Oxford Whole House Carbon Reduction Project

Part of the Retrofit for the Future Programme
Sponsored by the Technology Strategy Board

www.oxford.gov.uk
OXFORD CITY COUNCIL

Leadbitter Group

OXFORD BROOKES UNIVERSITY

RIDGE

Contents

Retrofit for the Future

Central Government targets have been set to reduce UK greenhouse gas (GHG) emissions by 80% of the 1990 levels by 2050.

In order to assess the practicalities of these targets the Technology Strategy Board (TSB) (see back cover for website addresses) released an innovation challenge called *Retrofit for the Future Programme* to review how to achieve 80% reduction in CO_2 levels.

The objective of the works at Nelson Street, along with the other agreed 85 houses that form the *Retrofit for the Future Programme*, is to collect data from all around the UK to help the Government and Local Authorities assess how best to reduce the carbon footprint of the social and private housing stocks in the UK by 80% by 2050.

Typical 80m^2 semi-detached house

- Emissions rate of 104 kg CO_2/m^2/year
- TSB Target 17 kg CO_2/m^2/year

Average UK housing stock

- Primary Energy Target = 365 kWh/m^2/year
- TSB Energy Target 115 kWh/m^2/year

The *Retrofit for the Future Programme* is seen as part of the research and development pilot studies.

The costs per tonne of CO_2 saved has been assessed and does rise disproportionately as targets increase. That is to say, it is much more expensive to increase the carbon saving by 10% from 70–80% saved than from 40–50% saving.

Technology Strategy Board Programme

November 2009

Ridge submitted a Phase 1 feasibility study (developed with the Oxford Team, including Oxford Brookes and Oxford City Council) along with 380 other countrywide applicants.

January 2010

Ridge submitted a Phase 2 study (with Oxford Brookes and Oxford City Council) along with 200 other applicants.

April 2010

86 live projects developed with contractors. Leadbitter is invited to join the Oxford Team. Building and resident monitoring begins.

August 2010

Nelson Street retrofit house started.

December 2010

Nelson Street building work completed.

January 2011

Building and resident monitoring recommences.

January 2013

Building monitoring to be completed.

Oxford Whole House Carbon Reduction Project

Specific Aims of the Project

- Improve fresh air into the centre of the house with an MVHR system.
- Improve daylighting via a sunpipe on the landing and removal of a section of ground floor wall between rooms to allow light to flow from the brighter front of the house to the rear areas.
- Refit the ground floor bathroom to make it more user friendly as a wet room for disabled residents.
- Refit all the wet areas to reduce the water demand, providing a water meter as well as a water collection butt in the garden.
- Improve the air quality of the internal environment by using VOC-free paint finishes.
- Ensure the resident storage space is not adversely affected.
- Monitor for two years in line with the requirements of the Energy Saving Trust (EST) to review the actual reduced energy consumption.
- Assess how resident lifestyle affects the energy used.

This Oxford City Council Victorian semi-detached house in Nelson Street with two rear extensions added in 1972 and 2003, was described as a very cold house by the residents, especially the first floor bathroom that had three exposed external walls and a roof.

Project Core Objectives

- Reduce the carbon emissions from the energy consumption of the property by 80%.
- Reduce fuel bills from £600 per year to £150 per year.
- Use practical tried and tested technologies.
- Improve health, comfort and quality of life for tenants.
- Identify lessons learnt and apply to wider social housing stock.

These objectives were to be achieved by:

1. Raising the property's standard of insulation to higher energy efficiency levels and minimising heat losses through air leakage by airtight sealing thus reducing the heating load and cutting CO_2 emissions by 66%.
2. Adding more efficient water heating and lighting, electrical loads could be further reduced resulting in an overall CO_2 emissions reduction of 75%.
3. Adding micro-generation through solar thermal and PV cells installed on the roof further offset energy consumption, achieving a reduction of CO_2 emissions by 85% surpassing the target.

Insulating blocks and triple-glazed doors and windows

Oxford City Council

Since 2005 Oxford City Council has had a *Climate Change Action Plan* and in April 2008 we agreed our carbon management plan called *Getting Our House in Order* (see our website www.oxford.gov.uk).

We have committed to:

- Reducing the Council's CO_2 emissions by 25% by March 2011.
- Increasing the uptake of low carbon initiatives in Oxford.
- Raising awareness and understanding of climate change.
- Increasing the energy efficiency of new developments.
- Transforming Oxford into a low-carbon city.

