year. The bills of the Decent Home Plus were also reduced, by 28%, as a result of the insulation works and energy efficient measures. This means that £560 was actually saved per year on energy bills.

Capital Investment and Payback

The Decent Homes Plus scheme carbon saving measures, including wall insulation, boiler and window upgrades, cost approximately £13,000. The Passivhaus scheme carbon saving measures cost approximately £80,000. A financial analysis of the Decent Homes Plus scheme shows a payback of between 12 and 20 years depending on assumptions on fuel prices.

Thermal Comfort

The sizeable costs of energy efficiency measure in the Passivhaus also yielded considerable improvements in terms of thermal comfort and Indoor Air Quality. The yearly average temperatures were 22.1°C in the Passivhaus living room and 19.4°C in the typical scheme living room. The improvements in thermal comfort were even more striking during the peak winter week (February 2012), during which the average temperature in the Passivhaus living room was 20.8°C, 4.4°C higher than the typical scheme living room. Moreover, this level of thermal comfort was achieved while using 88% less energy. Those results hold, to a lesser extent, for the Decent Home Plus.

Indoor Air Quality

The Passivhaus presented good levels of Indoor Air Quality (Average $C0_2$ concentration of 620 ppm and 50% relative humidity). Peaks in CO_2 concentration and relative humidity were controlled much more efficiently in the Passivhaus that in the two other schemes. $C0_2$ rarely went beyond 1,000 ppm and relative humidity always remained below 70% in the occupied rooms.

Water usage

Average daily water consumption in the Passivhaus was 85 Litres per person and per day, which is equivalent to a Code for Sustainable Homes rating of 5 out of 5 in the "Internal water use" category. As a comparison, the Decent Home Plus water usage was 137 Litres per person per day and 195 Litres in the typical scheme.

Final Energy Demand
Princedale Road

Introduction

Burning of fossil fuels for energy represents the main anthropogenic source of greenhouse gases. Today, space and water heating, services (cooking and appliances), cooling and lighting of domestic buildings is directly and indirectly responsible for about 15% of the total UK carbon emissions (Sources: Department for Business, Innovation and Skills, 2010; Department for Energy and Climate Change, 2012).

Improving energy efficiency of buildings is a major priority for Registered Social Landlords. Wherever energy is used to provide a service, efficiency can be improved, often quite considerably. The required measures for this can be carried out together with new acquisitions (such as energy-saving appliances or light fittings) or with maintenance or modernisation measures (e.g. thermal insulation of the envelope to reduce space heating demand).

The Passivhaus Institut has set stringent energy targets to be achieved by certified dwellings: 44 kWh/(m^2a) for Final Energy Demand and only 6 kWh/(m^2a) for space heating demand. A typical scheme in London uses more than 350 kWh/(m^2a) overall (Source: Monitoring analysis, See Final Energy Demand Section).

Monitoring features

Final Energy Demand has been monitored in the three schemes from June 2011 to May 2012. The figures include all kinds of energy demands in the houses: space heating, water heating, pumps and fans, lightings, cooking and appliances.

Dwellings at number 89 and 102 Princedale Road use main gas for space and water heating (gas boiler and hot water cylinder) whereas the Passivhaus only uses electricity (Mechanical Ventilation with Heat Recovery (MVHR), Solar Thermal, and a small heat pump "Combi' system).

Assumptions

Because of the Typical scheme's reluctance to contribute to the monitoring process at number 89 Princedale Road, electricity meters in the house have been switched off during the entire monitoring period and the tenants have not accepted to give their energy bills details to Octavia Housing. As a reasonable assumption, electricity usage (for pumps, fans, lighting and appliances) of the typical scheme has been assumed to be similar to the electricity usage in the Decent Home Plus. Gas usage in the typical scheme and the Decent Home Plus has been monitored correctly.

The dwellings areas used in the computation of Final Energy Demand are similar and correspond to the area used in the Passivhaus Planning Package (PHPP) software, which does not include landings and stairs.

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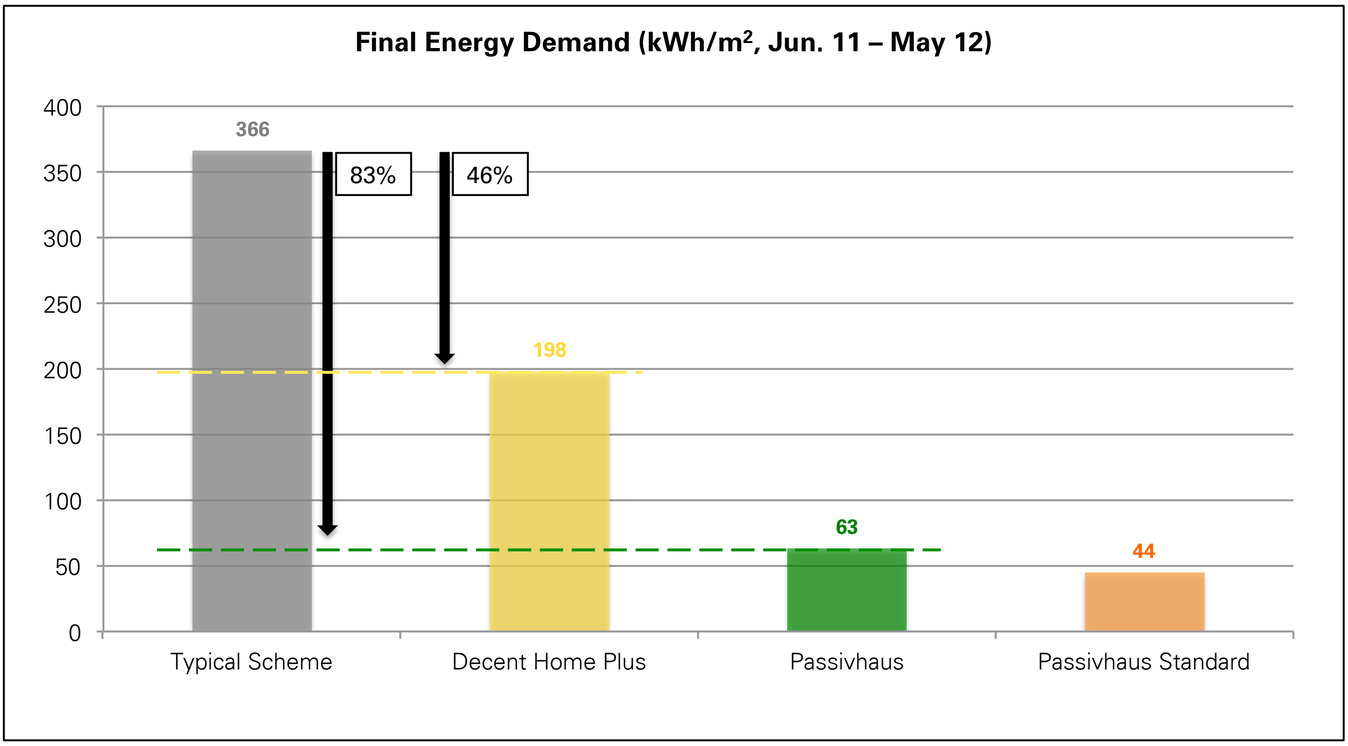
Final Energy Demand
Princedale Road

Key resuslts of one year of monitoring

The analysis of the monitored Final Energy Demand in the three houses highlights huge savings for both the Passivhaus and the Decent Home Plus compared to the typical scheme. Final Energy Demand for the Passivhaus was 63 kWh/(m^{2}a) as against 198 kWh/(m^{2}a) for the Decent Home Plus and 366 kWh/(m^{2}a) for the typical scheme,

This yields an 83% reduction for the Passivhaus and 46% for the Decent Home Plus compared to the typical scheme.

However, the Passivhaus standards are slightly exceeded during this first year of occupancy.



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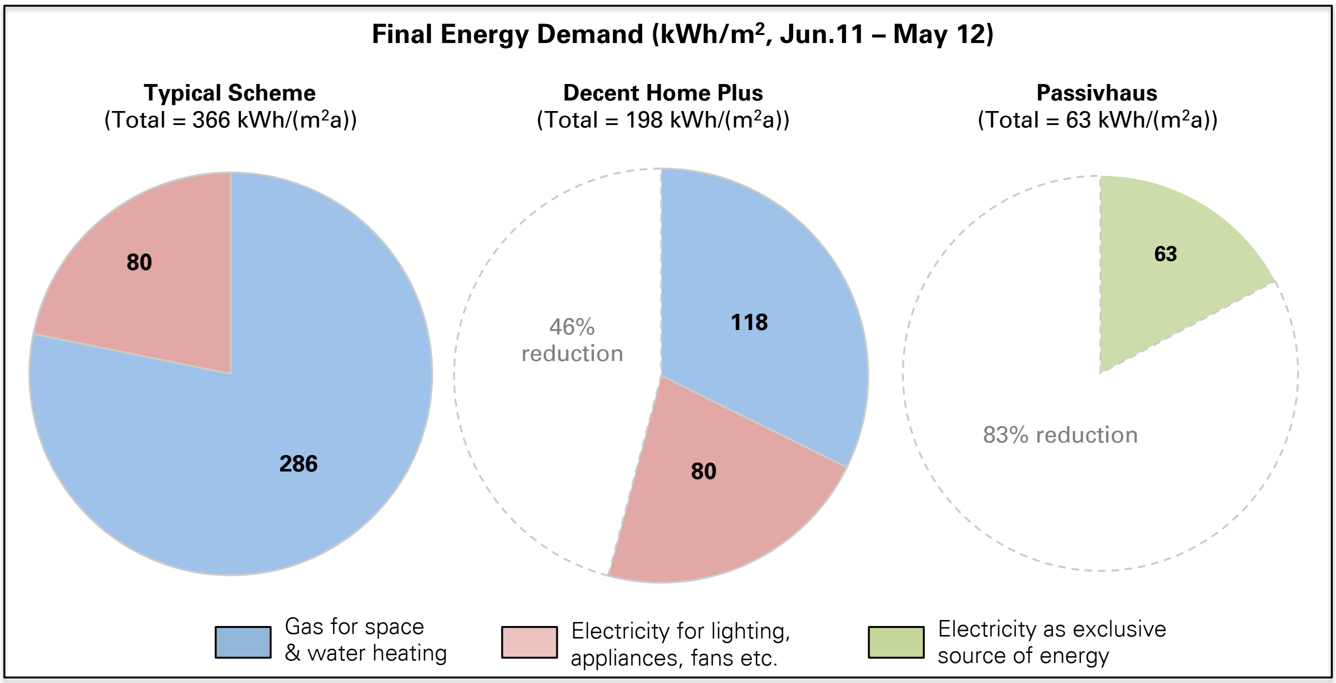
Final Energy Demand
Princedale Road

Energy Usage

Different energy strategies have been implemented in the Passivhaus and in the two other dwellings.

In the Passivhaus, most of the hot water is provided by a highly efficient solar thermal system, which can provide up to 85% of the yearly hot water demand. It is connected to a "Combi" unit, which supplies the remainder of hot water as well as providing Mechanical Ventilation with Heat Recovery (MVHR) and all space heat requirements with an exhaust air heat pump. No central heating system or radiators are required; the house is not connected to the gas network.

On the other hand, the Decent Home Plus and the typical scheme use main gain for space and water heating and cooking, along with electricity for appliances, lighting, pumps and fans.



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Final Energy Demand – Daily Consumption
Princedale Road

Average Daily Consumption

The gap between the retrofitted schemes and the typical scheme's average daily consumption dramatically increased during the cold winter months.

Between the most energy intensive month (February 2012) and the least energy intensive month (July 2011), Final Energy Demand was more than 4 times higher in the typical scheme, whereas it only doubled in the Passivhaus.

	Passivhaus		**Typical Scheme**	
	Jul. 11	Feb. 12	Jul. 11	Feb. 12
Average Daily PED (kWh/day)	10	21	40	173
% Increase	-	110%	-	333%

This analysis demonstrates two main results:

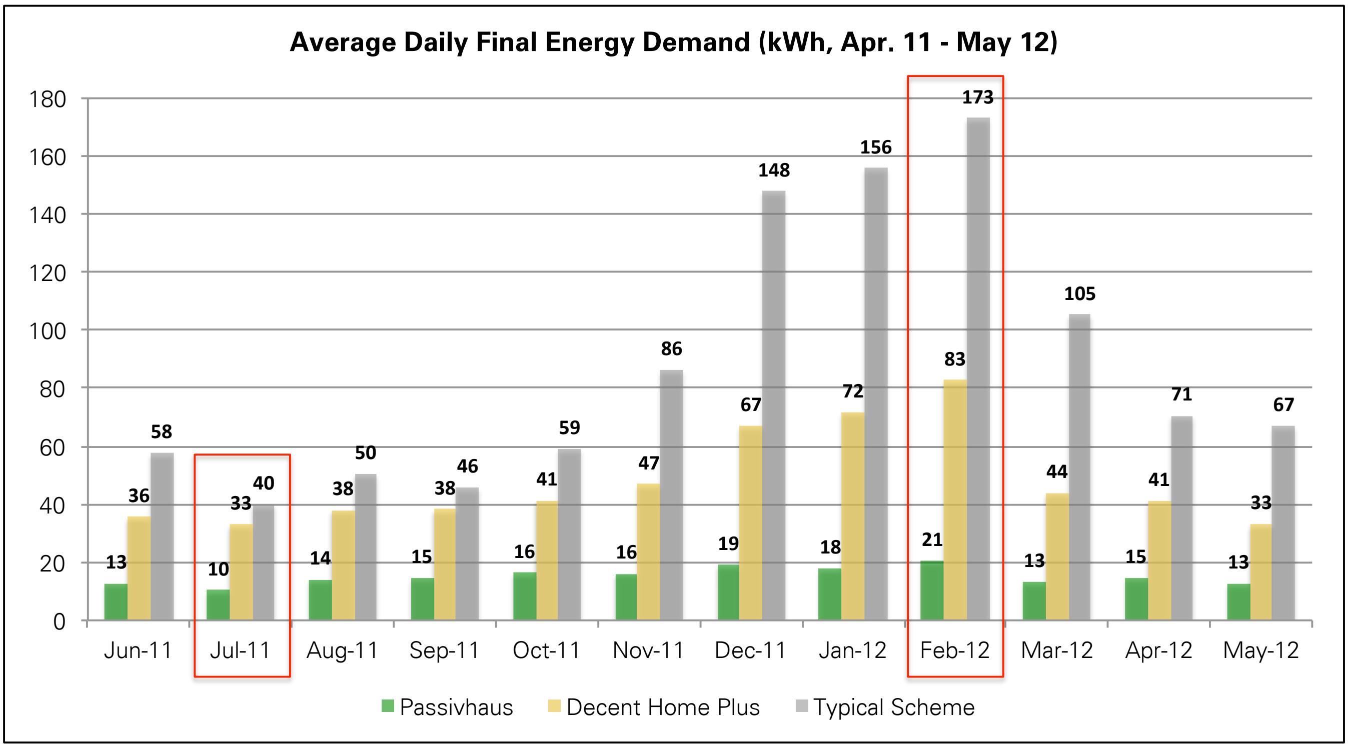
- The increase in Final Energy Demand during the winter was obviously due to an increase in space heating demand. This increase was much more important in the typical scheme than in the two other schemes, which brings evidence of the very good performance of the building fabric and insulation of the Passivhaus in terms of energy efficiency.

- Stability in PED provided financial stability in the Passivhaus, for which winter bills were comparable to summer bills. One the other hand, the typical scheme was much more likely to be subject to volatile charged bills between different periods of the year.

Those results hold, though to a lesser extent, for the Decent Home Plus.