It is through this type of scheme, working in alliance with experts in their fields that demonstrates Oxford's commitment to carbon reduction for all types of properties.

This property was carefully chosen as one which would not fit the usual standard package of solutions. We wanted to ensure that the project delivered would provide the best value for money for this type of property, its residents and the housing sector at large. Following the completion of the works, we will be able to advance the understanding of the future requirements of the national housing stock by the continued monitoring of this property's performance while in normal use by the residents.

Criteria for choice

This property is:

- A typical older style home.
- Is not in a conservation area.
- Still has some architectural features that require saving, such as the decorative brickwork on the front elevation.

Also, the residents:

- Had a significant period of residency to provide details of how the property operated before the retrofit works.
- Are unlikely to change lifestyle, e.g. not have children about to leave home.
- Are willing to become part of this scheme and tolerate the intrusion that this may entail.

Original Property Assessment

Original construction

- Walls: solid brick.
- Roof: timber trussed slate.
- Ground floor: concrete slab.
- Windows: uPVC double-glazed.

Two rear extensions

- Walls: unfilled brick cavity.
- Roofs: flat felt roofs with little insulation.

Residency

The house is occupied most of the time.

In-use monitoring of the home

Data was collected for a range of physical parameters for the duration of two months (October and November 2009). The data was used to triangulate findings from the energy audit and the residents' feedback survey to allow greater confidence in the results and also provide cues to specific problems within the property.

Energy consumption: predicted and actual

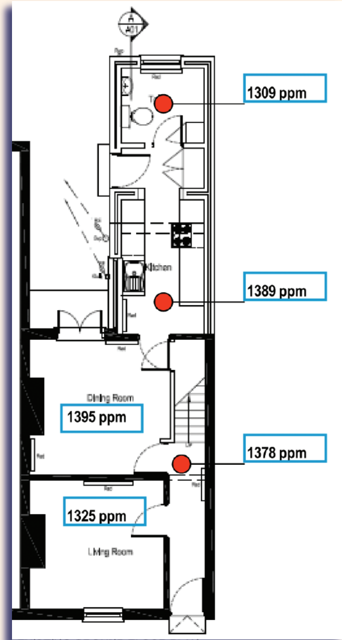
Standard Assessment Procedure (SAP) 2005 estimated the total gas requirement to heat the home and water system to be about 24,800 kWh, while the actual gas use from fuel bills was found to be only 9,465 kWh. Investigating this discrepancy showed that the average temperature in rooms was much lower at 14–18°C than the recommended 18–21°C and hence, the annual gas bills were less than half of what the SAP predicted. The residents also complained about a 'cold' house, which was difficult to heat due to a lack of insulation and rising fuel costs.

	SAP 2005 prediction	Actual energy use 2008-09
Gas (kWh/yr)	24,800	9,465
Electricity (kWh/yr)	803	2,481
Total energy (kWh/m^2/yr)	333	155

Temperature

The house also had a low temperature range. This could possibly explain the lower than average gas consumption in the house as highlighted by the fuel bills and SAP analysis.

Temperature (°C)	October 2009	November 2009
External	11.0	8.1
Living room	18.4	17.1
Master bedroom	16.8	14.4
Rear bedroom	17.9	16.2



Existing ground floor plan showing CO_2 levels

Original Property Assessment

Daylight

Monitoring also showed that the house had very low levels of natural light with most internal spaces recording daylight factors as low as 0.2–0.4%, thereby setting a design challenge to increase natural light in the house. The only exceptions were the main bedroom and the sitting room at the front of the house, which had daylight factors of more than 2%.

Air quality

Air quality was evaluated by taking carbon dioxide (CO_2) spot readings at different places in the house using a CO_2 sensor. The house showed CO_2 levels averaging at 1,300 ppm with the living room as high as 1,395 ppm, CO_2 readings above 1,000 ppm exceeds the recommended guidelines and could have direct health consequences.