Final Energy Demand – Daily Consumption

Princedale Road



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Final Energy Demand – Space Heating Demand
Princedale Road

Monitoring Problems

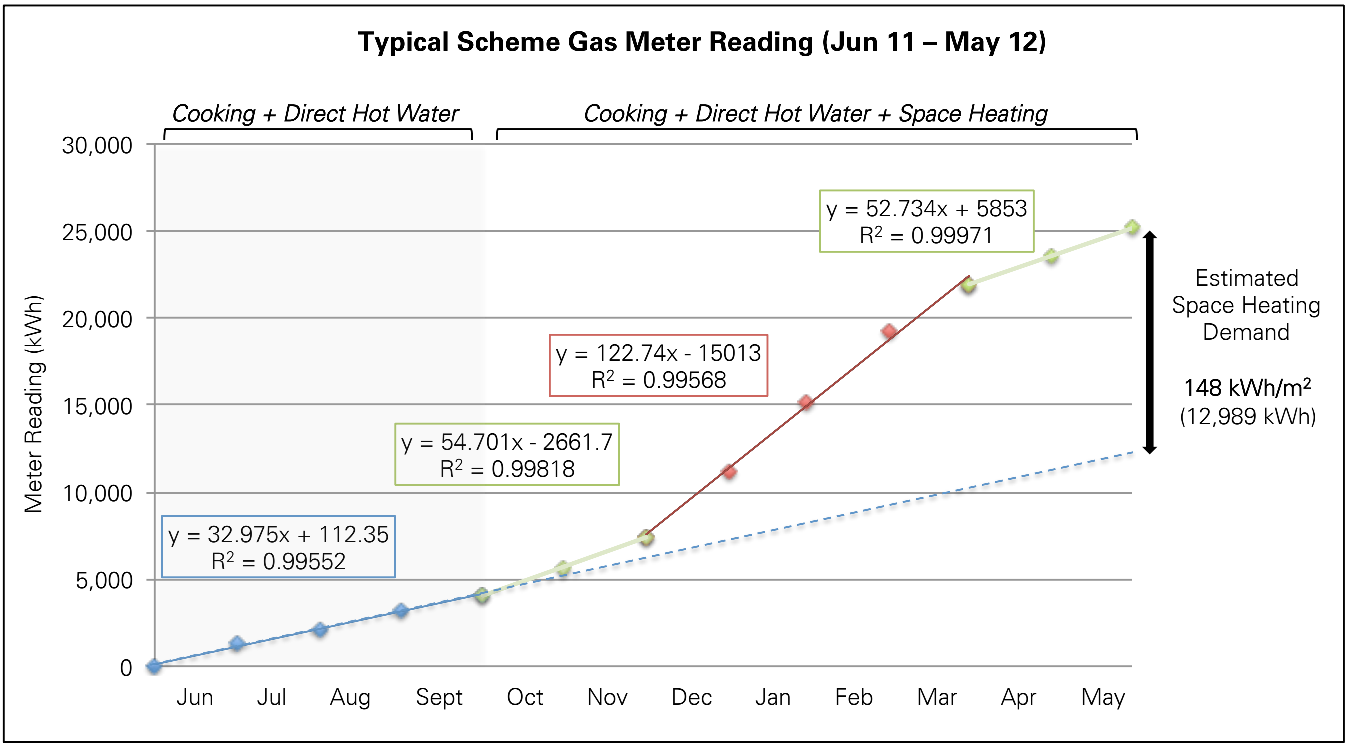
Due to monitoring difficulties, space heating demand as a proportion of overall Final Energy Demand in the three schemes was not directly available for the relevant period of time. Only overall Final Energy Demand figures are available.

Space Heating Demand in the Typical Scheme

However, an estimation of space heating demand can be made by comparing different gas consumption rates during the year:

- Summer: Gas was used for water heating and cooking only.
- Spring/Autumn/Winter: Gas was used for water & space heating and cooking.

The difference between the consumption rates demonstrates that the space heating demand in the Typical Scheme was 148 kWh/m²/yr from June 2011 to May 2012.



Space Heating Demand in the Decent Home Plus

Similar analysis shows that yearly space heating demand in the Decent Home Plus was 29 kWh/m²/yr.

Final Energy Demand – Space Heating Demand
Princedale Road

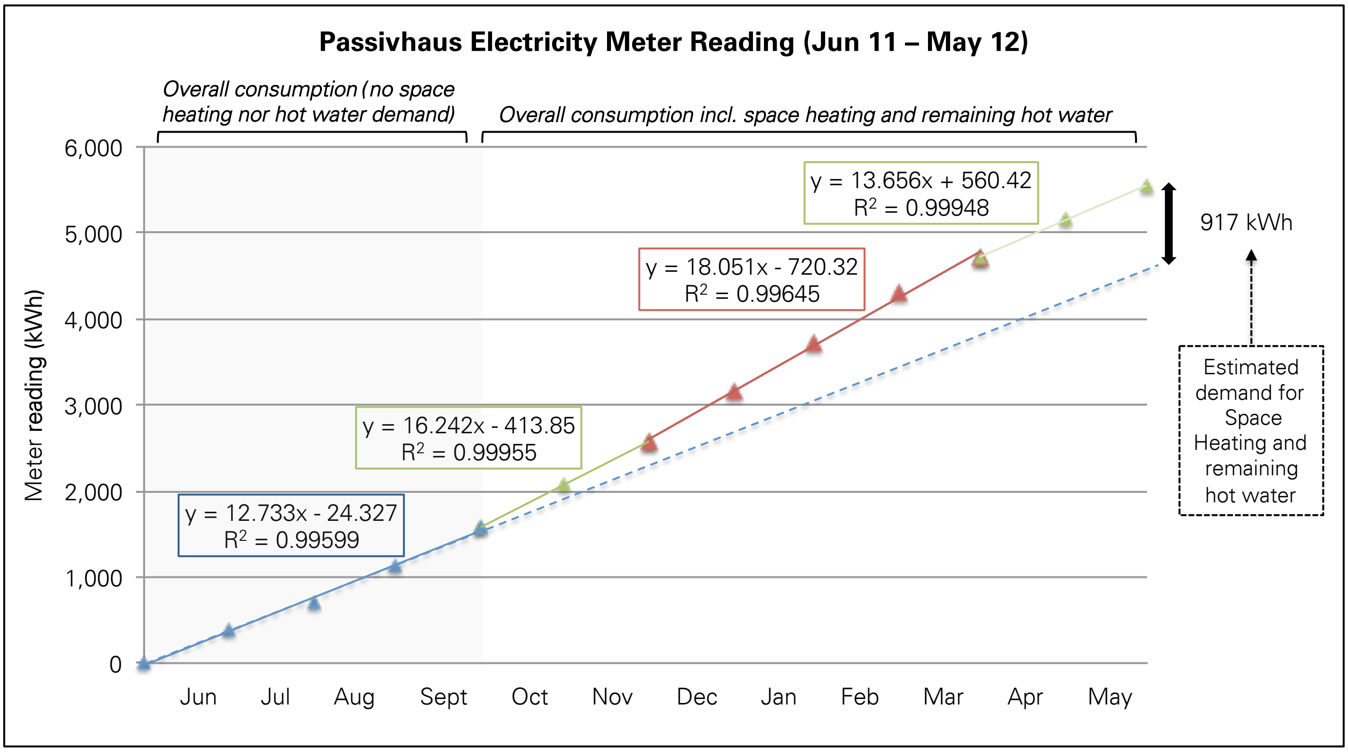
Space Heating Demand in the Passivhaus

The analysis is slightly different for the Passivhaus.

Solar Thermal was assumed to provide all the hot water to the dwelling during the "summer" months (June 2011 – September 2011). The difference between the electricity consumption rates between the "summer" and the other times of the year corresponded to the space heating demand and the energy required to provide the remaining hot water (not provided by the solar panels due to too low solar radiations in Spring/Autumn/Winter).

According to the manufacturer's specification, the Genvex system can provide up to 85% of domestic hot water. Hence electricity demand to supply the remaining hot water was estimated at 400kWh, resulting in a Space Heating Demand of 6 kWh/(m^{2}a).

Energy for space-heating and remaining hot water	917 kWh	10 kWh/m^2
Energy for remaining hot water only	400 kWh	4 kWh/m^2
Space Heating Demand	517 kWh	6 kWh/m^2



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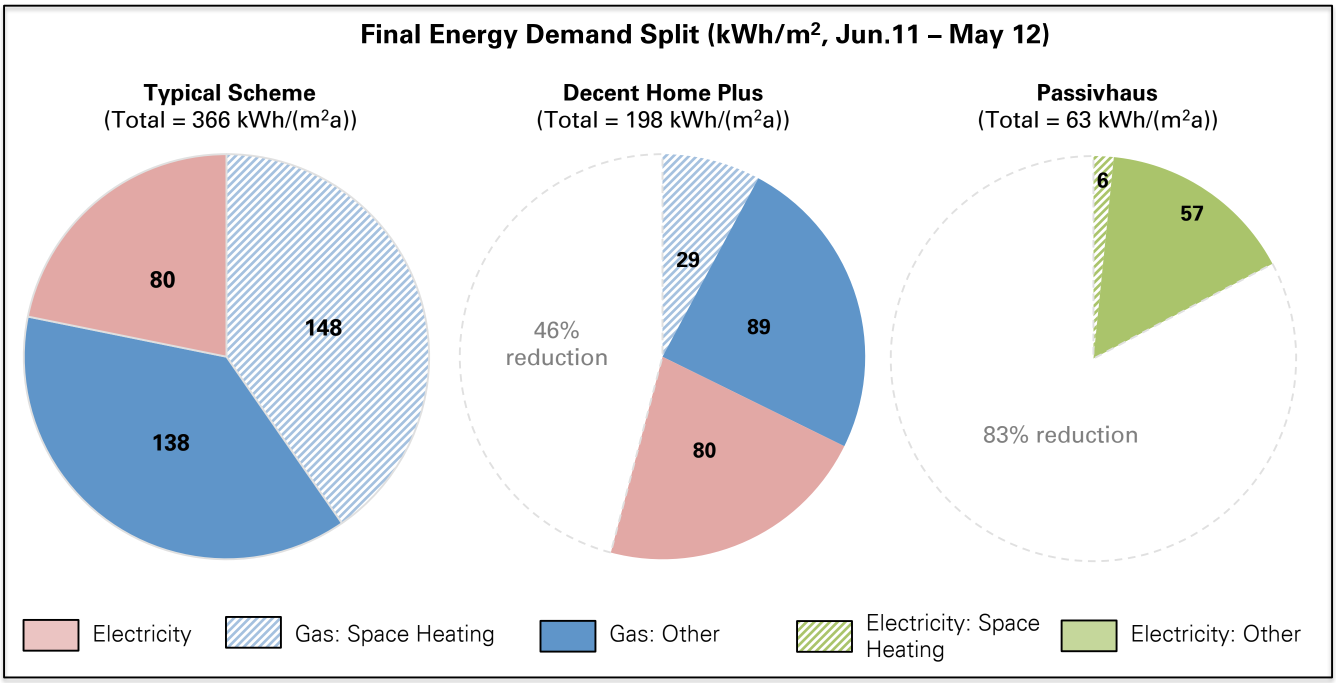
Final Energy Demand - Summary

Princedale Road

Summary of analysis

The monitoring analysis highlights an 83% reduction in Final Energy Demand in the Passivhaus and 46% in the Decent Home Plus compared to the typical baseline.

Reduction in space heating demand is even more sizeable: 96% in the Passivhaus and 80% in the Decent Home Plus. The Passivhaus standards in terms of space heating demand are fully met.



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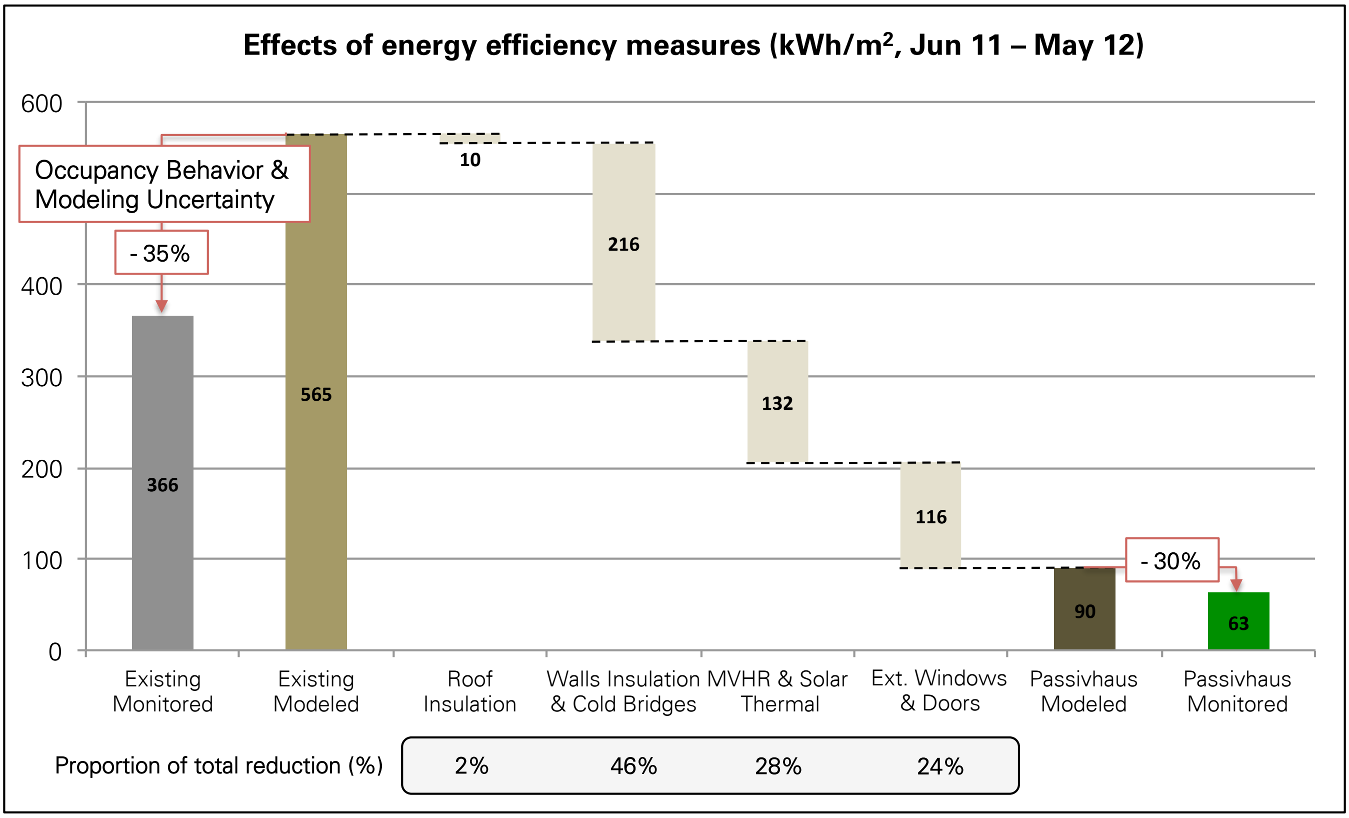
Final Energy Demand - Modelling

Princedale Road

Impact of energy efficiency measures

The different energy efficiency measures implemented had various impacts on the dwelling energy consumption.

The modelling (SAP 2005 v9.81 software) suggests that the walls insulation and cold bridges resolution have the biggest impact on Final Energy Demand and enable the Passivhaus to save approximately 200 kWh/m² (46% of total PED reduction) each year compared to the typical scheme.



Carbon Emissions
Princedale Road

Introduction

The Climate Change Act 2008 established a long-term framework to tackle climate change. The Act aims to encourage the transition to a low-carbon economy in the UK through unilateral legally binding emissions reduction targets. This means a reduction of at least 34% in greenhouse gas emissions by 2020 and at least 80% by 2050 compared to 1990 levels.

In the building environment, $C0_2$ emissions are arising from the operation of the each dwelling and its services, The annual dwelling CO_2 emissions ($KgCO_2$/year) is calculated by adding up emissions from space heating and cooling, water heating, ventilation and lighting, and those associated with appliances and cooking.

Assumptions

$C0_2$ emissions of the three schemes have been directly computed by using the Final Energy Demand figures of the previous section and the values of carbon intensity of gas and electricity taken from Building Regulation Part L 2006 (Passivhaus year built):

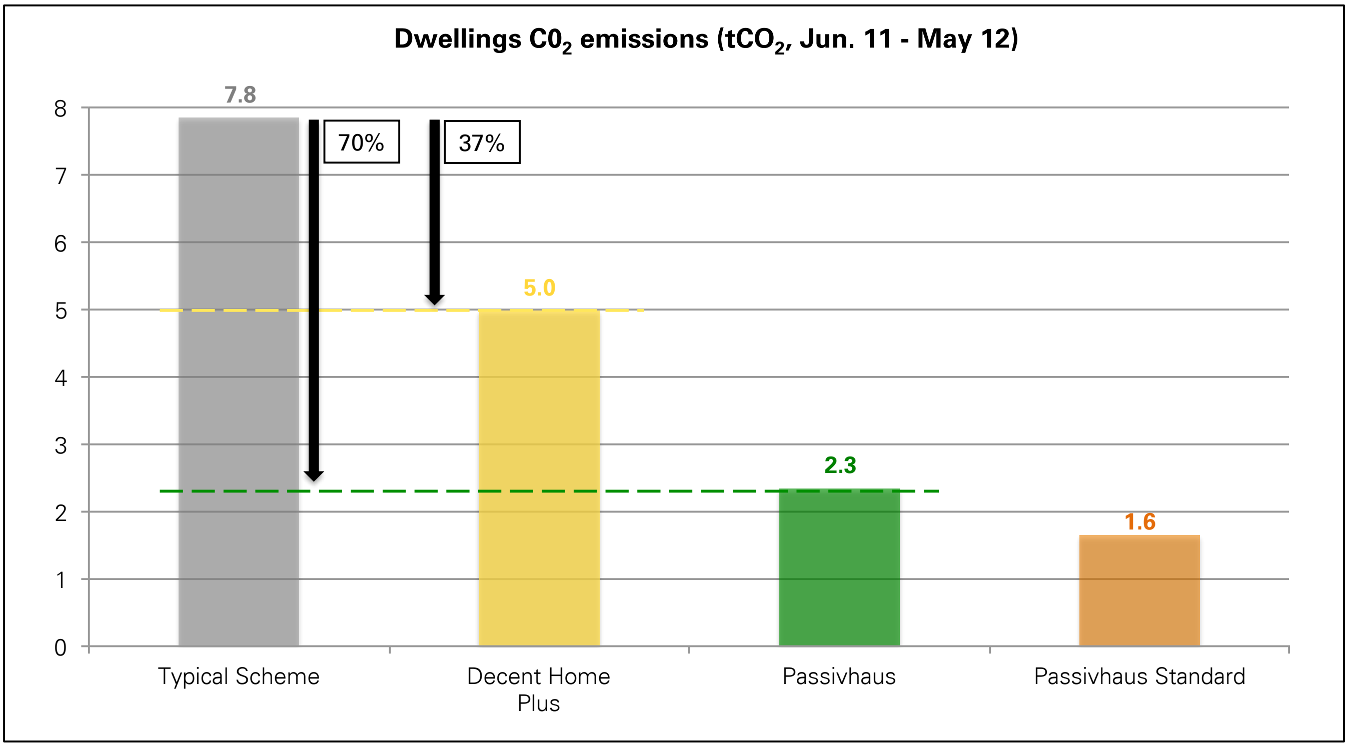
- Carbon intensity of gas: 0.194 $KgCO_2$ per kWh used
- Carbon intensity of electricity (from grid): 0.422 $KgCO_2$ per kWh used.

Key results of one year of monitoring

The Passivhaus achieved a 70% reduction in carbon emissions compared to the typical scheme, which is equivalent to a reduction of 5.5 tons of $C0_2$ emitted per year. The Decent Home Plus reduction in carbon emissions was 37%, equivalent to 2.8 tons of CO_2 saved per year.

Reduction in carbon emissions resulting from the Passivhaus retrofit of number 100 Princedale Road are sizeable despite the fact that the scheme is using electricity for space and water heating, which is more carbon intensive than main gas (used in the two other schemes).

Carbon Emissions
Princedale Road



Financial Analysis
Energy Bills
Princedale Road

Introduction

Addressing fuel poverty in the UK is a major concern for social landlords and policy makers in the building environment. In 2010, more than 4 million household suffered from fuel poverty (Source: Annual Report on Fuel Poverty 2012, DECC, 2012). This means that more than 10% of those households' yearly income was spent on fuel to maintain a satisfactory heating regime (usually around 21 degrees for the main living area, and 18 degrees for other occupied rooms).

Assumptions

For consistency reasons, the bills of the three schemes have been computed using the same baseline, which corresponds to the Passivhaus details:

- Energy supplier: Southern Electric
- Payment Method: Pay quarterly, on receipt of bills
- Electricity prices (Southern Electric):
  - Daily fixed price: £0.1821 per day
  - Variable unit price: £0.127 per kWh used
- Gas prices (Southern Electric):
  - Daily fixed price: £0.3173 per day
  - Variable unit price: £0.0378 per kWh used

Key results of one year of monitoring

For one year of electricity consumption, the Passivhaus energy bills added up to £772, resulting in a 62% reduction in energy bills compared to the standard house. This is equivalent to £1,255 saved per year. The bills of the Decent Home Plus were also reduced, by 28%, as a result of the insulation works and energy efficient measures. This means that £560 was actually saved per year on energy bills.

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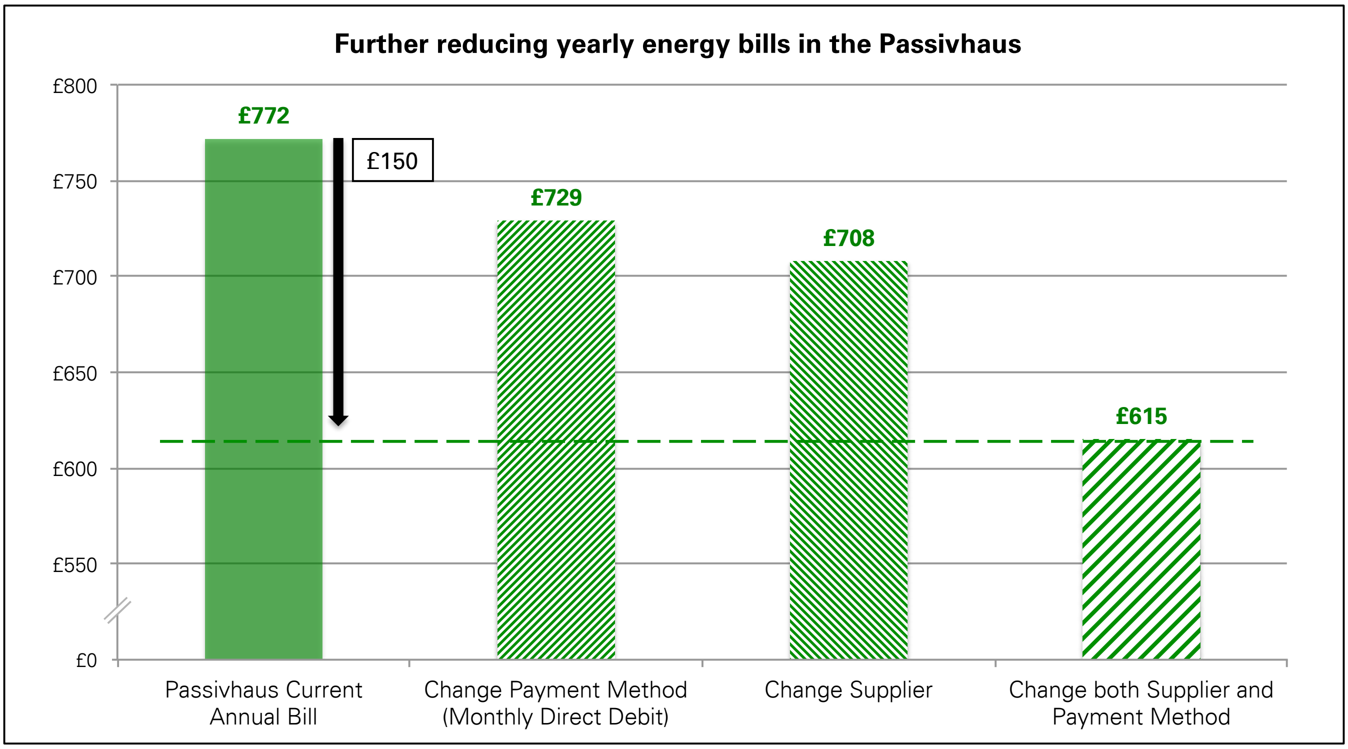
Financial Analysis
Energy Bills
Princedale Road

Further Reducing energy bills

Further bills reduction could be achieved subject to supplier and / or payment method change. Current payment method for the family in the Passivhaus is quarterly payment on receipt of bills. However, bills are always cheaper when choosing to pay by Monthly Direct Debit, and changing both supplier and payment method would enable the family to save an additional £150 per year.



Source: UKpower.co.uk

Financial Analysis
Payback Period
Princedale Road

Introduction

The payback period is the estimated time required to recover from the upfront costs invested in the energy efficiency measures on site. The benefits of such measures will be based on energy bills savings only. Benefits of such measures in terms of thermal comfort and Indoor Air Quality will be assessed in other sections.

Assumptions and Methodology

The methodology used in this section consists in computing the Net Present Value of the implementation of energy efficient measures. Savings on energy bills will progressively balance the corresponding upfront costs.

The future benefits (i.e. actual savings on bills) of the retrofit projects expressed in present monetary terms need to be discounted. Discounting is a technique used to compare costs and benefits that occur in different time periods. E.g. saving £2,000 on energy bills now or in 20 years does not have the same value. This is because the money saved now can be invested in fixed and low-risk rates and yield extra monetary benefits (net of tax) in the future.

Discounting of the future energy bills savings of the Passivhaus has been made using the Green Book guidance for long-term projects.

Period of Year	0-30	31-75	76-125	126-200
Discount Rate	3.5%	3.0%	2.5%	2.0%

Source: www.hm-treasury.gov.uk/d/green_book_complete.pdf

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Financial Analysis
Payback Period
Princedale Road

Passivhaus Energy Efficiency measures costs

Energy efficiency measure	Cost
Roof Insulation	£1,554
Walls and floors insulation, and cold bridges resolution	£23,676
External windows and doors	£32,007
Heating system, Underground heat exchanger and Solar Thermal	£30,240
Total	**£87,478**

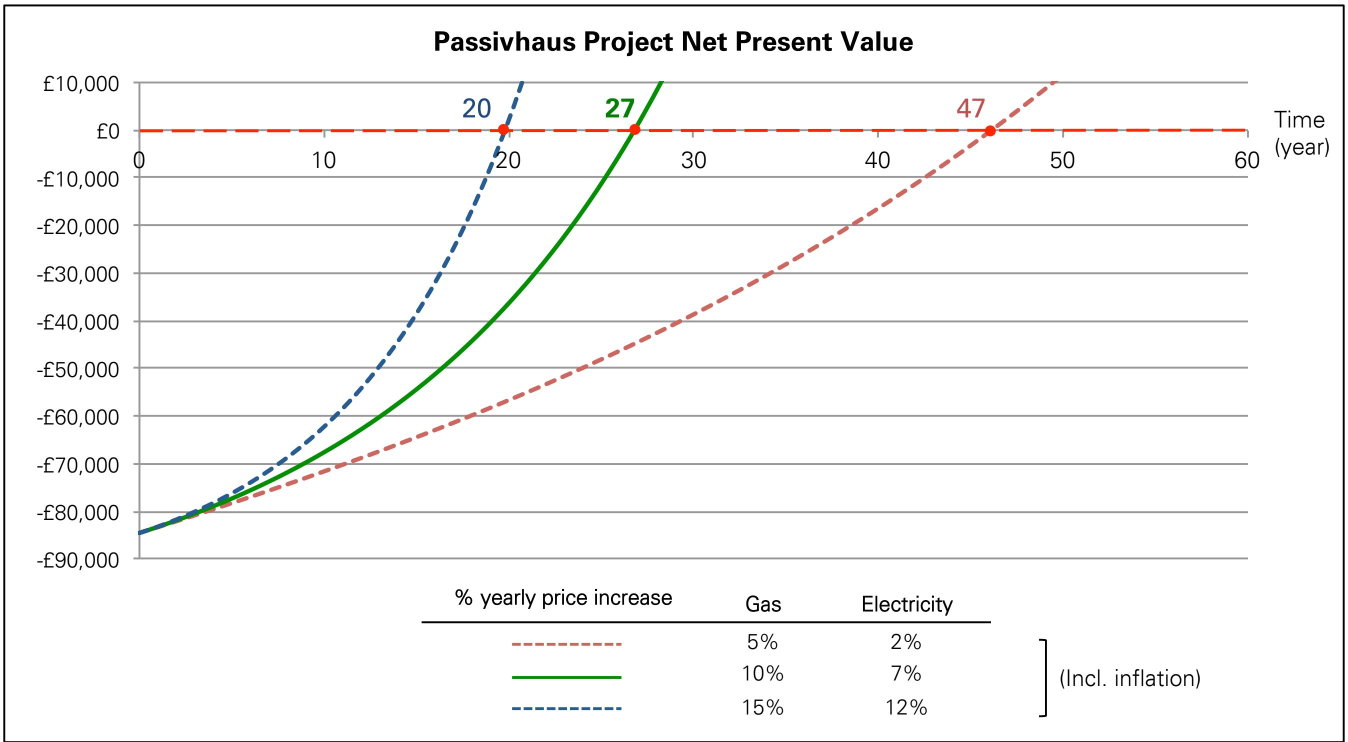
Fuel Prices

Different scenarios regarding fuel prices evolution have been considered. The "preferred" scenario is based on the average yearly increase in UK domestic fuel prices between 2001 and 2011 (10% yearly increase in domestic gas prices and 7% yearly increase in electricity prices (incl. inflation)).