Due to the poor air quality, a few windows in the house were monitored to gauge how often the residents ventilate the house. State loggers were used to record the opening and closing of three windows frequently used for ventilating the house. In a continuous period of 28 days, the windows in each space were only opened on an average of four days (not the same day for each space). The master bedroom window was opened for the longest duration, while the kitchen and the bathroom windows were opened for a shorter period of time. This substantiated the reasons for the higher-than-average CO_2 levels recorded. Also, the inability of the house to be heated to comfortable temperatures usually between 18–20°C may explain why residents did not open windows regularly to avoid losing further heat.

Key Issues Highlighted

Space quality and design

- Inadequate natural light in most spaces, except rooms at the front of the house.
- Preference for a bigger living area with space for dining table, by combining the current living and office/sitting room.
- Inadequate storage and kitchen area.
- Garden and central location of the house were positive features.

Space heating

- Heating system responsive, but still inadequate to maintain comfortable temperatures; house felt very cold.
- Secondary heating in living space helped.
- Occupants adapted by wearing extra layers of clothes indoors.

Other issues

- Future adaptability of the house for the occupant with health concerns.

Analysis and Feasibility of the Whole House Carbon Reduction Project

Resident feedback

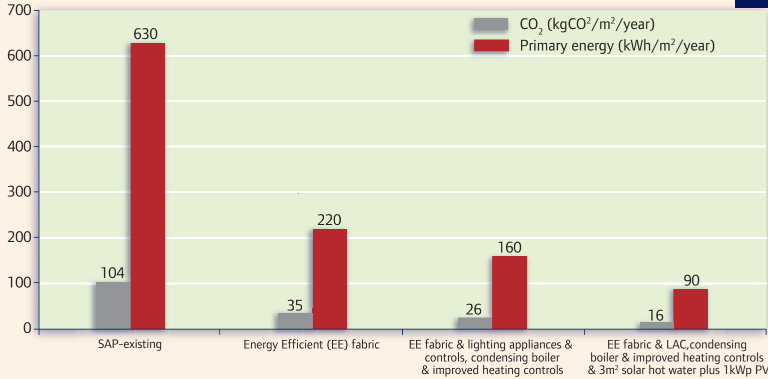
Overall both residents considered the house comfortably warm or comfortable, even though the monitoring of the building showed that the temperature in the house was much below accepted levels. A possible reason might be that the residents have probably adapted to the cold house by wearing more clothes even when indoors and do not feel 'uncomfortable' any more.

Given the lack of insulation in the house and the residents' concerns about the property being cold, a 'low-energy first and then low-carbon' approach was adopted for the house by first encouraging energy demand reduction measures, and then deploying a nominal level of well-proven zero-carbon technologies that can be easily integrated into the building fabric.

As previously noted, and indicated in the table below, in order to address the high levels of CO_2 and low levels of daylight in the house, a sunpipe with low U-values to minimise heat loss has been added. This would not have been incorporated without the findings from the pre-refurbishment, in-use monitoring and resident feedback.

Key findings	Low carbon refurbishment proposals
Poor daylight levels in most rooms.	Sunpipe with good U-values.
Poor indoor air quality throughout.	MVHR for good air quality; optimise airtightness.
Uninsulated fabric; difficult to heat house for comfort.	Highly insulated fabric, triple-glazing, MVHR.
Future adaptability for residents with health issues.	Potential for living room change to bedroom and refurbishment of ground floor toilet to a wet room.

Reductions achieved in CO_2 emissions and primary energy



Sealing all gaps to prevent heat loss

Building Proposals

Over 60% of the energy savings proposed are gained through improvements to the building fabric; therefore, the improved insulation and reduced air leakages and draughts have been primary to the success of the project.

The insulation and the airtight barriers to external walls have been installed without break wherever possible.

All internal walls have also been insulated to reduce heat loss into the foundations.

All windows have been replaced with triple-glazing in order to raise the surface temperatures inside the house but also to reduce the difference in the thermal efficiencies between the walls and windows.

Post completion thermographic imaging has been taken of the external walls to assess if there are any other cold bridging points.

Airtightness membranes have been installed in first floor ceilings with all service pipe areas sealed. All gaps and holes in outside walls have been filled. All junctions between floors and walls have been sealed to ensure a low level of heat loss from air leaking out of the building and cold air from entering.

Post completion, an air pressure test has been carried out which indicated an air permeability close to $1 m^3/hm^2$ @ 50 Pa. (2010 Building Regulations require $10 m^3/hm^2$ @ 50 Pa.)

Airtight vapour barrier under slate roof and tape seals around all plumbing

Energy Saving Measures

Front Wall

82.5mm internal insulation plaster board on existing solid brickwork wall. Decorative brickwork retained externally. U-value $0.24W/m^2K$

Rear Wall

82.5mm internal insulation plasterboard on existing solid brickwork wall. 200mm rendered external insulation. U-value $0.1W/m^2K$

Gable Wall

200mm external EPS insulation on existing brickwork wall plastered internally. U-value $0.24W/m^2K$

Rear Extension Walls

Existing masonry cavity walls, lined internally with 27mm insulated plasterboard. Cavity wall filled with injected insulation. 200mm rendered external insulation. U-value $0.1W/m^2K$

Internal Walls

All masonry walls have been lined with insulated plasterboard.

Roof

420mm loft insulation at ceiling line with Intelloplus airtight vapour barrier. U-value $0.1W/m^2K$. Additional ventilation provided in the existing slate roof to avoid the risk of condensation. Insulation added to the cold water tank.

Flat Roofs

230mm loft insulation over existing felt and covererd with a high performance membrane.

First Floor

Timber floor structure retained with masonry fireplace, hearths removed and rotten boards replaced. Wall insulation continuous through floor. Airtightness continuity ensured with ecological building systems tapes.

Insulation and airtight membranes sealed with blue ecological system tapes

Energy Saving Measures (continued)

Ground Floor

New floating chipboard floor with 10mm Spacetherm C insulation on existing screed and concrete floor, taped to existing masonry walls to ensure airtightness without open gaps at joints.

Mechanical Ventilation Heat Recovery (MVHR)

Mechanical ventilation ductwork in loft dropping to:

- supply air to all habitable rooms (living room, dining room and bedrooms).
- extract air from wet rooms (bathrooms and kitchen).
- Heat Recovery Unit in loft extracts heat from return air into supply air to prevent the cold air supplied from outside in winter from cooling the house.

Monovent Sunpipe

To improve natural light and natural ventilation in the darkest part of the house, a sunpipe has been installed in the roof over the stairs. There is also a controllable vent around the sunpipe to allow a natural stack effect in the summer to prevent overheating.

Windows

New triple-glazed windows 0.8 W/m^2K U-value.

Photovoltaic Cells (PVs)

$8m^2$ of solar panels on the roof provide a 1kW/hr peak load supply to the property. This is sub-metered to allow the feed-in tariffs to be collected, in addition to the free electricity the panels provide.