Source: Department of Energy and Climate Change Statistics, 2011

Results

		% Yearly Increase in Gas Prices		
Expected Payback Period (years)		5%	10%	15%
% Yearly Increase in Electricity Prices	2%	47	28	21
	7%	42	27	21
	12%	34	26	20



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Financial Analysis
Payback Period
Princedale Road

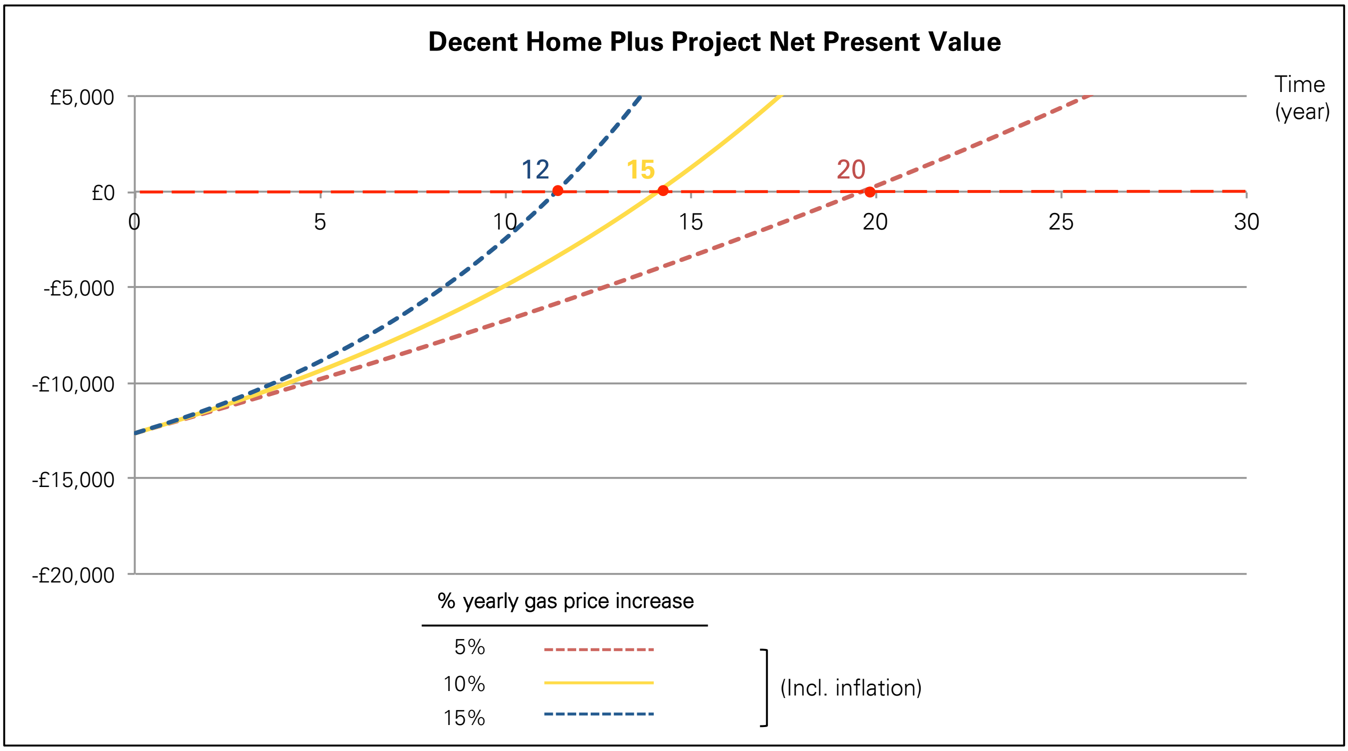
Decent Home Plus Energy Efficiency measures costs

Energy efficiency measure	Cost
Roof Insulation	£405
Walls and floors insulation, and cold bridges resolution	£2,073
Openings	£7,596
Heating system (new boiler)	£3,000
Total	£13,074

Results

Since the electricity bills have been assumed to be equal in the Decent Home Plus and the typical scheme, the payback periods only depend on the expected yearly increase in gas prices. The most likely scenario (10% increase in gas prices yearly incl. inflation) suggests a shorter payback period (due to lower costs od energy efficiency measures): 15 years.

Expected Payback Period (years)		*% Yearly Increase in Gas Prices* 5%	10%	15%
% Yearly Increase in Electricity Prices	2%	20	15	12
	7%	20	15	12
	12%	20	15	12



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Financial Analysis
Internal Rate of Return
Princedale Road

Internal Rate of Return

Formally, the Internal Rate of Return (IRR) is the discount rate (applied to future savings) for which the Net Present Value of the project is equal to £0 at the expected end of the project. It is an estimation of the return on investment of the project.

An assumption about the length of the project has to be made in order to calculate the expected Internal Rate of Return of the two projects. The length of the project refers to the number of years during which energy savings on bills are actually made as a direct consequence of energy efficiency measures implemented in 2011.

For instance, assuming that the projects length will be 100 years, the expected IRR for the Passivhaus and the Decent Home Plus are respectively 10.2% and 14.1%.

The calculations have been carried out based on energy bills savings results of the previous sections, the costs of energy efficiency measures, and expected yearly increase in domestic fuel prices (Preferred scenario: 10% for gas and 7% for electricity from grid).

Expected Length of Energy Efficiency Savings	Passivhaus Project IRR	Decent Home Project IRR
25 years	2.3%	10.0%
50 years	8.2%	13.3%
100 years	10.2%	14.1%

Passivhaus vs. Decent Home Plus

Based on these figures, the case for the Decent Home Plus refurbishment seems more compelling.

However, factors in other issues such as the increased thermal comfort and indoor air quality sizeably balance the longer payback period and slightly lower Internal Rate of Return for the Passivhaus. More importantly, the strongest argument of all, the government's 80% reduction in carbon emissions by 2050 aim, means that the Passivhaus project is the most adapted to green refurbishment.

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Financial Analysis
Family Budget
Princedale Road

Aim of the section

The aim of this section is to highlight the evolution of the proportion of disposable income (i.e. gross income minus social security contributions and income taxes) spent on energy bills between now and 2032 (20 years period).

Assumptions

Energy bills:
- 10% increase in gas prices;
- 7% increase in electricity prices.

(Including inflation, most likely scenario described in the previous section).

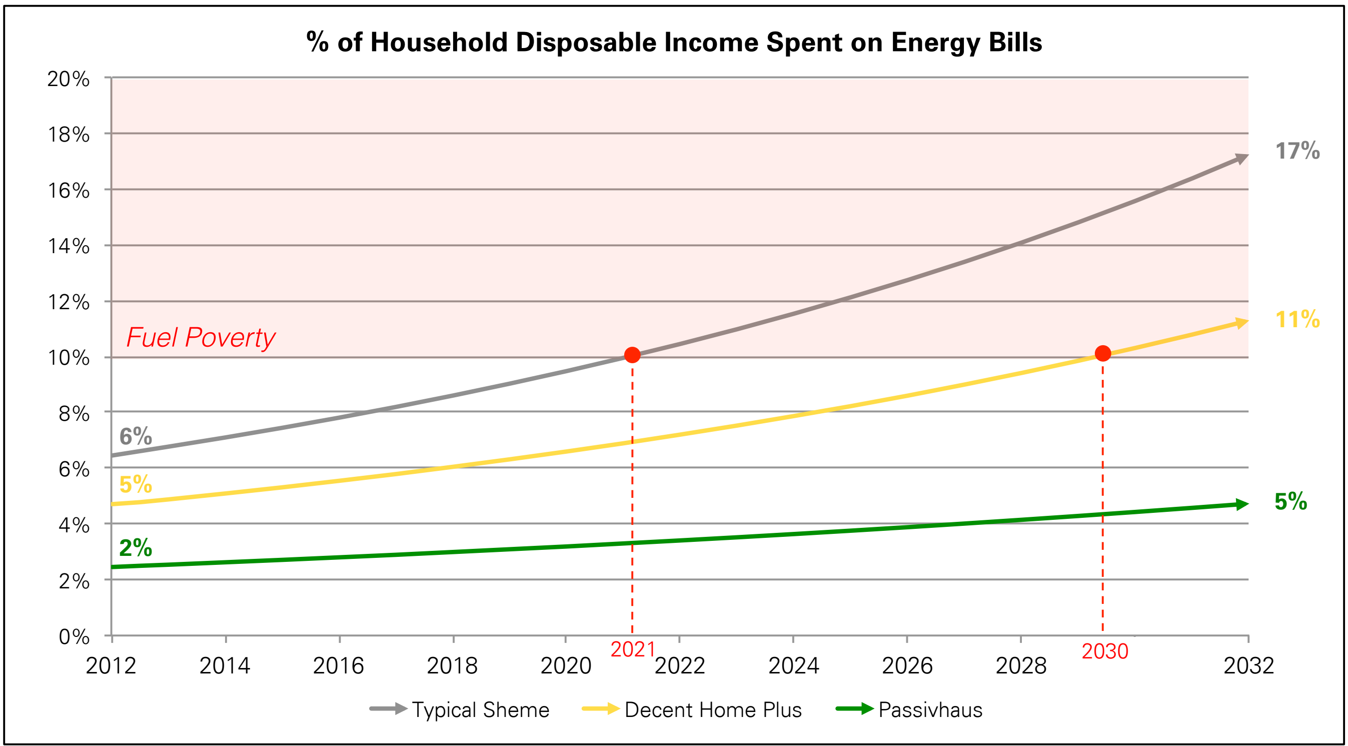
Households income:
- Based on of UK average disposable income in 2010 and forecasts*;
- Two sources of income (£14,600 each in 2010).

For consistency reason, disposable income has been assumed to be equal in the three schemes.

(*) Source: Income and Expenditure: United Kingdom, Euromonitor International, April 2011.

Results

In 20 years time, the Passivhaus is expected to spend only 5% of disposable income to pay energy bills (against 2% today). On the other hand, the typical scheme will face huge fuel cost increase, and is expected to spend 17% of disposable income on energy bills by 2032 (above fuel poverty threshold).



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Financial Analysis
Family Budget
Princedale Road

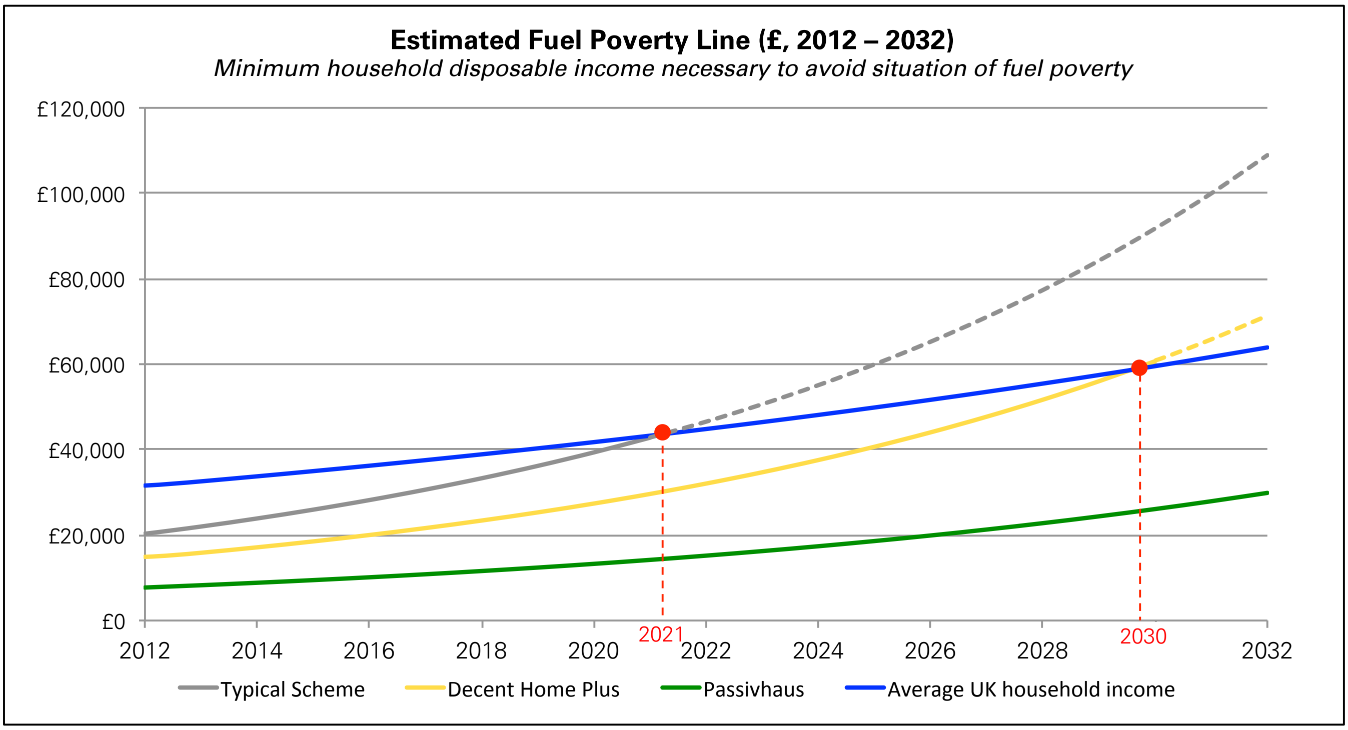
Fuel Poverty Line

The fuel poverty line corresponds to the minimum household disposable yearly income necessary to avoid being in a situation of fuel poverty.

The threshold household incomes in the three schemes are sizeably different since they each correspond to 10 times the amount of expected energy bills.

Once again, analysis has been made based on the "preferred" scenario of domestic fuel price increase (10% for gas and 7% for electricity).

Year	Minimum household yearly income necessary to avoid situation of fuel poverty		
	Typical Scheme	Decent Home Plus	Passivhaus
2020	£39,400	£27,400	£13,300
2030	£91,800	£60,700	£26,000



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Thermal Comfort Passivhaus Yearly Profile

Princedale Road

Introduction

Formally, thermal comfort is "established when the heat released by the human body is in equilibrium with its heat production" (Passipedia.org). However, many subjective perceptions can also influence living comfort - even the colour of the surroundings plays a certain role.

In this section, thermal comfort has been assessed in the different dwellings using data collected in various rooms (bedrooms, living-rooms, utilities, etc.). Focus of analysis was on the temperature levels (incl. overheating control during the summer and cold winter week resilience) and on temperatures stability throughout the year.

Key results of one year of monitoring

Temperatures in the Passivhaus have turned out to be very comfortable all year long, even during winter weeks, with an average of 22.1°C in the living room and 22.4°C in the master bedroom.

Temperatures have also been very stable throughout the year. For instance, temperatures standard deviation in the living room was 1.4°C, which means that the temperature in the living room was between 19.3°C and 24.9°C during more than 95% of the time.

Overheating has also been limited throughout the dwelling with less than 5% of the time above 26°C in the bedrooms and only 0.2% of the time above 28°C in the living room. The results also demonstrate that, on average in the dwelling, the Passivhaus overheating standard is met (less than 10% of the time above 25°C).

Temperature in the Passivhaus (°C, Jun 11 - Mar 12)

Average	Std. Dev.	% time > 25°C	Overheating*
22.4°C	2.1°C	10.8%	4.4%
22.2°C	1.5°C	5.5%	2.3%
22.1°C	1.4°C	2.4%	0.2%
12.5°C	6.2°C	2.3%	1.6%

(*) Living room: % time above 28°C
Bedrooms & external: % time above 26°C

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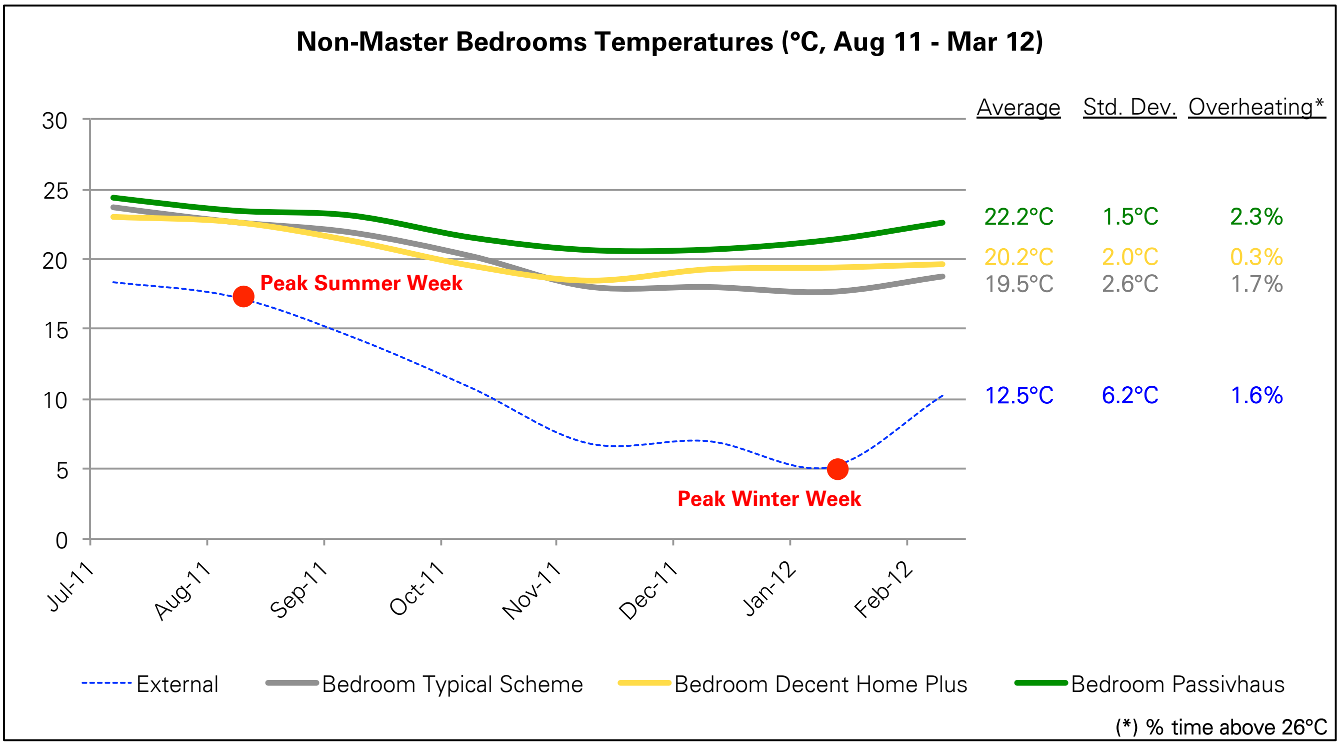
Thermal Comfort Schemes Yearly Profiles
Princedale Road

Comparison with the other properties
(Non-master bedrooms)

The major benefits of the Passivhaus in terms of thermal comfort compared with the Decent Home Plus or the typical scheme were related the temperature stability and resilience to cold winter temperatures.

Temperatures were warmer in the Passivhaus than in the two other schemes, with a gap in temperatures during the winter reaching 2/3°C compared to the Decent Home Plus and 4/5°C compared to the typical scheme. A detailed analysis of the Peak Winter Week will be carried out in the following sections.

In addition, the value of temperatures standard deviation demonstrates the stability of temperatures throughout the year in the Passivhaus (1.5°C in the Passivhaus as against 2.6°C in the typical scheme).



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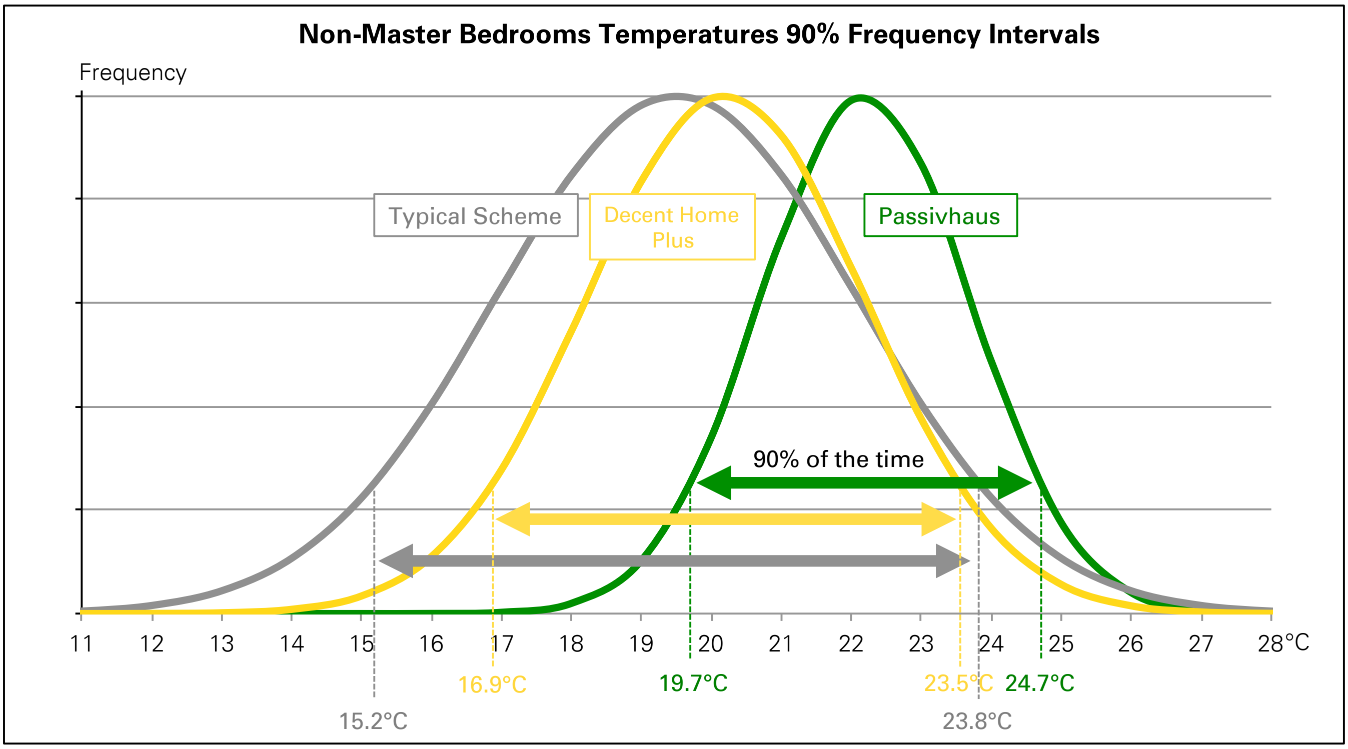
Thermal Comfort Temperature Intervals
Princedale Road

Temperatures Intervals

The averages and standard deviations of the temperature yearly profiles provide statistical intervals corresponding to different levels of frequency of these temperatures.

% Time within interval	Typical Scheme	Decent Home Plus	Passivhaus
50%	[17.7 ; 21.3]	[18.9 ; 21.5]	[21.2 ; 23.2]
80%	[16.2 ; 22.8]	[17.6 ; 22.8]	[20.3 ; 24.1]
90%	[15.2 ; 23.8]	[16.9 ; 23.5]	[19.7 ; 24.7]



The Passivhaus bedroom temperature remains between 19.7°C and 24.7°C during 90% of the time, hence achieving remarkable levels of thermal comfort all year long. As a comparison, the typical scheme monitored bedroom remains in this interval of temperature only 45% of the time, which suggests more extreme temperatures during both winter and summer. Peak winter and summer weeks will be analysed in further details in the following sections.

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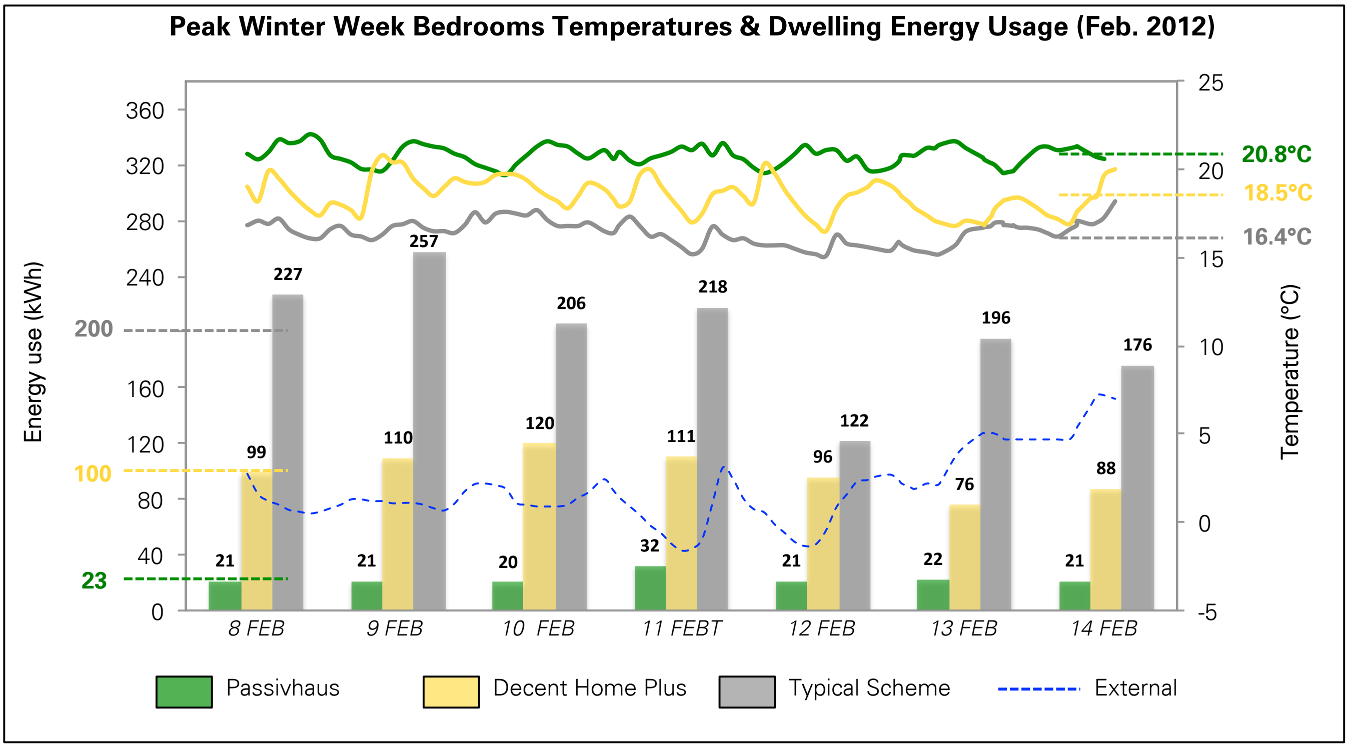
Thermal Comfort
Peak Winter Week
Princedale Road

Peak Winter Weak

The graph below highlights the temperatures in non-master bedrooms of the three dwellings during the coldest week of the 2011-2012 winter.

Temperature is the Passivhaus's bedroom remained very comfortable (20.8°C) compared to the typical scheme's bedroom (16.4°C) and this level of comfort was achieved by using 88% less energy daily (23 kWh used per day in the Passivhaus as compared with 200 kWh used per day in the typical scheme).

Same results, although of lower amplitude, stand out from the monitoring data of the Decent Home Plus. While using 50%less energy daily than the typical scheme, the level of thermal comfort achieved is much more comfortable (18.5 °C on average in the bedroom).

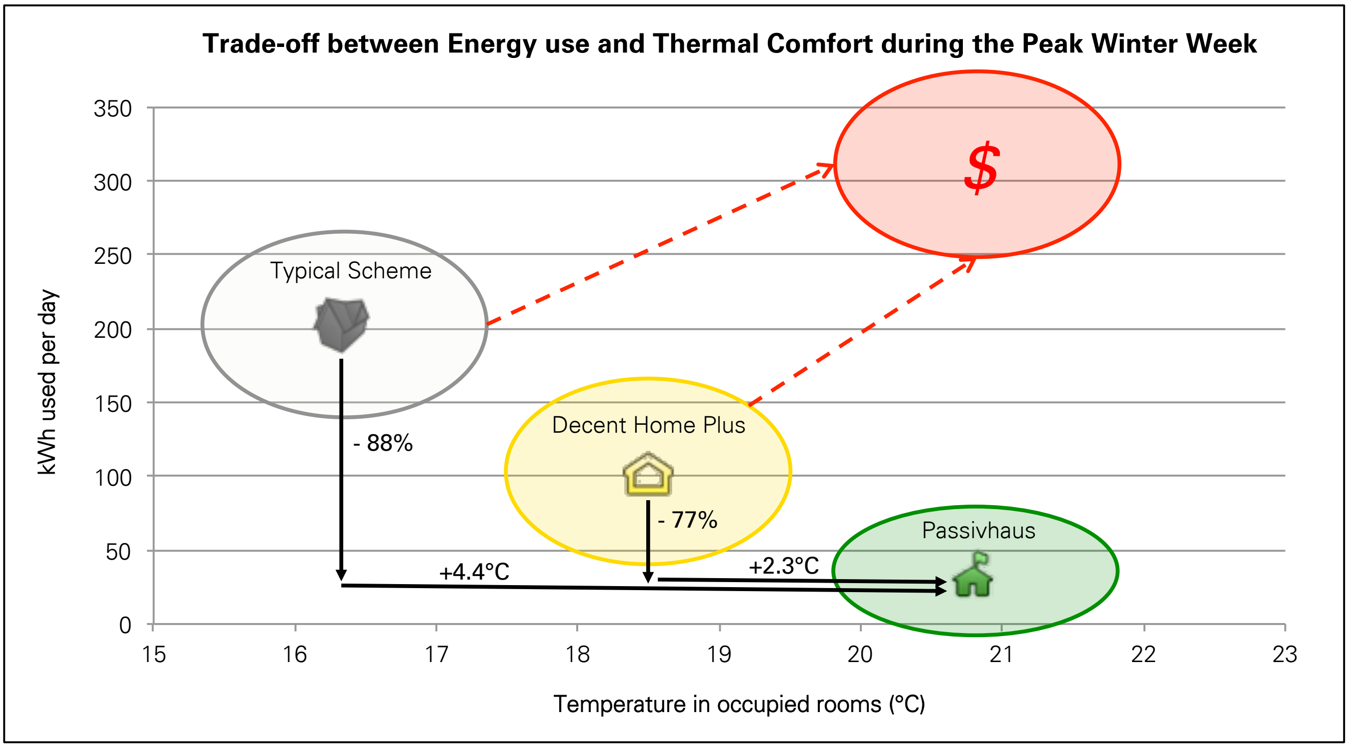


Thermal Comfort 'Winter Dilemma'
Princedale Road

Is there a dilemma between thermal comfort and space heating expenses?

This sub-section suggests that a trade-off exists during the coldest winter weak between thermal comfort and budget dedicated for space heating in most dwellings.

The Passivhaus and the Decent Home Plus seemed less subject to this dilemma thanks to their efficient building fabric, which enable the two dwellings to achieve good levels of thermal comfort at reasonable cost, even during the coldest winter days.



Thermal Comfort Valuing Thermal Comfort

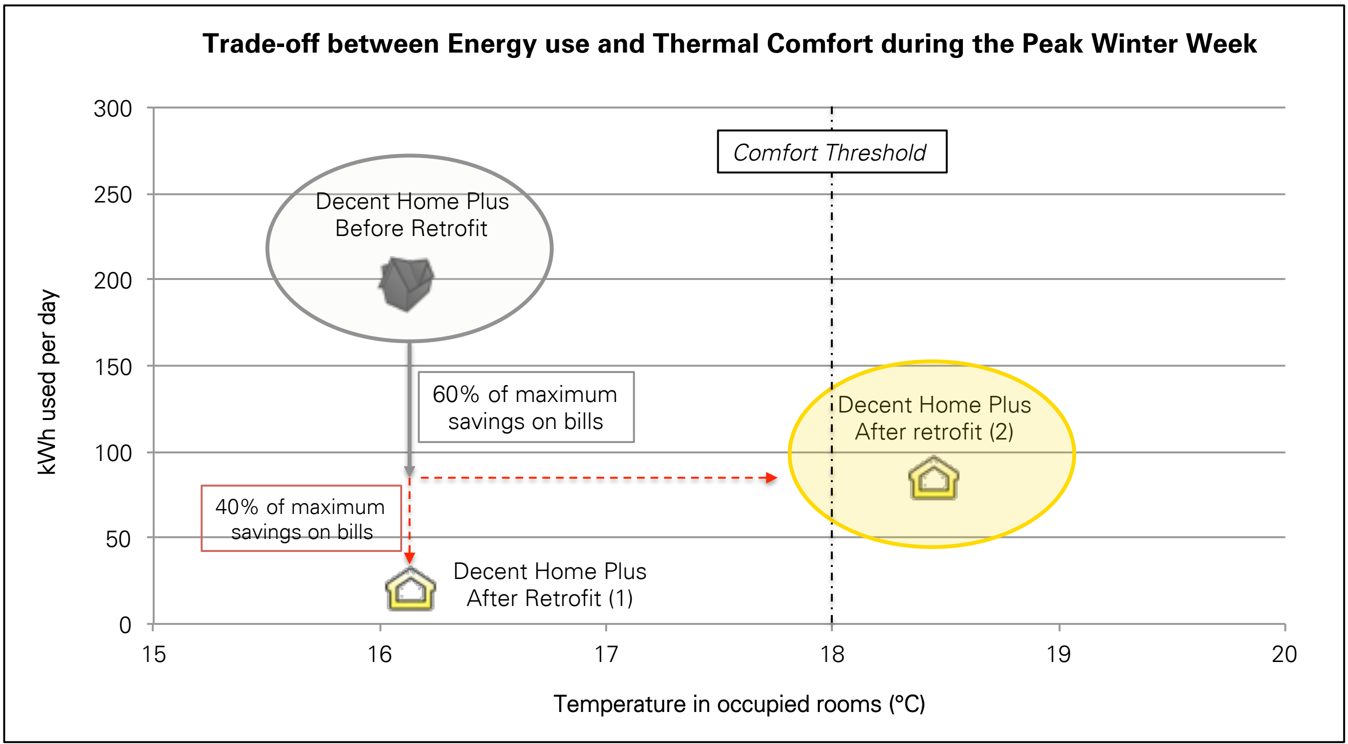
Princedale Road

Literature review

Is it possible to put a monetary value on comfortable indoor temperatures during the winter?
Yes, according to J. Peter Clinch and John D. Haley from University College Dublin. The study demonstrates that tenants who benefit from energy efficiency measures for their dwelling are willing to forgo 40% of maximum possible energy savings in order to increase the winter thermal comfort (the threshold of comfort being 18°C). The value of "being above 18 °C" shall be at least equal to the value of energy savings forgone.