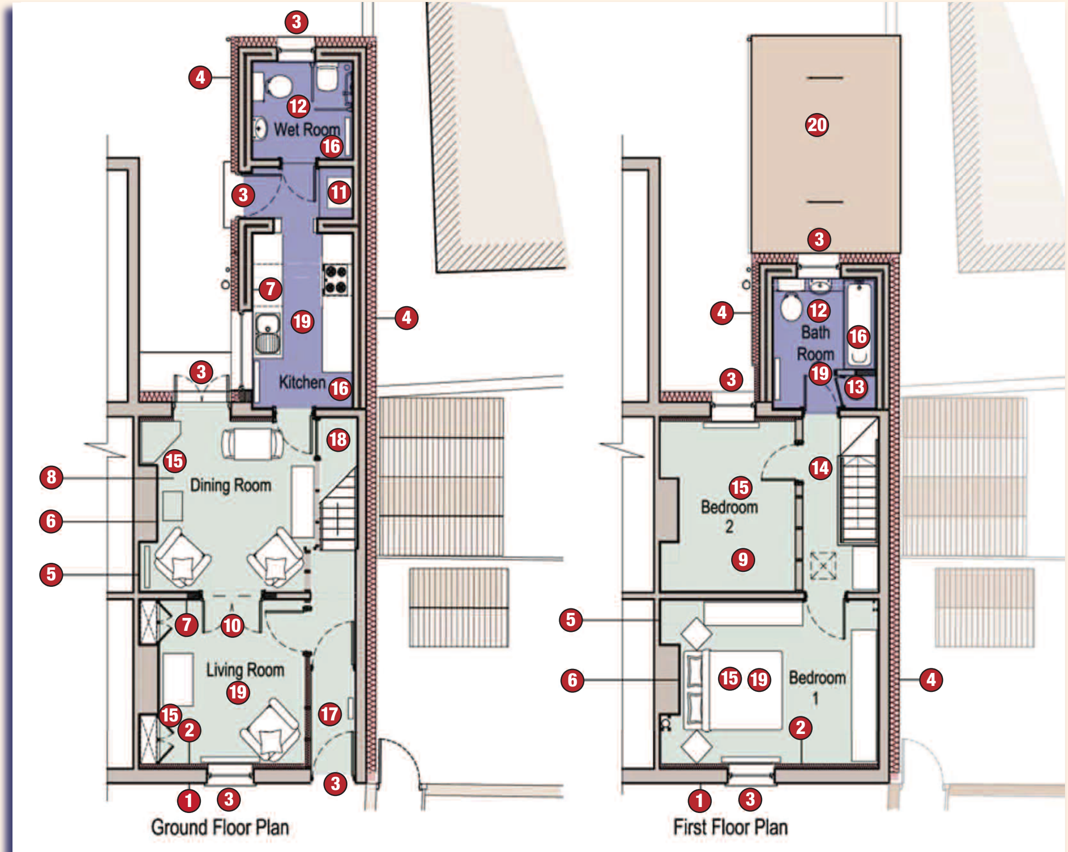
Solar Thermal Hot Water

Evacuated tubes have been installed on the south-east facing roof to supply hot water to the water cylinder in the first floor bathroom.

Paints

Natural Building Technology (NBT) water-based natural paints have been used without any toxic oil-based chemicals such as VOCs.

Retrofitted Nelson Street Property Floor Plans



Key

1. Original recycled decorative brickwork retained
2. Internal insulation to solid wall to reduce heat loss without affecting external appearance
3. New triple-glazed windows and doors reduce heat loss and raise internal surface temperatures
4. External insulation reduced heat loss further on northern sides of house
5. Party walls insulated
6. Chimney stacks insulated
7. Internal masonry walls insulated to reduce cold bridge into footings
8. Ground floor slab insulated throughout
9. 420mm of loft insulation above ceiling line with additional ventilation provided for cold roof space
10. New opening with fully glazed doors to allow light through house
11. New energy-efficient gas fired boiler
12. Low flow water-efficient appliance
13. New insulated hot water cylinder supplied by solar thermal tubes on roof
14. Monovant Suncatcher on landing providing natural light and background ventilation
15. Heat recovery unit in loft supplies tempered air to living areas
16. Ventilation system extracts air from kitchen and bathroom wet areas to heat recovery unit in loft
17. Insulated entrance lobby with fully-glazed doors
18. Pulse meters fitted to monitor consumption and micro generation from PVs on the roof
19. Rooms monitored for temperature, humidity and CO_2 levels
20. New insulated warm flat roof

Considerate Constructor

Educating not only the workforce, but also the wider community was one of the core objectives of the project. Leadbitter made a presentation at the nearby St Barnabas primary school explaining how the project would help the environment. We also achieved a Considerate Constructor Gold-standard score for the manner in which we worked with the local community.

Building Contractor: Leadbitter's Assessment

Programme

Overall, the works took 16 weeks to complete; it was important we finished in time for Christmas 2010. Part of the challenge of the programme was in the co-ordination of all the trades and suppliers within such a tight space, particularly with the specialist elements such as the high performance windows and the renewable technologies. It was important to have everybody on board early so that we could collectively resolve co-ordination issues before they arose on site.

Quality

To achieve the required airtightness standards it was paramount that Leadbitter built in quality 'hold points' within the programme. We took great care to educate the personnel on site to ensure they understood the importance of the airtightness detailing and its impact on the performance of the building.

Local Labour

Everyone working on the project lived within a 20 mile radius of the site, and we worked in partnership with Oxford City Council's own operational staff to carry out the works.