Application

Applying these conclusions to the Decent Home Plus in order to value the benefits of living above 18 °C in the winter as compared to below 18 °C. This is a relevant case study because the mean temperature in the Decent Home Plus is just above the comfort threshold of 18°C.
The £560 saving on bills (computed in the previous sections) shall correspond to 60% of the maximum possible energy saving. There is a trade-off for the 40% remaining saving:
(1) Actually save those additional 40%, but remain at the same level of comfort than before retrofit, i.e. below 18°C.
(2) Increase the level of thermal comfort above 18°C while forgoing these 40% of potential savings on bills (Choice actually made by the Decent Home Plus household).
Hence, the value of "crossing the 18°C threshold" is 40%*560/60% ~ **£330**.



Thermal Comfort
Overheating
Peak Summer Week
Princedale Road

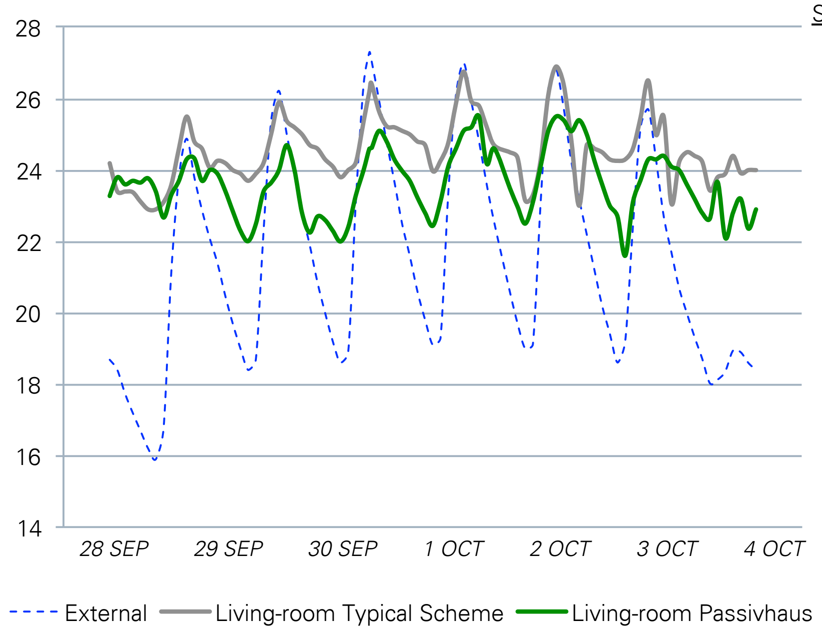
Living rooms overheating

Overheating is limited in the Passivhaus living room throughout the year (see Thermal Comfort - Passivhaus Yearly Profile Section).

Overheating has been analysed in further details during the peak summer week (week with the highest average external temperatures (but not necessarily the highest peak temperatures).

During the peak summer week 2011-2012, temperature in both schemes never exceed 28°C. However, the Passivhaus overheating standard of 25°C is exceeded during 11% of the time (as against 27% in the typical scheme), which suggests that the Passivhaus living room was less impacted by high temperatures during the peak summer week than the typical scheme living room.

Peak Summer Week in the living rooms (°C, Sept./Oct. 2011)



Std. Dev.	% time > 25°C Peak Week	% time > 25°C Year	Overheating* Peak Week	Overheating* Year
0.9°C	27%	8.0%	0%	0.1%
0.9°C	11%	2.4%	0%	0.2%
3.0°C	18%	2.3%	0%	0.9%

(*) % time above 28°C

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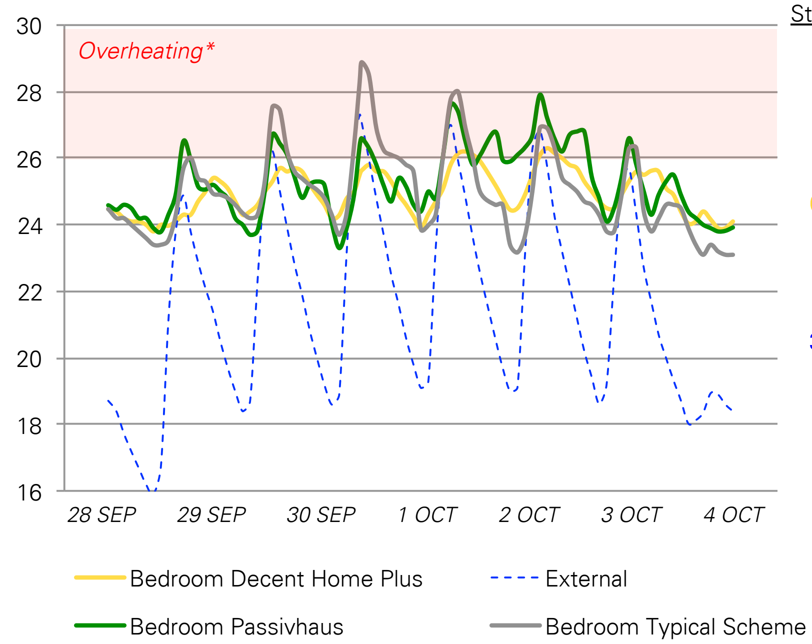
Thermal Comfort
Overheating
Peak Summer Week
Princedale Road

Non-master bedrooms overheating

Occupants' behaviour can have a major impact on overheating. Indeed it seems intuitive to open the windows during the hotest summer days. This could however have unexpected negative consequences on the house overheating, since the insulation will keep the heat inside once it has entered the house through the windows. The occupants were not aware of this issue (confirmed by occupants feedback gathered when meeting the family) and used to leave the windows open, contributing to important overheating during the peak winter days (28% of the time above 26°C in the Passivhaus, as against 7% in the Decent Home Plus and 24% in the typical scheme).

Occupants are now aware that the best strategy during hot days is to leave the windows closed during the day, minimise solar gains with closed curtains, and open the windows during the night to let the fresh air come inside. This should result is better overheating performances in both dwellings during summer 2012 (monitoring not included in this report).

Peak Summer Week – Bedrooms Temperatures (Sept./Oct 2011)



Std. Dev.	% Time > 25°C Peak Week	% Time > 25°C Year	Overheating* Peak Week	Overheating* Year
1.0°C	53%	5.5%	28%	2.3%
0.7°C	42%	2.2%	7%	0.3%
1.4°C	40%	3.3%	24%	1.7%
3.0°C	18%	2.3%	10%	1.6%

(*) % time above 26°C

Indoor Air Quality CO_2 concentration Princedale Road

Introduction

Good Indoor Air Quality (IAQ) is a top priority in any building and includes good levels of CO_2 concentration in the living rooms is a key component. Too high CO_2 concentration could cause discomfort such as headache or breathing problems.

The Pettenkofer value of 0.1 vol. % is considered as the limit value for good indoor air quality. This is equivalent to a CO_2 concentration of 1,000 ppm.

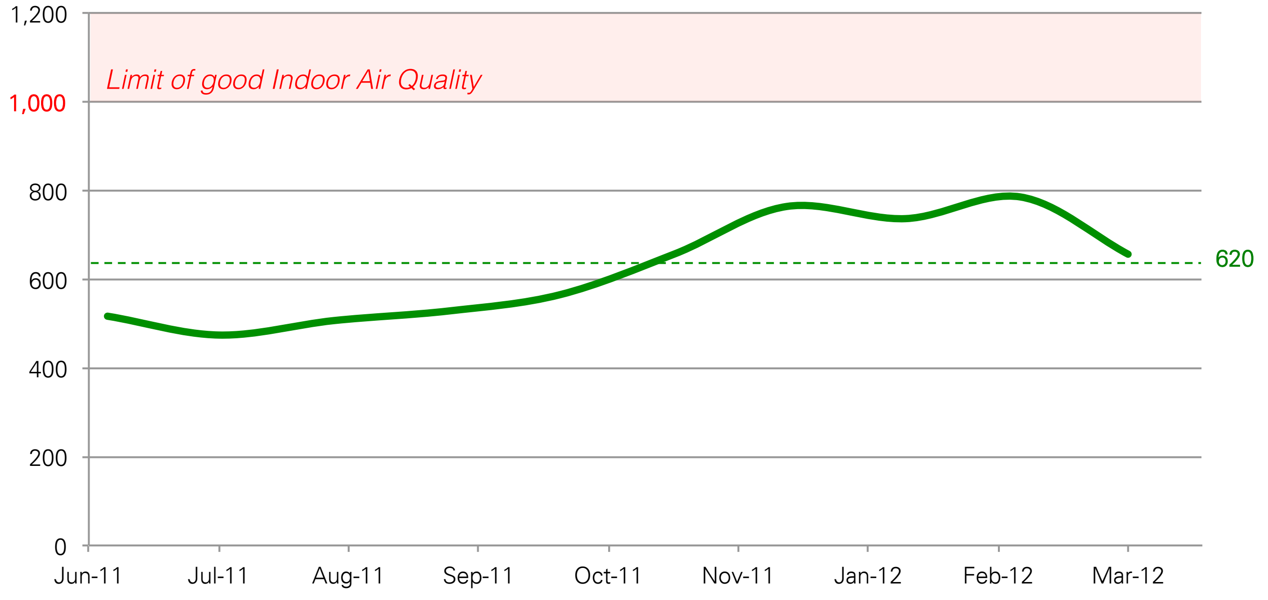
Key results

CO_2 concentration has been correctly monitored in the Passivhaus, living room but there has been monitoring issues in the Decent Home Plus (CO_2 not monitored) and in the typical scheme (monitored for only a few months).

The yearly average CO_2 concentration in the Passivhaus is 620 ppm, and the highest average monthly concentration is below 800 ppm. Hence good Indoor Air Quality is achieved all year long in terms of CO_2 concentration in the Passivhaus.

The data points in the graph below are the monthly average CO_2 concentration. Peak concentration can punctually occur and will be analysed in the following section.

CO_2 concentration in the Passivhaus living room (ppm, Jun 11 – Mar 12)



Those results shows that that the Mechanical Ventilation Heat Recovery system is efficient in regulating CO_2 concentration in addition to contributing to heating during the winter and cooling during the summer.

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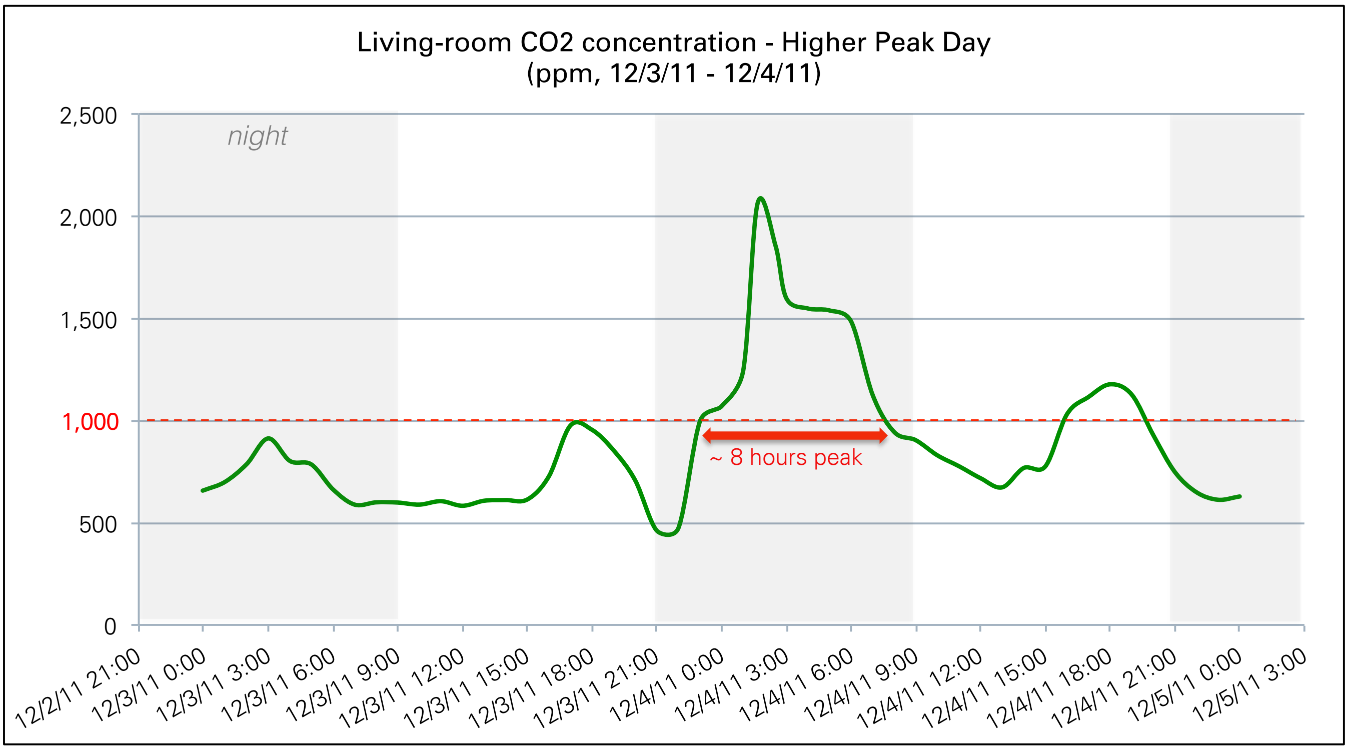
Indoor Air Quality
$C0_2$ concentration
Princedale Road

CO_2 peak times

Even if the monthly average $C0_2$ concentration in the Passivhaus is always below the comfort threshold of 1,000 ppm, some peaks in concentration regularly occured in the leaving room. The highest ($C0_2$ concentration up to 2,100 ppm) and longest (8 hours) peak happened on December 3rd 2011, probably during a house party with guest sleeping in the living room with closed windows and doors.

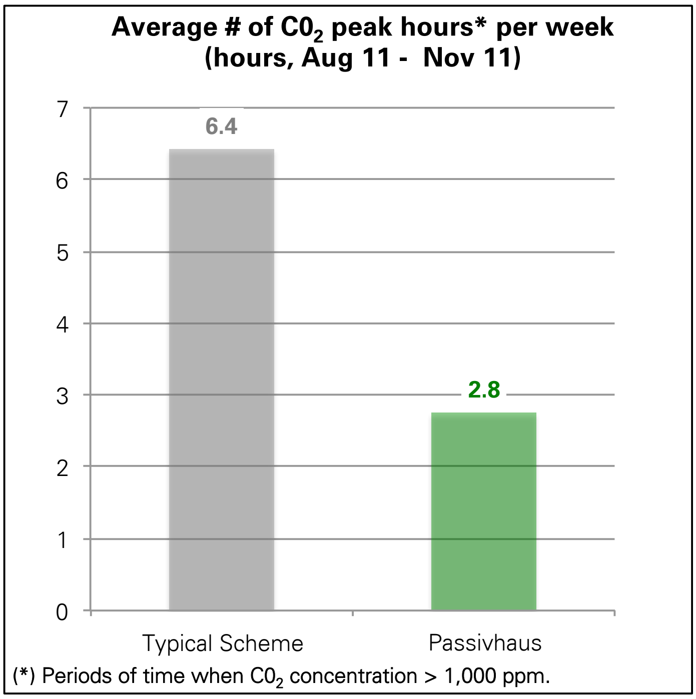


Indoor Air Quality $C0_2$ Concentration Peak Control Princedale Road

CO_2 peak control

The analysis of peak control is a relevant indicator of how efficient the ventilation system of a dwelling is. On the relevant period of time (the monitoring was working on the typical scheme from August to November 2011), the actual average number of peak hours per week shows that the Passivhaus was more that twice as efficient in regulating CO_2 peaks than the typical scheme.

However, those results have to be qualified by bearing in mind that this number of peak CO_2 hours is heavily related to the occupants' behaviour (e.g. evening parties, guests and family visits, sport activities in the living room, etc.).



(*) Peak hours are defined as periods of time when $C0_2$ concentration > 1,000 ppm.

Moreover, $C0_2$ regulation in the typical scheme's living room is only achieved by natural ventilation and air infiltration, which sizeably contributes to the building heat losses. On the other hand, MVRH provides good $C0_2$ regulation in the Passivhaus while both contributing to heating the house in the winter and providing cooling in the summer.

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Indoor Air Quality
Relative Humidity
Princedale Road

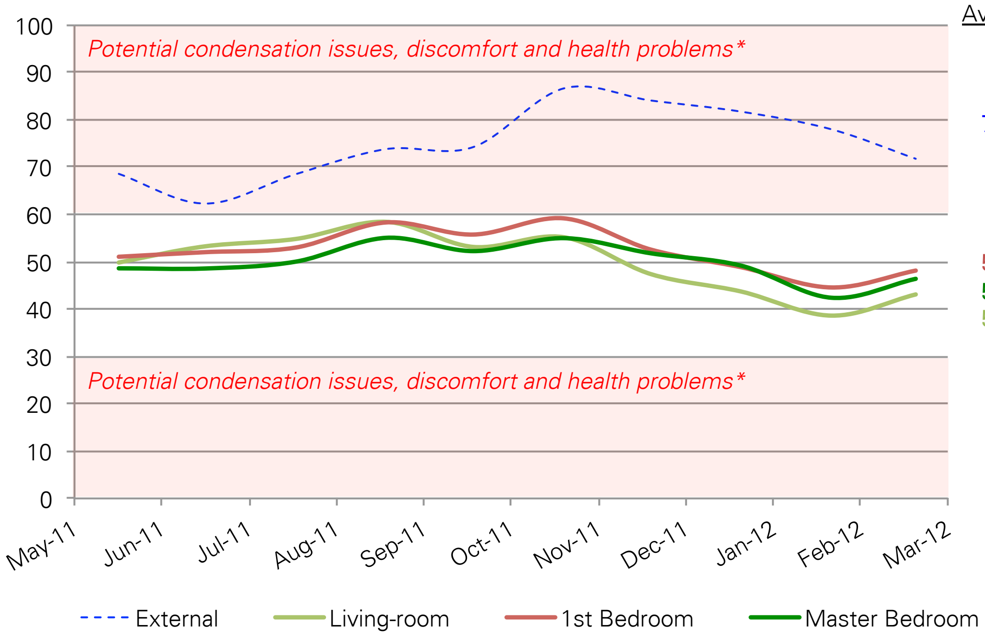
Introduction

Relative humidity is another component of Indoor Air Quality. Too low level of relative humidity (below 30%) is a source of discomfort because of too dry ambient air, and high levels (above 60%) may cause condensation issues within the dwelling fabric, and discomfort or health problems for the occupants.

Key results of one year of monitoring

Relative humidity has been monitored in various rooms of the Passivhaus. The relative humidity was 50% on average, and was also very stable throughout the year.
This demonstrates that the MVHR system was efficient in terms of relative humidity regulation as well.

Relative Humidity in the Passivhaus (%, Jun 11 - Mar 12)



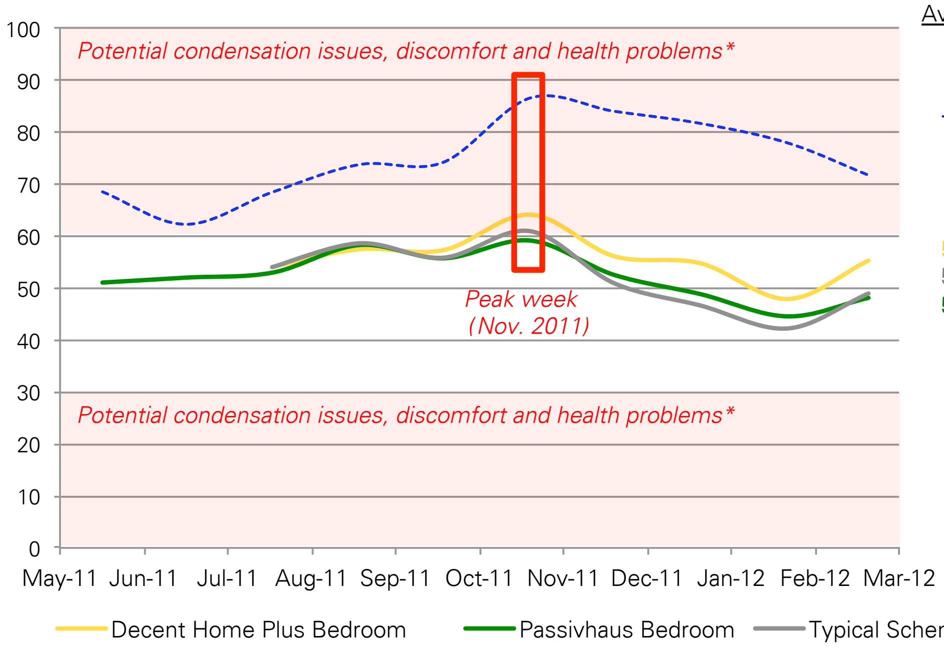
Average	Std. Dev.	% time >60%	% time >70%
75%	13%	86%	72%
52%	6%	12%	0%
50%	5%	2%	0%
50%	8%	10%	0%

(*) Source: Passivhaus Institut (www.passipedia.org)

Indoor Air Quality
Relative Humidity
Princedale Road

Comparison with the other properties

However, relative humidity in the Decent Home Plus seemed to be regulated less efficiently. Even if the average relative humidity was within the targeted interval, it exceeded the maximum levels during several winter months. This is mainly because of the high levels of envelope insulation and less efficient ventilation system that requires the occupants to manually open the windows to regulate relative humidity.



Average	Std. Dev.	% time > 60%	% time > 70%
75%	13%	86%	72%
56%	7%	29%	0.2%
53%	8%	18%	0%
50%	6%	12%	0%

(*) Source: Passivhaus Institut (www.passipedia.org)

Indoor Air Quality Relative Humidity Peak Week (Nov. 2011)

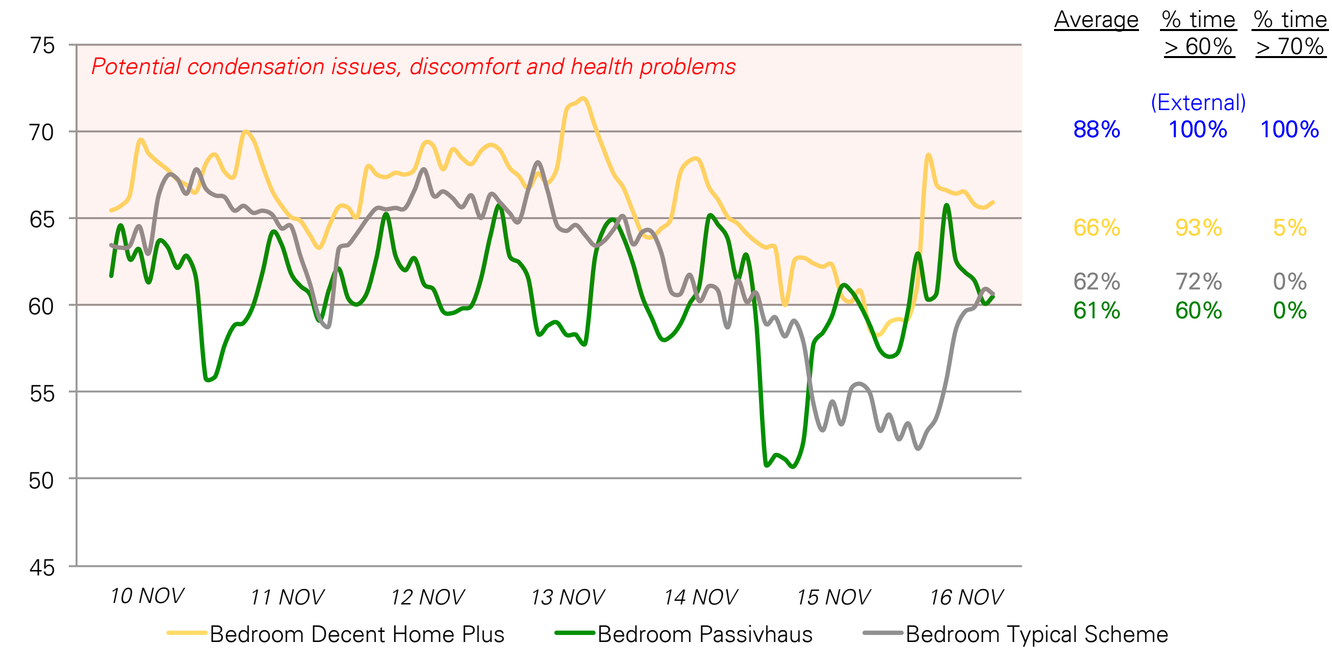
Princedale Road

Key results

During the peak week, the Decent Home Plus presented considerably high levels of relative humidity, which is not regulated efficiently enough (relative humidity is above 60% during 93% of the time).

The Passivhaus and typical scheme seemed better regulated, with an average relative humidity slightly above the maximum recommended indoor air quality level.

Relative Humidity Peak Week (% in bedrooms, Nov. 2011)

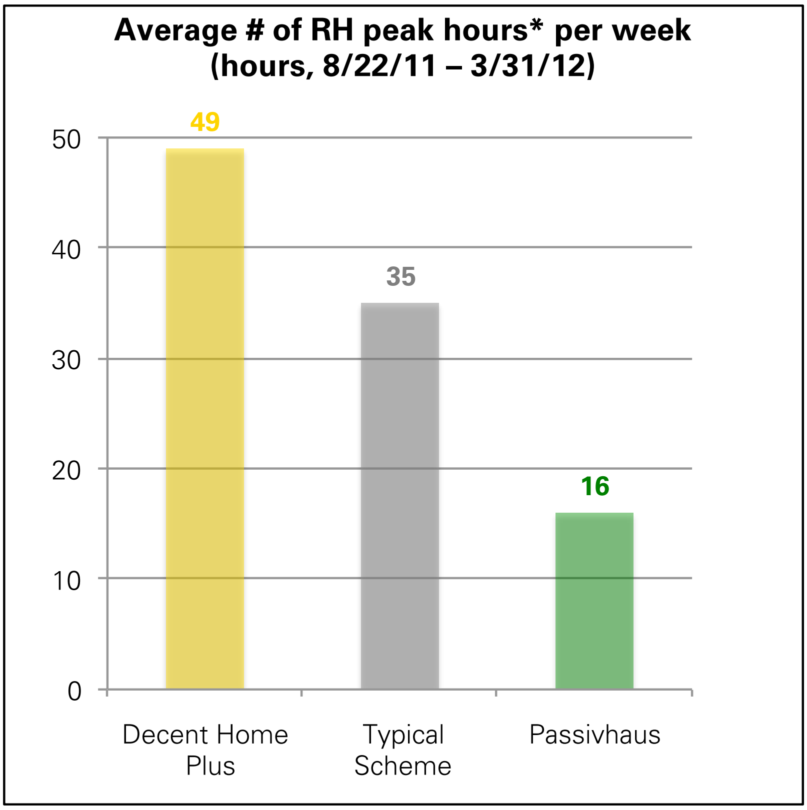


Indoor Air Quality
Relative Humidity
Princedale Road

Relative Humidity Peaks

The Passivhaus performed better than the two other schemes at preventing peak moments of relative humidity in the house. The Decent Home Plus failed to efficiently regulate relative humidity (the dwelling is above the maximum threshold 7 hours per day).

Similarly to the $C0_2$ peak results, those results have to be qualified because of their high reliance on tenants' behaviour.



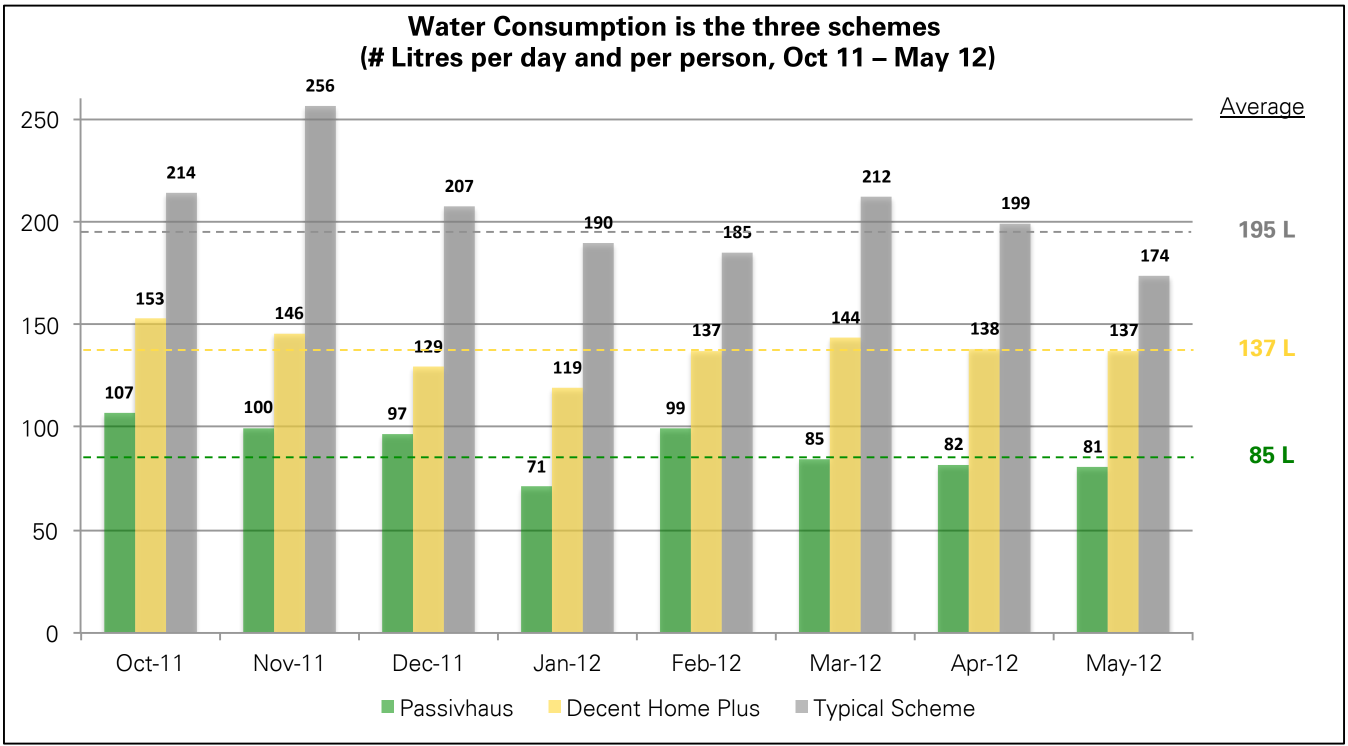
*) Peak hours are defined as periods of time when %RH > 60% in occupied rooms.