In-use Monitoring and Post-Residency Evaluation January 2011 to January 2013

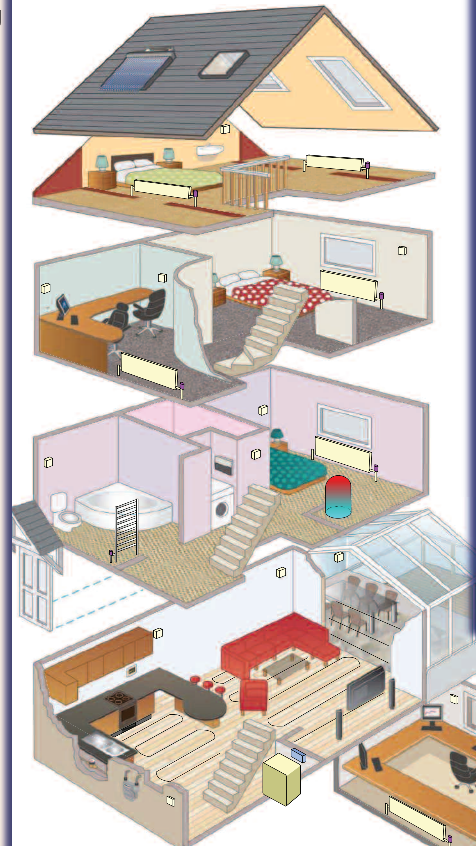
A team of researchers led by Dr Rajat Gupta of the Low Carbon Building Group of Oxford Brookes University will undertake detailed in-use monitoring and post-occupancy evaluation (POE) of the house over 24 months, post-retrofitting.

Collected data of all 86 homes will be recorded and made available through a special section of the retrofit diary website (see back cover). The methodology used for the post-retrofit evaluation and analysis will be guided by the pre-retrofit monitoring and resident feedback survey.

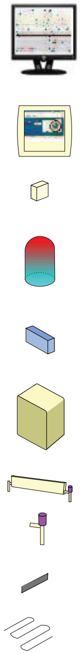
In line with the requirements of the *Retrofit for the Future Programme*, the core elements of the monitoring and POE include:

- Post-construction fabric testing using airtightness test and thermography.
- Walk-through surveys.
- Meter readings and fuel bills to compare with new SAP results.
- Monitoring of internal and external temperatures, relative humidity, daylight levels and air quality.
- Actual performance of solar thermal system: heat meter, electricity meter and solarimeter.
- Actual performance of solar PV system: electricity meter, solarimeter.
- Residents' feedback survey.
- Residents' satisfaction questionnaires (once every season, four times per year).
- Semi-structured open-ended interviews (opinion surveys).

Typical uWatt 'e-zone' energy management system

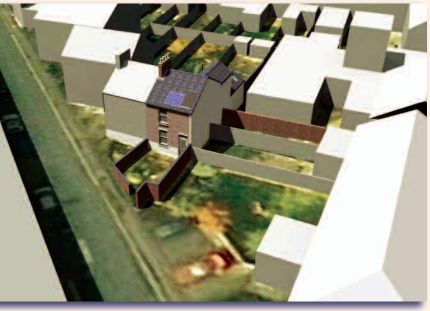


Key



The following extra performance measures have been included to give a better idea of the performance of the home in use and residents' lifestyle:

- Short-term one-off test of MVHR system for airflow rates and electricity consumption.
- Appliance energy consumption: detailed logging of all electrical circuits.
- Hot water use will be monitored separately from space heating.
- Door and window data logging will be collected for seasonal use behaviour and cross-referenced with temperature monitoring.
- Daylight readings will be taken four times per year to represent the daylight levels for the four seasons.
- Real-time display of energy use and fuel costs.
- The state logger record for opening/closing of windows.
- Thermal comfort log sheets by residents.
- Heating schedule log sheets (for heating systems).



Oxford Future: Low Carbon City

What You Can Do About Climate Change

It's easy to feel powerless when looking at major schemes as outlined in this project. However, there is still significant work you can do.

In Oxford we are lucky to have some leading climate scientists and campaigners plus many community groups who want to act on climate change. Visit the community pages of the *Oxford Is My World* website for details of local environmental groups.

As an individual it really is possible to make a difference:

- Add your voice to those who are concerned about climate change by signing the *Oxford Citizen's Climate Change Pledge* (see our website).
- Register for your free copy of *Oxford Is My World: Your Guide to Saving the Planet* on our *Oxford Is My World* website.
- Reduce your home energy use. See Oxford City Council's Home Energy Advice pages for more details.
- Reduce your energy use at work. See Oxford City Council's Business Energy Advice pages for more details.
- Find out if you are eligible for a grant for energy efficiency by visiting Oxford City Council's Grants and Offers page or by contacting us using the details on the right of this page.
- See Oxford City Council's *Energy Efficiency, Controlling Costs and Affordable Warmth* leaflet.