Similarly to $C0_2$ regulation, Relative Humidity regulation is made in the Passivhaus is an energy efficient way, while it contributes to heat loss in the winter and overheating in the summer in the Decent Home Plus and the typical scheme.

Water Usage
Princedale Road

Introduction	UK has less available water per person than most other European countries. Water supplies are coming under strain from a combination of increasing population density in low rainfall areas, increasing water usage trends, changing weather patterns and infrastructure depreciation.

Key results of one year of monitoring	Average daily consumption in the Passivhaus was 85 Litres per person per day, which is equivalent to a Code for Sustainable Homes rating of 5 out of 5 in the internal water use category. As a comparison, the UK average water usage is approximately 150 Litres per person per day. Water use in the Decent Home Plus sizeably exceeded the Passivhaus consumption with 137 Litres per person and per day. In the typical scheme, an average of 197 Litres of water was used per person per day, which is 131% more than the Passivhaus consumption. The below graph shows the average daily water consumption during months when data was available for three schemes.



Water Usage
Bill savings
Princedale Road

Those results suggest that living in a Passivhaus (and to a lesser extent in a Decent Home Plus) encourages the occupants to actually live in a more sustainable way, beyond the primary objectives regarding Final Energy Demand, thermal comfort and Indoor Air Quality.

Water bill savings

Based on Water Thames water prices, the expected yearly water bills in the Passivhaus were almost £200 cheaper than those in the typical scheme.

	Typical Scheme	Decent Home Plus	Passivhaus
Volume charge per year (£)	£340	£235	£145
Savings vs. typical scheme	-	**£105**	**£195**

The calculation were based on a volume charge per cubic meter of water supply of 117,82 pence (Thames Water 2011-2013 prices).

Source: thameswater.co.uk/cps/rde/xbcr/corp/201112-metered-charges-leaflet.pdf

Conclusion
Princedale Road

Conclusion

Providing affordable housing and bills while ensuring decent levels of thermal comfort, and reducing dwellings carbon emissions in line with national targets without disrupting the occupants' lifestyle or architectural heritage are the major current challenges for Registered Social Landlords.

From a short and long term perspective, the Passivhaus refurbishment case is the most compelling. Although requiring higher upfront costs for energy efficiency measures, the results in terms of financial security and thermal comfort sizeably exceed those of the Decent Home Plus and typical scheme.

In addition, the government's 80% reduction in carbon emissions by 2050 aim means there is only one option and that is deep green refurbishment along the lines of Passivhaus rather than Decent Homes Plus.

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Appendix 1 Summary of Key Figures

Princedale Road

Key Resuslts of one year of monitoring (June 2011 - May 2012)	Typical Scheme	Decent Home Plus	Passivhaus
Final Energy Demand			
Gas usage (kWh/yr)	25,170	10,399	0
Electricity usage (kWh/yr)	7,024	7,025	5,553
Total (kWh)	32,194	17,424	5,553
Total (kWh/m2/yr))	366	198	63
% Reduction vs. Typical Scheme	-	46%	83%
Estimated Space Heating Demand (kWh/m2/yr)	148	29	6
% Reduction vs. Typical Scheme	-	80%	96%
Most energy intensive month usage (Feb 2012, averge kWh/day)	173	83	21
% Reduction vs. Typical Scheme	-	52%	88%
Less energy intensive month usage (July 2011, averge kWh/day)	40	33	10
% Reduction vs. Typical Scheme	-	18%	75%
% Increase in consumption between the 2 extreme months	333%	152%	110%
C02 emissions			
Total emissions resulting from dwelling operation and services (kgC02/yr)	7,847	4,982	2,343
% Reduction vs. Typical Scheme	-	37%	70%
Energy Bills			
Yearly energy bills	£2,026	£1,468	£772
Savings on bills vs. Typical Scheme	-	£558	£1,254
Cost of energy efficiency measures	-	£13,074	£87,478
Payback period (In years, assuming 10% yearly increase in fuel prices (incl. Inflation))		15	27
Internal Rate of Return (100 years projects)	-	14.1%	10.2%
Thermal Comfort			
Average yearly temperature in non-master bedrooms	19.5°C	20.2°C	22.2°C
Temperature standard deviation in non-master bedrooms	2.6°C	2.0°C	1.5°C
% time between 18°C and 26°C in non-master rooms (yearly)	70.1%	86.5%	97.7%
90% of the time within temperature interval	[15.2 ; 23.8]	[16.9 ; 23.5]	[19.7 ; 24.7]
Peak Winter Week			
Average temperature in non-master bedrooms	16.4°C	18.5°C	20.8°C
Average daily energy use (kWh/day)	200	100	23
Passivhaus Standard (% time above 25°C)			
Living room	N/A	N/A	2.4%
Non-master bedroom	N/A	N/A	5.5%
Master bedroom	N/A	N/A	10.8%
Overheating			
Living room - peak week (% time above 28°C)	0%	N/A	0%
Living room - yearly (% time above 28°C)	0.1%	N/A	0.2%
Non-master bedroom - peak week (% time above 26°C)	24%	7%	28%
Non-master bedroom - Yearly (% time above 26°C)	1.7%	0.3%	2.3%
Indoor Air Quality			
Average C02 concentration	650 ppm	N/A	620 ppm
Average % relative humidity in non-master bedrooms	53%	56%	50%
% time above 60%	18%	29%	12%
% time above 70%	0%	0.2%	0%
Water Consumption			
Water usage (L/person/day)	£195	£137	£85
Volume charge per year (£)	£340	£235	£145
Savings on water bills vs. Typical scheme	-	£105	£195

Appendix 2 Underground Heat Exchanger

Princedale Road

Effect of the Underground Heat Exchanger in the Passivhaus

Before entering the Mechanical Ventilation with Heat Recovery system, the external air is pre-heated during the winter by going through the underground heat exchanger built under the basement of the house.

Hence, the external is heated in three 3 stages before entering into the house: in the underground heat exchanger, through heat recovery with exhaust air in the MVHR, and via heat provided by the heat pump.

The underground heating system is very efficient in heating the cold external air. 12.5°C are gained when it goes through the underground labyrinth. The Mechanical Ventilation Heat Recovery system allows 5.7 °C additional gains, before the heat pump warms the air at 41.5 °C (temperature of admission when the heat pump is working).

	External	Underground Heat Exchanger	Heat Recovery through MVHR	Heat Pump effect
Air Temperature	0 °C	12.5 °C	18.2 °C	41.5 °C
°C Gains	-	12.5 °C	5.7 °C	23.3 °C

(Source: Genvex date during peak winter week (11.02.2012)).

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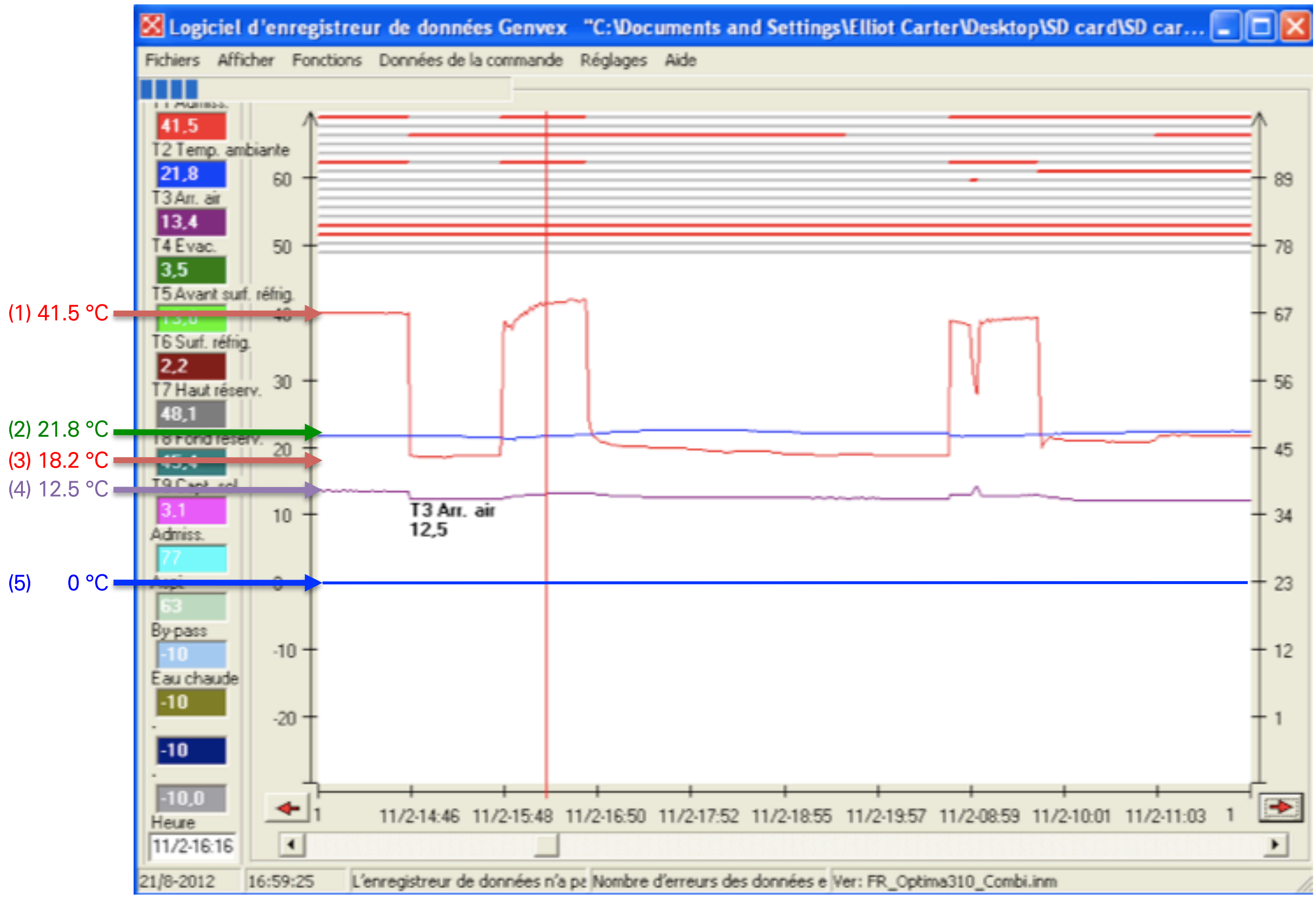
Appendix 2 Underground Heat Exchanger

Princedale Road

Heating process during the peak winter week (Feb. 2012)

(1) Air temperature of admission when the heat pump is ON
(2) Internal Temperature
(3) Admission temperature when the heat pump is OFF
(4) Air temperature after the underground heat exchanger
(5) External temperature



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Appendix 2
Underground Heat Exchanger
Princedale Road

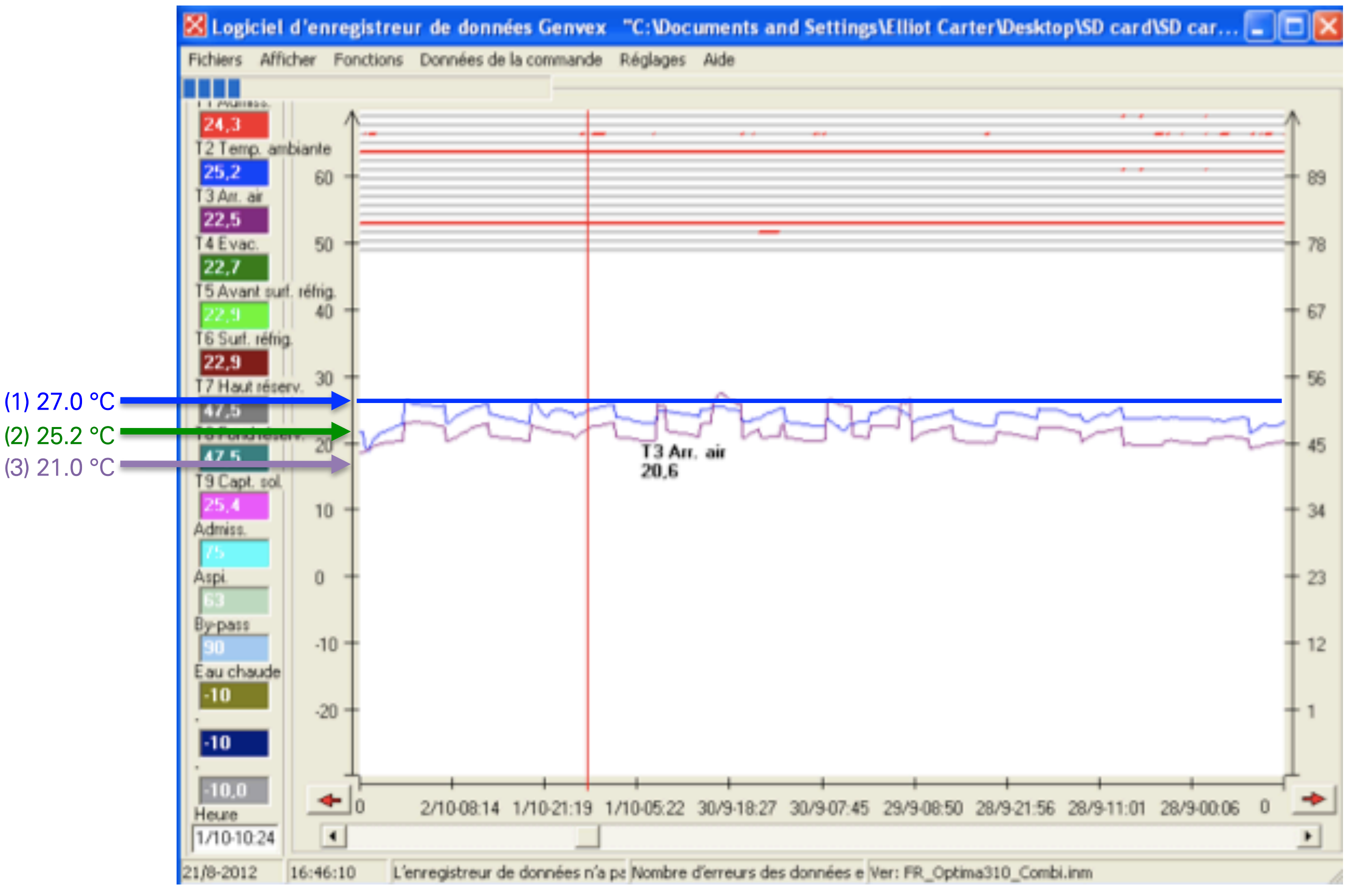
Effect of Underground Heat Exchanger in the summer

The underground heat exchanger also provides cooling during the summer: the air entering the MVHR after going through the underground labyrinth was at 21 °C during a hot peak summer day (6 °C loss compared to external temperature).

Thanks to the bypass automatically activated in the summer, the incoming air is not heated by the exhaust air of the house, and enters the room at the same temperature, 21°C and cools the house (25°C internal temperature).

Key of the Genvex software screenshot below:

(1) External Temperature
(2) Internal Temperature
(3) Air temperature after the underground heat exchanger = Admission Temperature (MVHR bypass)



Appendix 3
Data Availability
Princedale Road