Contact Details

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Glossary

2006 Building Regulations
U-value minimum standards:
Walls = 0.35 W/m^{2}K
Floors = 0.25 W/m^{2}K
Roof = 0.25 W/m^{2}K
Windows/Doors = 2.2 W/m^{2}K

2010 Building Regulations
U-value minimum standards:
Walls = 0.28 W/m^{2}K
Floors = 0.22 W/m^{2}K
Roof insulated at ceiling line = 0.16 W/m^{2}K
Flat Roof = 0.18 W/m^{2}K

Air test reading m^3/h/m^2 @ 50Pa is so many metres cubed of air lost per hour per square metre of surface area including floor @ 50 Pascals of air pressure difference inside to outside.

Airtightness The airtightness of a building is known as its 'air permeability' or leakage rate. Air leakage can occur through gaps, holes and cracks in the fabric of the building envelope, which may not always be visible, e.g. floor boards. This air leakage affects the building's performance, affecting the amount of fuel needed to heat it. The less airtight a building is, the more air leakage and draught, meaning there is more heat loss and more fuel required to heat it, increasing the CO_2 produced and the carbon footprint.

Airtightness membrane An airtight sheet in this case, at first floor ceiling level.

Cold bridges Areas where heat might be lost through the building fabric.

Daylight Factor BS 8206 recommends average daylight factors of at least 1% in bedrooms, 1.5% in living rooms and 2% in kitchens.

Evacuated tubes Heat from the sun is absorbed by copper pipes within glass tubes that have had the air removed, making a vacuum. Most of the heat from the sun is absorbed by these sealed pipes, which contain an anti-freeze type liquid. As heat rises, hot vapours from the anti-freeze rise up to the top of the pipe where its copper tip connects with a header pipe through which more anti-freeze flows. This hot anti-freeze is then pumped through pipes inside the hot water tank with the end result that the water gets hotter and the anti-freeze cooler. The anti-freeze then continues its journey around the system and back out to the solar water heater to be reheated. The copper at the tip of the heat tube can reach well over 200ºC, easily heating water to 90ºC on hot days and to 60ºC even in the winter.

EPS Expanded polystyrene.

Hold points When tests are carried out at critical stages.

MVHR Mechanical Ventilation Heat Recovery.

Pa, Pascal A measure of pressure.

Passive ventilation Draws out heat from kitchen and bathrooms diverting the heat to bedrooms.

Photovoltaic cells (PVs) Solar panels that generate power by converting solar radiation into electricity through the photovoltaic effect – creating a voltage (or a corresponding electric current) in a material when exposed to light.

PPM Parts per million.

Solarimeter A type of measuring device used to measure combined direct and diffused solar radiation. An integrating solarimeter measures energy developed from solar radiation based on the absorption of heat.

State loggers Electronic sensors.

Thermography Infrared thermography uses thermal imaging cameras to detect heat in the form of infrared radiation leaving a building. The red/yellow parts of an image highlight greater heat loss where insulation is missing or where building elements are performing badly. Green/blue areas indicate those that retain heat.

U-value The U-value measures how well a building component, e.g. a wall, roof or a window, keeps heat inside a building. The U-value is a measure of the heat flow through a building element in terms of Watts per metre squared. The higher the U-value the more heat flows through, so a good U-value is as low as possible (see Building Regulations).

VOC Volatile organic compound (undesirable solvents).

Wet room Walk-in shower with toilet and handwashing basin.

Oxford Whole House
Carbon Reduction Project

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Links

Technology Strategy Board
www.innovateuk.org

Retrofit for the Future Projects
www.retrofitforthefuture.org

Energy Saving Trust
www.energysavingtrust.org.uk

Microwatt
www.microwatt.co.uk

Airtightness Barriers and Membranes
www.ecologicalbuildingsystems.com

Monovent Sunpipe
www.monodraught.com

Vectaire Ventilation
vectaire.co.uk

Envirowall – External Insulation
www.envirowall.co.uk

Kingspan Wall Insulation
www.insulation.kingspan.com

Insulated Plasterboard
www.britishgypsum.com

Rockwool Loft Insulation
www.guide.rockwool.co.uk

Proctorgroup Flooring Insulation
www.proctorgroup.com

Sheerframe Windows
www.sheerframe.co.uk

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